Single Phase Transformerless Seven Level Inverter for Adjustable Speed AC Motor Drive

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Abstract - *Transformer less inverters have shown considerable improvements with respect to transformer isolated inverters. In particular, transformer less inverters have smaller size and weight, lower cost and higher efficiency, which makes them the preferred solution in grid-connected photovoltaic (PV) applications. Since no transformer is present, then there is a galvanic connection between the power converter and the electrical grid. As a result, a leakage current may flow through the ground path and the power circuit. The leakage current flowing path involves the equivalent parasitic capacitances, which are the capacitances formed between the PV cells and the grounded frame of the PV panel. The values of capacitances are in the order of nano farad to microfarad, and depend on atmospheric and physical operation conditions, namely, moisture, dust, PV panel size, frame structure etc. The leakage current may affect the system efficiency and reliability and may cause electromagnetic interference (EMI) issues. Additionally, it represents a potential electric hazard to humans in contact with the PV array. Hence, the lack of galvanic isolation may represent a huge safety risk, if the leakage current is not properly handled. The common mode analysis or a detailed leakage current analysis of the presented topology is done.*

Key Words: Transformer less inverters, Multilevel inverters, Photovoltaic, DC-DC Converter, PWM

1.INTRODUCTION

The global power demand is increasing day by day and most of the developing countries as well as the under developed ones are relying almost completely on the conventional sources of power. Even the developing new infrastructures have brought the fossil fuel usage very high. The excessive use of fossil fuels have caused climatic impacts and it is high time we move to the renewable energy sources like solar and wind. The recent developments in the power electronic sector have enabled the extensive use of solar energy conversion system (SECS) and wind energy conversion system (WECS). The converters make use of power electronic switches like IGBTs and MOSFETs for conversion purpose. The multilevel inverters are becoming significant in these energy conversion systems. The energy storage requirement in the present scenario is met with the DC power only. This stored DC power is converted to AC for industrial applications. Presently used two level inverters have higher switching losses owing to high switching frequency at which it operates. The lower voltage stress across each switch and a lower total harmonic distortion (THD) contributes to better performance with multilevel inverters. The three basic topologies are diode clamped, capacitor clamped and cascaded H-bridge multilevel inverter. There are many other topologies described in the literature. The grid connected multilevel inverters are used for active power injection into the grid whenever the grid demands power. This kind of distributed generation are encouraged in many developed countries where the transition from the conventional energy sources have already begun. The reactive power supplied by the grid connected multilevel inverter helps in improving the power quality of the system. Hence, the unity power factor condition is achieved as all the reactive power required by the load is supplied through the multilevel inverters. Since the multilevel inverters have higher number of levels, its THD value will be much lesser compared to the two-level inverters. Thus, only a small ripple filter is required at the output. The transformer less inverters have several improvements with respect to transformer isolated inverters. Particularly, smaller size, weight, lower cost and higher efficiency which makes it preferable in grid tied applications.

A transformerless inverter having smaller size and weight lower cost and high efficiency, which make them preferred solution in grid connected renewable energy applications [1]. There is no transformer is present a galvanic connection is present between the converter and grid so a large leakage current may flow through the ground path. Parasitic capacitance present between renewable energy cell and grounded frame, that capacitance depended on atmospheric temperature and physical conditions [2]. The leakage current may affect the system efficiency. It will cause electromagnetic interference. Also, huge safety risk due to lack of galvanic isolation [3]. In multilevel inverter both magnitude and frequency of the leakage current generated in a renewable energy system mainly depends on inverter tropology and modulation technique [4]. A single-phase H-bridge converter with bipolar PWM and the neutral point clamped converter that present initially low leakage current [5]. One of the main goals in the design of transformer less grid connected converters is to reduce or eliminate the leakage current. The solutions reported so far can be classified in the design of modulation and control schemes [7], and the proposal of new transformer less grid-connected inverter topologies [8]- [9]. In [10], a modulation strategy for a new topology of a three-phase NPC converter is proposed. This topology consists of two additional switches, two diodes and split capacitors on the DC-side. In this topology, the diodes and the capacitive divider limit the blocking voltage of the switches. Multilevel topologies have demonstrated certain advantages to inject power towards the grid with respect to simpler topologies. For instance, it has been shown that a cascade multilevel inverter (CMI) does not need a voltage-boost converter stage for a proper operation, which improves the overall efficiency of the PV system. Moreover, as the AC output voltage is formed by multiple voltage levels, then the total harmonic distortion (THD) is considerably reduced, which reduces the size of the output filter. Multilevel topologies and the associated modulation schemes have also been presented to reduce leakage current. In [11], a modified H6 inverter topology without input split capacitor is proposed, which uses a hybrid modulation scheme. This topology can be considered as a T-type inverter, as it uses a bidirectional switch to create the five levels in the output voltage. The bidirectional switch is built out of four diodes and one switch, where the diodes may affect the efficiency. The modulation scheme is close to a level shifted technique, where an offset over the control signal is added. Moreover, the proposed solution does not deal with the leakage current issue. A multilevel inverter named as Cascaded Half-Bridge based Multilevel Inverter is proposed [12]. The main applications of these multilevel inverters are in the permanent magnet (PM) motor drives employing a PM motor of very low inductance and distributed power generation involving fuel cells and photovoltaic cells. A MLI with three input DC levels is comprises of cascaded half-bridge cells, with each cell having its own DC source. It has separate level-generation and polarity-generation parts which in turn alternates the polarity to produce a multilevel AC waveform. Another multilevel inverter topology named as the packed U-cell (PUC) topology proposed [13]. Each U-cell consists of an arrangement of two power switches and one DC source. It utilizes small number of active and passive devices and cost also reduced. A single-phase structure of the packed U-cell topology with three input DC levels. In this article the authors have proposed an elaborate methodology to calculate the asymmetric voltage levels. This feature however is not feasible for the PUC topology with more than two number of input DC levels. One source is taken as a floating capacitor in which the voltage is maintained at one-third of the voltage level of the other source. the control scheme though is fairly complex in nature. [14]A single-phase multilevel inverter consisting of an H-bridge and DC sources which can be connected in series and in parallel. An important application suggested for electric vehicular applications. The topology requires the same of number of voltage sources as required by a cascaded H-bridge topology but it synthesizes same number of output levels with lesser number of power switches. The possibility of combining two or more sources in series and parallel gives enough flexibility for meeting voltage/power requirements in the vehicle drive system. The topology with four input DC sources is consists of two parts, level-generation part which consists of the switched sources and synthesizes a bus voltage and the polarity-generation part which synthesizes positive and negative cycles of voltage. Although the topology enables the synthesis of all additive combinations of the input sources. [15] A new class of MLI topology. It shows the single-phase structure of the topology with four input voltage sources. The topology requires all the switches to be bidirectional to synthesize the required voltage levels at the output. Each cell consisting of a source and two power switches. Without H bridge it produces both polarity voltages at the load terminals.

2. METHODOLOGY

DC-DC converter topologies are created to meet the demands of particular DC loads. Buck, boost and buck-boost are some of the DC-DC converters that can be used as switching regulators to regulate unregulated DC voltage by converting it to suitable utilization voltage by increasing or decreasing the DC output voltage with the help of a PWM switching technique which operates at a fixed frequency. When a converter is required, it needs power switching devices to turn on and off. Depending on the parameters and applications of the circuit design, power switching devices such as thyristors, BJTs, MOSFETs and IGBTs are used. Appropriate gate drive signals produced by a gate driver circuit must be considered when triggering power switching devices Pulse Width Modulation. PWM switching is used to regulate the voltage frequency and phase delay of the DC-DC converters.

2.1 Proposed Approach

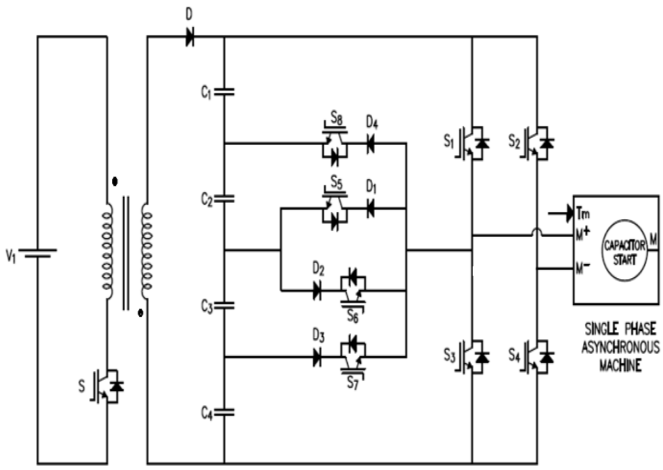

Fig -1: Proposed DC-AC converter system

Fig.1 shows the circuit of single phase 7 level inverter. It is based on H bridge configuration and a t type configuration. It has two parts; a converter part and inverter part. In converter side there is a flyback converter that will boost the input dc voltage to desired dc voltage. Then the seven-level inverter in the second stage has functions of regulating dc bus voltage and converting dc power to ac power. It is lighter and more compact compared to other multilevel topologies. This topology has less switching power loss, reduced harmonic distortion and reduced EMI.

2.2 Flyback Converter

When the switch S is closed the primary of the transformer is directly connected to the input voltage source. The primary current and magnetic flux in the transformer increases, storing energy in the transformer. The voltage induced in the secondary winding is negative, so the diode is reverse-biased (i.e. blocked). The output capacitor supplies energy to the output load. When the switch S is opened, the primary current and magnetic flux drops. The secondary voltage is positive, forward-biasing the diode, allowing current to flow from the transformer. The energy from the transformer core recharges the capacitor and supplies the load.

2.3 Single Phase Seven Level Inverter

Single phase 7 level PWM inverter to reduce the harmonic components of output voltage and load current are used in the proposed system. PWM inverters has able to control output voltage and frequency simultaneously. It has simple structure and a smaller number of switches. In the inverter topology is an H-bridge based topology and could be used in transformer less inverter applications [12]. Here, one of the legs of the inverter is modified in such a way as to gain access to the midpoint of the split DC link. This is achieved by using a bidirectional switch and this leg is termed as a T-type leg. The other leg is kept unmodified. The modulation scheme used is a pulse width modulation scheme. The main feature of this modulation is that the two-level leg commutes at fundamental frequency. The circuit diagram is shown in Fig.1. This 7-level T shaped asymmetrical H-bridge inverter is based on an H-bridge configuration. The bidirectional switch is introduced to connect the midpoint of the DC link formed by S1 and S3. This allows a three-level generation from the T-type leg. The different modes of operation are explained in detail.

In mode I operation, the inverter voltage obtained is, $V_{AB} = V_1$. During positive half cycle of the inverter operation, $V_{C1} = V_{C2} = V_{C3} = V_{C4} = \frac{V_1}{4}$ are generated across the capacitors. In this figure, switches S_1 and S_4 are on. This corresponds to normal operation of a cascaded H-bridge inverter. Output voltage is positive and maximum. Current enters through S_1 and returns through S_4 from the DC source.

In mode II operation, the inverter output still in positive half cycle, S_1 is turned off whereas S_6 is turned on simultaneously. D_2 is forward biased here. Switch S_4 remains in on condition. The output voltage is half the DC link voltage and positive, that is $V_{AB} = V_1/2$. The output current flows from lower capacitor C_2 through switches S_6, S_4 and diode D_2.

In mode III operation, the inverter output still in positive half cycle, S_1 is turned off whereas S_7 is turned on simultaneously. D_3 is forward biased here. Switch S_4 remains in on condition. The output voltage is one fourth of the DC link voltage and positive, that is $V_{AB} = V_1/4$. The output current flows from lower capacitor C_4 through switches S_7, S_4 and diode D_3.

In mode IV, the zero or null state is produced in two different ways, simultaneously switching on S_1 and S_2 or S_3 and S_4, keeping other switches off in both the cases. Zero state can also be achieved by switching off all the switches.

In mode VI, the negative half cycle of the inverter output voltage begins. The voltage level generated is $-V_1/4$. The switches acting during this mode are S_8 and S_2. The diode conducting is D_4. The other semiconductor devices do not conduct

In mode VI, the voltage level generated is $-V_1/2$. The switches acting during this mode are S_5 and S_2. The diode conducting is D_1. The other semiconductor devices do not conduct.

In mode-VII, the voltage level generated is $-V_1$. The switches acting during this mode are S_3 and S_2. The diodes do not conduct in this mode. The other semiconductor switches do not conduct.

Fig.2 shows the sector distribution along one grid period. For better visualization, the plot on the left has been shown with lower switching frequency.

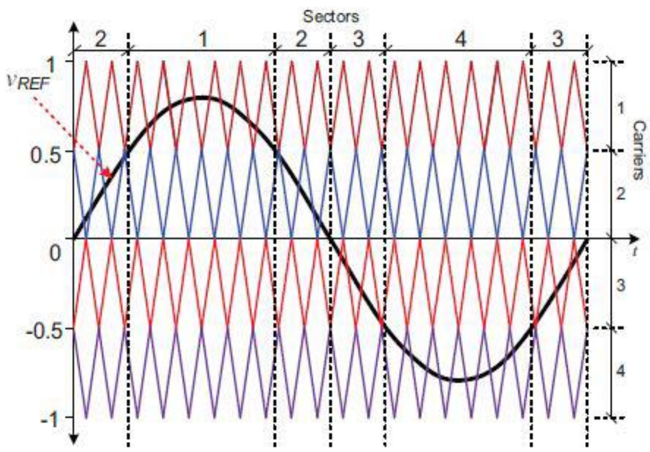

Fig -2: Definitions of sectors and carriers in PWM strategy

3. SIMULATION RESULTS

Simulations are conducted using MATLAB/Simulink to verify the system performance. Simulation results are obtained using designed equations and output was obtained as expected. TABLE II shows the simulation parameters of proposed system.

Table -1: MATLAB Parameters

COMPONENTS	SPECIFICATIONS
Input voltage	36V
Output voltage	230 V
Rated power	200 W
Switching frequency	100 kHz
capacitors (C_1,C_2)	2 μF
Load resistor	100 Ω

The proposed converter system was designed for a power of 200 W, input voltage 36 V, output voltage 230 V and switching frequency of 100 kHz. The duty cycle for the flyback converter operating is 0.4.

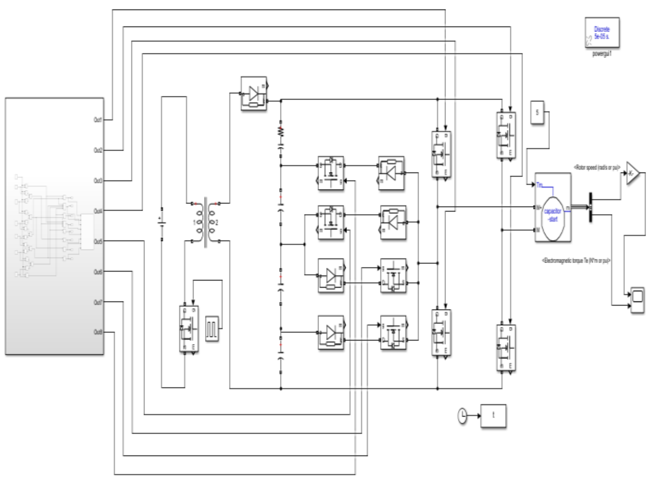

Fig -3: Simulation diagram of proposed DC-AC converter system

The Fig. 3 shows the simulation diagram of the seven-level inverter. Fig. 4 shows the switching pulses to inverter by SPWM technique. Fig. 5 shows the input and output voltage waveforms and output current waveforms. The speed and torque of the single phase AC motor is shown in the Fig. 6. The FFT analysis shown in Fig 7.

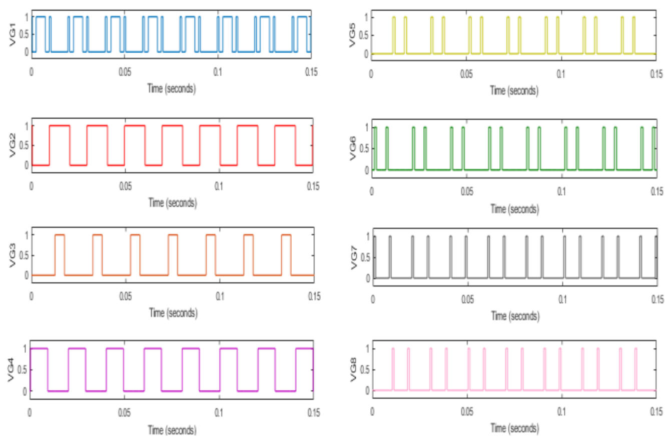

Fig -4: SPWM pulses to inverter switches

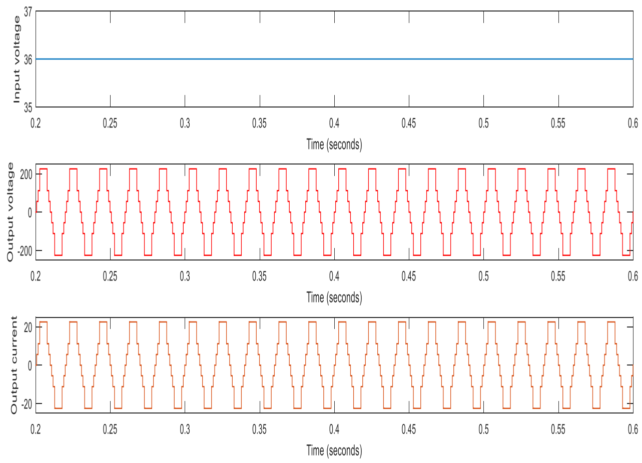

Fig -5: Input voltage, output voltage, output current waveforms.

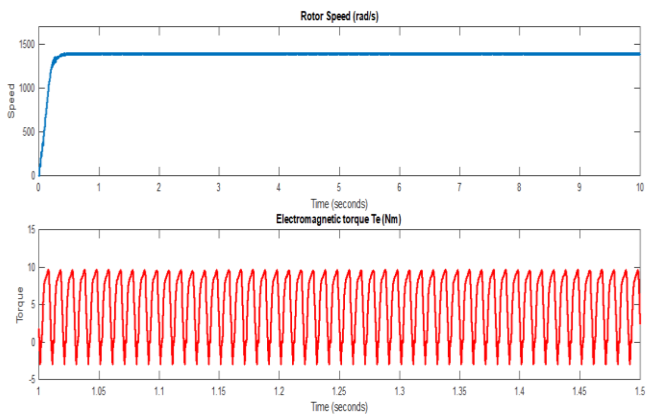

Fig -6: speed and torque of the motor load

4. CONCLUSIONS

In this paper a multilevel transformerless topology and its modulation technique were proposed. The topology was based in the conventional H-bridge inverter with an auxiliary circuit. The latter consisted of a bidirectional switch formed by two IGBTs or MOSFETs and two diodes. The bidirectional switch was connected between the middle point of the first leg in the H-bridge and the middle point of the input split capacitor, i.e., a T-type leg. The other leg is kept unchanged. Therefore, the topology was referred as asymmetrical T-type. The proposed topology provided seven output voltage levels, which turns out to be an important advantage regarding other commercial single-phase topologies. Besides, to control the power flowing from the DC source to the load, a PWM modulation strategy based on a sinusoidal multicarrier technique was proposed. Both inverter and PWM were aimed to overcome the leakage current issue in low power transformerless PV systems applications. The proposed inverter and its modulation strategy were tested by numerical simulations and experimentally, the results showed that the common mode voltage allows an operation with a RMS value of the leakage current below the maximum value allowed by the German standard DIN VDE 0126-1-1. Moreover, the multilevel characteristic lowers the harmonic content, which permits the reduction of filters. According to the analysis and the numerical and experimental results, it was concluded that the proposed topology and the modulation technique were suitable for transformerless PV applications.

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