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Comparison of Single Stage and Two Stage HB LLC Resonant Converter with Reduced Losses for a Wide Range of Low Input Voltage

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Abstract:
In this paper, the comparison between single stage half bridge LLC resonant converter and two stage half bridge LLC resonant converter is presented. The power loss in two stage HB LLC resonant converter is reduced by adopting a boost converter in the front end of HB LLC resonant converter.

Keywords: Half Bridge (HB), Zero Voltage Switching (ZVS), Asymmetric Pulse Width Modulation (APWM)

I. INTRODUCTION

Power electronic designs have generally been cost driven. Simple circuit topologies with low complexity, low component count, and simple controls have traditionally been preferred in practical designs. However, with increasing electronic content in industrial and consumer applications, and wider deployment of renewable energy systems, power electronics is required to have much higher performance. Power conversion systems can generally be grouped into single-stage converters and multi-stage converters. In single-stage converters, multiple tasks (e.g., output voltage modulation, input current shaping) are realized in a single power stage. They have low circuit complexity and simple control, but cannot achieve high performance while meeting requirements such as wide operating ranges and high power density. Two-stage converters have two power conversion stages with each stage performing one or more functions. Each stage can be optimally designed to only address a portion of the system requirements. As a result, the overall system performance is often better, while the total component count and complexity is usually higher. Loss in two stage converter will be less when compared with single stage because in two stage we have a boost converter to increase the input of next stage.

II. CONCEPT OF SINGLE STAGE LLC RESONANT CONVERTER

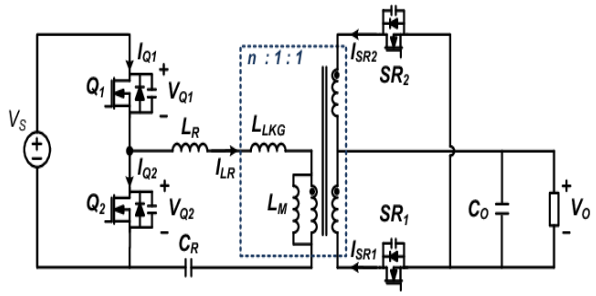

Figure.1. Circuit diagram of single stage HB LLC resonant converter

The converter configuration in Fig.1. has three main parts: Power switches Q_1 and Q_2 , which are usually MOSFETs, are configured to form a square-wave generator. This generator produces a unipolar square-wave voltage, V_S, by driving switches Q_1 and Q_2 , with alternating 50% duty cycles for each switch. A small dead time is needed between the consecutive transitions, both to prevent the possibility of cross- conduction and to allow time for ZVS to be achieved. The resonant circuit, also called a resonant network, consists of the resonant capacitance, C_R, and two inductances—the series resonant inductance, L_R, and the transformer's magnetizing inductance, L_M. The transformer turns ratio is n. The resonant network circulates the electric current and, as a result, the energy is circulated and delivered to the load through the transformer. The transformer's primary winding receives a bipolar square-wave voltage, V so. This voltage is transferred to the secondary side, with the transformer providing both electrical isolation and the turns ratio to deliver the required voltage level to the output. The load includes losses from the transformer and output rectifiers. The output capacitor smoothen the rectified voltage and current. The rectifiers can also be implemented with MOSFETs forming synchronous rectification to reduce losses, especially beneficial in low-voltage and high-current applications. This converter has simple structure with small component count. But for wide input voltage, it is hard to achieve the optimized efficiency. Moreover, due to low input voltage and limited transformer ratio, large current is reflected in the primary side. As a result, the loss becomes large, thus efficiency becomes low. To cover the design limitation of single stage HB LLC, we are moving to two stage HB LLC.

III. CONCEPT OF TWO STAGE RESONANT CONVERTER

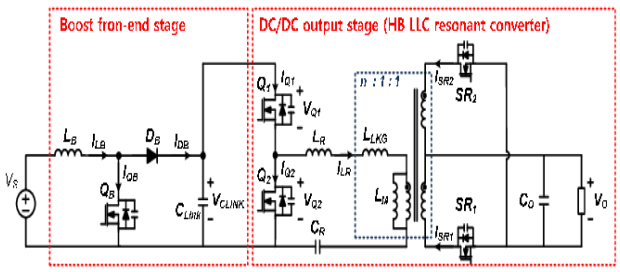

Figure.2. Circuit diagram of two stage HB LLC resonant converter

The converter configuration in Fig.2. shows, two stage HB LLC resonant converter. In two stage HB LLC, a boost converter is added at the front end of HB LLC. So, it consists of front end boost converter and dc/dc output stage. By applying the front end boost converter, V_{CLINK}, which is the input voltage of HB LLC resonant converter is increased. Thus, loss at the LLC stage can be reduced. The reduction is because of small reflected current from the secondary side due to large voltage gain and transformer turns ratio. The two stage LLC resonant converter has overcome the drawbacks of single stage HB LLC by adopting Zero voltage switching.

A. ZVS Operation

In the HB LLC stage of the conventional two-stage approach, the ZVS operation can be easily achieved under the entire load range because of large ZVS energy of L_M. On the other hand, in the presented converter, the ZVS conditions are changed because the currents on Q_1 and Q_2 are different and uneven due to the switch integration. As shown in Fig. 6.2, in a case of Q_1, since the HB LLC stage operates in the above region and the direction of I_{LB} and I_{LR} is opposite, the ZVS conditions can be obtained as follows:

$$C_{OSS} V^2_{CLINK} < (1 / 2L_B I^2_{LB} (t_1) + 1 / 2L_R I^2_{LR} (t_1))$$

It notes that the ZVS energy becomes the sum of the energy stored in L_B and L_R, and the ZVS capability ofQ_2can be easily achieved with large I_{LB} and I_{LR}. In case of Q_2, the ZVS equation can be expressed as follows:

$$C_{OSS}V^2_{CLINK} < (1 / 2L_M I^2_{LM} (t_5) – 1 / 2L_B I^2_{LB} (t_5))$$

To achieve ZVS operation on the entire load range, L_B should be selected as larger also considering the power density. It makes the large L_M acceptable. It results in high efficiency due to the small magnetizing current and small turn-OFF switching loss.

B. Duty Cycle Control Scheme to Cover Wide Input Voltage Range

In conventional LLC resonant converter, the output voltage (V_O) is regulated by pulse frequency modulation (PFM) control. In the integrated converter, PFM can be used but when symmetric duty ratio is applied, the input voltage range is wide and it can affect high efficiency. Therefore, asymmetric pulse width modulation can be applied. According to the input voltage, since V_{CB} is changed, i.e.,

$$V_{CB} = DV_S / (1 - D)$$

by the APWM control, the input voltage range can be compensated. The input voltage to the HB LLC resonant converter is V_{CLINK} which is the sum of V_S and V_{CB}. The range of V_{CLINK} can be narrowed by APWM control.

IV. RESULT

A. Single Stage HB LLC Resonant Converter

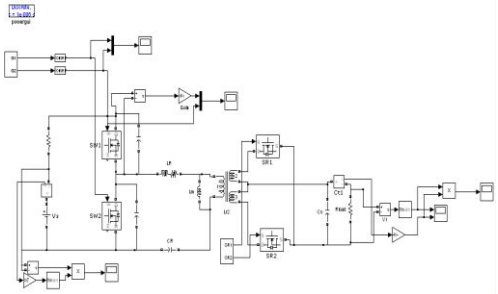

Figure.3. Simulation diagram of single stage HB LLC Resonant converter

The single stage LLC resonant converter is simulated with 48 V nominal voltage, the losses across MOSFET drives are calculated.

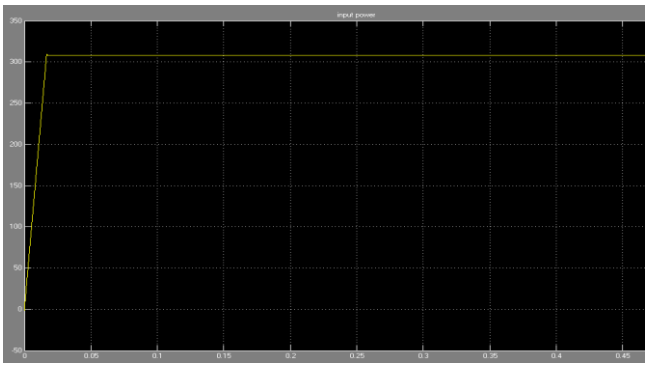

Figure.3.1. input power of single stage LLC resonant converter

The input power of the single stage LLC resonant converter is 310W.

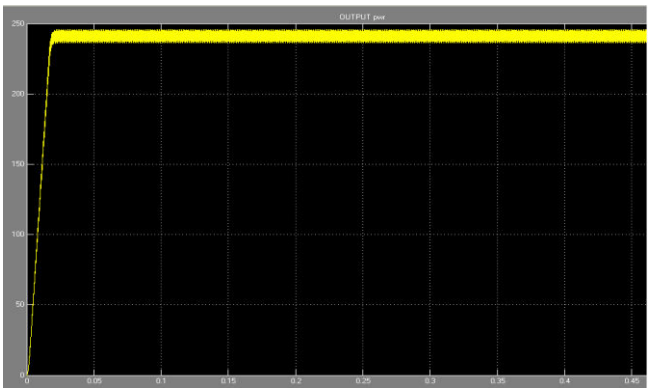

Figure.3.2. output power of single stage LLC resonant converter

The output power of single stage LLC resonant converter is 245 W is obained in above waveform.

Efficiency= output power / input power = 245 / 310= 0.79 = 79%

Total losses = i/p - o/p = 310-245 W

= 65 W

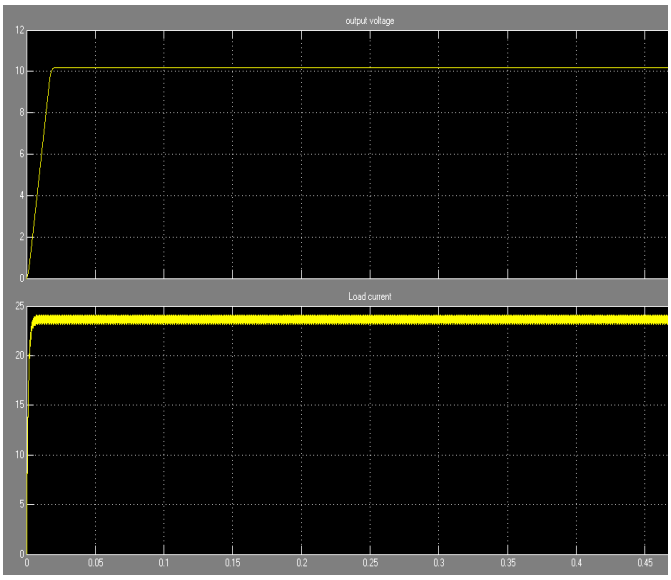

Figure. 3.3. output voltage and load current

The output voltage obtained in the single stage LLC resonant converter is 10V. The load current obtained in the single stage resonant converter is 24 A.

B. Two Stage HB LLC Resonant Converter

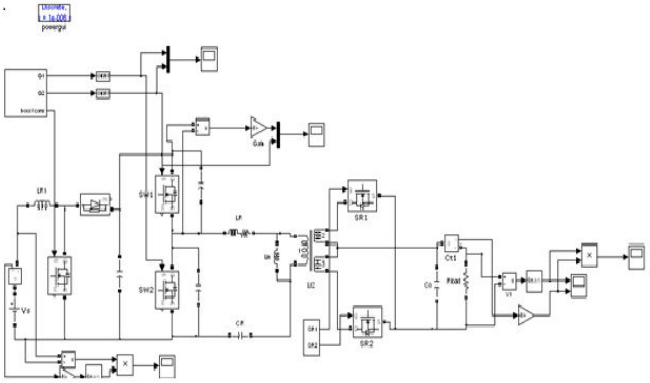

Figure. 3.4. Simulation diagram of two stage LLC resonant converter

The two stage LLC resonant converter is simulated as same as single stage LLC resonant converter by adding boost converter in front of the primary circuit.

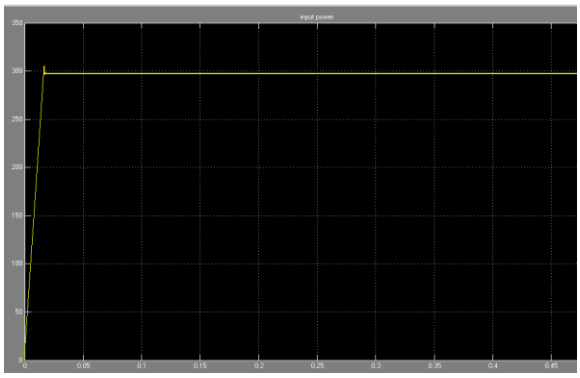

Figure. 3.5. input power of two stage resonant converter

The input power of two stage resonant converter is 300 W is obtained in above waveform.

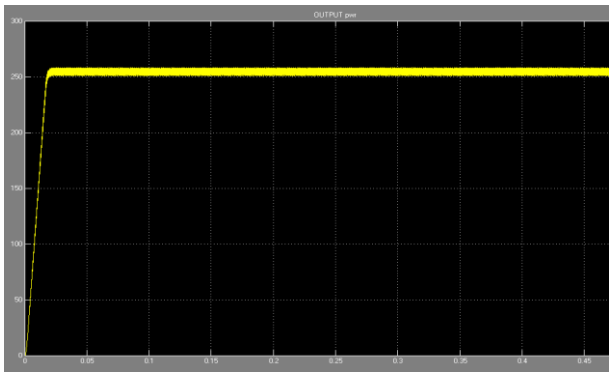

Figure. 3.6 output power of two stage resonant converter.

The output power of two stage resonant converters is 250 W.

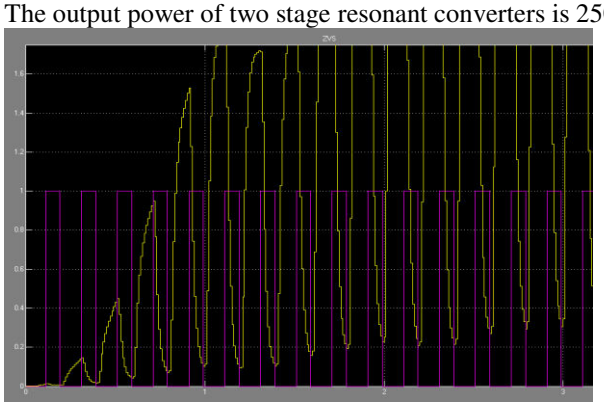

Figure.3.7 zero voltage switching in two stage resonant converter.

ZVS operation takes place at zero voltage to reduce total losses. Efficiency= output power/input power = 250/300 = 0.833 = 83.3%

Total losses obtained here is

= 300-250

= 50 W.

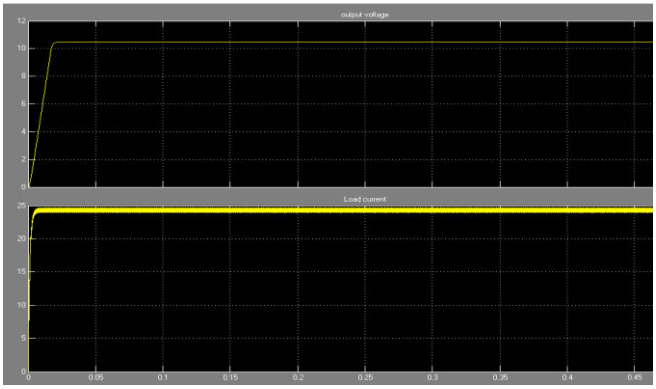

Figure.8. output voltage and load current of two stage resonant converter

The output voltage of two stage resonant converter is 11V and the load current of two stage resonant converter is 25 A.

V. TABLE

	Single stage HB LLC resonant converter	**Two stage HB LLC resonant converter**
Cost	Low	High
Power loss	High	Low
Efficiency	Low	High

VI. CONCLUSION

In this paper single stage half bridge resonant converter for the dc/dc power system with wide range of low input voltage such as 48 V_{DC} battery systems has been compared with two stage resonant converter. The two stage converter is derived by adding boost converter at the front end of HB LLC. The two stage converter has advantages such as small loss when compared with single stage HB LLC.

VII. REFERENCES

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