Novel Three-Phase Smart Soft Switching PWM Inverter with Enhanced Performance

N.ISMAYIL KANI
Assistant Professor, Department of EEE
S.Veerasamy Chettiar College of Engineering and Technology, Puliyangudi, Tamilnadu, India
Email:ismayilkani@gmail.com

B.V.MANIKANDAN
Mepco Schlenk Engineering College, Sivakasi, Tamilnadu, India
bvmani@mepcoeng.ac.in

Abstract: *In order to reduce switching losses this work first proposes a new control scheme for an existing three-phase ZVS inverter circuit that uses one auxiliary switch. The proposed scheme called the one-switch ZVS enables all main switches diodes and auxiliary switches to be turned ON under zero-voltage conditions and in the meantime provides an opportunity to achieve zero-voltage turn-on for the main switches. However the main drawback of conventional method of three phase soft switching inverter using more number of auxiliary switches is the high cost and large space associated with the auxiliary switches. To overcome this problem this work further proposes a new three phase ZVS inverter topology that uses only one auxiliary switch. The proposed three-phase soft switching PWM Inverters operation and experimental result are presented*

Key words: *Zero voltage switching, High frequency, voltage stress, switching losses*

1. Introduction

Three-phase pulse-width-modulation (PWM) inverters are widely used in motor drives, uninterruptible power supplies (UPSs), and utility interfaces. In order to reduce the size of output filter and eliminate audio noise, switching frequency must be increased. However, the high-switching-frequency operation of three-phase PWM inverters is thermally limited by the switching losses of the power devices; the current handling capability of the devices, which also affects the inverter power density, is electrically limited by the dynamic switching stresses of the devices at turn-on and turn-off transitions. The purpose of soft switching techniques is to decease or eliminate the overlap between voltage and current prior to switching transitions. In hard switching inverter the switching frequency is directly proportional to switching losses. so increasing switching frequency leads to increased switching losses, which consequently increase the size of snubber circuits, heat sinks and cost. In addition, electromagnetic interference increases, and efficiency is decreased. In [1] a transformer based resonant DC-link inverter for brushless DC motor drive system was proposed. In this method soft switching is achieved by two auxiliary switches. . It is one of the failing of this method. The control circuits are simplified and reduce the cost, the number of auxiliary circuits reduced. To increase the efficiency of converters and to decrease electromagnetic interference, it is necessary to use soft switching techniques [2]–[4]. ZVS based soft-switching based three phase rectifier-type high-frequency-link bidirectional power converter principle for the front-end isolated DC/DC converter was proposed [5].In combination through a back-end, DC/AC converter working along with a new patent-filed hybrid modulation technique is sketched, which minimizes the number of hard-switched commutation per switching cycle. The presented ZVZCS technique which results in less overall switching losses than other conventional switching schemes. The designed ZVZCS technique is efficient for different load conditions and works flawlessly with a simple active-clamp circuit. Along with these techniques, quasi-resonant dc-link inverters contain the advantages of zero voltage switching (ZVS) for the main switches, a low number of the auxiliary switches and low voltage stress on the main switches [6].

In [7] the number of inductors was reduced to one and used two auxiliary switches. This reasons only main switches operated under soft switching condition but the auxiliary switches to operate under hard switching conditions. So the overall efficiency reduced.

The soft switching inverters presented in [8] and [9] have no auxiliary switch and the soft switching condition is achieved by a DC-link switch. The

BUPT

disadvantage of these inverters is that their DC-link switch is turned off under an approximately zero voltage state due to the subsistence of a leakage inductor in series with the DC-link switch. This causes a voltage spike across the switch at the turn off instant. To reduce this voltage spike a passive turn off snubber must be utilized, which add extra losses to the circuit.

Soft switching inverters generally do not have a passive snubber. The soft switching inverter presented in [10] in addition to having an auxiliary switch, requires such a snubber for the auxiliary switch. The auxiliary circuit presented in [11] reduced the number of extra elements at the expense of adding a capacitive voltage divider at the inverter input and losing control over the zero voltage interval of the inverter DC-link.

It is more challenging to develop soft switching techniques in bidirectional converters. Therefore it is desirable to use an auxiliary circuit to achieve soft switching in both power flow directions. [12] In some of the conventional proposed bidirectional converters have a two auxiliary circuits are employed to achieve soft switching when the power flows in both directions. The additional numbers of components are used .so conduction losses increased along with increased complexity, cost, weight and size of the converter. This is the main drawback of the conventional bidirectional converters.

In [13] AC-DC converter with a buck converter for single phase PFC applications with snubber circuit. In the snubber circuit is used to achieve zero voltage switching. The efficiency was decreased and the input current THD was improved during at light loads conditions.

In [14] analysis of Interleaved Soft Switching Boost Converter for Single-Phase PV-PCS. The effectiveness of the converter increase due to 2-phase interleaved boost converter incorporated with soft switching cells is utilized. Therefore, the presented circuit has a high effectiveness trait because of low switching losses. To examine the power losses of the designed converter, two experimental sets are constructed. A ZVS buck-boost converter with ZVS for all converter switches has been proposed in [15] but the converter still needs two auxiliary switches.

The auxiliary circuit presented in [16] reduced the number of extra elements at the expense of adding a capacitive voltage divider at the inverter input and losing control over the zero voltage interval of the inverter DC-link. The control of the DC-link zero voltage intervals are used in various switching methods such as space vector modulation.

In [17] snubber circuit was recognized isolated converter. The proposed snubber circuit the switch was stressed due to the energy present in the snubber inductor for the main diode across high voltage stress. So the main diode was suffered.

A new soft switching inverter with one auxiliary switch is proposed in this paper. These switches are turned on under the zero voltage switching (ZVS) condition. Since the sources of the DC-link capacitor are connected in between auxiliary and main switches of inverter circuits. The switch voltage is clamped to the dc link voltage and PWM schemes can be used to control the inverter output voltage. The proposed inverter has a lower number of extra elements in comparison with previous converters while all of the switches are fully soft switched.
The proposed inverter is presented and its operating modes are discussed in section II. The design considerations of the proposed inverter are provided in section III and the experimental results of a 400W, 50Hz prototype inverter are presented in section IV. The presented experimental results confirm the theoretical analysis.

2. Proposed Inverter Description and Operation

The proposed three-Phase PWM inverters with single switch soft switching Technique circuit diagram are shown in Fig. 1.

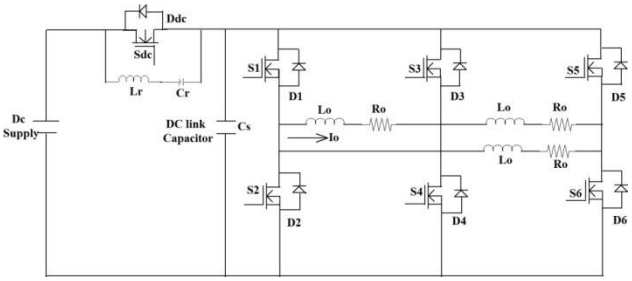


Fig.1. Power circuit configuration of the proposed three-phase PWM inverters with single switch soft switching technique

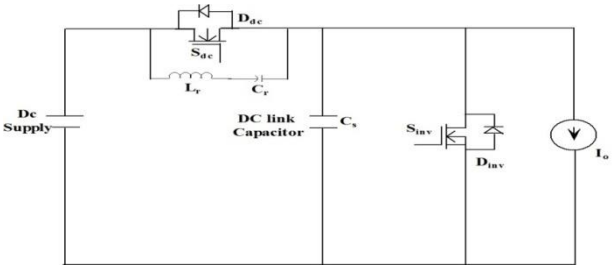


Fig. 2. Equivalent circuit of the proposed inverter.

BUPT

The main inverter is composed of S_1 to S_6.The auxiliary circuits consist of the auxiliary switch S_{dc} parallel with resonant inductor L_r and resonant capacitor C_r. The dc-link capacitor connected in between the auxiliary circuits and main circuits, the inverter with a three phase load can be replaced by the current source I_o, as shown in Fig. 2. Io abruptly alters when the state of the inverter switches changes. In order to simplify the explanation of the inverter operating intervals, all circuit elements are assumed ideal. The proposed inverter has seven distinct operating modes in a switching cycle. The equivalent circuit of each operating mode is shown in Fig. 3. Before the first operating interval, it is supposed that S_{inv} is on, and the output current Io freewheels through D_{inv}.

Mode 1 ($t_0 \le t \le t_1$): At t_0, the auxiliary circuit switch is turning ON under zero voltage condition. The resonant inductor current linearly increases. The inductor current is

$$I_{Lr}(t) = \frac{V_s}{L_r}(t_1 - t_0) \quad (1)$$

Mode 2 ($t_1 \le t \le t_2$): The resonant capacitor already charged. At t_1, instant resonant capacitor charge is discharge through DC link capacitor C_s .The starting of the mode DC link Capacitor voltage zero. so the inverter main switches are off conditions The C_s voltage and L_r current are

$$V_{C_s}(t) = Z_r(I_i - I_o)\sin\omega_r(t_2 - t_1) + V_s\left(1 - \cos\omega_r(t_2 - t_1)\right) \quad (2)$$

Here

$$\omega_r = \frac{1}{\sqrt{L_r C_r}}$$

$$Z_r = \sqrt{\frac{L_r}{C_r}}$$

This mode continues until V_{Cs} reaches V_s. Therefore, the duration of this mode is

$$\Delta t_2 = t_2 - t_1 = \sqrt{L_r C_r}\tan^{-1}\left(\frac{V_s}{Z_r(I_i - I_o)}\right) \quad (3)$$

At the end of the mode resonant completely discharged.

Mode 3 ($t_2 \le t \le t_3$): During this period diode D_{inv} turns ON. So the DC link capacitor C_s Charged. The inductor current slowly reaches to zero.

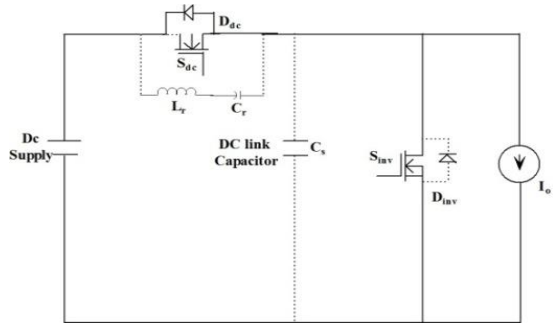
$$I_{L_r}(t_2) = \sqrt{\left(\frac{V_s}{Z_r}\right)^2 + (I_i - I_o)^2} + I_o \quad (4)$$

At the end of this mode the auxiliary switch S_{dc} turn-off.

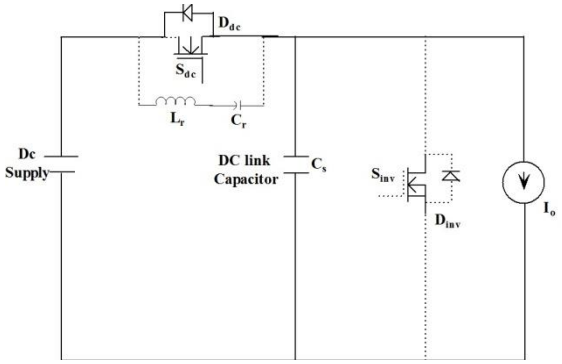
Mode 4 ($t_3 \le t \le t_4$): In this mode inverter switches S_{inv} turned ON under zero voltage condition. Now the DC link capacitor starts discharging through resonant capacitor and resonant inductor .This mode continues until the C_s voltage reaches zero. The duration of this mode is

$$V_{C_r}(t) = V_s - Z_r I_i \sin\left(\frac{\omega_r}{n}\frac{1}{\omega_r}\tan^{-1}\left(\frac{V_s}{Z_r(I_i - I_o)}\right)\right) \quad (5)$$

Mode 5 ($t_5 \le t \le t_6$): At t_5, the L_r current reaches zero, and D_{inv} turn off. At the end of this interval switch S_{dc} will be on.



Mode1



Mode2

BUPT

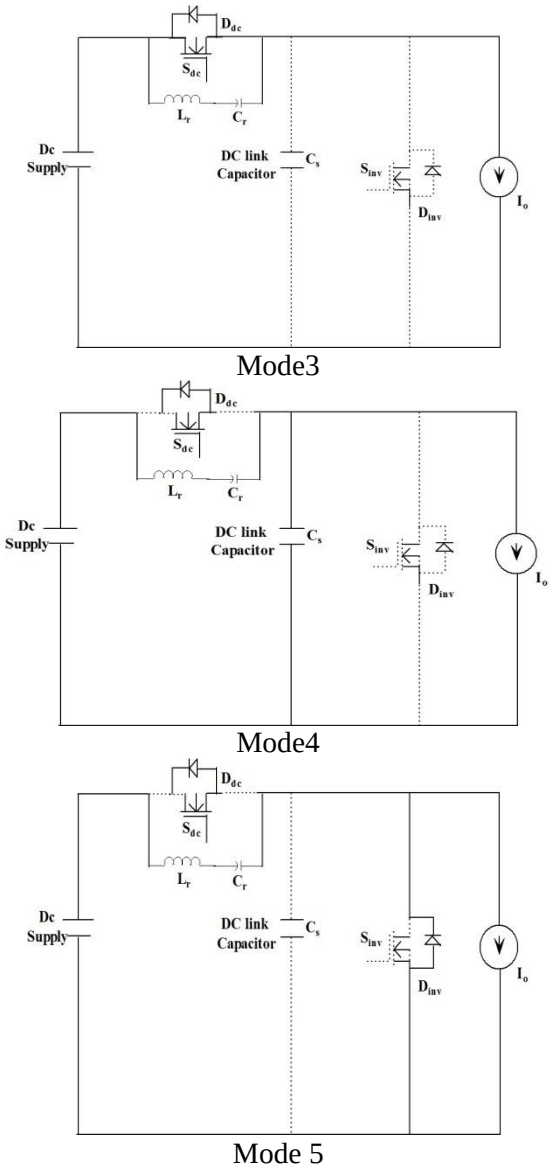


Fig. 3. Equivalent circuit of each operating mode.

3. Design Considerations

The auxiliary circuits consist of Switch S_{dc} Parallel with Resonant inductor and resonant capacitor. The resonant capacitor is chosen such that the resonant frequency between resonant capacitor C_r and resonant inductor L_r should be much lower than the switching frequency. The resonant frequency f_r is given by

$$f_r = \frac{1}{[2\pi(L_r C_r)^{0.5}]} \qquad (6)$$

The resonant inductor L_r is selected to be 32 µH to limit the di/dt of the anti-parallel diodes to 7A/ µs.with such a low di/dt, the reverse recovery losses will be negligible. Choosing a resonant frequency f_r= 12.5 kHz and C_r=5farads.

3.1 snubber capacitance

The snubber capacitor is chosen to reduce the turnoff losses. A larger snubber capacitor will reduce the turnoff loss, but it will increase the conduction losses in the dc link switch Sdc. Let the snubber capacitance (including the output capacitance of the switch) across each bridge switch (S_1-S_6) be C_{sw} (C_1=C_2=C_3=C_4=C_5=C_6= C_{sw}) and the capacitance across the dc link switch S_{dc} be C_{dc}. The effective snubber capacitance Cs is given by

$$C_s = C_{dc} + 2C_{sw} \qquad (7)$$

4. Experimental Results

The proposed three phase soft switching inverter simulation circuit is as shown in figure.4 and hardware model is as show in figure.7.PWM pulse can be generated 120◦-shifted sine waves compared with the saw tooth waveform .The pulse is given to the inverter switches depends on the dc link capacitor voltage zero. The gate pulse is given to the S_{dc} switch and two main switches. Because at the operating time one leg upper switch and another switch lower leg working.

A prototype of the proposed soft switching inverter is implemented at a 20 kHz switching frequency. The input voltage V_{dc}=400V, output voltage: V_{ac}=208V; output frequency: f=50Hz and the output load power is 400 W with a 0.9 power factor. The output frequency is 50Hz.

According to the design procedure, the auxiliary circuit parameters are calculated as C_s=500pF, and L_r =32µH.A photograph of the prototype inverter circuit is shown in figure 7. The switches in the inverter are IRF450, 500 V, 14 A at 25 C. The inverter load is a simple R-L load. A photograph of the prototype control circuit is shown in Fig. 7. The gate pulses are produced with an ATMEGA16 microcontroller and the gate drivers are IR2113

BUPT

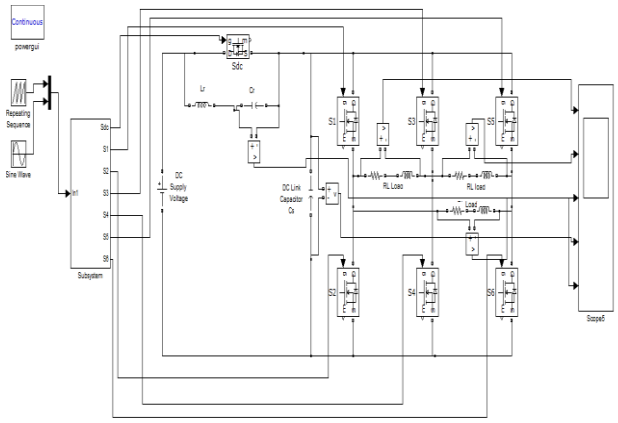


Fig.4 Simulation model for proposed three-phase PWM inverters with single switch soft switching technique.

The voltage and current waveforms of the inverter main switches along with the DC-link voltage are shown in Fig. 6. It can be seen from this figure that the inverter main switches are turned on and off under the ZVS conditions. This improvement is one of the several advantages of soft switching. Other advantages include a reduction in electromagnetic interference and an increase in the switching frequency of the inverter.

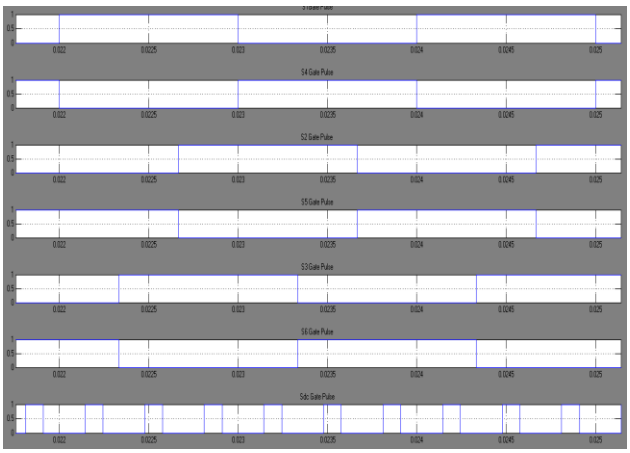


Fig.5 Gate Pluses for the Switch S_1, S_2, S_3, S_4, S_5, S_6 and S_{dc}

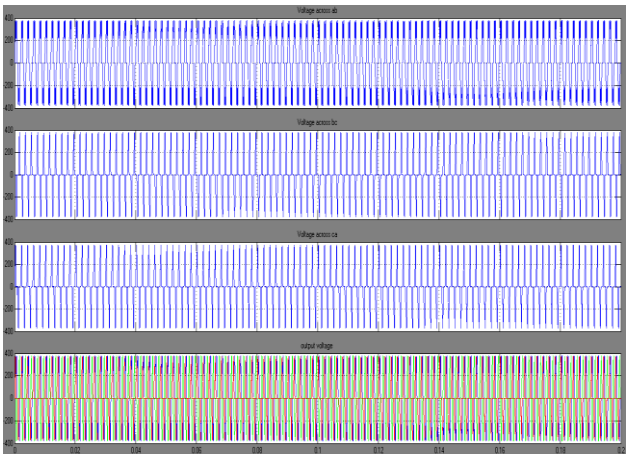


Fig. 6.Simulation output for the Voltage across V_{ab}, V_{bc}, V_{ca} and output voltage of the three-phase PWM inverters with single switch soft switching technique phase

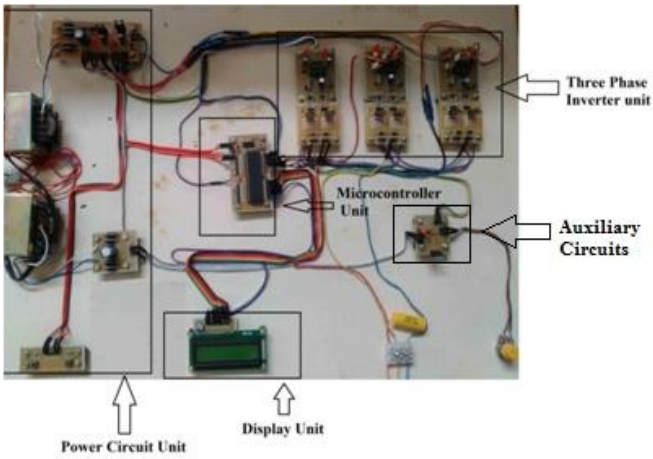


Fig. 7. Photograph of the prototype three-phase PWM inverters with single switch soft switching technique circuits

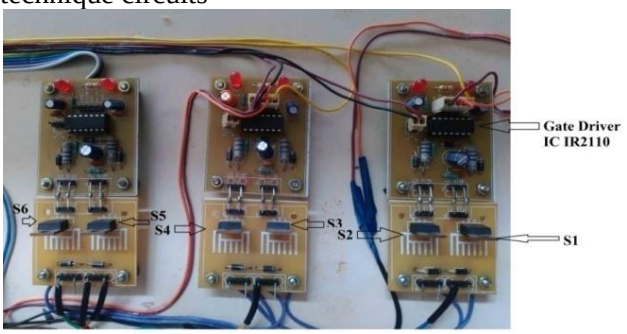


Fig.8.Photograph of the prototype inverter circuit

5. Conclusion

In these paper three Phase PWM inverters with single switch soft switching Technique is presented. Soft-switching techniques can increase both the switching frequency and current handling capability of the devices. While minimizing switching losses is a major expectation the architecture is desired in

BUPT

soft-switching topologies. In this inverter, the auxiliary circuit has only one auxiliary switch. With reducing the number of the auxiliary switches the control circuit becomes simple. All auxiliary switches of the proposed inverter operate at soft switching condition. The auxiliary circuit reduces DC link voltage of the inverter to zero in switching times and thus, the inverter main switches operate at zero voltage switching conditions. All operating modes of the inverter are discussed in this paper. Also simulation results are presented to confirm the theoretical analysis.

References

1 Pan, ZY & Luo, FL.: *Novel soft-switching inverter for brushless dc motor variable speed drive system* . In:IEEE Trans. Power Electron, vol. 19, no. 2, pp. 280-288.2014.

2 M. Mahdavi and H. Farzanehfard.: *A new zero voltage transition bridgeless PFC with reduced conduction losses.*In: Journal of Power Electronics, Vol. 9, No. 5, pp.708-717, Sep. 2009.

3 M. R. Amini and H. Farzanehfard,.: *Novel family of PWM soft-singleswitched DC-DC converters with coupled inductors.* In: IEEE Trans. Ind.Electron., Vol. 56, No. 6, pp. 2108-2114, Jun. 2009.

4 E. Adib and H. Farzanehfard.: *Family of isolated zero current transition PWM onverters.* In: Journal of Power Electronics, Vol. 9, No. 2, pp.156- 163, Mar. 2009.

5 Rongjun Huang & Sudip Mazumder, K.: *A Soft-Switching Scheme for an Isolated DC/DC Converter With Pulsating DC Output for a Three-Phase High-Frequency-Link PWM Converter.*In: IEEE Transactions on Power Electronics, vol. 24, no. 10, pp. 2276-2288.2009.

6 H. Bodur, A.F. Bakan .: *A new ZVT-PWM Dc-Dc converter* . In: IEEE Trans. on Power Electronics, vol.17, no.1, pp.40-47, Jan 2002.

7 E. Sanchis-Kilders, A. Ferreres, E. Maset, J. B. Ejea, J. Jordan, A. Garrigos, and J.Calvente.: *Soft switching bidirectional converter for battery discharging–charging.* In: Proc. IEEE APEC Conf. Rec., 2006, pp. 603–609.

8 M. R. Amini and H. Farzanehfard,.: *Novel quasi-parallel resonant dc-link inverter with one auxiliary switch.* In: Proceeding IEEE International Conference on Power and Energy, pp. 614-618, 2008.

9 M. R. Amini and H. Farzanehfard.: *Three phase soft switching inverter with minimum components.*In: IEEE Trans. Ind. Electron., Vol. 58, No.6, pp. 2258-2264, Jun. 2011.

10 M. R. Amini and H. Farzanehfard.: *Quasi resonant dc link inverter with simple auxiliary circuit.* In:Journal of Power Electronics, Vol. 11, No. 1, pp. 10-15, Jan. 2011.

11 S. Mandrek and P. J. Chrzan,.: *Quasi-resonant dc-link inverter with a reduced number of active elements.* In: IEEE Trans. Ind. Electron., Vol. 54, No. 4, pp. 2088-2094, Aug. 2007.

12 H. Bodur, and A.F. Bakan.: *An improved ZCT-PWM Dc-Dc converter for high power and frequency applications.* In:IEEE Trans. on Industrial Electronics, vol.51,no.1, pp. 89- 95, Feb. 2004.

13 Chang. CH, Cheng. CA, Chang, EC & Cheng. HL & Yang: 'An integrated high-power-factor converter with ZVS transition', IEEE Transactions on Power Electronics, 2016, vol. 31, no. 3, pp. 2362-2371.

14 Jae-Hyung Kim, Yong-Chae Jung, Su-Won Lee, Tae-Won Leez & Chung-Yuen Won.: *Power Loss Analysis of Interleaved Soft Switching Boost Converter for Single-Phase PV-PCS.:* In Journal of Power Electronics, vol. 10, no. 4, pp. 335-341.2010.

15 X. Yan; A. Seckold and D. Patterson.: Development of a zero-voltage-transition bidirectional Dc-Dc converter for a brushless DC machine EV propulsion system. In: PIEEE PESC Conf, 2002. Vol.4, no., pp. 1661- 1666.

16 Mohammad Reza Amini and Hosein Farzanehfard.: *Quasi-resonant dc-link inverter with a simple auxiliary circuits.*.In: Journal of Power Electronics., Vol.11, No. 4, pp. 10-15, Jan2011.

17 Mohammadi. M, Adib. E & Yazdani. MR:'Family of soft switching single-switch PWM converters with lossless passive snubber', IEEE Transactions on Industrial Electronics, 2015, vol. 62, no. 6,pp. 3473-3481.

BUPT