POPULAR SCIENTIFIC ABSTRACT

Mohammad Najjar

Modeling and Analysis of High Power Density Multi Level Grid-Connected Converters Using Wide Bandgap Devices

The application of active rectifiers as dc voltage suppliers are increasing due to the demand for dc loads such as electric vehicle battery charging, information and communication technology equipment, and variable speed drives. Active rectifiers have gotten more attention considering grid regulations and electromagnetic interference (EMI) standards regarding harmonic and noise injections. Besides these, increasing the power density and the efficiency of converters make the converters more appealing to the industry. Therefore, the main objectives of this thesis are to improve the efficiency and power density of active rectifiers considering an EMI standard.

Multilevel converters have some benefits over two-level converters, such as lower voltage across switches, staircase output voltage, and smaller filter size. Considering the number of devices and complexity of modulation techniques, three-level converters are desirable for industries among different multilevel topologies. The active neutral point clamped (ANPC) structure and T-type converter can be considered as two well-known industry candidates. A comprehensive comparison between these two topologies and the common two-level converter to reach higher power density utilizing the best switch technologies in the market is carried out in this study. This study shows that ANPC owing to its structure, can utilize the merit of gallium nitride (GaN) transistors, and that gives a considerable benefit over T-type and two-level configuration in terms of higher power density. Therefore, ANPC is chosen to be the topology under study.

To achieve high power density as well as high efficiency, all components of the converter, such as switches, EMI filter, and dc-link parameters should be optimized. Increasing the switching frequency can be considered as a solution to improve the power density and result in reducing the filter size. However, increasing switching frequency introduces more power loss and, therefore, lower efficiency or possibly lower power density due to increasing the heatsink size. Wide bandgap (WBG) devices are alternatives to silicon devices that present lower switching losses. Therefore, through employing WBG devices, the switching frequency can be increased with lower switching losses. On the other hand, increasing switching frequency propagates harmonics with bigger amplitudes in the EMI range. To attenuate these noises based on standards and to reduce the EMI filter size, an EMI filter with few stages is utilized. Therefore, the switching frequency should be selected considering the efficiency and EMI filter size. A comprehensive study is carried out in this work on the impact of the switching frequency on the size of the EMI filter. This study defines a region that is the best for a specific modulation technique, and it results in a smaller EMI filter.

Based on these analyses, to prove the concept and to achieve a high power density converter, a 10 kW three-phase laboratory prototype of the converter, including an EMI filter, is built and different experiments are carried out. In the structure of the converter, both GaN and Si MOSFETs are utilized. The peak efficiency of 99.34% and full load efficiency of 99% are achieved at rectifier mode with the switching frequency of 140 kHz. The obtained power density is 2.4 kW/dm^3. In addition, CISPR 11 Class A conducted EMI standard is fulfilled.

The 3-level ANPC presents some limitations when the structure is considered for single-phase applications. This structure cannot produce full dc-link voltage at the output, and always a dc-link capacitor is in the current path. As a result, the structure should be modified for single-phase application. One way is to use two 3-level ANPC converters to reach a single-phase 5-level converter, in which the structure includes 12 switches. A solution to reach the same number of output voltage levels is to utilize the switch reduced ANPC structure in which eight switches are applied in the structure. A 2 kW SiC/Si based laboratory prototype of this converter is built, and the efficiency measurement is performed. At the switching frequency of 70 kHz, the peak efficiency of 98.4 % is achieved.