High Efficiency Power Converter for Low Voltage High Power Applications

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

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