Design and Analysis of a Novel Multilevel Inverter Topology Suitable for Renewable Energy Sources Interfacing to AC Grid for High Power Applications

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Abstract- A novel topology for cascaded multilevel inverters which is suitable for renewable energy source interfacing to grid is proposed in this paper. The proposed topology significantly reduces the usage of number of dc voltage sources, switches, and power diodes as the number of output voltage levels increase. The world electrical energy consumption is rising and there is a steady increase of the demand on the power capacity, efficient production, distribution and utilization of electrical energy. The traditional power systems are changing, number of renewable energy sources such as wind turbines, photovoltaic generators, fuel cells, small hydro, wave generators, are being integrated into power systems at distribution level. The multilevel converters plays an essential part in the integration of the renewable energy sources. This paper reviews the application of multilevel converters in the integration of renewable energy sources. This new type of converters are suitable for high voltage and high power application due to their ability to synthesize waveforms with reduced harmonic distortion. Number of topologies have been introduced and widely studied ,amongst the CHB topology is the proper option from the point of view of modularity and simplicity of control. Main disadvantage of multilevel configuration is increase in number of power semiconductor switches and its complexity to design gate driver circuit individually, its cost and switching losses. Complexity of the system reduces reliability of the inverter. By reducing number of switches for the same levels of voltages these disadvantages can be reduced effectively This project presents a new technique for getting a synthesized multilevel output and also uses PWM control techniques for CHB topology, in this technique, the number of dc voltage sources, switches, and power diodes used for the dc to ac conversion is reduced. So this dc to ac conversion significantly reduces the initial cost. The modes of operation are outlined for 7-level inverter, as similar modes will be realized for higher levels. Simulations of seven level of the proposed inverter topology along with with experimental results are presented. MATLAB simulink environment is used to simulate the results.

Index Terms- Cascaded multilevel inverters,RES interfacing, harmonic distortion, reduced number of devices

I. INTRODUCTION

Multilevel voltage source inverter is recognized as an important alternative to the normal two level voltage source inverter especially in high voltage application[1]. Using multilevel technique, the amplitude of the voltage is increased, stress in the switching devices is reduced and the overall harmonics profile is improved. Among the familiar topologies, the most popular one is cascaded multilevel inverter. It exhibits several attractive features such as simple circuit layout, less component counts, modular in structure and avoid unbalance capacitor voltage problem. However as the number of output level increases, the circuit becomes bulky due to the increase in the number of power devices. In this project, it is proposed to employ a new technique to obtain a multilevel output using less number of power semiconductor switches when compared to ordinary cascaded multilevel inverter, which is suitable for renewable energy source interfacing. Voltage source converters are also required for various industrial applications, smart grid technologies etc. Due to high power requirement in these applications, using one power semiconductor switch directly is not advisable. For high power and medium voltage applications multilevel converters are introduced [2]. Using multilevel converters renewable energy sources can be easily interfaced to the grid. Using several low voltage DC sources such as capacitors, batteries and renewable sources with series power semiconductor switches high power converter can be achieved. The rated voltage of the switches depends only upon the rating of DC voltage sources to which they are connected. These converters have several advantages over two level converters. Multilevel converters can generate the output voltages with low distortion and less dv/dt stresses. Small common mode voltage reduces the stress in the bearings of motor connected to multilevel converter. Input current with low distortions, range of the switching frequency are further advantages of multilevel converters. But due to large number of switches, each switch requires its related gate drive circuit increase cost and complexity. Major multilevel converter structures are Cascaded H bridge converter, Diode clamped converter, Capacitor clamped converter. Different pulse width modulation techniques developed such as sinusoidal pulse width modulation (SPWM), Selective harmonic elimination (SHE-PWM), space vector modulation (SVM) and so on[3]. In cascaded H bridge converter, depending on the number of voltage levels required, some single

phase full bridges or H bridges are connected in series with individual separate DC source. Number of voltage levels is equal to 2n+1 where n is the number of separate DC sources. In Diode clamped converter converter all of the three phases share a common DC bus, which minimize the capacitance requirements of the converter. Hence a back to back topology is possible. Efficiency is high for fundamental frequency switching. But number of clamping diodes required is quadratic ally related to number of levels, which can be cumbersome for units with a high number of levels. Capacitor clamped or flying capacitor structure is similar to diode clamped converter except that instead of using clamped diodes, the inverter uses capacitors in their places. In this converter real and reactive power can be controlled. The large number of capacitors enables the inverter to ride through short duration outages and deep voltage sags. For real power transmission efficiency is poor in this converter. Control is complicated to track all the voltage levels of capacitors. Because of its fast response and autonomous control, the use of a multilevel converter to control the frequency and voltage output from renewable energy sources will provide significant advantages. These converters can also control the real and reactive power flow from a utility connected renewable energy source. Multilevel converters can control system dynamic behavior, also reduce power quality problems such as voltage harmonics and voltage imbalances. In case of PV system it's advantageous to use cascaded H bridge converter as each converter requires separate DC sources. Additional advantages are possible elimination of the DC/DC converters, significant reduction of the power drops caused by sun darkening and hence potential increase of efficiency and reliability. In case of wind generation, converting variable magnitude, variable frequency voltages generated from wind generator into fixed magnitude, fixed frequency voltages is more advantageous with multilevel converter to improve efficiency over a wide range of operating points and energy capture. Main disadvantage of multilevel configuration is increase in number of power semiconductor switches and its complexity to design gate driver circuit individually, its cost and switching losses. Complexity of the system reduces reliability of the inverter. By reducing number of switches for the same levels of voltages these disadvantages can be reduced effectively. A single-phase structure of an m-level cascaded inverter is illustrated in Figure 1. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1, where s is the number of separate dc sources.

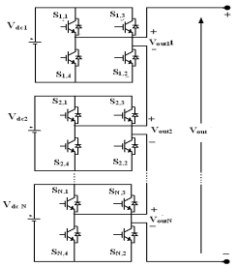

Fig1 Single-phase structure of a multilevel cascaded H-bridges inverter

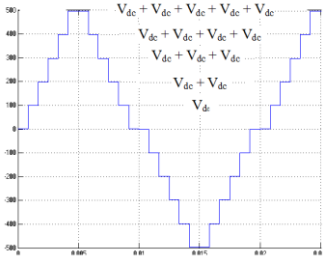

Fig 2 Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources.

Cascaded inverters are ideal for connecting renewable energy sources with an ac grid, because of the need for separate dc sources, which is the case in applications such as photovoltaic's or fuel cells. Cascaded inverters have also been proposed for use as the main traction drive in electric vehicles, where several batteries or ultra capacitors are well suited to serve as SDCSs [4]. The cascaded inverter could also serve as a rectifier/charger for the batteries of an electric vehicle while the vehicle was connected to an ac supply as shown in Figure. Additionally, the cascade inverter can act as a rectifier in a vehicle that uses regenerative braking. The main advantages and disadvantages of multilevel cascaded H-bridge converters are as follows The number of possible output voltage levels is more than twice the number of dc sources (m = 2s + 1). The series of H-bridges makes for modularized layout and packaging. This will enable the manufacturing process to be done more quickly and cheaply.

II. Number of Levels and Voltage Rating of Active Devices

A multilevel inverter, determining the number of levels will be one of the most important factors because this affects many of the other sizing factors and control techniques [5]. This margin can be incorporated into a design factor for the inverter. Because the dc link voltage and the voltage at the connection point can both vary, the design factor used in the rating selection process incorporates these elements as well as the small voltage drops that occur in the inverters during active device conduction. The product of the number of the active devices in series (m-1) and the voltage rating of the devices V_{dev} must then be such that

$$V_{\substack{device\\rating}} \cdot (m-1) \geq \sqrt{2} \cdot V_{nom} \cdot D_{\substack{design\\factor}}$$

The minimum number of levels and the voltage rating of the active devices (IGBTs, GTOs, power MOSFETs, etc.) are inversely related to each other. More levels in the inverter will lower the required voltage device rating of individual devices; or looking at it another way, a higher voltage rating of the devices will enable a fewer minimum number of levels to be used. Increasing the number of levels does not affect the total voltage blocking capability of the active devices in each phase leg because lower device ratings can be used.

III. PROPOSED MULTILEVEL CONVERTER TOPOLOGY

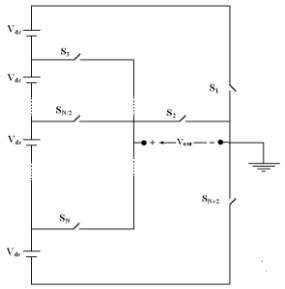

Fig 3: schematic of a Proposed multilevel converter topology

The number of required switches against required voltage levels is a very important element in the design. To provide a large number of output levels without increasing the number of bridges, a new power circuit topology and a suitable method to determine the dc voltage sources level for symmetrical and asymmetrical multilevel converter are proposed. The proposed circuit also provides decreased voltage stress on the switch by the series configuration of the applied bidirectional switches. The proposed converter consists of less number of switches when compared to the other familiar topologies. The initial cost reduces because of the switch reduction. So, it looks attractive and an apt one for industrial applications. The block diagram of the proposed multilevel inverter is shown in the the general circuit diagram of the proposed multilevel inverter is shown in the figure 2. The switches are arranged in the manner as shown in the figure. For the proposed topology, we just need to add only one switch for every increase in levels. So initial cost get reduced. Let us see operation in the next subdivision in detail for the seven-level inverter. The proposed multilevel inverter for seven levels is shown figure 3.The inverter consists of seven MOSFET switches and three separate DC sources with a load. By switching the MOSFETS at the appropriate firing angles, we can obtain the seven level output voltage. MOSFET is preferred because of its fast switching nature. The advantage of the new topology the reduction in the number of switches and hence the initial cost, Controlling becomes easier. Losses become less due to the elimination of the harmonics. Overall weight reduces because of the usage of less number of components

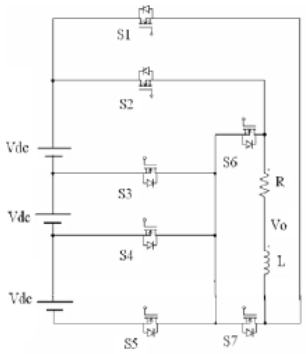

Figure 4. Circuit Diagram of a basic Seven Level Proposed Multilevel Inverter

IV. SIMULATION RESULTS

Simulation results of the proposed converter for seven levels using MATLAB/simulink. The PWM technique is used for pulse generation. The MOSFET switches are used because of its fast switching capability. The input supply for each DC source is 100V. The load used is a R-L load. The output waveform is phase voltage and it comprises seven levels. The PWM technique is used to produce the control signal . The MATLAB simulation circuit for the proposed inverter which comprises only seven MOSFET switches for producing seven levels is shown in the figure 4. The MATLAB circuit used for generating gate pulse using PWM technique is shown in the figure 6. The pulse generated by the circuit shown in the figure 10. The output waveform of the proposed inverter for seven levels with PWM technique is shown in the figure 9. The pulse is generated using comparison between constant DC voltage and power supply .The comparison is done using operational amplifiers. For the first pulse we give a DC voltage of lesser amplitude and moderate amplitude for the second pulse. Likewise we have to increase the amplitude to reduce the pulse width. The PWM technique is used to obtain a good harmonic spectrum. The gating pulse is generated from the above mentioned process and given separately to the respective MOSFETs. The supply is given through three separate DC sources. The R-L load is used for the simulation purpose. The simulation results show that the circuit is operating properly. The output waveform has three levels in the positive side and three levels in the negative side and a zero level. Totally there are seven levels. Thus the proposed multilevel inverter for seven levels is successfully simulated. And the results are shown below in sequential manner.

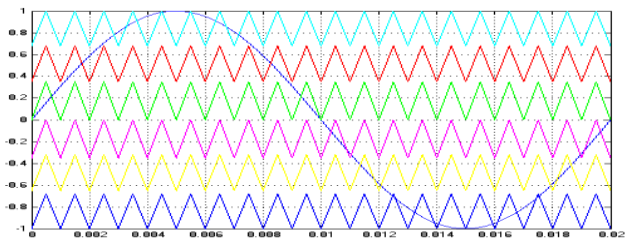

Fig 5: Triangular wave comparison with sine wave for the 7-level converter

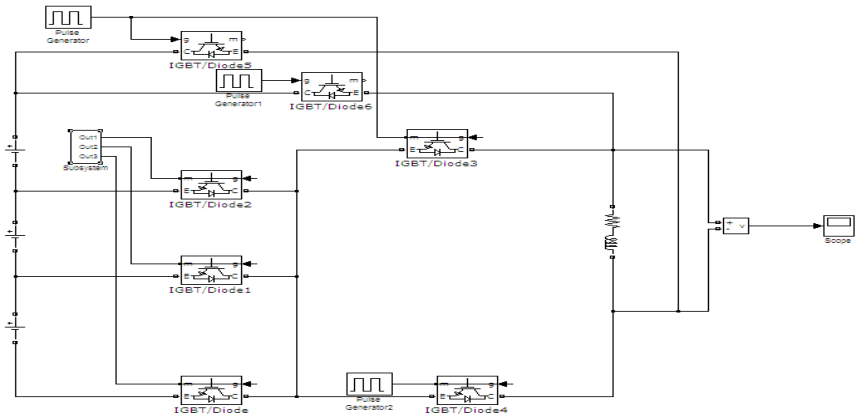

Fig 6: Proposed Multilevel Inverter for Seven Levels

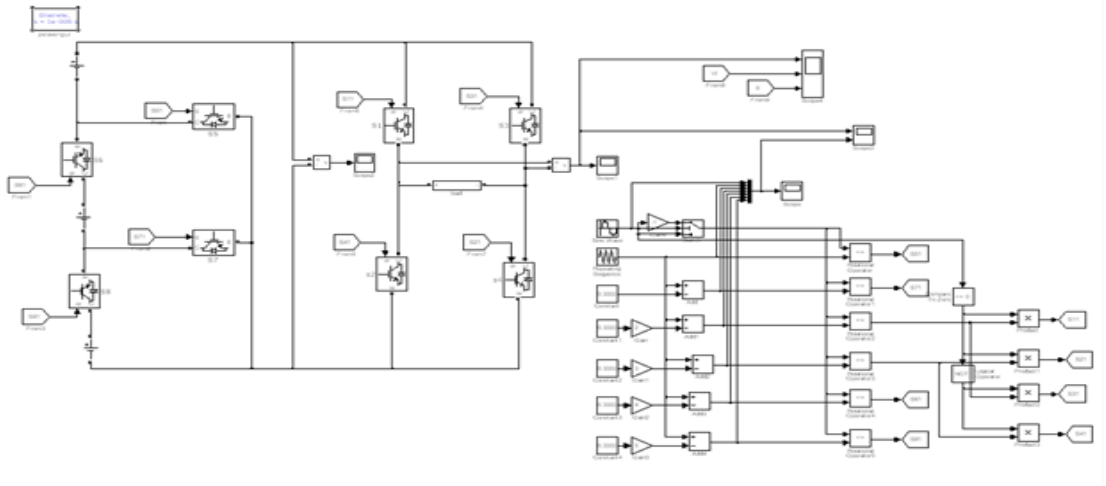

Fig 7 Simulink model of a praposed multilevel Converter

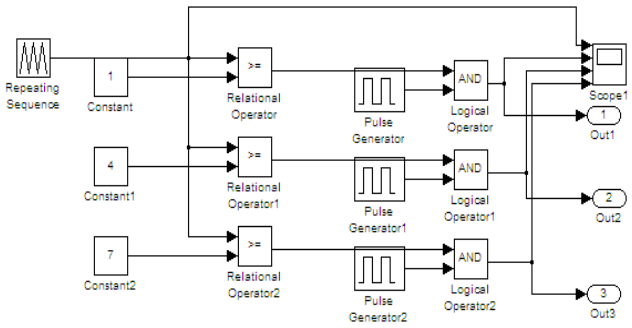

Fig 8: Gate Pulse Generation Circuit With PWM Technique

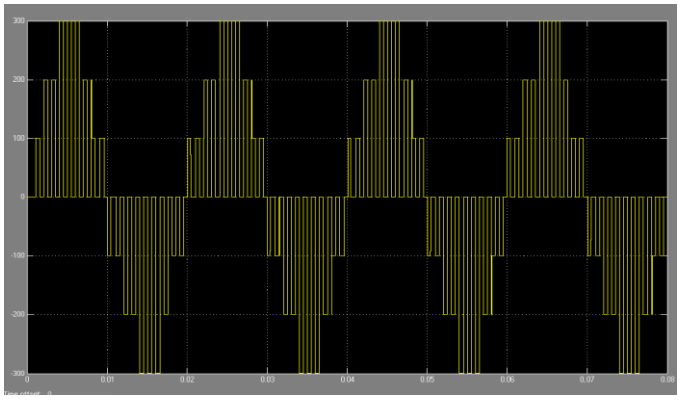

Fig 9 :Output Voltage Waveform Using PWM Technique

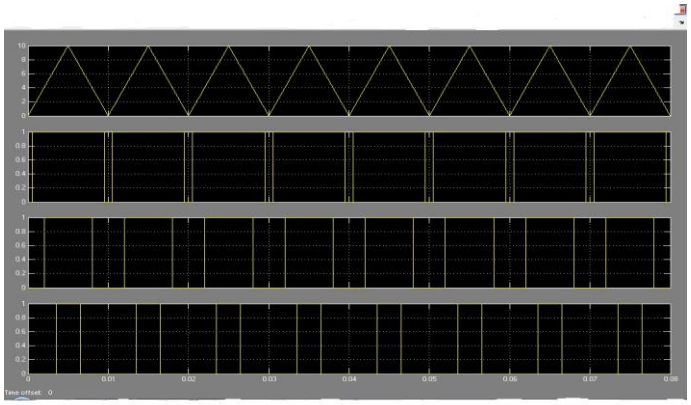

Fig 10 : Pulses Generated Using PWM Technique

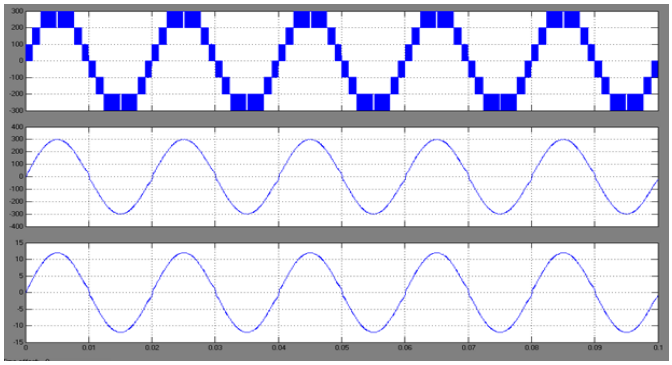

Fig 11: Input voltage, load voltage and load current

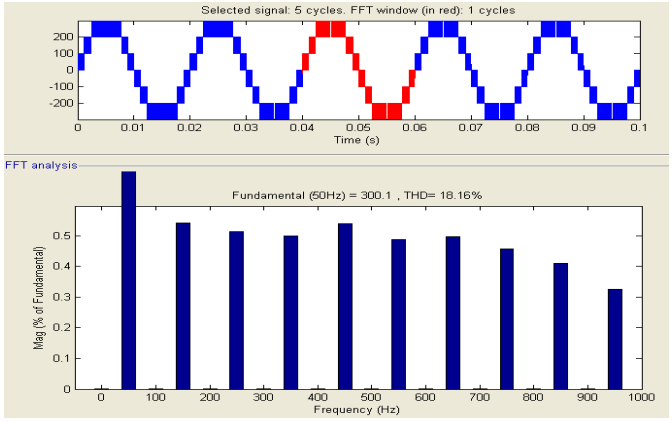

Fig 12: Input Voltage THD Response 18.16%

V. CONCLUSION

A novel multilevel converter topology development is presented in this paper. The simulation of the seven-level multilevel inverter is successfully done using pulse width modulation technique for the proposed multilevel converter. The proposed topology significantly reduces the usage of number of dc voltage sources, switches, IGBTs, and power diodes as the number of output voltage levels increase. When we increase the levels, the number of switches used is very less compared to the other topology. The most important and useful feature of the system proposed is that it is convenient for expanding and increasing the number of output levels, simply without using any bidirectional switches. The proposed method results in the reduction of the number of switches, losses and cost of the converter. Based on the presented switching algorithm, the multilevel converter generates near-sinusoidal output voltage and as a result, has very low harmonic content.. The proposed topology provides more flexibility to designers and can generate more voltage levels without losing any level and shows lower THD characteristics.. Simulation results shows that the proposed converter topology generates a high-quality output voltage waveform with lower order THD of output voltage and current and hence which is suitable for renewable energy sources interfacing to ac grid.

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