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Simulation of ZVS inverter with space vector modulation using Simulink

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Abstract: **-- In this paper, a Zero Voltage Switching inverter with high efficiency are expected since switching losses are reduced with a proper design. In order to reduce zvs condition the auxiliary circuit is connected which includes the inductor, capacitor and switches are embedded. It is impossible to realize the maximum efficiency with the conventional method. Space vector modulation is a digital technique and specified by eight switching states. switching pulses using space vector modulation controls fundamental voltage, reduces the harmonics and improves the performance of the inverter. This is simulated using MATLAB Simulink.**

Index Terms: **Auxiliary circuit, space vector modulation, MATLAB Simulink.**

I. INTRODUCTION

Inverter plays an vital role in renewable energy generation as the interface between the renewable energy and the grid. High conversion efficiency and miniaturization are essential requirements of inverters. Hard switching inverters are utilized to limit switching losses but the major drawback is audible noise and bulky passive component. Soft switching techniques provides practical solutions for inverters to achieve high efficiency with reduced size. one of the main drawback of soft switching is voltage stress on the switches. This leads to the output power quality issues. To overcome the output power quality issues discrete PWM is utilized but voltage stresses cannot be reduced. Inverters with auxiliary circuit and SVM Technique were reported to achieve low voltage stresses and reduced switching losses across all switches.

The advantages of resonant converters are derived from their L-C circuit and they are as follows: sinusoidal-like wave shapes, inherent filter action, reduced dv/dt and di/dt and EMI, facilitation of the turn-off process by providing zero current crossing for the switches and output power and voltage control by changing the switching frequency. In addition, some resonant converters e.g., quasi-resonant converters, can accomplish zero current and/or zero voltage across the switches at the switching instant and reduce substantially the switching losses. The literature categorizes these converters as hard switched and soft switched converters. Unlike hard switched converters the switches in soft switched converters, quasi-resonant and some resonant converters are subjected to much lower switching stresses. Note that not all resonant converters offer zero current and/or zero voltage switching, that is, reduced switching power losses. In return for these advantageous features, the switches are subjected to higher forward currents and reverse voltages than they would encounter in a non resonant configuration of the same power. The variation in the operation frequency can be another drawback.

In resonant switch converters, resonant circuits are connected to the semiconductors to ensure soft switching and to reduce the switching losses. In practice, zero current switching (ZCS) and zero voltage switching (ZVS) are possible. Because the voltage on the semiconductors increases with simple ZVS converter.

The main properties of ZVS are highlighted as follows:

• The switch turn-on and turn-off occurs at zero voltage which significantly reduces the switching losses.

• Sudden current and voltage changes in the switch are avoided in ZVS, respectively. The di/dt and dv/dt values are rather small. EMI is reduced.

• In the ZVS, the switch must withstand the forward voltage Vdc ,+ ZoIo and ZoIo must exceed Vdc.

• The output voltage can be varied by the switching frequency.

• The internal capacitances of the switch are discharged during turn-on in ZCS which can produce significant switching loss at high switching frequency. No such loss occurs in ZVS.

II. RELATED BACKGROUND

M. Calais and V. G. Agelidis, proposed “Multilevel converters for single-phase grid connected photovoltaic systems-an overview,”. Multilevel voltage source inverters offer several advantages compared to their conventional counterparts. By synthesising the AC output terminal voltage from several levels of voltages, staircase waveforms can be produced, which approach the sinusoidal waveform with low harmonic distortion, thus reducing filter requirements. The need of several sources on the DC side of the converter makes multilevel technology attractive for photovoltaic applications. This paper provides an overview an different multilevel topologies and investigates their suitability for single-phase grid connected photovoltaic systems.

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T.S.Wu , M.D.Bellar , A.Tchamdjou , J.Mahdavi and M.Ehsani proposed , "A Review of Soft-Switched DC-AC Converters" , Soft switching techniques have recently been applied in the design of dc-ac converters in order to achieve better performance, higher efficiency and high power density. In this paper, the operating principles and their performance evaluation of soft switching are presented and design limitations are discussed.

Giri Venkataramanan and Deepak Divan proposed, " Pulse width Modulation with resonant Dc link converters" proposed a technique for realizing PWM capability in resonant dc link converters is discussed. This technique eliminates the sub harmonics present in the conventional methods. Control techniques and design analysis involved are presented.

Deepak raj M Dewan proposed, " The Resonant DC Link Converter-A New Concept in Static Power Conversion" proposed a new approach to realizing efficient high performance power converters is presented. The concept of a resonant dc link inverter has been proposed and realized with the addition of only one small inductor and capacitor to a conventional VSC circuit. The topology is suitable for high power applications using GTO based devices.

Mohammad Reza Amini and Hosein Farzanehfard proposed, "Three Phase Soft Switching Inverter with Minimum Components" presents a novel three phase soft switching inverter. The inverter switch turn on and turn off are performed under ZVS Condition. This inverter has only one auxiliary switch, which is also soft switched . The proposed inverter is designed , analysed and experimental results of prototype are found.

III. PROPOSED METHODOLOGY

SVPWM FOR ZVS INVERTER

The SVPWM method is now a well documented PWM control technique that yields high voltage gain and les harmonic distortion compared to other modulation technique. Here the three phase input current and output voltage are represent as a space vector. Representing three phase quantities as space vector is particularly is useful for power electronic applications. Essentially thus method defines a three phase system with single unity power factor. Eight possible switching combinations are generated by the switching network and are referred as active states. Six out of these eight topologies producing a non zero output voltage are known as the non-zero switching states and the remaining two topologies producing zero output voltage are known as zero switching states.

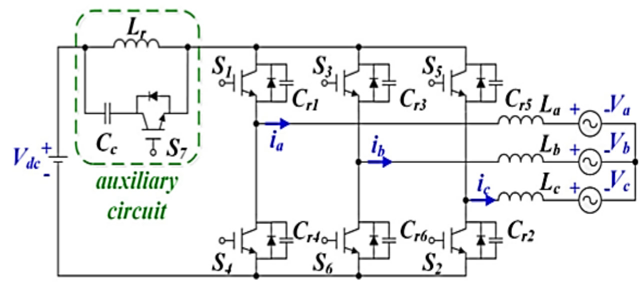

Fig 1:- Circuit diagram of zcs inverter with auxiliary switch

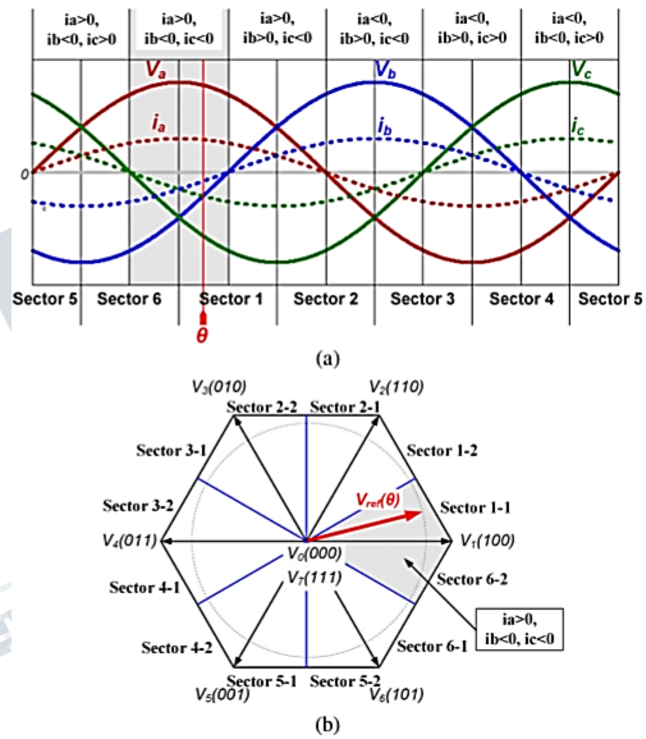

Fig 2:- Analysis of zvs inverter using SVM technique

Stage 1 ($t_0 - t_1$): In this stage, the operation state is in vector V_7 (111). The current direction of each phase indicates that S_1 ,D_3 and D_5 are in conducting state. Auxiliary switch S_7 is in conducting state in this stage, and the resonant inductor L_r is charged by the clamping capacitor C_c . The capacitance of C_c is large enough that V_{Cc} , the voltage across C_c , can be treated as constant during the switching cycle. Therefore, the current through L_r changes linearly at the rate of $-V_{Cc}/L_r$. In this stage, V_{bus} is clamped to be $V_{dc} + V_C$ and i_{S7}

Stage 2 ($t_1 - t_2$): At t_1 , S_7 is turned off. Oscillation between the resonant inductor L_r and the resonant capacitors C_{r2} , C_{r4} , C_{r6} , and C_{r7} is provoked. During this stage, V_{bus} keeps reducing, while V_{S7} increases. With the help of the resonant capacitors, S_7 is turned off under ZVS conditions. This stage ends at t_2 , when V_{bus} oscillates to zero and V_{S7} oscillates to

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be $V_{dc} + V_{Cc}$. At around t_1 , i_{Lr} reaches its minimum value $i_{Lr\,min}$.

Stage 3 (t_2 –t_3): After t_2 , V_{bus} equals zero. After resonance, L_r still has residual energy to keep current i_{Lr} negative. D_4 , D_6 , and D_2 conduct in freewheeling mode. S_6 and S_2 are turned on during this stage under ZVS condition. i_{Lr} increases with a rate of V_{dc}/L_r in this stage.

Stage 4 (t_3 –t_4): At t_3 , i_{Lr} reduces to zero. Currents in phase b and phase c begin to transfer from D_3 and D_5 to S_6 and S_2 , respectively. During this period, the changing rate of i_{S3} and i_{S5} is restrained to a small value by L_r so that the reverse recovery losses on D_3 and D_5 can be eliminated. i_{S3} and i_{S5} reduce to zero by time t_4 .

Stage 5 (t_4 –t_5): At t_4 , S_4 is turned on to construct a short-circuit path with S_1 . L_r is charged during this stage to store enough energy to fulfill the ZVS condition for the next switching cycle. During this stage, V_{bus} equals zero, and S_4 is turned on under ZVS condition.

Stage 6 (t_5 –t_6): After the charging period, S_4 is turned off at t_5 . With the buffer of the resonant capacitors, S_4 is turned off under ZVS conditions. Another resonance occurs among L_r , C_{r3} , C_{r4} , C_{r5} , and C_{r7} . During this resonance, V_{bus} increases and V_{S7} decreases. At time t_6 , V_{bus} resonances to $V_{dc} + V_{Cc}$, while V_{S7} reduces to zero. At around t_6, i_{Lr} reaches its maximum value $i_{lr\,max}$ .In this stage, $i_{S7} = -i_{Lr} - i_a$.

Stage 7 (t_6 –t_7): After the oscillation, S_7 can be turned on under ZVS condition since V_{S7} equals zero. The inverter operates in vector V_1 (100) in this stage.

Stage 8 (t_7 –t_8): At t_7 , S_6 turns off. The output current i_b charges C_{r6} and discharges C_{r3} . With the buffer of the resonant capacitor, this action is a ZVS-off. This stage ends at t_8 when V_{S3} reduces to zero and D_3 conducts in freewheeling mode.

Stage 9 (t_8 –t_9): In this stage, inverter is operated in vector V_2 (110) and $i_{S7} = i_c - i_{Lr}$.

Stage 10 (t_9 –t_{10}): At t_9 , S_2 is turned off. The output current i_c charges C_{r2} and discharges C_{r5} simultaneously. With these capacitors, S_2 is turned off under ZVS conditions. This stage ends at t_{10} when V_{S5} reduces to zero and D_5 conducts in free-wheeling mode. After stage 10, the inverter returns to stage 1 of a new vector cycle.

Stage 3:- At t7, s6 turns off . The output current ic charges ic charges cr2 and discharges cr5 simultaneously. With these capacitors, s2 is turned off

IV. IMPLEMENTATAION AND RESULTS

The simulation for proposed zvs inverter is conceded out using MATLAB/Simulink ans simulated model is shown in fig 3.

ADVANTAGES OF MATLAB:-

- MATLAB is a commonly used device within the electrical engineering community.
- Advantages of utilizing MATLAB for inspecting vigour method consistent state behaviour and is capable for simulating transients in power method and power electronics.
- It can be used for simple mathematical manipulation using matrices.
- Simulink is a graphical extension to MATLAB for modelling and simulation of systems.
- Simulink is the ability to model nonlinear system, which a transfer function is unable to do.

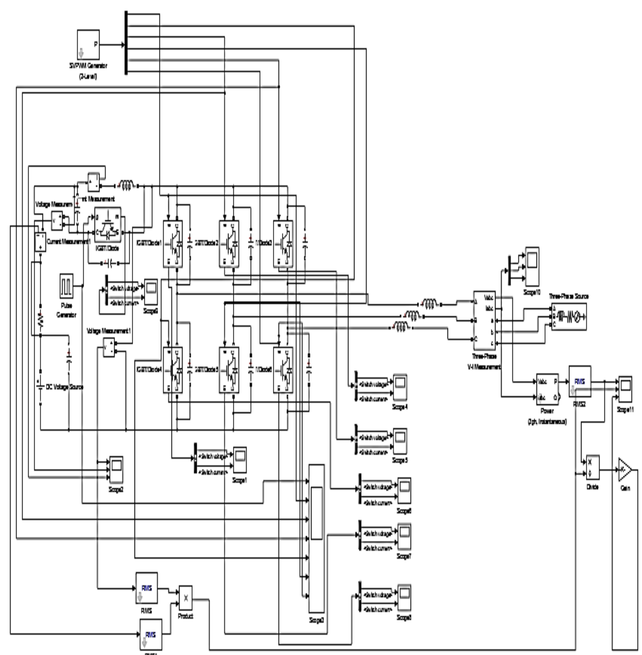

Fig 3:- Implementation of zvs inverter using Simulink

Results:- Efficiency is shown below

Fig 4:- Output of zvs inverter comprising input power, output power and efficiency

$$\text{Efficiency}=\frac{p_{out}}{p_{in}}$$

V. CONCLUSION

Conventional design methodologies for a ZVS inverter involve a subset of design variables, tuning several of the remaining design variables and observing the results. This step is repeated, which requires extensive efforts to obtain acceptable results. This paper utilizes an optimization methodology to optimize the efficiency of the ZVS inverter. In order to obtain higher efficiency, switching losses must be reduced. The SVM control technique are implemented for reducting switching losses of ZVS inverter and hence efficiency increases.

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