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MODIFIED THREE PHASE VSI WITH GENERALIZED PULSEWIDTH MODULATION

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Abstract— ***A novel three phase voltage source inverter is proposed in this paper. The proposed inverter does not require dead time, and thus avoids the shoot through problems of standard voltage source inverters, thus enhancing the system reliability. Even it is a hard switching inverter the proposed topology allows the use of power MOSFETs instead of IGBTs as active switches. As a result, it has the advantage of low switching losses, and hence it can be designed at high switching frequency to reduce current ripple and passive components size. To reduce computational burden a generalized pulse width modulation is introduced, different PWM methods were applied to a modified three-phase inverter, including sinusoidal PWM (SPWM), space vector PWM (SVPWM) and discontinuous PWM (DPWM).***

Keywords— Three phase inverter,Voltage source inverter, DPWM.

I. INTRODUCTION

In conventional three phase voltage source inverter, the presence of two active switches in one phase leg results into some common problems, such as the need of dead time or band between the two active switches of the same phase leg; shoot through especially at some fault condition. The other problem is that the power MOSFETs cannot be simply used due to the reverse recovery problems of the body diode [1]-[3]. But it is required to obtain the advantages such as low resistive conduction voltage drop, low switching loss and fast switching speed which allows reduction of current ripple and the passive components. The conventional approaches adopt soft switching techniques [4]-[5].

The proposed voltage source inverter is shown in Fig. 1. It is a hard switching inverter, but it can incorporate the use of power MOSFETs as the active switches. The number of devices used is same to that of the standard three phase voltage source inverter using insulated gate bipolar junction transistor. From the single phase half bridge and full bridge dual buck inverter the modified three phase inverter is developed [6]-[8]. It does not require dead time or band and so no shoot through, as in conventional inverter. In traditional inverters the outgoing switch does not turn off instantaneously due to its finite turn off delay, due to this both switches conduct simultaneously for a short time. This is known as cross conduction or shoot-through fault. This can be avoided by introducing a dead band or delay between the switches. Therefore, during the dead -band interval no device receives base drive. Hence the dead band should be longer than the turn off time of the power devices used in the inverter circuit. In the proposed inverter even as the body diode of the power MOSFET never conducts, it can be hard switched.

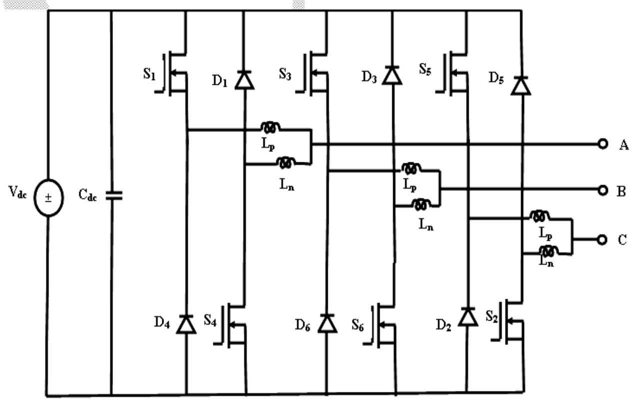


Fig 1 : Proposed three- phase VSI with MOSFETs.

In order to minimize the switching losses, the freewheeling diodes can be chosen independently with fast reverse recovery features. When compared with single phase dual buck inverter the three phase inverter does not have the double fundamental frequency ripple on the dc bus, and it can be modulated by DPWM to further reduce the switching losses, thus fully utilizing the dc bus voltage. To modulate the three phase inverter, a generalized PWM is adopted [9].

Here the generalized PWM method used has less computational burden compared to traditional SVPWM calculations. By the unique operating principle of the modified three phase inverter, the generalized PWM is modified to use the voltage reference to generate the required gate signals. In this method different

PWM methods can be considered as special cases which include sinusoidal pulse width modulation (SPWM), space vector pulse width modulation (SVPWM), and discontinuous pulse width modulation (DPWM).

Classical space vector PWM with equal duration of application of zero state vectors V_O and V_7 was modified. The time of application of vector V_7 (and V_0) was made changeable from 0 to 100% over the time T_0 for their combined application. The ratio of the duration of application of vector V_0 vs. V_7 can be kept constant or changed on a sample by sample basis with a significant impact on the characteristics of the PWM. But the modified space vector PWM (with a classical space vector PWM as a special case) can be implemented by triangle comparison method with added zero sequence. A new algorithm for the implementation of the modified space vector method by triangle comparison PWM method is proposed. This paper first presents the basic operating principle of the proposed converter and then it analyzes the specific generalized PWM technique applied to the modified three phase inverter.

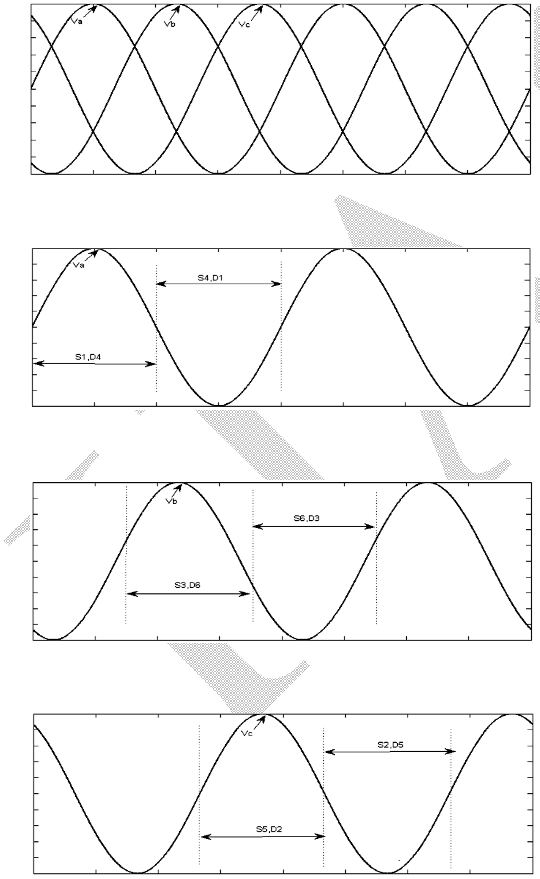
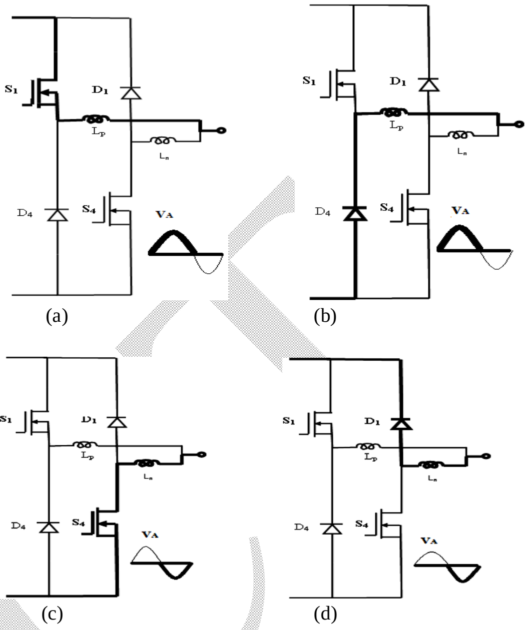


Fig 2 : Relation between phase voltages and conducting devices.

II. PROPOSED TOPOLOGY AND OPERATION PRINCIPLE



(a) (b)

(c) (d)

Fig.3. Four switching states for phase A.(a) S_1 on, $V_A > 0$. (b) D_4 on $V_A > 0$. (c) S_4 on $V_A < 0$. (d) D_1 on $V_A < 0$.

Fig. 1 shows the proposed three phase modified voltage source inverter, the PWMs for the active switches are obtained by the phase output voltages, since the voltages are taken as reference. The relation between the polarity of phase voltage and the operation of switches is shown in Fig.2. The operating principle is as follows when phase A is considered, for V_A is positive, S_1 and D_4 devices conduct and when V_A is negative, S_4 and D_1 devices conduct. Similar operation principle applies for the phase B and the phase C.

Fig.3 shows the four switching states in case of phase A. From the operating principle it can be seen that the body diodes of S_1 and S_4 never have the opportunity to conduct, thus ensuring the safe switching of the power MOSFETs in the circuit. Here as there is only one active switch per leg the problem of shoot through is no longer possible. Thus the reliability of the proposed modified three phase inverter is more when compared to conventional voltage source inverters.

In this case no dead time is needed as when S_1 operates S_4 is always OFF and when S_4 operates S_1 is always OFF. Thus the output waveforms are more sinusoidal and the energy is transferred completely without the dead time or band effect. As the power MOSFET and diode can be selected independently the efficiency of the system is improved further. In order to minimize the conduction loss, a power MOSFET with smaller on-resistance and a power diode with smaller forward voltage is chosen. To optimize the switching losses the diode which has fast reverse recovery characteristics is chosen.

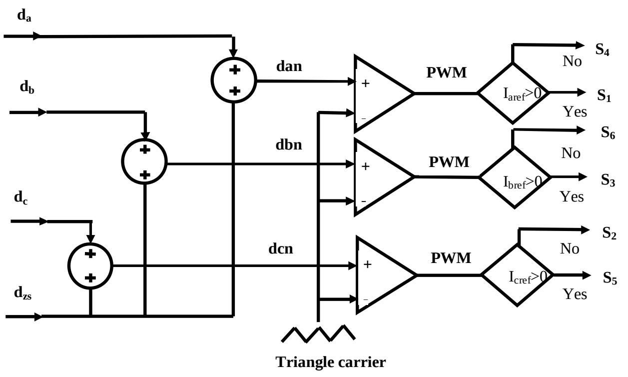


Fig 4 : Generalized PWM generation block diagram.

III. GENERALIZED PWM ANALYSIS

Even the MOSFETs are used for the three-phase voltage source inverter to reduce the switching losses; it is still a hard switching voltage source inverter. It would be better to further reduce the switching losses by using generalized PWM. By adopting the methods of SVPWM and generalized PWM the dc bus voltage can be fully utilized when compared to SPWM. Traditionally SVPWM methods [10] need to do trigonometric calculations and perform recombination of actual gating times. The generalized PWM methods [9] SVPWM and DPWM can be equivalently generated with the help of triangle carrier comparison like SPWM, which reduces the computational burden to great extent.

The generalized PWM generation block diagram is shown in Fig.4. Based on the voltage reference polarity the switch to which PWM is applied is selected. The d_a, d_b and d_c are the phase duty cycles of the inverter. The zero sequence duty cycle d_{zs} which is injected is obtained by the following equation [9]

$$d_{zs} = - [(1-k_0)+k_0*d_{max}+(1-k_0)*d_{min}] \tag{1}$$

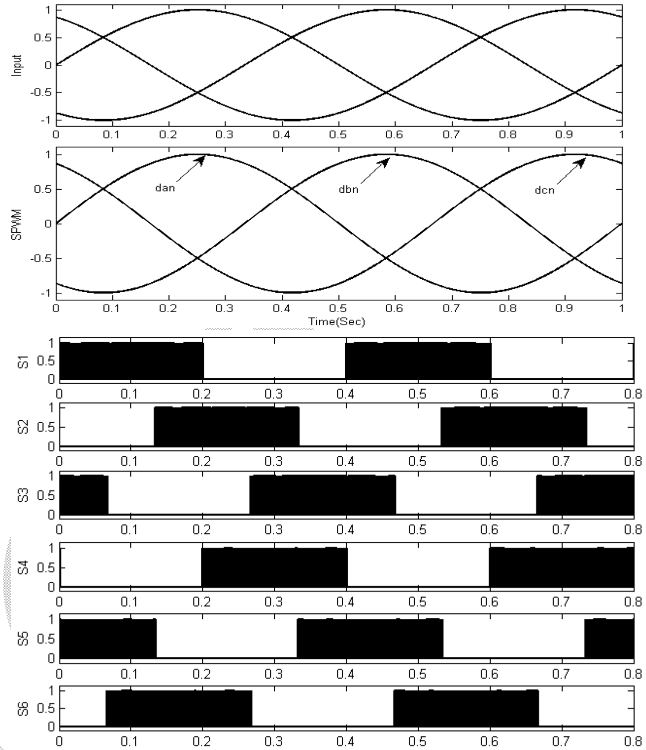
Where $d_{max}=\max(d_a, d_b, d_c)$ and $d_{min}=\min(d_a, d_b, d_c)$.

Where k_0 is known as PWM determination factor. In the generalized pulse width modulation scheme if k_0 is 0.5, the output PWM is SVPWM and if k_0 follows relation (2), then the output PWM is DPWM with non switching state at phase voltage 60^0 peak region.

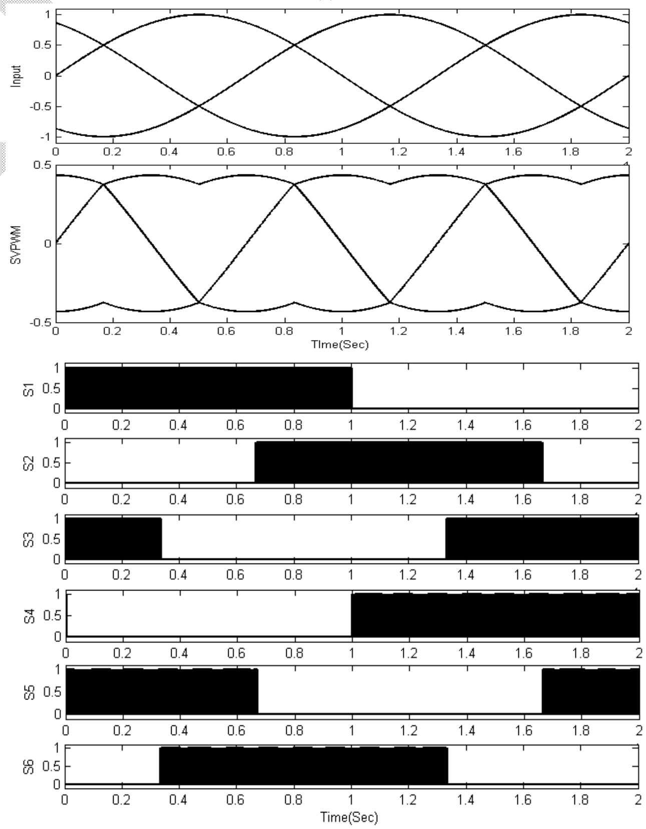
$K_0 = 1 \quad J>0$
$K_0 = 0 \quad J<0$

$$J=\max(v_{aref}, v_{bref}, v_{cref})+\min(v_{aref}, v_{bref}, v_{cref}) \tag{2}$$

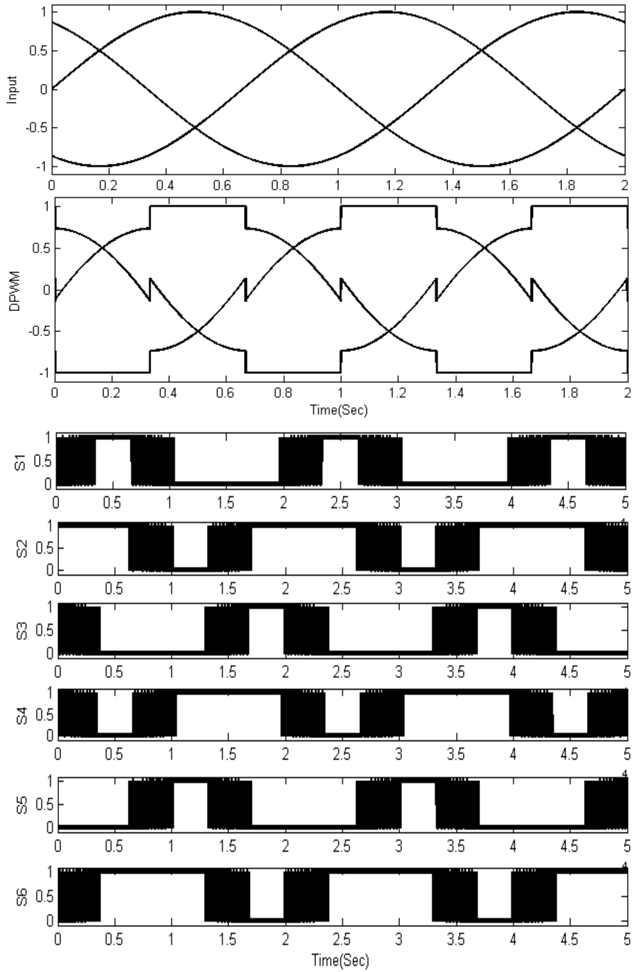
IV. SIMULATION RESULTS



(a)



(b)



(c)

Fig.5. Generalized PWM simulation results. (a) SPWM. (b) SVPWM (c) DPWM.

The simulation results of PWM generation by the generalized PWM scheme is shown in Fig.5 with duty cycles $d_a = d_b = d_c = 1$. Fig.5 (a) shows the results of SPWM with $d_{zs}=0$; Fig.5 (b) shows the results of SVPWM when $k_0 = 0.5$; Fig.5 (c) shows the results of DPWM when k_0 follows relation (2).

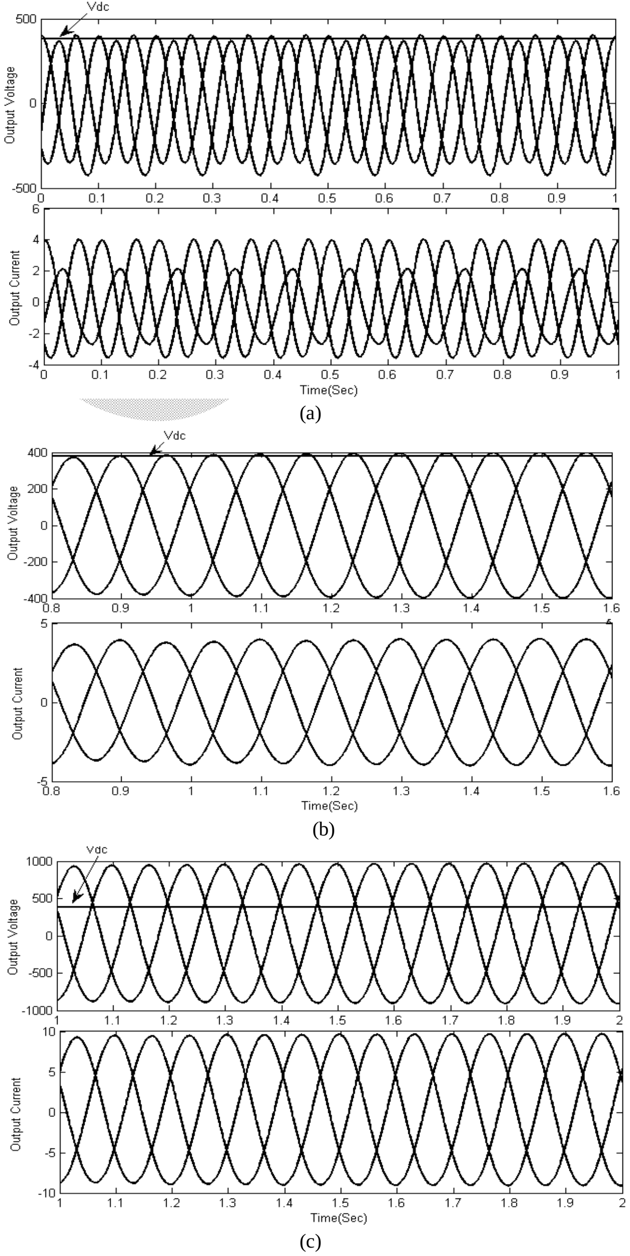
In general the maximum phase duty cycle in case of SPWM is 1, but after injecting d_{zs}, the SVPWM and DPWM can boost the phase duty cycle up to 1.15, it means that there is 15% more dc bus voltage utilization. From simulation results shown in fig.5, in terms of switching losses, the SPWM is almost same as the SVPWM.

But DPWM can further decrease the switching losses because here each phase will not switch for a 60º interval when its absolute phase voltage is the largest among the three phase voltages. From the relations (1) and (2) it is clear that the calculation burden required is very small in order to implement the generalized PWM. The d_j (j=a, b, c) is the phase duty cycle, L_f and C_f are the filter inductance and capacitance, and L_j is the output inductor of each phase. The inductance $L = L_j + L_f$

Where

$$\begin{aligned} L_j &= L_p \quad \text{for } v_j > 0 \\ L_j &= L_n \quad \text{for } v_j < 0 \end{aligned} \tag{3}$$

The proposed three phase modified voltage source inverter is evaluated with the generalized PWM methods at switching frequency of 15KHZ. The passive components are selected as $L_p = L_n = 250\mu H$, $L_f = 1mH$, $C_f = 2.4\mu F$. The load is a resistive load bank.



(a)

(b)

(c)

Fig.6. Output voltage and current waveforms at dc bus voltage of 380V. (a)SPWM (b)SVPWM (c)DPWM.

Fig.6. shows the three phase output voltages, the phase to neutral voltage waveforms and the three phase output currents for the three PWM methods. Fig.6 (a) shows the output voltage and output current for SPWM; Fig.6 (b) shows the output voltage and output current for SVPWM; Fig.6 (c) shows the output voltage and output current for DPWM, at which the dc bus voltage is set at 380V.

V. CONCLUSION

A novel three phase voltage source inverter is proposed in this paper. Three different modulation techniques are applied to the proposed voltage source inverter. This voltage source inverter does not require dead time in driving pulses and therefore the shoot through is eliminated. A simple generalized PWM algorithm is proposed for both SVPWM and DPWM. The proposed generalized pulse width modulation algorithm has better performance when compared with SPWM technique.

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