Design Specifications and Performance analysis of Single and Two Stage HB LLC Converters

A. Jenifer, Y. Sukhi, V. Karthika, A. Fayaz Ahamed

Abstract*: *In this paper a Single stage and Two stage Half Bridge LLC (HB LLC) converter topologies for DC/DC applications with low input voltage. The basic operation and design procedure for LLC converter is illustrated. Simulation of the proposed converter is done using the design parameters and the results are discussed and then analysis is done to know its performance. The efficiency of the converters is analyzed by MATLAB Software Package.

Keywords: Single Stage HB LLC (SS HB LLC),Two Stage HB LLC (TW HB LLC) , Resonant Converter.

I. INTRODUCTION

At present there are many applications like LED lighting, data centers, automobiles where use of 48V has become necessary to a specific application. Power conversion from high voltage level to low voltage has a large range of applications in power distributed generation, energy storage and auxiliary power supplies for train traction systems. First of all, since 48 V_{DC} power supplies are connected in parallel with 48 V_{DC} battery systems, the power system has many strengths such as high reliability and easy maintenance. Therefore, 48 V_{DC} systems are used in many applications. A distributed power network is to be used in an electric vehicle application which is of 48Vdc distribution network will be used throughout the vehicle [4], [8]-[9].

In view of its simple structure, the single stage power systems with only one topology, for low-to-medium power capability in 48 V_{DC} power systems are extensively applied [4]. Amongst, the single-stage

half- bridge (HB) LLC resonant converter has been widely used because of its advantages like high efficiency at high input voltage, low voltage stress on secondary rectifier. But having wide range of the low input voltage, this converter has design limitations. Since the requirement to operate with a wide input voltage range (36–72 V_{DC}) comes from a consideration of the dynamic battery voltage [1], [6]-[9]. The conduction loss in the primary side becomes large in single stage because of reflected current in primary of the

transformer, thus this converter shows low efficiency. To overcome the design limitation of the single-stage converter, a two stage approach, which consists of the front-end boost converter stage and dc/dc output stage was implemented which reduces the conduction losses.

In this paper, the concept and design steps for resonant converters are discussed. Simulation of the converters is done and the comparison of both the converters is done.

II. CONCEPT AND OPERATIONAL PRINCIPLE OF THE CONVERTERS

Fig.1(a) shows circuit diagram of Single stage half bridge LLC resonant converter. Without the magnetizing inductance Lm, this converter is the same as series resonant converter. With participation of Lm, the operation and characteristic of the proposed converter is very different from SRC then. Secondary rectifier is used instead of diodes since it provides high efficiency. The circuit has three passive components, L_r, C_r and L_m. The secondary side is a center-tapped rectifier followed by a capacitive filter. The primary side of this diagram is a Half Bridge configuration; it could also be full bridge or other topologies. Since there is a capacitor in series with power path, automatic flux balancing can be achieved. In this converter, two resonant frequencies exist. They are the resonant frequency produced due to the inductor L_r and capacitor C_r, another is the resonant frequency produced by L_m plus L_r with C_r. When the applied load is light, the maximum value reaches resonant frequency produced by L_m+L_r and C_r. When load becomes heavier, the maximum value of resonant frequency is produced by L_r and C_r, and gain is unity at resonant frequency f_o and does not dependent on load change. In the proposed converter, MOSFET switches are used as primary switches, so ZVS is preferred [1]-[4], [6]. The current and voltage waveforms of the proposed circuit are shown in Fig 2.

Fig. 1(b) shows circuit diagram of two-stage converter adopting boost converter and LLC resonant converter. The two stage approach, consists of the front-end boost converter stage and dc/dc output stage. By applying the front-end boost converter, V_{CLINK}, which is the input voltage of the resonant converter, can be increased. This converter is used to achieve wide range of input voltage. The waveforms of the proposed converter are shown in Fig 3.MOSFET switches are turned on with ZVS. Since the turn off current is decided by magnetizing inductance Lm, which is not related to load condition, ZVS can be achieved with any load condition. For turn off of MOSFET, turn off current is much smaller than load

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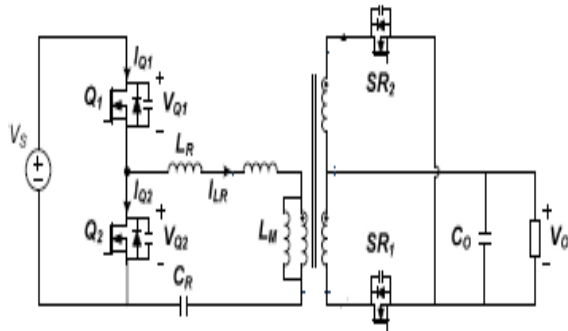current, so turn off loss can be reduce.

Fig.1. (a) Single stage HB LLC converter (SS HBLLC)
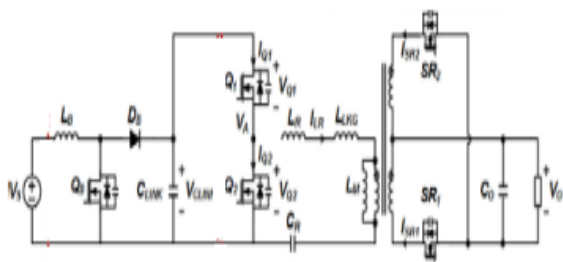

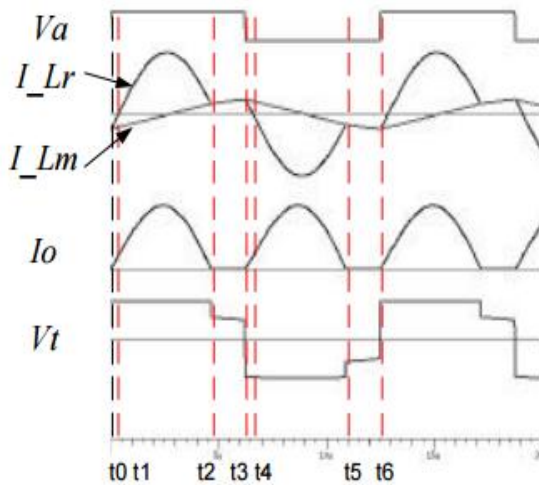Fig.1. (b) Two stage HB LLC converter (TS HBLLC)

Fig. 2. Waveforms of SS HBLLC

With all these, resonant conditions the switching loss of both the converters are very small.

III. DESIGN SPECIFICATIONS

This section demonstrates the step-by-step deign procedure for resonant network design. The converter's electrical specifications are as follows:

Input voltage:36-72 V_{DC}
Rated output power:300W
Output voltage:12 V_{DC}
Rated output current: 25A
Output-Voltage line regulation(I_o=1.0A)≤1%
Output-Voltage load regulation(V_{in}=48V)≤1%

Efficiency (V_{in}=48V and I_o=25A)≥90%
Switching frequency(normal operation): 33KHz
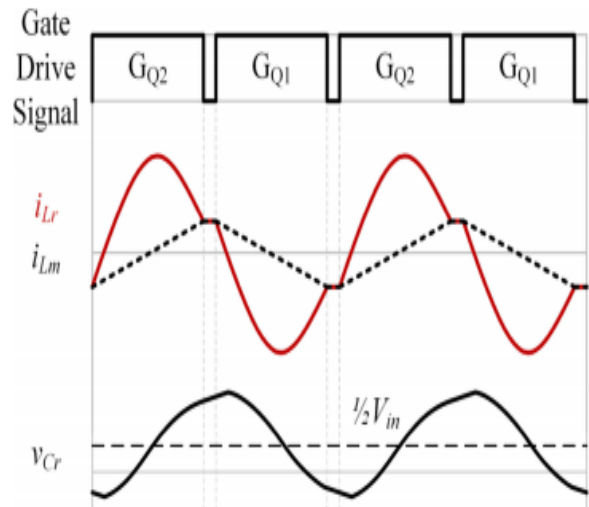Resonant frequency (f_o)=100KHz

Fig. 3. Current and Voltage Waveforms

A. Determine Transformer Turns Ratio

The transformer turns ratio is determined by

$$n = \frac{(V_{in\_nom})/2}{V_{o\_nom}}$$

$$= \frac{48/2}{12} = 2$$

B. Determine Voltage gain

M_{g_min} and M_{g_max} can be calculated using the following equations

$$M_{g\_min} = \frac{n \times (V_{o\_min} + V_F)}{V_{in\_max}/2}$$

$$=0.67$$

$$M_{g\_max} = \frac{n \times (V_{o\_max} + V_F + V_{loss})}{V_{in\_min}/2}$$

$$M_{g\_max} = \frac{2 \times (12 + 0.7 + 1.05)}{36/2}$$

$$=1.527$$

V_{loss} is assumed for voltage drop due to power losses.

C. Select Inductance L_n and Quality Factor Q_e

From peak gain curves the values of L_n and Q_e are selected as 3.5 and 0.45.

D. Determine the equivalent Load resistance

At full load, Re is calculated as

$$R_e = \frac{8 \times n^2}{\pi^2} \times \frac{V_0}{I_0}$$

$$R_e = \frac{8 \times 2^2}{\pi^2} \times \frac{12}{25}$$

$$= 1.556\Omega$$

At 110% overload,

$$R_e = \frac{8 \times n^2}{\pi^2} \times \frac{V_0}{I_0}$$

$$R_e = \frac{8 \times 2^2}{\pi^2} \times \frac{12}{25 \times 110\%}$$
$$= 1.414\Omega$$

E. Design resonant circuit parameters

Resonant frequency is selected as 100KHz and the resonant parameters can be calculated at full load:

$$C_r = \frac{1}{2\pi \times Q_e \times f_0 \times R_e}$$
$$C_r = \frac{1}{2\pi \times 0.45 \times 100 \times 10^3 \times 1.556}$$
$$=22.8\text{nF}$$
$$L_r = \frac{1}{(2\pi \times f_0^2) C_r}$$
$$L_r = \frac{1}{(2\pi \times 100 \times 10^3).^2 \times 22.8 \times 10^{-9}}$$
$$=8.1\mu H \text{ (approximated to 10 } \mu H)$$
$$L_m = L_n \times L_r$$
$$L_m = 3.5 \times 10 \ \mu H$$
$$=35 \ \mu H$$

F. Verify the Resonant-circuit design

Series Resonant Frequency

$$f_0 = \frac{1}{2\pi \times \sqrt{L_r \times C_r}}$$
$$f_0 = \frac{1}{2\pi \times \sqrt{10 \ \mu \times 22.8n}}$$
$$=105.45\text{KHz}$$

Inductance Ratio
$L_n = L_m/L_r$
$=35\mu H/10 \ \mu H$
$=3.5 \ \mu H$

IV. SIMULATION RESULTS

Simulation models of both converters were built with MATLAB package. For the same design values of resonant components and switching frequency both the converters are simulated and the waveforms are observed. Fig.4 and Fig.5 show the simulation circuit of Single Stage HB LLC converter and two Stage HB LLC converter respectively.
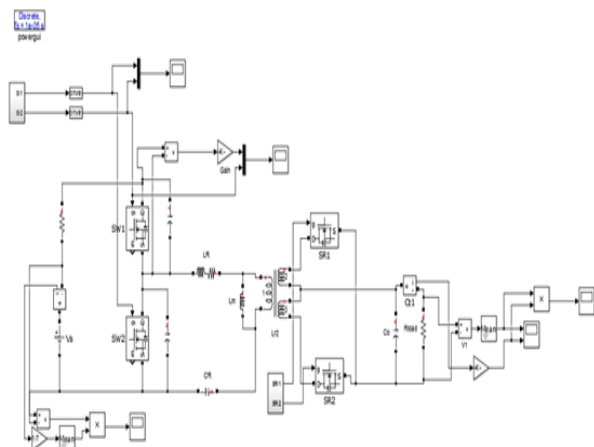

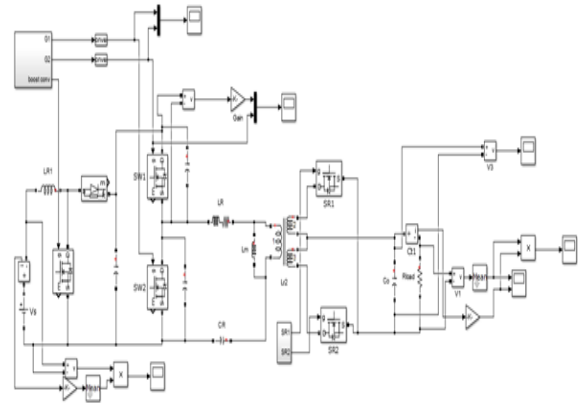Fig. 4. Simulation circuit of SS HB LLC converter

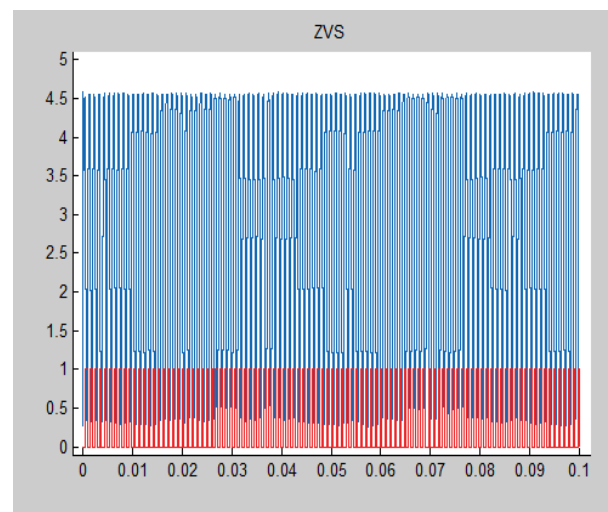Fig. 5. Simulation circuit of TW HB LLC converter
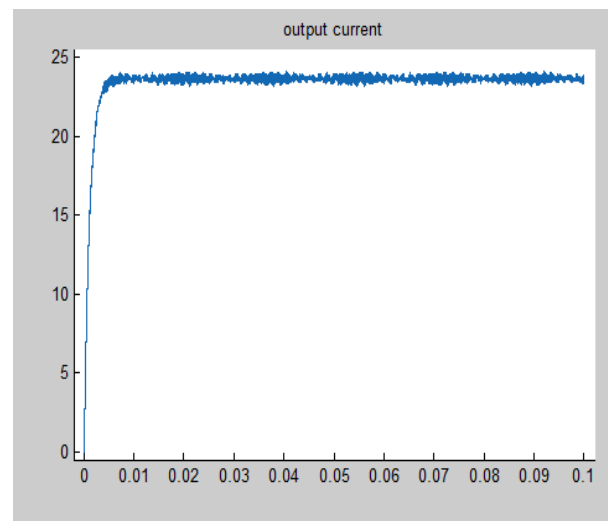

Fig. 6. ZVS of SS HBLLC converter

Fig. 7. (a) Output current waveform Waveforms of SS HBLLC

For an input voltage of V_{in} = 36 to 72 V (V_{nom}=48V), Switching frequency f_s = 33KHz , Resonant frequency f_o = 100KHz at full load is simulated.
It is observed from the SS

HBLLC, the current waveform is highly asymmetrical at high input voltage and hence it is used for wide input range because the efficiency is less 88% can only achieved. The conduction loss is also high. But the TS HBLLC waveforms show that it can cover wide input range and with high input voltage it gives an efficiency of 93% which is 5% improvement from the former and the conduction loss is also less. Fig 6 shows the ZVS. Fig 7 (a) and (b) shows the output current and voltage waveforms of HB LLC converter.
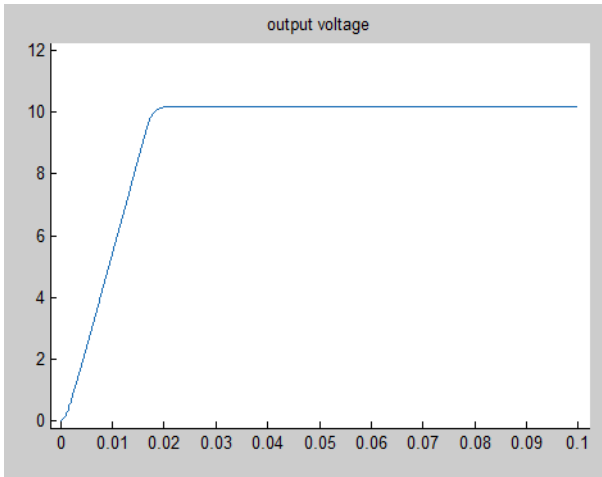

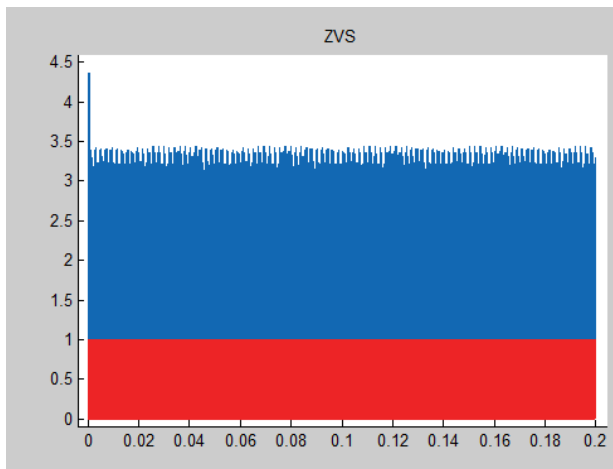Fig. 7. (b) Output voltage waveform for single stage HB LLC
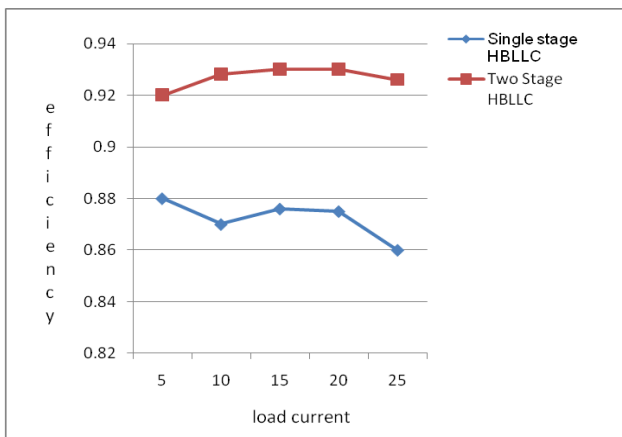

Fig. 8. ZVS of TS HBLLC

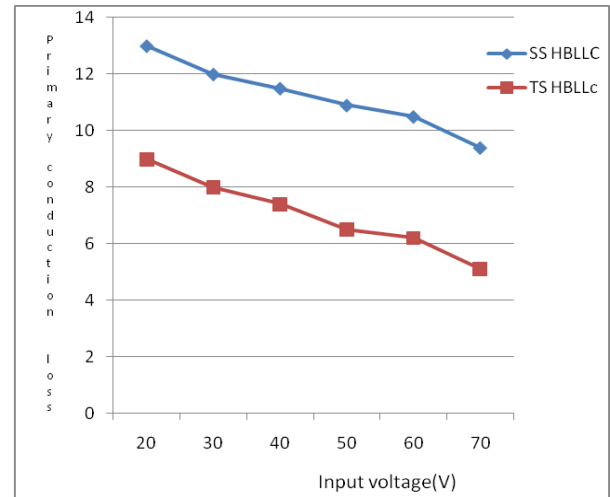Fig. 9. Efficiency comparison of the converters

Fig 10 Comparison of primary conduction loss

When simulated at the nominal input voltage 48V an output voltage of 11V and output current of 24A is obtained for SS HBLLC for rated 300W.The calculation of power density using the formula Efficiency= P_{out}/Volume of the converter shows that power density is less in TS HBLLC since the number of components in two stage converter is more.

Fig. 9 shows the comparison of the converters with load change which clearly evident two stage HB LLC is more efficient. In Fig 10 it is showed that conduction loss is less in two stage HB LLC.

The Fig.11 shows the comparison of both the converters since the number of components id less in single stage its cost is low comparatively.
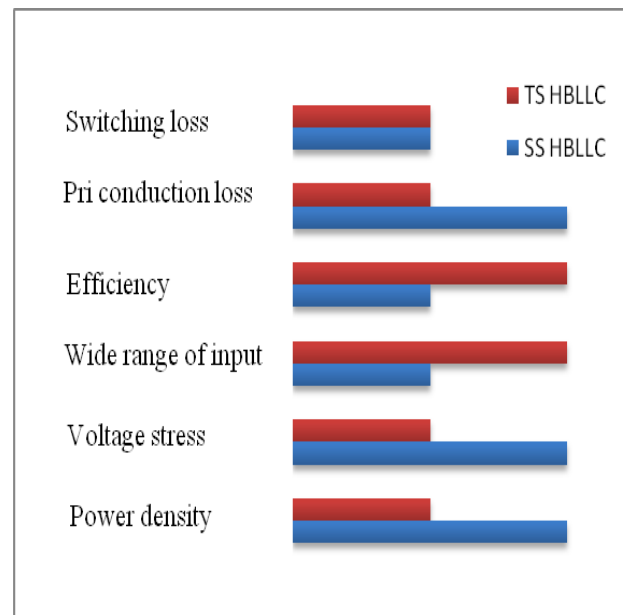

Fig. 11. Overall comparison the converters

V. CONCLUSION

In this paper the design specifications of single and two stage resonant converter. The

waveforms are analyzed using simulation tool and the efficiency comparison is done. The results shows that the two stage HBLLC converter is more efficient and the performance is good.

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