Combined active and reactive power control in an operation of a wind farm

The present disclosure relates to a method and system for controlling an operation of a wind farm connected to a grid, the wind farm comprising a plurality of wind turbines, each wind turbine having a local controller, the method comprising the steps of: minimizing a central voltage deviation in a point of connection between the grid and the wind farm compared to a reference voltage provided by the grid; and/or minimizing local voltage deviations compared to local bus reference voltages for each connection to the wind turbines, by: calculating sensitivity coefficients for the wind turbines; and regulating local power references comprising an active power reference and a reactive power reference to each of the local controllers based on the calculated sensitivity coefficients.

Adaptive Control of Wind Turbines for Maximum Power Point Tracking

This chapter presents an adaptive controller for maximum power point tracking (MPPT) of a small variable-speed wind energy conversion system (WECS). According to the speed control criterion, WECSs can be classified into two types: fixed speed and variable speed. The chapter focuses on the generator control of wind turbines for maximum power point tracking in the partial-load regime. The MPPT control methods can be classified into the following three categories: hill-climbing search control, power signal feedback control and tip-speed ratio control. A full-converter wind turbine with a squirrel cage induction generator (SCIG) is used to illustrate the generator control system for a variable-speed WECS. The chapter also presents case studies have been carried out to verify the developed adaptive controller for WECSs. WECSs are non-linear systems with parameter uncertainties and which are subject to disturbances, in the form of non-linear and unmodeled aerodynamics.
Analyzing and Validating the Economic Efficiency of Managing a Cluster of Energy Hubs in Multi Carrier Energy Systems

The interdependency across natural gas, power and heating systems is increasingly tightened due to the wide development of cogeneration plants and electrified heating facilities. Multi-energy integration is a prevalent trend and the energy hub, which acts as an intermediary agent between providers and consumers, is expected to play a central role in allocating energy resources more efficiently. However, uncertainties originating from multiple kinds of energy demands challenge the operation of energy hubs and may compromise system efficiency. Energy trading and sharing among individual hubs offer a unique opportunity to increase system flexibility and reduce the cost under demand uncertainty. In this paper, three quintessential schemes for organizing a cluster of energy hubs at demand side, i.e., individual, sharing market, and aggregation, are studied under a stochastic framework with probabilistic load forecasts. First, we perform theoretical analysis and compare their economic efficiencies from a maximum-utility (or minimum-cost) perspective. Utility curves of respective schemes are given, and several important phenomena are revealed from the economic analysis. Then we discuss the concrete decision-making models of energy hubs under the three schemes, taking into account the change of electricity price in response to the total demand, which give rise to bilevel optimization problems and are technically transformed into mixed-integer linear programs. Finally, we conduct numerical experiments, which validate the theoretical outcomes, and reveal that the sharing scheme can achieve nearly optimal efficiency without a central organizer, and hence appears to be a promising direction for future multi-energy systems.
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 6.93 SJR 3.158 SNIP 3.218
Web of Science (2014): Impact factor 5.613
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 6.59 SJR 3.06 SNIP 3.346
Web of Science (2013): Impact factor 5.261
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 5.69 SJR 2.778 SNIP 3.076
Web of Science (2012): Impact factor 4.781
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 5.5 SJR 2.416 SNIP 2.827
Web of Science (2011): Impact factor 5.106
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.531 SNIP 2.259
Web of Science (2010): Impact factor 3.915
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.992 SNIP 1.85
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 0.95 SNIP 1.206
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.168 SNIP 1.704
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.95 SNIP 1.277
Scopus rating (2005): SJR 1.02 SNIP 0.988
Web of Science (2005): Indexed yes
Scopus rating (2004): SJR 0.67 SNIP 0.844
Web of Science (2004): Indexed yes
Scopus rating (2003): SJR 0.713 SNIP 0.775
Scopus rating (2002): SJR 0.589 SNIP 0.779
Web of Science (2002): Indexed yes
Scopus rating (2001): SJR 0.368 SNIP 0.567
Scopus rating (2000): SJR 0.154 SNIP 0.498
Scopus rating (1999): SJR 0.181 SNIP 0.443
Original language: English
Keywords: Demand uncertainty, Energy hub, Energy-sharing market, Multi-Carrier Energy Systems, Organization scheme, Stochastic bilevel game
Electronic versions:
DOIs:
10.1016/j.apenergy.2018.08.112
Source: PublicationPreSubmission
Source-ID: 152178699
Research output: Research - peer-review › Journal article – Annual report year: 2018
An Optimal Coordinated Method for EVs Participating in Frequency Regulation under Different Power System Operation States

This paper proposes an optimal coordinated method for electric vehicles (EVs) participating in frequency regulation (FR) under different power system operation states (PSOSs). In the proposed methodology, the FR power of EVs and generators is coordinated with different optimization objectives for power system secure and economic operations. When a power system operates in normal state, the minimum FR cost is used as an optimization objective considering the battery degradation cost. In the abnormal state, the minimum frequency restoring time is considered in the optimization objective. Based on the optimized results in different scenarios, the output power coordinated control rule between EVs and generators is drawn. Simulations on an interconnected two-area power system have validated the superiority of the proposed optimized coordinated control strategy.

A Numerical Approach for Hybrid Simulation of Power System Dynamics Considering Extreme Icing Events

The global climate change leads to more extreme meteorological conditions such as icing weather, which have caused great losses to power systems. Comprehensive simulation tools are required to enhance the capability of power system risk assessment under extreme weather conditions. A hybrid numerical simulation scheme integrating icing weather events with power system dynamics is proposed to extend power system numerical simulation. A technique is developed to efficiently simulate the interaction of slow dynamics of weather events and fast dynamics of power systems. An extended package for PSS/E enabling hybrid simulation of icing event and power system disturbance is developed, based on which a hybrid simulation platform is established. Numerical studies show that the functionality of power system simulation is greatly extended by taking into account the icing weather events.
Bi-level decentralised active power control for large-scale wind farm cluster

This study presents a bi-level decentralised active power control (DAPC) for a large-scale wind farm cluster (WFC), consisting of several wind farms for better active power dispatch. In the upper level, a distributed active power control scheme based on the distributed consensus is designed to achieve fair active power sharing among multiple wind farms, which generates the power reference for each wind farm. A distributed estimator is used to estimate the total available power of all wind farms. In the lower level, a centralised control scheme based on the model predictive control is proposed to regulate active power outputs of all wind turbines (WTs) within a wind farm, which reduces the fatigue loads of WTs...
while tracking the power reference obtained from the upper-level control. A WFC with 8 wind farms and totally 160 WTs, was used to test the control performance of the proposed DAPC scheme.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University, North China Electric Power University, Technical University of Denmark
Contributors: Huang, S., Wu, Q., Guo, Y., Lin, Z.
Pages: 1486-92
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: I E T Renewable Power Generation
Volume: 12
Issue number: 13
ISSN (Print): 1752-1416
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.18 SJR 0.979 SNIP 1.453
Web of Science (2017): Impact factor 3.488
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 3.55 SJR 0.878 SNIP 1.434
Web of Science (2016): Impact factor 2.635
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.13 SJR 0.976 SNIP 1.555
Web of Science (2015): Impact factor 1.562
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 3.56 SJR 1.229 SNIP 2.282
Web of Science (2014): Impact factor 1.904
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 4.96 SJR 1.601 SNIP 2.799
Web of Science (2013): Impact factor 2.28
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 4.64 SJR 1.353 SNIP 2.787
Web of Science (2012): Impact factor 1.718
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 4.43 SJR 1.204 SNIP 2.301
Web of Science (2011): Impact factor 1.742
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 1.617 SNIP 2.54
Web of Science (2010): Impact factor 2.328
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.705 SNIP 2.834
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.721 SNIP 2.413
Bi-Level Decentralized Active Power Control for Large-Scale Wind Farm Cluster

This paper presents a bi-level decentralized active power control (DAPC) for a large-scale wind farm cluster, consisting of several wind farms for better active power dispatch. In the upper level, a distributed active power control scheme based on the distributed consensus is designed to achieve fair active power sharing among multiple wind farms, which generates the power reference for each wind farm. A distributed estimator is used to estimate the total available power of all wind farms. In the lower level, a centralized control scheme based on the Model Predictive Control (MPC) is proposed to regulate active power outputs of all wind turbines (WTs) within a wind farm, which reduces the fatigue loads of WTs while tracking the power reference obtained from the upper level control. A wind farm cluster with 8 wind farms and totally 160 WTs, was used to test the control performance of the proposed decentralized active power control scheme.
This chapter presents a dynamic discrete time piecewise affine (PWA) model of a wind turbine. This can be used for the advanced optimal control of a wind farm, in approaches such as model predictive control (MPC). The nonlinearity identification is based on a clustering-based algorithm, which combines clustering, linear identification, and pattern recognition techniques. The chapter focuses on the identification of a PWA wind turbine model for wind farm control applications. The wind turbine model developed by US National Renewable Energy Laboratory (NREL) consists of several subsystems, including representations of the aerodynamics, drivetrain, tower, generator, pitch actuator and the wind turbine controller. The chapter also presents a case study of the developed PWA model that was verified by the comparison with the 5-MW NREL non-linear wind turbine model. The developed PWA model is suitable for advanced optimal control at wind farm level, including MPC and the linear-quadratic regulator.

This paper proposes a comprehensive scheme for day-ahead congestion management of distribution networks with high penetration of distributed energy resources (DERs). In the proposed scheme, the dynamic tariff (DT), network reconfiguration and re-profiling products are integrated, which combines the advantages of these methods. In addition, the previously proposed DT model is relaxed in order to handle possible infeasibility of the DT problem and set a limit for the DT. With the utilization of the flexibilities from various types of DERs and the advantages of the three congestion management methods, the proposed comprehensive scheme can solve the congestion more effectively and at the same time ensures that the congestion management prices are within an acceptable level. Three case studies were conducted with the modified Roy Billinton Test System (RBTS) to validate the effectiveness and advantages of the proposed comprehensive scheme.
Comprehensive Power Losses Model for Electronic Power Transformer

The electronic power transformer (EPT) has higher power losses than the conventional transformer. However, the EPT can correct the power factor, compensate the unbalanced current and reduce the line power losses in the distribution network. Therefore, the higher losses of the EPT and the consequent reduced power losses in the distribution network require a comprehensive consideration when comparing the power losses of the EPT and conventional transformer. In this paper, a comprehensive power losses analysis model for the EPT in distribution networks is proposed. By analyzing the EPT self-losses and considering the impact of the non-unity power factor and the three-phase unbalanced current, the overall power losses in the distribution network when using the EPT to replace the conventional transformer are analyzed, and the conditions in which the application of the EPT can cause less power losses are obtained. Based on this, the sensitivity analysis for the EPT comprehensive power losses model is carried out by comparing the value of each
parameter variation impact on the EPT losses model. In case study, the validity of the comprehensive power losses model is verified.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hunan University
Contributors: Yue, Q., Li, C., Cao, Y., He, Y., Cai, B., Wu, Q., Zhou, B.
Pages: 14926 - 14934
Publication date: 2018
Peer-reviewed: Yes

**Publication information**
Journal: IEEE Access
Volume: 6
ISSN (Print): 2169-3536
Ratings:
- Web of Science (2018): Indexed yes
- Scopus rating (2017): CiteScore 4.49
- Web of Science (2017): Impact factor 3.557
- Web of Science (2017): Indexed yes
- Scopus rating (2016): CiteScore 5.13
- Web of Science (2016): Impact factor 3.244
- Scopus rating (2015): CiteScore 4.32
- Web of Science (2015): Impact factor 1.27
- Scopus rating (2014): CiteScore 3.16
Original language: English
Keywords: Comprehensive power losses model, Electronic power transformer, Distribution network, Power factor, Unbalanced current
Electronic versions:
- 08255614.pdf
DOIs:
- 10.1109/ACCESS.2018.2791587
Research output: Research - peer-review › Journal article – Annual report year: 2018

**Coordinated Pitch & Torque Control of Large-Scale Wind Turbine Based on Pareto Eciency Analysis**
For the existing pitch and torque control of the wind turbine generator system (WTGS), further development on coordinated control is necessary to improve effectiveness for practical applications. In this paper, the WTGS is modeled as a coupling combination of two subsystems: the generator torque control subsystem and blade pitch control subsystem. Then, the pole positions in each control subsystem are adjusted coordinately to evaluate the controller participation and used as the objective of optimization. A two-level parameters-controllers coordinated optimization scheme is proposed and applied to optimize the controller coordination based on the Pareto optimization theory. Three solutions are obtained through optimization, which includes the optimal torque solution, optimal power solution, and satisfactory solution. Detailed comparisons evaluate the performance of the three selected solutions and provide the optimized controller coordination suggestions according to different requirements.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, North China Electric Power University, Technical University of Denmark
Contributors: Lin, Z., Chen, Z., Wu, Q., Yang, S., Meng, H.
Pages: 812-825
Publication date: 2018
Peer-reviewed: Yes

**Publication information**
Journal: Energy
Volume: 147
ISSN (Print): 0360-5442
Ratings:
- BFI (2018): BFI-level 2
- Web of Science (2018): Indexed yes
|------|-------------------------|--------------------------------------------------|-----------------------------------------|----------------------------------|
Day-Ahead Congestion Management Scheme for Distribution Networks with Dynamic Tariff and Re-profiling Products

This paper proposes a day-ahead congestion management scheme for distribution networks with the dynamic tariff (DT) and re-profiling products. In the proposed scheme, the DT method is first employed to resolve congestion before the energy bidding process and the re-profiling product is used afterwards to resolve remaining congestion through the flexibility market. Moreover, the original DT model is relaxed to resolve the possible infeasible issue of the DT problem and set a maximum limit for DTs. With the combination of the DT and re-profiling product, the proposed scheme can resolve congestion more effectively while ensuring that the DTs are within an acceptable range. Two case studies were conducted with the Roy Billinton Test System (RBTS) to validate the effectiveness of the proposed scheme.

Decentralized Coordinated Voltage Control for VSC-HVDC Connected Wind Farms Based on ADMM

This paper proposes a decentralized coordinated voltage control scheme (DCVCS) for voltage-source-converter high voltage direct current (VSC-HVDC) connected wind farms based on the Model Predictive Control (MPC) which regulates the voltage profile across the wind farm network within the feasible range by optimally coordinating the VSC and wind turbines (WTs). Firstly, the centralized voltage control problem based on the MPC is formulated to minimize voltage deviations and reactive power output fluctuations of WTs. Secondly, the decentralized solution methodology based on Alternating Direction Method of Multipliers (ADMM) with fast convergency is used to solve the MPC problem in a decentralized manner without losing the optimality of the primal problem. A wind farm with 64 WTs was used to validate the effectiveness and optimality of the proposed DCVCS.
Distributed coordinated active and reactive power control of wind farms based on model predictive control

This paper proposes a distributed coordinated active and reactive power control scheme for wind farms based on the model predictive control (MPC) along with the consensus-based distributed information synchronization and estimation, which can optimally dispatch the active power of wind turbines (WTs) and regulate the voltages within the wind farm. For the active power control, the pitch angle and generator torque of WTs are optimally controlled to alleviate fatigue loads of WTs while tracking the power reference of the wind farm required by system operators. For the reactive power/voltage control, the reactive power outputs of WTs are controlled to mitigate the voltage deviations and simultaneously optimize reactive power sharing. Considering the high ratio of the wind farm collector systems, the impact of active power variations on voltages is taken into account to improve the voltage regulation. The proposed scheme is center-free and only requires a sparse communication network. Each WT only exchanges information with its immediate neighbors and the local optimal control problems are solved in parallel, implying good scalability and flexibility for large-scale wind farms. The predictive model of a WT is derived and then the MPC problem is formulated. A wind farm with ten WTs was used to verify the proposed control scheme.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University, Illinois Institute of Technology
Distributed Model Predictive Active Power Control of Wind Farms

This chapter explores a distributed model predictive control (D-MPC) approach for optimising active power of a wind farm. The control scheme is based on the fast gradient method via dual decomposition. The developed D-MPC approach is implemented using the clustering-based piecewise affine (PWA) wind turbine model. Wind farm control can be implemented either by the utilization of a separate energy storage device or through derated operation of the wind turbines. Model predictive control (MPC) is an effective scheme for multi-objective wind farm control. The chapter describes the key properties required to apply the fast dual gradient method. Due to their flexible charging and discharging characteristics, energy storage system (ESSs) are considered effective tools to enhance the flexibility and controllability of wind farms. The chapter presents a case study of a wind farm comprising ten 5-MW wind turbines that is used as the test system.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Wuhan University
Contributors: Wu, Q., Sun, Y.
Pages: 151-173
Publication date: 2018

Distributed Multi-Energy Coordination of Multi-Microgrids with Biogas-Solar-Wind Renewables

This paper proposes a distributed multi-energy management framework for the coordinated operation of interconnected biogas-solar-wind microgrids. This framework, each microgrid not only schedules its local hybrid biogas-solar-wind renewables for coupled multi-carrier energy supplies based on the concept of energy hub, but also exchanges energy with interconnected microgrids and via the transactive market. The multi-microgrid scheduling is a challenging optimization problem due to its severe constraints and strong couplings. A multi-microgrid multi-energy coupling matrix is thus formulated to model and exploit the inherent biogas-solar-wind energy couplings among electricity, gas and heat flows. Furthermore, a distributed stochastic optimal scheduling scheme with minimum information exchange overhead is proposed to dynamically optimize energy conversion and storage devices in the multi-microgrid system. The proposed method has been fully tested and benchmarked on different scaled multi-microgrid system over a 24-hour scheduling horizon. Comparative results demonstrated that the proposed approach can reduce the system operating cost and enhance the system energy-efficiency, and also confirm its scalability in solving large-scale multi-microgrid problems.

General information
State: Accepted/In press
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hunan University, Hong Kong Polytechnic University, Guangxi University, North China Electric Power University
Distributed Optimization based Dynamic Tariff for Congestion Management in Distribution Networks

This paper proposes a distributed optimization based dynamic tariff (DDT) method for congestion management in distribution networks with high penetration of electric vehicles (EVs) and heat pumps (HPs). The DDT method employs a decomposition based optimization method to have aggregators explicitly participate in congestion management, which gives more certainty and transparency compared to the normal DT method. With the DDT method, aggregators reveal their final aggregated plan and respect the plan during operation. By establishing an equivalent overall optimization, it is proven that the DDT method is able to minimize the overall energy consumption cost and line loss cost, which is different from previous decomposition-based methods such as multiagent system methods. In addition, a reconditioning method and an integral controller are introduced to improve convergence of the distributed optimization where challenges arise due to multiple congestion points, multiple types of flexible demands and network constraints. The case studies demonstrate the efficacy of the DDT method for congestion management in distribution networks.

General information
State: Accepted/In press
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hunan University
Contributors: Huang, S., Wu, Q., Zhao, H., Li, C.
Number of pages: 10
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English
Distribution Locational Marginal Pricing for Optimal Electric Vehicle Charging through Chance Constrained Mixed-Integer Programming

This paper presents a distribution locational marginal pricing (DLMP) method through chance constrained mixed-integer programming designed to alleviate the possible congestion in the future distribution network with high penetration of electric vehicles (EVs). In order to represent the stochastic characteristics of the EV driving patterns, a chance constrained optimization of the EV charging is proposed and formulated through mixed-integer programming (MIP). With the chance constraints in the optimization formulations, it guarantees that the failure probability of the EV charging plan fulfilling the driving requirement is below the predetermined confidence parameter. The efficacy of the proposed approach was demonstrated by case studies using a 33-bus distribution system of the Bornholm power system and the Danish driving data. The case study results show that the DLMP method through chance constrained MIP can successfully alleviate the congestion in the distribution network due to the EV charging while keeping the failure probability of EV charging not meeting driving needs below the predefined confidence.
Dynamic Power Tariff for Congestion Management in Distribution Networks

This paper proposes dynamic power tariff (DPT), a new concept for congestion management in distribution networks with high penetration of electric vehicles (EVs), and heat pumps (HPs). The DPT concept is proposed to overcome a drawback of the dynamic tariff (DT) method, i.e., DPT can replace the price sensitivity parameter in the DT method, which is relatively unrealistic in practice. Based on the control theory, a control model with two control loops, i.e., the power flow control and voltage control, is established to analyze the congestion management process by the DPT method. Furthermore, an iterative method based on distributed optimization is proposed to determine the DPT rates, which enables active participation of aggregators in the congestion management. The case studies demonstrate the efficacy of the DPT method for congestion management in distribution networks, and show its ability to save congestion management cost compared to the DT methods.

General information

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Illinois Institute of Technology
Contributors: Huang, S., Wu, Q., Shahidehpour, M., Liu, Z.
Number of pages: 10
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
Article number: 1-10
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes

Node importance evaluation of power grids plays an important role in the safe operation and planning of power systems. This paper proposes an electrical LeaderRank (ELR) method to identify the important nodes in complex power grids, considering the renewable energy uncertainties, system topological structure, transmission power flow and the loss of loads caused by cascading failures. The proposed method uses an ELR value function to represent the importance of a system node, which can be derived iteratively from the weighted distribution strategy of its in-linked nodes. Furthermore, the uncertainties of wind and solar energy generation are modelled as interval numbers, and the interval power flow calculation is employed to obtain the interval power in transmission lines, direct adjacent matrix, and finally the interval ELR values. The performance of ELR method has been fully tested and benchmarked on the IEEE 118-bus power system and the Western Liaoning Power Grid of China. Comparative results on four performance criteria have not only demonstrated the validity and superiority of the proposed method, but also confirmed its capability to cope with the node importance evaluation of practical power grids.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hunan University
Pages: 45-55
Publication date: 2018
Peer-reviewed: Yes

Publication information
Volume: 106
ISSN (Print): 0142-0615
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.63 SJR 1.276 SNIP 1.662
Web of Science (2017): Impact factor 3.61
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Enhanced Voltage Control of VSC-HVDC Connected Offshore Wind Farms Based on Model Predictive Control

This paper proposes an enhanced voltage control strategy (EVCS) based on model predictive control (MPC) for voltage source converter based high voltage direct current (VSHVDC) connected offshore wind farms (OWFs). In the proposed MPC based EVCS, all wind turbine generators (WTGs) as well as the wind farm side VSC are optimally coordinated to keep voltages within the feasible range and reduce system power losses. Considering the high ratio of the OWF collector system, the effects of active power outputs of WTGs on voltage control are also taken into consideration. The predictive model of VSC with a typical cascaded control structure is derived in details. The sensitivity coefficients are calculated by an analytical method to improve the computational efficiency. A VSC-HVDC connected OWF with 64 WTGs was used to validate the proposed voltage control strategy.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University, Illinois Institute of Technology
Contributors: Guo, Y., Gao, H., Wu, Q., Zhao, H., Østergaard, J., Shahidehpour, M.
Number of pages: 13
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Sustainable Energy
Volume: 9
Issue number: 1
ISSN (Print): 1949-3029
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 7.42 SJR 2.318 SNIP 2.452
Web of Science (2017): Impact factor 6.235
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.8 SJR 2.368 SNIP 2.967
Evaluation Method of Distribution Network Resilience Focusing on Critical Loads

With the frequent occurrence of extreme weather events in the world, the ability of power system to resist disasters has attracted more and more attention. In this paper, a method to evaluate the resilience of distribution networks by focusing on the impact of critical loads under extreme weather events is proposed, and typhoon is taken as the representative to formulate a vulnerability curve of components. Furthermore, the Monte Carlo method is used to simulate the whole process of extreme weather disaster and to generate the fault scenario. Different weights are assigned to different levels of load according to the importance of load, and the weighted loss of load is selected as the evaluation index of resilience. Finally, the method is verified by the IEEE-33 bus system. The results show that this method is effective to quantify the resilience of distribution networks under extreme weather events.

General information
State: Accepted/in press
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hunan University, Guangdong Power Grid Corporation
Number of pages: 7
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Access
ISSN (Print): 2169-3536
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
Fatigue load minimization in an operation of a wind farm

The present disclosure relates to a method and system for controlling an operation of a wind farm connected to a grid, the wind farm comprising a central controller and a plurality of wind turbines, each wind turbine having a local controller, the method comprising the steps of: calculating a load sensitivity in the local controller of each wind turbine based on fluctuations of at least one fatigue load parameter of said wind turbine; providing an exchange signal between each of the local controllers and the central controller, said exchange signal comprising the calculated load sensitivity; solving an optimal dispatch algorithm for minimizing an overall fatigue load of the wind turbines in the central controller based on the calculated load sensitivities of the wind turbines and power reference tracking provided by the grid, thereby providing local power references to each of the local controllers. The disclosure further relates to system for controlling an operation of a wind farm connected to a grid, the system comprising: at least one central controller comprising a central hardware processor and at least a first non-transitive, computer-readable storage device for storing instructions that, when executed by the central hardware processor, causes the at least one central hardware processor to perform the step of solving an optimal dispatch algorithm for minimizing an overall fatigue load of the wind turbines according to the disclosed method, thereby providing local power references to each of the local controllers; and local controllers, each local controller comprising a local hardware processor for each of a plurality of local wind turbines, and secondary non-transitive, computer-readable storage devices associated with the local hardware processors for storing instructions that, when executed by the local hardware processors, perform the step of calculating load sensitivities according to the disclosed method.
Fault Ride Through Enhancement of VSC-HVDC Connected Offshore Wind Power Plants
Voltage source converter-high voltage direct current (VSC-HVDC) connections have become a new trend for long-distance offshore wind power transmission. In order to facilitate the derivation of the feedforward DC voltage control based fault ride through (FRT) technique, this chapter describes the model of a VSC-HVDC-connected offshore wind power plant (WPP) with an external grid. It proposes a feedforward DC voltage control based FRT technique to control the AC voltage at the WPP collector network during grid-side faults. Time-domain simulations have been used to verify the efficacy of the proposed feedforward DC voltage control based FRT technique for VSC-HVDC-connected WPPs. Time-domain simulation results shows that the proposed FRT scheme can successfully enable VSC-HVDC-connected WPPs to ride through balanced and unbalanced faults in host power systems, as well as faults in the WPP collector system, with a fast and robust response.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Siemens A/S
Contributors: Sharma, R., Wu, Q., Jensen, K. H., Rasmussen, T. W., Østergaard, J.
Pages: 215-231
Publication date: 2018

Host publication information
Title of host publication: Modeling and Modern Control of Wind Power
Publisher: Wiley-IEEE press
ISBN (Print): 9781119236382
DOIs: 10.1002/9781119236382.ch11
Research output: Research - peer-review › Book chapter – Annual report year: 2018

Fractal Characteristics Analysis of Blackouts in Interconnected Power Grid
The power failure models are a key to understand the mechanism of large scale blackouts. In this letter, the similarity of blackouts in interconnected power grids (IPGs) and their sub-grids is discovered by the fractal characteristics analysis to simplify the failure models of the IPG. The distribution characteristics of blackouts in various sub-grids are demonstrated based on the Kolmogorov-Smirnov (KS) test. The fractal dimensions (FDs) of the IPG and its sub-grids are then obtained by using the KS test and the maximum likelihood estimation (MLE). The blackouts data in China were used to demonstrate the similarity of distribution characteristics and FDs of the IPG and its sub-grids. The results are consistent with the development of the power grids (PGs).

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hunan University
Contributors: Wang, F., Li, L., Li, C., Wu, Q., Cao, Y., Zhou, B., Fang, B.
Number of pages: 2
Pages: 1085-1086
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Power Engineering Letters
Volume: 33
Issue number: 1
Original language: English
Keywords: Blackout, Complex network, Fractal dimensions, Interconnected power grid, Power failure models
Electronic versions:
Fractal_Characteristics_Analysis_of_Blackouts_in_Interconnected_Power_Grid.pdf
DOIs: 10.1109/TPWRS.2017.2704901
Source: PublicationPreSubmission
Source-ID: 132056560
Research output: Research - peer-review › Journal article – Annual report year: 2018

Fractional-Order Modeling and Sliding Mode Control of Energy-Saving and Emission-Reduction Dynamic Evolution System
This paper proposes the fractional-order modeling for sliding mode control of a complex four-dimensional energy-saving and emission-reduction system (ESERS). In the proposed methodology, the fractional calculus techniques are employed to accurately model the dynamics of the ESERS, and the fractional-order model of the energy-saving and emission-
The reduction system (FOESERS) is formulated. With the proposed FOESERS, all of the equilibrium points and the corresponding eigenvalues are obtained, and the instability region and the state trajectories of FOESERS are also given. The FOESERS can represent complex dynamic behaviours with chaotic and unstable states on the energy conservation, carbon emissions, economic growth, and renewable energy development, and have a great impact on the formulation of government energy policies. Furthermore, based on the fractional Lyapunov stability and robust control theory, a sliding-mode controller is designed to control the FOESERS with model uncertainties and external disturbances to the equilibrium point in the finite time. Finally, simulation results confirm the effectiveness and robustness of the proposed scheme.
Guest Editorial: Coordinated Control and Protection of Offshore Wind and Combined AC/DC Grid

Voltage source converter (VSC) based High Voltage Direct Current (HVDC) Technologies have attracted more and more attention for integration of offshore wind power due to its good controllability. Coordinated control strategies shall be developed to utilize ancillary services from combined alternating current (AC)/DC grids and wind power plants, maintain good voltages, and mitigate the potential resonance problem. Besides, the fault current situation in DC grids depends on the control strategy and the interaction between the DC and AC grids. It is important to investigate the fault current situation considering both factors and design protection schemes. This Special Issue on Coordinated Control and Protection of Offshore Wind and Combined AC/DC Grid contains 17 high quality papers that are relevant to this topic, including frequency control, voltage control, optimal operation, fault analysis and protection of wind power and AC/DC grids, and HVDC technologies.
H∞ Current Damping Control of DFIG based Wind Farm for Sub-Synchronous Control Interaction Mitigation

This paper proposes an H∞ damping controller for the doubly-fed induction generator (DFIG) based wind farm (WF) to mitigate sub-synchronous control interactions (SSCI) with series capacitor compensated lines. A multi-input multi-output (MIMO) uncertain state-space model is developed to reflect the main SSCI characteristics considering the uncertainties of wind speed, series compensation (SC) levels and system parameters. The SSCI is analyzed using the eigenvalue analysis of the uncertain system model. In order to damp the SSCI between the WF and series capacitor compensated lines under uncertainties, an H∞ damping controller is designed for the rotor side converter (RSC). The weighting functions are designed to meet the mitigation requirements of sub-synchronous oscillation currents and output power. The robust stability (RS) and robust performance (RP) of the system are validated by the µ analysis. The performance of the H∞ damping controller is demonstrated by time domain simulations of a 90 MW wind farm model with different wind speed, and SC levels. The case study with 6 m/s wind speed and 70% SC level shows superior performance of the H∞ damping controller.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shenzhen University
Contributors: Wang, Y., Wu, Q., Yang, R., Tao, G., Liu, Z.
Pages: 509-519
Publication date: 2018
Peer-reviewed: Yes

Publication information
Volume: 98
ISSN (Print): 0142-0615
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.63 SJR 1.276 SNIP 1.662
Web of Science (2017): Impact factor 3.61
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.3 SJR 1.472 SNIP 1.843
Web of Science (2016): Impact factor 3.289
Hierarchical Control of Thermostatically Controller Loads for Primary Frequency Control

This paper proposes a hierarchical control of Thermostatically Controlled Loads (TCLs) to provide primary frequency control support. The control architecture is comprised of three levels. At the high level, an aggregator coordinates multiple distribution substations and dispatches the primary reserve references. At the middle level, distribution substations estimate the available power of TCLs based on the aggregated bin model, and dispatch control signals to individual TCLs. At the local level, a supplementary frequency control loop is implemented at the local controller, which makes TCLs respond to the frequency event autonomously. Case studies show that the proposed controller can efficiently respond to frequency events and fulfill the requirement specified by the system operator. The users’ comforts are not compromised and the short cycling of TCLs is largely reduced. Due to the autonomous control, the communication requirement is minimized.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University
Contributors: Zhao, H., Wu, Q., Huang, S., Zhang, H., Xue, Y.
Pages: 2986-2998
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
Volume: 9
Issue number: 4
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English
Keywords: Markov transition matrix, Primary frequency support, Thermostatically controlled loads
Electronic versions:
Hierarchical_Control_of_Thermostatically_Controlled_Loads_for_Primary_Frequency_Support.pdf
Mixed H₂/H∞ Pitch Control of Wind Turbine with a Markovian Jump Model

This paper proposes a Markovian jump model and the corresponding H₂/H∞ control strategy for the wind turbine driven by the stochastic switching wind speed, which can be used to regulate the generator speed in order to harvest the rated power while reducing the fatigue loads on the mechanical side of wind turbine. Through sampling the low-frequency wind speed data into separate intervals, the stochastic characteristic of the steady wind speed can be represented as a Markov process, while the high-frequency wind speed in each interval is regarded as the disturbance input. Then, the traditional operating points of wind turbine can be divided into separate subregions correspondingly, where the model parameters and the control mode can be fixed in each mode. Then, the mixed H₂/H∞ control problem is discussed for such a class of Markovian jump wind turbine working above the rated wind speed to guarantee both the disturbance rejection and the mechanical loads objectives, which can reduce the power volatility and the generator torque fluctuation of the whole transmission mechanism efficiently. Simulation results for a 2 MW wind turbine show the effectiveness of the proposed method.
Modeling and Modern Control of Wind Power

This book covers the modeling of wind power and application of modern control methods to the wind power control—specifically the models of type 3 and type 4 wind turbines. The modeling aspects will help readers to streamline the wind turbine and wind power plant modeling, and reduce the burden of power system simulations to investigate the impact of wind power on power systems. The use of modern control methods will help technology development, especially from the perspective of manufactures.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Wuhan University
Contributors: Wu, Q. (ed.), Sun, Y. (ed.)
Number of pages: 280
Publication date: 2018

Publication information
Publisher: Wiley-IEEE press
ISBN (Print): 978-1-119-23626-9
Original language: English
Research output: Research - peer-review › Book – Annual report year: 2018

Model Predictive Voltage Control of Wind Power Plants

This chapter proposes an autonomous wind farm voltage controller (WFVC) based on model predictive control (MPC). It also introduces the analytical expressions for the voltage sensitivity to tap positions of a transformer. The chapter then
describes the discrete models for the wind turbine generators (WTGs) and static var compensators (SVCs)/static var generators (SVGs). Next, it describes the implementation of the on-load tap changing (OLTC) in the MPC. Furthermore, the chapter examines the cost function as well as the constraints of the MPC-based WFVC for both control modes. In order to test the efficacy of the proposed WFVC, two case scenarios were designed: the wind farm is under normal operating conditions and the internal wind power fluctuation is considered; and besides internal power fluctuation, the impact of the external grid on the wind farm is considered.

**General information**

**State:** Published  
**Organisations:** Department of Electrical Engineering, Center for Electric Power and Energy  
**Contributors:** Zhao, H., Wu, Q.  
**Pages:** 175-192  
**Publication date:** 2018

**Host publication information**

**Title of host publication:** Modeling and Modern Control of Wind Power  
**Publisher:** Wiley-IEEE press  
**ISBN (Print):** 9781119236382  
**DOIs:** 10.1002/9781119236382.ch9  
**Research output:** Research - peer-review  
**Book chapter – Annual report year:** 2018

**MPC based coordinated voltage regulation for distribution networks with distributed generation and energy storage system**

This paper presents a Model Predictive Control (MPC)-based coordinated voltage control scheme for distribution networks with high penetration of distributed generation (DG) and energy storage. In this scheme, the DG units, energy storage devices and on-load tap changer (OLTC) are optimally coordinated to maintain all bus voltages in the network within a permissible range. To better coordinate the economical operation and voltage regulation, two control modes are designed according to the operating conditions. In the preventive mode, the DG units operate in the maximum power point tracking (MPPT) mode. State-of-charge (SoC) of energy storage system (ESS) units and power outputs of DG and ESS units are optimized while maintaining the voltages within the feasible range. In the corrective mode, active power curtailment of DG units is also used as a necessary method to correct the severe voltage deviations. The voltage sensitivity coefficients with respect to the power injections and tap changes are updated in real time using an analytical sensitivity calculation method to improve the computation efficiency. A test system consisting of two 20kV feeders fed from the same substation based on a real distribution network was used to validate the proposed coordinated voltage control scheme under both normal and large-disturbance conditions.

**General information**

**State:** Accepted/In press  
**Organisations:** Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Harvard University, Zhejiang University, Shandong University  
**Contributors:** Guo, Y., Wu, Q., Gao, H., Chen, X., Østergaard, J., Xin, H.  
**Number of pages:** 9  
**Publication date:** 2018  
**Peer-reviewed:** Yes

**Publication information**

**Journal:** IEEE Transactions on Sustainable Energy  
**ISSN (Print):** 1949-3029  
**Ratings:**  
**BFI (2018):** BFI-level 2  
**Web of Science (2018):** Indexed yes  
**BFI (2017):** BFI-level 1  
**Scopus rating (2017):** CiteScore 7.42 SJR 2.318 SNIP 2.452  
**Web of Science (2017):** Impact factor 6.235  
**Web of Science (2017):** Indexed yes  
**BFI (2016):** BFI-level 1  
**Scopus rating (2016):** CiteScore 7.8 SJR 2.368 SNIP 2.967  
**Web of Science (2016):** Impact factor 4.909  
**Web of Science (2016):** Indexed yes  
**BFI (2015):** BFI-level 1  
**Scopus rating (2015):** CiteScore 7.09 SJR 2.717 SNIP 3.22
Multi-agent modeling and analysis of EV users' travel willingness based on an integrated causal/statistical/behavioral model

An electric vehicle (EV) centred ecosystem has not yet been formed, the existing limited statistic data are far from enough for the analysis of EV users’ travel and charge behaviors, which however tends to be affected by many certain and uncertain factors. An experimental economics (EE) based simulation method can be used to analyze the behaviors of key participants in a system. However, it is restricted by the system size, experimental site and the number of qualified human participants. Therefore, this method is hard to be adopted for the behavioral analysis of a large number of human participants. In this paper, a new method combining a questionnaire statistics and the EE-based simulation is proposed. The causal relationship is considered in the design of the questionnaires and data extraction, then a multi-agent modeling integration method is introduced in the EE-based simulation, which enables the integration of causal/statistical/behavioral models into the multi-agent framework to reflect the EV users’ travel willingness statistically. The generated multi-agents are used to replace human participants in the EE-based simulation in order to evaluate EV users’ travel demands in different scenarios, and compare the differences of simulated or measured travel behaviors between potential EV users and internal combustion engine (ICE) vehicle users.
Optimal operation of integrated electrical, district heating and natural gas system in wind dominated power system

Nowadays, installed capacity of renewable energy sources is increasing at a high rate and even higher increase is expected in the future. In order to accommodate renewable energy sources, integration of gas, electricity and district heating network is a promising solution. This paper provides a coordinated operation and analysis of electricity, district heating and natural gas system with integrated wind farm. The interactions among different energy sectors will provide more flexibility required by the future renewable energy system. A nonlinear optimization problem is presented with focus on decreasing the operational cost and improving efficiency of integrated system, as well as meeting the demands. Optimal operation is performed for a test case system including constraints of individual systems and linkages between each of the systems. The test system includes electrical, district heating and natural gas subsystem with thermal and gas storages, combined heat and power and power to gas units and wind turbine. Simulation results show that integration of electricity, heating and natural gas system decreases the operational cost and provides higher flexibility to the system. Moreover, wind curtailment is reduced with integration of P2G.

General information
State: Accepted/In press
Organisations: Center for Electric Power and Energy, Electric Power Systems, Department of Electrical Engineering
Contributors: Turk, A., Zeng, Q., Wu, Q., Nielsen, A. H.
Number of pages: 10
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: International Journal of Smart Grid and Clean Energy
ISSN (Print): 2315-4462
Ratings:
Web of Science (2017): Indexed yes
Original language: English
Keywords: Combined heat and power, Electrical system, District heating system, Natural gas system, Optimal dispatch
Electronic versions:
E0007_Optimal_operation_of_integrated_electrical_district_heating_and_natural_gas_system_in_wind-dominated_power_system.pdf
Source: PublicationPreSubmission
Source-ID: 154963307
Research output: Research - peer-review; Journal article – Annual report year: 2018

Optimal Scheduling of Biogas-Solar-Wind Renewable Portfolio for Multi-Carrier Energy Supplies

This paper proposes a multi-source multi-product framework for coupled multi-carrier energy supplies with a biogas-solar-wind hybrid renewable system. In this framework, the biogas-solar-wind complementarities are fully exploited based on digesting thermodynamic effects for the synergetic interactions of electricity, gas and heating energy flows, and a coupling matrix is formulated for the modeling of production, conversion, storage, and consumption of different energy carriers. The multi-energy complementarity of biogas-solar-wind renewable portfolio can be utilized to facilitate the mitigation of renewable intermittency and the efficient utilization of batteries, and a multi-carrier generation scheduling scheme is further presented to dynamically optimize dispatch factors in the coupling matrix for energy-efficient con-version and storage, while different energy demands of end-users are satisfied. The proposed methodology has been fully tested and benchmarked on a stand-alone Microgrid over a 24-hour scheduling horizon. Comparative results demonstrate that the proposed scheme can lower the battery charging/discharging actions as well as the degradation cost, and also confirm its
capability to accommodate high penetration of variable renewables
Orthogonal Genetic Algorithm Based Power System Restoration Path Optimization

Optimizing the power system restoration path is a key issue for the system restoration after a blackout. Because the optimization is a complex nonlinear programming problem, artificial intelligent algorithms are widely employed to solve this problem due to its modeling flexibility and strong optimization capability. However, because the dimension of restoration path optimization is very high especially for large scale systems, artificial intelligent algorithms in current works are easy to be trapped in the local optima. In order to improve the optimal solution from the artificial intelligence algorithms, an orthogonal genetic algorithm is employed in this paper to optimize the restoration path, which can search the solution space in a statistically sound manner. Firstly, the experimental design method was employed to generate orthogonal array as the initial population which was scattered uniformly over the feasible solution space. Then, the orthogonal crossover operator based on the orthogonal experimental design was employed to generate a small but representative feasible solution as the potential offspring. Finally, the proposed method is validated using the IEEE 118-bus test system and part of the Jiangsu power grid in China.
Parsimonious Short-Term Load Forecasting for Optimal Operation Planning of Electrical Distribution Systems

The optimal operation planning (OOP) of electrical distribution systems (EDS) is very sensible to the quality of the short-term load forecasts. Assuming aggregated demands in EDS as univariate non-stationary seasonal time series, and based on historical measurements gathered by smart meters, this paper presents a parsimonious short-term load forecasting method to estimate the expected outcomes of future demands, and the standard deviations of forecast errors. The chosen short-term load forecasting method is an adaptation of the multiplicative autoregressive integrated moving average (ARIMA) models. Seasonal ARIMA models are parsimonious forecasting techniques because they require very few parameters and low computational resources to provide an adequate representation of stochastic time series. Two approaches are used in this paper to estimate the parameters that constitute the proposed multiplicative ARIMA model: a frequentist and a Bayesian approach. Advantages and disadvantages of both methods are compared by simulating a centralized self-healing scheme of a real EDS that uses the forecasts to deploy a robust restoration plan. Results shown that the proposed seasonal ARIMA model is a fast, precise, straightforward and adaptable load forecasting method, suitable for OOP of highly supervised EDS.

General information
State: Accepted/In press
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, University of Campinas
Contributors: López, J. C., Rider, M. J., Wu, Q.
Number of pages: 10
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Power Systems
ISSN (Print): 0885-8950
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.742 SNIP 2.662
Web of Science (2017): Impact factor 5.255
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.368 SNIP 3.584
Web of Science (2016): Impact factor 5.68
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 6.6 SJR 3.315 SNIP 3.386
Participation of an Energy Hub in Electricity and Heat Distribution Markets: An MPEC Approach

Integration of electricity and heat distribution networks offers extra flexibility to system operation and improves energy efficiency. The energy hub (EH) plays an important role in energy production, conversion and storage in such coupled infrastructures. This paper provides a new outlook and thorough mathematical tool for studying the integrated energy system from a deregulated market perspective. A mathematic program with equilibrium constraints (MPEC) model is...
proposed to study the strategic behaviors of a profit-driven energy hub in the electricity market and heating market under the background of energy system integration. In the upper level, the EH submits bids of prices and quantities to a distribution power market and a heating market; in the lower level, the two markets are cleared and energy contracts between the EH and two energy markets are determined. Network constraints of physical systems are explicitly represented by an optimal power flow problem and an optimal thermal flow problem. The proposed MPEC formulation is approximated by a mixed-integer linear program via performing integer disjunctions on the complementarity and slackness conditions and binary expansion technique on the bilinear production terms. Case studies demonstrate the effectiveness of the proposed model and method.

General information
State: Accepted/In press
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University, Harvard John A. Paulson School of Engineering and Applied Sciences
Contributors: Li, R., Wu, Q., Wei, W., Mei, S., Hu, Q.
Number of pages: 13
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English
Keywords: Energy hub, District heating network, Distribution power network, Strategic bidding, MPEC
DOIs:
10.1109/TSG.2018.2833279
Source: PublicationPreSubmission
Source-ID: 147064380
Research output: Research - peer-review; Journal article – Annual report year: 2018
Reactive power and voltage control interaction and optimization in the Danish largest wind power plant at Kriegers Flak

With the total 600MW power production capacity, Kriegers Flak will be the largest offshore wind power plant (OWPP) in Denmark. Kriegers Flak will utilize the two unequal sections, 400MW and 200MW, on the two offshore platforms interconnected via a 9 km 200kV cable and connected to the onshore substation via two 80 km 220kV cables. From the onshore 220kV substation, the 220kV connections continue to the two different 400/220kV substations of the Danish transmission grid. From the 400MW offshore platform, the connection continues to the 150kV offshore infrastructure of Germany. The Kriegers Flak grid connection resamples a meshed offshore grid (MOG) which increases complexity of and requirements to its overall voltage and reactive power control. This presentation describes how the overall voltage and reactive power control system is proposed and designed for optimized operation and reduction of the stress and efforts on the control equipment of the Kriegers Flak 220kV system.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Energinet.dk, Technical University of Denmark
Contributors: Akhmatov, V., Wu, Q., Takarics, T.
Number of pages: 11
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: Journal of Physics: Conference Series
Volume: 1102
Article number: 012031
ISSN (Print): 1742-6596
Ratings:
BFI (2018): BFI-level 1
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 0.48 SJR 0.241 SNIP 0.447
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 0.45 SJR 0.24 SNIP 0.401
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 0.35 SJR 0.252 SNIP 0.374
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 0.32 SJR 0.264 SNIP 0.352
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 0.25 SJR 0.245 SNIP 0.293
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 0.33 SJR 0.293 SNIP 0.387
ISI indexed (2012): ISI indexed no
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 0.43 SJR 0.293 SNIP 0.356
ISI indexed (2011): ISI indexed no
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.288 SNIP 0.351
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.259 SNIP 0.346
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.264 SNIP 0.301
Web of Science (2008): Indexed yes
Review of Service Restoration Methods in Distribution Networks

Service restoration (SR) is one of the most important strategies to improve the resilience of the modern distribution network. After the fault location is identified and isolated, a proper SR plan should be determined to resupply out-of-service areas. This paper reviews the existing methods for SR in distribution networks, which can be categorized into two types, namely centralized methods and decentralized methods, according to their implementation. These methods utilize one or more techniques to derive the SR plan. The used techniques consist of expert systems, heuristic algorithms, meta-heuristic algorithms, graph theory, multi-agent systems and mathematical programming.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, University of Southern Denmark, University of Campinas, Hunan University
Contributors: Shen, F., Wu, Q., Huang, S., López, J. C., Li, C., Zhou, B.
Number of pages: 6
Publication date: 2018

Host publication information
Title of host publication: Proceedings of 8th IEEE PES Innovative Smart Grid Technologies Conference
Publisher: IEEE
Keywords: Centralized methods, Decentralized methods, Distribution networks, Service restoration

Second-Order Conic Programming Model for Load Restoration Considering Uncertainty of Load Increment based on Information Gap Decision Theory

Load restoration is an important issue for power system restoration after a blackout. A second order conic programming (SOCP) model is proposed based on the information gap decision theory (IGDT) to maximize load pickup considering the uncertainty of load increment. Because distribution functions of load increment are difficult to obtain, the optimization of load pickup is transformed to maximize the fluctuation range of load increment by the IGDT. The derived optimal fluctuation range can ensure that the reenergized system is secure, and the amount of load pickup is always better than the specified expectation. Moreover, because the optimization model of the fluctuation range is a mixed-integer nonlinear model which is challenging to solve accurately and efficiently, the nonlinear model is transformed into a SOCP model that can be efficiently solved using CPLEX. The efficiency of the IGDT-based SOCP model is validated using the New England (10-machine 39-bus) system. The simulation results show that the derived load pickup shows expected robustness with respect to the load increment uncertainty.

General information
State: Accepted/In press
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Nanjing University of Science and Technology, Electric Power Research Institute of State Grid Jiangsu Electric Power Company
Contributors: Xie, Y., Xi, C., Wu, Q., Qian, Z.
Number of pages: 17
Publication date: 2018
Peer-reviewed: Yes
Sparsity Prevention Pivoting Method for Linear Programming

When the simplex algorithm is used to calculate a linear programming problem, if the matrix is a sparse matrix, it will be possible to lead to many zero-length calculation steps, and even iterative cycle will appear. To deal with the problem, a new pivoting method is proposed in this paper. The principle of this method is avoided choosing the row which the value of the element in the b vector is zero as the row of the pivot element to make the matrix in linear programming density and ensure that most subsequent steps will improve the value of the objective function. One step following this principle is inserted to reselect the pivot element in the existing linear programming algorithm. Both the conditions for inserting this step and the maximum number of allowed insertion steps are determined. In the case study, taking several numbers of linear programming problems as examples, the results indicate that this method can effectively improve the efficiency of linear programming for the sparse matrix.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hunan University
Contributors: Li, P., Li, Q., Li, C., Zhou, B., Cao, Y., Wu, Q., Fang, B.
Pages: 19560 - 19567
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Access
Volume: 6
ISSN (Print): 2169-3536
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 4.49
Web of Science (2017): Impact factor 3.557
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 5.13
Web of Science (2016): Impact factor 3.244
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 4.32
Web of Science (2015): Impact factor 1.27
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.16
BFI (2013): BFI-level 1
Original language: English
Keywords: Linear programming, Pivoting rules, Simplex algorithm, Sparse matrix
Electronic versions:
08320785.pdf
DOIs:
10.1109/ACCESS.2018.2817571

Status of Wind Power Technologies
With the development of wind turbine technology, wind power will become more controllable and grid-friendly. It is desirable to make wind farms operate as conventional power plants. Wind turbine generators (WTGs) were mainly used in rural and remote areas for wind power generation. WTG-based wind energy conversion systems (WECS) can be divided into the four main types (type 1-4). Due to the inherent variability and uncertainty of the wind, the integration of wind power into the grid has brought challenges in several different areas, including power quality, system reliability, stability, and
planning. The impact of each is largely dependent on the level of wind power penetration in the grid. In many countries, relatively high levels of wind power penetration have been achieved. This chapter shows the estimated wind power penetration in leading wind markets.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: Zhao, H., Wu, Q.
Pages: 1-10
Publication date: 2018

**Host publication information**
Title of host publication: Modeling and Modern Control of Wind Power
Publisher: Wiley-IEEE press
ISBN (Print): 9781119236382
DOIs: 10.1002/9781119236382.ch1
Research output: Research - peer-review › Book chapter – Annual report year: 2018

**Stochastic Economic Dispatch with Wind using Versatile Probability Distribution and L-BFGS-B Based Dual Decomposition**
This paper focuses on economic dispatch (ED) in power systems with intermittent wind power, which is a very critical issue in future power systems. A stochastic ED problem is formed based on the recently proposed versatile probability distribution (VPD) of wind power. The problem is then analyzed and proved to be strictly convex. Although such convex optimization is tractable in many cases, it may take a long time to solve due to its large scale. This paper proposes a dual decomposition method to decompose the large problem. Then two methods are employed to solve the decomposed problem, namely, the subgradient method and a faster method, limited-memory BFGS with box constraints (L-BFGS-B, a quasi-Newton method). Case studies were conducted to verify the efficiency of the dual decomposition and L-BFGS-B method for solving the stochastic ED problem.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Wuhan University
Contributors: Huang, S., Sun, Y., Wu, Q.
Pages: 6254 - 6263
Publication date: 2018
Peer-reviewed: Yes

**Publication information**
Journal: IEEE Transactions on Power Systems
Volume: 33
Issue number: 6
ISSN (Print): 0885-8950
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.742 SNIP 2.662
Web of Science (2017): Impact factor 5.255
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.368 SNIP 3.584
Web of Science (2016): Impact factor 5.68
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 6.6 SJR 3.315 SNIP 3.386
Web of Science (2015): Impact factor 3.342
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.31 SJR 2.475 SNIP 3.485
Transactive Real-time Electric Vehicle Charging Management for Commercial Buildings with PV On-site Generation

In the future smart grids, it is important for the prosumers to manage the uncertainties from the distributed renewable energy sources (RES) such as PV generation. As a type of distributed energy resources (DERs), electrical vehicles (EVs) are regarded as a promising solution of the problem. In this paper, a transactive real-time EV charging management scheme is proposed for the building energy management system (BEMS) of commercial buildings with PV on-site generation and EV charging services. Instead of direct EV charging control, the proposed EV charging management scheme applies a transactive energy concept based approach to address the real-time EV charging management. With the proposed scheme, the BEMS can schedule its net electricity exchange with the external grid under the uncertainties of PV generation and EV parking and maximize its profit in the real-time operation. Meanwhile, the EV owners need not provide the BEMS with any further private information (such as future driving plans) but only their real-time charging...
requirements and preference setting of the response to the BEMS’s pricing signal in the proposed scheme. As such, the BEMS as a charging service provider only requires the minimal necessary information from the EV owners. The EV owners’ charging requirements, preference setting of the response curves and their required reimbursements for the response are respected by the real-time charging management and their contributions to the demand response are reimbursed by the BEMS. Case studies with real world driving data from the Danish National Travel Survey were carried out to verify the proposed framework.
Two-Stage Load Shedding for Secondary Control in Hierarchical Operation of Islanded Microgrids

A two-stage load shedding scheme is presented to cope with the severe power deficit caused by microgrid islanding. Coordinated with the fast response of inverter-based distributed energy resources (DERs), load shedding at each stage and the resulting power flow redistribution are estimated. The first stage of load shedding will cease rapid frequency decline in which the measured frequency deviation is employed to guide the load shedding level and process. Once a new steady-state is reached, the second stage is activated, which performs load shedding according to the priorities of loads. The effectiveness of the proposed scheme is verified through time-domain simulation in PSCAD/EMTDC based on a scaled-down microgrid system.

General information
State: Accepted/In press
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Illinois Institute of Technology
Contributors: Zhou, Q., Li, Z., Wu, Q., Shahidehpour, M.
Number of pages: 8
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English
Keywords: Microgrid islanding, Secondary control, Controllable loads, Renewable energy resources, Load Shedding
DOIs:
10.1109/TSG.2018.2817738
Source: PublicationPreSubmission
Source-ID: 143451860
Two-Stage Optimal Scheduling of Electric Vehicle Charging based on Transactive Control
In this paper, a two-stage optimal charging scheme based on transactive control is proposed for the aggregator to manage day-ahead electricity procurement and real-time EV charging management in order to minimize its total operating cost. The day-ahead electricity procurement considers both the day-ahead energy cost and expected real-time operation cost. In the real-time charging management, the cost of employing the charging flexibility from the EV owners is explicitly modelled. The aggregator uses a transactive market to manage the real-time charging demand to provide the regulating power. A model predictive control (MPC) based method is proposed for the aggregator to clear the transactive market. The real-time charging decisions of the EVs are determined by the clearing of the proposed transactive market according to the real-time requests and preferences of the EV owners. As such, the aggregators decisions in the real-time EV charging management and regulating power markets can be optimized. At the same time, the charging requirements and response preferences of the EV owners are respected. Case studies using real world driving data from the Danish National Travel Surveys were conducted to verify the proposed framework.

General information
State: Accepted/In press
Contributors: Liu, Z., Wu, Q., Ma, K., Shahidehpour, M., Xue, Y., Huang, S.
Number of pages: 11
Publication date: 2018
Peer-reviewed: Yes

Publication information
Journal: I E E E Transactions on Smart Grid
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English
Voltage Balancing for Bipolar DC Distribution Grids: A Power Flow based Binary Integer Multi-Objective Optimization Approach

The re-emergence of 2-phase bipolar DC distribution network, which utilizes the neutral wire for efficient distribution, has spurred research interest in recent years. In practice, system efficiency (power loss) and voltage unbalance are major concerns for the planning and design of the 2-phase DC bipolar network. While most of the existing methodologies are power electronics solutions, there are very few works on resolving the problem from the power system perspective. This paper proposes a model based optimization method by firstly formulating the power flow model for 2-phase DC bipolar network using the single line modeling technique and nodal analysis. Secondly, a binary integer load distribution model is proposed to consider the redistribution of unipolar loads across the two unipolar distribution poles. Together with the power flow model, the system power loss and system voltage unbalance indices are formulated as a binary integer quadratic model. Thirdly, a multi-objective optimization model is formulated and solved using the weighted sum approach. The proposed method is applied to a DC LED lighting system design which considers both voltage unbalance and power loss. Using a 15 bus single source and a 33 bus multi-source network as case studies, the developed power flow model is validated with very high accuracy. Compared to existing iterative methods, the proposed model-based approach is able to significantly improve the voltage balancing across the distribution system.
A Combined Reliability Model of VSC-HVDC Connected Offshore Wind Farms Considering Wind Speed Correlation

This paper proposes a combined reliability model of voltage source converter-based high voltage direct current (VSC-HVDC) connected offshore wind farms (WFs) using the frequency and duration technique. Firstly, a two-dimensional multi-state WF model is developed considering wind speed variations and WTGs outage. The wind speed correlation between different WFs is included in the two-dimensional multistate WF model by using an improved k-means clustering method. Then, the entire system with two WFs and a three-terminal VSC-HVDC system is modeled as a multi-state generation unit. The proposed model is applied to the Roy Billinton test system (RBTS) for adequacy studies. Both the probability and frequency indices are calculated. The effectiveness and accuracy of the combined model is validated by comparing results with the sequential Monte Carlo simulation (MCS) method. The effects of the outage of VSC-HVDC system and wind speed correlation on the system reliability were analyzed. Sensitivity analyses were conducted to investigate the impact of repair time of the offshore VSC-HVDC system on system reliability.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University
Contributors: Guo, Y., Gao, H., Wu, Q.
Number of pages: 10
A Meteorological Information Mining-Based Wind Speed Model for Adequacy Assessment of Power Systems With Wind Power

Accurate wind speed simulation is an essential prerequisite to analyze the power systems with wind power. A wind speed model considering meteorological conditions and seasonal variations is proposed in this paper. Firstly, using the path analysis method, the influence weights of meteorological factors are calculated. Secondly, the meteorological data are
classified into several states using an improved Fuzzy C-means (FCM) algorithm. Then the Markov chain is used to model the chronological characteristics of meteorological states and wind speed. The proposed model was proved to be more accurate in capturing the characteristics of probability distribution, auto-correlation and seasonal variations of wind speed compared with the traditional Markov chain Monte Carlo (MCMC) and autoregressive moving average (ARMA) model. Furthermore, the proposed model was applied to adequacy assessment of generation systems with wind power. The assessment results of the modified IEEE-RTS79 and IEEE-RTS96 demonstrated the effectiveness and accuracy of the proposed model.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University
Contributors: Guo, Y., Gao, H., Wu, Q.
Pages: 406-413
Publication date: 2017
Peer-reviewed: Yes

**Publication information**
Volume: 93
ISSN (Print): 0142-0615
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 4.63 SJR 1.276 SNIP 1.662
Web of Science (2017): Impact factor 3.61
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 4.3 SJR 1.472 SNIP 1.843
Web of Science (2016): Impact factor 3.289
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 3.97 SJR 1.441 SNIP 2.031
Web of Science (2015): Impact factor 2.587
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 4.34 SJR 1.328 SNIP 2.312
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 4.54 SJR 1.231 SNIP 2.731
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 4.37 SJR 1.106 SNIP 2.758
Web of Science (2012): Impact factor 3.432
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 3.46 SJR 0.985 SNIP 2.394
Web of Science (2011): Impact factor 2.247
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.948 SNIP 2.258
Web of Science (2010): Impact factor 2.212
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 1.047 SNIP 1.901
This paper proposes a combined wind farm controller based on Model Predictive Control (MPC). Compared with the conventional decoupled active and reactive power control, the proposed control scheme considers the significant impact of active power on voltage variations due to the low X/R ratio of wind farm collector systems. The voltage control is improved. Besides, by coordination of active and reactive power, the Var capacity is optimized to prevent potential failures due to Var shortage, especially when the wind farm operates close to its full load. An analytical method is used to calculate the sensitivity coefficients to improve the computation efficiency and overcome the convergence problem. Two control modes are designed for both normal and emergency conditions. A wind farm with 20 wind turbines was used to verify the proposed combined control scheme.

### General information

**State:** Published  
**Organisations:** Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Argonne National Laboratory, Illinois Institute of Technology, State Grid Electric Power System Research Institute  
**Contributors:** Zhao, H., Wu, Q., Wang, J., Liu, Z., Shahidehpour, M., Xue, Y.  
**Number of pages:** 11  
**Pages:** 1177-1187  
**Publication date:** 2017  
**Peer-reviewed:** Yes

### Publication information

**Journal:** IEEE Transactions on Energy Conversion  
**Volume:** 32  
**Issue number:** 3  
**ISSN (Print):** 0885-8969  
**Ratings:**  
  - BFI (2018): BFI-level 2  
  - Web of Science (2018): Indexed yes  
  - BFI (2017): BFI-level 2  
  - Scopus rating (2017): CiteScore 5.42 SJR 1.377 SNIP 2.124  
  - Web of Science (2017): Impact factor 3.767  
  - Web of Science (2017): Indexed yes
Combined time-varying forecast based on the proper scoring approach for wind power generation

Compared with traditional point forecasts, combined forecast have been proposed as an effective method to provide more accurate forecasts than individual model. However, the literature and research focus on wind-power combined forecasts are relatively limited. Here, based on forecasting error distribution, a proper scoring approach is applied to combine plausible models to form an overall time-varying model for the next day forecasts, rather than weights-based combination. To validate the effectiveness of the proposed method, real data of 3 years were used for testing. Simulation results demonstrate that the proposed method improves the accuracy of overall forecasts, even compared with a numerical weather prediction.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Hohai University
Pages: 67-72
Publication date: 2017
Peer-reviewed: Yes

Publication Information
Journal: The Journal of Engineering
ISSN (Print): 2051-3305
Ratings:
Web of Science (2018): Indexed yes
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 0.51 SJR 0.154 SNIP 0.312
Scopus rating (2015): SJR 0.152 SNIP 0.476
Scopus rating (2014): SJR 0.15 SNIP 0.397
ISI indexed (2013): ISI indexed no
Original language: English
Keywords: Wind power plants, Power system planning and layout, Load forecasting, Numerical weather prediction, Weights-based combination, Forecasting error distribution, Wind-power combined forecasts, Point forecasts, Wind power generation, Proper scoring approach, Combined time-varying forecasting
Electronic versions:
JOE.2017.0843.pdf
DOIs:
10.1049/joe.2017.0843
Source: FindIt
Source-ID: 2395594381
Research output: Research - peer-review › Journal article – Annual report year: 2018

Coordinated Voltage Control Scheme for VSC-HVDC Connected Wind Power Plants

This paper proposes a coordinated voltage control scheme based on model predictive control (MPC) for voltage source converter-based high voltage direct current (VSC-HVDC) connected wind power plants (WPPs). In the proposed scheme, voltage regulation capabilities of VSC and WTGs are fully utilized and optimally coordinated. Two control modes, namely operation optimization mode and corrective mode, are designed to coordinate voltage control and economic operation of the system. In the first mode, the control objective includes the bus voltages, power losses and dynamic Var reserves of wind turbine generators (WTGs). Only the terminal voltages of WTGs are taken into account in the second mode. The predictive model of the system including VSC and WTGs is developed firstly. The calculation of sensitivity coefficients is done by an analytical method to improve the computational efficiency. Simulation results are presented to demonstrate the effectiveness of the proposed controller and the control performance is compared with conventional optimal control and loss minimization control. Besides, the robustness of the proposed controller to communication time delay and measurement errors is investigated in the last.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University
Contributors: Guo, Y., Gao, H., Wu, Q., Zhao, H., Østergaard, J.
Pages: 198 - 206
Publication date: 2017
Peer-reviewed: Yes
Fatigue Load Sensitivity Based Optimal Active Power Dispatch For Wind Farms

This paper proposes an optimal active power dispatch algorithm for wind farms based on Wind Turbine (WT) load sensitivity. The control objectives include tracking power references from the system operator and minimizing fatigue loads experienced by WTs. The sensitivity of WT fatigue loads to power references is defined which simplifies the formulation of the optimal power dispatch problem. Since the sensitivity value is calculated at the local WT controller, the computation burden of the central wind farm controller is largely reduced. Moreover, explicit analytical equations of the fatigue load sensitivity are derived, which significantly improves the computation efficiency of the local WT controller. The proposed algorithm can be implemented in different active power control schemes. Case studies were conducted with a wind farm under balance control for both low and high wind conditions. By comparing the rainflow cycles and Damage Equivalent Load (DEL), the efficacy of the proposed algorithm is verified.

General information
State: Published
Contributors: Zhao, H., Wu, Q., Huang, S., Shahidehpour, M., Guo, Q., Sun, H.
Number of pages: 13
Pages: 1247-1259
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Sustainable Energy
Volume: 8
Issue number: 3
ISSN (Print): 1949-3029
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 7.42 SJR 2.318 SNIP 2.452
Web of Science (2017): Impact factor 6.235
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.8 SJR 2.368 SNIP 2.967
Web of Science (2016): Impact factor 4.909
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 7.09 SJR 2.717 SNIP 3.22
Web of Science (2015): Impact factor 3.727
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.03 SJR 2.554 SNIP 3.898
Web of Science (2014): Impact factor 3.656
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 7.03 SJR 2.043 SNIP 3.712
Web of Science (2013): Impact factor 3.842
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 6.58 SJR 1.243 SNIP 3.744
ISI indexed (2012): ISI indexed no
Scopus rating (2011): CiteScore 5.13 SJR 0.73 SNIP 3.01
ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Fatigue load, Load sensitivity, Optimal active power dispatch, Wind Farm, Wind turbine
Electronic versions: final_version.pdf
DOIs:
Load Flow Analysis of Hybrid AC-DC Power System with Offshore Wind Power

The offshore wind power has received immense attention because of higher wind speed and lower opposition for construction. A wide range of combinations of high-voltage AC/DC transmission have been proposed for integrating offshore wind farms and long-distance power transmission. This paper is to model such hybrid AC-DC systems including the interfacing converters, which have several control parameters that can change the load flow of the hybrid systems. Then, the paper proposes a Load Flow algorithm based on the Newton-Raphson method, which covers three different section types of the transmission system: the AC parts, the DC parts and the interfacing converters. Finally, this paper validates this algorithm through a detailed case study with a typical hybrid network.

Measurement-Based Transmission Line Parameter Estimation with Adaptive Data Selection Scheme

Accurate parameters of transmission lines are critical for power system operation and control decision making. Transmission line parameter estimation based on measured data is an effective way to enhance the validity of the parameters. This paper proposes a multi-point transmission line parameter estimation model with an adaptive data selection scheme based on measured data. Data selection scheme, defined with time window and number of data points, is introduced in the estimation model as additional variables to optimize. The data selection scheme is adaptively adjusted...
to minimize the relative standard deviation (RSD) of estimated parameters. An iterative technique derived from the Newton method is adopted to solve the proposed model by fitting the relationship between the RSD and data selection scheme with exponential functions. Simulated data are applied to illustrate the performance of the proposed model. Some 500kV transmission lines from a provincial power system of China are estimated to demonstrate the applicability of the presented model. The superiority of the proposed model over fixed data selection schemes is also verified.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, University of Manchester, Shandong University
Contributors: Li, C., Zhang, Y., Zhang, H., Wu, Q., Terzija, V.
Pages: 5764 - 5773
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
Volume: 9
Issue number: 6
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English
Keywords: Adaptive data selection, Parameters estimation, Power systems, Supervisory control and data acquisition system (SCADA), Transmission line, Wide area measurement system (WAMS)
Electronic versions:
Measurement_Based_Transmission_Line_Parameter_Estimation_with_Adaptive_Data_Selection_Scheme.pdf
DOIs: 10.1109/TSG.2017.2696619

Bibliographical note
Non-Cooperative Regulation Coordination Based on Game Theory for Wind Farm Clusters during Ramping Events

With increasing penetration of wind power in power systems, it is important to track scheduled wind power output as much as possible during ramping events to ensure security of the system. In this paper, a non-cooperative coordination strategy based on the game theory is proposed for the regulation of wind farm clusters (WFCs) in order to track scheduled wind power of the WFC during ramping events. In the proposed strategy, a non-cooperative game is formulated and wind farms compete to provide regulation to the WFC during ramping events. A regulation revenue function is proposed to evaluate the competition process of wind farms to provide regulation to the WFC which includes revenue of effective regulation (ER), power support regulation and punishment regulation. The multi-time-interval Nash equilibrium condition is derived for the regulation competition process of wind farms. By setting parameters of the regulation revenue function according to the derived Nash equilibrium condition, the ER strategy is the Nash equilibrium of the regulation competition. Case studies were conducted with the power output data of wind farms from State Grid Jibe Electric Power Company Limited of China to demonstrate the efficacy of the proposed coordination strategy during ramping events.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shandong University
Contributors: Qi, Y., Liu, Y., Wu, Q.
Number of pages: 11
Pages: 136-146
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: Energy
Volume: 132
ISSN (Print): 0360-5442
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 5.6 SJR 1.99 SNIP 1.923
Web of Science (2017): Impact factor 4.968
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 5.17 SJR 1.974 SNIP 1.823
Web of Science (2016): Impact factor 4.52
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 5.03 SJR 2.22 SNIP 2.037
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.7 SJR 2.575 SNIP 2.602
Web of Science (2014): Impact factor 4.844
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 5.02 SJR 2.458 SNIP 2.556
Web of Science (2013): Impact factor 4.159
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Optimal approach for the interaction between DSOs and aggregators to activate DER flexibility in the distribution grid

The process of predicting the behaviors of distributed energy resources (DER) and controlling them is complex. It will require a huge effort from the DSO to establish communication channels to all available DERs in the network and to integrate new ones into the automation system. It is therefore important that a third party takes care of the communication with DERs in the network. This third party is called the Aggregator (A). This paper will focus on the following: 1. DSO functionalities that enable communication with the flexibility market and the aggregator. 2. The aggregator role and the functionalities required to be a successful business entity. 3. The approach (DSO/aggregator model) that was identified and adopted by the IDE4L project as the most efficient one to solve congestion and to ensure harmony in the sequence of events. The paper concludes and recommends the IDE4L approach, which is the approach that was adopted by the IDE4L project. Based on the achieved results, we believe that the IDE4L approach is the optimal method of communication that ensures efficiency, effectiveness and harmony in communication among the DSO and all other flexibility market players. However, a full-scale field demonstration of the whole IDE4L approach was not applicable during the duration of the IDE4L project. Therefore, it's hereby recommended for future projects.
Optimal Day-ahead Charging Scheduling of Electric Vehicles through an Aggregative Game Model

The electric vehicle (EV) market has been growing rapidly around the world. With large scale deployment of EVs in power systems, both the grid and EV owners will benefit if the flexible demand of EV charging is properly managed through the electricity market. When EV charging demand is considerable in a grid, it will impact spot prices in the electricity market and consequently influence the charging scheduling itself. The interaction between the spot prices and the EV demand needs to be considered in the EV charging scheduling, otherwise it will lead to a higher charging cost. A day-ahead EV charging scheduling based on an aggregative game model is proposed in this paper. The impacts of the EV demand on the electricity prices are formulated with the game model in the scheduling considering possible actions of other EVs. The existence and uniqueness of the pure strategy Nash equilibrium are proved for the game. An optimization method is developed to calculate the equilibrium of the game model through quadratic programming. The optimal scheduling of the individual EV controller considering the actions of other EVs in the game is developed with the EV driving pattern distribution. Case studies with the proposed game model were carried out using real world driving data from the Danish National Travel Surveys. The impacts of the EV driving patterns and price forecasts on the EV demand with the proposed game model were also analysed.
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Original language: English
Keywords: Aggregative game model, Day-Ahead Market, Electric vehicles (EVs), Game theory, Nash equilibrium
Electronic versions:
TSG_01323_2016.pdf
DOIs:
10.1109/TSG.2017.2682340

Bibliographical note
(c) 2017 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other users, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works for resale or redistribution to servers or lists, or reuse of any copyrighted components of this work in other works.
Source: PublicationPreSubmission
Source-ID: 130393595
Research output: Research - peer-review; Journal article – Annual report year: 2018

Optimal Power Flow Modelling and Analysis of Hybrid AC-DC Grids with Offshore Wind Power Plant
In order to develop renewables based energy systems, the installation of the offshore wind power plants (WPPs) is globally encouraged. However, wind power generation is intermittent and uncertain. An accurate modelling and evaluation reduces investment and provide better operation. Hence, it is essential to develop a suitable model and apply optimization algorithms for different application scenarios. The objective of this work is to develop a generalized model and evaluate the Optimal Power Flow (OPF) solutions in a hybrid AC/DC system including HVDC (LCC based) and offshore WPP (VSC based). This paper also shows the significance and impact of control parameters in OPF applications. An integrated hybrid power system network is adopted in this paper and OPF techniques are applied on it by considering the impact of different control parameters. In addition to the impact of the control variables, the wind power production level also plays a major role in a hybrid system on transmission loss evaluation. The developed model is tested in Low, Medium and High wind power production levels to determine the objective function of the OPF solution. MATLAB Optimization Toolbox and MATLAB script are used to develop the model for the case studies.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Technical University of Denmark
Contributors: Dhua, D., Huang, S., Wu, Q.
Number of pages: 8
Pages: 572-579
Publication date: 2017
As the power control technology of wind farms develops, the output power of wind farms can be constant, which makes it possible for wind farms to participate in power system restoration. However, due to the uncertainty of wind energy, the actual output power can't reach a constant dispatch power in all time intervals, resulting in uncertain power sags which may induce the frequency of the system being restored to go outside the security limits. Therefore, it is necessary to optimize the dispatch of wind farms participating in power system restoration. Considering that the probability distribution function (PDF) of transient power sags is hard to obtain, a robust optimization model is proposed in this paper, which can maximize the output power of wind farms participating in power system restoration. Simulation results demonstrate that the security constraints of the restored system can be kept within security limits when wind farm dispatch is optimized by the proposed method.

Optimized dispatch of wind farms with power control capability for power system restoration

General information

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Nanjing University of Science and Technology, State Grid Jiangsu Electric Power Company
Contributors: Xie, Y., Liu, C., Wu, Q., Li, K., Zhou, Q., Yin, M.
Number of pages: 9
Pages: 908-916
Publication date: 2017
Peer-reviewed: Yes
This paper investigates the performance of Phasor Measurement Units (PMUs) under interference conditions which can appear in a power system and are not tested by the C37.118.1 standard. Three PMUs from different vendors configured for the M-class requirements were used to test three possible interference condition scenarios. In the first scenario, noise is added to the PMU input signal. The test runs a sweep of Signal-to-Noise Ratios (SNR) and the accuracy versus the noise level is obtained. The second scenario injects multiple harmonics with the input to test the influence on accuracy. The last scenario focuses on instrument transformer saturation which leads to a modified waveform injected in the PMU. This test goes through different levels of Current Transformer (CT) saturation and analyzes the effect of saturation on the accuracy of PMUs. The test results show PMU measurements will be degraded when the input signal is distorted by high noise or a saturated current waveform, but is not particularly affected by multiple harmonics. This information can be used when selecting a PMU to ensure it will provide a reliable measurement for the intended use. It can also be used for developing more robust PMUs and applications resistant to degraded measurements.
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 4.52 SJR 1.814 SNIP 2.211
Web of Science (2017): Impact factor 3.35
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 4.47 SJR 1.634 SNIP 2.536
Web of Science (2016): Impact factor 3.218
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 3.96 SJR 1.788 SNIP 2.587
Web of Science (2015): Impact factor 2.032
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 3.4 SJR 1.508 SNIP 2.631
Web of Science (2014): Impact factor 1.733
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 3.51 SJR 1.412 SNIP 2.769
Web of Science (2013): Impact factor 1.657
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 3.28 SJR 1.222 SNIP 2.577
Web of Science (2012): Impact factor 1.519
ISI indexed (2012): ISI indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.89 SJR 0.99 SNIP 2.242
Web of Science (2011): Impact factor 1.353
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.999 SNIP 2.012
Web of Science (2010): Impact factor 1.415
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.862 SNIP 1.999
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.975 SNIP 2.155
Scopus rating (2007): SJR 0.85 SNIP 1.979
Scopus rating (2006): SJR 0.876 SNIP 1.752
Scopus rating (2005): SJR 0.874 SNIP 1.891
Scopus rating (2004): SJR 0.696 SNIP 1.905
Scopus rating (2003): SJR 1.354 SNIP 1.832
Scopus rating (2002): SJR 0.977 SNIP 1.739
Scopus rating (2001): SJR 1.112 SNIP 1.221
Scopus rating (2000): SJR 0.45 SNIP 1.695
Web of Science (2000): Indexed yes
Scopus rating (1999): SJR 0.424 SNIP 1.456

Original language: English
Keywords: Interference conditions, Phasor Measurement Unit (PMU), PMU testing
Electronic versions:
Phasor_Measurement_Unit_under_Interference_Conditions.pdf
Phasor model of full scale converter wind turbine for small-signal stability analysis

The small-signal stability analysis of power system electromechanical oscillations is a well-established field in control and stability assessment of power systems. The impact of large wind farms on small-signal stability of power systems has been a topic of high interest in recent years. This study presents a phasor model of full scale converter wind turbines (WTs) implemented in MATLAB/SIMULINK for small-signal stability studies. The phasor method is typically used for dynamic studies of power systems consisting of large electric machines. It can also be applied to any linear system. This represents an advantage in small-signal stability studies, which are based on modal analysis of the linearised model and are usually complemented with dynamic simulations. The proposed model can represent a single WT or an aggregated wind power plant. The implemented model for small-signal stability analysis was tested in the Kundur's two area system. The results show that the proposed WT model is accurately linearised and its impact on power system oscillation is similar to that of previous research findings.

Predictive Control of Wind Turbine for Load Reduction during Ramping Events

With increasing penetration of wind power, the impact of its intermittence and volatility on power systems becomes more severe. A predictive control strategy for wind turbines (WTs) is proposed to deal with wind power ramping events and reduce WT load on the blades. The blade load model is based on the Blade Element Momentum (BEM) theory. The generator speed and pitch angle are simultaneously regulated to realize the control objectives. A two-stage optimization is designed in order to reduce the computational complexity. The objectives of the first stage are minimizing the ramping rate and maximizing the power generation. A trade-off is made between the two contradictory objectives by setting weight coefficients. The second stage reduces the WT load and meanwhile guarantees the power reference from the first stage is tracked. Feedback is designed based on neural network prediction to compensate the error of the prediction model. Case studies with a 1.5 MW WT were conducted to demonstrate the efficacy of the proposed predictive control strategy. Simulation results show that the proposed control can reduce the WT load during ramping events and the risk of ramping...
Real-Time Congestion Management in Distribution Networks by Flexible Demand Swap

In addition to the day-ahead congestion management in distribution networks, the real-time congestion management is very important because many unforeseen events can occur at the real operation time, e.g. loss of generation of distributed energy resources (DERs) or inaccurate forecast of energy consumption or production. Flexibility service from demand will be a good option to solve the real-time congestions if the cost of activating the flexibility service is fully addressed. This paper proposes a new method, namely “swap”, to employ the flexibility service from electric vehicles (EVs) and heat pumps (HPs) for real time congestion management. The swap method can maintain the power balance of the system and avoid the imbalance cost of activating the flexibility service. An algorithm for forming swaps through optimal power flow (OPF) and mixed integer linear programming (MILP) is proposed to implement the swap method. Case studies were carried out to validate the efficacy of the proposed swap method for real time congestion management and the proposed algorithm for forming swaps. The settlement process for the swaps in different markets is analyzed.
Remote Off-Grid Solutions for Greenland and Denmark

Renewable off-grid solutions are steadily growing in both developed and developing countries (R. Kempener et al. 2015). With the decreasing cost and improving performance of small hydro installations, solar power, wind power, and energy storage systems, renewable energy is expected to supplement or replace existing diesel grids on islands and in remote areas.

General information
State: Published
Contributors: Wu, Q., Larsen, E., Heussen, K., Bindner, H. W., Douglass, P. J.
Pages: 64-73
Publication date: 2017
Peer-reviewed: Yes

Publication information
Journal: IEEE Electrification Magazine
Volume: 5
Issue number: 2
ISSN (Print): 2325-5987
Original language: English
DOIs:
10.1109/MELE.2017.2685959
Source: PublicationPreSubmission
Source-ID: 132875179
Research output: Research - peer-review → Journal article – Annual report year: 2017

Stability and Accuracy Considerations in the Design and Implementation of Wind Turbine Power Hardware in the Loop Platform
There is increasing interest in the evaluation of wind turbine control capabilities for providing grid support. Power hardware in the loop (PHIL) simulation is an advanced method that can be used for studying the interaction of hardware with the power network, as the scaled-down actual wind turbine is connected with a simulated system through an amplifier. Special
consideration must be made in the design of the PHIL platform to ensure that the system is stable and yields accurate results. This paper presents a method for stabilizing the PHIL interface and improving the accuracy of PHIL simulation in a real-time application. The method factors in both the power and voltage scaling level, and a phase compensation scheme. It uses the reactive power control capability of the wind turbine inverter to eliminate the phase shift imposed by the feedback current filter. This is accomplished with no negative impact on the dynamic behavior of the wind turbine. The PHIL simulation results demonstrate the effectiveness of the proposed stability analysis method and phase compensation scheme. The strength of the platform is demonstrated by extending the simulation method to wind turbine control validation.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, China Electric Power Research Institute
Contributors: Luo, K., Shi, W., Chi, Y., Wu, Q., Wang, W.
Pages: 167-175
Publication date: 2017
Peer-reviewed: Yes

**Publication information**
Volume: 3
Issue number: 2
ISSN (Print): 2096-0042
Ratings:
Web of Science (2018): Indexed yes
Web of Science (2017): Indexed yes
Web of Science (2016): Indexed yes
Original language: English
Keywords: Phase compensation, Power hardware in the loop (PHIL), Stability and accuracy, Wind turbine
DOI:
10.17775/CSEEJPES.2017.0021
Source: PublicationPreSubmission
Source-ID: 134060525
Research output: Research - peer-review; Journal article – Annual report year: 2017

**Stability Boundaries for Offshore Wind Park Distributed Voltage Control**
In order to identify mechanisms causing slow reactive power oscillations observed in an existing offshore wind power plant, and be able to avoid similar events in the future, voltage control is studied in this paper for a plant with a static synchronous compensator, type-4 wind turbines and a park pilot control. Using data from the actual wind power plant, all stabilizing subsystem voltage proportional-integral controller parameters are first characterized based on their Hurwitz signature. Inner loop current control is then designed using Internal Mode Control principles, and guidelines for feed forward filter design are given to obtain required disturbance rejection properties. The paper contributes by providing analytical relations between power plant control, droop, sampling time, electrical parameters and voltage control characteristics, and by assessing frequencies and damping of reactive power modes over a realistic envelope of electrical impedances and control parameters.

**General information**
State: Published
Pages: 1496 - 1504
Publication date: 2017
Peer-reviewed: Yes

**Publication information**
Journal: I E E E Transactions on Control Systems Technology
Volume: 25
Issue number: 4
ISSN (Print): 1063-6536
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Three Phase Power Imbalance Decomposition into Systematic Imbalance and Random Imbalance

Uneven load allocations and random load behaviors are two major causes for three-phase power imbalance. The former mainly cause systematic imbalance, which can be addressed by low-cost phase swapping; the latter contribute to random imbalance, which requires relatively costly demand-side managements. To reveal the maximum potential of phase swapping and the minimum need for demand-side managements, this paper first proposes a novel a priori judgment to classify any set of three-phase power series into one of four scenarios, depending on whether there is a definite maximum phase, a definite minimum phase, or both. Then, this paper proposes a new method to decompose three-phase power series into a systematic imbalance component and a random imbalance component as the closed-form solutions of quadratic optimization models that minimize random imbalance. A degree of power imbalance is calculated based on the systematic imbalance component to guide phase swapping. Case studies demonstrate that 72.8% of 782 low voltage substations have systematic imbalance components. The degree of power imbalance results reveal the maximum need for phase swapping and the random imbalance components reveal the minimum need for demand side management, if the three phases are to be fully rebalanced.
Transactive Energy: A Review of State of The Art and Implementation

In future smart grids, large-scale deployment of distributed energy resources (DERs) and renewable energy sources (RES) is expected. In order to integrate a high penetration level of DERs and RES in the grid while operating the system safely and efficiently, new control methods for power system operations are in demand so that the flexibility of the responsive assets in the grid can be further explored. Transactive control, considered as one of the most novel distributed control approaches for power system operations, has been extensively discussed and studied around the world in recent years. This paper provides a bibliographical review on the researches and implementation of the transactive energy concepts and transactive control techniques in power systems. The ideas of transactive control are introduced mainly according to the transactive energy framework proposed by the GridWise Architecture Council. The implementation pilots and research studies on transactive control applications in power systems are reviewed subsequently.

General information
State: Published
Wind Power Plant Voltage Control Optimization with Embedded Application of Wind Turbines and Statcom

Increasing wind power penetration and the size of wind power plants (WPPs) brings challenges to the operation and control of power systems. Most of WPPs are located far from load centers and the short circuit ratio at the point of common coupling (PCC) is low. The fluctuations of wind power will cause voltage variations. An optimal voltage control scheme for WPPs with STATCOMs is presented in the paper. It ensures that the voltages within the WPPs and at the high voltage side of the WPPs are within the limits and maximizes the dynamic Var reserve of the WPPs. Case studies were conducted with the simplified Anholt offshore WPP and the case study results demonstrate the efficacy of the proposed optimal voltage control scheme.

Adaptive ultra-short-term wind power prediction based on risk assessment

A risk assessment based adaptive ultra-short-term wind power prediction (USTWPP) method is proposed in this paper. The method first extracts features from the historical data, and split every wind power time series (WPTS) into several subsets defined by their stationary patterns. A WPTS that does not match with any of the stationary patterns is then included into a subset of non-stationary patterns. Every WPTS subset is then related to the USTWPP model which is specially selected and optimized offline based on the proposed risk assessment index. For on-line applications, the pattern of the last short WPTS is first recognized, and the relevant prediction model is applied for USTWPP. Experimental results confirm the efficacy of the proposed method.
A Sufficient Condition on Convex Relaxation of AC Optimal Power Flow in Distribution Networks

This paper proposes a sufficient condition for the convex relaxation of AC Optimal Power Flow (OPF) in radial distribution networks as a second order cone program (SOCP) to be exact. The condition requires that the allowed reverse power flow is only reactive or active, or none. Under the proposed sufficient condition, the feasible sub-injection region (power injections of nodes excluding the root node) of the AC OPF is convex. The exactness of the convex relaxation under the proposed condition is proved through constructing a group of monotonic series with limits, which ensures that the optimal solution of the SOCP can be converted to an optimal solution of the original AC OPF. The efficacy of the convex relaxation to solve the AC OPF is demonstrated by case studies of an optimal multi-period planning problem of electric vehicles (EVs) in distribution networks.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, University of Chicago
Contributors: Huang, S., Wu, Q., Wang, J., Zhao, H.
Pages: 1359 - 1368
Publication date: 2016
Peer-reviewed: Yes
Web of Science (2015): Impact factor 3.342
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.31 SJR 2.475 SNIP 3.485
Web of Science (2014): Impact factor 2.814
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 6.33 SJR 2.523 SNIP 4.243
Web of Science (2013): Impact factor 3.53
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.84 SJR 1.941 SNIP 3.387
Web of Science (2012): Impact factor 2.921
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 5.34 SJR 1.586 SNIP 3.205
Web of Science (2011): Impact factor 2.678
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.708 SNIP 2.759
Web of Science (2010): Impact factor 2.355
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 2
Scopus rating (2009): SJR 1.622 SNIP 2.675
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 2
Scopus rating (2008): SJR 1.309 SNIP 2.45
Web of Science (2008): Indexed yes
Scopus rating (2007): SJR 1.12 SNIP 2.48
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 1.147 SNIP 2.259
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 1.41 SNIP 2.482
Scopus rating (2004): SJR 0.938 SNIP 2.807
Scopus rating (2003): SJR 2.078 SNIP 2.607
Scopus rating (2002): SJR 1.404 SNIP 2.284
Scopus rating (2001): SJR 1.553 SNIP 1.847
Scopus rating (2000): SJR 0.515 SNIP 3.179
Scopus rating (1999): SJR 0.475 SNIP 1.644
Original language: English
Keywords: AC optimal power flow (AC OPF), Convex relaxation, convexity, Electric vehicle (EV), Power distribution network, Second order cone program (SOCP)
Electronic versions:
DOIs:
10.1109/TPWRS.2016.2574805

Bibliographical note
(c) 2016 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other users, including reprinting/republishing this material for advertising or promotional purposes, creating new collective works for resale or redistribution to servers or lists, or reuse of any copyrighted components of this work in other works.
Source: PublicationPreSubmission
Source-ID: 123912406
Autonomous Voltage Security Regions to Prevent Cascading Trip Faults in Wind Turbine Generators
Cascading trip faults in large-scale wind power centralized integration areas bring new challenges to the secure operation of power systems. In order to deal with the complexity of voltage security regions and the computation difficulty, this paper proposes an autonomous voltage security region (AVSR) for each wind farm and the point of common coupling (PCC) substation, whose voltage can be controlled in a decoupled way. The computation of the AVSR can be completed using a stepwise search method exchanging voltage and power information between the control center and the wind farms. At each wind farm, an AVSR is determined to guarantee the normal operation of each wind turbine generator (WTG), while in the control center, each region is designed in order to guarantee secure operation both under normal conditions and after an N-1 contingency. A real system in Northern China was used to carry out case studies to verify the effectiveness of the AVSRs proposed, and good performance was demonstrated using the Monte Carlo method.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University, Xi'an Jiaotong University
Contributors: Niu, T., Guo, Q., Sun, H., Wu, Q., Zhang, B., Ding, T.
Pages: 1306 - 1316
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Sustainable Energy
Volume: 7
Issue number: 3
ISSN (Print): 1949-3029
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 7.42 SJR 2.318 SNIP 2.452
Web of Science (2017): Impact factor 6.235
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.8 SJR 2.368 SNIP 2.967
Web of Science (2016): Impact factor 4.909
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 7.09 SJR 2.717 SNIP 3.22
Web of Science (2015): Impact factor 3.727
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.03 SJR 2.554 SNIP 3.898
Web of Science (2014): Impact factor 3.656
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 7.03 SJR 2.043 SNIP 3.712
Web of Science (2013): Impact factor 3.842
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 6.58 SJR 1.243 SNIP 3.744
ISI indexed (2012): ISI indexed no
Scopus rating (2011): CiteScore 5.13 SJR 0.73 SNIP 3.01
ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Autonomous voltage security region (AVSR), N-1 contingency, Voltage control, Wind power integration
Congestion management of distribution networks with day-ahead dynamic grid tariffs

In order to reduce CO2 emissions and alleviate the global warming issue, many countries are setting goals to increase the percentage of renewable energy in the total energy consumption. In this process, a large number of distributed energy resources (DER), distributed generation (DG), electric vehicles (EV) and heat pumps (HP), will be largely deployed in electrical distribution networks. Congestion management will be important in the future active distribution networks. In the IDE4L project, work package 5 is dedicated to develop different kinds of congestion management methods. Demand response (DR) is one of the important methods. In this report, as one task of work package 5, the day-ahead dynamic tariff (DADT) method for congestion management in distribution networks is presented. The dynamic tariff (DT) can motivate the flexible demands (EV and HP) to shift their energy consumption in a way that favours the secure operation of distribution networks. Therefore, the DADT method belongs to the DR programs.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Huang, S., Wu, Q.
Number of pages: 54
Publication date: 2016

Convex relaxation of Optimal Power Flow in Distribution Feeders with embedded solar power

There is an increasing interest in using Distributed Energy Resources (DER) directly coupled to end user distribution feeders. This poses an array of challenges because most of today’s distribution feeders are designed for unidirectional power flow. Therefore when installing DERs such as solar panels with uncontrolled inverters, the upper limit of installable capacity is quickly reached in many of today’s distribution feeders. This problem can often be mitigated by optimally controlling the voltage angles of inverters. However, the optimal power flow problem in its standard form is a large scale non-convex optimization problem, and thus can’t be solved precisely and also is computationally heavy and intractable for large systems. This paper examines the use of a convex relaxation using Semi-definite programming to optimally control solar power inverters in a distribution grid in order to minimize the global line losses of the feeder. The mathematical model is presented in details. Further, case studies are completed with simulations involving a 15-bus radial distribution system. These simulations are run for 24 hour periods, with actual solar data and demand data.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Number of pages: 9
Pages: 43-49
Publication date: 2016
Peer-reviewed: Yes
Coordinated Control of Multi-terminal DC Grid for Wind Power Integration
Multi-terminal HVDC (MTDC) technology using voltage source converter (VSC) is a good option for wind power integration. Compared with point to point DC connection, MTDC provide better controllability based on different control strategies. In this paper, proportional-integral (PI) controllers with tuned PI parameters are designed to coordinate DC flow among the DC grid with good dynamic performance. In order to overcome the disadvantages of the conventional PI control, a simple adaptive PI control strategy is proposed based on the system transfer function. Case studies were conducted with PowerFactory.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Technical University of Denmark
Contributors: Hao, Y., Zhao, H., Wu, Q.
Pages: 702-706
Publication date: 2016

Host publication information
Title of host publication: Proceedings of 2016 IEEE PES Asia-Pacific Power and Energy Engineering Conference
Publisher: IEEE
ISBN (Print): 9781509054183
Keywords: Coordinated, Control strategy, Multi-terminal DC, PI tuning, PowerFactory

Coordinated Voltage Control of a Wind Farm based on Model Predictive Control
This paper presents an autonomous wind farm voltage controller based on Model Predictive Control (MPC). The reactive power compensation and voltage regulation devices of the wind farm include Static Var Compensators (SVCs), Static Var Generators (SVGs), Wind Turbine Generators (WTGs) and On-Load Tap Changing (OLTC) Transformer, and they are
coordinated to keep the voltages of all the buses within the feasible range. Moreover, the reactive power distribution is optimized throughout the wind farm in order to maximize the dynamic reactive power reserve. The sensitivity coefficients are calculated based on an analytical method to improve the computation efficiency and overcome the convergence problem. Two control modes are designed for both voltage violated and normal operation conditions. A wind farm with 20 wind turbines was used to conduct case studies to verify the proposed coordinated voltage control scheme under both normal and disturbance conditions.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University, State Grid Electric Power System Research Institute
Contributors: Zhao, H., Wu, Q., Guo, Q., Sun, H., Huang, S., Xue, Y.
Pages: 1440-51
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Sustainable Energy
Volume: 7
Issue number: 4
ISSN (Print): 1949-3029
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 7.42 SJR 2.318 SNIP 2.452
Web of Science (2017): Impact factor 6.235
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.8 SJR 2.368 SNIP 2.967
Web of Science (2016): Impact factor 4.909
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 7.09 SJR 2.717 SNIP 3.22
Web of Science (2015): Impact factor 3.727
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.03 SJR 2.554 SNIP 3.898
Web of Science (2014): Impact factor 3.656
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 7.03 SJR 2.043 SNIP 3.712
Web of Science (2013): Impact factor 3.842
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 6.58 SJR 1.243 SNIP 3.744
ISI indexed (2012): ISI indexed no
Scopus rating (2011): CiteScore 5.13 SJR 0.73 SNIP 3.01
ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Dynamic reactive power reserve, Model predictive control, Sensitivity coefficient, Wind farm, Voltage control
Electronic versions:
Paper_WFVC_20160308.pdf
DOIs:
10.1109/TSTE.2016.2555398

Bibliographical note
(c) 2016 IEEE. Personal use of this material is permitted. Permission from IEEE must be obtained for all other users, including reprinting/ republishing this material for advertising or promotional purposes, creating new collective works for resale or redistribution to servers or lists, or reuse of any copyrighted components of this work in other works."
Dynamic subsidy (DS) is a locational price paid by the distribution system operator (DSO) to its customers in order to shift energy consumption to designated hours and nodes. It is promising for demand side management and congestion management. This paper proposes a new DS method for congestion management in distribution networks, including the market mechanism, the mathematical formulation through a two-level optimization, and the method solving the optimization by tightening the constraints and linearization. Case studies were conducted with a one node system and the Bus 4 distribution network of the Roy Billinton Test System (RBTS) with high penetration of electric vehicles (EVs) and heat pumps (HPs). The case studies demonstrate the efficacy of the DS method for congestion management in distribution networks. Studies in this paper show that the DS method offers the customers a fair opportunity to cheap energy prices and has no rebound effect.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Huang, S., Wu, Q.
Pages: 2140 - 2151
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
Volume: 9
Issue number: 3
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 13.33 SJR 1.797 SNIP 6.273
ISI indexed (2012): ISI indexed no
Web of Science (2012): Indexed yes
Scopus rating (2011): CiteScore 11.78 SJR 0.778 SNIP 5.653
ISI indexed (2011): ISI indexed no
Web of Science (2011): Indexed yes
Renewable energies are increasingly integrated in electric distribution networks and will cause severe overvoltage issues. Smart grid technologies make it possible to use coordinated control to mitigate the overvoltage issues and the optimal power flow (OPF) method is proven to be efficient in the applications such as curtailment management and reactive power control. Nonconvex nature of the OPF makes it difficult to solve and convex relaxation is a promising method to solve the OPF very efficiently. This paper investigates the geometry of the power flows and the convex-relaxed power flows when high penetration level of renewables is present in the distribution networks. The geometry study helps understand the fundamental nature of the OPF and its convex-relaxed problem, such as the second-order cone programming (SOCP) problem. A case study based on a three-node system is used to illustrate the geometry profile of the feasible sub-injection (injection of nodes excluding the root/substation node) region.
Hardware-in-the-loop (HIL) Test of Demand as Frequency Controlled Reserve (DFR)

This paper presents the hardware-in-the-loop (HIL) test of the demand as frequency controlled reserve (DFR). The HIL test refers to a test in which parts of a pure simulation have been replaced by actual physical components. It is used to understand the behavior of a new device or controller. The DFR has been tested by offline simulations to illustrate the efficacy of this technology. The DFR control logics have been implemented in the SmartBox. The HIL was conducted by having the SmartBox connected to the real time simulations and the performance of the SmartBox was tested with difference frequency events in the simulated power systems. The HIL test results show that the implemented DFR in the SmartBox can efficiently arrest the system frequency.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Technical University of Denmark
Contributors: Wu, Q., Zimmermann, K., Østergaard, J., Nielsen, A. H.
Number of pages: 6
Publication date: 2016

Host publication information
Title of host publication: Proceedings of 10th International Conference on Advances in Power System Control, Operation and Management,
Publisher: Institution of Engineering and Technology
Keywords: Demand as frequency controlled reserve, Hardware-in-the-loop, Real Time Digital Simulator
Electronic versions:
Hardware_in_the_loop_Test_for_Demand_as_Frequency_Controlled_Reserve.pdf
Source: PublicationPreSubmission
Source-ID: 115327655
Research output: Research - peer-review › Article in proceedings – Annual report year: 2016
H∞ Robust Current Control for DFIG Based Wind Turbine subject to Grid Voltage Distortions

This paper proposes an H∞ robust current controller for doubly fed induction generator (DFIG) based wind turbines (WTs) subject to grid voltage distortions. The controller is to mitigate the impact of the grid voltage distortions on rotor currents with DFIG parameter perturbation. The grid voltage distortions considered include asymmetric voltage dips and grid background harmonics. An uncertain DFIG model is developed with uncertain factors originating from distorted stator voltage, and changed generator parameters due to the flux saturation effect, the skin effect, etc. Weighting functions are designed to efficiently track the unbalanced current components and the 5th and 7th background harmonics. The robust stability (RS) and robust performance (RP) of the proposed controller are verified by the structured singular value μ. The performance of the H∞ robust current controller was demonstrated with a 1.5 MW DFIG model, showing its harmonics suppression ability with DFIG parameter perturbation and improved robustness.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Shenzhen University, China Southern Power Grid Ltd., DONG Energy AS
Contributors: Wang, Y., Wu, Q., Gong, W., Gryning, M. P. S.
Pages: 816 - 825
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Sustainable Energy
Volume: 8
Issue number: 2
ISSN (Print): 1949-3029
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 7.42 SJR 2.318 SNIP 2.452
Web of Science (2017): Impact factor 6.235
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.8 SJR 2.368 SNIP 2.967
Web of Science (2016): Impact factor 4.909
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 7.09 SJR 2.717 SNIP 3.22
Web of Science (2015): Impact factor 3.727
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.03 SJR 2.554 SNIP 3.898
Web of Science (2014): Impact factor 3.656
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 7.03 SJR 2.043 SNIP 3.712
Web of Science (2013): Impact factor 3.842
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Scopus rating (2012): CiteScore 6.58 SJR 1.243 SNIP 3.744
ISI indexed (2012): ISI indexed no
Scopus rating (2011): CiteScore 5.13 SJR 0.73 SNIP 3.01
ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Doubly fed induction generator (DFIG), Grid harmonics, Grid voltage distortion, Robust control, Wind turbine
Electronic versions:
H_Robust_Control_of_DFIG_Based_Wind_Turbines_Subject_to_Grid_Distortions_20161023_post_print.pdf
DOIs:
Optimal Active Power Control of A Wind Farm Equipped with Energy Storage System based on Distributed Model Predictive Control

This paper presents the Distributed Model Predictive Control (D-MPC) of a wind farm equipped with fast and short-term Energy Storage System (ESS) for optimal active power control using the fast gradient method via dual decomposition. The primary objective of the D-MPC control of the wind farm is power reference tracking from system operators. Besides, by optimal distribution of the power references to individual wind turbines and the ESS unit, the wind turbine mechanical loads are alleviated. With the fast gradient method, the convergence rate of the DMPC is significantly improved which leads to a reduction of the iteration number. Accordingly, the communication burden is reduced. Case studies demonstrate that the additional ESS unit can lead to a larger wind turbine load reduction, compared to the conventional wind farm control without ESS. Moreover, the efficiency of the developed D-MPC algorithm is independent from the wind farm size and is suitable for the real-time control of the wind farm with ESS.
Optimal Operation of EVs and HPs in the Nordic Power System

The Nordic countries, including Denmark, Finland, Norway and Sweden, have great ambitions in seeking a fully carbon neutral or low-carbon electric power system by 2050. The large scale deployment of electric vehicles (EVs) and heat pumps (HPs) is considered not only as an efficient method to limit the greenhouse gas (GHG) emission and the fossil fuel consumption in the transportation and heating sectors but also as a potential approach to cope with the intermittency due to the further utilization of renewable energy sources (RES) in the Nordic region. With increasing amounts of RES in the power system, more reserves will be needed by the grid due to the inherent uncertainties of RES. EVs and HPs will play a more important role in the future power system of the Nordic region by providing extra flexibility to the grid. The main objective of the Ph.D. study is to investigate the impacts of the possible large scale deployment of EVs and HPs in the Nordic region on the electrical power system. To facilitate such objective, the study in the Ph.D. project focuses on the following aspects:

• The modeling of the EV and HP demand in the Nordic context.
• The optimal scheduling of EVs and HPs with a high penetration level in the market environment.
• The feasibility investigation of EVs and HPs to provide frequency reserves to the Nordic power system.

To accomplish the researches mentioned above, the driving patterns of the vehicles in the Nordic region and the impacts of the EV and HP demand on the day-ahead electricity market are also analyzed in the Ph.D. study. The electrical demand of EVs and HPs under non-market environments is modeled with the detailed driving and heating requirements in the Nordic countries. With the uncontrolled charging scheme, the peak EV charging demand coincides with the peak conventional demand. With the timed charging scheme, the EV charging demand is delayed to avoid the conventional peak demand to some extend. However, most of the charging congregates in a short period when the timed charging is set started. The HP demand with the least-energyconsumption control scheme is consistent with the environmental weather pro-
files. The increasing HP demand in the evening coincides with the conventional peak hours of the power system which may stress the grid.

A chance constrained programming model through mixed-integer programming (MIP) is proposed to formulate the EV demand in the day-ahead electricity market considering the stochastic characteristics of the EV driving patterns. The model guarantees that the driving requirements of the EVs are met by the day-ahead energy planning with the predefined confidence parameter. A robust optimization model is proposed to formulate the HP demand in the day-ahead electricity market considering the uncertainty of the weather forecast used in the HP energy planning. The heating requirements for the HPs are guaranteed by the day-ahead energy plans through the robust optimization model.

An aggregative game model is proposed to model the demand of large scale deployment of EVs and HPs in the day-ahead electricity market. The impacts of the EV and HP demand on the electricity spot price are considered in the EV and HP day-ahead energy planning by the proposed model. With a high penetration level, the demand of EVs and HPs shows a "valley-fill" pattern to the grid when it is introduced into the day-ahead electricity market. A combined modeling of the EV and HP energy planning is proposed for both the energy plans in the day-ahead electricity market and the frequency reserve provision decisions in the ancillary service market. It is shown that both EVs and HPs can provide considerable frequency reserves to the power system along the day in the Nordic region. Vehicle-to-Grid (V2G) technologies which enable the EVs to discharge the batteries in the reserve operations can further utilize the capacity of the EVs and consequently increase the ability of EVs to provide frequency reserves to the power system. Further, the intense weather of the Nordic region in winter does not decrease the ability of EVs and HPs to provide frequency reserves to the power system.
Optimal reconfiguration-based dynamic tariff for congestion management and line loss reduction in distribution networks

This paper presents an optimal reconfiguration-based dynamic tariff (DT) method for congestion management and line loss reduction in distribution networks with high penetration of electric vehicles. In the proposed DT concept, feeder reconfiguration (FR) is employed through mixed integer programming when calculating the DT, leading to minimized energy cost and reduced DT as compared with the DT concept without FR. This paper further demonstrates that the line losses can be taken into account during the calculation of DT. As a result, the line loss reduction can be realized in a decentralized manner through the DT framework. Three case studies were conducted to validate the optimal reconfiguration-based DT method for congestion management and line loss reduction in distribution networks.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University
Contributors: Huang, S., Wu, Q., Cheng, L., Liu, Z.
Pages: 1295-1303
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Smart Grid
Volume: 7
Issue number: 3
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 7.77 SJR 2.582 SNIP 3.687
Web of Science (2014): Impact factor 4.252
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 9.88 SJR 2.581 SNIP 4.642
Web of Science (2013): Impact factor 4.334
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Probabilistic modeling of nodal electric vehicle load due to fast charging stations

In order to reduce greenhouse gas emission and fossil fuel dependence, Electric Vehicle (EV) has drawn increasing attention due to its zero emission and high efficiency. However, new problems such as range anxiety, long charging duration and high charging power may threaten the safe and efficient operation of both traffic and power systems. This paper proposes a probabilistic approach to model the nodal EV load at fast charging stations in integrated power and transport systems. Following the introduction of the spatial-temporal model of moving EV loads, we extended the model by taking fast charging station into consideration. Fuzzy logic inference system is applied to simulate the charging decision of EV drivers at fast charging station. Due to increasing EV loads in power system, the potential traffic congestion in fast charging stations is modeled and evaluated by queuing theory with spatial-temporal varying arrival and service rates. The time-varying nodal EV loads are obtained by the number of operating fast chargers at each node of the power system. System studies demonstrate that the combination of AC normal and DC charging may share the EV charging demand and alleviate the impact to power system due to fast charging with high power.

General information

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Nanyang Technological University
Contributors: Tang, D., Wang, P., Wu, Q.
Number of pages: 7
Pages: 1-7
Publication date: 2016

Host publication information

Title of host publication: Proceedings of 2016 International Conference on Probabilistic Methods Applied to Power Systems
Publisher: IEEE
ISBN (Print): 9781509019700
(2016 International Conference on Probabilistic Methods Applied To Power Systems (pmaps)).
Keywords: Charging stations, Estimation, Decision support systems, Electric vehicles, Load modeling, fast charging station, Probabilistic model, power system, electric vehicle
DOIs: 10.1109/PMAPS.2016.7764219
Source: FindIt
Source-ID: 2349553180
Research output: Research - peer-review › Article in proceedings – Annual report year: 2016

Real Time Emulation of Dynamic Tariff for Congestion Management in Distribution Networks

This paper presents the real time evaluation of the dynamic tariff (DT) method for alleviating congestion in a distribution networks with high penetration of distributed energy resources (DERs). The DT method is implemented in a real time digital testing platform that emulates a real distribution network. The platform returns power system status that indicates the efficiency of the DT method in a real power system as a congestion management tool. Results show that the current formulation of the DT method through direct current optimal power flow (DCOPF) has some limitations as reactive power flows are ignored in the DCOPF. Reactive power flows causes overloaded transmission lines when the DT method allows consumption at network buses that meets active power transfer capability of transmission lines. Based on the real time emulation of the DT method, possible changes are suggested for the DT method that increases the efficiency of the method.
Review of VSC HVDC Connection for Offshore Wind Power Integration
Voltage Source Converter (VSC) High Voltage Direct Current (HVDC) connection has become a new trend for long distance offshore wind power transmission. It has been confirmed by a lot of research that the maximum distance of a High Voltage Alternative Current (HVAC) sub-marine cable transmission system is limited due to surplus charging current of the cables. The VSC HVDC transmission system has the ability to overcome the limitation and offers other advantages over the HVAC transmission system. This paper is to review the VSC HVDC transmission technology and its application for offshore wind power integration. Firstly, the main components, configuration and topology of the VSC HVDC transmission system are described. Secondly, the converter control system and control strategies are presented. Following that, the capabilities of the VSC HVDC technology are described. Finally, the focus is given on the control methods of the VSC HVDC transmission system for fulfilling grid code requirements concerning Low Voltage Ride-Through (LVRT) and frequency regulation.
This paper presents a flexible testing method and the steady-state compliance of PMUs under the C37.118.1a amendment. The work is focused on the changes made to the standard for the harmonic rejection and out-of-band interference tests for which the ROCOF Error limits have been suspended. The paper aims to provide an indication whether these limits should be reinstated or not. The test platform consists of a test signal generator capable of providing three phase voltages and currents, and playing back digitized files, PMUs under test, and a PMU test result analysis kit. Three PMUs from different vendors were tested simultaneously in order to provide a fair comparison of the devices. The results for the steady state tests are discussed in the paper together with the strengths and weaknesses of the PMUs and of the test setup.
Study of Demand as Frequency Controlled Reserve in Nordic Power System

This paper investigates the efficacy of Demand Frequency Reserve (DFR) in Nordic power system. Heat pump, due to its switching flexibility, less disturbing impacts to customers and promising future in application, is used to represent DFR in the study. Thermodynamics of the heat pump unit is modelled to investigate the dynamic behaviour of DFR. Two DFR control logics, designed according to different appliance features, are implemented into the heat pump model. In this study, DFR acts as both disturbance and normal operation reserves to fulfill the requirement of frequency reserve by Danish Transmission System Operator (TSO). Accordingly, two case scenarios are designed for the contingency and normal operation, respectively. The simulation models are implemented in RTDS, by means of which the Hardware In the Loop (HIL) test of the developed frequency response device (SmartBox) is carried out.

Sub-Synchronous Interaction Analysis between DFIG Based Wind Farm and Series Compensated Network

This paper analyzes the sub-synchronous interaction (SSI) phenomenon between the doubly fed induction generator (DFIG) based wind farm (WF) and the series capacitor compensated network. The possible types of SSI in the DFIG based WF are studied. The factors influencing the SSI of DFIG based WF are investigated. The large signal stability and small signal stability of the DFIG based WF with different series compensation (SC) level and wind speed are simulated and compared.
Uncertainty Management of Dynamic Tariff Method for Congestion Management in Distribution Networks

The dynamic tariff (DT) method is designed for the distribution system operator (DSO) to alleviate congestions that might occur in a distribution network with high penetration of distributed energy resources (DERs). Uncertainty management is required for the decentralized DT method because the DT is determined based on optimal day-ahead energy planning with forecasted parameters such as day-ahead energy prices and energy needs which might be different from the parameters used by aggregators. The uncertainty management is to quantify and mitigate the risk of the congestion when employing the DT method, which is achieved by first formulating the problem as a chance constrained two-level optimization and then solving the problem through an iterative procedure. Two case studies were conducted to demonstrate the efficacy of the uncertainty management of DT method.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University
Contributors: Huang, S., Wu, Q., Cheng, L., Liu, Z., Zhao, H.
Pages: 4340-4347
Publication date: 2016
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Power Systems
Volume: 31
Issue number: 6
ISSN (Print): 0885-8950
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.742 SNIP 2.662
Web of Science (2017): Impact factor 5.255
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.368 SNIP 3.584
Web of Science (2016): Impact factor 5.68
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 6.6 SJR 3.315 SNIP 3.386
Web of Science (2015): Impact factor 3.342
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.31 SJR 2.475 SNIP 3.485
Web of Science (2014): Impact factor 2.814
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 6.33 SJR 2.523 SNIP 4.243
Web of Science (2013): Impact factor 3.53
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.84 SJR 1.941 SNIP 3.387
Web of Science (2012): Impact factor 2.921
A Secondary Voltage Control Method for an AC/DC Coupled Transmission System Based on Model Predictive Control

For an AC/DC coupled transmission system, the change of transmission power on the DC lines will significantly influence the AC systems’ voltage. This paper describes a method to coordinated control the reactive power of power plants and shunt capacitors at DC converter stations nearby, in order to keep the voltage of the pilot bus tracking its set point considering the DC system's transmission schedule change. The approach is inspired by model predictive control (MPC) to compensate for predictable voltage change affected by DC side transmission power flow and the potential capacitor switching at DC converter stations. The control strategies are calculated from a multi-step dynamic optimization problem that is solved by mixed integer quadratic programming method. Time-domain simulations showed positive results of the proposed voltage controller.
Distributed Model Predictive Control of A Wind Farm for Optimal Active Power Control: Part I: Clustering based Wind Turbine Model Linearization

This paper presents a dynamic discrete-time Piece-Wise Affine (PWA) model of a wind turbine for the optimal active power control of a wind farm. The control objectives include both the power reference tracking from the system operator and the wind turbine mechanical load minimization. Instead of partial linearization of the wind turbine model at selected operating points, the nonlinearities of the wind turbine model are represented by a piece-wise static function based on the wind turbine system inputs and state variables. The nonlinearity identification is based on the clustering-based algorithm, which combines the clustering, linear identification and pattern recognition techniques. The developed model, consisting of 47 affine dynamics, is verified by the comparison with a widely-used nonlinear wind turbine model. It can be used as a predictive model for the Model Predictive Control (MPC) or other advanced optimal control applications of a wind farm.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University, State Grid Electric Power System Research Institute
Contributors: Zhao, H., Wu, Q., Guo, Q., Sun, H., Xue, Y.
Number of pages: 10
Pages: 831-839
Publication date: 2015
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Sustainable Energy
Volume: 6
Issue number: 3
ISSN (Print): 1949-3029
Ratings:
Distributed Model Predictive Control of A Wind Farm for Optimal Active Power Control: Part II: Implementation with Clustering based Piece-Wise Affine Wind Turbine Model.

This paper presents a dynamic discrete-time Piece-Wise Affine (PWA) model of a wind turbine for the optimal active power control of a wind farm. The control objectives include both the power reference tracking from the system operator and the wind turbine mechanical load minimization. Instead of partial linearization of the wind turbine model at selected operating points, the nonlinearities of the wind turbine model are represented by a piece-wise static function based on the wind turbine system inputs and state variables. The nonlinearity identification is based on the clustering-based algorithm, which combines the clustering, linear identification and pattern recognition techniques. The developed model, consisting of 47 affine dynamics, is verified by the comparison with a widely-used nonlinear wind turbine model. It can be used as a predictive model for the Model Predictive Control (MPC) or other advanced optimal control applications of a wind farm.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University, State Grid Electric Power System Research Institute
Contributors: Zhao, H., Wu, Q., Guo, Q., Sun, H., Xue, Y.
Distribution Locational Marginal Pricing through Quadratic Programming for Congestion Management in Distribution Networks

This paper presents the distribution locational marginal pricing (DLMP) method through quadratic programming (QP) designed to alleviate the congestion that might occur in a distribution network with high penetration of flexible demands. In the DLMP method, the distribution system operator (DSO) calculates dynamic tariffs and publishes them to the aggregators, who make the optimal energy plans for the flexible demands. The DLMP through QP instead of linear programming as studied in previous literatures solves the multiple solution issue of the aggregator optimization which may cause the decentralized congestion management by DLMP to fail. It is proven in this paper, using convex optimization
theory, the aggregator's optimization problem through QP is strictly convex and has a unique solution. The Karush–Kuhn–Tucker (KKT) conditions and the unique solution of the aggregator optimization ensure that the centralized DSO optimization and the decentralized aggregator optimization converge. Case studies using a distribution network with high penetration of electric vehicles (EVs) and heat pumps (HPs) validate the equivalence of the two optimization setups, and the efficacy of the proposed DLMP through QP for congestion management.
Driving pattern analysis of Nordic region based on the national travel surveys for electric vehicle integration

EVs show great potential to cope with the intermittency of renewable energy sources (RES) and provide demand side flexibility required by the smart grid. On the other hand, the EVs will increase the electricity consumption. Large scale integration of EVs will probably have substantial impacts to the power system. This paper presents a methodology to transform driving behavior of persons into the one of cars in order to analyze the driving pattern of electric vehicles (EVs) based on the National Travel Surveys. In the proposed methodology, a statistical process is used to obtain the driving behavior of cars by grouping the survey respondents according to the driving license number and car number and mapping the households with similar characteristics. The proposed methodology was used to carry out the driving pattern analysis in the Nordic region. The detailed driving requirements and the charging/discharging availability of the vehicles along the day were obtained. Two types of EV availabilities were studied in this paper considering different charging/discharging conditions of EVs for the power system integration, i.e. EV availability all day and EV availability at home. The results show that the daily driving requirements of the Nordic region are not very intensive. The driving patterns of the vehicles in the Nordic region vary on weekdays and weekends. The two types of EV availabilities are quite different from each other.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Department of Transport, Transport policy and behaviour, Tampere University of Technology, State Grid Electric Power System Research Institute
Contributors: Liu, Z., Wu, Q., Christensen, L., Rautiainen, A., Xue, Y.
Pages: 180–189
Publication date: 2015
Peer-reviewed: Yes

Publication Information
Dynamic PMU Compliance Test under C37.118.1aTM-2014
This paper presents a flexible testing methodology and the dynamic compliance of PMUs as per the new C37.118.1a amendment published in 2014. The test platform consists of test signal generator, a Doble F6150 amplifier, PMUs under test, and a PMU test result analysis kit. The Doble amplifier is used for providing three phase voltage and current injections to the PMUs. Three PMUs from different vendors were tested simultaneously in order to provide a fair comparison of the devices. The new 2014 amendment comes with significant changes over the C37.118.1 - 2011 standard regarding the dynamic tests.

General information
State: Published
Contributors: Ghiga, R., Wu, Q., Martin, K., El-Khatib, W. Z., Cheng, L., Nielsen, A. H.
Number of pages: 5
Publication date: 2015

Effect of full converter wind turbines on inter-area oscillation of power systems
By increasing in the penetration level of wind turbines, the influence of these new added generation units on the power system oscillations specifically inter-area oscillations has to be thoroughly investigated. In this paper, the impact of
increasing in the penetration of full rate converter wind turbines (FRC-WTs) on the inter-area oscillations of power system is examined. In order to have a comprehensive evaluation of the effects of FRC-WT on the inter-area oscillations, different scenarios associated with the wind power penetration levels, wind farm locations, strength of interconnection line, and different operating conditions of synchronous generators are investigated. The synchronous generators, exciter systems and power system stabilizers (PSSs) as well as the FRC-WT grid-side converter and its related controllers are modelled in detail in Matlab in order to evaluate the effects of FRC-WTs on the inter-area mode oscillations precisely. The results show that FRC-WTs can affect the inter-area oscillations considerably in some simulation scenarios.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Technical University of Denmark
Contributors: Askari, H. H., Hashemi Toghroljerdi, S., Eriksson, R., Wu, Q.
Pages: 270 - 276
Publication date: 2015

Host publication information
Title of host publication: 2015 International Conference on Clean Electrical Power.
Publisher: IEEE
ISBN (Print): 9781479987047
Keywords: Wind turbine, Full rate converter, Interarea oscillations, Power system
DOIs: 10.1109/ICCEP.2015.7177635
Source: PublicationPreSubmission
Source-ID: 114894268
Research output: Research - peer-review › Article in proceedings – Annual report year: 2015

EV and HP Providing Ancillary Services in the Nordic Region
This report covers the analysis of the electric vehicle (EV) and heat pump (HP) providing ancillary services to the power system of the Nordic region including Denmark, Finland, Norway and Sweden. The analysis is to investigate the feasibility of EVs and HPs to serve as demand as frequency reserve (DFR) providers in the distribution power system in the four mentioned Nordic countries.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Liu, Z., Wu, Q.
Number of pages: 46
Publication date: 2015

Publication information
Publisher: Technical University of Denmark, Department of Electrical Engineering
Original language: English
Keywords: Ancillary Services, Distribution Network, Electric Vehicle, Frequency Reserve, Heat Pump

Bibliographical note
D2.5 of the Norstrat project funded by the Nordic Energy Research (Norden)
Source: PublicationPreSubmission
Source-ID: 127180417
Research output: Research › Report – Annual report year: 2015

EV and HP Scheduling with Network Constraints in the Nordic Region
Large scale deployment of electric vehicles (EVs) and heat pumps (HPs) holds great potential not only to limit the greenhouse gas (GHG) emission and fossil fuel consumption in the transportation and heating sectors but also to cope with the intermittency due to the further utilization of renewable energy sources (RES) in the Nordic region including Denmark, Finland, Norway and Sweden. It is therefore an important pathway to the goal of achieving a carbon neutral electric power system in the Nordic region by 2050.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Liu, Z., Wu, Q.
Number of pages: 60
Publication date: 2015
Fault Ride-Through Capability Enhancement of VSC HVDC connected Offshore Wind Power Plants

This paper presents a feed forward direct current (DC) voltage control based fault ride-through (FRT) scheme for voltage source converter (VSC) high voltage DC (HVDC) connected offshore wind power plants (WPPs) in order to achieve active control of the WPP collector network AC voltage magnitude, and to improve the FRT capability. During steady state operation, an open loop AC voltage control is implemented at the WPP side VSC of the HVDC system such that any possible control interactions between the WPP side VSC and the wind turbine VSC are minimized. Whereas during any grid faults, a dynamic AC voltage reference is applied based on both the DC voltage error and the AC active-current from the WPP collector system which ensures fast and robust FRT of the VSC HVDC connected offshore WPPs. Under unbalanced fault conditions in the host power system, the resulting oscillatory DC voltage is directly used into the WPP side VSC AC voltage controller such that the unbalance in the main grid is also reflected at the WPP collector system voltage. Time domain simulations have been carried out to verify the efficacy of the proposed feed forward DC voltage control based FRT scheme. The time domain simulation results have shown satisfactory FRT responses of the VSC HVDC connected offshore WPP under balanced and unbalanced faults in the host power system, and under a severe fault at the WPP collector network.
Fuzzy Logic based Coordinated Control of Battery Energy Storage System and Dispatchable Distributed Generation for Microgrid

Microgrid is an efficient solution to integrate renewable energy sources (RES) into power systems. In order to deal with the intermittent characteristics of the renewable energy based distributed generation (DG) units, a fuzzy-logic based coordinated control strategy of the battery energy storage system (BESS) and dispatchable DG units is proposed in this paper for the microgrid management system (MMS). In the proposed coordinated control strategy, the BESS is used to mitigate the active power exchange at the point of common coupling of the microgrid for the grid-connected operation, and is used for the frequency control for the island operation. The effectiveness of the proposed control strategy was verified by case studies using DIgSILENT/PowerFactory.
Hierarchical Load Tracking Control of a Grid-connected Solid Oxide Fuel Cell for Maximum Electrical Efficiency Operation

Based on the benchmark solid oxide fuel cell (SOFC) dynamic model for power system studies and the analysis of the SOFC operating conditions, the nonlinear programming (NLP) optimization method was used to determine the maximum electrical efficiency of the grid-connected SOFC subject to the constraints of fuel utilization factor, stack temperature and output active power. The optimal operating conditions of the grid-connected SOFC were obtained by solving the NLP problem considering the power consumed by the air compressor. With the optimal operating conditions of the SOFC for the maximum efficiency operation obtained at different active power output levels, a hierarchical load tracking control scheme for the grid-connected SOFC was proposed to realize the maximum electrical efficiency operation with the stack temperature bounded. The hierarchical control scheme consists of a fast active power control and a slower stack temperature control. The active power control was developed by using a decentralized control method. The efficiency of the proposed hierarchical control scheme was demonstrated by case studies using the benchmark SOFC dynamic model.
Implementation and Validation of IEC Generic Type 1A Wind Turbine Generator Model

This paper presents the implementation of the International Electrotechnical Commission (IEC) generic Type 1A wind turbine generator (WTG) model in Power Factory (PF) and the validation of the implemented model against field measurements. The IEC generic Type 1A WTG model structure is briefly described. The details are explained regarding how the two mass mechanical model is implemented when the generator mass is included in the PF built-in generator model. In order to verify the IEC generic Type 1A WTG model, the model to field measurement validation method was employed. The model to field measurement validation of the implemented model was carried out by using the “play-back” approach and the measurement data from Siemens Wind Power. The results of the model to field measurement validation show that there is a good match between the simulation results and the measurements. The errors between the simulation results and measurements were calculated according to the voltage dip windows and the index definition specified in the IEC 61400-27-1 committee draft. Copyright © 2014 John Wiley & Sons, Ltd.

General information
State: Published
Contributors: Zhao, H., Wu, Q., Margaris, I., Bech, J., Sørensen, P. E., Andresen, B.
Pages: 1804–1813
Publication date: 2015
Peer-reviewed: Yes

Publication information
Journal: International Transactions on Electrical Energy System
Volume: 25
Issue number: 9
ISSN (Print): 2050-7038
Ratings:
Web of Science (2018): Indexed yes
Scopus rating (2017): CiteScore 1.63
Web of Science (2017): Impact factor 1.619
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 1.16 SJR 0.435 SNIP 0.709
Web of Science (2016): Impact factor 1.085
Scopus rating (2015): CiteScore 1.14 SJR 0.38 SNIP 0.834
Web of Science (2015): Impact factor 1.084
Web of Science (2015): Indexed yes
Scopus rating (2014): CiteScore 0.47 SJR 0.537 SNIP 0.766
Web of Science (2014): Impact factor 0.49
Scopus rating (2013): CiteScore 0.1 SJR 0.454 SNIP 0.903
Web of Science (2013): Impact factor
Scopus rating (2012): SJR 0.405 SNIP 0.818
Web of Science (2012): Impact factor 0.63
Web of Science (2012): Indexed yes
Long Term Incentives for Residential Customers Using Dynamic Tariff

This paper reviews several grid tariff schemes, including flat tariff, time-of-use, time-varying tariff, demand charge and dynamic tariff (DT), from the perspective of the long term incentives. The long term incentives can motivate the owners of flexible demands to change their energy consumption behavior in such a way that the power system operation issues, such as system balance and congestion, can be alleviated. From the comparison study, including analysis and case study, the DT scheme outperforms the other tariff schemes in terms of cost saving and network operation condition improving.

Multi-agents modelling of EV purchase willingness based on questionnaires

Traditional experimental economics methods often consume enormous resources of qualified human participants, and the inconsistency of a participant’s decisions among repeated trials prevents investigation from sensitivity analyses. The problem can be solved if computer agents are capable of generating similar behaviors as the given participants in experiments. An experimental economics based analysis method is presented to extract deep information from questionnaire data and emulate any number of participants. Taking the customers’ willingness to purchase electric
vehicles (EVs) as an example, multi-layer correlation information is extracted from a limited number of questionnaires. Multiagents mimicking the inquired potential customers are modelled through matching the probabilistic distributions of their willingness embedded in the questionnaires. The authenticity of both the model and the algorithm is validated by comparing the agent-based Monte Carlo simulation results with the questionnaire-based deduction results. With the aid of agent models, the effects of minority agents with specific preferences on the results are also discussed.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, State Grid Electric Power Research Institute, Shanghai Municipal Electric Power Co., Ltd., Queen's University Belfast, Zhejiang University, State Grid Electric Power System Research Institute, Nanjing University of Information Science & Technology
Pages: 149-159
Publication date: 2015
Peer-reviewed: Yes

Publication information
Journal: Journal of Modern Power Systems and Clean Energy
Volume: 3
Issue number: 2
ISSN (Print): 2196-5625
Ratings:
Web of Science (2018): Indexed yes
Scopus rating (2017): CiteScore 3.81
Web of Science (2017): Impact factor 2.122
Web of Science (2017): Indexed yes
Scopus rating (2016): CiteScore 3.35
Web of Science (2016): Impact factor 1.532
Web of Science (2016): Indexed yes
Scopus rating (2015): CiteScore 2.45 SNIP 1.478
Web of Science (2015): Impact factor 0.975
Web of Science (2015): Indexed yes
Scopus rating (2014): SNIP 0.678
Web of Science (2014): Indexed yes
ISI indexed (2013): ISI indexed no
Web of Science (2013): Indexed yes
Original language: English
Keywords: Behavioral analysis, Experimental economics, Human experimenters, Knowledge extraction, Multi-agents, EV purchase
Electronic versions:
Multi_agents_modelling_of_EV_purchase_willingness_based_on_questionaires.pdf
DOIs:
10.1007/s40565-015-0112-4

Bibliographical note
© The Author(s) 2015. This article is published with open access at Springerlink.com
Source: PublicationPreSubmission
Source-ID: 110362432
Research output: Research - peer-review › Journal article – Annual report year: 2015

Ofshore Wind Park Control Assessment Methodologies to Assure Robustness
The transition from fossil fuels to renewable energy is an expensive but necessary process to ensure a habitable world for future generations. Renewable energy sources such as hydro-, solar- and wind energy continues to increase their share of the total power production. With national goals set by the Renewable Energy Directive of the European Commission to decrease carbon dioxide emission, the demand for renewable energy is increasing. Wind energy has been harnessed since 1887 [1] and has seen a large growth since the first multi-megawatt turbine in 1978. Gradually the wind energy technology has matured to a point where turbines are reaching a production capability exceeding 6 megawatt and the turbines have moved offshore due to stronger wind, and to avoid proximity to populated areas. The placement of wind power plants (WPP) with a typical size of 60 large turbines in remote locations with a weak grid interconnection point, is a challenge with respect to power system stability. This dissertation considers the interaction between the offshore grid and the control of power electronic devices (PED), its effect on system stability and challenges with respect to unwanted interaction between controllers in the rather complex control hierarchy on an offshore WPP. The output waveform of
modern turbines utilizing PEDs is distorted at high frequencies, and the stability of the control system is affected by resonances and harmonics present in the weak offshore grid. These phenomena pose a risk to drive the system to instability, as they exist within the bandwidth of the turbine controllers. The resonances and the number of turbines in operation are characteristics of the grid, which are partly unknown at the controller design stage. The uncertainty and the unwanted interaction in the grid are difficult challenges for control designers. This project deals with these challenges and provides insight in root causes to phenomena that have been issues during wind power plant commissioning in the past. This is done through development of design and validation methods for controllers, by analyzing turbine interaction with the grid and suggestion of design guidelines to ensure proper operation of stacked controllers. Two specific faults serve as basis for the analysis and development, a rotor blade deformation and an unwanted oscillation in the reactive power, both of which experienced at a WPP. The low frequency reactive power oscillations observed were suspected to be i caused by the voltage control at the point of common coupling. The fault was thought to involve the interaction between the static synchronous compensator (STATCOM), the wind turbine voltage control and the power plant control (PPC). By establishing bounds on the sets of possible parameters of all involved controllers, the thesis replicates the phenomena by simulation and a method is proposed that analytically finds the set of control parameters, which ensure stable operation. The method enables DONG Energy to calculate bounds on controller parameters based on network parameters and the thesis contributes by ensuring proper operation before energization. The analysis of the voltage control philosophy related to the reactive power oscillations showed the need for proper handling of the resonances introduced by the offshore grid in the turbine control structure. The dissertation contributes to this area with the development of a robust H∞ converter controller employing notch filters in the performance specification to suppress harmonics of the grid frequency. This method combines attenuation of selected resonance frequencies with system stability and performance within the defined envelope of uncertainty of the grid. The controller is tested in a model of the WPP, and is shown to improve performance, control effort and output disturbance rejection compared to standard PI control. The second fault was that a turbine rotor blade was observed to deform in a WPP. This severe fault was suspected to have contributory causes from both mechanical and electrical systems. A preceding investigation was conducted which ruled out physical generator phenomena such as cogging torque, as well as network voltage disturbances and delays in the converter control system. The investigation indicated that the problem was an insufficient implementation of the rotor speed controller. The thesis addresses the problem by the development of control methods to limit the shaft stress, and thereby the rotor blade vibration. The contributions include a feedback linerization controller and an observer based backstepping controller for a wind turbine. The thesis consists of an introduction part that briefly describes the field, the investigations conducted in the study, the models developed and the controller designs suggested to deal with the challenges described above. The main results of this research are highlighted in the introduction and the detailed results are described in four papers, which are enclosed in the last part of the thesis.

General information
State: Published
Contributors: Gryning, M. P. S., Blanke, M., Andersen, K. H., Wu, Q., Niemann, H. H.
Number of pages: 200
Publication date: 2015

Publication information
Publisher: Technical University of Denmark, Department of Electrical Engineering
Original language: English
Electronic versions:
PhD_Thesis_Mikkel_Peter_Sidoroff_Gryning_08A4_Paper_08A4Size.pdf

Bibliographical note
Source: PublicationPreSubmission
Source-ID: 119090945
Research output: Research › Ph.D. thesis – Annual report year: 2015

Optimal Siting and Sizing of Energy Storage System for Power Systems with Large-scale Wind Power Integration
This paper proposes algorithms for optimal siting and sizing of Energy Storage System (ESS) for the operation planning of power systems with large scale wind power integration. The ESS in this study aims to mitigate the wind power fluctuations during the interval between two rolling Economic Dispatches (EDs) in order to maintain generation-load balance. The charging and discharging of ESS is optimized considering operation cost of conventional generators, capital cost of ESS and transmission losses. The statistics from simulated system operations are then coupled to the planning process to determine the optimal siting and sizing of storage units throughout the network. These questions are investigated using an IEEE benchmark system

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Tsinghua University, State Grid Electric Power System Research Institute
Real-time Distributed Economic Dispatch for Distributed Generation Based on Multi-Agent System

The distributed economic dispatch for distributed generation is formulated as an optimization problem with equality and inequality constraints. An effective distributed approach based on multi-agent system is proposed for solving the economic dispatch problem in this paper. The proposed approach consists of two stages. In the first stage, an adjacency average allocation algorithm is proposed to ensure the generation-demand equality. In the second stage, a local replicator dynamics algorithm is applied to achieve Nash equilibrium for the power dispatch game. The approach is implemented in a fully distributed manner with local computation and communication among neighboring agent. The feasibility and effectiveness of this approach is demonstrated by a numerical test system.

Review of Energy Storage System for Wind Power Integration Support

With the rapid growth of wind energy development and increasing wind power penetration level, it will be a big challenge to operate the power system with high wind power penetration securely and reliably due to the inherent variability and uncertainty of wind power. With the flexible charging-discharging characteristics, Energy Storage System (ESS) is considered as an effective tool to enhance the flexibility and controllability not only of a specific wind farm, but also of the entire grid. This paper reviews the state of the art of the ESS technologies for wind power integration support from different aspects. Firstly, the modern ESS technologies and their potential applications for wind power integration support are introduced. Secondly, the planning problem in relation to the ESS application for wind power integration is reviewed, including the selection of the ESS type, and the optimal sizing and siting of the ESS. Finally, the proposed operation and control strategies of the ESS for different application purposes in relation to the wind power integration support are summarized. The conclusion is drawn in the end.
The dynamic tariff (DT) method is designed for the distribution system operator (DSO) to alleviate the congestions that might occur in a distribution network with high penetration of distribute energy resources (DERs). Sensitivity analysis of the DT method is crucial because of its decentralized control manner. The sensitivity analysis can obtain the changes of the optimal energy planning and thereby the line loading profiles over the infinitely small changes of parameters by differentiating the KKT conditions of the convex quadratic programming, over which the DT method is formed. Three case studies were conducted to demonstrate the impact of small and big changes of parameters on the line loading profiles and the effectiveness of the DT method.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Huang, S., Wu, Q., Liu, Z., Zhao, H.
Number of pages: 6
Publication date: 2015

Host publication information
Title of host publication: Proceedings of 2015 IEEE PES General Meeting
Publisher: IEEE
ISBN (Print): 9781467360409
Keywords: Congestion management, Convex quadratic programming, Distribution system operator (DSO), Distribute energy resources (DERs), Sensitivity analysis
Electronic versions: Sensitivity_Analysis.pdf
DOI: 10.1109/PESGM.2015.7285728
Source-ID: 106278249
Research output: Research - peer-review › Article in proceedings – Annual report year: 2015

The qualitative criterion of transient angle stability
In almost all the literatures, the qualitative assessment of transient angle stability extracts the angle information of generators based on the swing curve. As the angle (or angle difference) of concern and the threshold value rely strongly on the engineering experience, the validity and robust of these criterions are weak. Based on the stability mechanism from the extended equal area criterion (EEAC) theory and combining with abundant simulations of real system, this paper analyzes the criterions in most literatures and finds that the results could be too conservative or too optimistic. It is concluded that misjudgment would be taken if an angle (or angle difference) of concern departing from the concept of the controlling mode or a constant threshold value is used in the criterion.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Nanjing University of Science and Technology, State Grid Electric Power Research Institute, Hohai University
Wind turbine inverter robust loop-shaping control subject to grid interaction effects
An $H_\infty$ robust control of wind turbine inverters employing an LCL filter is proposed in this paper. The controller dynamics are designed for selective harmonic filtering in an offshore transmission network subject to parameter perturbations. Parameter uncertainty in the network originates from the grid and the number of wind turbines connected. Power converter based turbines inject harmonic currents, which are attenuated by passive filters. A robust high order active filter controller is proposed to complement the passive filtering. The $H_\infty$ design of the control loop enables desired tracking with integral effect while bounding the induced change. The design was tested in an aggregated model of the London Array offshore wind power plant and compared with traditional PI controller designs. Robust stability and performance and a reduction of control effort by 25% are obtained over the full envelope of operation.
The impact of wind power prediction (WPP) on power systems is discussed and the factors affecting the accuracy of WPP are summarized. Then the paper unscrambles the WPP process from the viewpoint of information flow, classifies its research status and discusses the requirements of evaluation index for WPP results. It is proposed that the error evaluation index should reflect the WPP quality of the whole time window, and possible breakthroughs of WPP are also predicted.
Closure to Discussion on "Distribution Locational Marginal Pricing for Optimal Electric Vehicle Charging Management"

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, University of California at Berkeley
Contributors: Li, R., Wu, Q., Oren, S. S.
Pages: 1867
Publication date: 2014
Peer-reviewed: Yes

Publication information
Journal: IEEE Transactions on Power Systems
Volume: 29
Issue number: 4
ISSN (Print): 0885-8950
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.742 SNIP 2.662
Web of Science (2017): Impact factor 5.255
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.368 SNIP 3.584
Web of Science (2016): Impact factor 5.68
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 6.6 SJR 3.315 SNIP 3.386
Web of Science (2015): Impact factor 3.342
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.31 SJR 2.475 SNIP 3.485
Web of Science (2014): Impact factor 2.814
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 6.33 SJR 2.523 SNIP 4.243
Web of Science (2013): Impact factor 3.53
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
Coordinated control of wind power and energy storage

Nowadays, wind power has become one of the fastest growing sources of electricity in the world. Due to the inherent variability and uncertainty, wind power integration into the grid brings challenges for power systems, particularly when the wind power penetration level is high. The challenges exist in many aspects, such as reliability, power quality and stability. With the rapid development of energy storage technology, the application of Energy Storage System (ESS) is considered as an effective solution to handle the aforementioned challenges. The main objective of this study is to investigate the coordinated control of wind power and ESS. Due to the different technical characteristics, such as power and energy density, ESS can play different roles either in generation-side, grid-side or demand side. This thesis focuses on the following two scenarios: • Scenario 1: As a part of wind farm, the ESS plays a generation-side role which aims to improve the grid-friendliness of the wind farm. • Scenario 2: As a part of microgrid, the ESS is used to efficiently accommodate the wind power fluctuation. Around the main objective, the relevant research fields including the wind turbine modeling and control, wind farm modeling and control, planning of ESS are also studied in this thesis. The implementation and validation of the International Electrotechnical Commission (IEC) generic Type 1A models in PowerFactory (PF) can represent the relevant dynamics during normal operation and fault conditions. The model against measurements validation was carried out to verify the implemented wind turbine generator model. For the wind turbine control strategy, the L1 adaptive controller for Maximum Power Point Tracking (MPPT) of a small variable speed Wind Energy Conversion System (WECS) is developed. It showed good tracking performance towards the optimum Tip Speed Ratio (TSR) and robustness with fast adaptation to uncertainties.
and disturbances. For the wind farm control, the optimal active power control based on Distributed Model Predictive Control (D-MPC) is proposed. With the developed D-MPC, most of computation tasks are distributed to the local D-MPCs equipped at each actuator (wind turbine or ESS). This control structure is independent from the scale of the wind farm. The algorithms for optimal siting and sizing of ESS in the grid with a significant penetration of wind power are studied and implemented in a test network. For the point of view the grid operator, the optimal sizing and siting of ESS are analyzed, which enhance the controllability and derive the global benefit of the whole grid.

**General information**
State: Published
Contributors: Zhao, H., Wu, Q., Rasmussen, C. N., Xu, H.
Number of pages: 270
Publication date: 2014

**Publication information**
Publisher: Technical University of Denmark, Department of Electrical Engineering
Original language: English
Electronic versions:
Thesis_HaoranZhao.pdf
Research output: Research › Ph.D. thesis – Annual report year: 2015

**Day-Ahead Congestion Management in Distribution Systems through Household Demand Response and Distribution Congestion Prices**
With the development of smart grid technologies, some of the electric demands which are traditionally considered fixed and inflexible will become promising distributed energy resources (DERs) in future power systems. However, the participation of small scale or household energy sources into balancing power might challenge the operation of electric distribution systems and cause congestions. This paper presents a distribution congestion price (DCP) based market mechanism to alleviate possible distribution system congestions. By employing the locational marginal pricing (LMP) model, the proposed DCPs are able to reflect the real congestion cost and further direct the schedule of the responses of electric demands. Based on the NordPool Spot market structure, the interactions between aggregators and the distribution system operator (DSO) are discussed, and the procedure for calculating DCPs is proposed. Finally, a practical Danish 60kV/10.5kV distribution system is employed as the test case to verify the proposed method for mitigating congestion.

**General information**
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Zhejiang University
Contributors: Liu, W., Wu, Q., Wen, F., Østergaard, J.
Pages: 2739-2747
Publication date: 2014
Peer-reviewed: Yes

**Publication information**
Journal: IEEE Transactions on Smart Grid
Volume: 5
Issue number: 6
ISSN (Print): 1949-3053
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 9.02 SJR 2.854 SNIP 2.995
Web of Science (2017): Impact factor 7.364
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 7.92 SJR 2.73 SNIP 2.837
Web of Science (2016): Impact factor 6.645
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 8.48 SJR 3.424 SNIP 3.284
This paper presents the day-ahead energy planning of passenger cars with 100% electric vehicle (EV) penetration in the Nordic region by 2050. EVs will play an important role in the future energy systems which can both reduce the greenhouse gas (GHG) emission from the transport sector and provide demand side flexibility required by the smart grids. On the other hand, the EVs will increase the electricity consumption. In order to quantify the electricity consumption increase due to the 100% EV penetration in the Nordic region to facilitate the power system planning studies, the day-ahead energy planning of EVs has been investigated with different EV charging scenarios. Five EV charging scenarios have been considered in the energy planning analysis which are uncontrolled charging all day, uncontrolled charging at home, timed charging, spot price based charging all day and spot price based charging at home. The demand profiles of the five charging analysis show that timed charging is the least favorable charging option and the spot priced based EV charging might induce high peak demands. The EV charging demand will have a big share of the energy consumption in the future Nordic power system.

**General information**

State: Published  
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Shenzhen University  
Contributors: Liu, Z., Wu, Q., Nielsen, A. H., Wang, Y.  
Pages: 1733-1749  
Publication date: 2014  
Peer-reviewed: Yes

**Publication information**

Journal: Energies  
Volume: 7  
ISSN (Print): 1996-1073  
Ratings:  
BFI (2018): BFI-level 2  
Web of Science (2018): Indexed yes  
BFI (2017): BFI-level 2  
Scopus rating (2017): CiteScore 3.11 SJR 0.67 SNIP 1.34  
Web of Science (2017): Impact factor 2.676  
Web of Science (2017): Indexed yes  
BFI (2016): BFI-level 2
Development of Energy and Reserve Pre-dispatch and Re-dispatch Models for Real-time Price Risk and Reliability Assessment

In the future energy framework of European Union and other countries, renewable energy plays an important role tackling the problems of the climate change and security of energy supply. The share of fluctuating and less predictable renewable power production will increase significantly the needs of securing proper balancing between generation and demand. The high penetration of renewable energy sources will also increase the burden of system operator for maintaining system reliabilities. However the current strategy of reliability management developed for conventional power systems and existing electricity market design may not cope with the future challenges the power system faces. The development of smart grid will enable power system scheduling and the electricity market to operate in a shorter time horizon for better integrating renewable energy sources into power systems. This paper presents an electricity market scheme including a multi-period energy and reserve pre-dispatch model and an energy re-dispatch model for real time operation considering their coupling with the day-ahead market, respectively. The multi-period energy and reserve pre-dispatch model is formulated using the multi-period optimal power flow technique, which pre-schedules the generation output for satisfying the expected demand and determines up and down spinning reserve for each time interval in the operational hour. The ex-ante electricity prices and reserve capacity prices are also evaluated correspondingly. During the real time operation, the energy re-dispatch model is used for contingency management and providing balancing services based on the results of the energy and reserve pre-dispatch model. The energy re-dispatch model is formulated as a single-period AC OPF model, which is used to determine generation re-
dispatch, load curtailment as well as real-time electricity prices. The modified IEEE-RTS has been analyzed to illustrate the techniques. The proposed market scheme coupled with a contingency analysis methodology has been used to evaluate both real-time electricity price risk and short term reliabilities during the operational hour in the new environment.

**General information**

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, University of Hong Kong
Contributors: Ding, Y., Xie, M., Wu, Q., Østergaard, J.
Pages: 1338 - 1345
Publication date: 2014
Peer-reviewed: Yes

**Publication information**

Journal: IET Generation Transmission and Distribution
Volume: 8
Issue number: 7
ISSN (Print): 1751-8687
Ratings:
BFI (2018): BFI-level 1
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 3.31 SJR 0.907 SNIP 1.305
Web of Science (2017): Impact factor 2.618
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 3.2 SJR 1.03 SNIP 1.457
Web of Science (2016): Impact factor 2.213
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 2.74 SJR 1.01 SNIP 1.496
Web of Science (2015): Impact factor 1.576
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 2.36 SJR 0.923 SNIP 1.61
Web of Science (2014): Impact factor 1.353
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 2.73 SJR 1.088 SNIP 1.923
Web of Science (2013): Impact factor 1.307
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 1
Scopus rating (2012): CiteScore 2.58 SJR 0.899 SNIP 1.782
Web of Science (2012): Impact factor 1.414
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 1
Scopus rating (2011): CiteScore 2.27 SJR 0.766 SNIP 1.768
Web of Science (2011): Impact factor 1.197
ISI indexed (2011): ISI indexed yes
BFI (2010): BFI-level 1
Scopus rating (2010): SJR 0.723 SNIP 1.444
Web of Science (2010): Impact factor 1.152
Web of Science (2010): Indexed yes
BFI (2009): BFI-level 1
Scopus rating (2009): SJR 0.747 SNIP 1.254
Web of Science (2009): Indexed yes
BFI (2008): BFI-level 1
Scopus rating (2008): SJR 0.596 SNIP 1.114
Distributed Model Predictive Control for Active Power Control of Wind Farm

This paper presents the active power control of a wind farm using the Distributed Model Predictive Controller (D-MPC) via dual decomposition. Different from the conventional centralized wind farm control, multiple objectives such as power reference tracking performance and wind turbine load can be considered to achieve a trade-off between them. Additionally, D-MPC is based on communication among the subsystems. Through the interaction among the neighboring subsystems, the global optimization could be achieved, which significantly reduces the computation burden. It is suitable for the modern large-scale wind farm control.

Electromagnetic Transient Response Analysis of DFIG under Cascading Grid Faults Considering Phase Angel Jumps

This paper analysis the electromagnetic transient response characteristics of DFIG under symmetrical and asymmetrical cascading grid fault conditions considering phase angle jump of grid. On deriving the dynamic equations of the DFIG with considering multiple constraints on balanced and unbalanced conditions, phase angle jumps, interval of cascading fault, electromagnetic transient characteristics, the principle of the DFIG response under cascading voltage fault can be extract. The influence of grid angle jump on the transient characteristic of DFIG is analyzed and electromagnetic response characteristics under both symmetrical and asymmetrical failure types are compared.
EV Charging Analysis Based on the National Travel Surveys of the Nordic Area

This paper presents the charging demand profiles of electric vehicles (EVs) based on the National Travel Surveys of the Nordic area. The EV charging analysis is carried out considering different types of charging patterns which are dumb charging, timed charging and spot price based charging. The driving behavior of the vehicles is studied through the National Travel Surveys of Denmark, Finland, Norway and Sweden. The features of the charging demand are discussed based on the results of the analysis. The study in this paper provides an estimation of the possible level and patterns of the EV charging demand in the Nordic area.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: Liu, Z., Wu, Q.
Number of pages: 5
Publication date: 2014

Experimental study on EV purchases assisted by multi-agents representing a set of questionnaires

An experimental economics (EE) method is used to analyze the influences of subjective willingness on the development of the electric vehicle (EV) industry. It is difficult to run large-scale EE-based simulations and to support decision optimizations due to the limited number of qualified human participants and the incomparability among repeated trials. Taking the customers’ willingness to buy EVs as an example, this paper extracts multi-layer correlation information from a limited number of questionnaires and builds a multi-agent model to match the probabilistic distributions of multi-responder behaviors, for the purpose of reflecting the truly statistic information embedded from the questionnaires. The vraisemblance of both the model and the algorithm is validated by comparing the agent-based Monte Carlo simulation results with the questionnaire-based deduction results. Based on the work presented in this paper, the influence of a key factor on the EV development can therefore be analyzed by using a simulation platform with mixed inputs from agents modelled in this paper and human participants.

General information
State: Published
Number of pages: 11
Fast Coordinated Control of DFIG Wind Turbine Generators for Low and High Voltage Ride-Through

This paper presents a fast coordinated control scheme of the rotor side converter (RSC), the DC chopper and the grid side converter (GSC) of doubly fed induction generator (DFIG) wind turbine generators (WTGs) which is to improve the low voltage ride through (LVRT) and high voltage ride through (HVRT) capability of the DFIG WTGs. The characteristics of DFIG WTGs under voltage sags and swells were studied focusing on the DFIG WTG stator flux and rotor voltages during the transient periods of grid voltage changes. The protection schemes of the rotor crowbar circuit and the dc chopper circuit were proposed considering the characteristics of the DFIG WTGs during voltage changes.

The fast coordinated control of RSC and GSC were developed based on the characteristic analysis in order to realize efficient LVRT and HVRT of the DFIG WTGs. The proposed fast coordinated control schemes were verified by time domain simulations using MATLAB-Simulink.
This paper presents a coordinated control strategy of a battery energy storage system (BESS) and distributed generation (DG) units for the island operation of the Danish island of Bornholm. The Bornholm power system is able to transit from the grid connected operation with the Nordic power system to the isolated island operation. In order to ensure the secure island operation, the coordinated control of the BESS and the DG has been proposed to stabilize the frequency of the system after the transition to the island operation. In the proposed coordinate control scheme, the BESS is used to provide the primary frequency control and the DG units are used to provide the secondary frequency control. As such, the proposed control scheme can strike a balance of the frequency control speed and the energy used from the BESS for the frequency control support. The real-time model of the Bornholm power system was used to carry out case studies using real time digital simulator (RTDS) to illustrate the performance of the coordinated control strategy. Case study results show that the proposed control strategy can efficiently help stabilize the frequency under different conditions.
Hardware-in-the-loop Test for Demand as Frequency Controlled Reserve

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems, Technical University of Denmark
Contributors: Liu, Z., Zimmermann, J. K., Wu, Q.
Number of pages: 39
Publication date: 2014

Publication information
Publisher: Technical University of Denmark, Department of Electrical Engineering
Original language: English
Electronic versions:
Hardware_in_the_loop_Test_DFR.pdf

Bibliographical note
Report of the framework agreement project
Source: PublicationPreSubmission
Source-ID: 127180449
Research output: Research › Report – Annual report year: 2014

Impact study of PV integration in Bornholm power system

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Korompili, A., Zimmermann, J. K., Wu, Q.
Number of pages: 27
Publication date: 2014

Publication information
Publisher: Technical University of Denmark, Department of Electrical Engineering
Original language: English
Electronic versions:
L1 Adaptive Speed Control of a Small Wind Energy Conversion System for Maximum Power Point Tracking

This paper presents the design of an L1 adaptive controller for maximum power point tracking (MPPT) of a small variable speed Wind Energy Conversion System (WECS). The proposed controller generates the optimal torque command for the vector controlled generator side converter (GSC) based on the wind speed estimation. The proposed MPPT control algorithm has a generic structure and can be used for different generator types. In order to verify the efficacy of the proposed L1 adaptive controller for the MPPT of the WECS, a full converter wind turbine with a squirrel cage induction generator (SCIG) is used to carry out case studies using Matlab/Simulink. The case study results show that the designed L1 adaptive controller has good tracking performance even with unmodeled dynamics and in the presence of parameter uncertainties and unknown disturbances.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Automation and Control
Contributors: Zhao, H., Wu, Q., Rasmussen, C. N., Blanke, M.
Pages: 576–584
Publication date: 2014
Peer-reviewed: Yes

Publication Information
Journal: IEEE Transactions on Energy Conversion
Volume: 29
Issue number: 3
ISSN (Print): 0885-8969
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 5.42 SJR 1.377 SNIP 2.124
Web of Science (2017): Impact factor 3.767
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 5.08 SJR 1.356 SNIP 2.25
Web of Science (2016): Impact factor 3.808
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 5.22 SJR 1.454 SNIP 2.631
Web of Science (2015): Impact factor 2.596
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.03 SJR 1.471 SNIP 2.817
Web of Science (2014): Impact factor 2.326
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 5.67 SJR 1.798 SNIP 3.21
Web of Science (2013): Impact factor 3.353
ISI indexed (2013): ISI indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.48 SJR 1.565 SNIP 3.154
Web of Science (2012): Impact factor 2.427
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
The main focus of the electrical engineers nowadays, is to develop a smart grid that is able to monitor, evaluate and control the power system operation. The integration of Intelligent Electronic Devices (IEDs) to the power network, is a strong indication of the inclination to lead the power network to a more reliable, secure and economic operation. The implementation of these devices though, demands the warranty of a secure operation and high-accuracy performance. This paper describes the procedure of establishing a PMU (Phasor Measurement Unit)–PDC (Phasor Data Concentrator) platform that is able to derive and communicate synchrophasor measurements of different parts of the power network and the development of tests, according to IEEE standards, that evaluate the performance of PMUs and PDCs. The tests are created by using a Real Time Digital Simulation (RTDS) system. The results obtained from testing are analyzed to evaluate the performance of the devices.
PowerFactory model for multi-terminal HVDC network with DC voltage droop control

Nowadays, most of the installed HVDC systems are based on line commutated converters (LCC), since this technology offers a series of advantages, mainly low costs and losses. However, voltage source converters (VSCs) have recently drawn more and more attention, due to their high controllability. Moreover, recent developments have improved efficiency and power quality. For multi-terminal HVDC grids, the advantages of VSCs become so large, that VSC-HVDC systems are the only viable solution. Nevertheless, no VSC-based multi-terminal HVDC grids exist to date. This is the reason for which many research projects have recently focused on this topic.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Korompili, A., Wu, Q.
Number of pages: 17
Publication date: 2014

Power Hardware In The Loop Validation of Fault Ride Through of VSC HVDC Connected Offshore Wind Power Plants

This paper presents the power hardware in the loop (PHIL) validation of a feed forward DC voltage control scheme for the fault ride through (FTR) of voltage source converter (VSC) high voltage DC (HVDC) connected offshore wind power plants (WPPs). In the proposed FRT scheme, the WPP collector network AC voltage is actively controlled by considering both the DC voltage error and the AC current from the WPP AC collector system which ensures fast and robust FRT of the VSC HVDC connected offshore WPPs. The PHIL tests were carried out in order to verify the efficacy of the proposed feed forward DC voltage control scheme for enhancing the FRT capability of the VSC HVDC connected WPPs. The PHIL test results have demonstrated the proper control coordination between the offshore WPP and the WPP side VSC and the efficient FRT of the VSC HVDC connected WPPs.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Siemens A/S
Contributors: Sharma, R., Wu, Q., Cha, S., Jensen, K. H., Rasmussen, T. W., Østergaard, J.
Pages: 23-29
Publication date: 2014
Peer-reviewed: Yes
Real-Time Market Concept Architecture for EcoGrid EU—A Prototype for European Smart Grids

Industrialized countries are increasingly committed to move towards a low carbon generating mix by increasing the penetration of renewable generation. Additionally, the development in communication technologies will allow small end-consumers and small-scale distributed energy resources (DER) to participate in electricity markets. Current electricity markets need to be tailored to incorporate these changes regarding how electricity will be generated and consumed in the future. The EcoGrid EU is a large-scale EU-funded project, which establishes the first prototype of the future European intelligent grids. In this project, small-scale DERs and small end-consumers can actively participate in a new real-time electricity market by responding to 5-min real-time electricity prices. In this way, the market operator will also obtain additional balancing power to cancel out the production variation introduced by renewable electricity generation. The real-time market concept architecture for EcoGrid EU is introduced in this paper, which provides a market-based platform and information and communication technology (ICT) infrastructure that extends the current electricity market to a shorter time horizon and to smaller assets.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Energinet.dk
Pages: 2006-2016
Publication date: 2014
Peer-reviewed: Yes
Review of Congestion Management Methods for Distribution Networks with High Penetration of Distributed Energy Resources

This paper reviews the existing congestion management methods for distribution networks with high penetration of DERs documented in the recent research literatures. The congestion management methods for distribution networks reviewed can be grouped into two categories – market methods and direct control methods. The market methods consist of dynamic tariff, distribution capacity market, shadow price and flexible service market. The direct control methods are comprised of network reconfiguration, reactive power control and active power control. Based on the review of the existing methods, the authors suggest a priority list of the existing methods.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: Huang, S., Wu, Q., Liu, Z., Nielsen, A. H.
Number of pages: 6
Pages: 1-6
Publication date: 2014

Host publication information
Title of host publication: Proceedings of 2014 ISGT Europe
Publisher: IEEE
Keywords: Congestion management, Direct control methods, Distribute energy resource, Distribution network, Market methods
Electronic versions:
A_review_of_distribution_grid_congestion_management_methods_2_1.pdf
DOIs:
10.1109/ISGTEurope.2014.7028811
Source: PublicationPreSubmission
Source-ID: 99895412
Research output: Research - peer-review › Journal article – Annual report year: 2014

Robust Current Control of Doubly Fed Wind Turbine Generator under Unbalanced Grid Voltage Conditions

This paper presents the design of a $H_{\infty}$ current controller for doubly fed induction generators (DFIGs) in order to maintain stable operation under unbalanced voltage conditions. The $H_{\infty}$ current controller has a multi-input and multi-output
(MIMO) structure and is designed using the loop shaping method. Case studies have been carried out in order to verify the efficacy of the proposed $H\infty$ current controller for DFIGs. The case study results show that the proposed $H\infty$ current controller can realize different control objectives, i.e. stable stator current, stable stator active power and stable stator reactive power. It is also shown that the $H\infty$ current controller is less sensitive to the parameter perturbation.

**General information**

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Chinese Academy of Sciences, Shenzhen University
Contributors: Wang, Y., Gong, W., Wu, Q.
Number of pages: 4
Publication date: 2014

**Host publication information**

Title of host publication: Proceedings of IEEE PES APPEEC 2013
Publisher: IEEE
Article number: 0146
Keywords: DFIG, $H\infty$ current controller, MIMO, Unbalanced voltage conditions
Electronic versions:
Robust Current Control of Doubly Fed Wind Turbine.pdf
Source: dtu
Source-ID: u::10472
Research output: Research - peer-review › Article in proceedings – Annual report year: 2014

### Scenarios for a Nordic Power System without Greenhouse Gas Emissions

The paper presents scenarios for power production without greenhouse gas (GHG) emissions in Denmark, Finland, Norway and Sweden by 2050. The Nordic region already has a high share of renewables in its power production portfolio (about 60% in 2010), and possibilities for further deployment are very good. The main target group of the scenario results is the Transmission System Operators (TSOs), but the results will also be relevant for the Nordic politicians and investment decision makers in the power industry. The scenarios will among other be used for the following purposes:
- Identify profitable investments in transmission grids with particular focus on the interconnections between the Nordic region and Continental Europe.
- Technical simulations of the power system with focus on balancing of large shares of non-dispatchable renewable resources in a future system.
- Assess impacts on the power system with large-scale deployment of electric vehicles.
- Discuss necessary governance transformation related to the transmission grid development.

The paper presents a scenario methodology where each scenario consists of a possible future and a strategy for how the decision maker (TSOs) can act within that future. Each future consists of a set of uncertainties which are factors/developments that cannot be directly controlled by the decision makers. Each strategy contains a combination of technical and non-technical options for decision makers. Application of this methodology for the study of a Nordic power system free of GHG emissions is described. Furthermore, the paper describes the resulting scenarios and compares them with the Nordic Energy Technology Perspective (NETP). Finally, quantification of input data for technical analyses is given. The input data are mainly based on statistical data from the four countries and information about established and planned projects for new renewable power production in the Nordic region.

**General information**

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, SINTEF, Stockholm Environment Institute, Statnett SF
Contributors: Graabak, I., Nilsson, M., Wu, Q., Bakken, B. H.
Number of pages: 15
Publication date: 2014

**Host publication information**

Title of host publication: Proceedings of 27th International Conference on Efficiency, Cost, Optimization, Simulation and Environmental Impact of Energy Systems 2014
Electronic versions:
ECOS_April_2014.pdf
Research output: Research - peer-review › Article in proceedings – Annual report year: 2014

### SW-platform for R&D in Applications of Synchrophasor Measurements for Wide-Area Assessment, Control and Visualization in Real-Time

The Danish research project "Secure Operation of Sustainable Power Systems (SOSPO)" is currently being conducted in a collaboration by a group of partners from academia and industry. The focus of the project is on how to achieve secure operation of the power grid as large scale thermal power plants, supplied by fossil fuel, are phased out in favor of non-
controllable renewable energy sources like wind and solar energy. In particular, the SOSPO project aims to develop real-time stability and security assessment methods as well as wide-area control methods to re-establish stable and secure operation when a critical operation has been identified. An important part of the SOSPO project is the development of a SW-platform that enables testing and demonstrations of the various methods for wide-area assessment, control and visualization the project delivers. In order to test the methods under realistic conditions, the future system scenarios are represented in a real-time grid simulator that is an integrated part of the platform. The SW-platform provides structured access to any model parameter as well as access to real-time phasor measurement unit (PMU) and remote terminal unit (RTU) snapshots. Having such structured access to relevant data greatly eases the implementation process of new methods. The SW-platform is facilitated by PowerLabDK at the Technical University of Denmark, which is a new state-of-the-art experimental laboratory for technology development, testing, training and demonstration of technologies within electric power and energy. More specifically, the SW-platform exploits the Intelligent Control Lab facilities in PowerLabDK, which provides access to a powerful Real-Time Digital Simulator, a SCADA system, a full-scale experimental power system control room with a video wall and an IBM Blade center for the implementation of the SW-platform and the wide-area methods developed in SOSPO. This paper provides insights into the details of the SOSPO SW-platform including the technical infrastructure and the platform architecture.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Automation and Control, RTDS Technology Inc
Contributors: Jóhannsson, H., Morais, H., Pedersen, A. H. B., Wu, Q., Ouellette, D.
Number of pages: 8
Publication date: 2014

Host publication information
Title of host publication: Grid of the Future
Keywords: Real-Time Stability and Security Assessment, SW-Platform for Wide-Area Applications, Synchrophasors and Applications, Wide Area Monitoring and Control.

Bibliographical note
PowerPoint presentation
Source: PublicationPreSubmission
Source-ID: 99895397
Research output: Research - peer-review > Article in proceedings – Annual report year: 2014

基于实验经济学仿真构建碳排放交易的多代理模型
The market efficiency and regulation effects of carbon emission trading strongly depend on decisions made by different kinds of participants in the carbon emission market. Therefore, the participants, especially the policy designers and regulators, should understand the participants’ trading behaviors and their underlying mechanisms. Experimental economics can reflect participants’ “bounded rationality” characteristic through humans’ participating in experiments. However, the scale of experiment is limited due to the difficulty to have enough qualified human participants, and the comparability among the multi-scenario experiments is also limited due to the variations of human participants’ concentration level. This paper adopts a hybrid interactive simulation methodology. Human-subjected experiments with a small group of human participants are conducted. Major driving factors and their influencing rules on human participants’ uncertain behaviors are extracted, which can aid the construction of multi-agent stochastic models with the same distribution characteristics. In this way, only a small group of humans are needed to represent the special decision makers, who can interact with large numbers of multi-agents constructed by the aforementioned method. The methodology discussed can overcome the scale limitations and meanwhile maintain the merits of experimental economics.

General information
State: Published
Contributors: Chao, J., Yusheng, X., Jie, H., Wu, Q., Yang, G.
Pages: 80-86
Publication date: 2014
Peer-reviewed: Yes

Publication information
Journal: Dianli Xitong Zidonghua
Volume: 38
Issue number: 17
ISSN (Print): 1000-1026
In the electricity market environment, a reasonable market mechanism is demanding for guiding the behaviors of interruptible loads and flexible loads such as the charging loads of electric vehicles (EVs) to alleviate peak demands and system congestion. First, according to the response characteristics of different kinds of loads, the temperature controlled domestic loads are chosen as controllable loads. Besides, the EV charging demand and discharging power with the vehicle to grid (V2G) mode are considered as flexible loads. The demand response models of the controllable/EV demands are presented based on their thermal models/charging and discharging characteristics. Then, given the economic rationality of the retail agents (RAs) for interruptible and EV loads and the demand response models, RAs will formulate the initial bidding plans for the next trading day; the initial bidding plans will be verified by the distribution system operator, and an optimal power flow model will be employed to calculate congestion fees if applicable. Afterwards, the RAs will employ these congestion fees to reschedule and coordinate the domestic controllable loads and EV charging/discharging loads, given that the customers’ needs and constraints are properly respected. With the proposed market mechanism, the peak demands can be alleviated and distribution system congestion avoided to a great extent. Finally, the developed market mechanism, mathematical models and congestion management strategy are demonstrated through the modified IEEE 33-bus distribution system.
This paper presents an integrated distribution locational marginal pricing (DLMP) method designed to alleviate congestion induced by electric vehicle (EV) loads in future power systems. In the proposed approach, the distribution system operator (DSO) determines distribution locational marginal prices (DLMPs) by solving the social welfare optimization of the Electric distribution system which considers EV aggregators as Price takers in the local DSO market and demand price elasticity. Nonlinear optimization has been used to solve the social welfare optimization problem in order to obtain the DLMPs. The efficacy of the proposed approach was demonstrated by using the bus 4 distribution system of the Roy Billinton Test System (RBTS) and Danish driving data. The case study results show that the integrated DLMP methodology can successfully alleviate the congestion caused by EV loads. It is also shown that the socially optimal charging schedule can be implemented through a decentralized mechanism where loads respond autonomously to the posted DLMPs by maximizing their individual net surplus.

General information

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, University of California at Berkeley
Contributors: Li, R., Wu, Q., Oren, S. S.
Pages: 203-211
Publication date: 2013
Peer-reviewed: Yes

Publication information

Journal: IEEE Transactions on Power Systems
Volume: 29
Issue number: 1
Distribution Network Expansion Planning Based on Multi-objective PSO Algorithm
This paper presents a novel approach for electrical distribution network expansion planning using multi-objective particle swarm optimization (PSO). The optimization objectives are: investment and operation cost, energy losses cost, and power congestion cost. A two-phase multi-objective PSO algorithm was proposed to solve this optimization problem, which can accelerate the convergence and guarantee the diversity of Pareto-optimal front set as well. The feasibility and effectiveness of both the proposed multi-objective planning approach and the improved multi-objective PSO have been verified by the 18-node typical system.

Economical evaluation of large-scale photovoltaic systems using Universal Generating Function techniques
Solar energy plays an important role in the global energy framework for future. Comparing with conventional generation systems using fossil fuels, the cost structure of photovoltaic (PV) systems is different: the capital cost is higher while the operation cost is negligible. Reliabilities of the PV system can also influence the cost for producing electricity. Investors, planners and regulators require deep insight into the return and cost of a PV project. A reliability based economical assessment of large-scale PV systems has been conducted utilizing Universal Generating Function (UGF) techniques. The reliability models of solar panel arrays, PV inverters and energy production units (EPUs) are represented as the corresponding UGFs. The expected energy production models for different PV system configurations have also been developed. The expected unit cost of electricity has been calculated to provide informative metrics for making optimal decisions. The proposed method has been applied to determine the PV system configuration which provides electricity for a water purification process.
Electricity demand profile with high penetration of heat pumps in Nordic area

This paper presents the heat pump (HP) demand profile with high HP penetration in the Nordic area in order to achieve the carbon neutrality power system. The calculation method in the European Standard EN14825 was used to estimate the HP electricity demand profile. The study results show there will be high power demand from HPs and the selection of supplemental heating for heat pumps has a big impact on the peak electrical power load of heating. The study in this paper gives an estimate of the scale of the electricity demand with high penetration of heat pumps in the Nordic area.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: Liu, Z., Wu, Q., Nielsen, A. H., Østergaard, J., Ding, Y.
Number of pages: 5
Publication date: 2013

EV Charging Analysis with High EV Penetration in the Nordic Region

This report covers the driving pattern analysis and the electric vehicle (EV) charging analysis of Denmark, Sweden, Norway and Finland. The contents in the report are driving pattern analysis of the passenger cars and electrical charging load profiles of EVs based on the analyzed driving patterns in the four mentioned Nordic countries.
Extension of market concept with market-driven optimisation of distribution system operation

This report describes the development of a pricing mechanism for the alleviation of congestion at the 10kV distribution network level using demand flexibility in a 5-minute real-time market environment. Demand was incorporated into an OPF based market clearing procedure in which demand bids were not explicitly submitted, but derived from historic demand response behaviour. The locational prices resulting from this local optimisation were used to alleviate the congestion that would result from response to a global price, as issued within the EcoGrid EU real time market for system balancing services from distributed resources. A complementary direct control framework was developed to operate in tandem with the pricing mechanism to ensure the reliable alleviation of congestion.

General Expansion Planning Considering Integrating Large-scale Wind Generation

Generation expansion planning (GEP) is the problem of finding the optimal strategy to plan the Construction of new generation while satisfying technical and economical constraints. In the deregulated and competitive environment, large-scale integration of wind generation (WG) in power system has necessitated the inclusion of more innovative and sophisticated approaches in power system investment planning. A bi-level generation expansion planning approach considering large-scale wind generation was proposed in this paper. The first phase is investment decision, while the second phase is production optimization decision. A multi-objective PSO (MOPSO) algorithm was introduced to solve this optimization problem, which can accelerate the convergence and guarantee the diversity of Pareto-optimal front set as well. The feasibility and effectiveness of the proposed bi-level planning approach and the MOPSO algorithm have been verified by a numerical test system.
Grid Integration of Electric Vehicles in Open Electricity Markets

Presenting the policy drivers, benefits and challenges for grid integration of electric vehicles (EVs) in the open electricity market environment, this book provides a comprehensive overview of existing electricity markets and demonstrates how EVs are integrated into these different markets and power systems.

Unlike other texts, this book analyses EV integration in parallel with electricity market design, showing the interaction between EVs and differing electricity markets. Future regulating power market and distribution system operator (DSO) market design is covered, with up-to-date case studies and examples to help readers carry out similar projects across the world.

With in-depth analysis, this book describes:
• the impact of EV charging and discharging on transmission and distribution networks
• market-driven EV congestion management techniques, for example the day-ahead tariff based congestion management scenario within electric distribution networks
• optimal EV charging management with the fleet operator concept and smart charging management
• EV battery technology, modelling and tests
• the use of EVs for balancing power fluctuations from renewable energy sources, looking at power system operation support, including frequency reserve, power regulation and voltage support

An accessible technical book for power engineers and grid/distributed systems operators, this also serves as a reference text for researchers in the area of EVs and power systems. It provides distribution companies with the knowledge they need when facing the challenges introduced by large scale EV deployment, and demonstrates how transmission system operators (TSOs) can develop the existing system service market in order to fully utilize the potential of EV flexibility. With thorough coverage of the technologies for EV integration, this volume is informative for research professors and graduate students in power systems; it will also appeal to EV manufacturers, regulators, EV market professionals, energy providers and traders, mobility providers, EV charging station companies, and policy makers.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: Wu, Q. (ed.)
Number of pages: 306
Publication date: 2013

Impact and Cost Evaluation of Electric Vehicle Integration on Medium Voltage Distribution Networks

This paper presents the analysis of the impact of electric vehicle (EV) integration on medium voltage (MV) distribution networks and the cost evaluation of replacing the overloaded grid components. A number of EV charging scenarios have been studied. A 10 kV grid from the Bornholm Island in the city area has been used to carry out case studies. The case study results show that the secondary transformers are the bottleneck of the MV distribution networks and the increase of EV penetration leads to the overloading of secondary transformers. The cost of the transformer replacement has been evaluated. The transformer replacement cost reaches 72% of the total transformers value with 50% EV penetration and 3 Phase charging.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Tsinghua University, Technical University of Denmark
Contributors: Wu, Q., Cheng, L., Pineau, U., Nielsen, A. H., Østergaard, J.
Number of pages: 5
Publication date: 2013
Implementation of IEC Generic Model of Type 1 Wind Turbine Generator in PowerFactory and Simulink

This paper presents the implementation work of IEC generic model of Type 1 wind turbine generator (WTG) in two commercial simulation tools: DIgSILENT PowerFactory (PF) and Matlab Simulink. The model topology, details of the composite blocks and implementation procedure in PF and Simulink environments are described. Case studies under both normal and fault conditions have been conducted with the implemented IEC Type 1 WTG model. The dynamic responses are captured and analyzed. The simulation results of both models are compared and analyzed. It is verified that the IEC generic model can correctly represent the performance of Type 1 WTG for power system stability studies.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Department of Wind Energy, Siemens A/S
Contributors: Zhao, H., Wu, Q., Sørensen, P. E., Bech, J., Andresen, B.
Number of pages: 8
Publication date: 2013

Implementation of IEC Generic Model of Type 1 Wind Turbine Generator in DIgSILENT PowerFactory

The implementation method for the International Electrotechnical Commission (IEC) generic models of Type 1 wind turbine generator (WTG) in DIgSILENT PowerFactory is presented. The following items are described, i.e. model structure, model blocks and how to implement these blocks in the PowerFactory environment. Case studies under both normal and fault conditions are done with the implemented IEC generic models of Type 1 WTG, and dynamic responses are captured and analyzed. The case study results show that the IEC generic models of Type 1 WTG can correctly represent the performances of Type 1 WTG under both normal and fault conditions. © 2013 State Grid Electric Power Research Institute Press.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Department of Wind Energy, Siemens A/S
Contributors: Zhao, H., Wu, Q., Margaris, I., Sørensen, P. E.
Pages: 26-33
Publication date: 2013
Peer-reviewed: Yes
Large Scale Deployment of Electric Vehicles (EVs) and Heat Pumps (HPs) in the Nordic Region
This report describes the study results of large scale deployment of electric vehicles (EVs) and heat pumps (HPs) in the Nordic countries of Denmark, Norway, Sweden and Finland, focusing on the demand profiles with high penetration of EVs and HPs in 2050

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Liu, Z., Wu, Q., Petersen, P. F.
Number of pages: 60
Publication date: 2013

Publication information
Publisher: Technical University of Denmark, Department of Electrical Engineering
Original language: English
Keywords: Electric Vehicle, Heat Pump, Demand Profile, Yearly Energy Consumption

Bibliographical note
D2.1 of the Norstrat project funded by the Nordic Energy Research (Norden)
Source: PublicationPreSubmission
Source-ID: 127180399
Research output: Research › Report – Annual report year: 2013

Policies and Initiatives for Carbon Neutrality in Nordic
Policies and initiatives promoting carbon neutrality in the Nordic heating and transport systems are presented. The focus within heating systems is the promotion of HPs (heat pumps) while the focus within transport systems is initiatives regarding EVs (electric vehicles). It is found that the conversion to HPs in the Nordic region relies on both private economic and national economic incentives. Initiatives toward carbon neutrality in the transport system are mostly concentrated on research, development and demonstration for deployment of a large number of EVs. All Nordic countries
have plans for the future heating and transport systems with the ambition of realizing carbon neutrality

**General information**

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: Wu, Q., Møller, J. G., Østergaard, J., Nielsen, A. H.
Pages: 1745-1753
Publication date: 2013
Peer-reviewed: Yes

**Publication information**

Journal: Journal of Energy and Power Engineering
Volume: 7
ISSN (Print): 1934-8975
Ratings:
- BFI (2018): BFI-level 1
- BFI (2017): BFI-level 1
- BFI (2016): BFI-level 1
- BFI (2015): BFI-level 1
- BFI (2014): BFI-level 1
- BFI (2013): BFI-level 1
- ISI indexed (2013): ISI indexed no
- ISI indexed (2012): ISI indexed no
- ISI indexed (2011): ISI indexed no
Original language: English
Keywords: Policies and initiatives, Carbon neutrality, Heat pumps, Electric Vehicles
Electronic versions:
- 14-JEPE12122003.pdf
Source: dtu
Source-ID: u::10193
Research output: Research - peer-review › Journal article – Annual report year: 2012

**Study on VSC HVDC Modeling and Control Strategies for Wind Power Integration**

Recently, more and more offshore wind farms have been integrated to the power systems. In the next years, these offshore power plants are going to be rated at higher capacities and located in larger distances from the coast. This results in greater interest in the transmission technologies, which are available for the grid connection of the offshore wind farms.

In this report various transmission systems are presented. Precisely, the HVAC systems, which have dominated up until now in the power transfer sector, are briefly analysed, by providing their advantages, as well as the bottlenecks that occur in their applications. The main focus is given in the HVDC transmission systems, since they do not exhibit these disadvantages, whereas they additionally present beneficial attributes. This is the reason for which the applications of HVDC systems have been increased in the latest years. A brief description of different application cases is provided in the introduction of this report, while the rest chapters deal with the use of the HVDC technology for the grid connection of offshore wind farms. The main structure of the HVDC system is analysed, by describing the role and operation of its main components. Especially the converter configurations, the devices for reactive power compensation, the filter systems and the DC breakers are presented in details. The presence of different components, with different characteristics, leads to alternative system structures. Therefore, a comparison between the different structures is performed, regarding power losses, costs, equipment aspects and control capabilities. It is concluded that the VSC-HVDC system exhibits the most advantageous features for the grid connection of offshore wind farms. In addition, various topologies of the HVDC converter stations are analysed. Furthermore, the control schemes and strategies of the VSC are described in details. The capabilities of the VSC-HVDC technology, provided by its control system, are analysed. These attributes give the opportunity to the VSC-HVDC transmission system to provide grid support. They imply also benefits for the design of the wind turbines, as well as for the operation of the TSOs. Special focus is given on control strategies for fulfilling requirements concerning LVRT and frequency regulation. The corresponding technical rules, included in grid codes, are provided and the relevant structures and methods are described. Finally, more specific requirements are given for the grid connection of offshore wind farms through HVDC systems. These rules derived from the combination of grid codes for the integration of offshore wind farms and grid codes for the operation of HVDC transmission systems, connecting power plants to the AC network.

**General information**

State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Korompili, A., Wu, Q.
A Generic Danish Distribution Grid Model for Smart Grid Technology Testing
This paper describes the development of a generic Danish distribution grid model for smart grid technology testing based on the Bornholm power system. The frequency dependent network equivalent (FDNE) method has been used in order to accurately preserve the desired properties and characteristics of the original Bornholm power system. In particular, the proposed approach uses a coherency based dynamic equivalent technique along with relation & participation factors, and is suitable for use with real time digital simulator (RTDS). The validity and efficiency of the proposed approach is demonstrated by comparing the transient response of the original Bornholm power system model and the developed generic model under significant fault conditions. The results clearly show that the equivalent generic distribution grid model retains the dynamic characteristics of the original system, and can be used as a generic Smart Grid benchmark model for testing purposes.
Agent based Particle Swarm Optimization for Load Frequency Control of Distribution Grid

This paper presents a Particle Swarm Optimization (PSO) based on multi-agent controller. Real-time digital simulator (RTDS) is used for modelling the power system, while a PSO based multi-agent LFC algorithm is developed in JAVA for communicating with resource agents and determines the scenario to stabilize the frequency and voltage after the system enters into the islanding operation mode. The proposed algorithm is based on the formulation of an optimization problem using agent based PSO. The modified IEEE 9-bus system is employed to illustrate the performance of the proposed controller via RTDS to verify its practical efficacy. Case studies are presented under different operating conditions.

Cooperative Operation of Battery Energy Storage System and Dispatchable Distributed Generations in Microgrid System

Microgrid is an efficient solution to the utilization of renewable energy. According to the different operations (grid-connected or islanded), a fuzzy-logic based control strategy between BESS and dispatchable DG units is proposed in this paper, where the BESS plays a key role. The effectiveness of the proposed control strategy is simulated and verified using DgSILENT/PowertFactroy.

General information
State: Published
Organisations: Department of Electrical Engineering, Electric Energy Systems
Contributors: Cha, S., Wu, Q., Østergaard, J.
Number of pages: 8
Publication date: 2012
Peer-reviewed: Yes
Keywords: Microgrid, Coordinated control, Fuzzy-logic Control, BESS
Source: dtu
Source-ID: u::4364
Research output: Research - peer-review › Paper – Annual report year: 2012
Coordinated Control Scheme of Battery Energy Storage System (BESS) and Distributed Generations (DGs) for Electric Distribution Grid Operation

This paper describes a coordinated control scheme of battery energy storage system (BESS) and distributed generations (DGs) for electric distribution grid operation. The BESS is designed to stabilize frequency and voltages as a primary control after the electric distribution system enters into the islanding operation mode, while the centralized joint load frequency control (CJLFC) utilizing DGs handles the secondary frequency regulation. The BESS with the associated controllers has been modelled in Real-time digital simulator (RTDS) in order to identify the improvement of the frequency and voltage response. The modified IEEE 9-bus system, which is comprised of several DG units, wind power plant and the BESS, has been employed to illustrate the performance of the proposed coordinated flexible control scheme using RTDS in order to verify its practical efficacy.

General information
State: Published
Organisations: Department of Electrical Engineering, Electric Energy Systems, KTH - Royal Institute of Technology
Contributors: Cha, S., Zhao, H., Wu, Q., Saleem, A., Østergaard, J.
Number of pages: 7
Publication date: 2012

Current Electric Distribution Network Operation and Grid Tariffs

The aim of EcoGridEU task 1.4 is to extend the real-time price approach with an integrated optimization of the distribution system operation. This will be achieved by extending the basic real-time market concept with local location-dependant prices that reflect the grid operation, especially the grid losses and bottlenecks. Furthermore, the use of multidimensional price signals for management of reactive power / voltage control will be analyzed and evaluated.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Wu, Q.
Number of pages: 26
Publication date: 2012

Day-ahead tariffs for the alleviation of distribution grid congestion from electric vehicles

An economically efficient day-ahead tariff (DT) is proposed with the purpose of preventing the distribution grid congestion resulting from electric vehicle (EV) charging scheduled on a day-ahead basis. The DT concept developed herein is derived from the locational marginal price (LMP), in particular the congestion cost component of the LMP. A step-wise congestion management structure has been developed whereby the distribution system operator (DSO) predicts congestion for the coming day and publishes DTs prior to the clearing of the day-ahead market. EV fleet operators (FOs) optimize their EV charging schedules with respect to the predicted day-ahead prices and the published DTs, thereby avoiding congestion while still minimizing the charging cost. A Danish 400V distribution network is used to carry out case studies to illustrate the effectiveness of the developed concept for the prevention of distribution grid congestion from EV charging. The case study results show that the concept is successful in a number of situations, most notably a system over-load of 155% can be successfully alleviated on the test distribution network.

General information
Definition of multi-state weighted k-out-of-n: F systems
The Multi-state Weighted k-out-of-n System model is the generalization of the Multi-state k-out-of-n System model, which finds wide applications in industry. However only Multi-state Weighted k-out-of-n: G System models have been defined and studied in most recent research works. The mirror image of the Multi-state Weighted k-out-of-n: G System- the Multi-state Weighted k-out-of-n: F System has not been clearly defined and discussed. In this short communication, the basic definition of the Multi-state Weighted k-out-of-n: F System model is proposed. The relationship between the Multi-state Weighted k-out-of-n: G System and the Multi-state Weighted k-out-of-n: F System is also analyzed. ©RAMS Consultants.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: Ding, Y., Wu, Q., Zio, E., Li, Y., Zio, E., Cheng, L.
Pages: 217-219
Publication date: 2012
Peer-reviewed: Yes

Publication information
Journal: International Journal of Performability Engineering
Volume: 8
Issue number: 2
ISSN (Print): 0973-1318
Ratings:
BFI (2018): BFI-level 1
BFI (2017): BFI-level 1
Scopus rating (2017): CiteScore 0.66 SJR 0.263 SNIP 0.536
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 1
Scopus rating (2016): CiteScore 0.49 SJR 0.381 SNIP 0.57
BFI (2015): BFI-level 1
Scopus rating (2015): CiteScore 0.41 SJR 0.337 SNIP 0.634
BFI (2014): BFI-level 1
Scopus rating (2014): CiteScore 0.46 SJR 0.387 SNIP 0.891
BFI (2013): BFI-level 1
Scopus rating (2013): CiteScore 0.56 SJR 0.372 SNIP 0.972
ISI indexed (2013): ISI indexed no
Efficient determination of distribution tariffs for the prevention of congestion from EV Charging

A dual objective electric vehicle (EV) charging schedule optimisation is proposed here whereby both consumer driving requirements and grid constraints are respected. A day-ahead dynamic tariff (DT) for distribution systems is proposed as a price signal to EV fleet operators (FO) bidding into the day-ahead market. The DT acts to disperse charging at congested periods and locations, thereby preventing congestion on a day-ahead basis. The magnitude of the DT is determined from a simulated locational marginal prices (LMPs), and the time extent of the DT is determined from analysis of the system loading curve prior to the application of the DT. Case studies were performed using a sample distribution network modelled on a network from the Danish island of Bornholm. A variety of price profiles were used to illustrate the efficacy of this approach. The case study results show that this approach is highly efficient at grid congestion prevention, and the precise level of congestion that can be alleviated is dependent on the price profile of the optimisation period in question.

General information
State: Published
Organisations: Department of Informatics and Mathematical Modeling, Mathematical Statistics, Department of Electrical Engineering, Center for Electric Power and Energy
Contributors: O’Connell, N., Wu, Q., Østergaard, J.
Number of pages: 8
Publication date: 2012

Host publication information
Title of host publication: IEEE Power & Energy Society General Meeting
Publisher: IEEE
ISBN (Print): 978-1-4673-2727-5
Keywords: Day-ahead Dynamic Distribution System Tariff , Distribution System Constraints , Electric Vehicle (EV) Charging Schedule , Locational Marginal Pricing, Minimum EV Charging Cost
DOIs: 10.1109/PESGM.2012.6344846
Source: dtu
Source-ID: n::oai:DTIC-ART:compendex/370812477::26740
Research output: Research - peer-review : Journal article – Annual report year: 2012

Evaluation of Energy Storage System to Support Danish Island of Bornholm Power Grid

This paper presents a real-time evaluation and simulation approach of energy storage system (ESS) based on large renewable-based electricity generation, which can be used for grid support. The ESS is designed to maintain power quality as a primary regulation, while the conventional generation units handle the secondary frequency regulation to mitigate ramping issues. The real time models of Bornholm distribution grid, which is the combination of an aggregated wind power generation and the energy storage system (ESS) has been used to test the system and control approach in a real time grid simulator to identify the improvement of the grid support capability. The interactive simulation platform with real-time energy forecasting data running online with a link to the Bornholm power system data are being used to measure and validate the system performance with and without energy storage after a disturbance.
Frequency Stabilizing Scheme for a Danish Island Grid

This paper describes the development of frequency stabilizing control scheme for a small Danish island of Bornholm. The Bornholm power system is able to transit from interconnected operation with the Nordic power system to isolated islanding operation. During islanding operation the shedding of wind power is necessary to avoid unwanted power oscillations, which lead to uncontrolled oscillations in the power plant control. Since this might deteriorate power quality including frequency in an island grid, a frequency stabilizing control scheme or strategies using intelligent controller with a battery energy storage system (BESS) has been proposed. The real-time models of distribution grids of Bornholm power system were used to carry out case studies to illustrate the performance of centralized load frequency control as well as coordinated control scheme. Case study results show that the proposed coordinated control scheme can efficiently help stabilize the frequency after switching to islanding operation.

Heuristic Optimization Techniques for Determining Optimal Reserve Structure of Power Generating Systems

Electric power generating systems are typical examples of multi-state systems (MSS). Sufficient reserve is critically important for maintaining generating system reliabilities. The reliability of a system can be increased by increasing the reserve capacity, noting that at the same time the reserve cost of the system will also increase. The reserve structure of a MSS should be determined based on striking a balance between the required reliability and the reserve cost. The objective of reserve management for a MSS is to schedule the reserve at the minimum system reserve cost while maintaining the required level of supply reliability to its customers. In previous research, Genetic Algorithm (GA) has been used to solve most reliability optimization problems. However, the GA is not very computationally efficient in some cases. In this chapter a new heuristic optimization technique—the particle swarm optimization has been used to determine the optimal reserve structure for power generating systems, which can greatly improve the computational efficiency. The computational efficiency and accuracy of the proposed method have been compared with those of the GA technique in the illustrative example.
Impact Study of Electric Vehicle (EV) Integration on Low Voltage (LV) Grids

Large scale deployment of electric vehicles (EVs) has become a very interesting option because it can both reduce the greenhouse gas (GHG) emission from the transport sector and facilitate the integration of more renewable energy resources (RES) by providing the flexibility of EV charging demands. Although the EV grid integration is promising, the impact of the EV grid integration has to be investigated in order to identify the bottlenecks of power systems for the EV grid integration and assess different charging scenarios. This paper is focused on the impact of EV grid integration on low voltage (LV) grids. The work consists of modeling a typical LV grid, EV charging schedule management, and impact study of different charging scenarios on LV grid. The modelling work of the LV grid is done using the data from the Bornholm power system. The topology data of the LV grid are used to develop the single line diagram (SLD) of the LV grid. The demand profiles of end-users are determined by the end-user yearly consumption and averaged demand profiles of different customer types in Denmark. Five charging scenarios have been tested using the developed LV grid. The first two charging scenarios are dumb charging all day and dumb charging night. The third charging is timed charging. The fourth and fifth charging scenarios are fleet all day and fleet night charging scenarios. Beside the five charging scenarios, two charging power levels will be tested as well in combination with the charging scenarios. The two charging power levels are 1 phase 16 A and 3 phase 16 A. The loading of the power components and voltage profile are analyzed to quantify the impact of the charging scenarios and charging power levels on LV grids.
Implementation of IEC Generic Model Type 1 Wind Turbine Generators using RTDS

With the ever increasing penetration of the wind power generation, transmission system operators (TSOs) and distribution system operators (DSOs) are demanding an accurate dynamic wind turbine generator (WTG) models for power system stability studies. However, the confidential requirements from wind turbine manufacturers prevent the academia and researchers from working on a real or/and manufacturer specific models. A generic WTG model is of great interest that does not contain the confidential information meanwhile represents the manufacturer specific models. These generic dynamic simulation models are useful tools to evaluate the impact of the wind power on the power system stability. Thus, a strong stimulus exists for the development of a generic dynamic model in order to further investigate the dynamic response of WTG under grid disturbances. This paper presents the implementation of the IEC generic Type 1A and 1B WTG models in the real time digital simulator (RTDS) environment. Case studies have been carried out to verify the performance of the IEC generic Type 1 WTG model under both steady state and dynamic conditions. The case study results show that the IEC generic Type 1 WTG model can represent the performance of Type 1 WTGs under both steady state and dynamic conditions.

Policies and initiatives for carbon neutrality in nordic heating and transport systems

Policies and initiatives promoting carbon neutrality in the Nordic heating and transport systems are presented. The focus within heating systems is the propagation of heat pumps while the focus within transport systems is initiatives regarding electric vehicles (EVs). It is found that conversion to heat pumps in the Nordic region rely on both private economic and national economic incentives. Initiatives toward carbon neutrality in the transport system are mostly concentrated on research, development and demonstration for deployment of a large number of EVs. All Nordic countries have plans for the future heating and transport systems with the ambition of realizing carbon neutrality.
Real-Time Analysis of an Active Distribution Network - Coordinated Frequency Control for Islanding Operation

The increasing penetration of distributed generation (DG) and distributed energy resources (DERs), and the consequential requirement to accommodate and integrate them within distribution networks brings both challenges and opportunities to the distribution system operator (DSO). This will enable and require a transition from today's passive distribution networks to future active distribution networks (ADNs) which utilizes advanced operation and control strategies in order to improve power supply reliability, and realize the potential of DG to provide system support. The presence of DERs within distribution networks makes it possible to operate the distribution networks independently which is called islanding operation. However, it is a challenge to ensure secure and reliable operation of the islanded system due to a number of reasons. For example, low inertia in the islanded system, intermittency of some of the DERs, etc. Particularly during islanding operation, with relatively few DG units, the frequency and voltage control of the islanded system is not straightforward. DG units, specially based on renewable energy sources (RESs), i.e. wind and solar, have an intermittent nature and intrinsic characteristics, they can’t ensure the constant power supply required by loads. Furthermore, the DG units with relatively slow response have insufficient dynamic performance in terms of load following.

In order to meet the challenges, coordinated control strategies are needed to ensure smooth transition to the islanding operation and reliable operation of the islanded system. The goal of this Ph.D project is to develop effective frequency control strategies for the islanding operation of ADNs. The developed control strategies are comprised of a primary frequency control scenario with a battery energy storage system (BESS) and two secondary frequency control scenarios with DER units. During the islanding transition, the frequency is regulated by the fast-acting primary control of the BESS. The secondary control of the main management system (MMS) detects the status of the BESS and tries to return the power output of the BESS to reference value by assigning the total power difference to the dispatchable DG units. Hence, the dispatchable DG units can be coordinated to share the load following burden of the BESS. To that end, a reliable real-time model of the Bornholm distribution system is constructed using the real-time digital simulator (RTDS). The resulting model is capable of performing dynamic simulations of the islanded Bornholm distribution system to investigate the frequency regulation performance. In addition, a generic model of Born-holm distribution system is constructed, which can be used as a benchmark model for smart grid testing purposes. In both cases, the simulation results are compared and provided a desirable performance with very high degree of accuracy. Secondly, the simplified battery model is adopted and has been modeled in the RTDS in order to investigate the role of the BESS as a primary frequency regulator during islanding transition. The effectiveness of proposed primary frequency control strategy is illustrated by using two test cases (i.e. IEEE 9-bus and Bornholm). In both cases, the frequency regulation performance is highly improved without degrading the proposed control performance.

Thirdly, a new fuzzy logic based secondary frequency control strategy between a BESS and dispatchable DG units is proposed for further improving the system frequency performance as well as reducing output power fluctuations. The simulation results show that the frequency regulation performance is highly improved with fuzzy logic control (FLC) when the system enters into islanding operation. Lastly, an intelligent multi-agent based secondary frequency control strategy for the islanding operation of ADN is proposed. A complete software-in-the-loop (SIL) simulation is carried out and optimization of the parameters of the secondary controller is achieved in a simple manner through the effective application of particle swarm optimization (PSO) technique. Simulation results show that the proposed multi-agent based secondary frequency control strategy performs well, in comparison to the performance of proportional integral (PI) control design.
Real-Time Hardware-in-the-Loop Testing for Digital Controllers

This paper discusses general approaches and results of real-time hardware-in-the-loop (HIL) testing for power electronics controllers. Many different types of power electronic controllers can be tested by connecting them to a real-time digital simulator (RTDS) for closed-loop HIL testing. In this paper, two HIL digital controller tests are presented as application examples of the low-level signal interface in the closed-loop tests of power electronic controllers. In the HIL tests, the power system and the power electronics hardware are modeled in the RTDS. The required control functions of the power electronics hardware are not included in the RTDS. Instead, the control algorithms are coded using the native C code and downloaded to the dedicated digital signal processor (DSP)/microcontrollers. The two experimental applications illustrate the effectiveness of the HIL controller testing. Results of the HIL tests and hardware validations are presented to illustrate the real-time HIL testing method for power electronics controllers.

General information
State: Published
Organisations: Electric Energy Systems, Department of Electrical Engineering, RTDS Technology Inc
Contributors: Cha, S., Kwon, P. I., Wu, Q., Nielsen, A. H., Østergaard, J.
Publication date: 2012

Host publication information
Title of host publication: 2012 IEEE PES Asia-Pacific Power and Energy Engineering Conference
Publisher: IEEE
ISBN (Print): 978-1-4577-0546-5
Keywords: Hardware-in-the-loop (HIL), Power electronics controllers, Digital signal processor (DSP), Real time digital simulator (RTDS)

Real time Intelligent Control Laboratory (RT-ICL) of PowerLabDK for smart grid technology development

This paper presents the Intelligent Control Laboratory (ICL) of the PowerLabDK and describes examples of ongoing research work utilizing the ICL. The ICL is comprised of a real time digital simulator (RTDS) with 5 racks, a full scale SCADA system and experimental control room with a link to the Bornholm power system data, an IBM blade server for optimization and control implementation, and a Phasor Measurement Unit (PMU) Lab. It is possible to interface PMUs and other hardware with the RTDS for hardware-in-the-loop (HIL) and power-hardware-in-the-loop (PHIL) tests. The ICL can interface with the Electric Laboratory through a 4-quadrant power amplifier with 150 kW continuous power supply capability, Omicron and Doble amplifiers, relays, an electric vehicle with vehicle-to-grid (V2G) capability, LabCell boards, photovoltaic (PV) panels, and micro combined heat plant (μCHP) units. The interactive simulation platform with real power system data and distributed energy resources (DER) hardware makes the ICL a very well-suited test platform for smart grid technology development and validation. The ongoing research work with the ICL illustrates the capability and feasibility of using it as a platform for smart grid technology development.

General information
State: Published
Organisations: Department of Electrical Engineering, Electric Energy Systems
Contributors: Østergaard, J., Wu, Q., Garcia-Valle, R.
Pages: 61-64
Publication date: 2012

Host publication information
Title of host publication: 2012 IEEE Workshop on Complexity in Engineering : COMPENG 2012
Publisher: IEEE
ISBN (Print): 9781467316149
Keywords: Hardware, Hardware-in-the-loop (HIL), Intelligent Control Laboratory (ICL), Power conversion, Power-hardware-in-the-loop (PHIL), Real time digital simulator (RTDS), Real time systems, Smart grid, Smart grids, Wind power generation
Reliability Evaluation considering Structures of a Large Scale Wind Farm

Wind energy is one of the most widely used renewable energy resources. Wind power has been connected to the grid as large scale wind farm which is made up of dozens of wind turbines, and the scale of wind farm is more increased recently. Due to intermittent and variable wind source, reliability evaluation on wind farm is necessarily required. Also, because large scale offshore wind farm has a long repair time and a high repair cost as well as a high investment cost, it is essential to take into account the economic aspect. One of methods to efficiently build and to operate wind farm is to construct wind farm which is able to enhance a capability of delivering a power instead of controlling an uncontrollable output of wind power. Therefore, this paper introduces a method to evaluate the reliability depending upon structures of wind farm and to reflect the result to the planning stage of wind farm.

General information
State: Published
Organisations: Department of Electrical Engineering, Electric Energy Systems, Hanyang University
Contributors: Shin, J., Cha, S., Wu, Q., Kim, J.
Number of pages: 10
Publication date: 2012

Host publication information
Title of host publication: European Power Electronics (EPE) Wind Energy and T&D Chapter Seminar 2012
ISBN (Print): 978-1-61284-167-0
Keywords: Wind Farm, Reliability Evaluation, Structure, Power delivery ability, Expected Power Delivery Ratio
Electronic versions:
prod11340435960964.EPE_Ver.Final.pdf
DOIs:
10.1109/EPE.2013.6634750
Research output: Research - peer-review › Article in proceedings – Annual report year: 2012
Electric Vehicle (EV) Charging Management with Dynamic Distribution System Tariff

An electric vehicle (EV) charging schedule algorithm was proposed in this paper in order to charge EVs to meet EV users’ driving needs with the minimum EV charging cost and respect the local distribution system constraints. A day-ahead dynamic distribution system tariff scheme was proposed to avoid congestions in local distribution systems from the day-ahead planning perspective. Locational marginal pricing method was used to determine the dynamic distribution system tariff based on predicted day-ahead spot prices and predicted charging behaviors. Distribution grids of the Bornholm power system were used to carry out case studies to illustrate the proposed EV charging schedule algorithm.

General information
State: Published
Organisations: Intelligent Energy Systems Programme, Risø National Laboratory for Sustainable Energy, Electric Energy Systems, Department of Electrical Engineering, Centre for Electric Technology
Contributors: O'Connell, N., Wu, Q., Østergaard, J., Nielsen, A. H., Cha, S.
Publication date: 2011

Impact Study of Electric Vehicle (EV) Integration on Medium Voltage (MV) Grids

The impact study of electric vehicle (EV) grid integration on medium voltage (MV) grids was carried out to quantify the power component loading and voltage profile change in MV grids due to the extra demands from the EV charging. Three charging scenarios, dumb charging, time charging and fleet operator based charging, were considered in the impact study to assess the impacts of different charging options. In the mean time, different charging power levels were included in the impact study as well. A MV grid from the Bornholm power system was used to implement the case studies.

General information
State: Published
Organisations: Electric Energy Systems, Department of Electrical Engineering
Contributors: Wu, Q., Nielsen, A. H., Østergaard, J., Cha, S., Ding, Y.
Publication date: 2011

Modeling and Control for Islanding Operation of Active Distribution Systems

General information
State: Published
Organisations: Electric Energy Systems, Department of Electrical Engineering, KTH - Royal Institute of Technology
Contributors: Cha, S., Wu, Q., Saleem, A., Østergaard, J., Ding, Y.
Publication date: 2011
Multi-agent based controller for islanding operation of active distribution networks with distributed generation

The increasing amount of distributed generation (DG) in today’s highly complex restructured power networks gives more options for distribution system operators (DSOs) under contingency conditions. A low voltage distribution network with a large amount of DG can be operated as an islanded system if the distribution system is disconnected from the main grid due to the contingency. In order to successfully operate distribution systems under islanding mode, the possibility of small power islands within the distribution system needs to be considered. The control and management of these small power islands are important, and the overall network synchronism must be ensured in the islanded distribution system. In this paper, a multi-agent based controller has been proposed to stabilize the frequency and voltages of an active distribution system after it enters into the islanding operation mode. The modified IEEE 9-bus system was used to investigate the dynamic and steady state performance of the active distribution system during islanding operation. Case studies have been carried out using the Real-Time Digital Simulator (RTDS) based simulation platform. Case study results show that the proposed multi-agent controller can efficiently help stabilize the frequency and voltages of active distribution systems.

General information
State: Published
Organisations: Electric Energy Systems, Department of Electrical Engineering, KTH - Royal Institute of Technology
Contributors: Cha, S., Wu, Q., Østergaard, J., Saleem, A.
Publication date: 2011

Host publication information
Title of host publication: Proceedings of DRPT 2011
Publisher: IEEE
ISBN (Print): 9781457703645
Keywords: Multi-agents, Islanding operation, Distributed generation (DG), Real time digital simulator (RTDS), Active distribution system
DOIs: 10.1109/DRPT.2011.5994002
Source: orbit
Source-ID: 275274
Research output: Research - peer-review › Article in proceedings – Annual report year: 2011

Optimal charging schedule of an electric vehicle fleet

In this paper, we propose an approach to optimize the charging schedule of an Electric Vehicle (EV) fleet both taking into account spot price and individual EV driving requirement with the goal of minimizing charging costs. A flexible and suitable mathematic model is introduced to characterize the smart charging behavior and detailed parameters needed for charging behavior of an individual EV are analyzed. The individual charging schedule is extended to the EV fleet. Simulation results are presented to illustrate the effectiveness of the proposed model.

General information
State: Published
Organisations: Electric Energy Systems, Department of Electrical Engineering, Electric Components, Automation and Control
Contributors: Hu, J., You, S., Østergaard, J., Lind, M., Wu, Q.
Publication date: 2011

Host publication information
Title of host publication: Proceedings of UPEC 2011
Keywords: Linear Program, Fleet Operator, Charging Schedule, Electric Vehicle
Source: orbit
Source-ID: 312659
Research output: Research - peer-review › Article in proceedings – Annual report year: 2011

Potential Analysis of Electric Vehicle (EV) Grid Integration

Electric vehicles (EVs) have been considered as distributed energy resources (DER) to handle the fluctuation from renewable energy resources (RES), especially the wind power. The intelligent management of EV charging and discharging can achieve the goal of providing up and down regulating power from EVs to support the reliable and secure operation of future power systems with high penetration of RES. In the mean time, the EV charging management has to respect the driving needs of EV users.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Potential Analysis of Regulating Power from Electric Vehicle (EV) Integration in Denmark

The potential analysis of having electric vehicles (EVs) provide regulating power has been implemented. The possible regulating power capacity from EVs and the economic return for EV users by providing regulating power are obtained. A spot price based charging schedule scenario has been used to do the day-ahead charging schedule for all EVs based on the predicted driving pattern. On top of the obtained charging schedule, the predicted EV availability and the charging schedule are used to calculate the possible regulating power capacity from EVs for both up regulating power and down regulating power. The activated regulating power and regulating power prices in the Denmark West System in 2010 have been used to calculate the economic return for EV users if all the regulating power is provided by EVs.

Power-Hardware-In-the-Loop (PHIL) Test of VSC-based HVDC connection for Offshore Wind Power Plants (WPPs)

This paper presents a power-hardware-in-the-loop (PHIL) test for an offshore wind power plant (WPP) interconnected to the onshore grid by a VSC-based HVDC connection. The intention of the PHIL test is to verify the control coordination between the plant side converter of the HVDC connection and the wind turbines within the WPP in order to ensure smooth operation of the WPP under both normal operating condition and operating conditions with grid faults. The PHIL test platform is comprised of a real time digital simulator (RTDS), a Spitzenerger Spies three phase 7.5 kW amplifier, a Danfoss VSC based converter and a chopper. The WPP is simulated in the RTDS which consists of a number of full scale converter wind turbines (FSCWTs). The simulated WPP interacts with the plant side converter through the Spitzenerger Spies amplifier. The interfacing between the RTDS and the Spitzenerger Spies amplifier is done by the analogue I/O card of the RTDS and the input channel of the amplifier. The amplifier scales up the voltages at the point of common coupling (PCC) of the WPP to the voltage level for the converter. The plant side VSC converter supplies power to the chopper. The test results show the successful control coordination between the WPP and the plant side VSC converter of the HVDC connection of the WPP.
Research Developments on Power System Integration of Wind Power

This paper presents an overview on the recent research activities and tendencies regarding grid integration of wind power in Denmark and some related European activities, including power electronics for enhancing wind power controllability, wind turbines and wind farms modeling, wind power variability and prediction, wind power plant ancillary services, grid connection and operation, Smart grids and demand side management under market functionality. The topics of the first group of PhD program starting 2011 under the wind energy Sino-Danish Centre for Education & Research (SDC) are also mentioned.

General information
State: Published
Contributors: Chen, Z., Hansen, J. C., Wu, Q., Hansen, A. D., Bak-Jensen, B.
Publication date: 2011

Review of Integration of Distributed Energy Resources (DERs) into Power Systems

An overview of the integration of distributed energy resources (DER) into power systems has been presented in this report.

Different aspects of integration of DER into power systems have been reviewed and discussed which are listed below.

- needs of DER integration into power systems
- various state-of-the-art DER integration concepts
- relations existing DER integration concepts to the EV system

The power balancing challenges of power systems brought by high penetration of intermittent DER have been discussed, especially the wind power integration in the Danish context. The relevance of the integration of electric vehicles (EVs) to the DER integration concepts have been analyzed as well based on the energy storage potential of EVs.

Two main concepts for DER integration, virtual power plant (VPP) and microgrids, are described and a comparison of the two concepts have been done. The comparison of VPP and microgrids concepts shows that the VPP concept is more suitable for EV integration.

General information
State: Published
Organisations: Department of Electrical Engineering, Center for Electric Power and Energy, Electric Power Systems
Contributors: Wu, Q., Xu, Z.
Number of pages: 11
Publication date: 2011

Towards a European renewable-based energy system enabled by smart grid: status and prospects

Renewable energy plays an important role in the future energy framework of the European Union. The European Union will reach a 20% share of renewable energy in total energy consumption and increase energy efficiency by 20% by 2020.
Smart grids will be the backbone of the future electricity network for integrating the high penetration of renewable energy resources. The plans and status of renewable energy resources development and energy policy in Europe are introduced in this paper. The development of smart grid technologies in the European Union is also discussed. The role of Denmark, one of the leading countries for developing renewable energy technologies and using renewable energy resources has been emphasized in this paper. ©2011 State Grid Electric Power Research Institute Press.

A Real-Time Simulation Platform for Power System Operation

This paper describes the real-time digital simulation platform that can be used for power system operation, analysis, and power system modeling. This particular platform gives grid operators, planners and researchers the opportunity to observe how a power system behaves and can be used to demonstrate modeling, system disturbances of various types, and proper recovery actions, as well as to illustrate complex power system concepts. The Kundur power system consists of two fully symmetrical areas linked together by two 230kV lines is modeled by using RSCAD in order to carry out simulations in real time. Various phenomena commonly encountered when dealing with the two-area system is studied. Despite its small size, it mimics very closely the behavior of typical systems in actual operation. The electromagnetic transient type of simulation made in RSCAD enables the study of fast and detailed phenomena like single-phase faults in the two-area network and to observe their effects on a larger time scale. Also, the case study of 11 bus system with 5 generators has been also used and the results are presented.
Average Behavior of Battery - Electric Vehicles for Distributed Energy System Studies
The increase of focus on electric vehicles (EVs) as distributed energy resources calls for new concepts of aggregated models of batteries. Despite the developed battery models for EVs applications, when looking at energy storage scenarios using EVs, both geographical-temporal aspects and battery use conditions cannot be neglected for a proper estimation of available fleet energy. In this paper we describe an average behavior of battery-EVs. Main points of this concept include the definition of the energy window and lifetime of the batteries, in relation to existing models and battery use conditions. The obtained results show that EV fleets are non-linear time-variant systems which however can be described with good approximation taking into account a number of variables such as number of cycles, temperature, depth-of-discharge and current rates.

Communication Test for 'MatrikonOPC Server for SCADA DNP 3' with RTDS
The purpose of the communication test for 'MatrikonOPC server for SCADA DNP 3' with RTDS is to verify the data exchange between the 'MatrikonOPC server for SCADA DNP 3' and the RTDS using the DNP 3 protocol. The communication test is part of the work for the 'Wind in Øresund' project. The objective of the 'Wind in Øresund' project is to build a demonstration and education system of power system operation and control with a RTDS and a SCADA system.
Direct Load Control (DLC) Considering Nodal Interrupted Energy Assessment Rate (NIEAR) in Restructured Power Systems

A direct load control (DLC) scheme of air conditioning loads (ACL) considering direct monetary compensation to ACL customers for the service interruption caused by the DLC program is proposed in this paper for restructured power systems. The nodal interrupted energy assessment rate (NIEAR), which is used as the bids from the ACL customers, is utilized to determine the direct monetary compensation to the ACL customers. The proposed scheme was investigated for the PoolCo electricity market. The optimal DLC scheme is determined based on the minimum system operating cost which is comprised of the system energy cost, the system spinning reserve cost and the compensation cost to the ACL customers. Dynamic programming (DP) was used to obtain the optimal DLC scheme. The IEEE reliability test system (RTS) was studied to illustrate the proposed DLC scheme.
DNP Communication Function with RTDS: GTNET-DNP & ASE Interface Test Results

A simulation case is implemented on RSCAD for testing their communication. The case has two binary status points (mapped to DNP binary input objects 1 & 2) and two binary control points (mapped to DNP binary output objects 10 and controlled via DNP objects 12). There is also one analog status point (mapped to DNP analog input objects 30 & 32) and one analog control point (mapped to DNP analog output object 40 & control via DNP objects 41). In order to use the DNP function on the RTDS, the DNP control component must be assigned to a GPC processor on the GPC card to which the GTNET card is connected. The program ‘ASE 2000 Communication Test Set’ is used to verify the transmission of exchanged data.
Driving Pattern Analysis for Electric Vehicle (EV) Grid Integration Study

In order to facilitate the integration of electric vehicles (EVs) into the Danish power system, the driving data in Denmark were analyzed to extract the information of driving distances and driving time periods which were used to represent the driving requirements and the EV unavailability. The Danish National Transport Survey data (TU data) were used to implement the driving data analysis. The average, minimum and maximum driving distances were obtained for weekdays, weekends and holidays to illustrate the EV users’ driving requirements in different days. The EV availability data were obtained from the driving time periods to show how many cars are available for charging and discharging in each time period. The obtained EV availability data are in one hour time periods and one quarter time periods for different study purposes. The EV availability data of one hour time period are to be used for optimal EV charging study in energy power market. The EV availability data of quarter time periods are to be used to investigate the possibility of utilizing EVs for providing regulation power. The statistical analysis software, SAS, was used to carry out the driving data analysis.

Fuzzy logic-based direct load control of air conditioning loads considering nodal reliability characteristics in restructured power systems

A fuzzy logic-based direct load control (DLC) scheme of large air conditioning loads (ACL), which considers the reliability characteristics of nodes where the ACL are connected, is proposed for restructured power systems. Transmission system reliability is integrated into the determination procedure of the DLC scheme of ACL using nodal reliability indices. Fuzzy dynamic programming (FDP) is utilized to determine the optimal DLC scheme of ACL which can achieve a good tradeoff among peak load shaving, system operating cost reduction and system reliability improvement. The IEEE reliability test system (RTS) is used to illustrate the proposed technique. (C) 2009 Elsevier B.V. All rights reserved.
Grid Integration Issues for Large Scale Wind Power Plants (WPPs)
The penetration level of wind power into the power system over the world have been increasing very fast in the last few years and is still keeping the fast growth rate. It is just a matter of time that the wind power will be comparable to the conventional power generation. Therefore, many transmission system operators (TSOs) over the world have come up the grid codes to request the wind power plants (WPPs) to have more or less the same operating capability as the conventional power plants. The grid codes requirements from other TSOs are under development. This paper covers the steady state operation and low voltage ride through (LVRT) for the WPPs. The discussion of coping with the grid codes requirements is presented to come up with the grid codes complied WPPs solutions.

General information
State: Published
Organisations: Centre for Electric Technology, Department of Electrical Engineering, Electric Energy Systems
Contributors: Wu, Q., Xu, Z., Østergaard, J.
Publication date: 2010

Host publication information
Title of host publication: IEEE Power and Energy Society General Meeting 2010
Publisher: IEEE
ISBN (Print): 978-1-4244-6549-1
Keywords: Wind Power Plants (WPPs), Grid Integration Issues, Grid Codes, Transmission System Operators (TSOs), Frequency Control, Low Voltage Ride Through, PQ Capability, Voltage Control, Wind Power
Electronic versions:
64A64015d01.pdf
DOIs:
10.1109/PES.2010.5589952

Bibliographical note
Copyright 2010 IEEE. Personal use of this material is permitted. However, permission to reprint/republish this material for advertising or promotional purposes or for creating new collective works for resale or redistribution to servers or lists, or to reuse any copyrighted component of this work in other works must be obtained from the IEEE.
Source: orbit
Source-ID: 256651
Research output: Research - peer-review › Article in proceedings – Annual report year: 2010

Long-Term Reserve Expansion of Power Systems With High Wind Power Penetration Using Universal Generating Function Methods
In a power system with high wind power penetration, reliability based reserve expansion is a major problem of system planning and operation due to the uncertainty and fast fluctuation of wind speeds. This paper studied the impact of high wind power penetration on the system reserve and reliability from long term planning point of view utilizing universal generating function (UGF) methods. The reliability models of wind farms and conventional generators are represented as
the correspondin UGFs and the special operators for these UGFs are defined to evaluate the customer and the system reliabilities. The effect of transmission network on customer reliabilities is also considered in the system UGF. The power output models of wind turbine generators in a wind farm considering wind speed correlation and un-correlation are developed, respectively. A reliability-based reserve expansion method is proposed to determine the conventional reserve required for power systems with high wind power penetration. The IEEE-RTS has been modified to illustrate the applications of the proposed method.

**General information**
State: Published
Organisations: Electric Energy Systems, Department of Electrical Engineering, Centre for Electric Technology, Nanyang Technological University
Pages: 1-1
Publication date: 2010
Peer-reviewed: Yes

**Publication information**
Journal: IEEE Transactions on Power Systems
Issue number: 99
ISSN (Print): 0885-8950
Ratings:
BFI (2018): BFI-level 2
Web of Science (2018): Indexed yes
BFI (2017): BFI-level 2
Scopus rating (2017): CiteScore 6.58 SJR 2.742 SNIP 2.662
Web of Science (2017): Impact factor 5.255
Web of Science (2017): Indexed yes
BFI (2016): BFI-level 2
Scopus rating (2016): CiteScore 8.17 SJR 3.368 SNIP 3.584
Web of Science (2016): Impact factor 5.68
Web of Science (2016): Indexed yes
BFI (2015): BFI-level 2
Scopus rating (2015): CiteScore 6.6 SJR 3.315 SNIP 3.386
Web of Science (2015): Impact factor 3.342
Web of Science (2015): Indexed yes
BFI (2014): BFI-level 2
Scopus rating (2014): CiteScore 5.31 SJR 2.475 SNIP 3.485
Web of Science (2014): Impact factor 2.814
Web of Science (2014): Indexed yes
BFI (2013): BFI-level 2
Scopus rating (2013): CiteScore 6.33 SJR 2.523 SNIP 4.243
Web of Science (2013): Impact factor 3.53
ISI indexed (2013): ISI indexed yes
Web of Science (2013): Indexed yes
BFI (2012): BFI-level 2
Scopus rating (2012): CiteScore 5.84 SJR 1.941 SNIP 3.387
Web of Science (2012): Impact factor 2.921
ISI indexed (2012): ISI indexed yes
Web of Science (2012): Indexed yes
BFI (2011): BFI-level 2
Scopus rating (2011): CiteScore 5.34 SJR 1.586 SNIP 3.205
Web of Science (2011): Impact factor 2.678
ISI indexed (2011): ISI indexed yes
Web of Science (2011): Indexed yes
BFI (2010): BFI-level 2
Scopus rating (2010): SJR 1.708 SNIP 2.759
Web of Science (2010): Impact factor 2.355
Modeling of Electric Vehicles (EVs) for EV Grid Integration Study
In order to successfully integrate EVs into power systems, it is necessary to develop a detailed EV model considering both the EV users’ driving requirements and the battery charging and discharging characteristics. A generic EV model was proposed which takes into account charging and discharging characteristics of EV batteries, the driving distance per trip and the availability of EVs for charging and providing grid service. The charging and discharging characteristics of EV batteries were used to determine the upper and lower limits of the state of charge (SOC) of EV batteries and to calculate the charging and discharging power. The driving distance per trip and availability of EVs were used to reflect the driving requirements and to implement intelligent charging and discharging management.

System Architecture Design for Electric Vehicle (EV) Systems
The electric vehicle (EV) system should fulfill the energy needs of EVs to meet the EV users’ driving requirements and enable the system service from EVs to support the power system operation with high penetration of renewable energy resources (RES) by providing necessary infrastructures. In order to realize the functionalities of the EV system, a three-level conceptual EV system has been proposed. The proposed conceptual model comprises the three listed levels.

management/control level
information/communication level
physical level.

The control/management level is dealing with local control or aggregated control concept and market solutions. The information/communication level is comprised of information exchange and ICT infrastructure. The physical level consists of meters, network connections, charging facility and EVs. The details of the three levels have been discussed. The stakeholders and business issues of the proposed conceptual have been discussed as well.
**EV Portfolio Management and Grid Impact Study**

The EV portfolio management is to develop an EV charging management algorithm in order to determine EV charging schedules with the goal of utilizing renewable energy production for EV charging as much as possible and ensuring that EV energy requirements for driving needs are met. According to the day-ahead spot price pattern in the Nordic power market, the spot prices are normally low when there is a lot of wind power production. Therefore, a fleet operator based EV charging scenario considering day-ahead spot prices is proposed to achieve this goal. The developed EV charging algorithm is to determine the day-ahead charging schedules of a fleet of EVs in order to minimize the EV charging cost with EV energy constraints taken into account. In order to investigate the benefits of the spot price based EV charging scenario, two more charging scenarios have been studied as well, i.e. plug and charging scenario (dumb charging) and timed charging scenario.

**Nodal price volatility reduction and reliability enhancement of restructured power systems considering demand-price elasticity**

With the development of restructured power systems, the conventional "same for all customers" electricity price is getting replaced by nodal prices. Electricity prices will fluctuate with time and nodes. In restructured power systems, electricity demands will interact mutually with prices. Customers may shift some of their electricity consumption from time slots of high electricity prices to those of low electricity prices if there is a commensurate price incentive. The demand side load shift will influence nodal prices in return. This interaction between demand and price can be depicted using demand-price elasticity. This paper proposes an evaluation technique incorporating the impact of the demand-price elasticity on nodal prices, system reliability and nodal reliabilities of restructured power systems. In this technique, demand and price correlations are represented using the demand-price elasticity matrix which consists of self/cross-elasticity coefficients. Nodal prices are determined using optimal power flow (OPF). The OPF and customer damage functions (CDFs) are combined in the proposed reliability evaluation technique to assess the reliability enhancement of restructured power systems considering demand-price elasticity. The IEEE reliability test system (RTS) is simulated to illustrate the developed techniques. The simulation results show that demand-price elasticity reduces the nodal price volatility and improves both the system reliability and nodal reliabilities of restructured power systems. Demand-price elasticity can therefore be utilized as a possible efficient tool to reduce price volatility and to enhance the reliability of restructured power systems. (C) 2008 Elsevier B.V. All rights reserved.
Scopus rating (2007): SJR 0.472 SNIP 1.251
Web of Science (2007): Indexed yes
Scopus rating (2006): SJR 0.481 SNIP 0.876
Web of Science (2006): Indexed yes
Scopus rating (2005): SJR 0.556 SNIP 1.101
Scopus rating (2004): SJR 0.33 SNIP 1.062
Scopus rating (2003): SJR 0.742 SNIP 0.852
Web of Science (2003): Indexed yes
Scopus rating (2002): SJR 0.464 SNIP 0.709
Scopus rating (2001): SJR 0.407 SNIP 0.41
Scopus rating (2000): SJR 0.227 SNIP 0.559
Scopus rating (1999): SJR 0.225 SNIP 0.435
Original language: English
Keywords: Energy Engineering and Power Technology, Electrical and Electronic Engineering, CDFs, Demand-price elasticity, Nodal price volatility reduction, OPF, Reliability enhancement, Restructured power systems, Acoustic generators, Computer networks, Customer satisfaction, Elasticity, Electric power systems, Electric power transmission networks, Electric tools, Magnetism, Marketing, Power electronics, Power transmission, Sales, Strength of materials, And nodes, Customer damage functions, Electricity consumption, Electricity demands, electricity pricing, Elsevier (CO), IEEE-reliability test system, Load shifting, Nodal pricing, Optimal power flow (OPF), price elasticities, price volatility, reliability enhancement, Reliability Evaluation, simulation results, system reliability, Time slot (TS), Electricity, Demand–price elasticity, ENGINEERING,, ELECTRICITY MARKET, CONTRACTS, MODELS, restructured power systems, demand-price elasticity, nodal price volatility reduction
DOIs:
10.1016/j.epsr.2008.02.012
Source: FindIt
Source-ID: 6494213
Research output: Research - peer-review › Journal article – Annual report year: 2008

Projects:

**Optimal operation and real time control of integrated energy systems**
Turk, A., PhD Student, Department of Electrical Engineering
Wu, Q., Main Supervisor, Department of Electrical Engineering
Zeng, Q., Supervisor, Department of Electrical Engineering
01/10/2018 → 30/09/2021
Project: PhD

**Coordinated Control of Wind Power and Combined AC/DC Grid**
Wang, P., PhD Student, Department of Electrical Engineering
Wu, Q., Main Supervisor, Department of Electrical Engineering
Nielsen, A. H., Supervisor, Department of Electrical Engineering
15/10/2018 → 14/10/2021
Project: PhD

**Optimal Operation of Integrated Electricity and Heat Systems with Large Amounts of Wind and Solar Power**
Tan, J., PhD Student, Department of Electrical Engineering
Wu, Q., Main Supervisor, Department of Electrical Engineering
Zeng, Q., Supervisor, Department of Electrical Engineering
15/10/2018 → 14/10/2021
Project: PhD

**Robust Congestion Management and Self-healing for Active Distribution Networks**
Shen, F., PhD Student, Department of Electrical Engineering
Wu, Q., Main Supervisor, Department of Electrical Engineering
Huang, S., Supervisor, Department of Electrical Engineering
Xu, Y., Supervisor
Institut stipendie (DTU)
01/09/2017 → 31/08/2020
Award relations: Robust Congestion Management and Self-healing for Active Distribution Networks
Phasor Measurement Unit Applications for Small Signal Stability Assessment and Improvement of Power Systems
Ghiga, R., PhD Student, Department of Electrical Engineering
Nielsen, A. H., Main Supervisor, Department of Electrical Engineering
Wu, Q., Supervisor, Department of Electrical Engineering
Yang, G., Examiner, Department of Electrical Engineering
Fu, Y., Examiner
Uhlen, K., Examiner
Samfinansieret - Andet
01/01/2014 → 13/09/2017
Award relations: Phasor Measurement Unit Applications for Small Signal Stability Assessment and Improvement of Power Systems
Project: PhD

Real-Time Analysis of an Active Distribution Network - Coordinated Frequency Control for Islanding
Cha, S., PhD Student, Department of Electrical Engineering
Østergaard, J., Main Supervisor, Department of Electrical Engineering
Wu, Q., Supervisor, Department of Electrical Engineering
Tænholt, C., Examiner, Department of Electrical Engineering
Marnay, C., Examiner
Repo, S. P., Examiner
1/3 FUU, 1/3 inst 1/3 Andet
01/08/2009 → 04/04/2013
Award relations: Real-Time Analysis of an Active Distribution Network - Coordinated Frequency Control for Islanding
Project: PhD

Offshore Wind Park Control Assessment Methodologies to Assure Robustness and Fault tolerance
Gryning, M. P. S., PhD Student, Department of Electrical Engineering
Blanke, M., Main Supervisor, Department of Electrical Engineering
Andersen, K. H., Supervisor, Department of Automation
Niemann, H. H., Supervisor, Department of Electrical Engineering
Sørensen (fratrådt), T., Supervisor, Department of Electrical Engineering
Wu, Q., Supervisor, Department of Electrical Engineering
Cutululis, N. A., Examiner, Department of Wind Energy
Erlich, I., Examiner
Stoustrup, J., Examiner, Department of Applied Mathematics and Computer Science
Erlich, I., Examiner
ErhvervsPhD-ordningen VTU
01/09/2012 → 20/01/2016
Award relations: Offshore Wind Park Control Assessment Methodologies to Assure Robustness and Fault tolerance
Project: PhD

Early Warning for Cascading Outages in Electric Power Systems
Petersen, P. F., PhD Student, Department of Electrical Engineering
Nielsen, A. H., Main Supervisor, Department of Electrical Engineering
Jóhannsson, H., Supervisor, Department of Electrical Engineering
Wu, Q., Examiner, Department of Electrical Engineering
Repo, S. P., Examiner
Terzija, V., Examiner
Samfinansieret - Andet
01/11/2013 → 06/12/2017
Award relations: Early Warning for Cascading Outages in Electric Power Systems
Project: PhD

Exploring Market Models for a European Electricity Grid With a High Penetration of Renewable Energy Sources
Jensen, T. V., PhD Student, Department of Electrical Engineering
Pinson, P., Main Supervisor, Department of Electrical Engineering
Greiner, M. O. W., Supervisor
Wu, Q., Examiner, Department of Electrical Engineering
Bjørndal, M. H., Examiner
Papavasiliou, A., Examiner
Award relations: Exploring Market Models for a European Electricity Grid With a High Penetration of Renewable Energy Sources
Project: PhD

Congestion Management of Distribution Networks with High Penetration of Distributed Energy Resources (DERs)
Huang, S., PhD Student, Department of Electrical Engineering
Wu, Q., Main Supervisor, Department of Electrical Engineering
Nielsen, A. H., Supervisor, Department of Electrical Engineering
Træholt, C., Examiner, Department of Electrical Engineering
Hobbs, B. F., Examiner
Repo, S. P., Examiner
Samfinansieret - Andet
01/09/2013 → 13/09/2017
Award relations: Congestion Management of Distribution Networks with High Penetration of Distributed Energy Resources (DERs)
Project: PhD

Validation of Control Services in Future Sustainable Power Systems
Bondy, D. E. M., PhD Student, Department of Electrical Engineering
Bindner, H. W., Main Supervisor, Department of Electrical Engineering
Heussen, K., Supervisor, Department of Electrical Engineering
Niemann, H. H., Supervisor, Department of Electrical Engineering
Wu, Q., Examiner, Department of Electrical Engineering
Kamphuis, R., Examiner
Mathieu, J. L., Examiner
Kamphuis, R., Examiner
Mathieu, J. L., Examiner
Institut, samfinansiering
15/09/2012 → 10/05/2017
Award relations: Validation of Control Services in Future Sustainable Power Systems
Project: PhD

Dynamic Coverage and Flow Coordination in Multi-Agent Networks
Aabrandt, A., PhD Student, Department of Electrical Engineering
Træholt, C., Main Supervisor, Department of Electrical Engineering
Hansen, V. L., Supervisor
Poulsen, B., Supervisor
Wu, Q., Examiner, Department of Electrical Engineering
Jensen, A. N., Examiner
Scaglione, A., Examiner
Institut stipendie (DTU) Samf.
15/05/2013 → 08/02/2017
Award relations: Dynamic Coverage and Flow Coordination in Multi-Agent Networks
Project: PhD

Coordinated Control of Wind Power Plants and Energy Storage Systems
Zhao, H., PhD Student, Department of Electrical Engineering
Wu, Q., Main Supervisor, Department of Electrical Engineering
Rasmussen, C. N., Supervisor, Department of Electrical Engineering
Træholt, C., Examiner, Department of Electrical Engineering
Pöller, M., Examiner
Zhang, B., Examiner
Institut stipendie (DTU) Samf.
15/10/2011 → 27/02/2015
Award relations: Coordinated Control of Wind Power Plants and Energy Storage Systems
Project: PhD
Electric vehicle integration in a real-time market
Pedersen, A. B., PhD Student, Department of Electrical Engineering
Østergaard, J., Main Supervisor, Department of Electrical Engineering
Gantenbein, D., Supervisor
Poulsen, B., Supervisor, Department of Informatics and Mathematical Modeling
Wu, Q., Examiner, Department of Electrical Engineering
Jørgensen, P., Examiner
Kempton, W., Examiner, Department of Electrical Engineering
Jørgensen, P., Examiner
Institut stipendie (DTU) Samf.
01/02/2011 → 18/03/2015
Award relations: Electric vehicle integration in a real-time market
Project: PhD

Energy and Ancillary Services In Future Electricity Markets
Soares, T., PhD Student, Department of Electrical Engineering
Pinson, P., Main Supervisor, Department of Electrical Engineering
Wu, Q., Examiner, Department of Electrical Engineering
Bell, K. R. W., Examiner
Ernst, D., Examiner
Institut stipendie (DTU)
01/02/2014 → 10/05/2017
Award relations: Energy and Ancillary Services in Future Electricity Markets
Project: PhD

Optimal Operation of Distribution Networks with Electrification of Transport and Heating in Nordic Region
Liu, Z., PhD Student, Department of Electrical Engineering
Nielsen, A. H., Main Supervisor, Department of Electrical Engineering
Wu, Q., Supervisor, Department of Electrical Engineering
Træholt, C., Examiner, Department of Electrical Engineering
Sun, H., Examiner
Wang, L., Examiner
Institut stipendie (DTU) Samf.
01/10/2012 → 16/03/2016
Award relations: Optimal Operation of Distribution Networks with Electrification of Transport and Heating in Nordic Region
Project: PhD

IDE4L: Ideal grid for all
The IDE4L project will define, develop and demonstrate the entire system of distribution network automation, IT systems and applications for active network management. Active distribution networks will utilize distributed energy resources (DERs) for network management including both real time operation and long-term network planning viewpoints. DERs consist of aggregated distributed generation, demand response and other controllable loads. The starting point of development are existing distribution networks, their management systems, future expectations of penetration of renewable energy sources and high expectations of customers for continuity of service. The research and development work done in the project integrates many existing automation and IT systems utilizing available standard protocols in an innovative way and develops new applications based on that system. Demonstrations of integrated automation system and applications will be realized in real life networks in different parts of Europe where are connected large and small scale PV, wind power, heat pumps and EVs located in urban and rural areas. The outcome of the project will be applicable in very near future in all over Europe. Integrated distribution network automation system will be capable of monitoring, controlling, managing fast changing conditions and integrating large number of DERs in distribution network. Technical solutions utilizing the automation system will enhance the reliability of distribution network by improving fault location, isolation and supply restoration, will increase the hosting capacity of distribution network for renewables by managing network congestion with DERs, will optimize the operation of DERs by aggregating DERs and coordinating these with distribution network management, and will monitor dynamic behaviour of distribution network for system management.
Wu, Q., Project Participant, Department of Electrical Engineering, Center for Electric Power and Energy
01/09/2013 → 31/08/2016
Project: Research

FA ENDK: Rammeaftalе vedrørende udnyttelse af PowerlabDK's faciliteter
Indgået følgende aftale ("Rammeaftalе") om en ramme for Parternes fremtidige samarbejde og udnyttelse af PowerlabDK's faciliteter på Danmarks Tekniske Universitet ("DTU").
Wu, Q., Project Participant, Department of Electrical Engineering, Center for Electric Power and Energy
01/01/2013 → 31/12/2017
Electric vehicles (EVs) provide a unique opportunity to reduce the CO2 emissions from the transport sector. At the same time, EVs have the potential to play a major role in an economic and reliable operation of an electricity system with a high penetration of renewable energy. EVs will be a very important balancing measure to enable the Danish government's energy strategy, which implies 50% wind power penetration in the electric power system. An EV will be a storage device for smoothing power fluctuations from renewable resources especially wind power and provide valuable system services for a reliable power system operation. With the proper technology the cars can run on wind power and at the same time enable an increased share of RES in the power system for supply of the conventional electricity demand, and thereby, provide an overall economic, reliable, and sustainable energy system. Denmark does not have a car industry, and the Danish background for development of EVs themselves is limited. On the other hand Danish companies and research institutions have a very strong knowledge and competence regarding design, development, and operation of power systems with high penetration of distributed generation. Furthermore, Danish industry is involved in technologies, which
are critical to a widespread use of EVs such as strategy for optimised battery charging/discharging, and power electronics related to battery charging/discharging. This forms an ideal base for development of systems and integration solutions for EVs. The Danish competence can be utilised to develop optimal system solutions for EV system integration, including network issues, market solutions, and optimal interaction between different energy technologies. Furthermore, the Danish electric power system provides an optimal platform for demonstration of the developed solutions, and thereby, provides the commercial basis for Danish technology export. Furthermore, the advantage of being a “first mover” constitutes a business advantage, as well as, a possibility of a strong Danish influence on future standards for system integration of EVs, whereby optimal utilization of the EVs in the power system is obtained.

Wu, Q., Project Participant, Department of Electrical Engineering, Center for Electric Power and Energy
02/03/2009 → 31/12/2012
Project: Research

Pre-standardisation of wind power modelling
The purpose of the project is to support the standardisation work in IEC Technical Committee 88 (TC88) Working Group 27 (WG27) on electrical simulation models for wind power generation. This work is done in cooperation between DTU and industry partners. The role of DTU has been to implement the IEC models in Power Factory, and in cooperation with industry to parametrise and validate the models against test results.

Serensen, P. E., Project Manager, Department of Wind Energy, Wind Energy Systems
Hansen, A. D., Project Participant, Department of Wind Energy, Wind Energy Systems
Wu, Q., Project Participant, Department of Electrical Engineering, Center for Electric Power and Energy
01/05/2009 → 30/11/2013
Project: Research

EcoGrid EU: EcoGrid EU - Large scale Smart Grids demonstration of real time market-based integration of DER and DR
The EcoGrid EU project proposal offers Europe a “fast track” evolution towards Smart Grid dissemination and deployment in the distributed electricity grid. The aim is to contribute to the European 20-20-20 goals by showing that it is possible to operate a distribution power system (on the Danish island of Bornholm) with more than 50% renewable energy sources (RES) making active use of new communication technology and innovative market solutions. The EcoGrid EU concept will contribute to the operation of the transmission system by offering the TSOs additional balancing and ancillary services. EcoGrid EU is a large-scale demonstration of a complete power system including the following key elements: - The total distributed grid with all resources up to 60 kV, 28,000 customers, 55 MW peak load, 268 GWh electricity consumption and 500 GWh heat demand - All distributed RES including wind power, photo voltaic, biomass, biogas, five units with heat accumulation tanks for district heating and electric vehicles (EVs) - ICT systems and a new information architecture allowing all units of distributed energy resources (RES) and demand response (DR) to participate in the power market. There will be a communication and information system and new operational procedures - Full market participation utilizing all parts of the existing power market and developing a new near real-time market for deliverance of ancillary services both from RES and DR - "Smart" Meters, "Smart" Controllers and E-mobility by using electric vehicles as an integrated part of the total concept - Storage of energy will be demonstrated using heat appliances as well as batteries of the electric vehicles. The EcoGrid EU-project will combine knowledge from previous EU funded projects into a large-scale demonstration where the outcome of the project will be substantial contribution to a "Road map for European Smart Grids deployment".

Pedersen, A. B., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Ding, Y., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Feng, D., Project Participant, Department of Electrical Engineering
Larsen, E. M., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Nielsen, A. H., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Pedersen, R. R., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Pensini, A., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Pineda Morente, S., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Rasmussen, C. N., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Hashemi Toghroljerdi, S., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Wu, Q., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Yang, G., Project Participant, Department of Electrical Engineering, Electric Energy Systems
Østergaard, J., Project Participant, Department of Electrical Engineering, Center for Electric Power and Energy
Pinson, P., Project Participant, Department of Electrical Engineering, Center for Electric Power and Energy, Energy Analytics and Markets
Le Ray, G., Project Participant, Department of Electrical Engineering, Center for Electric Power and Energy, Energy Analytics and Markets

EU FP7: DKK178,725,000.00
01/04/2011 → 30/09/2015
Award relations: EcoGrid EU - Large scale Smart Grids demonstration of real time market-based integration of DER and DR
Documents:
Fact sheet EcoGrid EU 2015
Project: Research