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ANALYSIS AND SIMULATION OF FULL BRIDGE CONVERTER

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ABSTRACT

In the development of power electronics, a newly modify converter topology is proposed in this paper. It involves analysis and simulation study of Full Bridge Converter (DC-DC) with brief literature review. The analysis of proposed system is done with the help of MATLAB simulation. Lastly, it concludes that the proposed systems is efficient and highly implemented and have great future scope.

Keywords—Full Bridge Converter, DC-DC converter, Zero voltage switching, MATLAB.

I. INTRODUCTION

The modernization of industries and growing green power technologies raises the demands of power electronic interfaces rapidly with the objective of improved efficiency, compact size, and reduction in system cost with better power quality of supply.

Power electronics is the field of electrical engineering related to the use of semiconductor devices to convert power from the form available from a source to that required by a load. A power electronic system consists of one or more power electronic converters. A power electronic converter is made up of power semiconductor devices controlled by integrated circuits.

In DC-DC power conversion a switched topology is often the only way to achieve reasonable efficiency and can be done by using semiconductor switches and energy storage devices that ideally do not dissipate energy. The tradeoff for high efficiency is in size and cost of passive energy storage which can often time be the dominant factor. In order to reduce the size of passive components, it is necessary to go for higher frequency.

The incentive to move to higher frequency is not only given by the reduced size of the passive components, but also by transient performance. With smaller inductors and capacitors, less energy is stored in the converter, allowing for faster response to a change in load. It is thus clear that much can be gained from moving to a design that enables operation at very high frequency. In conventional hard switched converters upper bound for the switching frequency is determined by the losses associated with each switching cycle. One way to maintain high efficiency at higher switching frequency is to employ a low switching loss converter topology, incorporating zero voltage switching (ZVS) or zero current switching (ZCS).

From all the power converters, full-bridge converter is widely used in medium-to-high power dc–dc conversions because it can achieve soft-switching without adding any auxiliary switches. The soft-switching techniques for PWM full bridge converter can be classified into two kinds: one is zero-voltage-switching (ZVS) and the other is zero-voltage and zero-current-switching (ZVZCS) [1]. The leakage inductance of the transformer and the intrinsic capacitors of the switches are used to achieve ZVS for the switches. The ZVS characteristics are load dependent and will be lost at light load [2]–[6]. In ZVZCS PWM full-bridge converters, one leg achieves ZVS, and the other leg achieves ZCS [7]–[13]. However, there is serious voltage oscillation across the rectifier diodes caused by the reverse recovery no matter ZVS or ZVZCS is realized for the switches. To overcome this problem, a resonant inductance and two clamping diodes introduced into the primary side of transformer which is called as Modified converter.

II. LITERATURE REVIEW

The numbers of scientist are worked on DC-DC converters with its switching techniques, type of circuit, type of converter, performance methodology.

Xinbo RUAN and Yangguang YAN propose a family of modulation strategies for PWM full bridge converter including nine modulation strategies, to realize soft-switching for PWM full bridge converters. They also modified the converter techniques with ZCS and ZVS. The newly modified converter involve a novel phase-shifted zero voltage and zero-current-switching (ZVZCS) pulse width modulation full-bridge converter, which realizes ZVS for the leading leg and ZCS for the lagging leg which is shown in Fig.1 as below. [1],[8]. Guichao Hua, Fred C. Lee, and Milan M. Jovanovid worked on full bridge (FB) zero-voltage-switched (ZVS) pulse width-modulated (PWM) converter which employed saturable inductor is to improve its performance. They also study the comparison with those of the conventional FB-ZVS-PWM converter with the help of theoretical analysis and verification with a 500 KHz, 5 V/40 A converter.[4]

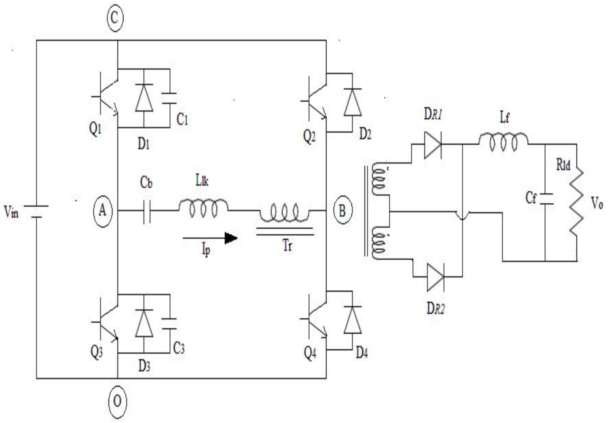

Fig.1 ZVZCS PWM FB converters

Ming Xu, Yuancheng Ren, Jinghai Zhou, and Fred C. Lee are developed 1-MHz Self-Driven ZVS Full-Bridge Converter for48-V Power Pod and DC/DC Brick. The Self-driven technique recycles the gate driving energy by making use of the input capacitor of the secondary side synchronous rectifier (SR) as the snubber capacitor of the primary side switches [5]. Brendan McGrath and Donald Holmes were proposed the design process for a 6-kW ZVS high-frequency DC-DC converter for use as a traction rolling stock battery charger. The design was based on a ZVS transformer coupled FB converter topology. It was shown that the design required a resolution of three key issues: the thermal management of the snubber dump loss at low load, the tail current loss at high load, and the minimization of the ZVS duty cycle loss. These issues relate to the selection of the ZVS capacitors, the transformer turns ratio, the series resonant inductor, and the IGBT devices [6].

Jung-Goo Cho, Juan A. Sabatk, Guichao were developed zero-voltage and zero-current-switching (ZVZCS) full-bridge (FB) pulse-width modulated (PWM) converter which is mostly helpful in High power applications. By using the dc blocking capacitor and adding a saturable inductor, the primary current during the freewheeling period is reduced to zero, allowing the lagging-leg switches to be operated with zero current- switching (ZCS). Meanwhile, the leading-leg switches are still operated with ZVS. The new converter is attractive for high-voltage (400-800 V), high-power (2-10 kW) applications where IGBT's are predominantly used as the power switches.[7]. After that

Hang-Seok Choi, Jung-Won Kim were developed a novel ZVZCS full-bridge PWM converter [3]–[9]. The proposed ZVZCS full bridge PWM converter employs a simple auxiliary circuit that consists of neither lossy components nor active switches. The circulating current is self-adjusted in accordance with the load condition, which guarantees high efficiency over wide load range. The principles of operation and design considerations are illustrated and verified on 4 kW, 80 kHz prototype converter using IGBTs.[9]

Song Ting Ting and Huang Nianci was studied A novel zero-voltage and zero-current-Switching (ZVSZCS) full-bridge PWM converter. [10]. A ZVZCS Full-Bridge DC/DC Converter with a Passive Auxiliary Circuit in the Primary Side was presented by Wuhua Li, Yanqun Shen, and Yan Deng [11]. They were designed a prototype with 1kW operating at 50 kHz is built in the lab to confirm the effectiveness of the converter. Jaroslav Dudrik, Pavol Spánik, and Nistor-Daniel Trip were worked on a novel zero-voltage and zero-current switching (ZVZCS) full-bridge phase-shifted pulse width modulation (PWM) converter. ZVZCS for all power switches is achieved for full load range from no-load to short circuit by adding active energy recovery snubber and auxiliary circuits [12],[13]. Richard Redl, Nathan *0.* Sokal were analyzed addition of an external commutating inductor and two clamp diodes to the phase-shifted PWM full-bridge dc/ dc converter substantially reduces the switching losses of the transistors and the rectifier diodes, under all loading conditions. They proposed practical design considerations, and experimental results for a 1.5-kW converter with 60-V, 25-A output, operating at 100-kHz clock frequency (i.e., 50-kHz switching frequency) and 95% efficiency [14].

By adding a simple external commutating aid circuit to the full bridge dc/dc converter with phase-shift control and by reducing the magnetizing inductance was analyzed by Laszlo Balogh, David W. Edwards. They achieved soft switching from full load down to 1% load. The efficiency was 92% at *8%* load, and stayed above 95% from 15% load to full load. Experimental data taken from a 3-kW converter with 200-kHz clock frequency verified the theoretical results [15]. They also presented equivalent circuits for the switch transitions of the full bridge soft-switching converter with an external commutating inductor and damp diodes. They also determined the commutating energy available for the passive to active leg[16]. Fuxin Liu also improved ZVS PWM full-bridge converter with clamping diodes by exchanging the position of the transformer and the resonant inductance such that the transformer is connected with the lagging leg [17].

To overcome the limitations shown by literature review of a modified full bridge DC-DC converter are proposed.

III. PROPOSED CONVERTER

The full-bridge converter is widely used in medium-to-high power dc–dc conversions because it can achieve soft-switching without adding any auxiliary switches. The leakage inductance of the transformer and the intrinsic capacitors of the switches are used to achieve ZVS for the switches. The ZVS characteristics are load dependent and will be lost at light load [2]–[6]. In ZVZCS PWM full-bridge converters, one leg achieves ZVS, and the other leg achieves ZCS [7]–[13]. However, there is serious voltage oscillation across the rectifier diodes caused by the reverse recovery no matter ZVS or ZVZCS is realized for the switches.

In order to overcome this problem, Redl et al. [14]–[16] introduced a resonant inductance and two clamping diodes into the primary side of transformer. Then this converter is said to be modified converter. The solution eliminates the voltage ringing and overshoot, thus the voltage stress of the rectifier diodes is reduced, and without introducing losses or an additional controlled power device. The difference between the two locations of the resonant inductance and the transformer was analyzed and an optimal position was presented. Ruan et al. [17] analyzed the issue in detail and also observed the effects of the blocking capacitor in different positions, and a best scheme was determined.

No matter what the positions of the transformer and the resonant inductance are, the resonant inductance is clamped and its current keeps constant when the clamping diodes conduct. The output filter inductance must had enough current ripple so that the clamping diodes turn off naturally, otherwise the clamping diodes will be forced to be turned off, resulting in serious reverse recovery.

In this converter, an auxiliary transformer winding is introduced to the ZVS PWM full-bridge converter to be in series with the resonant inductance. The introduced winding not only makes the clamping diode current decay rapidly and reduces the primary side conduction losses, but also can makes the current ripple of the output filter be smaller; hence the output filter capacitor can be reduced. The winding plays the role of forcing the clamping diode current to decay to zero, so it is called reset winding.

IV. ANALYSIS OF SYSTEM

1) Analysis of Proposed converter

The basic circuit diagram of proposed full-bridge DC/DC converter, which is shown in Fig.2, employs a full-bridge inverter, an isolation transformer, and an output rectifier. The full-bridge inverter utilizes fully controllable semiconductor switches and outputs high frequency AC voltage waveform by utilizing the input DC voltage.

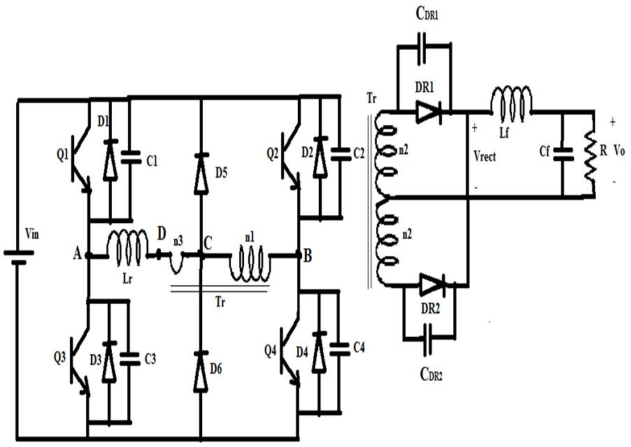

Fig.2 Circuit Diagram of Proposed System

Then, the inverter output voltage is isolated and scaled (if required) by the high frequency transformer. Following, the transformer output voltage is rectified by the diode bridge rectifier (half-bridge or full-bridge, depending on the application requirements) and finally filtered to provide smooth DC voltage or current. It should be kept in mind that the DC/DC converter system consists of mainly two stages DC/AC and AC/DC stages. Thus, the name DC/DC converter here is attributed to the system, rather than the individual converter topologies.

2) Modulation Strategies for DAB DC-DC converter

Three types of modulation strategies have been analyzed for DC-DC converter as shown in Fig3. From all of the three here we can control DC-DC by using PSM (Phase Shift Modulation). Hence mostly we focus on PSM only than other techniques [24].

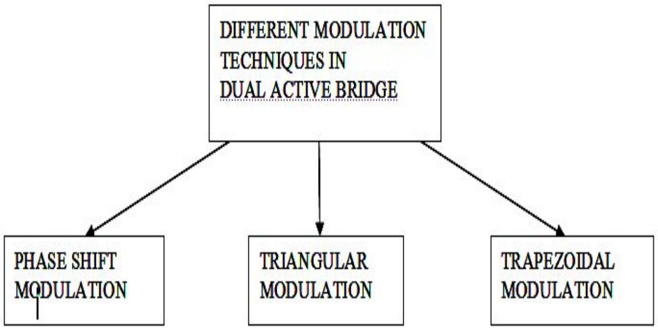

Fig.3 Modulation techniques for DC-DC

3) Phase Shift Modulation (PSM)

Phase shift modulation is the widely used in dual active bridge converter. For phase shift operation, rectangular transformer voltages, primary voltage and second voltage with switching frequency f_S and phase shift ϕ are applied to the transformer. The power transfer is controlled by the phase shift angle ϕ. The higher the phase difference, the higher is the power transferred.

The advantages of PS method are**:**

- Phase shift modulation is very simple to implement.
- It is possible to use half bridge circuits to generate the high frequency transformer voltages of primary and secondary.
- Less number of power electronic devices.

For ZVS operation of the full-bridge DC/DC converter, the operating method of the converter plays a critical role. Under phase-shifted switch pulse pattern operation (the switch logic signals of one leg are phase-shifted with respect to the other), the converter can operate with self-resetting capability. Thus, this PWM method is favorable when combined with ZVS of the converter. Operating under ZVS condition permits to increase the switching frequency, which results in smaller size, lower weight, and higher bandwidth. When the full-bridge DC/DC converter is operated with the phase-shifted PWM method, the converter and its switch pulse pattern are identified with the name “Full-Bridge Phase-Shifted (FB-PS) DC/DC Converter.” Further, when this converter is operated under ZVS condition, it is so called as “FB-PS-ZVS DC/DC Converter.” In the circuit, the resonance that provides ZVS operation is between the switch output capacitance and the transformer resonant inductance.

The FB-PS-ZVS DC/DC converter utilizes a full-bridge inverter, a high frequency transformer, a full-bridge diode rectifier (which may be replaced with a center-tap diode rectifier for high current applications), and a low pass filter (consisting of the passive components Lf and Cf) at the output. The gate PWM signals for the switches in the full bridge inverter are generated by utilizing the phase-shifted PWM method, which facilitates ZVS operation for the switches.

The capacitors (C1, C2, C3, and C4) which are connected across the switches in Fig.2 emphasize the parasitic output capacitances of the switches. If required, additional external capacitors can be inserted across the switches while keeping the same values for the total capacitance across the switches in the same inverter leg (C1 = C4 = C2 = C3). The inductor (Lr), which is connected in series with transformer primary winding, emphasizes the parasitic leakage inductance of the high frequency transformer. If required, an additional inductor can be connected in series with the transformer primary winding. The two parasitic components (the switch output capacitance and transformer leakage inductance), which normally decrease the performance of the DC/DC converters under hard-switching condition, are utilized advantageously in the phase-shifted PWM method to achieve ZVS. These parasitic components of the circuit elements are used as the main circuit elements to provide resonant transitions during the switching time intervals. The switches turn on under ZVS condition as a result of these resonant transitions. Due to the elimination of the switching losses, the FB-PS-ZVS DC/DC converter is a convenient converter topology for high frequency and high power applications. The proposed system is modeled by using MATLAB/Simulink.

V. SIMULATION STUDY

The full-bridge inverter section of the FB-PS-ZVS DC/DC converter is fed from the DC bus, which is represented by a constant voltage source (VDC) in Fig.2.The proposed converter consists of AC to DC converter, Isolation Transformer, and rectifier circuit to reduce voltage distortion and to get smooth DC output filter circuit used.

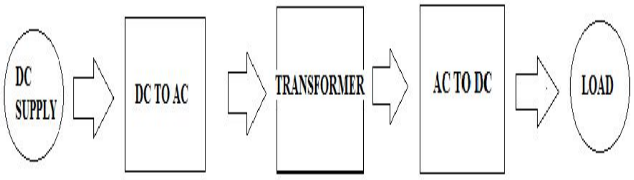

Fig.4 Block Diagram of Proposed Converter

The single phase full-bridge inverter consists of four gate controlled semiconductor switches (Q1, Q2, Q3, and Q4) such as IGBTs (as illustrated in Fig.2) with their freewheeling diodes (D1, D2, D3, and D4). All switches in the full-bridge inverter operate with a duty cycle of 50%, ideally.

In the phase-shifted PWM method, the gate PWM signals of Q2 and Q3 are delayed (phase-shifted) with respect to those of the switches Q1 and Q4. The switches Q1 and Q4 are fired at delay angle 45°. Hence it has a time period t0 is shown in Fig.5 and is given by,

$$t0 = \frac{1}{f} * \frac{Ton}{T} = \frac{1}{50} * \frac{45}{360} \quad \ldots\ldots\ldots\ldots\ldots(1)$$

In case of switches Q2 and Q3 are fired at 180° phase shift from switches Q1 and Q4. It means Q2 and Q3 are fired at 45°+π. Now time period t1for that is shown in Fig.6 and is given by,

$$t1 = \frac{1}{50} * \frac{45 + \pi}{360} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

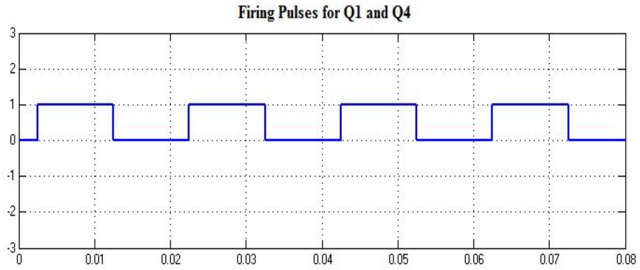

Fig.5 Gate signals for Q1 and Q4

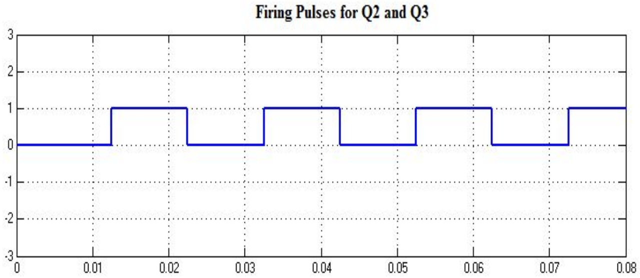

Fig.6 Gate signals for Q2 and Q3

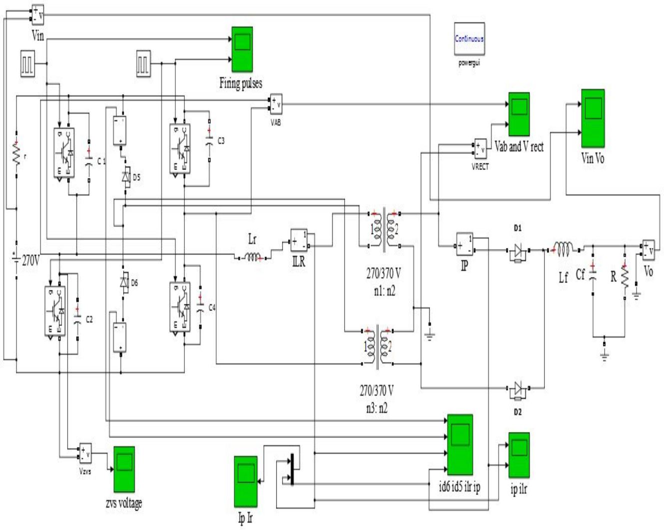

Fig.7 Simulink Model of Proposed System

The full-bridge inverter applies three different voltage levels to the transformer primary winding such as +VDC (while Q1 and Q4 are conducting simultaneously), -VDC (while Q3 and Q4 are conducting simultaneously), and 0 (while Q1 and Q3 or Q2 and Q4 are conducting simultaneously). In this converter the improved technique i.e. resonant inductance and clamping diodes are used to achieve ZVS switching operation which is shown in Fig.8 below.

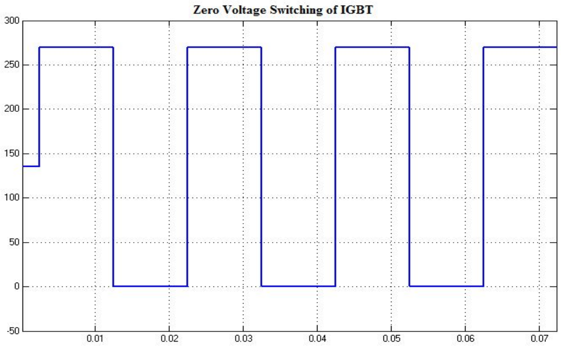

Fig.8 ZVS of IGBT

When potential at point C is greater than zero then D6 is reverse biased and after some delay D5 gets forward biased and the purpose of clamping to maintain the constant current. These diode currents are shown in Fig. 9 as iD6 and iD5 is shown in Fig.10.

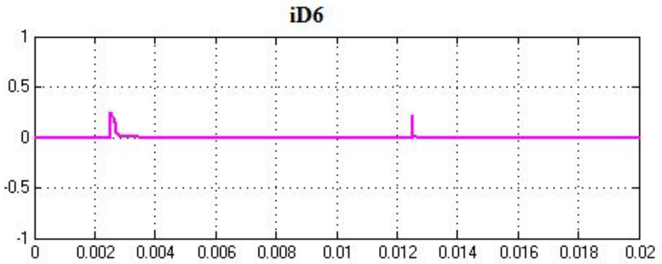

Fig.9 Current pass through D6

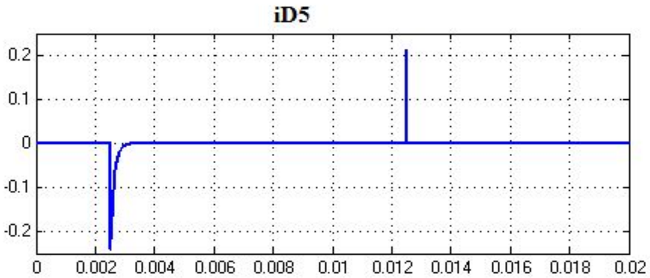

Fig.10 Current pass through D5

For positive voltage +Vin, When the clamping diode conducts ,the resonant inductance is shorted and its diode current keeps constant , which shows that the difference between the resonant inductance current iLr and primary current ip flows through the clamping diode are shown in Fig.11 and Fig.12,

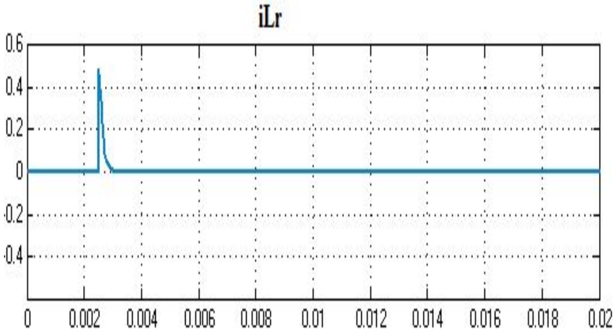

Fig.11 Current flowing through resonant inductance

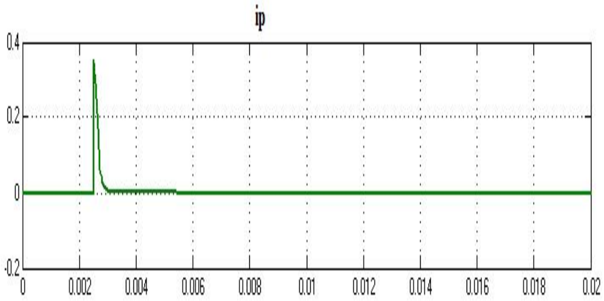

Fig.12 Current flowing through primary winding of transformer

For negative voltage –Vin, resonant inductance makes the clamping diode current towards minimum or zero. This results into rapid decrease in current which results into reduction in average value. As it reduced, the efficiency can be further increased. This transformer is not only used for isolation purpose but also for step up and step down of output voltage as per requirement. The transformer has 2:1 windings means have three windings such as primary windings, reset winding and secondary winding. Primary voltage 270 AC is given by DC to AC inverter to isolation transformer from 270 DC supplies and to get secondary voltage as 180V AC transformer turns ratio should be set as 270V: 370V. Because we use center tap rectifier i.e +180V-0- -180 V. Secondary winding voltage Vrect is directly supplied to centered tap rectifier to get required DC output as VAB. As here we can use pulse generator in design the inverter for triggering the switches which gives square wave output at maximum voltage 270 V AC. The transformer gives the required output which depends on the transformer voltage rating. The transformer output voltage Vrect and inverter output voltage as VAB is shown in Fig.13.

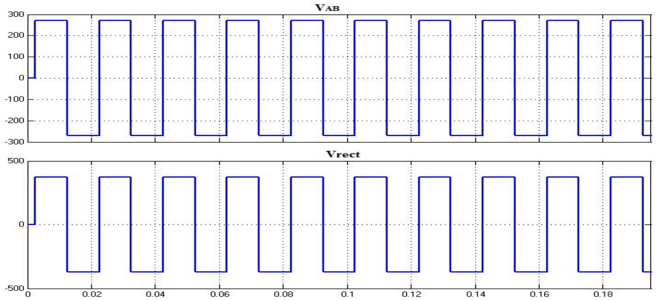

Fig.13 Inverter and transformer outputs

Now, AC voltage at the transformer secondary winding is rectified and then filtered by a low-pass filter (L_f and C_f) to obtain a smooth DC voltage at the output of the DC/DC converter. The filter design for this converter is as

$$L_f = \frac{(V_{in} - V_{out}).V_{out}}{V_{in}.f_{sw}.\Delta I_L} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

Where,

V_{in}=converter input voltage

V_{out}= converter output voltage

f_{sw}= converter switching frequency

L_f=filter inductance

ΔI_L=peak to peak filter inductor current ripple

ΔI_L to be between 20% to 40% of I_{out}.

The maximum current flowing in filter inductor is given by,

$$I_{Lmax} = I_{out,max} + \frac{\Delta I_{Lmax}}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots(4)$$

$$C_f = \frac{L_f.(I_{Lmax})^2}{(V_{out} + \Delta V_{out,overshoot})^2 - (V_{out})^2} \ldots\ldots(5)$$

$\Delta V_{out,overshoot}$ is 4% of V_{out}

This can be split into equal parts for the contribution of ESR (Equivalent Series Resistance),

$$\text{The maximum ESR} = \frac{\Delta V_{out,overshoot}}{I_{Lmax}} \quad \ldots\ldots\ldots(6)$$

$$L_f \le \frac{V_{in} - K.V_{out}}{K^2\left[\frac{2.V_{in}.\Delta I}{V_{out}.T_s.K} - \frac{I_{out}.R_{DS(ON)} - K.V_f}{K.L_r}\right]} \ldots\ldots(7)$$

Hence, finally we get the required output from this full bridge ZVS DC-DC converter which converts 270 V DC to 180V DC through LC low-pass filter. These MATLAB results are as follows:

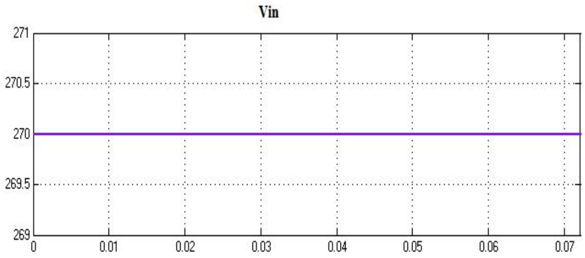

Fig.14. Input Voltage of Converter

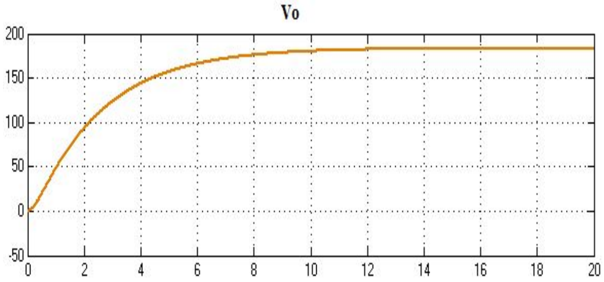

Fig.15. Output Voltage of Converter

VI. CONCLUSION

Finally, we conclude that the modified full bridge converter is most efficient and have high efficiency.

The simulation study shows that as resonant inductance minimizes clamping diode current results into increase in frequency. The main advantage of the converter is reduction in switching losses, minimization of voltage ringing and overshoot. MATLAB simulation verified the analysis and design of proposed converter which have great future scope.

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