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論文内容の要旨

In the last two decades, the concerns about fossil fuel depletion and global climate change are promoting the growth of electric vehicle (EV) market. In 1997, the Toyota Prius was released in Japan and became the world's first mass-produced plug-in hybrid electric vehicle (PHEV). In 2008, Tesla released its electric vehicle, Roadster, which was the first all-electric vehicle (EV) car using Li-ion battery cell and with a range greater than 200 miles per charge. Nissan also released a Li-ion-battery-based affordable family car, the Nissan LEAF, in 2010, which became the world's all-time best selling highway-capable all-electric car.

The global electric car stock has been growing fast since 2015. It has now reached around total 3.2 million EV vehicles cumulative sale in 2020, with expectations of reaching between 30 million by 2030.

For increasing millage range of Electrical Vehicles, the power capacity of the battery must be increased over time, from 24 kWh (Nissan Leaf) to current 85 kWh (Tesla S) for millage range from 175 km to current 426km.

For supplying power for fast charging, high voltage power source from Medium voltage (MV) electrical power line will be reduced to 400V level by step-down transformer, and then supply to the input of the fast charger.

The fast charger will be fabricated from multiple inverter modules. For example, one 120kWh power fast charger of Tesla will be created by 12 modules of 10kW charging dc/dc converter module. The 10kW power charging dc/dc converter is normally used to charge 400 VDC level battery with the full-charge voltage around 480 VDC-500 VDC. The motivation in this thesis is to create the scale-down charging circuit to 48V level battery, but with the same current rating in the circuit with 480 VDC, 10 kW circuit, therefore the rated charging power is designed as 48 VDC, 1 kW charging capacity DC-DC converter.

Among various DC-DC configurations, Dual-Active-Bridge (DAB) or Single-Active-Bridge (SAB) are normally used for battery charging due to their simple control and easy parallel-modules working characteristic for high power charging. For unidirectional power charging, SAB will be used to save cost. However, the SAB DC-DC converter suffers from high peak current, voltage stress, small output voltage range/voltage conversion ratio (0-0.7), low total power factor (TPF) (TPF=0.66 in this thesis) leading to the inefficient design/utilization of transformer core and the circuit.

This thesis focuses on the development a novel, unidirectional, high-frequency isolated DC–DC converter called a Secondary-Resonant Single-Active-Bridge (SR–SAB) DC–DC converter. The circuit topology of the SR–SAB converter is a resonant capacitor connected to each diode in parallel in order to construct the series resonant circuit in the secondary circuit. As a result, the SR–SAB converter achieves a unity voltage conversion ratio, lower 23% primary input voltage which can be translated into 23% reduction in primary winding (copper wire) and primary steel core design, current peak reduces by 40%, higher TPF (TPF=0.89), wider power supply/or output voltage range (0-1.7) as compared to the conventional SAB. The SR-SAB therefore can be designed smaller and more compact. Small and nonsignificant overshoot values of current and voltage waveforms are observed. Soft-switching commutations of the primary H-bridge circuit and the soft recovery of secondary diode bridge are achieved.

The SR-SAB DC converter can be described as a hybrid converter between the Dual-Active-Bridge (DAB), Single-Active-Bridge (SAB) and the LLC resonant DC-DC converter, in which, most of the duty cycle the SR-SAB will work with the same philosophy as the DAB or SAB converter, and part of the duty cycle work as LLC resonant converter with the resonance between the leakage inductor and the resonant capacitor installed in parallel with the diodes.

The thesis starts first with the background, motivation, analysis of most common type DC-DC converters, analysis of traditional SAB DC-DC converter.

Then the operating philosophy of SR-SAB is analyzed, and the design at rated designed condition is presented. It is then followed by the operation of the SR-SAB for adjusting output power by variable frequency (VF) with soft-switching, or Pulse Width Modulation (PWM), step-changed output power control in the Constant Voltage (CV) mode.

After that, the combination of variable frequency (VF) and Pulse Width Modulation (PWM) executed to achieve soft-switching for Constant Current (CV) battery charging mode is presented.

The effectiveness of the SR–SAB converter was verified by experiments using a 1 kW, 265 VDC/48 VDC, and 20 kHz laboratory prototype.

Finally, for the purpose of reducing half of the switching devices, diodes, or to make the circuit more compact, and reduce cost, a half-bridge version of SR-SAB which is called Secondary-Resonant Single-Active-Half-Bridge (SR-SAHB), is presented with operating philosophy, parameter design, and output power regulation by variable frequency control. The SR-SAHB is then validated by experimental demonstration with a laboratory prototype 2.4 kW 265 VDC/265 VDC, 20kHz SR-SHAB isolated dc-dc converter.