Resonant power converter with dead-time control of synchronous rectification circuit

The invention relates in a first aspect to a resonant power converter comprising a synchronous rectifier for supplying a DC output voltage. The synchronous rectifier is configured for alternatingly connecting a resonant output voltage to positive and negative DC output nodes via first and second semiconductor switches, respectively, separated by intervening dead-time periods in accordance with first and second rectification control signals. A dead-time controller is coupled to the resonant output voltage or the resonant input voltage and configured for adaptively adjusting lengths of the dead-time periods via the first and second rectification control signals.

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics, Department of Applied Electronics
Authors: Ekhtiari, M. (Intern), Zsurzsan, T. (Intern), Andersen, M. A. E. (Intern)
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Publication: Research › Patent – Annual report year: 2017

Analysis and optimization of coupled windings in magnetic resonant wireless power transfer systems with orthogonal experiment method

The coupled magnetic resonant unit (CMRU) has great effect on the transmitting power capability and efficiency of magnetic resonant wireless power transfer system. The key objective i.e. the efficiency coefficient kQ is introduced in the design of CMRU or the coupled windings based on the mutual inductance model. Then the design method with orthogonal experiments and finite element method simulation is proposed to maximize the kQ due to low precise analytical model of AC resistance and inductance for PCB windings at high-frequency. The method can reduce the design iterations and thereby can get more optimal design results. The experiments verified the design objective of kQ as well as the design method effectively. In the optimal PCB windings prototype at operating frequency of 4 MHz, the kQ and the maximum efficiency
are increased by about 12% and 4% respectively.

**General information**
State: Accepted/In press
Organisations: Department of Electrical Engineering, Electronics, Gutian River Hydropower Plant, Fuzhou University
Authors: Yudi, X. (Ekstern), Xingkui, M. (Ekstern), Mao, L. (Ekstern), Zhang, Z. (Intern), Andersen, M. A. E. (Intern)
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Scopus rating (2014): SJR 0.292 SNIP 0.653 CiteScore 0.66
Web of Science (2014): Indexed yes
Scopus rating (2013): SJR 0.252 SNIP 0.634 CiteScore 0.53
ISI indexed (2013): ISI indexed yes
Scopus rating (2012): SJR 0.226 SNIP 0.71 CiteScore 0.49
ISI indexed (2012): ISI indexed yes
Scopus rating (2011): SJR 0.203 SNIP 1.038 CiteScore 0.84
ISI indexed (2011): ISI indexed no
Scopus rating (2010): SJR 0.213 SNIP 0.3
Web of Science (2010): Indexed yes
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Web of Science (2004): Indexed yes
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Wireless power transfer, Magnetic resonant, Orthogonal experiments, Magnetic coupling structure optimization

**Analysis, Design, Modeling, and Control of an Interleaved-Boost Full-Bridge Three-Port Converter for Hybrid Renewable Energy Systems**

This paper presents the design, modeling, and control of an isolated dc-dc three-port converter (TPC) based on an interleaved-boost full-bridge converter with pulsewidth modulation (PWM) and phase-shift control for hybrid renewable energy systems. In the proposed topology, the switches are driven by phase-shifted PWM signals, where both phase angle and duty cycle are the controlled variables. The power flow between the two inputs is controlled through the duty cycle, whereas the output voltage can be regulated effectively through the phase shift. The primary-side MOSFETs can achieve zero-voltage-switching (ZVS) operation without additional circuitry. Additionally, due to the ac output inductor, the secondary-side diodes can operate under zero-current-switching (ZCS) conditions. In this study, the operation principles of the converter are analyzed and the critical design considerations are discussed. The dynamic behavior of the proposed ac-inductor-based TPC is investigated by performing state-space modeling. Moreover, the derived mathematical models are validated by simulation and measurements. In order to verify the validity of the theoretical analysis, design, and power decoupling control scheme, a prototype is constructed and tested under the various modes, depending on the availability of the renewable energy source and the load consumption. The experimental results show that the two decoupled control variables achieve effective regulation of the power flow among the three ports.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Mira Albert, M. D. C. (Intern), Zhang, Z. (Intern), Knott, A. (Intern), Andersen, M. A. E. (Intern)
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Main Research Area: Technical/natural sciences
Inductors, Topology, Renewable energy sources, Load flow, Switches, Mathematical model, Zero voltage switching, three-port converter, Energy storage, phase-shift and duty cycle control, renewable energy, state-space modeling

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Analytical Comparison of Dual-Input Isolated dc-dc Converter with an ac or dc Inductor for Renewable Energy Systems
This paper presents two configurations of dual-input (DI) or three-port (TPC) isolated dc-dc converters for hybrid renewable energy systems such as photovoltaics and batteries. These two converters are derived by integrating an interleaved boost converter and a single-active bridge converter with an ac inductor as a power interfacing element or phase-shift softswitching converter with an output dc inductor. Both converters are controlled by a pulse-width modulation and phase-shift hybrid modulation scheme. The two converter topologies are, even though quite similar from the topological and control perspective, distinct in operation principles, voltage/power transfer functions, loss distributions, soft-switching constraints, and power efficiency under the same operating conditions. Moreover, the inductor design differs greatly between these two cases. In this paper, a comprehensive comparison is given for the first time and thereby the corresponding design tradeoffs are discussed. Finally, a laboratory 1 kW prototype is constructed and tested to verify the theoretical analysis.

General information
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Organisations: Department of Electrical Engineering, Electronics
Authors: Zhang, Z. (Intern), Mira Albert, M. D. C. (Intern), Andersen, M. A. E. (Intern)
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Converter, dc-dc, Multiple inputs, Renewable Energies, Soft switching
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10.1109/IFEEC.2017.7992117
Source: PublicationPreSubmission
Source-ID: 132851082
Publication: Research - peer-review › Article in proceedings – Annual report year: 2017

Construction of Lightweight Loudspeaker Enclosures
On the basis of bass cabinets, this paper deals with the problem of reducing loudspeaker enclosure weight. An introductory market analysis emphasizes that lighter cabinets are sought, but maintenance of sound quality is vital. The problem is challenged through experiments and simulations in COMSOL Multiphysics, which indicate that weight reduction and sound quality maintenance is possible by reducing wall thickness and using adequate bracing and lining.

General information
State: Published
Organisations: Office for Innovation & Sector Services, Department of Mechanical Engineering, Engineering Design and Product Development, Department of Electrical Engineering, Electronics, Technical University of Denmark
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2017
Review of High Efficiency Bidirectional dc-dc Topologies with High Voltage Gain

A review of high voltage gain, high efficiency bidirectional dc-dc topologies is presented. Each converter's primary benefit is highlighted, and a summary of all the converters is presented. It is observed that voltage gains higher than 20 is only achieved with topologies using a transformer. The average efficiency of the topologies is slightly lower for isolated topologies. Different strategies are utilized in most of the topologies in order to achieve the high voltage gain, and high efficiency, for example charge pumps, resonant circuits, coupled inductors, and switching cells.

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Organisations: Department of Electrical Engineering, Electronics
Authors: Jørgensen, K. L. (Intern), Mira Albert, M. D. C. (Intern), Zhang, Z. (Intern), Andersen, M. A. E. (Intern)
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Source: PublicationPreSubmission
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2017

Accelerometer Based Motional Feedback Integrated in a 2 3/4" Loudspeaker

It is a well-known fact that loudspeakers produce distortion when they are driven into large diaphragm displacements. Various methods exist to reduce distortion using forward compensation and feedback methods. Acceleration-based motional feedback is one of these methods and was already thoroughly described in the 1960s showing good results at low frequencies. In spite of this, the technique has mainly been used for closed box subwoofers to a limited extent. In this paper, design and experimental results for a 23/4" acceleration-based motional feedback loudspeaker are shown to extend this feedback method to a small full-range loudspeaker. Furthermore, the audio quality from the system with feedback is discussed based on measurements of harmonic distortion, intermodulation distortion and subjective evaluation.

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics, Acoustic Technology, Technical University of Denmark
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Conference: 140th International Audio Engineering Society Convention, Paris, France, 04/06/2016 - 04/06/2016
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Source-ID: 124105078
Publication: Research - peer-review › Article in proceedings – Annual report year: 2016

Advances in Piezoelectric Systems: An Application-Based Approach.

Piezoelectricity is a fascinating research topic with wide-branching applications due to the unique property of bidirectional energy transfer. Piezoceramics can be used as both actuators and sensors without imposing any constraints on their supporting circuitry. This property, coupled with their low manufacturing costs and high robustness, has enabled widespread usage in applications ranging from simple spark lighters or pressure sensors to much more complicated energy harvesting systems and piezoelectric transformers. One governing property of piezoelectric devices is the existence of a mechanical frequency of resonance, or the natural frequency of the device paired with an antiresonance, which are material and size-dependent. From an electrical standpoint, the equivalent behavior of a piezoelectric device depends on how close or far from its natural resonance the device is excited in terms of frequency. Based on this classification, three
distinct, useful electrical behaviors can be identified: a capacitive behavior prominent at frequencies far from resonance, a resistive behavior encountered at resonance and antiresonance peaks and an inductive behavior, encountered at frequencies between the two. These three distinct behaviors encountered in any piezoelectric device represents the basis of discussion in the thesis. Therefore the present PhD dissertation is an application-based approach to researching all three behaviors individually, while nding solutions to the challenges encountered along the way. First, the capacitive behavior is studied, with the Piezoelectric Actuator Drive motor as a direct application. At low frequencies, piezoelectric devices are ideal as micro-and nanoscale positioning actuators but they are plagued by high levels of hysteretic nonlinearities. A model is developed to estimate this behavior, followed by a low-cost forward compensation method which achieves a positioning error reduction by a factor 20. Next, the characteristics of the PAD motor are researched and a method of extracting mechanical quality information and predict overload through feedback signal analysis is demonstrated. The next behavior studied is the inductive behavior, specically dealing with a bidirectional dc-dc power converter employing a piezoelectric transformer as major component. The main contribution here is achieving optimum tracking, hard-switching minimization and power ow control during bidirectional operation of a self-oscillating converter. Feasibility of using the converter in an MRI scanner is demonstrated. The third and nal behavior researched is the resistive behavior. This is widely encountered since most piezoelectric motors, ultrasonic baths and some energy harvesting systems operate at resonance. Friction control through squeeze-Im application is achieved in an electrostatic surface actuator for the rst time ever. This enables system functionality without glass gap material and concomitantly reduces minimum electrostatic operating voltage by 70%.

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics, Automation and Control
Authors: Zsurzsan, T. (Intern), Andersen, M. A. E. (Intern), Zhang, Z. (Intern), Andersen, N. A. (Intern)
Number of pages: 284
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Relations
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Analysis of bi-directional piezoelectric-based converters for zero-voltage switching operation
This paper deals with a thorough analysis of zero-voltage switching especially for bi-directional, inductorless, piezoelectric transformer-based switch-mode power supplies with a half-bridge topology. Practically, obtaining zero-voltage switching for all of the switches in a bi-directional piezoelectric power converter is a difficult task. However, the analysis in this work will be convenient for overcoming this challenge. The analysis deines the zero-voltage region indicating the operating points whether or not soft switching can be met over the switching frequency and load range. For the rst time, a comprehensive analysis is provided, which can be used as a design guideline for applying control techniques in order to drive switches in piezoelectric transformer-based converters. This study further conveys the proposed method to the region where all the switches can obtain soft switching. Moreover, the analysis can be applied to other types of resonant converters with or without piezoelectric transformers. Experimental and simulation results are provided, verifying the performed analysis.

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State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Ekhtiari, M. (Intern), Zhang, Z. (Intern), Andersen, M. A. E. (Intern)
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Main Research Area: Technical/natural sciences

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Class-D amplifier design and performance for driving a Piezo Actuator Drive servomotor.

This paper investigates the behavior of piezoelectric stacks in a Piezoelectric Actuator Drive (PAD) motor, which shows non-linear equivalent impedance and has a dramatic impact on the overall system performance. Therefore, in this paper, the piezo stack's model is discussed and an improved large signal model is proposed and verified by measurement. Finally, a Class-D amplifier as a power driver and its associated closed-loop control are implemented and tested to control PAD drive effectively.
Comparative Evaluation of the Loss and Thermal Performance of Advanced Three Level Inverter Topologies
This paper presents a comparative evaluation of the loss and thermal performance of two advanced three-level inverter topologies, namely the SiC based T-Type and the Hybrid-NPC, both of which are aimed at reducing the high switching losses associated with a conventional Si based T-Type inverter. The first solution directly replaces the 1200 V primary Si IGBT switches with lower loss 1200 V SiC MOSFETs. The second solution strategically adds 600 V CoolMos FET devices to the conventional Si T-Type inverter to reduce the primary commutation losses. Semiconductor loss models, experimentally verified on calibrated heat sinks, are used to show that both variations can significantly reduce the semiconductor losses compared to the Si based T-Type inverter. The results show that both alternatives are attractive if high efficiencies and reduced thermal stress are major requirements for the converter design.
switches with lower loss 1200V SiC MOSFETs. The second solution strategically adds 600V CoolMos FET devices to the conventional Si T-Type inverter to reduce the primary commutation losses. Semiconductor loss models, experimentally verified on calibrated heat sinks, are used to show that both variations can significantly reduce the semiconductor losses compared to the Si T-Type inverter. The results show that both alternatives are attractive if high efficiencies and reduced thermal stress are major requirements for the converter design.
Comparison of Simple Self-Oscillating PWM Modulators
Switch-mode power amplifiers has become the conventional choice for audio applications due to their superior efficiency and excellent audio performance. These amplifiers rely on high frequency modulation of the audio input. Conventional modulators use a fixed high frequency for modulation. Self-oscillating modulators do not have a fixed modulation frequency and can provide good audio performance with very simple circuitry. This paper proposes a new type of self-oscillating modulator. The proposed modulator is compared to an already existing modulator of similar type and their performances are compared both theoretically and experimentally. The result shows that the proposed modulator provides a higher degree of linearity resulting in around 2% lower Total Harmonic Distortion (THD).

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Dahl, N. J. (Ekstern), Iversen, N. E. (Intern), Knott, A. (Intern), Andersen, M. A. E. (Intern)
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Comparison_of_Simple_Self_Oscillating_PWM_Modulators_post_print.pdf
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Design of Efficient Sound Systems for Low Voltage Battery Driven Applications
The efficiency of portable battery driven sound systems is crucial as it relates to both the playback time and cost of the system. This paper presents design considerations when designing such systems. This include loudspeaker and amplifier design. Using a low resistance voice coil realized with rectangular wire one can boost the efficiency of the loudspeaker driver and eliminate the need of an additional power supply. A newly developed switching topology is described which is beneficial to near-idle efficiency (< 2 W), which is crucial for real audio applications in the consumer electronics space. A small sized sound system was implemented using the discussed design considerations. The amplifier efficiency performance was found to be very high with near-idle efficiency reaching a remarkably 88% at 2 W. The average output SPL was estimated to be up to 90 dB in half spheric anechoic conditions. Measured results are compared with current state-of-art and shows a 14% points efficiency improvement

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics, Merus Audio
Authors: Iversen, N. E. (Intern), Oortgiesen, R. (Ekstern), Knott, A. (Intern), Andersen, M. A. E. (Intern), Høyerby, M. (Ekstern)
Number of pages: 7
Publication date: 2016

Host publication information
Digital Control of a High Voltage (2.5 kV) Bidirectional Flyback DC-DC Converter for Driving a Capacitive Incremental Actuator

This paper presents a digital control technique to achieve valley switching in a bidirectional flyback converter used to drive a dielectric electro-active polymer based capacitive incremental actuator. The paper also provides the design of a low input voltage (24 V) and variable high output voltage (0-2.5 kV) bidirectional dc-dc flyback converter for driving a capacitive incremental actuator. The incremental actuator consists of three electrically isolated, mechanically connected capacitive actuators. It requires three high voltage (2-2.5 kV) bidirectional dc-dc converters, to accomplish the incremental motion by charging and discharging the capacitive actuators. The bidirectional flyback converter employs a digital controller to improve efficiency and charge/discharge speed using the valley switching technique during both charge and discharge processes, without the need to sense signals on the output high-voltage (HV) side. Experimental results verifying the bidirectional operation of a high voltage flyback converter are presented, using a 3 kV polypropylene film capacitor as the load. The energy loss distributions of the converter when 4 kV and 4.5 kV HV MOSFETs are used on HV side are presented. The flyback prototype with a 4 kV MOSFET demonstrated 89% charge energy efficiency to charge the capacitive load from 0 V to 2.5 kV, and 84% discharge energy efficiency to discharge it from 2.5 kV to 0 V, respectively.
Digitized self-oscillating loop for piezoelectric transformer-based power converters

A new method is implemented in designing of self-oscillating loop for driving piezoelectric transformers. The implemented method is based on combining both analog and digital control systems. Digitized delay, or digitized phase shift through the self-oscillating loop results in a very precise frequency control and ensures an optimum operation of the piezoelectric transformer in terms of voltage gain and efficiency. In this work, additional time delay is implemented digitally for the first time through 16 bit digital-to-analog converter to the self-oscillating loop. Delay control setpoints updates at a rate of 417 kHz. This allows the control loop to dynamically follow frequency changes of the transformer in each resonant cycle. The operation principle behind self-oscillating is discussed in this paper. Moreover, experimental results are reported.
Dynamic optimum dead time in piezoelectric transformer-based switch-mode power supplies
Soft switching is required to attain high efficiency in high-frequency power converters. Piezoelectric transformer-based converters can benefit from soft switching in terms of significantly diminished switching losses and stresses. Adequate dead time is needed in order to deliver sufficient energy to charge and discharge the input capacitance of piezoelectric transformers in order to achieve zero-voltage switching. This paper proposes a method for detecting the optimum dead time in piezoelectric transformer-based switch-mode power supplies. The provision of sufficient dead time in every cycle of the switching period results in the quick start up of resonant current inside the transformer. The new method is implemented by dynamically detecting the optimum dead time for each resonant cycle and results in reduced energy loss, and consequently, increased efficiency in the converter during initialization time and steady-state operation. The theory of optimum dead time operation is also discussed in this paper. Experimental results and simulation are provided to show the implementation of the concept.

General information
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Organisations: Department of Electrical Engineering, Electronics
Authors: Ekhtiari, M. (Intern), Andersen, T. (Intern), Andersen, M. A. E. (Intern), Zhang, Z. (Intern)
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Scopus rating (2016): CiteScore 9.96 SJR 2.728 SNIP 3.615
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): SJR 2.498 SNIP 3.819 CiteScore 9.2
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): SJR 2.299 SNIP 4.318 CiteScore 8.78
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): SJR 2.396 SNIP 4.427 CiteScore 8.41
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): SJR 1.945 SNIP 3.803 CiteScore 6.98
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): SJR 1.993 SNIP 3.359 CiteScore 7.12
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.796 SNIP 2.89
BFI (2009): BFI-level 2
Efficiency of Switch-Mode Power Audio Amplifiers - Test Signals and Measurement Techniques

Switch-mode technology is greatly used for audio amplification. This is mainly due to the great efficiency this technology offers. Normally the efficiency of a switch-mode audio amplifier is measured using a sine wave input. However this paper shows that sine waves represent real audio very poorly. An alternative signal is proposed for test purposes. The efficiency of a switch-mode power audio amplifier is modelled and measured with both sine wave and the proposed test signal as inputs. The results show that the choice of switching devices with low on resistances are unfairly favored when measuring the efficiency with sine waves. A 10% efficiency improvement was found for low power outputs. It is therefore of great importance to use proper test signals when measuring the efficiency.

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Iversen, N. E. (Intern), Knott, A. (Intern), Andersen, M. A. E. (Intern)
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Efficiency_of_Switch_Mode_Power_Audio_Amplifiers_post_print.pdf
Publication: Research - peer-review » Article in proceedings – Annual report year: 2016

Efficiency Study of Vertical Distance Variations in Wireless Power Transfer for E-Mobility

A Wireless Power Transfer (WPT) system is a safe, convenient and smart charging solution for Electric Vehicle (EV) users. However, a drawback of WPT systems is reduced efficiency in comparison to conventional wired charging due to lower coupling. By increasing the volume of EVs in the market, improving the system efficiency even a few percent, beside of being environmentally suitable, will benefit both consumers and distributors. According to the previous studies, efficiency improvement by decreasing the vertical distance (VD) between transmitter (TX) and receiver (RX) coils, has been one of the aims of the companies and universities. However, in low VD, system performance becomes highly sensitive, due to the magnetic coupling strength. The focus of this paper is to analyze the effects of decreasing the vertical distances to WPT resonance tank efficiency’s. Finally, some of the most significant parameters that affect the system efficiency at low VD such as quality factor and third harmonic interference are analyzed and a mitigating approach is proposed.
General information
State: Published
Organisations: Department of Electrical Engineering, Electronics, Center for Electric Power and Energy, Energy resources, services and control, Technical University of Denmark, Federal University of Maranhao, Aalborg University
Authors: Eftekhar, M. G. (Ekstern), Ouyang, Z. (Intern), Andersen, M. A. E. (Intern), Andersen, P. B. (Intern), Ribeiro, L. A. D. S. (Ekstern), Schaltz, E. (Ekstern)
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Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): SJR 0.48 SNIP 0.915 CiteScore 1.47
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): SJR 0.565 SNIP 1.207 CiteScore 1.77
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): SJR 0.715 SNIP 1.491 CiteScore 1.68
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): SJR 0.608 SNIP 1.424 CiteScore 1.75
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): SJR 0.788 SNIP 1.574 CiteScore 1.89
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): SJR 0.829 SNIP 1.445 CiteScore 1.69
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.698 SNIP 1.134
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.644 SNIP 1.098
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.788 SNIP 1.165
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 0.71 SNIP 1.152
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.913 SNIP 1.232
Scopus rating (2005): SJR 1.024 SNIP 1.258
Scopus rating (2004): SJR 0.813 SNIP 1.129
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 1.056 SNIP 1.094
Scopus rating (2002): SJR 1.078 SNIP 1.027
EMC Investigation of a Very High Frequency Self-oscillating Resonant Power Converter

This paper focuses on the electromagnetic compatibility (EMC) performance of a Very High Frequency (VHF) converter and how to lower the emissions. To test the EMC performance a VHF converter is implemented with a Class-E inverter and a Class-DE rectifier. The converter is designed to deliver 3 W to a 60 V LED, it has a switching frequency of 37 MHz and achieves an efficiency of 80%. For an LED driver to be used on the consumer market it has to fulfill the standard regarding EMC emissions. The conducted emission is often used as a reason to increase the switching frequency to the VHF range to avoid the regulations. This converter shows to be well below the levels for conducted emission even without filtering. For the radiated emissions the converter is above the limits without input and output filters. Several designs with different ways to lower the emissions are implemented and the different layouts and filtering are compared and discussed.

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Pedersen, J. A. (Intern), Knott, A. (Intern), Andersen, M. A. E. (Intern)
Pages: 1541-1546
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Grid-connected Photovoltaic Micro-inverter with New Hybrid Control LLC Resonant Converter

A high-efficiency photovoltaic (PV) micro-inverter consisting of two power stages i.e. a LLC resonant converter with a new hybrid control scheme and a dc-ac inverter is proposed, studied and designed in this paper. In the first power stage, the new hybrid control combining pulse-frequency modulation (PFM) and phase-shift pulse-width modulation (PS-PWM) is employed on a full-bridge LLC dc-dc converter, in order to achieve high efficiency when PV output voltage varies in a wide range. Moreover, a maximum power point tracking (MPPT) method based on power perturbation is implemented in the dc-ac inverter. Therefore, the complexity of regulating LLC converter can be reduced effectively, and efficiency optimal design can be carried out through the proposed designing procedure for the resonant tank of LLC converter. Finally, a prototype of the proposed PV micro-inverter (PVMI) is developed with rated power of 250W and output voltage of 220VAC/50Hz. The experiment shows that the peak efficiency of the PVMI is 95.5%, where efficiency of LLC converter is up to 97.7%, and the MPPT accuracy is more than 99%. Thus the validity of the proposed system structure, design and control method is verified.

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As research and development of renewable and clean energy based systems is advancing rapidly, the nonlinear source emulator (NSE) is becoming very essential for testing of maximum power point trackers or downstream converters. Renewable and clean energy sources play important roles in both terrestrial and nonterrestrial applications. However, most existing NSEs have only been concerned with simulating energy sources in terrestrial applications, which may not be fast enough for testing of nonterrestrial applications. In this paper, a high-bandwidth NSE is developed that is able to simulate the behaviors of a typical nonlinear source under different critical conditions that can happen during their operations. The proposed 200-W NSE, which consists of a fourth-order output filter buck converter and a novel nonlinear small-signal reference generator, can quickly react not only to an instantaneous change in the input source but also to a load step between nominal and open circuit. Moreover, all of these operation modes have a very fast settling time of only 10 μs, which is hundreds of times faster than that of existing works. This attribute allows for higher speed and a more efficient maximum power point tracking algorithm. The proposed NSE, therefore, offers a superior dynamic performance among devices of the same kind.
High Frequency AC Inductor Analysis and Design for Dual Active Bridge (DAB) Converters

The dual active bridge (DAB) converter is an isolated bidirectional dc-dc topology which is the most critical part for the power conversion systems such as solid-state transformers (SST). This paper focuses on analysis and design of high frequency ac inductors which are the power interfacing component in DAB converters or DAB’s derivative topologies for transferring energy between the primary and secondary sides. The DAB converter’s operation principles, and the corresponding voltage and current stresses over its ac inductor are analyzed. Hereby, six diverse winding arrangements are studied in order to find a design having the lowest ac resistance and core loss. Core loss is calculated by both GSE and iGSE methods, and then the results are compared under two operating conditions. Based upon the finite element method (FEM) simulation, winding losses are investigated. Finally, the case in which the core loss and the winding loss are almost equal is selected as the optimal one. The experimental results are presented to verify the validity of the analysis and design.
Inductorless bi-directional piezoelectric transformer-based converters: Design and control considerations.

Piezoelectric transformers were introduced to the world in 1954 and turned into the best alternative for replacing the magnetic transformers. Recently, the development of research on piezoelectric-based switch-mode power supplies has gathered pace and led to extensive research development. However, this brings an open area for conducting further research which has been subject of this project. The research on this type of power converters are progressive but still very new in the technology to become a successful commercial product. The unique characteristics of piezoelectric transformers i.e. low electromagnetic interference, compact, light, high power density and low cost allows for promising market in the near future. The piezoelectric transformer technology has the potential to be used in various applications e.g. motor driver for magnetic resonance imaging scans, the electronic ballast for fluorescent lamps, backlight for LCD displays in notebook computers. Piezoelectric ceramic devices vibrate at their mechanical resonance.

The operating principle of the piezoelectric transformers is based on electromechanical energy conversion. There is electromechanical coupling between the primary- and secondaryside of piezo ceramic, where the primary acts as a piezoelectric actuator and the secondary acts as a piezoelectric transducer. Therefore, piezoelectric transformers can be used as a replacement of resonant circuits in the power converters. This introduces piezoelectric transformers as applicable candidates for applications that have a high sensitivity to electromagnetic interference. The nonmagnetic bidirectional piezoelectric transformer-based switch-mode power supplies as the topic of this thesis is one of these applications. The dissertation presents the design, control and implementation of inductorless switch-mode power supplies employing piezoelectric transformers. The main focus of this research is on the functionality of the piezoelectric transformer-based power converters and applying control techniques in order to exploit advantages of the piezoelectric transformers for the power converters. Therefore, the research is devoted to stepwise development of all parts of the inductorless piezoelectric transformer-based switch-mode power supply. The developments have been mainly on the transformer design for internal resonant current sensing, increasing their capability in transferring energy and soft switching, following changes of the piezoelectric transformer in order to control operation of the piezoelectric transformer for the benefit of the power converters, digitizing control system, applying new control techniques compared to previously applied methods, implementing dynamic optimum dead time detector applicable for switch-mode power supplies, optimum phase detector, bi-directional wide bandwidth current sensor and a comprehensive analysis of piezoelectric transformer-based switch-mode power supplies for zero-voltage switching, where all finalized with improving the unidirectional topology with resistive and passive rectifiers as well as bi-directional topology with a capacitive load. The investigation of the piezoelectric transformers in terms of sensing the resonant current and increasing their capability of handling high power was carried out in collaboration with the project’s industry partner. New samples of piezoelectric transformers were designed, fabricated and tested. Experiments showed promising results on sensing the resonant current, but could not be used for the control system in this research since having both sensing electrode and zero-voltage switching could not be obtained in one package. Moreover, a progress of increasing power capability of piezoelectric transformer’s was a step forward to overcome the limitations in the technology of the piezoelectric transformers. Operation of unidirectional topology deals with finding solutions for advance control of piezoelectric transformers in terms of operating under various load, frequency and temperature changes. In order to follow changes in the characteristic of the transformers and control their operation, a digitized self-oscillating loop designed and implemented. The main advantage of the digitized self-oscillating loop is that the time delay inside the loop is able to be changed with the resolution of 1 ns. This provides the possibility of sweeping the operating point on the characteristic over the frequency range by very fine frequency steps where considerable changes in the output voltage of the transformer are visible. This is done by shifting the gate voltages of the switches versus the resonant current. Having access to the mechanical resonance of the piezoelectric material inside the piezoelectric transformer, known as "resonant current" in its equivalent electrical circuit, simplifies the control system of the entire converter. Therefore, attempts were made to find solutions for sensing the resonant current over the whole or part of the switching time period. The first approach was to design a piezoelectric transformer with feedback to sense the mechanical resonance. The second approach was to design a current sensor for measuring the input current to the transformer which is equal to the resonant current during the on time of the switches. The second approach requires a wide bandwidth bi-directional current sensor to be able to operate in the presence of the
high common-mode voltage. Part of this research allocates to implementation of the current sensor. A new method for optimizing the dead time in every switching cycle is proposed. The dynamic optimum dead time detector starts to detect the time point where the switching voltage reaches the rails or passes through its local maxima. This results in the minimum or the optimum dead time between the switching transitions and further expanding the duty cycle of the switches in order to provide more energy to the converter. The advantage will be reduction of the start-up time in the converter and the switching losses. The main achievement of this research is a new implementation of bi-directional piezoelectric transformer-based switch-mode power supply with two configurations. This implementation is applicable for the control system of switch-mode power supplies, specially resonant power converters. Finally, the outcome of the research is implemented and tested in the final prototype with combining all the designed sub-circuits to investigate the bi-directional functionality of the power supply, which resulted in a successful outcome in the control techniques.

Integrated Three-Port DC-DC Converter for Photovoltaic (PV) Battery Stand-alone Systems
Several power sources such as PV solar arrays and battery are often used to manage the power flow for a photovoltaic (PV) based stand-alone power system due to the fluctuation nature of solar energy resource, and deliver a continuous power to the users in an appropriate form. Traditionally, three different single-input single-output (SISO) dc/dc converters would have been used. To reduce the cost and improve the power density of the system, an integrated three-port isolated dc/dc converter is proposed in this paper. It can realize all functions of the energy delivery due to the fluctuation nature of solar energy. Moreover, a novel transformer configuration enables variable turns ratio controlled by the phase between the two current excitations subjected to the primary windings, allowing a wider input/output range. 1 kW experimental prototype has been built to demonstrate a well-managed power flow for PV and battery stand-alone system.

Investigation of Transformer Winding Architectures for High Voltage (2.5 kV) Capacitor Charging and Discharging Applications
Transformer parasitics such as leakage inductance and self-capacitance are rarely calculated in advance during the design phase, because of the complexity and huge analytical error margins caused by practical winding implementation issues. Thus, choosing one transformer architecture over another for a given design is usually based on experience, or a trial and error approach. This paper presents analytical expressions for calculating leakage inductance, self-capacitance and ac resistance in transformer winding architectures (TWAs), ranging from the common non-interleaved primary/secondary winding architecture, to an interleaved, sectionalized, and bank winded architecture. The calculated results are evaluated experimentally, and through finite element (FEM) simulations, for a RM8 transformer with a turns
ratio of 10. The four TWAs such as, non-interleaved and non-sectioned, non-interleaved and sectioned, interleaved and non-sectioned, and interleaved and sectioned, for an EF25 transformer with a turns ratio of 20, are investigated and practically implemented. The best TWA for a RM8 transformer in a high-voltage (HV) bidirectional flyback converter, used to drive an electro active polymer based incremental actuator, is identified based on the losses caused by the transformer parasitics. For an EF25 transformer, the best TWA is chosen according to whether electromagnetic interference (EMI) due to the transformer interwinding capacitance, is a major problem or not.

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Loss Distribution Analysis of a Three-Port Converter for Low-Power Stand-Alone Light-to-Light Systems

In locations far from the equator achieving high conversion efficiency in low-power solar systems is challenging due to low solar irradiance levels. This paper presents a high efficiency three-port converter (TPC) for light-to-light (LtL) applications where no direct solar conversion is required. The separation of the power flows allows to replace the conventional solution of two cascaded converters into a single structure with shared components. A loss distribution analysis of the proposed structure is performed, which shows very good match with the experimental results. A prototype of the TPC demonstrates high efficiency in both power flow paths. At low irradiation level, the power flow from the photovoltaic panel to the battery shows a peak efficiency of 99.1% at 1.5 W output power, and the LED driver stage presents a peak efficiency of 97.3% at 3 W output power.

New Incremental Actuators based on Electro-active Polymer: Conceptual, Control, and Driver Design Considerations.

This paper presents an overview of the widely used conventional linear actuator technologies and existing electroactivepolymer based linear and rotary actuators. It also provides the conceptual, control and driver design considerations for anew dielectric electro-active polymer (DEAP) based incrementalactuator. The DEAP incremental actuator consists of threeindependent DEAP actuators with a unique cylindrical design that potentially simplifies mass production and scalability compared to existing DEAP actuators. To accomplish the incremental motion, a high voltage (HV) bidirectional DC-DC converter, independently charges and discharges each capacitive DEAP actuator. The topology used for the HV driver is a peackurrent controlled bidirectional flyback converter. Thescalability of the proposed DEAP incremental actuator is discussed, and different scaled designs are provided. The estimated speeds and forces for various scaled incremental actuator designs are provided. The HV drivers are experimentally tested with a prototype of the DEAP incremental actuator. The energy efficiency measurement results of one of the HV driver are presented. The DEAP incremental actuator prototype achieved bidirectional motion with a maximum velocity of 1.5 mm/s, at 2.87 Hz incremental driving frequency, when all actuators are driven with 1.8 kV. Finally, two new improved concepts of DEAP based incremental actuator are presented.
Power enhancement of piezoelectric transformers for power supplies.
This paper studies power enhancement of piezoelectric transformers to be used in inductorless, half-bridge, piezoelectric-based switch mode power supplies for driving a piezo actuator motor system in a high strength magnetic environment for magnetic resonance imaging and computed tomography applications. A new multi element-piezo transformer solution is proposed along with a dual mode piezo transformer, providing power scaling and potentially improving the internal heat-up of a high power piezo transformer system.

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Relationship between voice coil fill factor and loudspeaker efficiency
In modern audio systems, utilizing switch-mode amplifiers, the total efficiency is dominated by the rather poor efficiency of the loudspeaker. For decades voice coils have been designed so that nominal resistances of 3 to 8 Ω are obtained, despite modern audio amplifiers, using switch-mode technology, can be designed to much lower loads. A thorough analysis of the loudspeaker efficiency is presented and its relation to the voice coil fill factor is described. In addition to this the influence of the driver's mass ratio is investigated and it is found that high mass ratios is beneficial for the efficiency of drivers using high fill factor voice coils. Different voice coil winding strategies are described and their fill factors analysed. It is found that by lowering the nominal resistance of a voice coil, using rectangular wire, one can increase the fill factor. However a practical realization of four voice coil designs could not proof this due to wire insulations issues. Despite that a good correlation between theory and experimental results is found and it is shown that the efficiency is dependent on the fill factor as predicted. Moreover the fill factor of a conventional 4 Ω voice coil was measured to be 53 % which leaves plenty of room for future fill factor optimization.

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Teaching Power Electronics with a Design-Oriented and Project-Based Learning Method at the Technical University of Denmark

Power electronics is a fast developing technology within the electrical engineering field. This paper presents the results and experiences gained from Design Oriented Project Based Learning of switch-mode power supply design within a power electronics course at the Technical University of Denmark (DTU). Project-based learning (PBL) is known to be a motivating and problem-centered teaching method that not only places students at the core of the teaching and learning activities but also gives students the ability to transfer their acquired scientific knowledge into industrial practices. Students are asked to choose a specification from different power converter applications such as a fuel cell power conditioning converter, a light-emitting diode (LED) driver or a battery charger. Based upon their choice, the students select topology, design magnetic components, calculate input/output filters and design closed-loop controllers in order to fulfill the requirements listed in the chosen specification; thereby meeting the corresponding project’s goals. In this paper, the course teaching plan and teaching methods are introduced, the assessment method is analysed and feedback from the students is studied.

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The Benefits of SiC MOSFETs in a T-Type Inverter for Grid-Tie Applications

It is well known that multilevel converters can offer significant benefits in terms of harmonic performance and reduced switching losses compared to their two-level counterparts. However, for lower voltage applications the Neutral-Point-Clamped (NPC) inverter suffers from relatively large semiconductor conduction losses because the output current always flows through two switching devices. In contrast, the T-Type multilevel inverter has less conduction losses because only a single outer loop switching device is required to connect the converter output to the upper and lower DC buses, albeit at the expense of increased switching losses since these outer switches must now block the full DC link voltage. Silicon Carbide (SiC) MOSFET devices potentially offer substantial advantage in this context with their lower switching losses, but the benefit of replacing all switching devices in a T-Type inverter with SiC MOSFETs is not so clear-cut. This paper now explores this issue by presenting a detailed comparison of the use of Si and SiC devices for a three-level T-Type inverter operating in grid-tie applications. The study uses datasheet values, switching loss measurements and calibrated heat sink thermal measurements to precisely compare semiconductor losses for these two alternatives for a T-Type inverter operating at or near unity power factor. The results show that replacing only the DC bus connection switches with SiC devices significantly reduces the semiconductor losses, allowing either the converter power level or the switching frequency to be significantly increased for the same device losses. Hence the use of SiC MOSFETS for T-Type inverters can be seen to be an attractive and potentially cost effective alternative, since only two switching devices per phase leg need to be upgraded.
Three-Port dc-dc Conversion in Light-to-Light Systems

Renewable energies, like solar or wind, provide unlimited, clean and free energy that helps reducing (CO2) emissions, which alleviates global warming and greenhouse effects. Moreover, the ability to produce off-grid electricity allows local electric power generation. However, the main disadvantage of renewable sources is that they are strongly dependent on the weather conditions, and, therefore, intermittent and unpredictable. For this reason they need to be combined with other power sources, or energy storage elements, in order to ensure reliable and constant power to the load.

Solar energy is one of the major renewable energies because the Sun is a vast, inexhaustible and clean resource. Photovoltaic cells transform sunlight into electrical energy and the generated power is proportional to the amount of solar irradiation.

Light-emitting diodes (LEDs) present higher luminous efficiency and lifetime than conventional light sources based on heated filaments (incandescent and halogen) and gas discharge (fluorescent, sodium, etc). The rapid development of this technology makes it possible to replace the conventional technologies towards high brightness LED lighting systems. The combination of these technologies—solar cells, energy storage elements and LEDs—in a stand-alone solar powered LED system, can provide light where otherwise it would be cumbersome; in rural areas, where cabling can be challenging and expensive, and also in the urban environment, where the cost of digging and construction is very expensive.

Solar powered systems are particularly challenging in locations far from the equator, where the solar resource is scarce, especially during winter, since the amount of solar irradiation is small and the length of the day is short. Therefore, these systems need to be optimized by maximizing the energy conversion efficiency under low irradiation conditions.

This work is part of a Ph.D. research project to study the feasibility of implementing three-port converter (TPC) topologies in solar powered LED, light-to-light (LtL) systems. After the introduction in Chapter 1, an overview of the state-of-the art of solar cells, LED technology and energy storage elements, as well as a review of TPC topologies is given in Chapter 2. Following, the study of a low-power (10 - 50 W) stand-alone PV-LED system with aim on high efficiency energy conversion is presented in Chapter 3. The implemented power stage is based on component reutilization and is optimized at low irradiation conditions, achieving a peak efficiency of 98.9%. A discussion on the magnetic component design, semiconductor evaluation based on switching energy measurement and study of the loss distribution is presented. Scalability and implementation of multiple LED outputs on the proposed topology are discussed and demonstrated on a second prototype. A TPC for grid-tied light-to-light applications (100 - 1000 W) is studied in Chapter 4. Analysis, modeling and power flow regulation with two control variables are discussed in this section. The dynamic modeling and measurements prove that completely decoupled power flow regulation can be achieved. Finally, the conclusion and future work are presented in Chapter 5. Other research topics—not directly related with the project objectives—are shown in Chapter 6.
Ultrasonic lubrication: concept and application

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US Mains Stacked Very High Frequency Self-oscillating Resonant Power Converter with Unified Rectifier

This paper describes a Very High Frequency (VHF) converter made with three Class-E inverters and a single Class-DE rectifier. The converter is designed for the US mains (120 V, 60 Hz) and can deliver 9 W to a 60 V LED. The converter has a switching frequency of 37 MHz and achieves an efficiency of 89.4%. With VHF converters the power density can be improved and the converter described in this paper has a power density of 2.14 W/cm3. The power factor (PF) requirements of mains connected equipment is fulfilled with a power factor of 0.96.

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Wide Input Range Power Converters Using a Variable Turns Ratio Transformer
A new integrated transformer with variable turns ratio is proposed to enable dc-dc converters operating over a wide input voltage range. The integrated transformer employs a new geometry of magnetic core with “four legs”, two primary windings with orthogonal arrangement, and “8” shape connection of diagonal secondary windings, in order to make the transformer turns ratio adjustable by controlling the phase between the two current excitations subjected to the two primary windings. Full-bridge boost dc-dc converter is employed with the proposed transformer to demonstrate the feasibility of the variable turns ratio. 1-kW experimental prototype targeting to the PV standalone system has been built to well demonstrate a wide input voltage operation with high efficiencies.

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On-line monitoring of high-voltage electrical equipment (HV-EE) aiming to detect faults effectively has become crucial to avoid serious accidents. Moreover, highly reliable power supplies are the key component for the wireless sensors equipped in such on-line monitoring systems. Therefore, in this paper, the wireless power supply via coupled magnetic resonance (MR-WPS) is proposed for powering the wireless sensor and the associated wireless sensor solution is also proposed. The key specifications of the MR-WPS working in switchgear cabinet with a harsh operation environment are analyzed and determined. Design of these key parameters of the coupled magnetic resonant unit (CMRU) in MR-WPS is provided as well as the method of optimizing the resonant windings is given. Finally, a prototype is built and tested. The experimental results are presented in order to show that sufficient and reliable power is able to be delivered to the wireless sensor through the designed MR-WPS, and therefore the theoretical analysis and design is verified.

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A Comparison between Boundary and Continuous Conduction Modes in Single Phase PFC Using 600V Range Devices

This paper presents an analysis and comparison of boundary conduction mode (BCM) and continuous conduction mode (CCM) in single phase power factor correction (PFC) applications. The comparison is based on double pulse tester (DPT) characterization results of state-of-the-art superjunction devices in the 600V range. The measured switching energy is used to evaluate the devices performance in a conventional PFC. This data is used together with a mathematical model for prediction of the conducted electromagnetic interference (EMI). This allows comparing the different devices in BCM and CCM operation modes and evaluating the performance as a function of the PFC power density and efficiency.

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Advances in PV Inverters

Renewable energies have experienced a significant growth and importance in the last two decades, of which energy from photovoltaic plants are a major contributor. Since solar cells have low efficiencies themselves, however, the necessity of high efficiency power converters at low cost and preferably low complexity leads to new research demands. This is especially true in the field of low cost residential PV inverters where efficiencies are used as major selling arguments. Therefore, research areas typically focus on both new topologies and utilizing more advanced semiconductor devices. To this end, semiconductor devices made of Silicon Carbide have been gaining increasing interest in the last two decades after the successful commercialization of high voltage power diodes. By now, the performance potential of switching devices made of Silicon Carbide is commonly accepted, though they have not found commonplace usage within commercial converter systems for several reasons, among others reliability, availability/cost and gate driver complexity. Therefore, more complex Silicon based converters can be used instead to achieve lower semiconductor losses. While there is no absolute solution in which direction to go to achieve the aforementioned design goals, this dissertation will thoroughly investigate two potential approaches and discuss their trade-offs. The contributions are:
• Comprehensive loss analysis and identification of major loss contributors within T-Type converter topology operating in inverter and rectifier context.
• Evaluation of the use and loss benefits of Silicon Carbide switching devices in the T-Type structure.
• Thorough investigation of the Hybrid-Neutral-Point-Clamped (Hybrid-NPC) topology as an alternative for the Silicon Carbide based T-Type converter.
• Alternative methodology of semiconductor loss model validation by experimental means. As to the advanced three-level T-Type converter topology, its unusual operation mode is thoroughly described identifying its limitations for high efficiency operation. With these results, the first approach utilizes low loss switching devices and their influence on the semiconductor loss behavior is analyzed. The results show that, for near unity power factor operation, a replacement of only two switching devices per phase leg can greatly reduce the semiconductor losses. The Hybrid-NPC converter can be seen as an attractive and cost competitive alternative to the Silicon Carbide based converter, also allowing to overcome the major drawbacks with the conventional Silicon IGBT based T-Type structure. Both alternatives are based on a semiconductor/topological level and thus this is where the loss reduction occurs. The difficulty in experimentally evaluating only the semiconductor losses within a converter operating context is addressed in this work by presenting an alternative measurement approach. Using known heat loads, and a careful calibration procedure on the device heat sink, analytically obtained semiconductor loss models based on datasheet information and in-circuit switching transitions measurements can be experimentally verified and thus a fair performance comparison between two approaches is enabled.
Advances in Very High Frequency Power Conversion

Resonant and quasi-resonant converters operated at frequencies above 30 MHz have attracted special attention in the last two decades. Compared to conventional converters operated at ~100 kHz, they offer significant advantages: smaller volume and weight, lower cost, and faster transient performance. Excellent performance and small size of magnetic components and capacitors at very high frequencies, along with constant advances in performance of power semiconductor devices, suggests a sizable shift in consumer power supplies market into this area in the near future. To operate dc-dc converter power devices at very high frequencies, switching loss needs to reduced or eliminated, as it would become prohibitively large. In addition, as the frequency increases, hard-switched gate driving becomes less and less of an option, as it embodies the same loss mechanism. A low-loss gate drive methods may need to be applied, especially at low power levels where gating loss becomes a significant percentage of the total loss budget. Various resonant gate drive methods have been proposed to address this design challenge, with varying size, cost, and complexity. This dissertation presents a self-oscillating resonant gate drive solution, which is applicable in cases when there are at least two power stages, and with minimal additional hardware requirements. It is experimentally confirmed that the method is suitable for both parallel and serial input configurations. Compared to state-of-the-art solutions, the proposed method provides low complexity and low gate loss simultaneously. A direct design synthesis method is provided for resonant SEPIC converters employing this technique. Most experimental prototypes were developed using low cost, commercially available power semiconductors. Due to very fast transient response of VHF converters, on/off control schemes are often used for their output control. The options presented so far demonstrated excellent performance, but with very strict timing constraints on all functional blocks in the feedback loop. Therefore, an on/off control method is proposed which allows the use of conventional ICs, while still providing high control bandwidth and performance comparable to state-of-the-art solutions. Since in many applications of interest galvanic isolation is not a requirement, the thesis proposes a method for providing a DC power path from input to output of a previously galvanic isolated converter. The method requires connection rearrangement in the existing converter only, and provides higher output power and converter efficiency for the same or lower voltage and/or current stresses in the converter components. Achieved results demonstrated that low-cost solutions, based on silicon power semiconductors and ICs, can achieve formidable performance even when operated at very high frequencies. The power devices employed in this thesis were not optimized for such operation. With proper optimization and new semiconductor materials, it is expected that VHF converters become frequent occurrence within the power conversion domain, rather than a curiosity.
Analytical Switching Cycle Modeling of Bidirectional High Voltage Flyback Converter for Capacitive Load Considering Core Loss Effect

With the advancement of material science, various smart materials with intrinsic capacitive property are emerging. The high voltage (HV) power electronics converters with bidirectional energy flow functionality for supplying the capacitive load are highly demanded. A switching cycle based analytical model of HV bidirectional converter driving capacitive load is beneficial in thoroughly understanding the operational behavior, investigating the energy efficiency and optimizing the design. In this paper, a HV bidirectional flyback converter for capacitive load is generally discussed in terms of configuration and working principle. Considering the parasitic elements as well as the core loss effect, the converter is modeled with analytical formulas for one switching cycle. The comparison between the model based calculation results and prototype experiments based measurement results are used to validate the analytical model.

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Scopus rating (2010): SJR 1.796 SNIP 2.89
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.786 SNIP 2.726
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.538 SNIP 3.073
Web of Science (2008): Indexed yes
Bidirectional Flyback Converter with Multiple Series Connected Outputs for High Voltage Capacitive Charge and Discharge Applications

This paper evaluates two different implementations of a bidirectional flyback converter for driving a capacitive electro active actuator, which must be charged and discharged from 0 V to 2.5 kV DC and vice versa, supplied from a 24 V battery. In one implementation, a high voltage MOSFET (4 kV) in series with a high voltage blocking diode is added, in parallel with a high voltage freewheeling diode of a conventional flyback topology, to enable bidirectional operation. Experimental result from a digitally controlled bidirectional flyback converter shows that the discharge energy efficiency is limited by the parasitics of the high voltage active components, which also prevent full utilization of valley switching during discharge process. A second implementation is therefore proposed, where the secondary of flyback transformer winding is split into multiple windings which are connected in series by lower voltage rating MOSFETs driven by a gate drive transformer. Simulation results to compare the operation of conventional and proposed converters are provided. The advantages of proposed implementation are improved energy efficiency and lower cost. Experimental results with two series connected secondary windings are provided to validate the proposed implementation.

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Characterization and Evaluation of 600 V Range Devices for Active Power Factor Correction in Boundary and Continuous Conduction Modes

Traditional characterization of semiconductors switching dynamics is performed based on clamped inductive load measurements using the double pulse tester (DPT) configuration. This approach is valid for converters operating in continuous conduction mode (CCM), however in boundary conduction mode (BCM), if valley switching detection is used, the amount of energy recovered from the semiconductor output capacitance and the converter switching frequency need to be accurately calculated. This paper presents a characterization and evaluation procedure for conventional power factor correction circuits operating in CCM and BCM.

Comparison of a state of the art Si IGBT and next generation fast switching devices in a 4 kW boost converter

This paper gives a comprehensive comparison of two promising silicon carbide (SiC) switching devices, i.e. normally-off SiC MOSFET and a normally-on SiC JFET, as alternatives to a conventional state of the art Si IGBT. The comparison uses datasheet information to determine conduction losses, switching transition measurements for switching loss calculations and electrical power measurements in a boost converter. Using SiC switching devices, switching energies can be reduced by almost 70% and the forward voltages of such devices are much lower compared to the IGBT which then reduce the conduction losses. This reduction in semiconductor losses can increase overall converter efficiencies up to 0.4% at 20kHz or enable high frequency operation up to 100 kHz which then reduces the size and weight of the inductor by more than 75% while still achieving efficiencies over 98.3%.
Control and sensor techniques for PAD servo motor drive
The Piezoelectric Actuator Drive (PAD) is a new type of electrical motor that employs piezoelectric multilayer actuators coupled with a form-fitted micro-mechanical gearing to generate rotary motion. The PAD is precise, having a positioning error of less than 2 arc-seconds. Its typical output torque is 4 Nm, without any additional gearing. The whole motor is fully non-magnetic, enabling its use in applications where magnetic neutrality is of importance. The main challenges of the PAD are the hysteretic behavior of the ceramic actuators used and their highly capacitive nature. After compensating for the hysteretic behavior, the current waveforms of the motor can be used to extract all necessary parameters for sensorless operation. Moreover, these signals provide a qualitative information about the precision in motor centering and show any mismatch between the actuators used.

General information
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Design and Evaluation of Accelerometer based Motional Feedback
The electro dynamic loudspeaker is often referred to as the weakest link in the audio chain due to low efficiency and high distortion levels at low frequencies and high diaphragm excursion. Compensating for loudspeaker non-linearities using feedback or feedforward methods can improve the distortion and enable radical design changes in the loudspeaker which can lead to efficiency improvements. In combination this has motivated a revisit of the accelerometer based motional feedback technique. Experimental results on a 8 inch subwoofer show that the total harmonic distortion can be significantly reduced at low frequencies and large displacements.

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Design of a 300-Watt Isolated Power Supply for Ultra-Fast Tracking Converters

This paper presents the design of a medium-power-rating isolated power supply for ultra-fast tracking converters and MOS-gate driver circuits in medium and high voltage applications. The key feature of the design is its very low circuit input-to-output parasitic capacitance, which maximizes its noise immunity from noise due to fast changes in voltage. The converter is a voltage-controlled current source, utilizing a transformer with extremely low inter-winding parasitic capacitance, which is achieved by separating the windings by a significant distance. Experimental measurements show that an overall circuit input-to-output parasitic capacitance of 10 pF in a 300 W prototype can be achieved. The circuit input-to-output capacitance per watt is therefore 30 times lower than that of existing approaches. A mathematical model of the inter-winding capacitance of the proposed transformer, circuit analysis, and experimental results are provided to prove the feasibility of the converter.

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Authors: Nguyen-Duy, K. (Intern), Ouyang, Z. (Intern), Petersen, L. P. (Intern), Knott, A. (Intern), Thomsen, O. C. (Intern), Andersen, M. A. E. (Intern)
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BFI (2008): BFI-level 2
Scopus rating (2008): SJR 2.538 SNIP 3.073
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Efficiency Evaluation on a CoolMos Switching and IGBT Conducting Multilevel Inverter

This paper deals with a three-level inverter topology in the 3 kW range as an alternative to commonly used three-level topologies. The topology is attractive for having low switching losses due to the utilization of CoolMos switching devices while keeping conduction losses low due to the utilization of IGBTs. A proper time delay between the CoolMos and IGBT devices increases the efficiency by 0.2%. Maximum efficiencies of 97.7 % are achieved and less than 0.2 % efficiency degradation is possible with doubled switching frequency. The case temperatures of the switching devices are below 60 °C at full power.

General information
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Efficiency Investigation of Switch Mode Power Amplifier Driving Low Impedance Transducers

The typical nominal resistance span of an electro dynamic transducer is 4 Ω to 8 Ω. This work examines the possibility of driving a transducer with a much lower impedance to enable the amplifier and loudspeaker to be directly driven by a low voltage source such as a battery. A method for estimating the amplifier rail voltage requirement as a function of the voice coil nominal resistance is presented. The method is based on a crest factor analysis of music signals and estimation of the electrical power requirement from a specific target of the sound pressure level. Experimental measurements confirms a huge performance leap in terms of efficiency compared to a conventional battery driven sound system. Future optimization of low voltage, high current amplifiers for low impedance loudspeaker drivers are discussed.

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Organisations: Department of Electrical Engineering, Electronics
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Efficiency Optimization by Considering the High Voltage Flyback Transformer Parasitics using an Automatic Winding Layout Technique

This paper presents an efficiency optimization approach for a high voltage bidirectional flyback dc-dc converter. The main goal is to optimize the converter for driving a capacitive actuator, which must be charged and discharged from 0 V to 2.5 kV dc and vice versa, supplied from a 24 Vdc supply. The energy efficiency is optimized using a proposed new automatic winding layout (AWL) technique and a comprehensive loss model. The AWL technique generates a large number of transformer winding layouts. The transformer parasitics such as dc resistance, leakage inductance and self-capacitance are calculated for each winding layout. An optimization technique is formulated to minimize the sum of energy losses during charge and discharge operations. The efficiency and energy loss distribution results from the optimization routine provide a deep insight into the high voltage transformer design and its impact on the total converter efficiency. The proposed efficiency optimization approach is experimentally verified on a 25 W (average charging power) with 100 W (peak power) flyback dc-dc prototype.

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Efficiency Optimization in Class-D Audio Amplifiers
This paper presents a new power efficiency optimization routine for designing Class-D audio amplifiers. The proposed optimization procedure finds design parameters for the power stage and the output filter, and the optimum switching frequency such that the weighted power losses are minimized under the given constraints. The optimization routine is applied to minimize the power losses in a 130 W class-D audio amplifier based on consumer behavior investigations, where the amplifier operates at idle and low power levels most of the time. Experimental results demonstrate that the optimization method can lead to around 30% of efficiency improvement at 1.3 W output power without significant effects on both audio performance and the efficiency at high power levels.

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Organisations: Department of Electrical Engineering, Electronics
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Electronics drivers for high voltage dielectric electro active polymer (DEAP) applications
Dielectric electro active polymer (DEAP) can be used in actuation, sensing and energy harvesting applications, but driving the DEAP based actuators and generators has three main challenges from a power electronics standpoint, i.e. high voltage (around 2.5 kV), nonlinearity, and capacitive behavior. In this paper, electronics divers for heating valves, loud speakers, incremental motors, and energy harvesting are reviewed, studied and developed in accordance with their
corresponding specifications. Due to the simplicity and low power capacity (below 10W), the reversible Fly-back converters with both magnetic and piezoelectric transformers are employed for the heating valve and incremental motor application, where only ON/OFF regulation is adopted for energy saving; as for DEAP based energy harvesting, the non-isolated Buck/Boost converter is used, due to the system high power capacity (above 100W), but the voltage balancing across the series-connected high voltage IGBTs is a critical issue and accordingly a novel gate driver circuitry is proposed and equipped; due to the requirements of the audio products, such as low distortion and noise, the multi-level Buck converter based Class-D amplifier, because of its high control linearity, is implemented for the loud speaker application. A synthesis among those converter topologies and control techniques is given; therefore, for those DEAP based applications, their diversity and similarity of electronics drivers, as well as the key technologies employed are analyzed. Therefore a whole picture of how to choose the proper topologies can be revealed. Finally, the design guidelines in order to achieve high efficiency and reliability are discussed.

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Improving Sound Systems by Electrical Means
The availability and flexibility of audio services on various digital platforms have created a high demand for a large range of sound systems. The fundamental components of sound systems such as docking stations, sound bars and wireless mobile speakers consists of a power supply, amplifiers and transducers. Due to historical reasons the design of each of these components are commonly handled separately which are indeed limiting the full performance potential of such systems. To state some examples the requirements of the amplifier distortion could be relaxed if the distortion of the transducer was considered, the power requirement of the power supply could be relaxed if the acoustical power requirement was known, the total sound system efficiency could be optimized which would properly require a radical design change for all the components, communication between the components could lead to intelligent control and protection functionality and so on. In this work different strategies towards improvements of sound systems by electrical means was investigated considering the interfaces between each component and the performance of the full system. The strategies can be categorized by improvements of sound quality, efficiency, size and cost as well as production. The transducer is considered the weakest component when it comes to sound quality which is especially apparent for micro-speakers. Historically the common voltage drive of a transducer has been challenged by the alternative current drive in relation to sound quality. Prior research points out that current drive provides a more direct control of the force applied to the moving parts of a transducer resulting in less distortion and thus improved sound quality but the information is quite sparse. In this work multi-tone distortion related to voltage and current drive of transducers with different characteristics were investigated using a non-linear transducer model. The goal was to predict if and when current drive is advantageous. Current drive was found to be most effective at higher audio frequencies where the non-linear voice coil inductance has a major effect on distortion. At lower audio frequencies transducer related distortions are more pronounced and an old motional feedback technique was revisited. An accelerometer is mounted on the moving parts of the transducer enabling
motional control which lead to a 14 dB distortion reduction in the best case. This technology is very promising since it compensates for most distortion mechanisms of the transducer such as non-linearities, production variation, wear-n-tear, temperature changes and so on. Furthermore the accelerometer output can be used for protection purposes. The only disadvantages are challenges in terms of cost and system complexity. The noise floor of the accelerometer prevents motional control at very low displacements. The main advantage of Class-D audio amplifiers is high efficiency which is often stated to be more than 90%. This is only true at high power levels but at low power levels the efficiency unfortunately drops due to severe switching losses in the semiconductors. This efficiency characteristic is an environmental concern since the amplifier is operating at low power levels for background music in more than 89% of the time and thus a lot of energy is wasted considering the amount of sound systems around the world. Even when the music is played at higher levels the average power is still quite low due to the dynamic behavior of music. In this work energy consumption and sound quality for Class-D audio amplifiers using a peak-tracking power supply scheme was investigated as a means to reduce these losses. It was proven that the efficiency of a class-d amplifier could be increased from approximately 55% to 90% at 1 W output power without sacrificing the distortion. A full tracking power supply scheme would further improve these numbers but the efficiency of the power supply also needs to be taken into account which should be addressed in future work. Power requirements of a sound system have been a large part of this project. There is a surprisingly big lack of scientific information regarding this topic and the goal has thus been to develop an intelligent approach to estimate the power requirements to obtain a size and cost reduction. The greatest challenge was to develop an analyzing tool to estimate the worst case power scenario versus time for a given loudspeaker application. Models including the influence of the enclosure and the most critical non-linearities were derived and experimental verified. Since the power requirement is related to the music material more than 400 music tracks were analyzed and it was proven that full power capability is only needed for a few milliseconds which inspire radical design changes and large reduction of size and cost for the power supply, the amplifiers and the transducers. The work on a power supply based on this research was performed showing a 5 times size reduction compared to a commercial power supply. Future work should expand this analysis to a range of different sound system applications and audio material. An alternative production method for the Class-D amplifier output inductor has been proposed and investigated. A hybrid winding concept for toroids were proposed where the traces in a printed circuit board completes the winding of bended copper foil cut-outs placed in a handy former. The main potential is expected to be production related and faster time to market since the former including the foil cut-outs can be pre-fabricated and pre-shipped to different suppliers around the world. A dynamic 3D model made in matlab and finite element analyses were used to optimize the shape of the bended copper foils to optimize the DC resistance. The DC resistance was reduced by 30% compared to the starting point for a 10 turn toroidal inductor using this method. The combined work indicate that large sound system improvements are in reach by use of electrical means. Innovative solutions have been investigated and improvements of sound quality, efficiency, size and cost as well as production have been demonstrated.
Investigation of Current Driven Loudspeakers

Current driven loudspeakers have previously been investigated but the literature is limited and the advantages and disadvantages are yet to be fully identified. This paper makes use of a non-linear loudspeaker model to analyse loudspeakers with distinct non-linear characteristics under voltage and current drive. A multi tone test signal is used in the evaluation of the driving schemes since it resembles audio signals to a higher degree than the signals used in total harmonic distortion and intermodulation distortion test methods. It is found that current drive is superior over voltage drive in a 5" woofer where a copper ring in the pole piece has not been implemented to compensate for eddy currents. However the drive method seems to be irrelevant for a 5" woofer where the compliance, force factor as well as the voice coil inductance has been optimized for linearity.

Investigation of Energy Consumption and Sound Quality for Class-D Audio Amplifiers using Tracking Power Supplies

The main advantage of Class-D audio amplifiers is high efficiency which is often stated to be more than 90% but at idle or low power levels the efficiency is much lower. The waste energy is an environmental concern, a concern in mobile applications where long battery operation is required and a concern in other applications where multiple amplifier channels are generating heat problems. It is found that power losses at low power levels account for close to 78% of the energy consumption based on typical consumer behavior investigations. This paper investigates the theoretical limits of stepless power supply tracking and its influence on power losses, audio performance and environmental impact for a 130 W class-D amplifier prototype as well as a commercialized class-D amplifier. Both modeled and experimental results verify that a large improvement of efficiency can be achieved. The total harmonic is found to be unaffected by stepless power supply tracking due the high supply rejection ratio of the used amplifiers under test.
**Low Impedance Voice Coils for Improved Loudspeaker Efficiency**

In modern audio systems utilizing switch-mode amplifiers the total efficiency is dominated by the rather poor efficiency of the loudspeaker. For decades voice coils have been designed so that nominal resistances of 4 to 8 Ohms is obtained, despite modern audio amplifiers, using switch-mode technology, can be designed to much lower loads. A thorough analysis of the loudspeaker efficiency is presented and its relation to the voice coil fill factor is described. A new parameter, the drivers mass ratio, is introduced and it indicates how much a fill factor optimization will improve a driver's efficiency. Different voice coil winding layouts are described and their fill factors analyzed. It is found that by lowering the nominal resistance of a voice coil, using rectangular wire, one can increase the fill factor. Three voice coils are designed for a standard 10” woofer and corresponding frequency responses are estimated. For this woofer it is shown that the sensitivity can be improved approximately 1 dB, corresponding to a 30% efficiency improvement, just by increasing the fill factor using a low impedance voice coil with rectangular wire.
Nonlinear Source Emulator
The world is rapidly changing from using the fossil based energy, which is facing exhaustion and having a lot of environmental issues, to the use of renewable energy sources such as sun energy and wind energy. Energy from the sun has become an important source for terrestrial applications and remains the prime source of energy in non-terrestrial applications such as those in sky-explorers. However, a renewable energy source is expensive, bulky, and its performance is weather dependent, which make testing of downstream converters very difficult. As a result, a nonlinear source emulator (NSE) is a good solution to solve the problems associated with the use of real nonlinear sources in testing phases. However, a recent technical survey conducted during this work shows that most existing NSEs have only been concerned with simulating nonlinear systems in terrestrial applications. Furthermore, their dynamic performance were not fast enough in order to imitate how a real nonlinear energy source would react under extreme conditions and operation modes. Particularly, a system in the sky can experience a step change of sunlight irradiation. Moreover, operation modes may include load step between nominal and open circuit, and load step between nominal and short circuit. Under these conditions, a practical nonlinear source system will react almost instantly, whereas the fastest among existing NSEs had a transient of about 3 milliseconds. It is the highlight of this thesis, to demonstrate the development of a proposed NSE system with high dynamic performance. The goal of the work is to achieve a state-of-the-art transient time of 10 µs. In order to produce the arbitrary nonlinear curve, the exponential function of a typical diode is used, but the diode can be replaced by other nonlinear curve reference generator unit. Because nonlinear energy sources come in different sizes and power rating, a single NSE may not be sufficient to simulate a wide selection of nonlinear sources. For this reason, the proposed NSE system is realized as modules. Stacking or connecting multiple modules in parallel will allow simulation of nonlinear source systems with higher output power. In this work, a module will consist of two fundamental units: an isolated power supply and an NSE. The isolated power supply has to possess a very low circuit input-to-output capacitance (very low Cio) in order to reduce the effect of conductive common-mode current produced by the high rate of change of voltage over time (high dv/dt) at the NSE output. v/xvii The contributions of the thesis are based on the development of both units: the low Cio isolated power supply and the high dynamic performance NSE. Both units are investigated theoretically and experimentally. For the very low Cio power supply, we propose a new topology and control, together with a novel transformer structure, in which, its two windings are separated by a significant distance, in order to attain a low interwinding capacitance. A mathematical model is proposed to accurately model the interwinding capacitance of the proposed transformer. The result achieved is a total converter Cio of 10 pF in a 300-W prototype, which is 30 times lower than that of existing approaches. For the NSE, we propose a new circuit consists of an ultrafast tracking converter and a novel nonlinear curve reference generator based on diode curve. Even though the nonlinear curve is based on diode p-n junction, the proposed NSE can simulate other arbitrary nonlinear sources if the diode is replaced by other appropriate nonlinear curve reference generator units. The prototype is 200-W rating. The experimental results show that the proposed NSE can react to a fast change in input source (such as an abrupt change of wind speed for wind turbine emulator), as well as to a load step from nominal to open circuit and vice versa, all within 10 µs. The proposed NSE, therefore, offers the state-of-the-art dynamic performance among devices of the same kind. It also offers a complete solution for simulation of nonlinear source systems of different sizes, both in terrestrial and non-terrestrial applications. Key words: Current transformers, dc-dc power converters, hysteresis, parasitic capacitance, system, stacking, switching converters.
increased electrical field strength and electron mobility compared to Si semiconductors. Moreover, both semiconductor materials are particularly interesting for high temperature operation. These characteristics makes integration of SiC and GaN devices as the next logical step to further increase efficiency and power density in SMPS. This work is part of the PhD project “Single phase PFC converter using wide band-gap devices” and focuses on attainable advantages by introducing wide band-gap semiconductors, and more particularly GaN devices in power factor correction circuits (PFC). First, an overview of current state-of-the-art semiconductor technology in the 600/650 V range, and recent developments on the integration of GaN devices in SMPS are provided. The second part of the thesis provides an insight on semiconductor characterization and compares state-of-the-art Si technology to current available GaN switches. After this overview, a comparison between continuous (CCM) and boundary conduction modes (BCM) in PFC applications is provided based on the semiconductor characterization data. The comparison takes into consideration the electro magnetic interference (EMI) filter size and the converter input inductor volume, as a necessary part for evaluating the converter efficiency and power density. The last part of the thesis provides technical aspects on the controllability of GaN switches in high switching frequency implementations. Moreover, a zero voltage switching (ZVS) control scheme for BCM implementations, capable of operating in the MHz switching frequency range is presented.
Outphasing control of gallium nitride based very high frequency resonant converters

In this paper an outphasing modulation control method suitable for line regulation of very high frequency resonant converters is described. The pros and cons of several control methods suitable for very high frequency resonant converters are described and compared to outphasing modulation. Then the modulation technique is described and the design equations given. Finally a design example is given for a converter consisting of two class E inverters with a lossless combiner and a common half bridge rectifier. It is shown how outphasing modulation can be used for line regulation while insuring equal and purely resistive loading of the inverters. Combined with a proper design of the inverters that, insures they can achieve zero voltage switching across a wide load range, and gallium nitride FETs for the switching devices, this makes it possible to achieve more than 90% efficiency across most of the input voltage range with good line regulation.

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Power Flow Control of a Dual-Input Interleaved Buck/Boost Converter with Galvanic Isolation for Renewable Energy Systems

DC microgrids or nanogrids have attracted increasing research interest in recent years. Therefore, as a critical component, dc-dc converters with multiple inputs are required. In this paper, a dual-input interleaved buck/boost converter is proposed and its corresponding power flow control methods are analyzed and designed accordingly. Furthermore, the design guidelines are discussed. Finally, in order to verify the validity of this study, the measurement results are presented.

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Preisach model of hysteresis for the Piezoelectric Actuator Drive

The Piezoelectric Actuator Drive (PAD) is a precise piezoelectric motor generating high-torque rotary motion, which employs piezoelectric stack actuators in a wobblestyle actuation to generate rotation. The piezoelectric stacked ceramics used as the basis for motion in the motor suffer from hysteretic nonlinearities. In order to model these nonlinearities, the first-order hysteresis reversal curves of the actuators are measured and a discrete Preisach model is derived. This forms a basis that enables the study of different compensation methods. The results show matching between measured and estimated responses within 95.8%.

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Self-oscillating Galvanic Isolated Bidirectional Very High Frequency DC-DC Converter

This paper describes a galvanic isolated bidirectional Very High Frequency (VHF = 30 MHz - 300MHz) ClassE converter. The reason for increasing the switching frequency is to minimize the passive components in the converter. To make the converter topology bidirectional the rectifier has to be synchronous. This increases the complexity of the gate drives, which in this paper is solved by using a self-oscillating gate drive. A bidirectional converter has been implemented and is described in this paper; the converter reaches efficiencies above 80% in forward conduction mode and 73.5% in reverse conduction mode. The designed converter operates at a switching frequency of 35.6 MHz, which is well within the VHF range. The same converter is also implemented with PCB embedded inductors to minimize cost and the physical volume of the total converter.

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Using squeeze-film effect to reduce surface friction in electrostatic actuators
This paper presents a method of reducing load friction in two degrees-of-freedom (2-DOF) transparent electrostatic induction actuator by using vibration-induced squeeze film effect. An experimental set-up was built to prove the concept. An overall 70% reduction in required driving voltage was obtained when the squeeze film is present.

Using_squeeze_film_Zsurzsan_Yamamoto.pdf

Validation of Power Requirement Model for Active Loudspeakers
The actual power requirement of an active loudspeaker during playback of music has not received much attention in the literature. This is probably because no single and simple solution exists and because a complete system knowledge from input voltage to output sound pressure level is required. There are however many advantages that could be harvested from such knowledge like size, cost and efficiency improvements. In this paper a recently proposed power requirement model for active loudspeakers is experimentally validated and the model is expanded to include the closed and vented type enclosures in addition to the main loudspeaker non-linearities.

Very High Frequency Switch-Mode Power Supplies: Miniaturization of Power Electronics
The importance of technology and electronics in our daily life is constantly increasing. At the same time portability and energy efficiency are currently some of the hottest topics. This creates a huge need for power converters in a compact form factor and with high efficiency, which can supply these electronic devices. This calls for new technologies in order to miniaturize the power electronics of today. One way to do this is by increasing the switching frequency dramatically and develop very high frequency switch mode power supplies. If these converters can be designed to operate efficiently, a huge size, weight and cost reduction can be achieved due to the smaller energy storing elements needed at these frequencies. The research presented in this thesis focuses on exactly this. First various technologies for miniaturization of power supplies are studied, e.g. piezo electric transformers, wide band gap semiconductors and integrated power supplies. Afterwards a wide range of topologies suited for operation at very high frequencies is investigated and the most
promising ones are tested experimentally. Through a comparison of these topologies the class DE inverter is found to be superior to the other alternatives, at least for converters with hundreds of volts as input and a few tens of watts output power. A class DE inverter does however require a high side gate drive, which have never been presented before for these frequencies and voltages. This thesis presents the worlds first high side gate drive capable of operating at these frequencies and voltage levels. With this gate drive the worlds first class DE inverter operating at very high frequencies with more than 100 V input is also developed and presented. These achievements are considered huge breakthroughs in the development of technologies for very high frequency switch mode power supplies. At these highly elevated frequencies normal bulky magnetics with heavy cores consisting of rare earth materials, can be replaced by air core inductors embedded in the printed circuit board. This is investigated thoroughly and both spirals, solenoids and toroids are considered, both for use as inductors and transformers. Two control methods are also investigated, namely burst mode control and outphasing. It is shown that a very flat efficiency curve can be achieved with burst mode. A 89.5% efficient converter is implemented and the efficiency only drops 5% at 10% load. This is some of the highest efficiencies presented for converters operating at these frequencies. Burst mode control does however have two major drawbacks, introductions of low frequency harmonics and decreased control bandwidth. Outphasing is therefore investigated as an alternative, which does not introduce these drawbacks. In the last chapter the conducted and radiated electromagnetic interference from two prototypes are investigated, one running with constant output and one with burst mode control implemented. By the end of the thesis it is shown, that a size reduction of 70%, weight reduction of 81%, cost reduction of 56% and efficiency gain of 4.5%-points can be achieved with a very high frequency class DE converter, compared to a commercial product.

**A Direct Driver for Electrostatic Transducers**

Electrostatic transducers represent a very interesting alternative to the traditional inefficient electrodynamic transducers. In order to establish the full potential of these transducers, power amplifiers which fulfill the strict requirements imposed by such loads (high impedance, frequency depended, nonlinear and high bias voltage for linearization) must be developed. This paper analyzes a power stage suitable for driving an electrostatic transducer under biasing. Measurement results of a ±400 V prototype amplifier are shown. THD below 1% is reported.

**A High Power Boost Converter for PV Systems Operating up to 300 kHz using SiC Devices.**

In this paper, a 3kW boost converter for PV applications using SiC devices is introduced. Main focus is to operate the converter over a wide range of switching frequency and to analyze the main loss distributors as well as the efficiency. The
switching element is a recently introduced normally-on SiC JFET and a SiC diode is used. The SiC JFET has been evaluated on an optimized double pulse test circuit showing switching energies four times lower than its Si IGBT competitor. Measurements show a maximum efficiency of 98.6% at 50 kHz. Thermal investigations show that the boost converter can be operated at full power for a switching frequency of 100 kHz using natural cooling. At 200 kHz the boost converter is capable of operating at full power when forced air cooling is applied having a JFET case temperature of less than 90 °C. The case temperature of the JFET increases up to 110 °C at a switching frequency of 300 kHz where a maximum efficiency of 97.5% is achieved.

A High-Voltage Class D Audio Amplifier for Dielectric Elastomer Transducers

Dielectric Elastomer (DE) transducers have emerged as a very interesting alternative to the traditional electrodynamic transducer. Lightweight, small size and high maneuverability are some of the key features of the DE transducer. An amplifier for the DE transducer suitable for audio applications is proposed and analyzed. The amplifier addresses the issue of a high impedance load, ensuring a linear response over the midrange region of the audio bandwidth (100 Hz – 3.5 kHz). THD+N below 0.1% are reported for the ± 300 V prototype amplifier producing a maximum of 125 Var at a peak efficiency of 95%.
Analysis and Comparison of Magnetic Structures in a Tapped Boost Converter for LED Applications

This paper presents an analysis and comparison of magnetic structures in a tapped boost converter for LED applications. The magnetic structure is a coupled inductor which is analyzed in a conventional wire-wound core as well as in a planar structure for different interleaving winding arrangements. The analysis is performed in terms of leakage inductance, winding capacitance and winding loss. Efficiency measurements are performed to verify the effect on the converter performance.

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Analysis and Comparison of Si and SiC Power Devices on a Grid-Tie Fuel Cell Energy Storage System

In renewable energy applications power conversion efficiency is major concern. This is especially true for grid-tie energy storage systems based on bidirectional dc-dc and dc-ac converters where power flows through these system components. Latest developments in power semiconductors technology significantly reduced switching and conduction losses in dc-dc and dc-ac converters allowing efficiencies above 98%. This paper analyzes the efficiency improvement that is achieved by the introduction of SiC power semiconductors in dc-dc and dc-ac converters. The analysis is focuses on fuel cell grid-tie energy storage systems. Results highlight dc-dc conversion efficiencies up to 98.2% with an isolated topology and dc-ac conversion efficiencies up to 97.7%. Overall system efficiency improvements above 1% are achieved compared to traditional Si devices. Results on efficiency improvement are analyzed based on two laboratory converter prototypes of an isolated full bridge boost converter (IFBHC) and a three level T-type inverter (BSNPC).

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A Review on the Implementation of Nonlinear Source Emulators
Renewable energy sources are playing an important role in industry as green sources of energy to reduce carbon dioxide emissions. They possess electrically nonlinear voltage-current characteristics. In the test and development of the downstream converters that utilize these renewable types of energy, the practice of using non-linear source emulators instead of the real non-linear sources has gained a lot of interest. Different methods of implementing non-linear source emulators have been reported in the literature, but no paper exists reviewing and assessing them from different technical points of view. This paper provides a review of the implementation of existing non-linear source emulators. Their configurations are redrawn as block diagrams and their circuit operations are discussed. Different industrial emulators are also briefly reviewed concerning their features.

A Three-Port Topology Comparison for a Low Power Stand-Alone Photovoltaic System
Three-port converter (TPC) topologies for renewable energy systems aim to provide higher efficiency and power density than conventional cascaded structures. This work proposes an analytical comparison of different TPC topologies for a photovoltaic LED lamp stand-alone system. A comparison using component stress factor (CSF) is performed, which gives a quantitative measure of the performance of the converter. The candidate topologies are compared to each other according to a defined LED lighting strategy and a solar irradiation profile.
A VHF Interleaved Self-Oscillating Resonant SEPIC Converter with Phase-Shift Burst-Mode Control

This paper presents design and implementation of the phase-shift burst-mode control method for interleaved self-oscillating resonant SEPIC converters for LED lighting applications. The proposed control method utilizes delays in the turn-on and turn-off of the power stage and control circuitry in order to reduce requirements for the comparator in the regulation circuit. The control method is experimentally evaluated on a 49 MHz dc-dc converter prototype, and the results are presented. The designed converter demonstrates peak efficiency of 81%, maintains efficiency above 75% from 20% load to full load, and is implemented using low-cost switches and integrated circuits.

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Bi-directional high-side current sense circuit for switch mode power supplies

In order to control a power supply using piezoelectric transformer, AC current in the transformer needs to be measured. Due to the control strategy it is necessary to measure amplitude, phase angle and zero crossing of this current. In some applications there is common ground between primary and secondary sides of the transformer which is internally implemented inside the transformer. Therefore, current must be measured from the high voltage line in the presence of high input switching voltage. This paper proposes a resistive current sensing circuit based on discrete components useful for input voltage in the order of 200 V. The bandwidth is at least 200 kHz to allow fundamental frequency detection of piezoelectric transformers in use.

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Characterization of Dielectric Electroactive Polymer transducers
This paper analysis the small-signal model of the Dielectric Electro Active Polymer (DEAP) transducer. The DEAP transducer have been proposed as an alternative to the electrodynamic transducer in sound reproduction systems. In order to understand how the DEAP transducer works, and provide guidelines for design optimization, accurate characterization of the transducer must be established. The small signal model of the DEAP transducer is derived and verified. Impedance measurements are shown for a push-pull DEAP based loudspeaker, and the dependency of the biasing voltage is explained.

A measuring setup is proposed, which allows the impedance to be measured, while the DEAP transducer is connected to its biasing source.

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Class D audio amplifiers for high voltage capacitive transducers
Audio reproduction systems contains two key components, the amplifier and the loudspeaker. In the last 20 – 30 years the technology of audio amplifiers have performed a fundamental shift of paradigm. Class D audio amplifiers have replaced the linear amplifiers, suffering from the well-known issues of high volume, weight, and cost. High efficient class D amplifiers are now widely available offering power densities, that their linear counterparts can not match. Unlike the technology of audio amplifiers, the loudspeaker is still based on the traditional electrodynamic transducer invented by C.W. Rice and E.W. Kellog in 1925 [1]. The poor efficiency of the electrodynamic transducer remains a key issue, and a significant limit of the efficiency of the complete audio reproduction systems. Also the geometric limits of the electrodynamic transducer imposes significant limits on the design of loudspeakers. The challenge of designing a flat loudspeaker based on the electrodynamic transducer is still not fulfilled. Alternatives to the electrodynamic transducer based loudspeaker is the piezoelectric, horn, electrostatic and distributed-mode loudspeaker. The directivity of the electrostatic loudspeaker combined with the low level of acoustical output power and complex amplifier requirements, have limited the commercial success of the technology. Horn or compression drivers are typically favoured, when high acoustic output power is required, this is however at the expense of significant distortion combined with a large volume of the loudspeaker enclosure. Piezoelectric loudspeakers suffers from the poor power handling capability of the piezoelectric ceramic. However a niche is found in the market of hydrophones, because of the excellent impedance matching between the piezoelectric transducer and water. Distributed-mode loudspeakers represent a very interesting attempt for designing flat loudspeakers. The poor bass response combined with the diffuse and uncorrelated acoustic output, remains a challenge [2, 3]. The work presented focuses on the development of an amplifier for a special type of transducer, the DEAP (Dielectric ElectroActive Polymer) one. DEAP based loudspeakers work on the principle of the electrostatic forces, and possess some of the ii same characteristics as the electrostatic loudspeaker. However, the DEAP transducer is constructed by printing compliant, corrugated electrodes on a silicone film. As a consequence a capacitive transducer emerges, which can be shaped into the loudspeaker membrane itself, rolled up into a transducer driving a membrane or being part of an active suspension system for the membrane. In order to document the full potential of the DEAP transducer, suitable amplifiers must be developed. The frequency response and linearity of these amplifier is essential, as the application considered is that of audio. Also the efficiency of the amplifier is a key concern. An introduction to the project is given in chapter 1, followed by a state-of-the-art study in chapter 2. Due to the similarities between the electrostatic loudspeaker and the DEAP transducer, the state-of-the-art has a special focus on amplifiers for electrostatic loudspeakers. Amplifiers for other type of capacitive transducers like piezoelectric ones are also considered. Finally the...
current state-of-the-art for class D audio amplifiers driving the electrodynamic transducer is presented. Chapter 3 gives an introduction to the DEAP transducer as a load in loudspeaker systems. The main purpose being to establish the frequency response of the DEAP input impedance, but also investigate the large signal implications of driving the non-linear transducer of the DEAP. 2-level modulated high voltage amplifiers driving the capacitive load of the DEAP transducer are addressed in chapter 4. An amplifier with fourth order output filter and full-state self-oscillating hysteresis based control loop is proposed. The control loop ensures high open loop gain and active damping. Active damping is a key feature in order to achieve high amplifier efficiency. In order to further increase the output voltage or reduce the semiconductor voltage stress, multilevel inverters as amplifiers for class D audio amplifiers was introduced. The flying capacitor three-level modulated inverter is analyzed, implemented and tested. A control scheme is proposed allowing for the balancing of the flying capacitor, while ensuring active damping. This subject is covered in chapter 5. It is concluded, that class D audio amplifiers for high voltage capacitive transducers can be constructed with THD+N below 0.1 % and peak efficiency above 80 %. However the complexity of the amplifier combined with the current high cost of components, makes the technology of DEAP based loudspeaker unfeasible. Suggestions to future work in the pursuit of successful commercialisation of the DEAP technology for audio applications is given in the final chapter.

Class D audio amplifier with 4th order output filter and self-oscillating full-state hysteresis based feedback driving capacitive transducers

A practical solution is presented for the design of a non-isolated high voltage DC/AC power converter. The converter is intended to be used as a class D audio amplifier for a Dielectric Electro Active Polymer (DEAP) transducer. A simple and effective hysteretic control scheme for the converter (buck with fourth-order output filter) is developed and analyzed. The proposed design is verified experimentally by a 125 VAR prototype amplifier, capable of delivering a peak output voltage of 240 V within the frequency range of 100 Hz – 3.5 kHz. A peak efficiency of 87 % is reported.

Comparative Study of Si and SiC MOSFETs for High Voltage Class D Audio Amplifiers

Silicon (Si) Metal-Oxide-Semiconductor Field-Effect Transistors (MOSFETs) are traditional utilised in class D audio amplifiers. It has been proposed to replace the traditional inefficient electrodynamic transducer with the electrostatic
transducer. This imposes new high voltage requirements on the MOSFETs of class D amplifiers, and significantly reduces the selection of suitable MOSFETs. As a consequence it is investigated, if Silicon-Carbide (SiC) MOSFETs could represent a valid alternative. The theory of pulse timing errors are revisited for the application of high voltage and capacitive loaded class D amplifiers. It is shown, that SiC MOSFETs can compete with Si MOSFETs in terms of THD. Validation is done using simulations and a 500 V amplifier driving a 100 nF load. THD+N below 0.3 % is reported

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Comprehensive Loss Evaluation of Neutral-Point-Clamped (NPC) and T-Type Three-Level Inverters based on a Circuit Level Decoupling Modulation.

In this paper, an efficiency comparison of neutral-point-clamped (NPC) inverters and bipolar switch NPC (T-Type) inverters is studied and the result shows that the T-Type inverter is more efficient at lower switching frequencies. Nevertheless, its efficiency suffers when the switching frequency increases due to high switching loss of the equipped high voltage power switches. In order to reduce switching loss and hereby enhance efficiency, a newly proposed circuit-level decoupling modulation (CLDM) scheme is applied for these two widely used three-phase three-level inverters, as well as their corresponding loss analyses are addressed. The switching loss reduction is evaluated comprehensively under variant modulation indices and load power factors. The analysis results reveal that the CLDM is an alternative discontinuous pulse-width modulation (DPWM) approach for inverters with high switching frequencies in order to achieve superior output voltage quality without lowering efficiency.

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Constant Switching Frequency Self-Oscillating Controlled Class-D Amplifiers

The self-oscillating control approach has been used extensively in class-D amplifiers. It has several advantages such as high bandwidth and high audio performance. However, one of the primary disadvantages in a self-oscillating controlled system is that the switching frequency of the amplifier varies with the ratio of the output voltage to the input rail voltage. In other words, the switching frequency varies with the duty cycle of the output. The drop in the frequency results in lower control bandwidth and higher output voltage ripple, which are undesirable. This paper proposes a new self-oscillating control scheme that maintains a constant switching frequency over the full range of output voltage. The frequency difference is processed by a compensator whose output adjusts the total loop gain of the control system. It has been proven by simulation that a constant switching frequency self-oscillating converter is achieved and the proposed control circuit performs satisfactorily.
DEAP actuator and its high voltage driver for heating valve application

Due to the advantages of DEAP (Dielectric Electro Active Polymer) material, such as light weight, noise free operation, high energy and power density and fast response speed, it can be applied in a variety of applications to replace the conventional transducers or actuators. This paper introduces DEAP actuator to the heating valve system and conducts a case study to discuss the feasible solution in designing DEAP actuator and its driver for heating valve application. First of all, the heating valves under study are briefly introduced. Then the design and the development for DEAP actuator is illustrated in detail, and followed by the detailed investigation of the HV driver for DEAP actuator. In order to verify the implementation, the experimental measurements are carried out for DEAP actuator, its HV driver as well as the entire heating valve system.
Design and Development of Autonomous High Voltage Driving System for DEAP Actuator in Radiator Thermostat

In radiator thermostat applications, DEAP (Dielectric Electro Active Polymer) actuator tends to be a good candidate to replace the conventional self-actuating or step motor based actuator due to its intrinsic advantages. The capacitive property and high voltage (HV) driving demand of DEAP actuator make a high voltage capacitive load driving system to be necessary. The only energy source battery determines it needs to be an autonomous system. The detailed system specifications have been introduced and the corresponding system level design has been proposed. In addition, the detailed design and implementation information has been provided as well, including the power and control stage inside the high voltage converter, the output voltage measurement circuit, the feedback control, etc. Finally, the experimental results have been provided to validate the capability and performance of the driving system.

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Design and Implementation of Power Flow Control for a novel Dual Input DC-DC Converter

In this paper a control strategy for controlling the power flow from input voltage sources of a novel dual-input dcdc converter to the load is introduced. The converter can be used in renewable energy applications with two independent power sources. Firstly, the operation principle of the converter is outlined; then the control method for adjusting power sharing is proposed. In the next step, the controller is implemented in an FPGA, and then a 350W dual input converter is built to verify operation of the proposed control strategy. The experimental results show the excellent ability of the controller to control the power flow in the converter. The implemented controller in FPGA is low cost and simple. The complete system can be practically used in power management for renewable energy sources.

General information
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Design Comparison of Autonomous High Voltage Driving System for DEAP Actuator

As a new type of smart material, the Dielectric Electro Active Polymer (DEAP) is introduced in terms of configuration, working principle and potential applications. The design of an autonomous high voltage driving system for DEAP actuator is investigated. The system configuration and the design methodology of a high voltage converter are discussed in detail. Based on the heating valve application, three different high voltage converter solutions have been proposed. The different proposals have been compared in terms of energy loss, volume and cost. Finally, the design selection suggestions are provided to be a reference for the future designers.

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Design of a 300-Watt Isolated Power Supply with Minimized Circuit Input-to-Output Parasitic Capacitance

This paper presents the design of a 300-Watt isolated power supply for MOS gate driver circuit in medium and high voltage applications. The key feature of the developed power supply is having a very low circuit input-to-output parasitic capacitance, thus maximizing its noise immunity. This makes it suitable for modular stacking applications. The converter is a voltage-controlled current source, utilizing a transformer that has an extremely low inter-winding parasitic capacitance. The experiments show that an overall circuit input-to-output parasitic capacitance of 10 pF can be achieved. Design analysis and experimental results are provided to prove the feasibility of the converter.

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Authors: Nguyen-Duy, K. (Intern), Petersen, L. P. (Intern), Knott, A. (Intern), Thomsen, O. C. (Intern), Andersen, M. A. E. (Intern)
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Design Comparison of Autonomous High Voltage Driving System for DEAP Actuator

As a new type of smart material, the Dielectric Electro Active Polymer (DEAP) is introduced in terms of configuration, working principle and potential applications. The design of an autonomous high voltage driving system for DEAP actuator is investigated. The system configuration and the design methodology of a high voltage converter are discussed in detail. Based on the heating valve application, three different high voltage converter solutions have been proposed. The different proposals have been compared in terms of energy loss, volume and cost. Finally, the design selection suggestions are provided to be a reference for the future designers.

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Design of a High Voltage Bidirectional DC-DC Converter for Driving Capacitive Incremental Actuators usable in Electric Vehicles (EVs)
This paper presents the design of a low input (24 V) and variable high output voltage (0-2.5 kV) bidirectional dc-dc converter for driving a capacitive actuator. The topology is a digitally controlled bidirectional flyback converter with a variable frequency control. The objective is, to design the converter for efficiently charging and discharging the capacitive actuator from 0 V to 2.5 kV and vice versa, respectively. The converter is used to drive a dielectric electro active polymer (DEAP) based capacitive incremental actuator, which has the potential to be used in automotive (e.g., EVs), space and medical industries. The design of the bidirectional flyback converter to charge and discharge a 400 nF capacitive actuator is presented, when 4 kV and 4.5 kV high voltage MOSFETs are used on the secondary high voltage side. The experimental results and efficiency measurements of the converter with the proposed design are provided.

Digital control of a high-voltage (2.5 kV) bidirectional DC-DC converter for driving a dielectric electro active polymer (DEAP) based capacitive actuator
This paper presents a digital control technique to achieve valley switching in a bidirectional flyback converter used to drive a dielectric electro active polymer based incremental actuator. The incremental actuator consists of three electrically isolated, mechanically connected capacitive actuators. The incremental actuator requires three high voltage (~2.5 kV) bidirectional DC-DC converters, to accomplish the incremental motion by charging and discharging the capacitive actuators. The bidirectional flyback converter employs a digital controller to improve efficiency and charge/discharge speed using the valley switching technique during both charge and discharge processes, without the need to sense signals on the output high-voltage side. Experimental results verifying the bidirectional operation of a single high voltage flyback converter are presented, using a film capacitor as the load. Energy efficiency measurements are provided.
Efficiency Investigations of a 3 kW T-Type Inverter for Switching Frequencies up to 100 kHz

This paper deals with a 3kW multilevel inverter used for PV applications. A comparison has been made based on simulations using IGBTs and SiC MOSFETs to see how much efficiency can be gained when SiC diodes are used. A prototype with the same IGBTs and SiC MOSFETs has been built but using regular soft-recovery Si diodes instead of SiC diodes. Efficiencies and switching transitions for different switching frequencies up to 100 kHz have been measured. Thermal investigations of both IGBTs and SiC MOSFETs have been conducted to analyze the feasibility of increased switching frequencies. When SiC MOSFETs are used in combination with Si diodes, switching frequencies could be doubled achieving the same efficiencies than the IGBT converter.

Evaluation of 600V Superjunction Devices in Single Phase PFC Applications under CCM Operation

This paper presents a power density/efficiency evaluation in single phase power factor correction (PFC) applications operating in continuous conduction mode (CCM). The comparison is based on semiconductor dynamic characterization and a mathematical model for prediction of the conducted electromagnetic interference (EMI). The dynamic characterization is based on a low inductive double pulse tester (DPT). The measured switching energy is used in order to evaluate the devices performance in a conventional PFC. This data is used together with the mathematical model for prediction of the conducted electromagnetic interference. The method allows comparing different devices and evaluating the performance as a function of the PFC power density and efficiency.
Frequency dependent loss analysis and minimization of system losses in switchmode audio power amplifiers
In this paper, frequency dependent losses in switch-mode audio power amplifiers are analyzed and a loss model is improved by taking the voltage dependence of the parasitic capacitance of MOSFETs into account. The estimated power losses are compared to the measurement and great accuracy is achieved. By choosing the optimal switching frequency based on the proposed analysis, the experimental results show that system power losses of the reference design are minimized and an efficiency improvement of 8 % in maximum is achieved without compromising audio performances.

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High Current Planar Magnetics for High Efficiency Bidirectional DC-DC Converters for Fuel Cell Applications
Efficiency is one of the main concerns during the design phase of switch mode power supply. Planar magnetics based on PCB windings have the potential to reduce the magnetic manufacturing cost however, one of their main drawbacks comes from their low filling factor and high stray capacitance. This paper presents an analysis of different planar windings configurations focusing on dc and ac resistances in order to achieve highly efficiency in dc-dc converters. The analysis considers different copper thicknesses form 70 μm up to 1500 μm (extreme copper PCB) taking into account manufacturing complexity and challenges. The analysis is focused on a high current inductor for a dc-dc converter for fuel cell applications and it is based on FEM simulations. Analysis and results are verified on a 6 kW dc-dc isolated full bridge boost converter prototype based on fully planar magnetics achieving a peak efficiency of 97.8%.

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High Current Planar Transformer for Very High Efficiency Isolated Boost DC-DC Converters
This paper presents a design and optimization of a high current planar transformer for very high efficiency dc-dc isolated boost converters. The analysis considers different winding arrangements, including very high copper thickness windings. The analysis is focused on the winding ac-resistance and transformer leakage inductance. Design and optimization procedures are validated based on an experimental prototype of a 6 kW dc-dc isolated full bridge boost converter developed on fully planar magnetics. The prototype is rated at 30-80 V 0-80 A on the low voltage side and 700-800 V on the high voltage side with a peak efficiency of 97.8% at 80 V 3.5 kW. Results highlights that thick copper windings can provide good performance at low switching frequencies due to the high transformer filling factor. PCB windings can also provide very high efficiency if stacked in parallel utilizing the transformer winding window in an optimal way.

General information
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High Efficiency Reversible Fuel Cell Power Converter

The large scale integration of renewable energy sources requires suitable energy storage systems to balance energy production and demand in the electrical grid. Bidirectional fuel cells are an attractive technology for energy storage systems due to the high energy density of fuel. Compared to traditional unidirectional fuel cell, bidirectional fuel cells have increased operating voltage and current ranges. These characteristics increase the stresses on dc-dc and dc-ac converters in the electrical system, which require proper design and advanced optimization. This work is part of the PhD project entitled "High Efficiency Reversible Fuel Cell Power Converter" and it presents the design of a high efficiency dc-dc converter developed and optimized for bidirectional fuel cell applications. First, a brief overview of fuel cell and energy storage technologies is presented. Different system topologies as well as different dc-ac and dc-dc converter topologies are presented and analyzed. A new ac-dc topology for high efficiency data center applications is proposed and an efficiency characterization based on the fuel cell stack I-V characteristic curve is presented. The second part discusses the main converter components. Wide bandgap power semiconductors are introduced due to their superior performance in comparison to traditional silicon power devices. The analysis presents a study based on switching loss measurements performed on Si IGBTs, SiC JFETs, SiC MOSFETs and their respective gate drivers. Magnetic components are a fundamental part in most power converters and have a significant impact on power converters performance and cost. After basic introduction on magnetic components, planar magnetics are evaluated for fuel cell (high current) applications as possible candidate for reducing the cost of magnetic components especially for large production volumes. At last, the complete converter design is presented in detailed and characterized in efficiency terms. Both benefits, provided by SiC power devices and by a redesign of the converter layout increased the converter power density up to 2.2 kW/l, achieving efficiency above 98%. A flyback derived topology designed for low power high voltage applications is also presented as a side task in connection to the PhD project.

Integrated magnetic transformer assembly

The present invention relates to an integrated magnetics transformer assembly comprising a first magnetically permeable core forming a first substantially closed magnetic flux path and a second magnetically permeable core forming a second substantially closed magnetic flux path. A first input inductor winding is wound around a first predetermined segment of the first magnetically permeable core and a second input inductor winding is wound around a first predetermined segment of the second magnetically permeable core. The integrated magnetics transformer assembly further comprises a first output inductor winding comprising series coupled first and second half-windings wherein the first half-winding is wound around a second predetermined segment of the first magnetically permeable core and the second half-winding is wound around a second predetermined segment of the second magnetically permeable core. A second output inductor comprises series
coupled first and second half-windings wherein the first half-winding is wound around a third predetermined segment of the first magnetically permeable core and the second half-winding is wound around a third predetermined segment of the second magnetically permeable core. The second half-winding of the first output inductor winding and the second half-winding of the second output inductor winding are configured to produce oppositely directed magnetic fluxes through the second substantially closed magnetic flux path and the first half-winding of the first output inductor winding and the first half-winding of the second output inductor winding are configured to produce aligned, i.e. in the same direction, magnetic fluxes through the first substantially closed magnetic flux path. The integrated magnetics transformer assembly is well-suited for use in a broad range of single input or multiple-input isolated power converter topologies.

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Investigating the Electromechanical Coupling in Piezoelectric Actuator Drive Motor Under Heavy Load
The Piezoelectric Actuator Drive (PAD) is an accurate, high-torque rotary piezoelectric motor that employs piezoelectric stack actuators and inverse hypocycloidal motion to generate rotation. Important factors that determine motor performance are the proper concentric alignment between the motor ring and shaft and the similarity of the stack actuators used. This paper investigates the electromechanical coupling of these factors into the motor current through experimental means.

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Investigation of Heat Sink Efficiency for Electronic Component Cooling Applications
Research and optimisation of cooling of electronic components using heat sinks becomes increasingly important in modern industry. Numerical methods with experimental real-world verification are the main tools to evaluate efficiency of heat sinks or heat sink systems. Here the investigation of relatively simple heat sink application is performed using
modeling based on finite element method, and also the potential of such analysis was demonstrated by real-world measurements and comparing obtained results. Thermal modeling was accomplished using finite element analysis software COMSOL and thermo-imaging camera was used to measure the thermal field distribution. Ideas for future research involving improvement of the experimental setup and modeling verification are given.

### General information
- **State:** Published
- **Organisations:** Department of Electrical Engineering, Electronics, Kaunas University of Technology
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### Investigation of Transformer Winding Architectures for High Voltage Capacitor Charging Applications
Transformer parameters such as leakage inductance and self-capacitance are rarely calculated in advance during the design phase, because of the complexity and huge analytical error margins caused by practical winding implementation issues. Thus, choosing one transformer architecture over another for a given design is usually based on experience or a trial and error approach. This work presents equations regarding calculation of leakage inductance, self-capacitance and AC resistance in transformer winding architectures, ranging from the common non-interleaved primary/secondary winding architecture, to an interleaved, sectionalized and bank winded architecture. The analytical results are evaluated experimentally and through FEM simulations. Different transformer winding architectures are investigated in terms of the losses caused by the transformer parasitics for a bidirectional high-voltage (~1500 V) flyback converter used to drive a dielectric electro active polymer based incremental actuator. The total losses due to the transformer parasitics for the best transformer architectures is reduced by more than a factor of ten compared to the worst case transformer architectures.
Leakage Inductance Calculation for Planar Transformers with a Magnetic Shunt

The magnetic shunt is generally inserted in a planar transformer to increase the leakage inductance which can be utilized as the series inductor in resonant circuits such as the LLC resonant converter. This paper presents a calculation methodology for the leakage inductance of the transformer with a magnetic shunt by means of the stored magnetic energy in the primary and secondary sides of the transformer using the magnetomotive force (MMF) variation method, as well as the stored energy in the shunt based on the reluctance model. The detailed calculation method is described. Both the FEA simulation and the experimental results have proven the validity of the proposed calculation method for leakage inductance.
Loss Performance Analysis of an Isolated Power Supply for Ultrafast Tracking Converters

This paper presents the loss performance analysis of an isolated power supply that is designed for ultra-fast tracking converters. The results of the analysis provide insights into the operation of the proposed power supply, how each physical component contributes to the total loss, and how its efficiency may be further improved.

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Low Capacitive Inductors for Fast Switching Devices in Active Power Factor Correction Applications

This paper examines different winding strategies for reduced capacitance inductors in active power factor correction circuits (PFC). The effect of the parasitic capacitance is analyzed from an electromagnetic compatibility (EMI) and efficiency point of view. The purpose of this work is to investigate different winding approaches and identify suitable solutions for high switching frequency/high speed transition PFC designs. A low parasitic capacitance PCB based inductor design is proposed to address the challenges imposed by high switching frequency PFC Boost converters.

Low Power DEAP Actuator Drive for Heating Valves

Modern heating systems play a key role in providing comfortable living environment and saving energy. The radiator heating valve and thermostat are essential elements to achieve the temperature control in the dwelling space. The existing actuator inside the thermostat either suffers from the operation noise issue, or cannot realize the accurate temperature regulation and remote control. Due to the advancement of the material science, in recent years, a new type of smart material, called DEAP (Dielectric Electro Active Polymer), gradually attracts the attention of researchers. The superior performances of DEAP actuator, such as noise free operation, high energy density, quick response time, etc, make it a possible solution to replace the conventional actuators inside the thermostat. To operate the DEAP actuator in the heating system and considering its intrinsic properties, a driver featuring high output voltage and capacitive load charging ability has been investigated. High voltage flyback converter is proved to be an applicable solution in the heating valve application. The conventional flyback topology and the multiple transformers based primary parallel secondary series flyback converter (PPSSFC) featuring the unidirectional energy flow are investigated in terms of fundamental working principle and practical implementation. The converter with bidirectional energy flow functionality is desired to improve the overall efficiency and has been studied as well. Based on this, the energy efficiency analysis has been carried out to achieve efficiency calculation model. Moreover, two system level control schemes are proposed to achieve the corresponding temperature control. The functionality and energy consumption of the high voltage driver have been verified through the test in the practical heating system with the radiator heating valve and the implemented DEAP actuator. The implemented high voltage flyback converters can achieve relatively low volume and satisfactory efficiencies. In addition, the switching cycle based analytical model and the energy efficiency analysis can be used to well predict the behaviour and efficiency in both charging and discharging mode. The system level energy consumption is relatively low when the burst mode control scheme is applied. If 2.5 Ah batteries are employed, the high voltage driving system with bidirectional converter can run for around 2.1 years.
This paper presents the design of a resonant converter with a switching frequency in the very high frequency range (30-300 MHz), a large step down ratio (10 times) and low output power (1 W). Several different inverters and rectifiers are analyzed and compared. The class E inverter and rectifier are selected based on complexity and efficiency estimates.

Three different power stages are implemented: one with a large input inductor, one with a switch with small capacitances and one with a switch with low on resistance. The power stages are designed with the same specifications and efficiencies from 60.7% to 82.9% are achieved.
Minimization of the transformer inter-winding parasitic capacitance for modular stacking power supply applications

In an isolated power supply, the inter-winding parasitic capacitance plays a vital role in the mitigation of common mode noise currents created by fast voltage transient responses. The lower the transformer inter-winding capacitance, the more immune the power supply is to fast voltage transient responses. This requirement is even more critical for modular stacking applications in which multiple power supplies are stacked. This paper addresses the issue by presenting a detailed analysis and design of an unconventional isolated power supply that uses a ring core transformer with a very low inter-winding parasitic capacitance of 10 pF. Considering its output power of 300 W, this approach yields about 0.033 pF/W inter-winding capacitance over output power, approximately thirty times lower than existing approaches in the literature. This makes the converter a suitable solution for modular stacking of fast voltage switching applications. Mathematical derivation of the inter-winding capacitance and experiments are carried out to prove the validity of the approach.

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Multilevel inverter based class D audio amplifier for capacitive transducers
The reduced semiconductor voltage stress makes the multilevel inverters especially interesting, when driving capacitive transducers for audio applications. A ±300 V flying capacitor class D audio amplifier driving a 100 nF load in the midrange region of 0.1-3.5 kHz with Total Harmonic Distortion plus Noise (THD+N) below 1% is presented.

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Optimization of Bi-Directional Flyback Converter for a High Voltage Capacitor Charging Application
This paper presents an optimization technique for a flyback converter with a bidirectional energy transfer. The main goal is to optimize the converter for driving an incremental dielectric electro active polymer actuator, which must be charged and discharged from 0 V to 2500 V DC, supplied from a 24 V battery. The proposed optimization routine sweeps through a database of low voltage switching devices, and transformer core types and sizes. For each core, important winding parameters such as, the vertical winding space allocation for primary and secondary windings, and the spacing between the secondary windings layers are also swept. This enables the optimization routine to calculate and optimize the losses caused by transformer parasitics such as leakage inductance, selfcapacitance and AC resistance which is crucial in achieving a high energy efficiency and high power density required for this application. The efficiency and loss distribution results provided by the optimization routine provide a deep insight into the transformer design and its impact on total converter efficiency. Finally, experimental work on a prototype of the bi-directional flyback converter is presented. The maximum charging and discharging energy efficiencies of the optimized design, are 96.1% and 85%, respectively.

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Overview of Planar Magnetic Technology — Fundamental Properties
The momentum towards high efficiency, high frequency, and high power density in power supplies limits wide use of conventional wire-wound magnetic components. This article gives an overview of planar magnetic technologies with respect to the development of modern power electronics. The major advantages and disadvantages in the use of planar magnetics for high frequency power converters are covered, and publications on planar magnetics are reviewed. A detailed survey of winding conduction loss, leakage inductance and winding capacitance for planar magnetics is presented so power electronics engineers and researchers can have a clear understanding of the intrinsic properties of planar magnetics.

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Planar magnetics, Transformer, Inductor winding loss, Fringing effect, Planar sandwiched magnetics, Parallel winding, Leakage inductance and winding capacitance
Parallel input parallel output high voltage bi-directional converters for driving dielectric electro active polymer actuators

Dielectric electroactive polymer (DEAP) actuators are capacitive devices which provide mechanical motions when charged electrically. The charging characteristics of a DEAP actuator depends on its size, voltage applied to its electrodes, and its operating frequency. The main idea of this paper is to design and implement driving circuits for the DEAP actuators for their use in various applications. This paper presents implementation of parallel input, parallel output, high voltage (~2.5 kV) bi-directional DC-DC converters for driving the DEAP actuators. The topology is a bidirectional flyback DC-DC converter incorporating commercially available high voltage MOSFETs (4 kV) and high voltage diodes (5 kV). Although the average current of the aforementioned devices is limited to 300 mA and 150 mA, respectively, connecting the outputs of multiple converters in parallel can provide a scalable design. This enables operating the DEAP actuators in various static and dynamic applications e.g. positioning, vibration generation or damping, and pumps. The proposed idea is experimentally verified by connecting three high voltage converters in parallel to operate a single DEAP actuator. The experimental results with both film capacitive load and the DEAP actuator are shown for a maximum charging voltage of 2 kV.

Piezoelectric power converter with bi-directional power transfer

The present invention relates to a bi-directional piezoelectric power converter comprising a piezoelectric transformer. The piezoelectric transformer comprises an input electrode electrically coupled to a primary section of the piezoelectric transformer and an output electrode electrically coupled to an output section of the piezoelectric transformer to provide a transformer output signal. A bi-directional switching circuit is coupled between the output electrode and a DC or AC output voltage of the power converter. Forward and reverse current conducting periods of the bi-directional switching circuit is based on the input drive signal or the transformer output signal such that a forward current is conducted from the output electrode through the bi-directional switching circuit to the DC or AC output voltage in a first state to charge the DC or AC output voltage. In a second state, a reverse current is conducted through the bi-directional switching circuit from the DC or AC output voltage to the output electrode to discharge the DC or AC output voltage and return power to the primary section of the piezoelectric transformer.
Piezoelectric stack actuator parameter extraction with hysteresis compensation

The Piezoelectric Actuator Drive (PAD) is a type of rotary motor that transforms the linear motion of piezoelectric stack actuators into a precise rotational motion. The very high stiffness of the actuators employed make this type of motor suited for open-loop control, but the inherent hysteresis exhibited by piezoelectric ceramics causes losses. Therefore, this paper presents a straightforward method to measure piezoelectric stack actuator equivalent parameters that includes nonlinearities. By folding the nonlinearities into a newly-defined coupling coefficient, the inherent hysteretic behavior of piezoelectric stack actuators can be greatly reduced through precompensation. Experimental results show a fitting accuracy of 98.8% between the model and measurements and a peak absolute error reduction by a factor of 10 compared to the manufacturer-provided parameter. This method improves both the static and dynamic performance of the Piezoelectric Actuator Drive (PAD) while still permitting open-loop control.
Practical investigation of the gate bias effect on the reverse recovery behavior of the body diode in power MOSFETs

This work considers an alternative method of reducing the body diode reverse recovery by taking advantage of the MOSFET body effect, and applying a bias voltage to the gate before reverse recovery. A test method is presented, allowing the accurate measurement of voltage and current waveforms during reverse recovery at high di/dt. Different bias voltages and dead times are combined, giving a loss map which makes it possible to evaluate the practical efficacy of gate bias on reducing the MOSFET body diode reverse recovery, while comparing it to the well known methods of dead time optimization. A selection of 60V devices for synchronous rectification are compared for their suitability for gate bias, while a selection of 600V devices are compared for the efficacy of gate bias for the zero voltage transition converter application. The results show that many of the tested devices benefit from greatly reduced reverse recovery after the application of gate bias.

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Predistortion of a Bidirectional Cuk Audio Amplifier.
Some non-linear amplifier topologies are capable of providing a larger voltage gain than one from a DC source, which could make them suitable for various applications. However, the non-linearities introduce a significant amount of harmonic distortion (THD). Some of this distortion could be reduced using predistortion. This paper suggests linearizing a nonlinear bidirectional Cuk audio amplifier using an analog predistortion approach. A prototype power stage was built and results show that a voltage gain of up to 9 dB and reduction in THD from 6% down to 3% was obtainable using this approach.

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Primary Parallel Secondary Series Flyback Converter (PPSSFC) with Multiple Transformers for Very High Step-Up Ratio in Capacitive Load Charging Applications
Flyback converters are widely used in several applications, however, with this topology it is very challenging to achieve high voltage operation especially with very high step-up ratio (>500) within limited space. This paper presents a new
flyback-based topology which utilizes primary parallel and secondary series transformer connection in order to achieve very high step-up ratio (up to 650) as well as high voltage operation (~2 kV) in a small volume. The topology is presented and analyzed. The advantages and disadvantages of the proposed topology are discussed. A prototype used to verify the proposed topology has been implemented. Finally, experimental results are used to validate the performance of the proposed topology.

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Requirements Specification for Amplifiers and Power Supplies in Active Loudspeakers

This work aims to provide designers with a method to develop a requirements specification for power supplies and amplifiers in active loudspeakers. The motivation is to avoid over-sizing and unnecessary cost. A realistic estimation of the power supplied during playback of audio in a given loudspeaker is obtained by considering a wide range of audio source material, loudness normalization of the source material, crossover filtering, driver characteristics as well as a perceived maximum loudness/volume level. The results from analysing a sub-woofer and a woofer reveal the peak power, peak voltage, peak current and apparent power - thus providing a solid foundation for a requirement specification.

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Self-Oscillating Resonant Gate Drive for Resonant Inverters and Rectifiers Composed Solely of Passive Components

This paper presents a new self-oscillating resonant gate drive composed solely of passive components. The gate drive can be used in various resonant converters and inverters and can be used for both low and high side gate drive. The paper presents examples of how higher order harmonics can be used to improve the performance of the gate drive and how the gate drive can be implemented in a class E inverter, a class DE inverter and in class E inverter with a synchronous class E rectifier. The paper shows practical implementations of all the proposed inverters and converters operating in the Very High Frequency (VHF) range, all showing good results with peak efficiency up to 82% and output regulation from 70% to full load without bursting.
State-of-the-art piezoelectric transformer-based switch mode power supplies

Inductorless switch mode power supplies based on piezoelectric transformers are used to replace conventional transformers in high power density switch mode power supplies. Even though piezoelectric-based converters exhibit a high degree of nonlinearity, it is desirable to use piezoelectric transformers due to their smaller size, lighter weight, lower electromagnetic interference, higher power density, higher efficiency, and lower cost. Moreover, PTs allow converters to operate in high switching frequencies and by obtaining soft switching condition, switching losses will decrease. This paper discusses power supplies with the trend evaluation of piezoelectric transformer-based converter topologies and control methods. The challenges of piezoelectric transformers regarding soft switching capability and nonlinearity are addressed. This paper can be used as a guideline for choosing a proper topology of piezoelectric-based switch mode power supply and a control method for the required application.
Switch-mode High Voltage Drivers for Dielectric Electro Active Polymer (DEAP) Incremental Actuators

Actuators based on dielectric electro active polymers (DEAPs) have attracted special attention in the recent years. The unique characteristics of DEAP are large strain (5-100%), lightweight (7 times lighter than steel and copper), high flexibility (100,000 times less stiff than steel), low noise operation, and low power consumption. DEAP actuators require very high voltage (2-2.5 kV) to fully elongate them. In general, the elongation or stroke length of a DEAP actuator is of the order of mm. DEAP actuators can be configured to provide incremental motion, thus overcoming the inherent size-to-stroke implications of conventional linear actuators, where the stroke is limited by their size. In incremental mode, DEAP actuators are several orders of magnitude shorter in their length compared to the stroke/elongation they provide. The dissertation presents design, control and implementation of switch-mode high voltage DC-DC converters for driving the DEAP based incremental actuators. The DEAP incremental actuator technology has the potential to be used in various industries, e.g., automotive, space and medicine. The DEAP incremental actuator consists of three electrically isolated and mechanically connected capacitive actuators. To accomplish the incremental motion, each capacitive actuator needs to be independently charged (from 0 V to 2.5 kV, within 40-60 ms) and discharged (from 2.5 kV to 0 V, within 40-60 ms) by a high voltage bidirectional DC-DC converter. This thesis investigates a low input voltage (24 V) and high output voltage (0-2.5 kV) bidirectional flyback converter topology for driving the capacitive actuators. Due to very high step-up ratio requirement, the transformer design becomes very complex for charging and discharging the capacitive load at very high voltage. Hence, the thesis particularly focuses on design and optimization of high voltage flyback transformer. The energy efficiency of the bidirectional flyback converter is optimized using a proposed new automatic winding layout (AWL) technique and a comprehensive loss model. Different transformer winding architectures such as non-interleaved and non-sectioned, interleaved and non-sectioned, non-interleaved and sectioned, and interleaved and sectioned have been investigated and implemented. A digital control technique to achieve the valley switching (variable frequency control) during both charge and discharge operations in a bidirectional flyback converter, has been proposed and implemented. Using the proposed digital control scheme, the converter achieved good charge and discharge energy efficiencies in the entire output voltage range, and was able to charge and discharge the capacitive load with in a minimum time period. This digital control scheme is very useful to control and change the charging and discharging profiles of the three high voltage drivers. The DEAP incremental actuator concept has been designed, built and tested. It is demonstrated that the DEAP is feasible for providing incremental motion with variable speed and bidirectional motion. The system integration has been performed by driving the three capacitive actuators (each having a capacitance of 400 nF) up to a maximum voltage of 1.8 kV. Each high voltage driver is able to charge and discharge the 400 nF capacitive actuator within 23 ms and 36 ms, respectively. Finally, a new bidirectional flyback converter topology with multiple series connected outputs is proposed. A theoretical comparison showed that the proposed converter could improve the overall energy efficiency, lower the cost and reduce the volume of high voltage driver. Key words: high voltage, switch-mode power converters, capacitive loads, flyback, transformer design, energy efficiency, dielectric electro active polymer actuators, digital control.
Thermal Modeling and Design of On-board DC-DC Power Converter using Finite Element Method

Power electronic converters are widely used and play a pivotal role in electronics area. The temperature causes around 54% of all power converters failures. Thermal loads are nowadays one of the bottlenecks in the power system design and the cooling efficiency of a system is primarily determined by numerical modeling techniques. Therefore, thermal design through thermal modeling and simulation is becoming an integral part of the design process as less expensive compared to the experimental cut-and-try approach. Here the investigation is performed using finite element method-based modeling, and also the potential of such analysis was demonstrated by real-world measurements and comparison of obtained results. Thermal modeling was accomplished using finite element analysis software COMSOL and thermo-imaging camera was used to measure the thermal field distribution. Also, the improved configuration of power converter was proposed.

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Thermal Modelling and Design of On-board DC-DC Power Converter using Finite Element Method

Power electronic converters are widely used and play a pivotal role in electronics area. The temperature causes around 54% of all power converters failures. Thermal loads are nowadays one of the bottlenecks in the power system design and the cooling efficiency of a system is primarily determined by numerical modelling techniques. Therefore, thermal design through thermal modelling and simulation is becoming an integral part of the design process as less expensive compared to the experimental cut-and-try approach. Here the investigation is performed using finite element method-based modelling, and also the potential of such analysis was demonstrated by real-world measurements and comparison of obtained results. Thermal modelling was accomplished using finite element analysis software COMSOL and thermo-imaging camera was used to measure the thermal field distribution. Also, the improved configuration of power converter was proposed.
A new integrated transformer for three-port dc-dc converter is proposed to overcome the power coupling effect existed in some known multiple inputs dc-dc converters. Orthogonal primary windings arrangement and in series connection of diagonal secondary Windings enables a fully power decoupling between the multiple inputs while the output power is still coupled with all inputs. The energy is accordingly allowed to deliver into the output load simultaneously or at any time-multiplexing scheme. 1-kW experimental prototypes have been built to demonstrate a well-managed power flow for photovoltaic (PV) and battery standalone system.
Ultrafast Switching Superjunction MOSFETs for Single Phase PFC Applications

This paper presents a guide on characterizing state-of-the-art silicon superjunction (SJ) devices in the 600V range for single phase power factor correction (PFC) applications. The characterization procedure is based on a minimally inductive double pulse tester (DPT) with a very low intrusive current measurement method, which enables reaching the switching speed limits of these devices. Due to the intrinsic low and non-linear capacitances in vertical SJ MOSFETs, special attention needs to be paid to the gate drive design to minimize oscillations and limit the maximum at turn off. This paper investigates the latest SJ devices in order to set a reference for future research on improvement over silicon (Si) attained with the introduction of wide bandgap devices in single phase PFC applications. The obtained results show that the latest generation of SJ devices set a new benchmark for its wide bandgap competitors.

Very High Frequency Half Bridge DC/DC Converter

This paper presents the first, off chip, class DE (resonant half bridge) converter working in the Very High Frequency (VHF) range. The benefits of using half bridge circuits both in the inverter and rectifier part of a VHF resonant dc/dc converter are analyzed and design equations for all components in the power stage are given. The circuit has been simulated to verify the accuracy of the presented equations and an efficiency of 89% has been shown. A prototype has been implemented with self-oscillating resonant gate drives driving the switches. The prototype has been used to drive an LED string and shows an efficiency of 85% at 29 MHz with 130 V input and 13.4 W output. The efficiency was above 82% in the range 110-150 V input with output power between 10.3 W and 16.5 W.
Wide Operating Voltage Range Fuel Cell Battery Charger

DC-DC converters for fuel cell applications require wide voltage range operation due to the unique fuel cell characteristic curve. Primary parallel isolated boost converter (PPIBC) is a boost derived topology for low voltage high current applications reaching an efficiency figure up to 98.2%. This paper proposes a new operation mode for extending the input and output voltage range in PPIBC. The proposed solution does not modify PPIBC power stage; the converter gain is modified by short-circuiting one of the parallel connected primary windings in the topology. The change in operation mode divides by two the converter input-to-output voltage gain. This allows covering the conditions when the fuel cell stack operates in the activation region (maximum output voltage) and increases the degrees of freedom for converter optimization. The transition between operating modes is studied because represents a change in the converter steadystate conditions. A solution is proposed based on precalculation of the duty cycle prior to the transition.

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Analysis and Design of Fully Integrated Planar Magnetics for Primary-Parallel Isolated Boost Converter

A high efficient planar integrated magnetics (PIM) design approach for primary-parallel isolated boost converters is presented. All magnetic components in the converter including two input inductors and two transformers with primary-parallel and secondary-series windings are integrated into an E-I-E core geometry, reducing the total ferrite volume and core loss. The transformer windings are symmetrically distributed into the outer legs of E-cores and the inductor windings are wound on the center legs of E-cores with air gaps. Therefore, the inductor and the transformer can be operated independently. Due to the low reluctance path provided by the shared I-core, the two input inductors can be integrated independently, and also the two transformers can be partially coupled each other. Detailed characteristics of the integrated
structure have been studied in this paper. AC losses in the windings and the leakage inductance of the transformer are kept low by interleaving the primary and secondary turns of the transformers substantially. Because of the combination of inductors and transformers, maximum output power capability of the fully integrated module needs to be investigated. Winding loss, core loss and switching loss of MOSFETs are analyzed in-depth in this work as well. To verify the validity of the design approach, a 2-kW prototype converter with two primary power stages is implemented for a fuel cell fed traction applications with 20-50 V input and 400-V output. An efficiency of 95.9% can be achieved during 1.5-kW nominal operating conditions. Experimental comparisons between the PIM module and three separated cases have illustrated the PIM module has advantages of lower footprint and higher efficiencies.
Analysis of DC/DC Converter Efficiency for Energy Storage System Based on Bidirectional Fuel Cells

Renewable energy sources are fluctuating depending on the availability of the energy source. For this reason, energy storage is becoming more important and bidirectional fuel cells represent an attractive technology. Fuel cells require high current low-voltage dc-dc or dc-ac converters as power interface to the grid. In power electronics, the converter efficiency is characterized at fixed operating voltage for various output power. This type of characterization is not suitable for fuel cells, since as the power from the fuel cell increases, the cell voltage decreases. This paper analyses how the fuel cell I-V characteristics influence the power electronics converter efficiency and their consequence on the overall system. A load dependent efficiency curve is presented based on experimental results from a 6 kW dc-dc converter prototype including the most suitable control strategy which maximizes the dc-dc conversion efficiency.

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An integrated magnetics component

The present invention relates to an integrated magnetics component comprising a magnetically permeable core comprising a base member extending in a horizontal plane and first, second, third and fourth legs protruding substantially perpendicularly from the base member. First, second, third and fourth output inductor windings are wound around the first, second, third and fourth legs, respectively. A first input conductor of the integrated magnetics component has a first conductor axis and extends in-between the first, second, third and fourth legs to induce a first magnetic flux through a first flux path of the magnetically permeable core. A second input conductor of the integrated magnetics component has a second coil axis extending substantially perpendicularly to the first conductor axis to induce a second magnetic flux through a first flux path of the magnetically permeable core. Another aspect of the invention relates to a multiple-input isolated power converter comprising the integrated magnetics component.

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An interface board for developing control loops in power electronics based on microcontrollers and DSPs Cores - Arduino/ChipKit/dsPIC/DSP/TI Piccolo

In this paper a new control-interface card for developing simple control loops and generating test signals for power electronic converters is presented. The control board can operate with two computational cores (Texas Instruments and Microchip) allowing using the preferred DSP architecture and development environment. Moreover, the interface board can operate with open hardware Arduino-like boards such as the ChipKit Uno32. The paper also describes how to enhance the performance of a ChipKit Uno32 with a dsPIC obtaining a more suitable solution for power electronics. The basic blocks and interfaces of the boards are presented in detail as well as the board main specifications. The board operation has been tested with three core platforms: TI Piccolo controlSTICK, a Microchip dsPIC and a ChipKit Uno32 (Arduino-like platform). The board was used for generating test signals for characterizing 1200 V Si and SiC power semiconductors. A 6 kW dc-dc converter prototype is presented; the converter is based on the developed interface board.

Boost converter with combined control loop for a stand-alone photovoltaic battery charge system

The converter control scheme plays an important role in the performance of maximum power point tracking (MPPT) algorithms. In this paper, an input voltage control with double loop for a stand-alone photovoltaic system is designed and tested. The inner current control loop with high crossover frequency avoids perturbations in the load being propagated to the photovoltaic panel and thus deviating the operating point. Linearization of the photovoltaic panel and converter state-space modeling is performed. In order to achieve stable operation under all operating conditions, the photovoltaic panel is linearized at the maximum power point (MPP) and at the voltage and current source regions. A settling time under 1 ms is obtained which allows fast MPP tracking implementation.
Design considerations for a digital audio Class D output stage with emphasis on hearing aid application

This work deals with power optimization of the audio signal processing back end (the interpolation filter, the ΣΔ modulator and the Class D power amplifier) as a whole. Understanding of the design parameter tradeoffs is used to derive the specifications for the back end and to understand the state-of-the-art. A figure-of-merit which allows judging the power consumption of the digital part of the back end early in the design process is proposed. The insight into the tradeoffs involved is subsequently used to optimize the interpolation filter and the system-level parameters of the ΣΔ modulator so that the switching frequency of the Class D power amplifier – the main power consumer in the back end - is minimized.

- In the multistage interpolation filter the first stage is implemented as a half-band IIR filter consisting of two parallel all-pass cells. A novel approach that does not require any rigorous numerical techniques is proposed to quantize the filter coefficients. Together with the simple all-pass cells the resulting filter has very low hardware / power demands compared to the state-of-the-art.
- The switching frequency of the Class D power amplifier is reduced at the cost of the increase of the maximum clock frequency in the digital part of the back end. This approach moves the burden from the Class D power amplifier to the digital part, which easily scales with the IC technologies of today - optimized for digital design.
- Judging by the figure-of-merit five design iterations are performed that lower the power consumption of the interpolation filter combined with the ΣΔ modulator by 82% and the switching frequency of the Class D power amplifier by 94% compared to the initial design.
- The result is the digital part of the back end optimized with respect to power, which provides audio performance comparable to the state-of-the-art. This is combined with the lowest switching frequency of the Class D power amplifier reported in literature for the ΣΔ modulator-based digital back end.

Future work for the digital ΣΔ modulator and the power amplifier with feedback is proposed.

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### Detailed Behavior Analysis for High Voltage Bidirectional Flyback Converter Driving DEAP Actuator

DEAP (Dielectric Electro Active Polymer) is a new type of smart material. The tubular actuator based on DEAP material has various potential applications and is fundamentally a capacitive load. A high voltage bidirectional converter is required to provide power for the actuator. A bidirectional flyback based converter has been implemented. The parasitic elements have serious influence for the operation of the converter, especially in the high output voltage condition. The detailed behavior analysis has been performed considering the impact of the critical parasitic parameters. The converter has been analyzed for both charging and discharging processes in low and high output voltage operating occasions. The experimental waveforms can validate the analysis.

### Dielectric Electro Active Polymer Incremental Actuator Driven by Multiple High-Voltage Bi-directional DC-DC Converters

This paper presents driving circuit for a recently invented dielectric electro active polymer (DEAP) incremental actuator. The basic operation of such an actuator is bioinspired from the movement of an inchworm. The actuator consists of three electrically isolated, and mechanically connected capacitive sub-actuators. It needs to be driven by three high voltage (~2.5 kV) DC-DC converters, to achieve the linear incremental motion. The topology used for this application is a bi-directional flyback DC-DC converter. The control of the incremental actuator involves, implementation of digital controller used for controlling charge and discharge sequences of the individual sub-actuators, and monitoring and adjustment of the output voltages of three high voltage DC-DC converters to provide over-voltage protection capability. Three power stages of the proposed converter were experimentally tested. The experimental results and efficiency measurements are shown.
Discontinuous PWM Modulation Strategy with Circuit-Level Decoupling Concept of Three-Level Neutral-Point Clamped (NPC) Inverter

A new pulse width modulation (PWM) strategy which is an alternative approach of discontinuous PWM (DPWM) for a three-level neutral point clamped (NPC) inverter is developed and presented in this paper. The proposed PWM scheme not only takes advantage of the special properties available in NPC inverters, but also reduces the switching loss of the inverter along with an inherent neutral point (NP) voltage control. Based on a circuit-level decoupling concept, the NPC inverter can be decoupled into two three-level Buck converters in every defined operating section, and thereby the controller design can be simplified. The salient features of the proposed scheme, as compared with the existing carrier-based DPWM strategies, are: 1) its reduced computational processing time, 2) its capability to balance the DC-link voltage without any additional control and 3) its reduced complexity e.g. only one carrier wave needed for pulse width modulating. Same as a space vector modulation, the maximum modulation index, 1.1547, can be attainable by the proposed scheme. Moreover, compared to conventional continuous sinusoidal pulse width modulation, using this technique here the switching losses of the devices can be reduced by one third. In order to explain the operation of this topology properly, the decoupling principle including the driving signal synthesis and the NP potential variation are analyzed in detail in this paper. Finally the viability and performance of the proposed modulation scheme are shown through simulation and experimental results in a laboratory prototype.

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Driving electrostatic transducers

Electrostatic transducers represent a very interesting alternative to the traditional inefficient electrodynamic transducers. In order to establish the full potential of these transducers, power amplifiers which fulfill the strict requirements imposed by such loads (high impedance, frequency depended, nonlinear and high bias voltage for linearization) must be developed. This paper analyzes power stages and bias configurations suitable for driving an electrostatic transducer. Measurement results of a 300 V prototype amplifier are shown. Measuring THD across a high impedance source is discussed, and a high voltage attenuation interface for an audio analyzer is presented. THD below 0.1% is reported.

General information

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This paper introduces a new zero-voltage-switching (ZVS) isolated DC-DC converter with two input ports which can be utilized in hybrid energy systems, for instance, in a fuel cell and super-capacitor system. By fully using two high frequency transformers, the proposed converter can effectively integrate a current-fed boost half-bridge (BHB) and a full-bridge (FB) into one equivalent circuit configuration which has dual-input ability and additionally it can reduce the number of the power devices. With the phase-shift control, it can achieve zero-voltage switching turn-on of active switches and zero-current switching (ZCS) turn-off of diodes leading to negligible reverse recovery loss. Voltage conversion ratio is higher compared to the conventional boost converter owing to the BHB circuit and the corresponding control. Finally, a
25~50 V input, 300~400 V output prototype with a 600 W nominal power rating are built up and tested to demonstrate the effectiveness of the proposed converter topology.

Estimation of Transformer Parameters and Loss Analysis for High Voltage Capacitor Charging Application
In a bi-directional DC-DC converter for capacitive charging application, the losses associated with the transformer makes it a critical component. In order to calculate the transformer losses, its parameters such as AC resistance, leakage inductance and self capacitance of the high voltage (HV) winding has to be estimated accurately. This paper analyzes the following losses of bi-directional flyback converter namely switching loss, conduction loss, gate drive loss, transformer core loss, and snubber loss, etc. Iterative analysis of transformer parameters viz., AC resistance, leakage inductance and stray capacitance of the HV winding will lead to a considerable reduction in converter losses. In this work, a 24 V to 2.5 kV bidirectional flyback converter has been implemented and the same has been used for loss calculation.

Evolution of Very High Frequency Power Supplies
The ongoing demand for smaller and lighter power supplies is driving the motivation to increase the switching frequencies of power converters. Drastic increases however come along with new challenges, namely the increase of switching losses in all components. The application of power circuits used in radio frequency transmission equipment helps to overcome those. However those circuits were not designed to meet the same requirements as power converters. This paper summarizes the contributions in recent years in application of very high frequency (VHF) technologies in power electronics, shows results of the recent advances and describes the remaining challenges. The presented results include a self-oscillating gate-drive, air core inductor optimizations, an offline LED driver with a power density of 8.9 W/cm3 and a 120 MHz, 9 W DC powered LED driver with 89 % efficiency as well as a bidirectional VHF converter. The challenges to be solved before VHF converters can be used effectively in industrial products are within those three categories: components, circuit architectures and reliability testing.
Forward Conduction Mode Controlled Piezoelectric Transformer-Based PFC LED Drive

Light-emitting diode (LED) illumination is getting more and more common; as LED’s performance is rising, the price is falling and is getting competitive. Some of the challenges of ac mains supplied illumination are the requirement of power factor correction (PFC) and the competitiveness of a low priced market. In this paper, a new forward conduction mode (FCM) control method for piezoelectric transformer (PT)-based power converters is proposed. A PT-based LED drive facilitating passive PFC is developed, utilizing and validating the FCM control method. The drive utilizes an inductorless half-bridge topology and for circuit minimization and simplicity it has no load regulation and has a 100-Hz output modulation. The proposed FCM control method ensures that the PT is operated at its optimal operation frequency, which ensures soft-switching operation and a constant gain. As a result a 6.5-W PT-based PFC LED drive has been developed, supplied from 230-V 50-Hz ac mains, achieving a power factor of 0.96.
Fuel Cell and Battery Powered Forklifts

A hydrogen-powered materials handling vehicle with a fuel cell combines the advantages of diesel/LPG and battery powered vehicles. Hydrogen provides the same consistent power and fast refueling capability as diesel and LPG, whilst fuel cells provide energy efficient and zero emission Electric propulsion similar to batteries. In this paper, the performance of a forklift powered by PEM fuel cells and lead acid batteries as auxiliary energy source is introduced and investigated. In this electromechanical propulsion system with hybrid energy/power sources, fuel cells will deliver average power, whilst batteries will handle all the load dynamics, such as acceleration, lifting, climbing and so on. The electrical part of the whole propulsion system for forklift has been investigated in details. The energy management strategy is explained and verified through simulation. Finally, experimental results from a prototype are given to present the validity of analysis and design.
High Voltage Bidirectional Flyback Converter Driving DEAP Actuator for Automotive Applications

DEAP (Dielectric Electro Active Polymer) is a new type of smart material. The actuator based on DEAP material tends to be applied in a variety of occasions. It will have prosperous future when employed in automotive field. This paper is focused on the design and implementation of a low input voltage and high output voltage bidirectional converter for driving the DEAP actuator. The detailed design and implemented parameters have been summarized, especially for the high voltage transformer. The experiments have been performed to validate the design and implementation.

High Voltage Bi-directional Flyback Converter for Capacitive Actuator

This paper presents a high voltage DC-DC converter topology for bi-directional energy transfer between a low voltage DC source and a high voltage capacitive load. The topology is a bi-directional flyback converter with variable switching frequency control during the charge mode, and constant switching frequency control during the discharge mode. The converter is capable of charging the capacitive load from 24 V DC source to 2.5 kV, and discharges it to 0 V. The flyback converter has been analyzed in detail during both charge and discharge modes, by considering all the parasitic elements in the converter, including the most dominating parameters of the high voltage transformer viz., self-capacitance and leakage inductance. The specific capacitive load for this converter is a dielectric electro active polymer (DEAP) actuator, which can be used as an effective replacement for conventional actuators in a number of applications. In this paper, the discharging energy efficiency definition is introduced. The proposed converter has been experimentally tested with the film capacitive load and the DEAP actuator, and the experimental results are shown together with the efficiency measurements.
Hybrid winding concept for toroids
This paper proposes a hybrid winding concept for toroids using the traces in a printed circuit board to make connection to bended copper foil cutouts. In a final product a number of strips with a certain thickness would be held by a former and the whole assembly could be placed by pick and placement machinery. This opens up the possibility for both an automated manufacturing process and an automated production process of toroidal magnetics such as power inductors, filtering inductors, air core inductors, transformers etc. Both the proposed hybrid and the common wire wound winding implementation is simulated using finite element modeling and the DC and AC resistance of the inductors are verified with experimental measurements on prototypes. It is found that commercial available layer thickness of printed circuit boards is a bottleneck for high power applications. Furthermore, the winding configuration is crucial for performance.

Hysteretic self-oscillating bandpass current mode control for Class D audio amplifiers driving capacitive transducers
A hysteretic self-oscillating bandpass current mode control (BPCM) scheme for Class D audio amplifiers driving capacitive transducers are presented. The scheme provides excellent stability margins and low distortion over a wide range of operating conditions. Small-signal behavior of the amplifier is analysis through transfer function based linear control methodology. Measurements are performed on a single-ended ± 300 V half-bridge amplifier driving a capacitive load of 100 nF. Total Harmonic Distortion plus noise (THD+N) below 0.1 % are reported. Transducers representing a capacitive load and obeying the rules of electrostatics have been known as very interesting alternatives to the traditional inefficient electrodynamic transducers. When driving capacitive transducers from a Class D audio amplifier the high impedance nature of the load represents a key challenge. The BPCM control scheme ensures a flat frequency response (within 3 db) over the midrange region of 200 Hz – 3.5 kHz.
Interleaved Boost-Half-Bridge Dual–Input DC-DC Converter with a PWM plus Phase-Shift Control for Fuel Cell Applications

This paper presents an isolated dual-input DC-DC converter with a PWM plus phase-shift control for fuel cell hybrid energy systems. The power switches are controlled by phase shifted PWM signals with a variable duty cycle, and thus the two input voltages as well as the output voltage can be regulated effectively. By using the second input capacitor and the high side switches as an inherent active clamping circuit, zero-voltage switching (ZVS) for the power MOSFETs on the primary side, and zero-current switching (ZCS) for the diodes on the secondary side are achieved respectively to improve the performance of the proposed PWM converter. The principle of operation is analyzed and some design considerations are discussed. Simulation results using PLECS are given to verify the proposed analysis and design. An experimental converter prototype has been designed, constructed and tested in the laboratory to verify the validity of the theoretical analysis and also demonstrate the converter’s performance over wide variations in input voltage.

Investigation of a Hybrid Winding Concept for Toroidal Inductors using 3D Finite Element Modeling

This paper investigates a hybrid winding concept for a toroidal inductor by simulating the winding resistance as a function of frequency. The problem of predicting the resistance of a non-uniform and complex winding shape is solved using 3D Finite Element Modeling. A prototype is built and tested experimentally to verify the simulation results. Finally COMSOL LiveLink to CAD is utilized to highlight a bottleneck for this kind of winding scheme.
This paper presents an isolated bidirectional dc/dc converter based on primary parallel isolated boost converter (PPIBC). This topology is an efficient solution in low voltage high power applications due to its ability to handle high currents in the low voltage side. In this paper, the converter has been modeled using non-ideal components and operated without any additional circuitry for startup using a digital soft-start procedure. Simulated and measured loop gains have been compared for the validity of the model. On-the-fly current direction change has been achieved with a prototype interconnecting two battery banks. A second prototype has been constructed and tested for supercapacitor operation in constant power charge mode.

Isolated Full Bridge Boost DC-DC Converter Designed for Bidirectional Operation of Fuel Cells/Electrolyzer Cells in Grid-Tie Applications

Energy production from renewable energy sources is continuously varying, for this reason energy storage is becoming more and more important as the percentage of green energy increases. Newly developed fuel cells can operate in reverse mode as electrolyzer cells; therefore, they are becoming an attractive technology for energy storage grid-tie applications. In this application dc-dc converter optimization is very challenging due to the large voltage range that the converter is expected to operate. Moreover, the fuel-electrolyzer cell side of the converter is characterized by low voltage and high current. Dc-dc converter efficiency plays a fundamental role in the overall system efficiency since processed energy is always flowing through the converter; for this reason, loss analysis and optimization are a key component of the converter design. The paper presents an isolated full bridge boost dc-dc converter (IFBB) designed for this new application focusing on losses analysis. The system topology is briefly discussed and the major concerns related to the system, cells stacks and converter operating points are analyzed. The dc-dc converter losses are modeled and presented in detail; the analysis is validated on adc-dc converter prototype rated at 6 kW 30-80 V 0-80 A on the low voltage side and 700-800 V on the high voltage side (for a grid-tie application). The prototype is based on fully planar magnetic, Si MOSFETs, Si IGBTs and SiC diodes; efficiencies up to ~96.5% and ~97.8% were demonstrated depending on the
Leakage Inductance Calculation for Planar Transformers with a Magnetic Shunt

The magnetic shunt is generally inserted in a planar transformer to increase the leakage inductance which can be utilized as the series inductor in resonant circuits such as the LLC resonant converter. This paper presents a calculation methodology for the leakage inductance of the transformer with a magnetic shunt by means of the stored magnetic energy in the primary and secondary sides of the transformer using the magnetomotive force (MMF) variation method, as well as the stored energy in the shunt based on the reluctance model. The detailed calculation method is described. Both the FEA simulation and the experimental results have proven the validity of the proposed calculation method for leakage inductance.

Low power very high frequency resonant converter with high step down ratio

This paper presents the design of a resonant converter with a switching frequency in the very high frequency range (30-300MHz), a large step down ratio and low output power. This gives the designed converters specifications which are far from previous results. The class E inverter and rectifier have been selected for the prototype and the circuits are analyzed and simulated. Three different power stages are implemented based on different design parameters. The first prototype is with a switch with small capacitances, the second one is with a switch with low on resistance and the last one is with a large input inductor. The power stages are designed with the same specs and efficiencies from 60.7–82.9% are achieved.
Modular space-vector pulse-width modulation for nine-switch converters

Recently, nine-switch inverter (NSI) has been presented as a dual-output inverter with constant frequency (CF) or different frequency (DF) operation modes. However, the CF mode is more interesting because of its lower switching device rating. This study proposes a new space-vector modulation (SVM) method for the NSI that supports both the CF and DF modes, whereas conventional SVM of NSI can be used only in the DF mode. The proposed SVM can be easily implemented based on the conventional six-switch inverter SVM modules. The performance of the proposed SVM is verified by the simulation and experimental results.
On the Ongoing Evolution of Very High Frequency Power Supplies
The ongoing demand for smaller and lighter power supplies is driving the motivation to increase the switching frequencies of power converters. Drastic increases however come along with new challenges, namely the increase of switching losses in all components. The application of power circuits used in radio frequency transmission equipment helps to overcome those. However those circuits were not designed to meet the same requirements as power converters. This paper summarizes the contributions in recent years in application of very high frequency (VHF) technologies in power electronics, describes the remaining challenges and shows results of the recent advances, among others a 120MHz, 9 W LED driver with 89% efficiency.

Optimizing dc-resistance of a foil wounded toroidal inductor combining matlab and comsol
An optimization routine is presented to optimize the shape of a foil winding of a toroid inductor in terms of the DC resistance. MATLAB was used to define the geometry of the foil winding and COMSOL was used to import the geometry and create a 3D finite element model. The initial parameters, the execution and the results of the optimization routine were all managed from a graphical user interface and the feedback from COMSOL in terms of DC resistance was used to find and plot the optimal shape of the foil. The DC resistance was improvement by 31% compared with previous work for a 10 turn toroidal inductor.
Optimizing Inductor Winding Geometry for Lowest DC-Resistance using LiveLink between COMSOL and MATLAB

An optimization routine is presented to optimize a hybrid winding geometry for a toroid inductor in terms of the DC resistance. The hybrid winding geometry consist of bended foil pieces connected through traces in a printed circuit board. MATLAB is used to create a graphical user interface that visually plots the winding using input parameters such as core dimensions, number of turns, clearance between windings, and the winding angle of each segment of the winding. COMSOL LiveLink is used to import the winding geometry from MATLAB and create a 2D finite element model to simulate the DC resistance. Finally the winding configuration with the lowest DC resistance is found by sweeping the parameters of the winding geometry and simulate and save the result in each step. An improvement of more than 30% compared to previous work where achieved in this way.
Self-oscillating loop based piezoelectric power converter

The present invention relates to a piezoelectric power converter comprising an input driver electrically coupled directly to an input or primary electrode of the piezoelectric transformer without any intervening series or parallel inductor. A feedback loop is operatively coupled between an output voltage of the piezoelectric transformer and the input driver to provide a self-oscillation loop around a primary section of the piezoelectric transformer oscillating at an excitation frequency. Electrical characteristics of the feedback loop are configured to set the excitation frequency of the self-oscillation loop within a zero-voltage-switching (ZVS) operation range of the piezoelectric transformer.

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SiC JFET Cascode Loss Dependency on the MOSFET Output Capacitance and Performance Comparison with Trench IGBTs

In power electronics there is a general trend to increase converters efficiencies and power densities; for this reason new power semiconductors based on materials such as Silicon Carbide (SiC) and Gallium Nitride (GaN) are becoming more popular. This is especially valid for renewable energies applications where the generated energy has a higher cost than with conventional energy sources. This paper proposes an experimental analysis of the switching performance of a high voltage SiC JFET connected in cascade connection with a low voltage MOSFET. The analysis focuses on the influence of the MOSFET output capacitance on the switching performance of the SiC Cascode connection in terms of switching energy loss, dV/dt and dI/dt stresses. The Cascode connection switching performances are compared with the switching performance latest Trench IGBTs. The analysis is based on a set of several laboratory measurements and data post-processing in order to properly characterize the devices and quantify whether the SiC JFET Cascode connection can provide good performances with a simple MOSFET gate driver.

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This paper presents a new zero-voltage-switching (ZVS) isolated dc-dc converter which combines a boost halfbridge (BHB) cell and a full-bridge (FB) cell, so that two different type of power sources, i.e. both current-fed and voltage-fed, can be coupled effectively by the proposed converter for various applications, such as fuel cell and super-capacitor hybrid energy system. By fully using two high frequency transformers and a shared leg of switches, number of the power devices and associated gate driver circuits can be reduced. With phase-shift control, the converter can achieve ZVS turn-on of active switches and zero-current switching (ZCS) turn-off of diodes. In this paper, derivation, analysis and design of the proposed converter are presented. Finally, a 25~50 V input, 300~400 V output prototype with a 600 W nominal power rating is built up and tested to demonstrate the effectiveness of the proposed converter topology.
Switching Performance Evaluation of Commercial SiC Power Devices (SiC JFET and SiC MOSFET) in Relation to the Gate Driver Complexity

Silicon Carbide (SiC) power devices can provide a significant improvement of power density and efficiency in power converters. The switching performances of SiC power devices are often a trade-off between the gate driver complexity and the desired performance; this is especially true for SiC BJTs and JFETs. The recent introduction of SiC MOSFET has proved that it is possible to have highly performing SiC devices with a minimum gate driver complexity; this made SiC power devices even more attractive despite their device cost. This paper presents an analysis based on experimental results of the switching losses of various commercially available Si and SiC power devices rated at 1200 V (Si IGBTs, SiC JFETs and SiC MOSFETs). The comparison evaluates the reduction of the switching losses which is achievable with the introduction of SiC power devices; this includes analysis and considerations on the gate driver complexity and cost.

Very High Frequency Interleaved Self-Oscillating Resonant SEPIC Converter

This paper describes analysis and design procedure of an interleaved, self-oscillating resonant SEPIC converter, suitable for operation at very high frequencies (VHF) ranging from 30 MHz to 300 MHz. The presented circuit consists of two resonant SEPIC DC-DC converters, and a capacitive interconnection network between the switches which provides self-oscillating and interleaved operation. A design approach to ensure zero voltage switching (ZVS) condition of the MOSFET devices is provided. To verify the proposed method, an 11 W, 50 MHz prototype was built using low-cost VDMOS devices and experimental results are presented. Peak achieved efficiency was 87%. 
Very High Frequency Resonant DC/DC Converters for LED Lighting

This paper presents a very high frequency DC/DC converter for LED lighting. Several resonant topologies are compared and their usability discussed. At the end the resonant SEPIC converter is chosen based on the achievable power density and total bill of material. Simulations of a 51 MHz converter with 40 V input and 15 V output are made. The simulation shows possibility of achieving efficiency up to 87% even with a HEXFET Power MOSFET. Three prototypes of the simulated converter are implemented showing good correlation with simulations. The prototypes have efficiencies up to 84% and power densities up to 8.9 W/cm³ (146 W/in³).

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VHF Series-Input Parallel-Output Interleaved Self-Oscillating Resonant SEPIC Converter

If the switches of two resonant SEPIC converters are capacitively coupled, it is possible to obtain a self-oscillating converter in which the two power stages operate in interleaved mode. This paper describes a topology where the inputs of two SEPIC converters are connected in series, thereby sharing the input voltage. For the same output power and switching frequency, the voltage stress of the switches is reduced by a factor of two while the voltage transformation ratio is doubled. This modification is possible with addition of only two capacitors in the power stage and a biasing circuit. Design considerations and challenges are investigated. To verify the proposed design, a 70 V input, 37 MHz prototype was built using low-cost switching and passive components, and experimental results are presented. Peak observed efficiency was 82%.

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A capacitive level shifter for high voltage (2.5kV)

A capacitive level-shifter as a part of a high voltage halfbridge gate driver is presented in this work. The level-shifter utilizes a differential capacitor pair to transfer the information from low side to high side. A thorough evaluation of the critical parts of the level-shifter is presented with focus on low power consumption as well as low capacitive load between the floating half-bridge node and ground (output capacitance). The operation of the level-shifter is tested and verified by measurements on a prototype half-bridge gate driver. Results conclude stable operation at 2.44kV, 50kHz with a current consumption of 0.5mA. Operation voltage was limited by test equipment. The output capacitance is 4pF@1.5kV.

Active Match Load Circuit Intended for Testing Piezoelectric Transformers

An adjustable high voltage active load circuit for voltage amplitudes above 100 volts, especially intended for resistive matching the output impedance of a piezoelectric transformer (PT) is proposed in this paper. PTs have been around for over 50 years, were C. A. Rosen is common known for his famous Rosen type design back in the 1950s. After the discovered of new piezoelectric materials and new PT designs have been invented, the PT based power converters are in the area where they can outperform tradition electromagnetic based converters in certain applications. The performance of PTs can be measured and compared on its zero voltage switching (ZVS) factor, power density, and efficiency. Common for these three parameters are that they need to be measured with a match load connected at the output of the PT.
A Fast-Processing Modulation Strategy for Three-Phase Four-Leg Neutral-Point-Clamped Inverter Based on the Circuit-Level Decoupling Concept

In this paper, a modulation strategy based on the circuit-level decoupling concept is proposed and investigated for the three-level four-leg neutral-point-clamped (NPC) inverter, with the aim of delivering power to all sorts of loads, linear/nonlinear and balanced/unbalanced. By applying the proposed modulation strategy, the four-leg NPC inverter can be decoupled into three three-level Buck converters in each defined operating section. This makes the controller design much simpler compared to the conventional four-leg NPC inverter controllers. Also, this technique can be implemented with a simple logic and can be processed very quickly. Moreover, the switching loss is reduced substantially and the dc-link capacitors' voltages balance is also achieved without any feedback control. The proposed modulation technique is verified by the experiment.

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A Fault-Tolerant Modulation Method to Counteract the Double Open-Switch Fault in Matrix Converter Drive Systems without Redundant Power Devices

This paper studies the double open-switch fault issue occurring within the conventional matrix converter driving a three-phase permanent-magnet synchronous motor system and proposes a fault-tolerant solution by introducing a revised modulation strategy. In this switching strategy, the rectifier-stage modulation is adjusted based on the knowledge of the switching logics of the inverter-stage and the operating input voltage sectors. However, the proposed fault-tolerant method does not rely on the assist of any redundant power devices or any reconfiguration of the matrix converter circuit by means of using redundant physical connections. It is shown that different locations of the double open switch affect the availability of the revised modulation. The steady state absolute speed error achieved with the proposed method is 4% of the nominal speed. Experimental results are performed to demonstrate the efficacy of the proposed methods.

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A high voltage DC-DC converter driving a Dielectric Electro Active Polymer actuator for wind turbine flaps
The Dielectric Electro Active Polymer (DEAP) material is a very thin (~80 μm) silicone elastomer film with a compliant metallic electrode layer on both sides. The DEAP is fundamentally a capacitor that is capable of very high strain. The property that the polymer changes its shape, as a result of the electrostatic forces generated by an applied voltage, can be used in actuators, for instance to adapt the trailing edges of wind turbine blades, for maximum efficiency and increased energy output. Conventional actuator technologies have not proven feasible solutions for driving the wind turbine flaps. With the DEAP based high power actuator, it is expected to make a reliable and light solution with superior controllability. The current DEAP technology requires high DC voltage in the range of kV to fully utilize the DEAP material as an actuator. In this paper we propose a flyback converter topology to obtain high voltage at low current, for driving the DEAP actuator. Simulation and experimental results for uni-directional flyback converter topology are shown.

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Analysis and Design of a Bidirectional Isolated DC-DC Converter for Fuel Cell and Super-Capacitor Hybrid System
Electrical power system in future uninterruptible power supply (UPS) or electrical vehicle (EV) may employ hybrid energy sources, such as fuel cells and super-capacitors. It will be necessary to efficiently draw the energy from these two sources as well as recharge the energy storage elements by the DC bus. In this paper, a bidirectional isolated DC-DC converter controlled by phase-shift and duty cycle for the fuel cell hybrid energy system is analyzed and designed. The proposed topology minimizes the number of switches and their associated gate driver components by using two high frequency transformers which combine a half-bridge circuit and a full-bridge circuit together on the primary side. The voltage doubler circuit is employed on the secondary side. The current-fed input can limit the input current ripple that is favorable for fuel cells. The parasitic capacitance of the switches is used for zero voltage switching (ZVS). Moreover, a phase-shift and duty cycle modulation method is utilized to control the bidirectional power flow flexibly and it also makes the converter operate under a quasi-optimal condition over a wide input voltage range. This paper describes the operation principle of the proposed converter, the ZVS conditions and the quasi-optimal design in depth. The design guidelines and considerations about the transformers and other key components are given. Finally, a 1- kW 30–50-V-input 400-V-output laboratory prototype operating at 100 kHz switching frequency is built and tested to verify the effectiveness of the presented converter.

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Analysis of Dielectric Electro Active Polymer Actuator and its High Voltage Driving Circuits

Actuators based on dielectric elastomers have promising applications in artificial muscles, space robotics, mechatronics, micro-air vehicles, pneumatic and electric automation technology, heating valves, loud speakers, tissue engineering, surgical tools, wind turbine flaps, toys, rotary motors, and grippers for material handling, etc. This paper focuses on the application of Dielectric Electro Active Polymer (DEAP) technology as an actuation mechanism for different applications. The DEAP material requires very high voltage (~2.5 kV DC) to fully utilize it as an actuator. In this paper the DEAP actuator is analyzed in detail and the actuator structures, for the wind turbine flap and the heating valve applications are shown. Different high voltage switch mode power supply topologies for driving...
the DEAP actuator are discussed. The simulation and experimental results are discussed.

**Analysis of Planar E+I and ER+I Transformers for Low-Voltage High-Current DC/DC Converters with Focus on Winding Losses and Leakage Inductance**

In this paper an analysis of two planar transformers designed for high-current switching applications is presented. Typical converter application is represented by fuel and electrolyser cell converters. The transformer designs are based on E+I and ER+I planar cores while the analysis focuses on winding resistance and leakage inductances which represent the main concerns related to low-voltage high-current applications. The PCB winding design has a one to one turn ratio with no interleaving between primary and secondary windings. The main goal was to determine if ER planar core could provide a significant advantage in terms of winding losses compared to planar E cores. Results from finite element analysis highlight that low frequency winding resistance is lower for the ER core since it is dominated by the lower mean turn length however, as the AC-resistance becomes dominating the winding eddy current losses increases more in the ER core than in the E core design. Calculated and simulated leakage inductances for the analyzed cores do not show relevant differences. A laboratory prototype based on E64 planar core is used as reference. Laboratory measurements highlight that FEM analysis provides more realistic results when computing the winding AC-resistance.

**A New Method for Start-up of Isolated Boost Converters Using Magnetic- and Winding-Integration**

A new solution to the start-up and low output voltage operation of isolated boost family converters is presented. By the use of integrated magnetics and winding integration, the transformer secondary winding is re-used during start-up as a flyback...
winding coupled to the boost inductor. The traditional added flyback winding coupled to the boost inductor is thus eliminated from the circuit, bringing substantial cost savings, increased efficiency and simplified design. Each subinterval of the converter operation is described through electrical and magnetic circuit diagrams, and the concept is extended to other isolated boost family topologies. The principle of operation is demonstrated with a 800W isolated boost prototype, and a 1600W primary parallel series secondary isolated boost converter. Efficiency measurements of both prototypes are presented, including measurements during both start-up and normal boost operation.

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Organisations: Electronics, Department of Electrical Engineering
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**A review and design of power electronics converters for fuel cell hybrid system applications**
This paper presents an overview of most promising power electronics topologies for a fuel cell hybrid power conversion system which can be utilized in many applications such as hybrid electrical vehicles (HEV), distributed generations (DG) and uninterruptible-power-supply (UPS) systems. Then, a multiple-input power conversion system including a decoupled dual-input converter and a three-phase neutral-point-clamped (NPC) inverter is proposed. The system can operate in both stand-alone and grid-connected modes. Simulation and experimental results are provided to show the feasibility of the proposed system and the effectiveness of the control methods.

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This paper gives an overview of the high voltage amplifiers, which are used to drive capacitive actuators. The amplifiers for both piezoelectric and DEAP (dielectric electroactive polymer) actuators are discussed. The suitable topologies for driving capacitive actuators are illustrated in detail, including linear as well as switched mode amplifiers. In the past much attention has been paid on the driver for piezoelectric actuator. As DEAP is a type of new material, there is not much literature reference for it.

Battery powered high output voltage bidirectional flyback converter for cylindrical DEAP actuator
DEAP (Dielectric Electro Active Polymer) actuator is essentially a capacitive load and can be applied in various actuation occasions. However, high voltage is needed to actuate it. In this paper, a high voltage bidirectional flyback converter with low input voltage is presented. The fundamental operating principle for both energy transfer process and energy recovery process is analyzed in detail. In order to verify the analysis, critical simulation results are provided. So far, a unidirectional flyback converter, which can realize the energy transfer process, has been implemented in the lab. The design parameters for flyback transformer and snubber circuits are illustrated. Moreover, the experimental waveforms are provided.
Current-Driven Switch-Mode Audio Power Amplifiers
The conversion of electrical energy into sound waves by electromechanical transducers is proportional to the current through the coil of the transducer. However, virtually all audio power amplifiers provide a controlled voltage through the interface to the transducer. This paper is presenting a switch-mode audio power amplifier not only providing controlled current but also being supplied by current. This results in an output filter size reduction by a factor of 6. The implemented prototype shows decent audio performance with THD + N below 0.1%.

Decoupled Power Solution for Dual-input Isolated DC-DC Converters Using Four Quadrants Integrated Transformers (FQIT)
A common limitation of power coupling effect in some known multiple-input dc-dc converters has been addressed in many literatures. In order to overcome this limitation, a new concept for decoupling the primary windings in the integrated multiple-winding transformers based on 3-dimensional (3D) space orthogonal flux is proposed in this paper. And thus a new geometry core and relative winding arrangements are proposed in accordance with the orthogonal flux decoupling technology. Due to the four secondary windings are arranged in a quadratic pattern at the base core plate with the two perpendicular primary windings, a name of “four quadrants integrated transformers” (FQIT) is therefore given to the proposed construction. Since the two primary windings are uncoupled, the FQIT allows the two input power stages to transfer the energy into the output load simultaneously or at any timemultiplexing scheme, which can optimize the utilization of diversified power energy sources, simplify the system structure, improve the flexibility and reduce the overall cost, so they are attractive for the hybrid renewable power system. Section IV initiates a discussion for the advantages of the FQIT. In order to verify the feasibility of the FQIT in multiple-input converter, a dual-input isolated boost dc-dc converter employing with the FQIT is designed and tested. The results have excellently demonstrated that the two input power stages can be operated independently and the correctness of all the analysis in the paper.

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General information
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Ouyang, Z. (Intern), Andersen, M. A. E. (Intern), Thomsen, O. C. (Intern)
Design Considerations of Very Low Profile Coupled Inductors for Flexible Photovoltaic Module

Power converters with flexible PCB integrated magnetic components are highly demanded in future photovoltaic (PV) applications, resulting in a higher power density. In this paper, a 1.5-mm thickness integrated coupled inductor with planar sandwich core structure is under investigation. Several important design issues for the sandwich core structure including self-inductance, leakage inductance, eddy current effect and core loss are analyzed in-depth in this work. Since the non-uniform flux is distributed in the core plates, the parameters calculation and the design considerations are completely different with the traditional magnetic approaches. Accordingly, this paper enables original design considerations as a guideline for sandwiched coupled inductor. In order to reduce the high frequency eddy current effect in sandwich core structure, section III initiates a discussion with adjustable core structures and winding arrangements such as closed core structure, gapped structure and meander winding. The tradeoffs among them are presented.

Design of Interleaved Interdigitated Electrode Multilayer Piezoelectric Transformer utilizing Longitudinal and Thickness Mode Vibrations

In applications of high voltage and low power capacitor charging, conventional magnetic based power converters often suffer from bulky components and poor efficiency. Piezoelectric transformer (PT) based converters however, are compact and efficient, especially at high step-up applications. In this paper an interleaved interdigitated electrode (IDE) multilayer PT utilizing longitude and thickness mode vibration for high step-up and high output voltage is developed, for driving capacitive loads of up to 2.5kV. The PT possesses native soft switching capabilities, enabling the utilization of inductor-less topologies. One of the main advantages of the IDE’s is that it enables the PT to operate in longitudinal vibration and thickness mode through the electromechanical coupling coefficient k33. This also permits the realization of the PT through a low build-up height (below 2-4mm), making the manufacturing much easier and cheaper. As a result an interleaved IDE PT, with a soft switching factor of 1.00 and a gain of 38 has been developed.
Design of interleaved multilayer rosen type piezoelectric transformer for high voltage dc/dc applications

Research and development within piezoelectric transformer (PT) based converters are rapidly increasing as the technology is maturing and starts to prove its capabilities. Especially for high voltage and high step-up applications, PT based converters have demonstrated good performance and DC/AC converters are widely used commercially. The availability of PT based converters for DC/DC applications are very limited and are not that developed yet. In this paper an interleaved multi layer Rosen-type PT for high step-up and high output voltage is developed, for driving a 2.5kV dielectric electro active polymer actuator [17]. The targeted application utilises an inductor-less half-bridge driving topology, where the reward of eliminating the series inductor is a reduction in component count, size and price. The absence of a series inductance calls for other means to avoid large hard switching losses and obtain soft switching capabilities. This can be achieved by utilising an advantageous PT structure, which is the main advantage of the interleaved Rosen-type PT. Furthermore the design should be further optimised, in order to achieve soft switching capability. The goal of this paper is to develop a soft switching optimised PT, capable of generating output voltages higher than 2kV from a 24V supply voltage. Furthermore finite element method (FEM) has been the main tool through the PT development.

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Dual-Input Isolated Full-Bridge Boost DC-DC Converter Based on the Distributed Transformers
In this paper, a new two-input isolated boost dc-dc converter based on a distributed multi-transformer structure which is suitable for hybrid renewable energy systems is investigated and designed. With a novel transformer winding-connecting strategy, the two input ports can be decoupled completely, so the proposed converter can draw the power from the two different dc sources, which have low output voltage, and transfer it to the dc bus, which has high voltage, separately or simultaneously. The detailed operation principles of the proposed topology have been analyzed in the dual-input mode and the single-input mode, respectively. The main advantage of the proposed topology is that the four transformers and the secondary rectifiers are fully utilized whether the converter is connected with two input power sources or only one input. Although the four transformers are employed, the nominal powers of each transformer and rectifier are both reduced by four times. Furthermore, some special issues on converter design, such as increasing number of the input ports, the magnetic integration and the ground loop decoupling are discussed. A 2 kW prototype was built and tested. Experiments on the converter's steady-state and transient operations verified the validity of the analysis and design.

General information
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This paper explores the characteristic of capacitance versus voltage for dielectric electro active polymer (DEAP) actuator, 2kV polypropylene film capacitor as well as 3kV X7R multi layer ceramic capacitor (MLCC) at the beginning. An energy efficiency for capacitively loaded converters is introduced as a definition of efficiency. The calculated and measured efficiency curves for charging DEAP actuator, polypropylene film capacitor and X7R MLCC are provided and compared. The attention has to be paid for the voltage dependent capacitive load, like X7R MLCC, when evaluating the charging efficiency of converter. Based on the capacitance voltage curve, the correct capacitance should be chosen when calculating the stored energy; otherwise misleading optimistic efficiency can always be obtained. Actually, when DEAP actuator is not available at the early developing stage, the voltage independent polypropylene film capacitor can be the equivalent capacitive load. Because of the voltage dependent characteristic, X7R MLCC cannot be used to replace the DEAP actuator. However, this type of capacitor can be used to substitute the capacitive actuator with voltage dependent property at the development phase.
Electrical Structure of Future Off-shore Wind Power Plant with a High Voltage Direct Current Power Transmission

The increasing demand of electric power and the growing consciousness towards the changing climate has led to a rapid development of renewable energy in the recent years. Among all, wind energy has been the fastest growing energy source in the last decade. But the growing size of wind power plants, better wind conditions at off-shore and the general demand to put them out of sight have all contributed to the installation of large wind power plants in off-shore condition. However, moving wind power plants far out in the off-shore comes with many associated problems. One of the main challenges is the transmission of power over long distance. Historically, the power transmission from off-shore wind power plants has been done via HVAC submarine cables. This provides a simple solution, but AC cables cannot be arbitrarily long. It is shown in the report that major issues with HVAC cable transmission system are related to surplus reactive power and added losses. On the other hand, HVDC transmission system can be arbitrarily long and for long distance power transmission requirement it provides much better efficiency compared to a corresponding HVAC system. HVDC may provide a viable solution for high power transmission over long distances, but some issues related to fulfilling different grid code requirements still need further clarification. A transmission system should foremost provide a stable power transmission and participate in network stabilizing by providing efficient support for AC voltage control and frequency response requirements. These objectives are discussed and verification with simulation results is included in the report. A concept of negative sequence voltage compensation during small voltage unbalances and asymmetrical faults at the grid are also discussed. Secondly, a large WPP is not allowed to trip off during temporary grid side faults, commonly described as low voltage fault-ride-through requirement. There are four different fault-ride-through options discussed in the report. The first option includes controlling of collector network frequency. This provides a very good opportunity to use simple fixed speed wind turbines in the wind power plant. Induction generators attached to a large rotating mass show good response to frequency rise by allowing the rotor to speed up while reducing the active power output. However, it is observed that the post fault recovery process is very difficult to control and as such a high current capacity of the WPP side VSC might be required. Detailed simulation results are included in the report. The other option is to use a DC chopper, the results of which are also presented in detail in the report. It is observed that a DC chopper can provide a simple solution but the efforts required to remove the total heat during power dissipation is enormous. Alternatively, a telecommunication signal may be used, but the reliability and speed of such a system is in doubt. Finally, a controlled AC voltage drop at the collector network is derived and discussed in detail. It is illustrated in the report that such an option is advantageous in the sense that a fault at the grid side and at the wind power plant side can be dealt in the same way. More importantly, a similar wind turbine type can be used regardless of HVAC or HVDC connection strategy. A good co-ordination between the full-scale wind turbine and wind power plant side voltage sourced converter is also verified in the laboratory model based on real time digital simulation of wind turbine connected to an external voltage source converter via a power amplifier. The overall results show that the power transmission from long distance off-shore wind power plant is viable via HVDC system and at the same time the strict gird code requirements can also be fulfilled by selecting proper control methods.
Empiric analysis of zero voltage switching in piezoelectric transformer based resonant converters

Research and development within piezoelectric transformer (PT) based converters are rapidly increasing, as the technology is maturing and starts to prove its capabilities. High power density and high efficiencies are reported and recently several inductor-less converters have emerged [1][2][7][10][13], which demonstrates soft switching capabilities. The elimination of a bulky inductor, reduces size and price of the converter, but demands a soft switching optimised PT. Several attempts of expressing the soft switching capability have been made [5][12], with some shortcomings. The goal of this paper is to derive a simple expression of the maximal obtainable soft switching capability (ZVS factor), for a specific PT design, assuming a matched load. The expression has been derived through series of parametric sweep simulations of the inductor-less half-bridge topology, which revealed that a linearization of the maximal soft switching capability can be performed, in the area of interest. This expression is intended to form a basic tool for development of soft switching optimised PT’s, which enables the utilisation of inductor-less topologies.

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Four Quadrants Integrated Transformers for Dual-input Isolated DC-DC Converters

A common limitation of power coupling effect in some known multiple-input dc-dc converters has been addressed in many literatures. In order to overcome this limitation, a new concept for decoupling the primary windings in the integrated multiple-winding transformers based on 3-dimensional (3D) space orthogonal flux is proposed in this letter. And thus a new geometry core and relative winding arrangements are proposed in accordance with the orthogonal flux decoupling technology. Due to the four secondary windings are arranged in a quadratic pattern at the base core plate with the two perpendicular primary windings, a name of “four quadrants integrated transformers” (FQIT) is therefore given to the proposed construction. Since the two primary windings are uncoupled, the FQIT allows the two input power stages to transfer the energy into the output load simultaneously or at any timemultiplexing scheme, which can optimize the utilization of input sources, simplify the system structure and reduce the overall cost, so they are attractive for the hybrid renewable power system. Section IV initiates a discussion for the advantages of the FQIT. In order to verify the feasibility of the FQIT in multiple-input converter, a dualinput isolated boost dc-dc converter with the FQIT is designed and tested. The results have excellently demonstrated that the two input power stages can be operated independently and the correctness of all the analysis in the letter.

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High Efficiency PFC Frontend for Class-D Amplifiers

This thesis investigates the design of high efficiency Power Factor Correction (PFC) converter for Class-D amplifier at universal line and 3.5kW power range. The work starts with an overview on different high efficiency Bridgeless PFC topologies and investigates their applicability with respect to the given specifications in Chapter 1. Based on the conclusions of Chapter 2, the single-phase Two-Boost-Circuit Bridgeless PFC converter topology is considered the most promising to start with regarding the achievable converter efficiency and the EMI performances. The subsequent Chapters discuss the method to optimize and improve the performance of Two-Boost-Circuit BPFC converter in detail. Chapter 3 explains the working principle of the Two-Boost-Circuit BPFC converter. And then, an optimized design procedure is implemented to achieve an useful compromise between efficiency and power density. Where, impacts of the Boost inductor design is analyzed carefully. Chapter 4 firstly presents a novel interleaved BPFC (IBPFC) topology, which can be consider as the extension version of traditional Two-Boost-Circuit BPFC in Chapter 3 for EMI improvement. And then, the IBPFC's EMI model is used to study the insight of the relationship of EMI reduction and the number of interleaved stages. Moreover, an multi-objective optimization design procedure is proposed for designing a high efficiency, high power density and low EMI IBPFC system. Finally, frequency dithering technique is researched and implemented for the proposed IBPFC to gain further EMI attenuation. Chapter 5 analyzes the measurement accuracy of the efficiency results presented in this thesis in Chapter 4, which makes the efficiency measurement in this report more convicive. Chapter 6 summarizes the obtained results and concludes this work. Furthermore, an outlook regarding future researches in the IBPFC converter is presented.

Integrated high voltage power supply utilizing burst mode control and its performance impact on dielectric electro active polymer actuators

Through recent years new high performing Dielectric Electro Active Polymers (DEAP) have emerged. To fully utilize the potential of DEAPs a driver with high voltage output is needed. In this paper a piezoelectric transformer based power supply for driving DEAP actuators is developed, utilizing a burst mode control technique. Controlling and driving a DEAP actuator between 250V to 2.5kV is demonstrated, where discrete like voltage change and voltage ripple is observed, which is introduced by the burst mode control. Measurements of the actuator strain-force reveal that the voltage ripples translates to small strain-force ripples. Nevertheless the driver demonstrates good capabilities of following an input reference signal, as well as having the size to fit inside a 110 mm x 32 mm cylindrical InLastor Push actuator, forming a "low voltage" DEAP actuator.
Interleaved Self-Oscillating Class E Derived Resonant DC/DC Converters

A new method for achieving self-oscillating, self-interleaved operation of class E derived resonant DC/DC converters is presented. The proposed method is suitable for operation at frequencies in the Very High Frequency (VHF) band. Interleaved and self-oscillating modes of operation are achieved at the same time with very small number of additional passive components in the interconnection network. To verify the proposed technique, a 110MHz prototype resonant boost converter was designed; experimental results and comparison with SPICE simulation are presented. Peak measured efficiency was 89% in continuous operation.

Method and device for current driven electric energy conversion

Device comprising an electric power converter circuit for converting electric energy. The converter circuit comprises a switch arrangement with two or more controllable electric switches connected in a switching configuration and controlled so as to provide a current drive of electric energy from an associated electric source connected to a set of input terminals. This is obtained by the two or more electric switches being connected and controlled to short-circuit the input terminals during a part of a switching period. Further, a low pass filter with a capacitor and an inductor are provided to low pass the output from the switch arrangement and designed such that a high impedance at a frequency range below the switching frequency is obtained, seen from the output terminals. Switches implemented by normally-on-devices are preferred, e.g. in the form of a JFET. The converter circuit may be in different configurations such as half bridge buck, full bridge buck, half bridge boost, or full bridge boost. A current driven conversion is advantageous for high efficient energy conversion from current sources such as solar cells or where a voltage source is connected through long cables, e.g. powerline cables for long distance transmission of electric energy. In many applications the total size of filter components (capacitors and inductors) can be reduced compared to voltage driven topologies. One application is an audio amplifier arranged to drive a loudspeaker.
Modeling and Control of a Dual-Input Isolated Full-Bridge Boost Converter
In this paper, a steady-state model, a large-signal (LS) model and an ac small-signal (SS) model for a recently proposed dual-input transformer-isolated boost converter are derived respectively by the switching flow-graph (SFG) nonlinear modeling technique. Based upon the converter's model, the controllers are then designed regarding to power stage parameters and system dynamic requirements. The entire system energy management has been designed as well with the consideration on static and dynamic characteristics of the two different input energy sources. A prototype has been fabricated and tested. The measured experimental results match the simulation results fairly well on both input source dynamic and step load transient responses.

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Modeling and Control of Primary Parallel Isolated Boost Converter
In this paper state space modeling and closed loop controlled operation have been presented for primary parallel isolated boost converter (PPIBC) topology as a battery charging unit. Parasitic resistances have been included to have an accurate dynamic model. The accuracy of the model has been tested by comparing the calculated and measured loop gains. The designed controller has been implemented in a DSP based control circuit and stable operation of the converter has been achieved.

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Nonlinear Effects in Piezoelectric Transformers Explained by Thermal-Electric Model Based on a Hypothesis of Self-Heating
As the trend within power electronic still goes in the direction of higher power density and higher efficiency, it is necessary to develop new topologies and push the limit for the existing technology. Piezoelectric transformers are a fast developing technology to improve efficiency and increase power density of power converters. Nonlinearities in piezoelectric transformers occur when the power density is increased enough. The simple linear equations are not valid at this point and more complex theory of electro elasticity must be applied. In this work a simplified thermo-electric model is developed to explain nonlinearities as voltage jumps and voltage saturation and thereby avoid the complex theory of electro elasticity. The model is based on the hypothesis of self-heating and tested with measurements with good correlation.

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Optimal Design and Tradeoff Analysis of Planar Transformer in High-Power DC–DC Converters
The trend toward high power density, high operating frequency, and low profile in power converters has exposed a number of limitations in the use of conventional wire-wound magnetic component structures. A planar magnetic is a low-profile transformer or inductor utilizing planar windings, instead of the traditional windings made of Cu wires. In this paper, the most important factors for planar transformer (PT) design including winding loss, core loss, leakage inductance, and stray capacitance have individually been investigated. The tradeoffs among these factors have to be analyzed in order to achieve optimal parameters. Combined with an application, four typical winding arrangements have been compared to illustrate their advantages and disadvantages. An improved interleaving structure with optimal behaviors is proposed, which constructs the top layer paralleling with the bottom layer and then in series with the other turns of the primary, so that a lower magnetomotive force ratio $m$ can be obtained, as well as minimized ac resistance, leakage inductance, and even stray capacitance. A 1.2-kW full-bridge dc–dc converter prototype employing the improved PT structure has been constructed, over 96% efficiency is achieved, and a 2.7% improvement, compared with the noninterleaving structure, is obtained.

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Authors: Ouyang, Z. (Intern), Thomsen, O. C. (Intern), Andersen, M. A. E. (Intern)
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Optimal Design of a Push-Pull-Forward Half-Bridge (PPFHB) Bidirectional DC–DC Converter With Variable Input Voltage

This paper presents a low-cost bidirectional isolated dc–dc converter, derived from dual-active-bridge converter for the power sources with variable output voltage like supercapacitors. The proposed converter consists of push-pull-forward circuit half-bridge circuit (PPFHB) and a high-frequency transformer; this structure minimizes the number of the switching transistors and their associate gate driver components. With phase-shift control strategy, all the switches are operated under zero-voltage switching (ZVS) condition. Furthermore, in order to optimize the converter performance and increase efficiency, optimal design methods and criteria are investigated, including coupled inductors design, bidirectional power flow analysis, harmonics analysis, and ZVS range extension. Based on all the optimal parameters, higher efficiency can be achieved. Finally, prototypes are built in laboratory controlled by digital signal processor for comparison purpose. Detailed test results verify the theoretical analysis and demonstrate the validity of optimization design method.

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Piezoelectric transformer based power converters; design and control

The last two decades of research into piezoelectric transformer (PT) based power converters have led to some extensive improvements of the technology, but it still struggles to get its commercial success. This calls for further research and has been the subject of this work, in order to enable the utilization of the PT technology advantages, reduce cost and increase competitiveness. First of all an overview of the basic PT technology used in general power converters is given, including the basic piezoelectric nature, converter topologies and control methods. Compared to traditional magnetic technology based power conversion, the PT technology has some obvious advantages, being the electromechanical energy conversion, low EMI profile, a compact and low profile design, as well as a high potential of high efficiency and power density. The utilized inductor-less half-bridge topology is investigated in detail, revealing its strong points, as well as some shortcomings. As a result of this investigation, a soft switching factor (ZVS factor) is derived, which describes the maximal achievable soft switching capability of the PT, as well as it is related to the structure of the PT, through the effective electromechanical coupling factors. In order to exploit the advantages of the inductor-less half-bridge, research into soft switching optimized PT’s has been conducted. Several innovative PT solutions have been proposed, simulated and optimized, using Finite Element Modeling (FEM) tools, all with the main goal of achieving soft switching capabilities. The proposed designs have been manufactured, tested and evaluated. The main achievement has been the development of an Interleaved interdigitated electrode (IDE) PT, which retains some of the easy manufacturing advantages, combined with the high efficiency of the thickness mode vibration. The main focus of this research has been control methods, due to the high control requirements of PT based power converters and the inductor-less half-bridge, as well as the shortcomings of the prior-art solutions, and has led to several innovative solutions. A self-oscillating control method is proposed that has a very tight and precise frequency control, which ensures optimal and soft switching operation at all times. Furthermore a forward conduction mode control method is proposed, which resembles a PLL control and ensures a constant and optimal operation, as well as having the advantage of being purely primary side based. A revolutionary bi-directional control method is proposed, which utilizes active phase shift of the output rectifier that enables bi-directional power flow. Soft switching operation is maintained over the full power flow modulation range, ensuring optimal and efficient operation. Furthermore, it enables line and load regulation.

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Authors: Rødgaard, M. S. (Intern), Andersen, M. A. E. (Intern), Bruun, E. (Intern)
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Primary Paralleled Isolated Boost Converter with Extended Operating Voltage Range

Applications requiring wide input and output voltage range cannot often be satisfied by using buck or boost derived topologies. Primary paralleled isolated boost converter (PPIBC) [1]-[2] is a high efficiency boost derived topology. This paper proposes a new operation mode for extending the input and output voltage range in PPIBC. The proposed solution does not modify PPIBC power stage, the converter gain is modified instead by short circuiting one of the paralleled connected primary windings present in this topology.

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Organisations: Department of Electrical Engineering, Electronics
Authors: Hernandez Botella, J. C. (Intern), Sen, G. (Intern), Mira Albert, M. D. C. (Intern), Thomsen, O. C. (Intern), Andersen, M. A. E. (Intern)
Number of pages: 6
Primary Parallel Isolated Boost Converter with Bidirectional Operation

This paper presents a bidirectional dc/dc converter operated with batteries both in the input and output. Primary parallel isolated boost converter (PPIBC) with transformer series connection on the high voltage side is preferred due to its ability to handle high currents in the low voltage side. The converter has been modeled using non-ideal components and operated without any additional circuitry for startup using a digital soft-start procedure. Simulated and measured loop gains have been compared for the validity of the model. On-the-fly current direction change has been achieved between input and output battery banks with a defined ramp.

Printed Circuit Board Integrated Toroidal Radio Frequency Inductors

Modern power semiconductors allow for switching frequencies of power converters in the very high frequency (VHF) band (30 MHz to 300 MHz). The major advantage of this frequency increase is a remarkable reduction of the size of power converters due to smaller passive components. However crucial attention needs to be payed to switching losses, so that the size reduction in electrical components does not get consumed by a major increase in heatsink size.

This paper is investigating the major size limiting component in power converters: the inductor. In the VHF range, inductors are typically implemented as solenoids, either in spiral or cylindrical form. Those have the disadvantage of excessive stray fields, which can cause losses and disturbances in adjacent circuitry. Therefore this paper presents the analysis, design and realization of a printed circuit board (PCB) integrated inductor under significant consideration of the losses in the inductor. The analysis results in a general design tool which is verified by a prototype inductor. Its inductance is 50 nH and has a quality of 149 at 100 MHz.
Research on EMI Reduction of Interleaved Bridgeless Power Factor Corrector using Frequency Dithering
This paper proposes a cost-efficient method to reduce the electromagnetic interference (EMI) of interleaved Bridgeless PFC (IBPFC) system in a wide frequency range by carefully designing and utilizing frequency dithering. In this work, a valuable frequency dithering design is implemented for a 3.5kW universal line 2-stage IBPFC for class-D amplifiers. Detailed evaluations of impacts on EMI reduction from frequency dithering are carried out through both of the theoretical and experimental analysis. Furthermore, the impact on EMI filter's performances under frequency dithering condition is also researched through mathematical derivations. Experiments prove that with a proper design, it is possible to gain an useful EMI reduction in the IBPFC system by frequency dithering.

Research on EMI Reduction of Multi-stage Interleaved Bridgeless Power Factor Corrector
Working as an electronic pollution eliminator, the Power Factor Corrector's (PFC) own Electromagnetic Interference (EMI) problems have been blocking its performance improvement for long. In this paper, a systematic research on EMI generation of a multi-stage Two-Boost-Circuit Interleaved Bridgeless PFC (IBPFC) is presented. The insight into relationship of interleaving stages, switching on/off oscillations and EMI reduction is discussed. Finally, a 3.5kW universal input 2-stage IBPFC prototype was built to verify the theoretical analysis. Experimental results show that significant EMI reductions at odd harmonics can be achieved by carefully designing the BPFC using interleaving technique.
Research on High Efficient Single-Phase Multi-Stage Interleaved Bridgeless PFC Frontend for Class-D Amplifiers
In this paper, a 3.5kW single-phase high efficient interleaved Bridgeless PFC (IBPFC) is proposed for class-D amplifiers. This topology achieves a relatively higher efficiency in a wide output power range, which helps to reduce the energy consuming of the whole system. In addition, a detailed analysis is given to reach a compromise of IBPFC’s volume, efficiency and EMI reduction. A 3.5kW 2-stage IBPFC prototype covering universal input (from 85Vac to 265Vac) and with 390Vdc output is built and optimized. The experimental verifications show good Power Factor (PF) and excellent efficiency of 98.6% at 230Vac and a 2.22kW load.

Separation of common and differential mode conducted emission: Power combiner/splitters
A conducted emission measurement contains a common and a differential mode component. Accurate separation of these two components is critical, when designing the input filter of a switch mode power supply. Many techniques exists for performing such separation. Some authors suggested the use of wideband transformers, while other prefer current probes. In this paper the use of commercial power splitters/combiners as noise separators are considered. The performance of the noise separators are analyzed and validated based on scattering parameters (S-parameters). Impedance and rejection ratios (common and differential mode) are shown. The results based on S-parameters are used to propose a complete noise separator design. This separator is verified through experimental measurements. Finally an example on how to use the separator, when measuring conducted noise is given.

Simulation of Piezoelectric Transformers with COMSOL
In this work COMSOL is utilized to obtain the Mason lumped parameter model for a piezoelectric transformer (PT) design. The Mason lumped parameters are relevant in the design process of power converters. The magnitude of the impedance is simulated for a specific: interleaved multilayer thickness mode PT. Interleaved indicates that the primary section of the PT has been interleaved into the secondary section. Furthermore the primary section is build with interdigitated electrodes (IDE). The PT design has been prototyped and the measurements results are compared with simulations. Two methods for simplifying the PT model are given in order to decrease the simulation time. This paper aims to aid electrical engineers
with less knowledge within the field of mechanics, to be able to simulate a PT design with COMSOL and extract the key electrical parameters.

**General information**

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**Organisations:** Department of Electrical Engineering, Electronics  
**Authors:** Andersen, T. (Intern), Andersen, M. A. E. (Intern), Thomsen, O. C. (Intern)  
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**Topics in Analysis and Design of Primary Parallel Isolated Boost Converter**

Efficient power processing through power electronics circuits has been a popular academic field for the past decades, especially after “green” vehicle applications based on fuel cells, batteries and super-capacitors emerged as alternative sources of propulsion for transportation. Dc-to-dc converters found their places in such applications as voltage / power regulators where relatively lower voltages with higher currents are to be handled. Among various converter topologies proposed and used in the literature, Primary Parallel Isolated Boost Converter (PPIBC) is a good candidate for such applications due to its simplicity and ability to handle higher currents.

Design of magnetic structures like transformers and inductors is part of power electronics engineering in which trade-offs exist between size, price and losses. In higher currents this becomes even more challenging since conventional wire wound design approach has some shortcomings. It is possible to use copper foil in windings however this will increase the amount of handcraft during manufacturing; so academic attention was needed for this part of low voltage high current switching converter design.

Planar magnetics and integration of magnetic components are becoming more widely used by switch mode designers since there is a trend towards high power density, high switching frequency and higher efficiency. Planar magnetic components are also suitable for Printed Circuit Board (PCB) compatible design which results in easier manufacturing. Integration of magnetic components together with planar magnetic technology offers unique solutions where some of the contributions of this thesis came from.

During this research the aim was to design a dc-to-dc converter module based on PPIBC topology for a fuel cell operated forklift manufactured by H2Logic A/S. This thesis is written based on the academic outcomes during this design process. Various aspects of PPIBC have been investigated and a number of contributions to the literature have been made.

- An integrated transformer structure has been proposed for PPIBC where modular design with less core volume and core loss due to flux cancellation has been obtained.
- An inductor with integrated current balancing transformer has been applied to PPIBC eliminating the need for a separate current balancing transformer. -Transformers and inductors of a PPIBC have been integrated into a single magnetic structure.
- Different current balancing configurations for PPIBC have been investigated.
- A modeling approach to PPIBC has been proposed for closed loop control.
- A bidirectional version of PPIBC has been built and tested successfully.

**General information**

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**Authors:** Sen, G. (Intern), Andersen, M. A. E. (Intern), Thomsen, O. C. (Intern)  
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Advances in Planar and Integrated Magnetics

The trend toward high power density, high operating frequency, and low profile in power converters has exposed a number of limitations in the use of conventional wirewound magnetic component structures. Transformers made of the planar principle eliminate virtually some shortcomings of old-fashioned wire wound types, and thus planar magnetics, has in recent years, become increasingly popular in high frequency power converters. First, an overview of basic planar magnetics technology used in general dc-dc converters is presented. PCB or flexible PCB windings as a main construction together with planar cores yield a number of advantages over the conventional magnetics. Meanwhile, some limitations of planar magnetics are also introduced. Secondly, fundamental characteristics of planar magnetics are investigated through winding conduction loss, core loss, leakage inductance and interwinding capacitance. Accordingly, a clear cognition for the intrinsic properties of planar magnetics has been given. Trade-offs is unavoidable in the magnetics design, and thus an analysis of tradeoffs is necessary for an optimum design in a high quality dc-dc converter. In addition, an improved interwinding arrangement is proposed to further reduce winding conduction loss, leakage inductance, and even interwinding capacitance. With the development of multilayer PCB, the integrated magnetics with planar structure can be easily implemented. Hence, planar integrated magnetics technique as a major part of this thesis is investigated. The history and the evolution of integrated magnetics in power converters have been described. It is recalled, that integrated magnetics allows less number of parts, lower volume and cost of the converter, and higher efficiency. Many innovative ideas are proposed and experimentally verified. • E-I-E core structure with integrated transformers and inductors is applied into the two recent developed dc-dc topologies. • A new method to integrate the current balancing transformer with common input inductor for the primary-parallel dc-dc converter is proposed. • A low profile and low cost integrated inductors with stacked I-cores for multiphase interleaved dc-dc converters is proposed. • Ultra-thin coupled inductors design for flexible PV module is introduced. A 1.5- mm thickness integrated coupled inductor with sandwich core structure is under investigation. • A “four quadrants integrated transformer” utilizing orthogonal flux to decouple the two primary windings has been applied to a dual-input isolated boost dc-dc converter.

Analysys of Current-Bidirectional Buck-Boost Based Automotive Switch-Mode Audio Amplifier

The following study was carried out in order to assess quantitatively the performance of the buck-boost converter when used as switch-mode audio amplifier. It comprises of, to begin with, the delimitation of design criteria based on the state-of-the-art solution, which is based in a differential mode buck-based amplifier with a boost converter as power supply. The averaged switch modelling of the differential mode current bidirectional topology is also used, in order to analyze the steady state and frequency domain behaviour of this converter and parameterize it to meet the design criteria. Next, several piecewise-linear simulation results are shown with detail enough to emphasize the features of the converter. A simple prototype is implemented to verify the main predicted features. Presently no previous publication could be found containing a thorough analysis of this topology in such configuration when applied for audio.
Analysis of current-bidirectional buck-boost based switch-mode audio amplifier

The following study was carried out in order to assess quantitatively the performance of the buck-boost converter when used as a switch-mode audio amplifier. It comprises of, to begin with, the definition of design criteria based on the state-of-the-art solution, which is based on a differential mode buck-based amplifier with a boost converter as power supply. The averaged switch modeling of the differential mode current bidirectional topology is also used, in order to analyze the steady state and frequency-wise behavior of this converter and parameterize it to meet the design criteria. Next, several piecewise-linear simulation results are shown with detail enough to emphasize the features of the converter. A simple prototype is implemented to verify the main predicted features. Presently no previous publication could be found containing a thorough analysis of this topology in such configuration when applied for audio.

General information
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Organisations: Electronics, Department of Electrical Engineering, Bang & Olufsen A/S
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A Novel Bridgeless Power Factor Correction with Interleaved Boost Stages in Continuous Current Mode

The operation and trade-off of Bridgeless Power Factor Correction (BPFC) circuit with interleaved Boost stages are investigated. By using interleaved BPFC, an overall reduction of the size of EMI filter can be achieved without increasing the switching frequency of the converter. And higher efficiency can be expected in interleaved BPFC through the universal line input comparing with traditional BPFC. Furthermore, an optimization procedure is implemented to improve system power density. Analysis and simulation results taken from a 3.5kW peak interleaved BPFC completed this paper.

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Source: orbit
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A Self-Oscillating Control Scheme for a Boost Converter Providing a Controlled Output Current

Most switched mode power supplies provide a regulated voltage at their output. However, there are applications requiring a controlled current. Among others are battery chargers, test equipment for converters driven by solar cells, and LED drivers. This paper describes a dc-dc power converter realizing such a current source. The converter is based on a boost converter, supplied by a voltage source and acting as a current source. The boost converter can increase the output voltage above the input voltage. The converter provides a high control bandwidth based on a self-oscillating current loop. As additional practical features, soft start and output overvoltage limitation are included and described in this paper. The
modulator, the control, and the power stage are described in detail and verified by the experiment.

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Scopus rating (2003): SJR 3.742 SNIP 3.056

Scopus rating (2002): SJR 3.953 SNIP 2.632

Scopus rating (2001): SJR 3.048 SNIP 1.904

Scopus rating (2000): SJR 0.664 SNIP 1.453

Scopus rating (1999): SJR 0.591 SNIP 2.399
A VHF Class E DC-DC Converter with Self-Oscillating Gate Driver

This paper describes the analysis and design of a DC-DC converter topology which is operational at frequencies in the Very High Frequency (VHF) band ranging from 30 MHz − 300 MHz. The presented topology, which consists of a class E inverter, class E rectifier, and self-oscillating gate driver, is inherently resonant, and switching losses are greatly reduced by ensuring Zero Voltage Switching (ZVS) of the power semiconductor devices. A design method to ensure ZVS operation when combining the inverter, rectifier, and gate driver is provided. Several parasitic effects and their influence on converter operation are discussed, and measurement results of a 100 MHz prototype converter are presented and evaluated. The designed prototype converter verifies the described topology.

Comparison of Current Balancing Configurations for Primary Parallel Isolated Boost Converter

Different current balancing configurations have been investigated for Primary Parallel Isolated Boost Converter (PPIBC). It has been shown that parallel branch current balancing is possible with several configurations of coupled/uncoupled inductors. Analytical expressions for branch currents have been derived for different cases of gate signal mismatch causing current imbalance. It has been observed that turn-on and turn-off delays in parallel power stages of the PPIBC have different effects in the branch currents deviating from ideal. It has also been observed that in some configurations inductance differences due to core tolerances play an important role in current imbalance. Analytical and simulation results have shown that another side effect of the gate signal delay and inductor value difference is additional voltage stress over the switches during the mismatch times. Advantages of each configuration in terms of effective current balancing, efficiency and manufacturing simplicity have been highlighted. Simulations with ideal components for each case have been carried out to confirm the analytical derivations. Experimental results have also been included to show the performances of different configurations where component non-idealities like transformer leakage inductances also become effective.
Fully Integrated planar magnetics for primary-parallel isolated boost converter

A high efficient planar integrated magnetics (PIM) design approach for primary parallel isolated boost converters is presented. All magnetic components in the converter including two input inductors and two transformers with primary-parallel and secondary-series windings are integrated into an E-I-E core geometry. Due to a low reluctance path provided by the shared I-core, the two transformers as well as the two input inductors can be integrated independently, reducing the total ferrite volume and core loss. AC losses in the windings and the leakage inductance of the transformer are kept low by interleaving the primary and secondary turns of the transformers. To verify the validity of the design approach, a 1-kW prototype converter with two primary power stages is implemented for a fuel cell fed battery charger application with 20–40 V input and 170–230 V output. An efficiency of 96% can be achieved during nominal operating conditions. Also experimental comparisons between the PIM module and two separate cases have been done in order to illustrate the advantages of the proposed method.

Integrated Current Balancing Transformer for Primary Parallel Isolated Boost Converter

A simple, PCB compatible integrated solution is proposed for the current balancing requirement of the primary parallel isolated boost converter (PPIBC). Input inductor and the current balancing transformer are merged into the same core, which reduces the number of components allowing a cheaper and more compact solution. Gyrator-Capacitor modeling technique has been used, providing an easy way for understanding integrated magnetic structures. Proposed idea has been verified by simulation and experimental results.

Isolated Bidirectional DC–DC Converter for SuperCapacitor Applications

This paper proposes a new bidirectional DC/DC converter for supercapacitor applications. The proposed converter has a parallel structure in supercapacitor side (where voltage is low and current is high) and a series structure in the other side. This structure increases efficiency of the converter. For current sharing in the parallel side of the proposed converter, two
different methods are recommended and compared in this paper: Current balancing transformer (CBT) and two separate inductors (TSI). Simulation and experimental results show performance of the proposed converter.

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Authors: Dehnavi, S. M. D. (Ekstern), Sen, G. (Intern), Thomsen, O. C. (Intern), Andersen, M. A. E. (Intern), Møller, L. (Ekstern)
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**Low profile, low cost, new geometry integrated inductors**
A new geometry of integrated inductors with low profile and low cost is presented in this paper. The new geometry integrates two inductors by stacking three I-cores. The middle I-core provides a shared low reluctance flux path. The air gaps are formed by separating the I-cores using copper foil windings with well-defined thickness. Many advantages and disadvantages are described in depth. In this work, inverse coupling and direct coupling in the new geometry integrated inductors have been analyzed. Coupling characteristic caused by a special saturation behavior has been emphasis. And also variable inductors caused by the special saturation behavior may be utilized in some applications. The new integrated inductors make it possible to build low-profile, low-cost, flexibility DC/DC converters, and it can be extensively designed for the low-voltage and high-current required by the modern digital applications. Experiment results obtained from a 48V-12V 30A two-phase interleaved bidirectional DC/DC converter, demonstrates the characteristic of new geometry and difference between inverse coupling and direct coupling.

**General information**
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**Low voltage driven dielectric electro active polymer actuator with integrated piezoelectric transformer based driver**
Today’s Dielectric Electro Active Polymer (DEAP) actuators utilize high voltage (HV) in the range of kilo volts to fully stress the actuator. The requirement of HV is a drawback for the general use in the industry due to safety concerns and HV regulations. In order to avoid the HV interface to DEAP actuators, a low voltage solution is developed by integrating the driver electronic into a 110 mm tall cylindrical coreless Push InLastor actuator. To decrease the size of the driver, a piezoelectric transformer (PT) based solution is utilized. The PT is essentially an improved Rosen type PT with interleaved sections. Furthermore, the PT is optimized for an input voltage of 24 V with a gain high enough to achieve a DEAP voltage of 2.5 kV. The PT is simulated and verified through measurements on a working prototype. With the adapted hysteretic based control system; output voltage wave forms of both impulse response and sinusoidal shapes up to 2.5 kV are demonstrated. The control system, together with a carefully designed HV output stage, contributes to low power consumption at a static DEAP force. The HV stage consists of a HV measurement circuit and a triple diode voltage

Low voltage driven dielectric electro active polymer actuator with integrated piezoelectric transformer based driver
doubler optimized for low leakage current drawn from the DEAP. As a result, a 95 mm x 13 mm x 7 mm driver is integrated in a 110 mm x 32 mm actuator, forming a low voltage interfaced DEAP actuator.

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**Planar Integrated Magnetics (PIM) Module in Hybrid Bidirectional DC-DC Converter for Fuel Cell Application**

In most power electronics converters, the overall volume is mainly determined by the number of parts and the size of passive components. Integrated magnetics and planar magnetics techniques therefore have been an excellent option in order to reduce the counts and the size of magnetic components, hereby increasing the power density of converters. In this paper, a new planar integrated magnetics (PIM) module for a phase-shift plus duty cycle controlled hybrid bidirectional dc-dc converter is proposed, which assembles one boost inductor and two transformers into an E-I-E core geometry, reducing the number of parts, the total volume of converter, as well as the total core loss of the magnetic components. AC losses in the windings and leakage inductance of the transformers are kept low by interleaving the primary and secondary turns of the transformers. To verify the validity of the design approach and theoretical analysis, a lab prototype employing the PIM module is implemented for a fuel cell application with 20~40 V input voltage and 400 V output voltage. Detailed results from the experimental comparisons demonstrate that the PIM module is fully functional and electromagnetically equivalent to the discrete magnetics and a significant reduction of size can be achieved by using the PIM module.
Preliminary investigations of piezoelectric based LED luminary
This paper presents a preliminary study of PT (Piezoelectric Transformer) based SMPS’s (Switch Mode Power Supplies) for LED luminary. The unique properties of PTs (efficiency, power density and EMI) make them highly suitable for this application. Power stage topologies, rectifiers circuits, modulation schemes, LEDs and LED driving conditions are analyzed. A prototype radial mode PT optimized for ZVS (Zero Voltage Switching) is designed. FEM (Final Element Method) and measurements validates the PT design. A prototype PT based AC/DC converter operating from European mains is proposed. The prototype constitutes a light source equivalent to the 40 W incandescent bulb. Experimental results shows, that the prototype are capable of ZVS and dimming (the later trough use of burst mode control).

Research on Power Factor Correction Boost Inductor Design Optimization – Efficiency vs. Power Density
Nowadays, efficiency and power density are the most important issues for Power Factor Correction (PFC) converters development. However, it is a challenge to reach both high efficiency and power density in a system at the same time. In this paper, taking a Bridgeless PFC (BPFC) as an example, a useful compromise between efficiency and power density of the Boost inductors on 3.2kW is achieved using an optimized design procedure. The experimental verifications based on the optimized inductor are carried out from 300W to 3.2kW at 220Vac input.

The Circuit-Level Decoupling Modulation Strategy for Three-Level Neutral-Point-Clamped (TL-NPC) Inverter
In this paper, a circuit-level decoupling modulation strategy is proposed for the three-level (TL) neutral-point-clamped (NPC) inverters. With the proposed modulation scheme, the TL-NPC inverter can be decoupled into two three-level Buck converters in each defined operating section, which makes the controller design much simpler. The decoupling principle including the driving signal synthesis and the neutral point potential variation are analyzed detailed. It is found that switching losses can be reduced by one third and the voltage balance between the dividing dc link capacitors can be achieved without any feedback control. The simulation results show the validity of theoretical analysis.
Improvement of out-of-band Behaviour In Switch-Mode Amplifiers and Power Supplies by their Modulation Topology

Switch-mode power electronics is disturbing other electronic circuits by emission of electromagnetic waves and signals. To allow transmission of information, a set of regulatory rules (electromagnetic compatibility (EMC)) were created to limit this disturbance. To fulfill those rules in power electronics, shielding and filtering is required, which is limiting the size reduction. The motivation for this project was to find alternative ways to avoid trouble with interference of switch-mode power electronics and transmission and receiver circuits. An especial focus is given to audio power amplifiers. After a historical overview and description of interaction between power electronics and electromagnetic compatibility (chapter 1), the thesis will first show the impact of the high frequency signals on the audio performance of switch-mode audio power amplifiers (chapter 2). Therefore the work of others will be put into perspective and self-oscillating amplifiers will be compared with external synchronized topologies. After that, solutions to the problem, which are widespread in industry will be given and explained (chapter 3). The challenges and advantages will be described. The improvement of the described problem where four different approaches: • Multi Carrier Modulation (MCM) • Active Electromagnetic Cancellation (AEC) • Current Driven Power Stages (CDP) • Radio Frequency Power Electronics (RF SMPS) Multi Carrier Modulation (chapter 4) is using more than one external carrier and generating multiple PWM signals. Those are combined by a logic circuit to one pulse coded information stream. The average of this stream is proportional to the modulated signal, while the spectral peaks of the switching frequencies are half compared to state-of-the art pulse width modulation (PWM). Active Electromagnetic Cancellation (chapter 5) has been known as active filtering in power electronics. It has been applied to switch mode audio power amplifiers. The specialty for the later will be described and a design is shown, decreasing the undesired spectrum by 15 dB. A different approach to tackle the problem is given by an alternative power stage in Current Driven Power Stages (chapter 6). A focus of this approach is to minimize the biggest components, the inductors, in the filters of switchmode power electronics. This approach results in a size reduction of the filters by around 84 %. A very promising approach to remove the interference of power electronics circuits and telecommunication circuits is to stay away from the frequencies used for information transmission. Even though the electromagnetic spectrum is used without any exceptions, the situation can be optimized for audio applications. This is done by using switching frequencies beyond the communication frequencies and will be described in Radio Frequency Power Electronics (chapter 7).

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High-Performance Control in Radio Frequency Power Amplification Systems
This thesis presents a broad study of methods for increasing the efficiency of narrow-band radio transmitters. The study is centered around the base station application and TETRA/TEDE networks. The general solution space studied is that of envelope tracking applied to linear class-A/B radio frequency power amplifiers (RFPAs) in conjunction with cartesian
feedback (CFB) used to linearize the overall transmitter system. On a system level, it is demonstrated how envelope tracking is particularly useful for RF carriers with high peak-to-average power ratios, such as TEDS with 10dB. It is also demonstrated how the envelope tracking technique introduces a number of potential pitfalls to the system, namely in the form of power supply ripple intermodulation (PSIM), reduced RFPA linearity and a higher impedance supply rail for the RFPA. Design and analysis techniques for these three issues are introduced and demonstrated. On subcomponent level, solutions for implementing the envelope tracking power supply are proposed and demonstrated. A number of buck-type DCDC converter topologies are investigated and compared, with the objective of showing the trade-offs involved between switching frequency, control bandwidth and ripple voltage. It is found that the simple fourth-order filter buck converter is ideal for TETRA and TEDS envelope tracking power supplies. The problem of extracting maximum control bandwidth from a given power topology is given particular attention, with a range of, arguably new, insights resulting. It is clearly shown that single-phase switch-mode control systems based on oscillation (controlled unstable operation) of the whole power train provide the highest possible control bandwidth. A study of the limitations of cartesian feedback is also included. It is shown that bandwidths in excess of 4MHz can be achieved for a 400MHz carrier frequency using readily available discrete components. Even higher CFB bandwidths are the key to flexible RFPA system capable of transmitting multiple RF carriers simultaneously. A number of key problem areas are identified and shown to need further research. Practically demonstrated is a high-efficiency 25W TEDS transmitter capable of meeting all base station adjacent channel power ratio and wideband noise specifications with ample margins. Efficiency is improved from 23% to 44% by application of envelope tracking - almost a doubling - at the cost of a single-phase buck converter and without any penalties in RFPA output spectrum purity.

A high efficient integrated planar transformer for primary-parallel isolated boost converters
A simple, easy to manufacture and high efficient integrated planar transformer design approach for primary parallel isolated boost converters is presented. Utilizing the same phase flux flow, transformers are integrated, reducing the total ferrite volume and core loss for the same peak flux density. Number of turns is minimized for easy manufacturing by cascade placement of planar cores increasing the effective cross-sectional area. AC losses in the windings as well as the leakage inductance of the transformer are kept low by extensive interleaving of the primary and secondary turns. The idea of transformer integration is further extended to multiple primary power stages using modular geometry of the planar core, further reducing the core loss and allowing a higher power density. To verify the validity of the design approach, a 4-kW prototype converter with two primary power stages is implemented for a fuel cell fed battery charger application with 50–110 V input and 65–105 V output. Input inductors are coupled for current sharing, eliminating the use of current sharing transformers. An efficiency of 94% is achieved during nominal operating condition where the input is 70-V and the output is 84-V.
A Novel Dual-input Isolated Current-Fed DC-DC Converter for Renewable Energy System

In this paper, a novel isolated current-fed DC-DC converter (boost-type) with two input power sources based on multi-transformer structure, which is suitable for fuel cells and super-capacitors hybrid energy system, is proposed and designed. With particular transformer windings connection strategy, the proposed converter can draw power from two different DC sources with lower voltage and deliver it to the higher voltage DC bus or load individually and simultaneously. The detailed operation principle of the proposed converter has been analyzed in dual-input mode and single-input mode, respectively. Furthermore, the method to increase the number of input ports, the magnetic integration structure, and ground loop decoupling are discussed. Experimental results from the lab prototype converter with two DC voltage sources verify the validity of the theoretical analysis and design of the converter.

A review of module inverter topologies suitable for photovoltaic system

This paper evaluates eight module inverter topologies and provides an overview of the merits and demerits of each on the basis of circuit level Pspice simulation. The complete system is modeled in Pspice and the model is made as realistic as possible by including the parasitic elements. Only the output stage is varied for different topologies keeping the system model unaltered with the same control system and degree of demodulation so as to differentiate the variation of efficiency of these topologies. The purpose of the analysis is to determine which of this topology would be a best fit for the system and what are the compromises to be made (if any) to select one of these topologies as the output stage in the PV system.

Energy harvesting from an exercise bike using a switch-mode converter controlled generator
This paper investigates the feasibility of using an alternator as means of harvesting energy from a stationary exercise bicycle. A switch mode converter was designed to regulate the current in the alternator rotor winding, thus regulating the power required to pedal, and consequently the power output of the bike. The complete controller design consists of this power stage, a control circuit, a startup circuit and an overvoltage protection circuit. A functional overview of the entire controller is presented in the paper, along with in-depth descriptions of the specific subcircuits designed. The system is self-starting and does not require an external power source. There are two modes of operation: Voltage regulated 12V output for connection to a standard inverter, and unregulated output for charging of a 24V battery, with direct linear control of the rotor current, thus simulating road bike gearing. Prototype bikes were built and used at several events, and the functionality was experimentally verified.

Full Space Vectors Modulation for Nine-Switch Converters Including CF & DF Modes
Recently, nine-switch inverter was presented as dual output inverter. Two constant frequency (CF) and different frequency (DF) modes are defined for nine-switch inverter. However CF mode is more interesting because reasonable rating. Several switching methods have been presented for nine switch converter. As a space vector modulation for DF mode has already been proposed by authors. This paper proposes a full space vector modulation (SVM) for both CF and DF modes. Also practical methods are presented for SVM proposed. In addition a special SVM is proposed that offers minimum total harmonic distortion (THD) in DF mode. The performance of the proposed SVM is verified by simulation results.
High-Efficiency Isolated Boost DCDC Converter for High-Power Low-Voltage Fuel-Cell Applications

A new design approach achieving very high conversion efficiency in low-voltage high-power isolated boost dc-dc converters is presented. The transformer eddy-current and proximity effects are analyzed, demonstrating that an extensive interleaving of primary and secondary windings is needed to avoid high winding losses. The analysis of transformer leakage inductance reveals that extremely low leakage inductance can be achieved, allowing stored energy to be dissipated. Power MOSFETs fully rated for repetitive avalanches allow primary-side voltage clamp circuits to be eliminated. The oversizing of the primary-switch voltage rating can thus be avoided, significantly reducing switch-conduction losses. Finally, silicon carbide rectifying diodes allow fast diode turn-off, further reducing losses. Detailed test results from a 1.5-kW full-bridge boost dc-dc converter verify the theoretical analysis and demonstrate very high conversion efficiency. The efficiency at minimum input voltage and maximum power is 96.8%. The maximum efficiency of the proposed converter is 98%.
High Efficiency Power Converter for Low Voltage High Power Applications

The topic of this thesis is the design of high efficiency power electronic dc-to-dc converters for high-power, low-input-voltage to high-output-voltage applications. These converters are increasingly required for emerging sustainable energy systems such as fuel cell, battery or photo voltaic based energy systems. Applications include systems for emergency power back-up (UPS), de-centralized combined heat and power systems, traction applications such as hybrid electrical vehicles, forklift trucks and special applications such as low emission power generation for truck and ship containers, and remote power generation for light towers, camper vans, boats, beacons, and buoys etc. A review of current state-of-the-art is presented. The best performing converters achieve moderately high peak efficiencies at high input voltage and medium power level. However, system dimensioning and cost are often determined by the performance at the system worst case operating point which is usually at minimum input voltage and maximum power. Except for the non-regulating V6 converters, all published solutions exhibit a very significant drop in conversion efficiency at minimum input voltage and maximum output power. A detailed analysis of dominant loss factors in high power converters for low voltage applications is presented. The analysis concludes that: • Power transformers for low voltage high power, if properly designed, will have extremely low leakage inductance. • If optimally designed, boost converters will be much more efficient than comparable buck type converters for high power low voltage applications. • The use of voltage clamp circuits to protect primary switches in boost converters is no longer needed for device protection. On the other hand, they will dramatically increase power losses. Moreover, if a converter is properly designed, primary side voltage clamp circuits will not even work in low voltage high power converters. • Very high conversion efficiency can be achieved. Peak efficiency of 98% and worst case minimum efficiency of 96.8% are demonstrated on a 1.5 kW converter. The ability to - and challenges involved in - scaling of power converters for low voltage applications in the power range of 1-10 kW are analyzed. The analysis concludes that power MOSFETs needs to be paralleled extensively to scale power level to 10 kW. Maintaining fast current switching and reliable current sharing is essential. Further, the high ac-current carrying loop on the converter primary side will become increasingly difficult to scale due to fundamental issues such as physical size of components and penetration depth in copper. Finally a new method for partial paralleling of multiple primary power stages in isolated boost converters is presented. Maximum benefit of scaling in terms of higher efficiency and lower cost is preserved by only paralleling primary switches and the critical high ac-current loop. Dynamic current sharing is inherently guaranteed between parallel power stages. The principle can be applied to all isolated boost type converters and, in principle, an unlimited number of power stages can be paralleled. Feasibility and operation of the new topology are demonstrated on a dual 3 kW and a quad 10 kW prototype converter. Measured peak efficiency is 98.2% and worst case minimum efficiency is between 96.5% and 96.9%.

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Modeling Distortion Effects in Class-D Amplifier Filter Inductors

Distortion is generally accepted as a quantifier to judge the quality of audio power amplifiers. In switchmode power amplifiers various mechanisms influence this performance measure. After giving an overview of those, this paper focuses on the particular effect of the nonlinearity of the output filter components on the audio performance. While the physical reasons for both, the capacitor and the inductor induced distortion are given, the practical in depth demonstration is done for the inductor only. This includes measuring the inductors performance, modeling through fitting and resulting into simulation models. The fitted models achieve distortion values between 0.03 % and 0.2 % as a basis to enable the design of a 200 W amplifier.

New Geometry Integrated Inductors in Two-channel Interleaved Bidirectional Converter

A new geometry of integrated inductors for two channel interleaved bidirectional converter is presented in this paper. The new geometry module integrates two individual inductors by stacking three I-cores. The middle I-core provides a shared flux path with low reluctance which uncouples the two inductors. The air gaps are constructed by separating the I-cores using copper foil windings with well-defined thickness. In this work, inverse connection and direct connection for the two integrated inductors have been analyzed. For the inverse connection, a unique saturation behavior in the middle I-core has been shown. The integrated inductors with new geometry make it possible to build low-profile, low-cost, flexibility DC/DC converters, and it can be extensively designed for low-voltage and high-current required by modern digital applications. Experiment results obtained from a 48V-12V 30A two-phase interleaved buck converter, demonstrates the difference in the inverse connection and the direct connection. Both efficiencies are above 91% from half to full output current.

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New Geometry Integrated Inductors in Two-channel Interleaved Bidirectional Converter

A new geometry of integrated inductors for two-channel interleaved bidirectional converter is presented in this paper. The new geometry module integrates two individual inductors by stacking three I-cores. The middle I-core provides a shared flux path with low reluctance which uncouples the two inductors. The air gaps are constructed by separating the I-cores using copper foil windings with well-defined thickness. In this work, inverse connection and direct connection for the two integrated inductors have been analyzed. For the inverse connection, a unique saturation behavior in the middle I-core has been shown. The integrated inductors with new geometry make it possible to build low-profile, low-cost, flexibility DC/DC converters, and it can be extensively designed for low-voltage and high-current required by modern digital applications. Experiment results obtained from a 48V-12V 30A two-phase interleaved buck converter, demonstrates the difference in the inverse connection and the direct connection. Both efficiencies are above 91% from half to full output current.

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Optimal Design and Tradeoffs Analysis for Planar Transformer in High Power DC-DC Converters

A planar magnetic is a low profile transformer or inductor utilizing planar windings instead of the traditional windings made of Cu-wires. In this paper, the important factors for planar transformer design including winding loss, core loss, leakage inductance and stray capacitance have been investigated individually. The tradeoffs among these factors have to be analyzed in order to achieve optimal parameters. Combined with a certain application, four typical winding arrangements have been compared to illustrate each their advantages and disadvantages. An improved interleaving structure with optimal behaviors is proposed, which constructs the top layer paralleling with the bottom layer and then in series with the other turns of the primary so that a lower magneto motive force (MMF) ratio can be obtained as well as minimized AC resistance, leakage inductance and even stray capacitance. A 1.2-kW full-bridge DC-DC converter prototype employing the improved planar transformer structure has been constructed, over 96% efficiency is achieved and a 2.7% improvement compared to the non-interleaving structure is obtained.

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Planar integrated magnetics design in wide input range DC-DC converter for fuel cell application

In the most power electronics converters, the overall volume is mainly determined by the number of parts and the size of passive components. Integrated magnetics and planar magnetics techniques therefore have been an excellent option in order to reduce the count and the size of magnetic components, hereby increasing the power density of converters. A new planar integrated magnetics (PIM) technique for a phase-shift plus duty cycle controlled hybrid bi-directional DC/DC converter is presented and investigated in this paper. The main magnetic components including one boost inductor and two independent transformers are integrated into an E-I-E core geometry. Utilizing the flux cancellation as the principle of uncoupling, the transformers and the boost inductor are integrated, to reduce the total ferrite volume and core loss. The transformers and inductor are wound in the outer legs and the center legs respectively. The uncoupling effect between them is determined by the winding connections. The middle I-core provides a shared low reluctance flux path, uncoupling the two independent transformers. With the air gaps shift into the center legs, the magnetizing inductance of transformers will not be decreased due to there is no air gap throughout the flux paths generated by the two transformers. The new PIM structure can be extended to other topologies. To verify the validity of design approach and theoretical analysis, a lab prototype with PIM has been built, and tested. Comparing with the discrete structure, the result demonstrated a great improvement in profile and volume without sacrificing electrical performance.

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Active Electromagnetic Interference Cancelation for Automotive Switch-Mode Audio Power Amplifiers

Recent trends in the automotive audio industry have shown the importance of active noise cancelation (ANC) for major improvements in mobile entertainment environments. These approaches target the acoustical noise in the cabin and superimpose an inverse noise signal to cancel disturbances. Electromagnetic interference between switch-mode audio power amplifiers and receivers show the same physical obstacle as the described ANC endeavors are targeting. The principle of active electromagnetic interference cancelation (AEC) is derived in this paper on a theoretical basis with verifications in simulation and experiment. The resulting switch-mode audio power amplifier of this experiment keeps its high efficiency and is able to deliver the signal with less than 0.1 % distortion, while improving the source of electromagnetic interference by 15 dB.

A DC-DC Converter with Wide Input Voltage Range for Fuel Cell and Supercapacitor Application

This paper proposes a novel phase-shift plus duty cycle controlled hybrid bi-directional DC-DC converter based on fuel cells and supercapacitors. The described converter employs two high frequency transformers to couple the half-bridge and full-bridge circuits together in the primary side and voltage doubler circuit in secondary side. Boost type converter can limit the output ripple current of the fuel cells; hybrid full-bridge structure can change operating modes according to the different input voltage; phase-shift with duty cycle control scheme is utilized to control the bidirectional power flow flexibly. All the switches can turn on under zero-voltage-switching condition (ZVS). The operating principles of the converter are described in details, and the experimental results based on the prototype controlled by DSP are presented to verify the validity of the analysis and design.
Analysis and Design of Bi-Directional DC-DC Converter in the Extended Run Time DC UPS System Based on Fuel Cell and Supercapacitor

Abstract—In this paper, an extended run time DC UPS system structure with fuel cell and supercapacitor is investigated. A wide input range bi-directional dc-dc converter is described along with the phase-shift modulation scheme and phase-shift with duty cycle control, in different modes. The delivered power and peak current are analyzed and calculated. The key parameters of the bi-directional dc-dc converter, the relationships between the input voltage, phase-shift angle, ratio of the transformer and leakage inductance are analyzed and optimized. Build the system mathematic model and a novel input voltage combined with load current feedback using PI controller with anti-windup scheme to realize closed-loop control of the whole system, and verify the feasibility of the control scheme proposed by simulation. A 1kW prototype controlled by TMS320F2808 DSP is implemented and tested. Experimental results show the validity of design.

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Analysis and design of PPFHB bidirectional DC-DC converter with coupled inductors

In this paper, a novel push-pull-forward half-bridge (PPFHB) bi-directional DC-DC converter with coupled inductors is proposed. All switches can operate under zero-voltage-switching (ZVS). The operation principle with phase-shift modulation scheme, characteristics of coupled inductors, the steady state relationship and small-signal model are
analyzed. The voltage controller based on the small-signal model in z-domain is designed. A 500W prototype controlled by TMS320F2808 DSP is implemented and tested. Experimental results show the validity of the analysis and design.

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**A New Very-High-Efficiency R4 Converter for High-Power Fuel Cell Applications**

A new very high efficiency 10 kW isolated R4 boost converter for low-voltage high-power fuel cell applications is presented. Using a new concept for partially paralleling of isolated boost converters, only the critical high ac-current parts are paralleled. Four 2.5 kW power stages, consisting of fullbridge switching stages and power transformers, operate in parallel on primary side and in series on secondary side. Current sharing is guaranteed by series connection of transformer secondary windings and three small cascaded current balancing transformers on primary side. The detailed design of a 10 kW prototype converter is presented. Input voltage range is 30-60 V and output voltage is 800 V. Test results, including voltage- and current waveforms and efficiency measurements, are presented. A record high converter efficiency of 98.2 % is achieved. The proposed R4 boost converter thus constitutes a low cost solution to achieve very high conversion efficiency in high input current applications.

**General information**

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Authors: Nymand, M. (Intern), Andersen, M. A. E. (Intern)  
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**A Novel PPFHB Bidirectional DC-DC Converter for Supercapacitor Application**

This paper presents a novel bidirectional DC-DC converter for the supercapacitor application. In the proposed converter, push-pull forward with half bridge (PPFHB) voltage doubler structure is used to reduce the number of the power switches and get higher voltage gain. Based on phase-shift modulation scheme, all the switches can realize zero-voltageswitching (ZVS) turn-on and bidirectional power flow can be controlled with phase-shift angle. The operating principles of the converter are described in detail, ZVS conditions are discussed, parameters are designed, and the experimental results based on the prototype controlled by DSP are presented to verify the validity of the analysis and design.
A Two-stage DC-DC Converter for the Fuel Cell-Supercapacitor Hybrid System

A wide input range multi-stage converter is proposed with the fuel cells and supercapacitors as a hybrid system. The front-end two-phase boost converter is used to optimize the output power and to reduce the current ripple of fuel cells. The supercapacitor power module is connected by push-pull-forward half bridge (PPFHFB) converter with coupled inductors in the second stage to handle the slow transient response of the fuel cells and realize the bidirectional power flow control. Moreover, this cascaded structure simplifies the power management. The control strategy for the whole system is analyzed and designed. A 1kW prototype controlled by TMS320F2808 DSP is built in the lab. Simulation and experimental results confirm the feasibility of the proposed two stage dc-dc converter system.
Carrier Distortion in Hysteretic Self-Oscillating Class-D Audio Power Amplifiers: Analysis and Optimization

An important distortion mechanism in hysteretic self-oscillating (SO) class-D (switch mode) power amplifiers—carrier distortion—is analyzed and an optimization method is proposed. This mechanism is an issue in any power amplifier application where a high degree of proportionality between input and output is required, such as in audio power amplifiers or xDSL drivers. From an average-mode point of view, carrier distortion is shown to be caused by nonlinear variation of the hysteretic comparator input average voltage with the output average voltage. This easily causes total harmonic distortion figures in excess of 0.1–0.2%, inadequate for high-quality audio applications. Carrier distortion is shown to be minimized when the feedback system is designed to provide a triangular carrier (sliding) signal at the input of a hysteretic comparator. The proposed optimization method is experimentally proven in an audio power amplifier leading to THD figures that are comparable to the state of the art. Experimental hardware is a hysteretic SO bandpass current-mode-controlled single-ended audio power amplifier capable of 45 W into 8 Ω or 80 W into 4 Ω from a ±34 V supply with less than 0.03% THD from 100 Hz to 6.7 kHz. Carrier distortion is shown to account for this limitation in THD performance.

General information
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Organisations: Automation, Department of Electrical Engineering, Electronics
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Web of Science (2013): Indexed yes
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Scopus rating (2012): SJR 1.945 SNIP 3.803 CiteScore 6.98
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
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Scopus rating (2010): SJR 1.796 SNIP 2.89
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Conduction Losses and Common Mode EMI Analysis on Bridgeless Power Factor Correction

In this paper, a review of Bridgeless Boost power factor correction (PFC) converters is presented first. Performance comparison on conduction losses and common mode electromagnetic interference (EMI) are analyzed between conventional Boost PFC converter and members of Bridgeless PFC family. Experiment results are given to validate the efficiency analysis and EMI model building.
DOUBLE-BOOST DC-AC CONVERTER WITH SLIDING-MODE CONTROL FOR PORTABLE AUDIO
The double-boost topology is studied for operation as a dc-ac converter and single stage audio amplifier. A sliding-mode controller is designed in order to achieve fast enough response for the whole audio frequency range. Symmetric, asymmetric and interleaved operation modes are analyzed.

General information
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Organisations: Electronics, Department of Electrical Engineering, Bang & Olufsen A/S
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Evaluation of single phase transformerless inverter topology for photovoltaic systems

General information
State: Published
Organisations: Electronics, Department of Electrical Engineering, SunSil A/S
Authors: Variath, R. C. (Intern), Jørgensen, A. M. (Ekstern), Andersen, M. A. E. (Intern)
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Investigation of switching frequency variations and EMI properties in self-oscillating class D amplifiers
Class D audio amplifiers have gained significant influence in sound reproduction due to their high efficiency. One of the most commonly used control methods in these amplifiers is self-oscillation. A parameter of key interest in self-oscillating amplifiers is the switching frequency, which is known for its variation. Knowledge of switching frequency variations is of great importance with respect to electromagnetic interference (EMI). This paper will investigate, whether the switching frequency is dependent on modulation index and audio reference frequency. Validation is done using simulations, and the results are compared with measurements performed on a 50 W prototype amplifier. The switching frequency is tracked through accurate spectrum measurements, and very good compliance with simulation results are observed.

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Organisations: Department of Electrical Engineering, Electronics, Harman/Becker Automotive Systems GmbH
Authors: Nielsen, D. (Intern), Knott, A. (Intern), Pfaffinger, G. (Ekstern), Andersen, M. A. E. (Intern)
Number of pages: 10
Publication date: 2009
Investigation of switching frequency variations in self-oscillating class D amplifiers

Class D audio amplifiers have gained significant influence in sound reproduction due to their high efficiency. One of the most commonly used control methods in class D amplifiers is known as self-oscillation. An parameter of key interest in self-oscillating class D amplifiers is the switching frequency, which can be directly related to the performance of the amplifier. This paper will clarify the myth of the switching frequency through investigation of its dependency on modulation index and reference frequency. Validation is done using simulations and an 50 W amplifier providing 0.2 % of distortion. The switching frequency is tracked through accurate spectrum measurements, and very good compliance with simulation results are observed.

Multi Carrier Modulation Audio Power Amplifier with Programmable Logic

While switch-mode audio power amplifiers allow compact implementations and high output power levels due to their high power efficiency, they are very well known for creating electromagnetic interference (EMI) with other electronic equipment. To lower the EMI of switch-mode (class D) audio power amplifiers while keeping the performance measures to excellent levels is therefore of high interest. In this paper a class D audio amplifier utilising Multi Carrier Modulation (MCM) will be analysed, and a prototype Master-Slave Multi Carrier Modulated (MS MCM) amplifier has been constructed and measured for performance and out of band spectral amplitudes. The basic principle in MCM is to use programmable logic to combine two or more Pulse Width Modulated (PWM) audio signals at different switching frequencies. In this way the out of band spectrum will be lowered compared with conventional class D amplifiers. Analytically expressions, simulations and measurements result in reduced switching frequency amplitudes using MCM techniques. It is also shown that the Total Harmonic Distortion (THD) tends to be compromised compared to conventional class D amplifiers due to intermodulation products of the switching frequencies entering the audio band. Still, the MS MCM topology with two carrier signals shows a 6 dB reduction of the switching frequency amplitudes as well as THD across the audio band below 1% at 55 W output power open loop.
New Primary-Parallel Boost Converter for High-Power High-Gain Applications

Abstract—A new simple and low cost method for paralleling multiple power stages in high-power high-gain isolated full-bridge boost converters is presented. A small current balancing transformer and serial connection of transformer secondary windings provides ideal current sharing between paralleled power stages. Effective and safe parallel operation of multiple switching stages can thus be performed. By splitting high-current ac-loops into multiple smaller loops of smaller ac-currents, switching losses are reduced. Transformer turns ratio and power level is reduced, simplifying transformer design and manufacturing. Extension of the principle to other isolated boost converter topologies are demonstrated as well as extension to higher numbers of parallel operated power stages. Test results from a 3 kW experimental prototype converter are presented, verifying converter operation and demonstrating current sharing capability. Very high converter efficiency is achieved. Worst case efficiency at minimum input voltage and maximum power is 96.9 %. Maximum efficiency is 98 %.

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Authors: Nymand, M. (Intern), Andersen, M. A. E. (Intern)
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Publication date: 2009

On the Myth of Pulse Width Modulated Spectrum in Theory and Practice

Switch-mode audio power amplifiers are commonly used in sound reproduction. Their well known drawback is the radiation of high frequent energy, which can disturb radio and TV receivers. The designer of switch-mode audio equipment therefore needs to make arrangements to prevent this coupling which would otherwise result in bad audio performance. A deep understanding of the pulse width modulated (PWM) signal is therefore essential, which resulted in different mythic models as pulse, trapezoidal or Double Fourier Series (DFS) representations in the past. This paper will clarify these theoretical approaches by comparing them with reality from both the time and the frequency domain perspective. For validation a switch-mode audio power amplifier was built, delivering the contents material with less than 0.06 % distortion across the audio band at 50 W. The switch-mode signals have been evaluated very precisely in time and spectral domain to enlighten the assumptions about the PWM spectra and decrypt this myth.

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Organisations: Electronics, Department of Electrical Engineering, Harman/Becker Automotive Systems GmbH
Authors: Knott, A. (Intern), Pfaffinger, G. (Ekstern), Andersen, M. A. E. (Intern)
Pages: 7799
Publication date: 2009
Reducing AC-Winding Losses in High-Current High-Power Inductors

Foil windings are preferable in high-current high-power inductors to realize compact designs and to reduce dc-current losses. At high frequency, however, proximity effect will cause very significant increase in ac resistance in multi-layer windings, and lead to high ac winding losses. This paper presents design, analysis and experimental verification of a two winding technique, which significantly reduces ac winding losses without compromising dc losses. The technique uses an inner auxiliary winding, which is connected in parallel with an outer main winding. The auxiliary winding is optimally designed with low ac resistance and leakage inductance to carry the ac current while the outer winding is designed for the large dc current. Detailed analysis and design of a 350 A, 10 kW inductor with the proposed technique are presented with discussions. Experimental results of a prototype 350 A inductor, used in a 10 kW fuel cell dc-dc converter, are also presented to demonstrate the validity of the proposed technique and its superior performance.

TEDS Base Station Power Amplifier using Low-Noise Envelope Tracking Power Supply

This paper demonstrates a highly linear and efficient TETRA enhanced data service (TEDS) base-station RF power amplifier (RFPA). Based on the well-known combination of an envelope tracking (ET) power supply and a linear class-A/B RFPA, adequate adjacent channel power ratio (ACPR) and wideband noise performance is shown to be enabled only by further incorporating high-bandwidth Cartesian feedback (CFB) and using a low-noise ET power supply. It is demonstrated that CFB loop bandwidth is limited by modulator/demodulator/RF path group delay to around 2 MHz in the considered setup, and that there exists a significant tradeoff between the depth of the ET and open-loop RFPA linearity, as well as overall efficiency. An empirical method for determining the permissible amount of switching ripple on the ET supply is presented, showing very good accuracy. Performance of the prototype RFPA system is verified experimentally with a 9.6-dB peak-to-average 50-kHz 16 quadrature amplitude modulation TEDS carrier, the setup providing 44-dBm (25 W) average RF output power at 400 MHz with 44% dc-to-RF efficiency state-of-the-art ACPR of less than $\pm$67 dBC, switching noise artifacts around $\pm$85 dBC, and an overall rms error vector magnitude below 4.5%.
The Analysis and Comparison of Leakage Inductance in Different Winding Arrangements for Planar Transformer

The coupling of the windings can be easily increased by using multiply stacked planar windings connection. Interleaving is a well-known technique used to reduce leakage inductance and minimize high-frequency winding losses. The paper aims to analyze leakage inductance based on magneto motive force (MMF) and energy distribution in planar transformer and correct the formula of leakage inductance proposed by previous publications. The investigation of different winding arrangements shows significant advantages of interleaving structure. In this work, a novel half turn structure is proposed to reduce leakage inductance further. Some important issues are presented to acquire desired leakage inductance. The design and modeling of 1 kW planar transformer is presented. In order to verify the analytical method for leakage inductance in this paper, finite element analysis (FEA) and measurement with impedance analyzer are presented. Good matching between calculation, FEA 2D simulation and measurement results is achieved.

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Organisations: Electronics, Department of Electrical Engineering
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What is the Best Converter for Low Voltage Fuel Cell Applications- A Buck or Boost?

Amongst many converter topologies that have been proposed and developed for low voltage fuel cell applications, isolated full-bridge Buck and Boost converters appear to be the most popular. Although the Buck topology is considered to be superior in performance, for particularly being more efficient, this claim has never been proved with a ‘proper’ comparison to the Boost topology. This paper presents a comprehensive comparison between Buck and Boost topologies, which are designed for the same specifications and tested under the same and stringent operating conditions using precision measuring equipment. Experimental results of two 1.5 kW prototype Buck and Boost converter units are presented with detailed discussions, and the paper explains why, in contrary to the popular belief, a properly designed Boost topology is superior in performance to Buck topology and more appropriate for low voltage fuel cell applications, as indicated by measured results.

General information
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Authors: Nymand, M. (Intern), Tranberg, R. (Ekstern), Madsen, M. E. (Ekstern), Madawala, U. K. (Ekstern), Andersen, M. A. E. (Intern)
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High Performance Low Cost Digitally Controlled Power Conversion Technology

Digital control of switch-mode power supplies and converters has within the last decade evolved from being an academic subject to an emerging market in the power electronics industry. This development has been pushed mainly by the computer industry that is looking towards digital power management in order to reduce the power consumption of servers and datacenters. The work presented in this thesis includes digital control methods for switch-mode converters implemented in microcontrollers, digital signal controllers and field programmable gate arrays. Microcontrollers are cheap devices that can be used for real-time control of switch-mode converters. Software design in the assembly language of the microcontroller is important because of the limited resources of the microcontroller. Microcontrollers are best suited for power electronics applications with low bandwidth requirements because the execution time of the software algorithm that realises the digital control law will constitute a considerable delay in the control loop. Digital signal controllers are powerful devices capable of performing arithmetic functions much faster than a microcontroller can. Digital signal controllers are well suited for digital control schemes involving multiple control loops such as digital control of a switch-mode power supply with several converter stages. Customised digital control solutions implemented in application specific integrated circuits are the best solution for high bandwidth digital control of non-isolated DC-DC converters. A customised digital control solution for a voltage mode control scheme should include a digital pulse width modulator which can generate a pulse width modulated signal with high switching frequency and high resolution, a digital compensator with a short execution time and an analogue to digital converter with a short sampling time. A digital self-oscillating modulator is proposed in the present thesis. The modulator is a free-running modulator which operates without an external carrier signal. Customised digital control solutions offers the best performance for non-isolated DC-DC converters. The best digital control solution presented in this thesis, which was implemented with the digital self-oscillating modulator, performs comparable to common analogue control IC solutions. It is however possible to achieve an even better performance with an analogue control circuit built with separate analogue components.

A New Approach to High Efficiency in Isolated Boost Converters for High-Power Low-Voltage Fuel Cell Applications

A new low-leakage-inductance low-resistance design approach to low-voltage high-power isolated boost converters is presented. Very low levels of parasitic circuit inductances are achieved by optimizing transformer design and circuit layout. Primary side voltage clamp circuits can be eliminated by the use of power MOSFETs fully rated for repetitive avalanche. Voltage rating of primary switches can now be reduced, significantly reducing switch on-state losses. Finally, silicon carbide rectifying diodes allow fast diode turn-off, further reducing losses. Test results from a 1.5 kW full-bridge boost converter verify theoretical analysis and demonstrate very high efficiency. Worst case efficiency, at minimum input voltage maximum power, is 96.8 percent and maximum efficiency reaches 98 percent.
A novel Modulation Topology for Power Converters utilizing Multiple Carrier Signals

Power converters are known to generate spectral components in the range of interest of electromagnetic compatibility measurements. Common approaches to manipulate some selected components in these frequency ranges are shown here. These approaches add components to the input signal of the modulator to derive a slightly varied spectrum. To achieve a rectangular output signal, those modulators use a triangular or saw tooth carrier signal. A novel family of modulators is shown here, using more than one carrier signal to obtain a completely changed spectrum while maintaining the rectangular shaped waveform at the output. The multiple carriers are fed into multiple comparators and their outputs are intelligently combined by logic gates to get a single signal to drive one power stage of any type of converter. This commutation distinguishes between the four members of the novel family: the first one uses an or-gate to combine the signals; the second one utilizes therefore an and-gate. The third modulator combines the outputs of those two and switches between the or-output and the and-output after each pulse. The last described modulator is commutating one of the described outputs dependent on the state of a master clock. The nonlinear operation of all modulators is described with nonlinear algebra in conjunction with Boolean algebra. The benefits for electromagnetic compatibility of the new schemes are presented, all modulators are examined in terms of steady state operation, dynamic behavior, maximum modulation range and added distortion. Finally the implementation of one of the modulators in a switch-mode power supply is presented. Experimental results are verifying the simulation.

General information
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10.1109/PESC.2008.4592172
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Source-ID: 220980
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A Versatile Discrete-Time Approach for Modeling Switch-Mode Controllers
This paper presents a universal method for modeling the frequency response of comparators in switchmode controllers. As the main non-linearity in most switchmode controllers, understanding the comparator is the key to understanding the system. Based on discrete-time modeling, the proposed method is demonstrated to allow very precise predictions of comparator frequency response in a variety of control schemes. In the presented work, the modeling method is exemplified for the standard PWM and two different self-oscillating (a.k.a. sliding mode) control schemes. The proposed method is believed by the authors to be the first method that is able to handle these fundamentally different control
schemes within a single modeling framework. Experimentally measured output impedance and comparator magnitude responses are compared to the model results. Great accuracy is achieved from DC to frequencies far beyond the switching frequency.
Comparison of three different Modulators for Power Converters with Respect to EMI Optimization

Switch-mode Power Converters are well known for emissions in the band of electromagnetic interference (EMI) interest. The spectrum shape depends on the type of modulator and its purpose. This paper gives design guidelines to choose the optimum topology depending on requirements of different applications. Spectral measurements on prototypes of a pulse width modulator (PWM), a -modulator and a hysteretic self-oscillating modulator are shown, which are verifying their simulations, with respect to different EMI challenges.

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Interleaved Buck Converter with Variable Number of Active Phases and a Predictive Current Sharing Scheme

The efficiency of an interleaved Buck converter is typically low at light load conditions because of the switching losses in each of the switching stages. Improvements in the converter efficiency can be achieved by dynamically changing the number of active phases depending on the load current. This paper addresses the issues related to the transient response of the converter when the number of active phases is changed by a digital control scheme. The problem arises because the current in the individual phases of the interleaved Buck converter will not be equal immediately after the controller has changed the number of active phases. This paper proposes a current equalisation scheme that adjusts the duty cycle of each phase in a manner that ensures equal average inductor current in all active phases in one or two PWM periods. The current equalisation scheme relies on the measurement of the output current and the knowledge of a few converter parameters and it does not require a measurement of the current in each phase. A digital PWM modulator has been designed that allows the current equalisation scheme to work. Simulations and measurements for a four phase interleaved Buck converter are presented and shows that the predictive current equalisation scheme can equalise the phase currents in a single PWM period.

General information
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Multi Carrier Modulator for Switch-Mode Audio Power Amplifiers

While switch-mode audio power amplifiers allow compact implementations and high output power levels due to their high power efficiency, they are very well known for creating electromagnetic interference (EMI) with other electronic equipment, in particular radio receivers. Lowering the EMI of switch-mode audio power amplifiers while keeping the performance measures to excellent levels is therefore of high general interest. A modulator utilizing multiple carrier signals to generate a two level pulse train will be shown in this paper. The performance of the modulator will be compared in simulation to existing modulation topologies. The lower EMI as well as the preserved audio performance will be shown in simulation as well as in measurement results on a prototype.

Optimized Envelope Tracking Power Supply for Tetra2 Base Station RF Power Amplifier

An ultra-fast tracking power supply (UFTPS) for envelope tracking in a 50kHz 64-QAM Tetra2 base station power amplification system is demonstrated. A simple method for optimizing the step response of the PID+PD sliding-mode control system is presented and demonstrated, along with a PLL-based scheme for locking the switching frequency to an external clock. High UFTPS efficiency (up to 95%), very low ripple (5mVpp) and a fast step response (10μs) are obtained from a single-phase buck converter with a 4th-order output filter. This ripple performance is demonstrated to be critical in the considered application. Also demonstrated is the effect of non-zero UFTPS output impedance on envelope tracking performance. At 13W average (156W peak) RF output, a reduction of DC input power consumption from 93W (14% efficiency) to 54W (24% efficiency) is obtained by moving from a fixed RF power amplifier supply to envelope tracking.
Parameterized Analysis of Zero Voltage Switching in Resonant Converters for Optimal Electrode Layout of Piezoelectric Transformers

Ring shaped PTs (Piezoelectric Transformers) are an attractive alternative to magnetics in power converters. The achievable energy efficiency is 98% and the power density is up to 30W/cm³. Additionally power supplies based on PTs display low levels of conducted and radiated EMI due to power conversion based on the piezoelectric effect. Rooted in the physics of this effect, both the in- and output terminal of a PT has a noticeable parasitic capacitance. In a common half-bridge power stage without any supporting magnetic components, the input parasitic capacitance can lead to hard switching losses that are in the range of the actual power rating of a specific PT. In this paper it is demonstrated how the electrode layout of a PT can be designed to enable ZVS (Zero Voltage Switching). This optimization is made simple with a novel set of accurate and simple symbolic equations which relates ZVS constraints to the physical electrode layout of a PT. These properties takes basis in the formulation of an equivalent electrical PT circuit that is valid around the frequency of operation.

Ultra-Fast Tracking Power Supply with 4th order Output Filter and Fixed-Frequency Hysteretic Control

A practical solution is presented for the design of a non-isolated DC/DC power converter with very low output ripple voltage and very fast output voltage step response. The converter is intended for use as an envelope tracking power supply for an RFPA (Radio Frequency Power Amplifier) in a Tetra2 base station. A simple and effective fixed-frequency hysteretic control scheme for the converter (buck with 4th order output filter) is developed and analyzed. The proposed approach is verified experimentally by a 500W output prototype, capable of delivering any voltage in the range of 10-30V within 10μs with 10mVpp of output ripple and efficiencies in the 88-95% range.
A 0.35μm 50V CMOS Sliding-Mode Control IC for Buck Converters

This paper presents a hysteretic (sliding mode) control IC for a buck DC/DC converter for use as an envelope tracking power supply to increase the efficiency of an RF power amplifier. The IC integrates a high-bandwidth error amplifier, a comparator with hysteresis, and a high-side driver for an external N-channel power MOSFET. The total control loop delay using the implemented IC is 35ns, this is shown to be a 30% reduction compared to a state-of-the-art discrete IC based solution. The presented results also show that it is viable to integrate a 100MHz operational amplifier on the same die as a high-voltage MOSFET driver operating with slew rates in excess of 5V/ns. The IC is demonstrated in a tracking power supply with 30W output power and 3μs rise/fall time, running from a 40V input. The complete IC, including pads, takes up 4mm² in a 0.35μm 50V CMOS process.

General information
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Accurate Sliding-Mode Control System Modeling for Buck Converters

This paper shows that classical sliding mode theory fails to correctly predict the output impedance of the highly useful sliding mode PID compensated buck converter. The reason for this is identified as the assumption of the sliding variable being held at zero during sliding mode, effectively modeling the hysteretic comparator as an infinite gain. Correct prediction of output impedance is shown to be enabled by the use of a more elaborate, finite-gain model of the hysteretic comparator, which takes the effects of time delay and finite switching frequency into account. The demonstrated modeling approach also predicts the self-oscillating switching action of the sliding-mode control system correctly. Analytical findings are verified by simulation as well as experimentally in a 10-30V/3A buck converter.

General information
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Høyerby, M. C. W. (Intern), Andersen, M. A. E. (Intern)
Pages: 0858
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Main Research Area: Technical/natural sciences
modeling, sliding mode control
Source: orbit
Source-ID: 201920
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A Comparative Study of Analog Voltage-mode Control Methods for Ultra-Fast Tracking Power Supplies

This paper presents a theoretical and experimental comparison of the standard PWM/PID voltage-mode control method for single-phase buck converters with two high-performance self-oscillating (aka. sliding mode) control methods. The application considered is ultra-fast tracking power supplies (UFTPSs) for RF power amplifiers, where the switching converter needs to track a varying reference voltage precisely and quickly while maintaining low output impedance. The small-signal analyses performed on the different controllers show that the hysteretic-type controller can achieve the highest loop gain, leading to superior output impedance performance in the UFTPS application; this is explained using a recently proposed small-signal model for the hysteretic comparator. The analytical findings are verified experimentally as well as by simulation. Experimentally, the use of hysteretic self-oscillating control is shown to reduce the worst-case UFTPS output impedance by a factor of 10.

General information
Digitally Controlled Envelope Tracking Power Supply for an RF Power Amplifier

A new Digital Self-Oscillating (DiSOM) modulator is presented in this paper. The advantage of the DiSOM is that it allows the sampling frequency of the digital compensator to be higher than the switching frequency, but it also has the ability to shape the quantization noise on the switching output due to clock frequency quantization. An envelope tracking power supply for an RF Power Amplifier (RFPA) can help improve system efficiency by reducing the power consumption of the RFPA. To show the advantage of the DiSOM over traditional counter based Digital PWM modulators two designs were compared in both simulation and by experiment. The results show that the DiSOM could give an increase in open loop bandwidth by more than a factor of two and an reduce the closed loop output impedance of the power supply by a factor of 5 at the output filter resonance frequency.

Digitally Controlled Offline Converter with Galvanic Isolation Based on an 8-bit Microcontroller

This paper presents an offline AC/DC converter with digital control and galvanic isolation that can be implemented using cheap commercially available components. An ATMEG ATTiny26 8-bit microcontroller is used to control the converter. The microcontroller is placed on the secondary side of the converter and an analogue primary side startup controller is used on the primary side. A prototype two-switch forward converter has been designed and experimental results are included to show the feasibility and performance of the proposed design.
Digitally Controlled Point of Load Converter with Very Fast Transient Response

This paper presents a new Digital Self-Oscillating Modulator (DiSOM) that allows the duty cycle to be changed instantly. The DiSOM modulator is shown to have variable switching that is a function of the duty cycle. Compared to a more traditional digital PWM modulator based on a counter and comparator the DiSOM modulator allows the sampling frequency of the output voltage control loop to be higher than the switching frequency of the power converter, typically a DC/DC converter. The features of the DiSOM modulator makes it possible to design a digitally controlled DC/DC converter with linear voltage mode control and very fast transient response. The DiSOM modulator is combined with a digital PID compensator algorithm is implemented in a hybrid CPLD/FPGA and is used to control a synchronous Buck converter, which is used in typical Point of Load applications. The computational time is only three clock cycles from the time the A/D converter result is read by the control algorithm to the time the duty cycle command is updated. A typical POL converter has been built and the experimental results show that the transient response of the converter is very fast. The output voltage overshoot is only 2.5% of the nominal output voltage when a load step of 50% - 100% of nominal output current is applied to the converter. The settling time is approximately 8 PWM cycles.

Digital Self-Oscillating Modulator

A digital self-oscillating modulator (1) having a digital reference signal as input (Vref) comprises a forward loop with a first output and a feedback loop. The feedback loop comprises a feedback block (18) having a transfer function (MFB) and a digital output. The forward loop comprises an alternating output stage (14), and a forward block (12) comprising a filter (12') with a transfer function (MFW) and has a digital output. The digital output from the forward block (12) is input to the alternating stage (14). The forward block (12) is provided with means for calculating the difference between the digital output from the feedback block (18) and the digital reference signal (Vref). The first output is in digital form fed back to the feedback block (18). Provided that the transfer function (MFW) of the forward block (12) is formed by a plurality of
integrators, the transfer function (MFB) of the feedback block (18) is not a unity transfer function.

**General information**  
State: Published  
Organisations: Automation, Department of Electrical Engineering  
Authors: Andersen, M. A. E. (Intern), Jakobsen, L. T. (Intern)  
Publication date: 2007

**Isolated EWiRaC: A New Low-Stress Single-Stage Isolated PFC Converter**

A new PFC-family of Efficient Wide Range Converters named EWiRaC was recently introduced. EWiRaC has a major advantage in terms of efficiency at low-line and handles challenges like inrush current limiting as an integrated part of the conversion scheme. The main objective of this paper is to investigate the performance of an isolated EWiRaC (I-EWiRaC) in a single-stage PFC configuration.

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  Links:  
  http://www.apec-conf.org

**Self-Oscillating Soft Switching Envelope Tracking Power Supply for Tetra2 Base Station**

This paper presents a high-efficiency, high-bandwidth solution to implementing an envelope tracking power supply for the RF power amplifier (RFPA) in a Tetra2 base station. The solution is based on synchronous rectified buck topology, augmented with high-side switch zero-current switching (ZCS) implemented with a series inductor and an external clamping power supply. Combined with advanced power stage components (die-size MOSFETs), a high-performance fixed-frequency self-oscillating (sliding mode) control strategy and a 4th-order output filter, this leads to a compact, effective and efficient overall solution switching at 1MHz with 88-95% efficiency. In a class-AB RFPA amplifying a 50kHz
Two-Phase Interleaved Buck Converter with a new Digital Self-Oscillating Modulator

This paper presents a new Digital Self-Oscillating Modulator (DiSOM) for DC/DC converters. The DiSOM modulator allows the digital control algorithm to sample the output voltage at a sampling frequency higher than the converter switching frequency. This enables higher control loop bandwidth than for traditional digital PWM modulators given a certain switching frequency. A synchronised version of the DiSOM modulator is derived for interleaved converters. A prototype interleaved Buck converter for Point of Load applications has been designed and built to test the performance of DiSOM modulator. The DiSOM modulator and a digital control algorithm have been implemented in an FPGA. Experimental results show that the converter has a very fast transient response when a loadstep is applied to the output. For a loadstep of 50% of nominal output current the output voltage overshoot is less than 2.5% of the nominal output voltage and the settling time is just 8 switching periods.
A 500-W Transformer-Less Efficient Universal Wide-Range Power Factor Preregulator

**General information**
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Jensen, A. (Ekstern), Petersen, L. (Ekstern), Andersen, M. A. E. (Intern)
Publication date: 2006

**Host publication information**
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Main Research Area: Technical/natural sciences
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2006

A small-signal model of the hysteretic comparator in linear-carrier self-oscillating switch-mode controllers

**General information**
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Høyerby, M. C. W. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2006

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Main Research Area: Technical/natural sciences
Source-ID: 189828
Publication: Research - peer-review › Article in proceedings – Annual report year: 2006

Comparison of two different high performance mixed signal controllers for DC/DC converters
This paper describes how mixed signal controllers combining a cheap microcontroller with a simple analogue circuit can offer high performance digital control for DC/DC converters. Mixed signal controllers have the same versatility and performance as DSP based controllers. It is important to have an engineer experienced in microcontroller programming write the software algorithms to achieve optimal performance. Two mixed signal controller designs based on the same 8-bit microcontroller are compared both theoretically and experimentally. A 16-bit PID compensator with a sampling frequency of 200 kHz implemented in the 16 MIPS, 8-bit ATTiny26 microcontroller is demonstrated.

**General information**
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Jakobsen, L. T. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2006

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Main Research Area: Technical/natural sciences
Conference: Tenth IEEE COMPEL Workshop, 01/01/2006
Source-ID: 190598
Publication: Research - peer-review › Article in proceedings – Annual report year: 2006
Efficient Wide Range Converters (EWiRaC): A new family of high efficient AC-DC Converters

The performance in terms of efficiency of the existing power supplies used for PFC is very dependent on the input voltage range. The boost converter is the most commonly used PFC converter because of its simplicity and high efficiency. But, the boost converter as well as other known converters suffers a major penalty in efficiency when used at the low end of the voltage range (90VAC) in a universal voltage range application (90-270VAC). This paper addresses this problem by suggesting a new family of converters that effectively reduces the apparent voltage range with a factor of 2 by changing the converter topology according to the input voltage. This new converter type has been named: efficient wide range converter (EWiRaC). The performance of the EWiRaC is experimental verified in a universal input range (90-270VAC) application with an output voltage of 185VDC capable of 500W output power. The EWiRaC exhibits a 1-2 percentage points higher efficiency compared to a boost converter using the same power components. This translates into a reduction of the power losses of 15%-30%.

General information
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Petersen, L. (Ekstern), Andersen, M. A. E. (Intern)
Number of pages: 7
Publication date: 2006
TBD
Efficient Audio Power Amplification - Challenges

For more than a decade efficient audio power amplification has evolved and today switch-mode audio power amplification in various forms are the state-of-the-art. The technical steps that lead to this evolution are described and in addition many of the challenges still to be faced and where extensive research and development are needed is covered.

General information
State: Published
Organisations: Department of Electrical Engineering, Automation
Authors: Andersen, M. A. E. (Intern)
Pages: 9-18
Publication date: 2005

Experimental Verification of the Thermal Droop Load Sharing Technique

General information
State: Published
Organisations: Department of Electric Power Engineering, Automation, Department of Electrical Engineering
Authors: Nesgaard, C. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2005
Four-quadrant flyback converter for direct audio power amplification

This paper presents a bidirectional, four-quadrant flyback converter for use in direct audio power amplification. When compared to the standard Class-D switching audio power amplifier with a separate power supply, the proposed four-quadrant flyback converter provides simple solution with better efficiency, higher level of integration and lower component count.

High-Bandwidth, High-Efficiency Envelope Tracking Power Supply for 40W RF Power Amplifier Using Paralleled Bandpass Current Sources

This paper presents a high-performance power conversion scheme for power supply applications that require very high output voltage slew rates (dV/dt). The concept is to parallel 2 switching bandpass current sources, each optimized for its passband frequency space and the expected load current. The principle is demonstrated with a power supply, designed for supplying a 40 W linear RF power amplifier for efficient amplification of a 16-QAM modulated data stream
Hybrid Control Method for a Single Phase PFC using a Low Cost Microcontroller

This paper presents a hybrid control method for single phase boost PFCs. The high bandwidth current loop is analog while the voltage loop is implemented in an 8-bit microcontroller. The design focuses on minimizing the number of calculations done in the microcontroller. A 1kW prototype has been designed and tested.

Hysteresis controller with constant switching frequency

Switch mode audio power amplifiers are showing up on market in still greater numbers because of advantages in form of high efficiency and low total system cost, especially for high power amplifiers. Several different modulator topologies have been made, ranging from standard PWM to various self-oscillating and digital modulators. Performance in terms of low distortion, noise and dynamic range differs significantly with the modulator topology used. Highest system performance is generally achieved with analog modulators made as a modulator loop including at least the power stage of the amplifier, because of benefits from continuous time operation and non-quantized resolution. This type of modulator uses no external carrier signal, and is called self-oscillating modulators. The work presented in this paper refers to switch mode audio power amplifier, but can be used within a wide range of DC-DC or DC-AC converters as well.
This paper deals with the design of integrated magnetics for HF-link converters, where the integrated magnetic components do not necessarily belong to the same voltage loop. Depending on the specific HF-link converter topology, the proposed integrated magnetics can either alleviate the derivation of independent auxiliary supply voltages from the main transformer or integrate other magnetic structures, thus saving board space and cutting costs.
New active load voltage clamp for HF-link converters

This paper proposes a new active clamp for HF-link converters, which features very high efficiency by returning the clamped energy back to the primary side through a small auxiliary converter. It also increases the reliability of HF-link converters by providing an alternative load current path during malfunctions of the secondary bidirectional bridge. The feasibility of the approach is shown on audio power amplifier prototype. New integrated magnetics design is presented that incorporates both the main power and auxiliary transformer on the same magnetic core.

General information
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Ljusev, P. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2005

New PWM method and commutation strategy for HF-link converters for fuel cells and photovoltaics

This paper presents a new PWM method and commutation strategy for HF-link converters, which leads to safe commutation of the load current in the output bidirectional bridge. The proposed implementation is independent of the particular HF-link converter topology and bidirectional switch selection and is therefore usable at all output power levels and switching frequencies. Theoretical analysis of the approach and experimental investigation are presented to prove the feasibility of the concept.

General information
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Ljusev, P. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2005

Self-oscillating modulators for direct energy conversion audio power amplifiers

Direct energy conversion audio power amplifier represents total integration of switching-mode power supply and Class D audio power amplifier into one compact stage, achieving high efficiency, high level of integration, low component count and eventually low cost. This paper presents how self-oscillating modulators can be used with the direct switching-mode audio power amplifier to improve its performance by providing fast hysteretic control with high power supply rejection ratio, open-loop stability and high bandwidth. Its operation is thoroughly analyzed and experimental results from prototype
amplifier are presented.

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Organisations: Automation, Department of Electrical Engineering
Authors: Ljusev, P. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2005

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Source: orbit
Source-ID: 201935
Publication: Research - peer-review › Article in proceedings – Annual report year: 2005

Simple single-phase HF-link UPS with new PWM approach

General information
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Ljusev, P. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2005

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Conference: International Telecommunications Energy Conference INTELEC 2005, 01/01/2005
DOIs:
10.1109/INTLEC.2005.335128
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Source-ID: 201931
Publication: Research - peer-review › Article in proceedings – Annual report year: 2005

Switching-mode Audio Power Amplifiers with Direct Energy Conversion
This paper presents a new class of switching-mode audio power amplifiers, which are capable of direct energy conversion from the AC mains to the audio output. They represent an ultimate integration of a switching-mode power supply and a Class D audio power amplifier, where the intermediate DC bus has been replaced with a high frequency AC link. When compared to the conventional Class D amplifiers with a separate DC power supply, the proposed single conversion stage amplifier provides simple and compact solution with better efficiency and higher level of integration, leading to reduced component count, volume and cost.

General information
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Ljusev, P. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2005

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Conference: AES Barcelona 2005, Barcelona, Spain, 01/01/2005
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Towards Active Transducers
One of the trends within consumer audio systems is the requirement for surround sound systems, based on 5-7 or even more audio channels, resulting in the same number of power amplifier channels and loudspeakers for each system. Most systems on the market today are based on linear amplifiers techniques developed in the middle of last century, which is surprising when the last few decades’ development within the audio source material, that is CD, DVD and SACD to mention the most popular, are taken into account. Audio performance of linear amplifiers has
reached a level suitable for high quality audio reproduction many product generations ago, but
the biggest disadvantages are still left untouched; power efficiency, size and cost.
With today’s technology, high efficient switch mode, or class D audio amplifiers based on pulse
width modulation, PWM, are realizable. With the class D technology, consumer audio systems
can benefit significantly from the highly increased power efficiency of class D amplifiers as well
as their reduced size without need for bulky heat sinks, and also very important, low cost.
The topic of this project is a total integration of switch mode audio amplifiers and loudspeakers
into one single unit using the voice coil of the loudspeaker as output filter for the amplifier, with
a perspective of highly reduced system power losses, system size and cost.
Standard switch mode audio amplifiers and loudspeakers on the market are designed for use in
traditional audio systems, and cannot without severe modifications be used for the integrated
system without sacrifice of power efficiency. For this reason techniques for dedication of
amplifier and loudspeaker for the specific purpose of the integration has been of major
importance in this project.
This thesis is a fundamental study of the loss mechanisms in loudspeakers and amplifiers and
suggestions for optimizations are made to reduce the system power losses and cost without
compromising the audio performance.
Some of the results obtained in the project are redesign of and optimization of the parts in a
loudspeaker, so the function of output filter for the amplifier can be obtained without significant
power losses. Guidelines for dedication of speaker and amplifier to the integration process with
significantly lower system power losses are also given. Furthermore, the work done in the project
has resulted in new switch mode amplifier topologies, with very high audio performance
realizable at a very low cost.

General information
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Organisations: Department of Electrical Engineering, Electronics
Authors: Poulsen, S. (Intern), Andersen, M. A. E. (Intern)
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Publication: Research › Ph.D. thesis – Annual report year: 2004

Fault Tolerant Power Systems

General information
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Organisations: Department of Electrical Engineering, Electronics
Authors: Nesgaard, C. (Intern), Andersen, M. A. E. (Intern)
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Approaches to building single-stage AC/AC conversion switch-mode audio power amplifiers
This paper discusses the possible topologies and promising approaches towards direct single-phase AC-AC conversion of
the mains voltage for audio applications. When compared to standard Class-D switching audio power amplifiers with a
separate power supply, it is expected that direct conversion will provide better efficiency and higher level of integration,
leading to lower component count, volume and cost, but at the expense of a minor performance deterioration.
Digitally-controlled PC-interfaced Boost Converter for Educational Purposes
This paper describes implementation of a simple digital PID control algorithm for a boost converter using a cheap fixed-point 8-bit microcontroller. Serial communication to a PC server program is established for easier downloading of compensator parameters and current and voltage waveform acquisition. At the end, client program is presented which uses TCP/IP connection for operating the digitally controlled boost converter over Internet. The aim of this cheap and flexible PC-interfaced boost converter bench is predominantly educational, to allow students to synthesize different digital controllers and compare their performance.

Efficiency improvement in redundant power systems by means of thermal load sharing
The demand for higher output currents at ever lower voltage levels is often solved by paralleling multiple converters. Provided redundancy is implemented this technique, besides being relatively easy to implement, has the advantage of improving the overall system reliability. Also, the parallel-connection concept forms the basis of a very cost-effective power system design, since the entire system often can be realized using off-the-shelf units. This paper verifies experimentally that the use of the thermal load sharing technique, proposed in [1], not only increases the overall system reliability but also has a positive impact on the system efficiency. The latter aspect is achieved by redistributing the current throughput of each converter, which in turn results in equal thermal conditions as opposed to the current sharing technique’s intent to establish equal currents.
High Bandwidth Automotive Power Supply for Low-cost PWM Audio Amplifiers

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Authors: Høyerby, M. C. W. (Intern), Andersen, M. A. E. (Intern), Andersen, D. R. (Ekstern), Petersen, L. (Ekstern)
Publication date: 2004

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Main Research Area: Technical/natural sciences
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Hysteresis Controller with constant switching frequency

General information
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Organisations: Department of Electrical Engineering
Authors: Poulsen, S. (Ekstern), Andersen, M. A. E. (Intern)
Publication date: 2004

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Main Research Area: Technical/natural sciences
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Integrating switch mode audio amplifiers and electro dynamic loudspeakers for a higher power efficiency

The work presented in this paper is related to integration of switch mode audio amplifiers and electro dynamic loudspeakers, using the speaker's voice coil as output filter, and the magnetic structure as heatsink for the amplifier.

General information
Integrating switch mode audio power amplifiers and electro dynamic loudspeakers for a higher power efficiency
The work presented in this paper is related to integration of switch mode audio amplifiers and electro dynamic loudspeakers, using the speaker's voice coil as output filter, and the magnetic structure as heatsink for the amplifier.

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Authors: Poulsen, S. (Intern), Andersen, M. A. E. (Intern)
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Integrating switch mode audio power amplifiers and electro dynamic loudspeakers for higher power efficiency

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Integrating switch mode audio power amplifiers and electro dynamic loudspeakers for higher power efficiency

General information
State: Published
Organisations: Department of Electrical Engineering
Authors: Poulsen, S. (Ekstern), Andersen, M. A. E. (Intern)
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Integrating switch mode audio power amplifiers and electro dynamic loudspeakers for higher power efficiency

General information
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Organisations: Department of Electrical Engineering
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Publication date: 2004

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Publication: Research - peer-review › Article in proceedings – Annual report year: 2004
Optimized load sharing control by means of thermal reliability management

With new applications for high-current low-output voltage power systems emerging nearly every day the need for new and cost-efficient power system designs is a matter of course. As output voltage levels continue to decrease an approach that seems more and more attractive is the implementation of distributed power configurations with point-of-load power conversion. This technique distributes a high voltage to all parts of the system, thus minimizing the voltage drops throughout the distribution network. However, this configuration only solves the problem of power losses in the distribution network while the problems of high-current low-output voltage conversion at the point-of-load remain a challenge. A common solution to the latter problem is the parallel-connection of multiple converter units. This technique is attractive for a number of reasons. The first and most obvious reason is that it provides the designer with a simple technique for reliability improvements as redundancy quite easily can be implemented. Another advantage of this particular technique is that it allows the designer to implement large power systems by means of off-the-shelf units, thus minimizing parameters such as design time and system cost. However, due to non-ideal parts each converter unit deviates from the ideal case, which makes a power system comprised of parallel-connected converters a rather poor performing system. To account for the non-ideal parts some form of load sharing is needed, whereby it is ensured that each converter in the configuration delivers its share of the total output power. In other words parallel-operation of multiple converters is employed when specifications require a highly reliable system, designable within a very short time frame and at low costs. However, to make full use of the system’s potential load sharing control is a must.

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Publication date: 2004

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Main Research Area: Technical/natural sciences
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Practical considerations for integrating switch mode audio amplifiers and loudspeakers for a higher power efficiency

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Organisations: Department of Electrical Engineering
Authors: Poulsen, S. (Intern), Andersen, M. A. E. (Intern)
Publication date: 2004

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Conference: 116th AES Convention, Berlin, Germany, 01/01/2004
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Source: orbit
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Publication: Research - peer-review › Article in proceedings – Annual report year: 2004
Safe-commutation principle for direct single-phase AC-AC converters for use in audio power amplification

This paper presents an alternative safe commutation principle for a single phase bidirectional bridge, for use in the new generation of direct single-stage AC-AC audio power amplifiers. As compared with the bridge commutation with load current or source voltage sensing, in this approach it is not required to do any measurements, thus making it more reliable. Initial testing made on the prototype prove the feasibility of the approach.

Self oscillating PWM modulators, a topological comparison

High precision control of the output voltage or current of a switch mode converter with fast response is required for a number of applications. Dependent on the type of application, the desired precision and transient response can be difficult, if not impossible, to achieve with standard PWM control caused by limitations in dynamic capabilities which often limits fast tracking of a reference signal, or fast settling during load steps due to too small achievable control loop bandwidth. Achievable open loop bandwidth for standard voltage and current mode PWM modulators is typical in the \( \frac{f_s}{10} \) or \( \frac{f_s}{8} \) range respectively, where \( f_s \) is the switching frequency of the converter. For some applications this will require unacceptably high switching frequency to achieve enough control loop bandwidth for the desired dynamic performance. With self oscillating modulators, the open loop bandwidth is equal to \( f_s \) which makes this type of modulators an excellent choice for a wide range of applications. Self oscillating PWM modulators can be made in a number of ways, either as voltage or current mode modulators, and the self oscillating behavior can be achieved either by using hysteresis control or by shaping the open loop function of the modulator so its gain and phase response causes a closed loop natural oscillation. The two main types of self oscillating modulators have many similarities, but differences in dynamic performance and linearity are present. The work presented is related to the author's work with switch mode audio power amplifiers, where linear tracking of the reference signal is of major importance. Use of the modulator topologies presented are not limited to this kind of equipment, but can be used in a very wide range of applications from very low to very high power levels.
Simple PWM modulator topology with excellent dynamic behavior

This paper proposes a new PWM modulator topology. The modulator is used in switch mode audio power amplifiers, but the topology can be used in a wide range of applications. Due to excellent transient behavior, the modulator is very suited for VRMs or other types of DC-DC or DC-AC applications.

General information
State: Published
Organisations: Department of Electrical Engineering, Automation
Authors: Poulsen, S. (Intern), Andersen, M. A. E. (Intern)
Pages: 486-492
Publication date: 2004

Host publication information
Title of host publication: APEC 2004 – Nineteenth Annual IEEE Applied Power Electronics Conference and Exposition
Volume: 1
Publisher: IEEE
ISBN (Print): 0-7803-8270-6
Main Research Area: Technical/natural sciences
Conference: 19th Annual IEEE Applied Power Electronics Conference and Exposition, Anaheim, CA, United States,
22/02/2004 - 22/02/2004
Electronic versions:
Poulsen.pdf
DOIs: 10.1109/APEC.2004.1295852

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Source: orbit
Source-ID: 201829
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Single conversion audio amplifier and DC-AC converters with high performance and low complexity control scheme

This paper proposes a novel control topology for a mains isolated single conversion audio amplifier and DC-AC converters. The topology is made for use in audio applications, and differs from prior art in terms of significantly reduced distortion as well as lower system complexity. The topology can be useful in a wide range of DC-AC applications such as motor drives or UPS systems requiring mains isolation as well.

General information
State: Published
Organisations: Department of Electrical Engineering
Authors: Poulsen, S. (Ekstern), Andersen, M. A. E. (Intern)
Publication date: 2004

Host publication information
Title of host publication: NORPIE2004
Main Research Area: Technical/natural sciences
Conference: NORPIE2004, Trondheim, 01/01/2004
Links:
Source: orbit
Source-ID: 181319
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

Single conversion audio amplifier and DC-AC converters with high performance and low complexity control scheme

This paper proposes a novel control topology for a mains isolated single conversion audio amplifier and DC-AC converters. The topology is made for use in audio applications, and differs from prior art in terms of significantly reduced distortion as well as lower system complexity. The topology can be useful in a wide range of DC-AC applications such as motor drives or UPS systems requiring mains isolation as well.

General information
State: Published
Organisations: Department of Electrical Engineering, Automation
Authors: Poulsen, S. (Intern), Andersen, M. A. E. (Intern)
High Efficient Rectifiers

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Petersen, L. (Intern), Andersen, M. A. E. (Intern)
Publication date: Dec 2003

Tracking Power Supply for Automotive Multichannel Single-ended PWM Audio

General information
State: Published
Organisations: Automation, Department of Electrical Engineering
Authors: Høyerby, M. C. W. (Intern), Andersen, M. A. E. (Intern), Andersen, D. R. (Ekstern)
Publication date: 2004

Host publication information
Title of host publication: 11th International Power Electronics and Motion Control Conference EPE-PEMC 2004
Main Research Area: Technical/natural sciences
Conference: 11th International Power Electronics and Motion Control Conference EPE-PEMC 2004, Riga, 01/01/2004
Source: orbit
Source-ID: 201833
Publication: Research - peer-review › Article in proceedings – Annual report year: 2004

High Efficient Rectifiers

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Petersen, L. (Intern), Andersen, M. A. E. (Intern)
Publication date: Dec 2003
Digitally Controlled Converter with Dynamic Change of Control Law and Power Throughput

With the continuous development of faster and cheaper microprocessors the field of applications for digital control is constantly expanding. Based on this trend the paper at hand describes the analysis and implementation of multiple control laws within the same controller. Also, implemented within the control algorithm is a thermal monitoring scheme used for assessment of safe converter power throughput. An added benefit of this thermal monitoring is the possibility of software implemented analytic redundancy, which improves system fault resilience. Finally, reliability issues concerning the substitution of analog controllers with their digital counterparts are considered. The outline of the paper is divided into two segments – the first being an experimental analysis of the timing behavior by means of code optimization – the second being an examination of the dynamics of incorporating two control laws using multiple control parameters.

Two-Stage Power Factor Corrected Power Supplies: The Low Component-Stress Approach

The discussion concerning the use of single-stage contra two-stage PFC solutions has been going on for the last decade and it continues. The purpose of this paper is to direct the focus back on how the power is processed and not so much as to the number of stages or the amount of power processed. The performance of the basic DC/DC topologies is reviewed with focus on the component stress. The knowledge obtained in this process is used to review some examples of the alternative PFC solutions and compare these solutions with the basic two-stage PFC solution.
Boost-omformeren til PFC

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Andersen, M. A. E. (Intern)
Number of pages: 22
Publication date: 1998

Publication information
Original language: Danish
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 175681
Publication: Research - peer-review › Report – Annual report year: 1999

Comparing Non-linear with Linear Control Methods for Error Correction in Switching Audio Amplifier Output Stages

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Taul, T. (Ekstern), Andersen, M. A. E. (Intern)
Number of pages: 43
Publication date: 1998

Host publication information
Title of host publication: AES 104th Convention
Main Research Area: Technical/natural sciences
Conference: 104th Audio Engineering Society Convention, Amsterdam, Netherlands, 16/05/1998 - 16/05/1998
Source: orbit
Source-ID: 201908
Publication: Research - peer-review › Article in proceedings – Annual report year: 1998

Control Circuit Analysis Applied to Power Electronics

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Andersen, M. A. E. (Intern)
Number of pages: 17
Publication date: 1998

Publication information
Original language: English
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 171785
Publication: Research - peer-review › Book – Annual report year: 1998

Ensrettere med ohmsk belastning af nettet.

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Andersen, M. A. E. (Intern)
Number of pages: 15
Publication date: 1998
Flyback-omformeren til PFC

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Andersen, M. A. E. (Intern)
Number of pages: 25
Publication date: 1998

Power Factor Correction, PFC.

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Andersen, M. A. E. (Intern)
Number of pages: 22
Publication date: 1998

Switch-mode audio effektførstærkere: CoolPower

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Andersen, M. A. E. (Intern)
Number of pages: 11
Publication date: 1998

Trefaset skiftekontakt med IGBT'er

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Andersen, M. A. E. (Intern)
Number of pages: 12
Publication date: 1998
Fast Prediction of Differential Mode Noise Input Filter Requirements for Flyback and Boost Unity Power Factor Converters

Two new and simple methods to make predictions of the differential mode (DM) input filter requirements are presented, one for flyback and one for boost unity power factor converters. They have been verified by measurements. They give the designer the ability to predict the DM input noise filter requirements early in the design.
Single Phase Low Distortion DC/AC-Inverter with high bandwidth to switching frequency ratio

General information
State: Published
Organisations: Department of Applied Electronics
Authors: Anderskouv, N. (Ekstern), Nielsen, K. (Intern), Andersen, M. A. E. (Intern)
Pages: 214-219
Publication date: 1997

Host publication information
Volume: 1
Place of publication: Brussel
ISBN (Print): 90-75815-02-6
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 171957
Publication: Research - peer-review › Article in proceedings – Annual report year: 1997

High Fidelity Pulse Width Modulation Amplifiers based on Novel Double Loop Feedback Techniques

General information
State: Published
Organisations: Automation, Department of Electrical Engineering, Department of Automation
Authors: Andersen, M. A. E. (Intern), Anderskouv, N. (Ekstern), Nielsen, K. (Intern)
Number of pages: 17
Pages: 4258
Publication date: 1996

Host publication information
Title of host publication: 100th Audio Engineering Society Convention
Publisher: AES
Main Research Area: Technical/natural sciences
Conference: 100th Audio Engineering Society Convention, Copenhagen, Denmark, 11/05/1996 - 11/05/1996
Source: orbit
Source-ID: 201919
Publication: Research - peer-review › Article in proceedings – Annual report year: 1996

MOS Gate Driver Circuit with Extremely High Galvanic Isolation

General information
State: Published
Organisations: Unknown
Authors: Andersen, M. A. E. (Intern)
Pages: 747-751
Publication date: 1995

Host publication information
Title of host publication: EPE 1995
Volume: 1
Publisher: EPE
Main Research Area: Technical/natural sciences
Conference: EPE 1995, Sevilla, Spain, 01/01/1995
Source: orbit
Source-ID: 201898
Publication: Research - peer-review › Article in proceedings – Annual report year: 1995

PC-programs for Designing Snubber Circuits
Possible Technical Solutions to Reduce Energy Consumption in Audio Products

A New Application for Zero-Current-Switched Full-Wave Resonant Converters

Comparison of three IGBT-Inverters, one Hard-Switched and two with Snubber Circuits using a Minimum Number of Components
PC-Program with Graphic Presentation for Fast Interactive Design Decisions for Snubber Circuits

General information
State: Published
Organisations: Unknown
Authors: Andersen, M. A. E. (Intern)
Pages: 513-518
Publication date: 1993

Host publication information
Title of host publication: IMACS-TC1
Main Research Area: Technical/natural sciences
Conference: IMACS-TC1, Montréal, Canada, 01/01/1993
Source: orbit
Source-ID: 201894
Publication: Research - peer-review › Article in proceedings – Annual report year: 1993

New Principle for Digital Audio Power Amplifiers

General information
State: Published
Organisations: Department of Electrical Engineering, Electronics
Authors: Andersen, M. A. E. (Intern)
Pages: 3226
Publication date: 1992

Host publication information
Title of host publication: 92nd Audio Engineering Society Convention
Publisher: AES
Main Research Area: Technical/natural sciences
Conference: 92nd Audio Engineering Society Convention, Vienna, Austria, 24/03/1992 - 24/03/1992
Source: orbit
Source-ID: 201891
Publication: Research - peer-review › Article in proceedings – Annual report year: 1992

Novel Simple Lossless Snubber Circuit for an IGBT-Inverter

General information
State: Published
Organisations: Unknown
Authors: Andersen, M. A. E. (Intern)
Pages: 624-631
Publication date: 1992

Host publication information
Title of host publication: ACEMP 1992
Volume: 2
ISBN (Print): 975-429-031-8
Main Research Area: Technical/natural sciences
Conference: ACEMP 1992, Kusadasi, Turkey, 01/01/1992
Source: orbit
Source-ID: 201892
Publication: Research - peer-review › Article in proceedings – Annual report year: 1992
Special purpose PC-computer program as a design tool for optimizing snubber circuits for an IGBT-inverter

A special purpose computer program running on a PC is proposed as a design tool which enables the user, quickly and easily, to make an optimum design of the values of the snubber components for an inverter with an asymmetrical circuit configuration. Design decisions for problem solving are discussed. A graphic presentation of the boundaries for the maximum ratings, defining the solution space is made in which the user can choose values to ensure safe operation. An evaluation criteria for making the optimum choice of the values the PC-based program further presents the turn-on switching energy loss in the IGBT, the turn-off switching energy loss in the IGBT, the energy loss in the snubber resistor for a single one turn-on and turn-off, and the total turn-on and turn-off switching time of the snubber circuit so that these criteria can be taken into account in the actual application.

General information
State: Published
Organisations: Technical University of Denmark
Authors: Andersen, M. A. E. (Intern)
Pages: 51-58
Publication date: 1992

Host publication information
Title of host publication: Proceedings of the IEEE 3rd Workshop on Computers in Power Electronics
Publisher: IEEE
ISBN (Print): 0-7803-0920-0
Main Research Area: Technical/natural sciences
Electronic versions:
Andersen.pdf
DOIs:
10.1109/CIPE.1992.247293

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Source: orbit
Source-ID: 201893
Publication: Research - peer-review › Article in proceedings – Annual report year: 1992

Computer Program for Designing Snubber Circuit for an IGBT-Inverter

General information
State: Published
Organisations: Unknown
Authors: Andersen, M. A. E. (Intern), Havemann (retired June, 2000), H. (Ekstern)
Pages: 155-159
Publication date: 1991

Host publication information
Title of host publication: EPE 1991
Volume: 1
Main Research Area: Technical/natural sciences
Source: orbit
Source-ID: 201889
Publication: Research - peer-review › Article in proceedings – Annual report year: 1991

Computer Program with Supplementary Design Graphs for Designing Snubber Circuit for an IGBT-Inverter

General information
State: Published
Organisations: Department of Applied Electronics, Department of Electric Power Engineering
Authors: Andersen, M. A. E. (Intern), Havemann, H. (Intern)
Pages: 56-59
Publication date: 1991
A Comparison of three Inverters with IGBTs, GTOs and Bipolar Transistors at 600V and 300A

Effektelektroniske kontaktelementer

GTO-Inverter with Computer Designed Optimal Values of the Snubber Components
TBD
Department of Electrical Engineering
Period: 15/02/2017 → 14/02/2020
Number of participants: 3
Phd Student:
Jørgensen, Kasper Lüthje (Intern)
Supervisor:
Andersen, Michael A. E. (Intern)
Main Supervisor:
Zhang, Zhe (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansieret - Andet
Project: PhD

Module Integrated Converter for Photovoltaic Systems
Department of Electrical Engineering
Period: 15/03/2016 → 14/03/2019
Number of participants: 3
Phd Student:
bin Abdul Rahman, Norjasmi (Intern)
Supervisor:
Ouyang, Ziwei (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Stipendie fra udlandet
Project: PhD

High Frequency Switch-Mode Audio Power Amplifiers
Department of Electrical Engineering
Period: 15/12/2014 → 21/03/2018
Number of participants: 3
Phd Student:
Iversen, Niels Elkjær (Intern)
Supervisor:
Andersen, Michael A. E. (Intern)
Main Supervisor:
Knott, Arnold (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Galvanic isolated off-line VHF switch-mode power supplies
Department of Electrical Engineering
Period: 15/12/2013 → 12/04/2017
Number of participants: 6
Phd Student:
Pedersen, Jeppe Arnsdorf (Intern)
Supervisor:
Andersen, Michael A. E. (Intern)
Main Supervisor:
Knott, Arnold (Intern)
Effects and Minimization of stray inductance in power electronics
Department of Electrical Engineering
Period: 01/12/2013 → 30/11/2016
Number of participants: 3
Phd Student:
Lindberg-Poulsen, Kristian (Intern)
Supervisor:
Andersen, Michael A. E. (Intern)
Main Supervisor:
Petersen, Lars Press (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Control and sensor techniques for PAD servo motor drives
Department of Electrical Engineering
Period: 15/02/2013 → 04/05/2016
Number of participants: 7
Phd Student:
Zsurzsan, Tiberiu-Gabriel (Intern)
Supervisor:
Andersen, Nils Axel (Intern)
Zhang, Zhe (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Petersen, Lars Press (Intern)
Radecker, Matthias (Ekstern)
Uchino, Kenji (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Samfinansierede - Virksomhed
Project: PhD

Relations
Publications:
Advances in Piezoelectric Systems: An Application-Based Approach.
Project: PhD

Multi-portBidirectional Current Controlled Power Supply
Department of Electrical Engineering
Period: 01/12/2012 → 15/06/2016
Number of participants: 6
Phd Student:
Mira Albert, Maria del Carmen (Intern)
Supervisor:
Knott, Arnold (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Ouyang, Ziwei (Intern)
Cobos, José A. (Ekstern)
Kazimierczuk, Marian K. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

On the Integration of Wide Band-gap Semiconductors in Single Phase Boost PFC Converters

Department of Electrical Engineering
Period: 01/12/2012 → 20/04/2016
Number of participants: 6
Phd Student:
Hernandez Botella, Juan Carlos (Intern)
Supervisor:
Petersen, Lars Press (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Knott, Arnold (Intern)
Balogh, Laszlo (Ekstern)
Prodic, Aleksandar (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.

Relations
Publications:
On the Integration of Wide Band-gap Semiconductors in Single Phase Boost PFC Converters
Project: PhD

Non-magnetic driver for piezo actuators

Department of Electrical Engineering
Period: 01/11/2012 → 04/05/2016
Number of participants: 6
Phd Student:
Ekhtiari, Marzieh (Intern)
Supervisor:
Zhang, Zhe (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Petersen, Lars Press (Intern)
Carazo, Alfredo Vazquez (Ekstern)
Foster, Martin Paul (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD
PV Inverter and control  
Department of Electrical Engineering  
Period: 01/11/2012 → 20/01/2016  
Number of participants: 6  
Phd Student:  
Anthon, Alexander (Intern)  
Supervisor:  
Zhang, Zhe (Intern)  
Main Supervisor:  
Andersen, Michael A. E. (Intern)  
Examiner:  
Knott, Arnold (Intern)  
Lomonova, Elena A. (Ekstern)  
Nee, Hans-Peter (Ekstern)  

Financing sources  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.  
Project: PhD

Very High Frequency Switch-Mode Power Supplies  
Department of Electrical Engineering  
Period: 01/06/2012 → 18/09/2015  
Number of participants: 6  
Phd Student:  
Madsen, Mickey Pierre (Intern)  
Supervisor:  
Knott, Arnold (Intern)  
Main Supervisor:  
Andersen, Michael A. E. (Intern)  
Examiner:  
Zhang, Zhe (Intern)  
Kazimierczuk, Marian K. (Ekstern)  
Redl, Richard (Ekstern)  

Financing sources  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.  
Project: PhD

Switch-Mode Power Amplifiers for Current Controlled Loudspeakers  
Department of Electrical Engineering  
Period: 15/12/2011 → 20/08/2015  
Number of participants: 6  
Phd Student:  
Schneider, Henrik (Intern)  
Supervisor:  
Knott, Arnold (Intern)  
Main Supervisor:  
Andersen, Michael A. E. (Intern)  
Examiner:  
Bruun, Erik (Intern)  
Bard, Delphine (Ekstern)  
Risbo, Lars (Intern)  

Financing sources  
Source: Internal funding (public)  
Name of research programme: Institut stipendie (DTU) Samf.
High efficiency reversible fuel cell power converter

Department of Electrical Engineering
Period: 01/12/2011 → 27/02/2015
Number of participants: 6
Phd Student: Pittini, Riccardo (Intern)
Supervisor: Zhang, Zhe (Intern)
Main Supervisor: Andersen, Michael A. E. (Intern)
Examiner: Petersen, Lars Press (Intern)
Ferreira, Jan Abraham (Ekstern)
Nee, Hans-Peter (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

High Performance Solar Array Simulator

Department of Electrical Engineering
Period: 01/12/2011 → 07/05/2015
Number of participants: 6
Phd Student: Nguyen-Duy, Khiem (Intern)
Supervisor: Knott, Arnold (Intern)
Main Supervisor: Andersen, Michael A. E. (Intern)
Examiner: Zhang, Zhe (Intern)
Kyyrä, Jorma (Ekstern)
Wolf, Christian (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

High Power DEAP actuator drive for wind turbine flaps

Department of Electrical Engineering
Period: 15/11/2011 → 27/02/2015
Number of participants: 6
Phd Student: Thummala, Prasanth (Intern)
Supervisor: Zhang, Zhe (Intern)
Main Supervisor: Andersen, Michael A. E. (Intern)
Examiner: Petersen, Lars Press (Intern)
Hurley, William Gerard (Ekstern)
Lomonova, Elena A. (Ekstern)
Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Low power DEAP actuator drive for heating valves
Department of Electrical Engineering
Period: 01/11/2011 → 27/02/2015
Number of participants: 6
Phd Student:
Huang, Lina (Intern)
Supervisor:
Zhang, Zhe (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Jørgensen, Ivan Harald Holger (Intern)
Sun, Jian (Ekstern)
Zhao, Zhengming (Ekstern)

Radio frequency switch-mode power supplies
Department of Electrical Engineering
Period: 01/11/2011 → 22/04/2015
Number of participants: 6
Phd Student:
Kovacevic, Milovan (Intern)
Supervisor:
Knott, Arnold (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Jørgensen, Ivan Harald Holger (Intern)
Bertilsson, Kent (Ekstern)
Foster, Martin Paul (Ekstern)

Piezoelectric transformer based LED lighting
Department of Electrical Engineering
Period: 01/08/2011 → 27/02/2015
Number of participants: 7
Phd Student:
Nielsen, Dennis (Intern)
Supervisor:
Kjærgaard, Claus (Intern)
Knott, Arnold (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Petersen, Lars Press (Intern)
Mouton, Hendrik du T. (Ekstern)
Pfaffinger, Gerhard (Ekstern)

Financial sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

High Performance Solar Array Simulator
Department of Electrical Engineering
Period: 01/02/2011 → 31/08/2011
Number of participants: 3
Phd Student:
Zhao, Shen (Intern)
Supervisor:
Knott, Arnold (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)

Financial sources
Source: Internal funding (public)
Name of research programme: 1/3 FUU, 1/3 inst 1/3 Andet
Project: PhD

Controller IC-design for piezoelectric transformer based power supply
Department of Electrical Engineering
Period: 01/07/2009 → 25/01/2013
Number of participants: 5
Phd Student:
Rødgaard, Martin Schøler (Intern)
Supervisor:
Bruun, Erik (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Carazo, Alfredo Vazquez (Ekstern)
Foster, Martin Paul (Ekstern)

Financial sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Design of digital audio Class-D output stage with feedback - emphasis on hearing aid application
Department of Electrical Engineering
Period: 01/07/2009 → 26/09/2013
Number of participants: 6
Phd Student:
Pracný, Peter (Intern)
Supervisor:
Andersen, Michael A. E. (Intern)
Main Supervisor:
Bruun, Erik (Intern)
Examiner:
Puthusserypady, Sadasivan (Intern)
Bogason, Gudmundur (Intern)
Wisland, Dag T. (Ekstern)
Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Piezoelectric transformer based power supply for DEAP

Department of Electrical Engineering
Period: 15/05/2009 → 20/09/2012
Number of participants: 6
PhD Student:
Andersen, Thomas (Intern)
Supervisor:
Thomsen, Ole Cornelius (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Petersen, Lars Press (Intern)
Carazo, Alfredo Vazquez (Ekstern)
Álvarez, José Marcos Alonso (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

High efficiency PFC frontend for class-D amplifiers

Department of Electrical Engineering
Period: 01/03/2009 → 20/09/2012
Number of participants: 8
PhD Student:
Li, Qingnan (Intern)
Supervisor:
Frium, Mads P. (Ekstern)
Hansen, Lars B. R. (Ekstern)
Thomsen, Ole Cornelius (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Petersen, Lars Press (Intern)
Kyyrä, Jorma (Ekstern)
Wolf, Christian (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD

Flexible power module for fuel cell hybrid power system in a fork-lift

Department of Electrical Engineering
Period: 15/12/2008 → 27/09/2012
Number of participants: 6
PhD Student:
Sen, Gokhan (Intern)
Supervisor:
Thomsen, Ole Cornelius (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Nymand, Morten (Intern)
Ferreira, Jan Abraham (Ekstern)
Sun, Jian (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Innovative magnetic-less high power density switch-mode power supplies based on piezoelectric transformers
Department of Electrical Engineering
Period: 15/12/2008 → 27/03/2012
Number of participants: 2
Phd Student:
Meyer, Kaspar Sinding (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

Planar Magnetics for High Grade Converters
Department of Electrical Engineering
Period: 15/12/2008 → 16/01/2012
Number of participants: 6
Phd Student:
Ouyang, Ziwei (Intern)
Supervisor:
Thomsen, Ole Cornelius (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Wolf, Christian (Intern)
Hurley, William Gerard (Ekstern)
Sun, Jian (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU) Samf.
Project: PhD

Digital DC-AC Boost Amplification for Portable Audio
Department of Electrical Engineering
Period: 01/12/2008 → 31/05/2011
Number of participants: 3
Phd Student:
Bolten Maizonave, Gert (Intern)
Supervisor:
Kjærgaard, Claus (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD
Electrical structure of future offshore wind turbine farms with a DC transmission connection

Department of Electrical Engineering
Period: 01/09/2008 → 16/01/2012
Number of participants: 8
Phd Student: Sharma, Ranjan (Intern)
Supervisor: Akhmatov, Vladislav (Intern)
Andersen, Michael A. E. (Intern)
Jensen, Kim Høj (Intern)
Main Supervisor: Rasmussen, Tonny Wederberg (Intern)
Examiner: Undeland, Tore (Ekstern)
Kjærgaard, Jens Peter (Ekstern)
Thiringer, Erik Torbjörn Valdemar (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

Energy Optimized Photovoltaic Module

Department of Electrical Engineering
Period: 01/07/2008 → 17/04/2013
Number of participants: 2
Phd Student: Variath, Reshmi C (Intern)
Main Supervisor: Andersen, Michael A. E. (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

Powering the future data centre

Department of Electrical Engineering
Period: 01/10/2007 → 19/01/2011
Number of participants: 6
Phd Student: Zhang, Zhe (Intern)
Supervisor: Andersen, Michael A. E. (Intern)
Nielsen, Henning Roar (Ekstern)
Main Supervisor: Thomsen, Ole Cornelius (Intern)
Examiner: Kjærgaard, Claus (Ekstern)
Sun, Jian (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: 1/3 DTU-stip, 2/3 FUR/andet
Project: PhD
Improvement of out-of-band Behaviour in Switch Mode Amplifiers and Power Supplies by their Modulation Topology

Department of Electrical Engineering
Period: 01/04/2007 → 29/09/2010
Number of participants: 6
Phd Student: Knott, Arnold (Intern)
Supervisor: Pfaffinger, Gerhard (Ekstern)
Main Supervisor: Andersen, Michael A. E. (Intern)
Examiner: Kjærgaard, Claus (Ekstern)
Kyyrä, Jorma (Ekstern)
Petersen, Lars Press (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: Institut stipendie (DTU)
Project: PhD

Modulær opbygning af effektelektroniske konvertere med galvanisk isolering i effektområdet 1-10kW

Department of Electrical Engineering
Period: 01/09/2006 → 22/09/2010
Number of participants: 5
Phd Student: Nymand, Morten (Intern)
Main Supervisor: Andersen, Michael A. E. (Intern)
Examiner: Thomsen, Ole Cornelius (Intern)
Kolar, Johann Walter (Ekstern)
Smedley, Keyue (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Ansat eksternt
Project: PhD

Ultra-fast Tracking Power Converters for RF power Amplifiers

Department of Electrical Engineering
Period: 01/01/2006 → 24/03/2010
Number of participants: 6
Phd Student: Høyerby, Mikkel Christian Kofod (Intern)
Supervisor: Larsen, Anders (Ekstern)
Main Supervisor: Andersen, Michael A. E. (Intern)
Examiner: Johansen, Tom Keinicke (Intern)
Maksimovic, Dragan (Ekstern)
Wolf, Christian (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD
New Technology-Driven Approaches in the Design of Preamplifiers for Condenser Microphones

Department of Electrical Engineering
Period: 01/07/2005 → 19/08/2009
Number of participants: 8
Phd Student:
Haas-Christensen, Jelena (Intern)
Supervisor:
Andreani, Pietro (Intern)
Rombach, Pirmin (Intern)
Stenberg, Lars Jørn (Ekstern)
Main Supervisor:
Bruun, Erik (Intern)
Examiner:
Andersen, Michael A. E. (Intern)
Jørgensen, Ivan Harald Holger (Intern)
Wisland, Dag T. (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

High performance low cost digital controlled power conversion technology

Department of Electrical Engineering
Period: 01/10/2004 → 29/08/2008
Number of participants: 8
Phd Student:
Jakobsen, Lars Tønnes (Intern)
Supervisor:
Niemann, Hans Henrik (Intern)
Thomsen, Ole Cornelius (Intern)
Tøttrup, Peter (Ekstern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Sparse, Jens (Intern)
Arefeen, Mohammed (Ekstern)
Nelms, R. Mark (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: InnovationsPhD
Project: PhD

Integrated Circuit Design of Switching Power Stages for Audio Power Amplification

Department of Electrical Engineering
Period: 01/08/2003 → 30/01/2007
Number of participants: 6
Phd Student:
Nyboe, Flemming (Intern)
Supervisor:
Risbo, Lars (Intern)
Main Supervisor:
Andreani, Pietro (Intern)
Examiner:
Andersen, Michael A. E. (Intern)
Berkhout, Marco (Ekstern)
Svensson, Lars (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: ErhvervsPhD-ordningen VTU
Project: PhD

SiCAM - Single Conversion Stage Amplier

Department of Electrical Engineering
Number of participants: 6
Phd Student:
Ljusev, Petar (Intern)
Supervisor:
Petersen, Lars Press (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Wolf, Christian (Intern)
Maksimovic, Dragan (Ekstern)
Vanderkooy, John (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Programbevilling
Project: PhD

Aktiv EMC Støjfilter

Department of Electrical Engineering
Period: 01/02/2002 → ...
Number of participants: 2
Phd Student:
Christensen, Frank Schwartz (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)

Financing sources
Source: Internal funding (public)
Name of research programme: DTU-lønned stipendie
Project: PhD

ACT- Active Transducer

Department of Electrical Engineering
Period: 01/05/2001 → 12/02/2005
Number of participants: 5
Phd Student:
Poulsen, Søren (Intern)
Main Supervisor:
Andersen, Michael A. E. (Intern)
Examiner:
Hendricks, Elbert (Intern)
Frederiksen, Thomas Mansachs (Intern)
Veltman, André (Ekstern)

Financing sources
Source: Internal funding (public)
Name of research programme: Blandet Finansiering
**Fejl tolerate powersystemer**

Department of Electrical Engineering  
Period: 01/02/2001 → 27/07/2004  
Number of participants: 5  
PhD Student:  
Nesgaard, Carsten (Intern)  
Main Supervisor:  
Andersen, Michael A. E. (Intern)  
Examiner:  
Niemann, Hans Henrik (Intern)  
Nymand, Morten (Intern)  
Weinberg, Simon Henry (Ekstern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: DTU-lønnet stipendie  
Project: PhD

**Energibesparende ensretter (ettrins konverter)**

Department of Electrical Engineering  
Period: 01/02/2000 → 12/01/2004  
Number of participants: 5  
PhD Student:  
Petersen, Lars Press (Intern)  
Main Supervisor:  
Andersen, Michael A. E. (Intern)  
Examiner:  
Wolf, Christian (Intern)  
Kolar, Johann Walter (Ekstern)  
Mohan, Ned (Ekstern)

**Financing sources**  
Source: Internal funding (public)  
Name of research programme: Offentlig finansiering  
Project: PhD

**Verification of power and energy measuring instruments**

Verification if specific power and energy measuring instruments can fulfill: 1-10W with an accuracy of +/-5%  
10-2300W with an accuracy of +/-2%  
Department of Applied Electronics  
Period: 17/05/1999 → 02/08/1999  
Number of participants: 1  
Project Manager, organisational:  
Andersen, Michael A. E. (Intern)

**Financing sources**  
Source: Unknown  
Name of research programme: Ukendt  
Amount: 17,850.00 Danish Kroner  
Project

**Pulse Edge Delay Error Correction**

Research in error correction for switch-mode audio power amplifiers with a digital input signal.  
Department of Applied Electronics
Department of Electrical Engineering
Bang & Olufsen A/S
Period: 01/08/1998 → 31/07/1999
Number of participants: 3
Project participant:
Christensen, Frank Schwartz (Intern)
Nielsen, Karsten (Intern)
Project Manager, organisational:
Andersen, Michael A. E. (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt
Amount: 400,000.00 Danish Kroner

Vertical Deflection in TV

Department of Applied Electronics
Department of Electrical Engineering
CETEC
Bang & Olufsen A/S
Period: 01/08/1998 → 31/07/1999
Number of participants: 2
Project participant:
Frederiksen, Thomas Mansachs (Intern)
Project Manager, organisational:
Andersen, Michael A. E. (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt
Amount: 4,915,522.00 Danish Kroner

Standby Power Supply
A very low power mains driven standby power supply with high efficiency based on research in low power SMPS technology. Key specifications: 85V-265V (AC) input voltage. 5V (DC) output voltage. ±5% output voltage tolerance. 1000mW output power @ 5V-DC. 80% efficiency at 1000mW load. 65% efficiency at 50mW load. 10cm3 volumen or less. Galvanic insulation. Estimated energy reduction in DK: 800GWh/year.

Department of Applied Electronics
Period: 01/03/1997 → 31/03/2000
Number of participants: 1
Project Manager, organisational:
Andersen, Michael A. E. (Intern)

Financing sources
Source: Unknown
Name of research programme: Ukendt
Amount: 8,397,455.00 Danish Kroner

Standby spændingsforsyninger
Department of Electrical Engineering
Power Factor Converters
Research in switch-mode converters for complying with EN61000-3-2 including both low cost input current shaping and high power factor converters. Optimization of power factor converters with respect to losses and volume. The energy storing elements are optimized and simple methods and models to predict differential mode noise from the converters have been found and verified experimentally.

Department of Applied Electronics
Period: 01/09/1995 → …
Number of participants: 1
Project Manager, organisational:
Andersen, Michael A. E. (Intern)
Project

High Efficiency Audio Power Amplifiers
By using switch-mode power electronics (class D, CoolPower) as an alternative to the classical class B audio power amplifiers it is possible to reduce the power dissipation and increase the efficiency without compromising the audio performance. This is done by using state-of-the-art analogue and digital control theory and signal processing in combination with high frequency power electronics. Furthermore research is done in multi-level PWM called PSCPWM - Phase Shifted Carrier Pulse Width Modulation.

Department of Applied Electronics
Period: 01/01/1992 → …
Number of participants: 1
Project Manager, organisational:
Andersen, Michael A. E. (Intern)
Project
**Miniature converters**  
**Period:** 20 Sep 2017  
**Michael A. E. Andersen (Invited speaker)**  
Department of Electrical Engineering  
Electronics  
Degree of recognition: National  
Links:  
https://hightechsummit.dk/  

**Related event**  
**High Tech Summit**  
20/09/2017 → 21/09/2017  
Kongnes Lyngby, Denmark  
Activity: Talks and presentations › Conference presentations  

**Dartmouth College (External organisation)**  
**Period:** 22 Mar 2017  
**Michael A. E. Andersen (Participant)**  
Department of Electrical Engineering  
Electronics  

**Description**  
Tenure Track Review Evaluation (Associate Professor with tenure)  

**Related external organisation**  
**Dartmouth College**  
United States  
Activity: Membership › Membership in review committee  

**External examiner on PhD defense by PhD student Mark Caris**  
**Period:** 30 Nov 2016  
**Michael A. E. Andersen (External examiner)**  
Department of Electrical Engineering  
Electronics  
Activity: Examinations and supervision › External examination  

**Head of committee at PhD defense by PhD student Juan Colmenares**  
**Period:** 14 Oct 2016  
**Michael A. E. Andersen (Main supervisor)**  
Department of Electrical Engineering  
Electronics  
Activity: Examinations and supervision › External examination  

**External examiner on PhD thesis by PhD student Vita Lystianingrum**  
**Period:** 6 Oct 2016  
**Michael A. E. Andersen (External examiner)**  
Department of Electrical Engineering  
Electronics  
Activity: Examinations and supervision › External examination  

**Committee member at PhD defense by PhD student Luyu Wang**  
**Period:** 19 Aug 2016
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

Fundamentals of Electrical Energy Conversion
Period: 10 Jun 2016
Michael A. E. Andersen (Guest lecturer)
Department of Electrical Engineering
Electronics
Description
EUROTECH Summer Doctoral School 2016
Related external organisation
EPFL
Lausanne, Switzerland
Activity: Talks and presentations › Guest lectures, external teaching and course activities at other universities

Integrated and Very High Frequency Converter
Period: 20 May 2016
Michael A. E. Andersen (Speaker)
Department of Electrical Engineering
Electronics
Description
Huawei Technology Workshop 2016
"Power Electronics for Network Energy in 2020, More Silicon - Less Copper"
Related external organisation
Huawei Technologies Sweden AB
Stockholm, Sweden
Activity: Talks and presentations › Talks and presentations in private or public companies and organisations

External examiner on PhD thesis by PhD student Xian Liang
Period: 3 Jan 2016
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

External examiner on PhD thesis by PhD student Ishtiyaq Amhed Makda
Period: 21 May 2015
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

External examiner on PhD thesis by PhD student Yi Wang
Period: 1 May 2015
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

**External examiner on PhD thesis by PhD student Ciaran Feeney**
Period: 27 Apr 2015
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

**External examiner on Doctoral Thesis by PhD student Toke Meyer Andersen**
Period: 13 Feb 2015
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

**Nordic Power Converters Aps (External organisation)**
Period: Dec 2014 → …
Michael A. E. Andersen (Participant)
Department of Electrical Engineering
Electronics

**Description**
Member of the Board

**Related external organisation**

**Nordic Power Converters Aps**
Activity: Membership › Board duties in companies, associations, or public organisations

**Committee member at PhD defense by PhD student Jonas Ottosson**
Period: 4 Dec 2013
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

**Committee member at PhD defense by PhD student Abdul Majid**
Period: 20 Nov 2013
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

**Committee member of Doctoral Examination of PhD student Frank van der Pijl**
Period: 15 Oct 2012
Michael A. E. Andersen (External examiner)
External examiner on PhD thesis by PhD student Sri Susovon Samanta
Period: Jul 2012
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering

IEEE Transactions on Power Electronics (Journal)
Period: 2010 → …
Michael A. E. Andersen (Editor)
Department of Electrical Engineering

Description
IEEE Transactions on Power Electronics
Associate Editor.

Related journal
IEEE Transactions on Power Electronics
0885-8993
Central database
Activity: Research › Journal editor

External examiner on PhD thesis by PhD student Jelena Haas-Christensen
Period: 2009
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering

Opponent på Doctoral Thesis af PhD-studerende Konstantiv Kostov
Period: 2009
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering

External examiner on PhD thesis by PhD student Flemming Nyboe
Period: 2006
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Committee member at PhD defense by PhD student Bengt Johansson
Period: 12 Jan 2005
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

Opponent on Doctoral Thesis by PhD student Vesa Toumainen
Period: Mar 2004
Michael A. E. Andersen (External examiner)
Department of Electrical Engineering
Electronics
Activity: Examinations and supervision › External examination

Center for Electrical Energy Systems (CEES) (External organisation)
Period: 2001 → …
Michael A. E. Andersen (Participant)
Department of Electrical Engineering
Electronics
Description
Member of the Board
Body type: Erhvervsdrivende fond
Links:
http://www.cees.dk

Related external organisation
Center for Electrical Energy Systems (CEES)
Activity: Membership › Board duties in companies, associations, or public organisations

Danish Energy Agency - Energy Research Program - EFP (External organisation)
Period: 1991 → 1992
Michael A. E. Andersen (Participant)
Department of Electrical Engineering
Electronics
Description
EFP - Energy Efficiency in Products and Industrial Processes

Related external organisation
Danish Energy Agency - Energy Research Program - EFP
Activity: Membership › Membership in review committee