December 12, 2016

Design and Optimization of Soft Switched Power Converters for Low and Medium Power Applications

Author licentiate thesis: Muhammad Abu Bakar
STC Research Centre
Mid Sweden University

Abstract

Power electronics technology is rapidly growing in most industrial applications. There is an increasing demand for efficient and low profile power converters in automotive industry, power grids, renewable energy systems, electric rail systems, home appliances, and information technology. The power requirement varies from few watts to MW. It is not possible to combine all industrial requirements into one solution if power converters are to remain efficient, low profile and most importantly cost efficient. Making power converters efficient, high power density and cost-effective depends on the topology chosen for the converter. Some topologies are easier to design, some are complex to control and some have low part count.

The focus of this thesis is on investigating power converter solutions both for lower power applications and medium power applications. For low power applications, the flyback converter is still a common choice for the electronics industry; it has low part count, simple to design for single output, multiple outputs and even for inverted output. The introduction of new devices such as silicon carbide (SiC) and gallium nitride (GaN) has made it possible to increase the power density of the converters by increasing the switching frequency up to a few MHz. This increased switching frequency increases the losses in the magnetics as well as in the switching devices. These losses severely degrades the performance of the converter. The traditional hard switched flyback converter along with the conventional wire wound transformers cannot meet the industry's requirements of low profile and energy efficient power converter.

This thesis discusses the losses in the hard switched flyback converters, switching both in continuous conduction mode and discontinuous conduction mode. For improvement in the efficiency, the possible soft switching techniques such as boundary conduction mode and quasi resonant conduction mode are studied. A flyback converter is designed using emerging gallium nitride GaN FET power devices in combination with the in-house 66-layer printed circuit board (PCB) transformer, which is then investigated both in boundary conduction mode and quasi resonant conduction mode. The control for soft switching is implemented by using the digital signal processor. The prototype of the converter is tested for the telecom input voltage range of 36-72Vdc while switching at the frequencies of up to 4MHz. The recorded highest energy efficiency of the converter is 94%, which according to the best of the author's knowledge is the highest efficiency ever achieved in flyback converters, switching in the MHz frequency region.

In soft switched power converters, the leakage inductance of the main transformer plays a vital role in achieving soft switching for the desired operating conditions. The intrinsic leakage energy of the transformer is usually not sufficient to obtain the necessary resonance with the parasitic capacitance of the power switches. The value of this leakage inductance also defines the range of zero voltage switching in these converters. In order to increase the total leakage induc-

Sensible Things that Communicate
PART OF MID SWEDEN UNIVERSITY

December 12, 2016

tance, an extra inductor is connected in series with the primary winding of the transformer. This inductor not only decreases the power density of the converter but also adds costs to the design.

Extensive work is carried out to add the extra inductor inside the main transformer. Some have suggested increasing the leakage inductance by increasing the inter-winding spacing and some have proposed to add a magnetic shunt inside the main transformer.

A new transformer is modelled in this thesis by combining both of the approaches into one transformer. This increases the leakage inductance in two steps, first by increasing the inter-winding spacing and then by adding the magnetic material in this spacing. It also gives better control over the leakage inductance compared to previous proposals. To predict the leakage inductance, an analytical approach is adopted. This approach makes the model more time efficient than using finite element analysis. The model is verified both by calculations and experimental measurements. To further verify the model in a practical application, a phase shifted full bridge topology is selected.

In medium power applications, the soft switched full bridge converter is getting more attention than its competitors such as resonant converters, quasi resonant converters and multi-level resonant converters. The main reason for this is that the soft switched full bridge converter belongs to the family of conventional pulse width modulated converters switching at constant frequency. However, the soft switching in other types can also be obtained without the addition of auxiliary winding, but the disadvantages are the non-conventional variable frequency, large circulating energy and high voltage as well as current stress. In order to validate the model, a transformer is designed and constructed for the phase shifted full bridge converter. The converter along with the modelled transformer is then investigated up to the output power of 500 watts and soft switching has successfully been observed for a wide range of output loads.

Earlier works have mainly focused on the actual value of leakage inductance and not studied the introduced losses in the transformer. By inserting magnetic material inside the transformer, the main part of the leakage flux flows through the magnetic material and consequently there must be some loss associated with it. It could also be the case when using an external inductor in series with the transformer. This thesis also studies the effects of increasing the leakage inductance on the performance of the transformer either by introducing the magnetic shunt or by increasing the inter-winding spacing. The cause of the losses is discussed in detail and suggestions are presented to reduce the extra losses. For the purpose of loss analysis, a transformer for increased leakage inductance is modelled and constructed. The modelling is performed both for introduced inter-winding spacing and magnetic shunt inside the transformer. The investigations show that increasing the leakage inductance by inserting a magnetic shunt can have severe degrading effects on the performance of the transformer if it is not designed adequately. Additional losses are also calculated and the effect is verified by the measurements.

Sensible Things that Communicate

PART OF MID SWEDEN UNIVERSITY