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RES Based Three Phase Multilevel Inverter using SPWM Technique for Grid Connected PV System

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Abstract:

Reformations in electricity sector along with various renewable energy promotion policies has increased the importance of small grid connected photovoltaic (PV) systems utilizing single-stage single-phase inverters. To improve the performance multilevel inverter are preferred over two, three and five levels. This paper proposes a three phase two, three and five level inverter for grid connected (PV) system. The output current of the inverter can be adjusted according to the voltage of the photovoltaic (PV) array. This control scheme is based on SPWM topology. Multilevel inverter as compared to two, three and five level inverter has advantages like minimum harmonic distortion and can operate on several voltage level inverters. This paper explain the basic type of Multilevel Inverter such as diode clamped multilevel inverter (neutral point clamped), flywheel capacitor multilevel inverter (capacitor clamped), cascade multilevel inverter also the modulation and control technique like Pulse Width Modulation and the gate signal through modulation technique is given to MLI in such a way to reduce harmonics.

Keywords:

Pulse width modulation; solar photovoltaic; voltage source inverte; multi level inverter.

I. INTRODUCTION:

In recent years, reformations in electricity sector along with various renewable energy has been increasing interest in Electrical energy Generation. Solar Energy is one of the best alternatives among available renewable sources. Photovoltaic (PV) systems are ideal distributed generation (DG) units, and they offer many advantages such as no fuel costs, no pollution, no noise, and little maintenance.

Solar photovoltaic arrays have been fastest growing energy sources in the world, and the growth is more penetrated in grid connected applications [1-3].Multi-level inverters have gained much attention in the application areas of medium voltage and high power owing to their various advantages such lower common mode voltage, lower voltage stress on power switches, lower dv/dt ratio to supply lower harmonic contents in output voltage and current. Comparing two-level inverter topologies at the same power ratings, multi-level inverter also have the advantages that the harmonic components of line-to-line voltages fed to load are reduced owing to its switching frequencies Multi Level Inverter (MLI) plays an important role in the area of power electronics and it is widely used in industrial and renewable energy applications [4-6]. It is not only achieves high power ratings, but also enables the use of renewable energy sources. Renewable energy sources such as photovoltaic, wind, and fuel cells can be easily interfaced to a multilevel converter system for high power application.

The concept of multilevel converters has been introduced since 1975. The term multilevel began with the three level converter. Subsequently, several multilevel converter topologies have been developed [7] .It is classified into a) Diode clamped multilevel inverter b) Flying capacitor multilevel inverter c) Cascaded H-bridge multi level inverter. This paper focuses on multi level (two and three level) inverter with reduced number of dc sources which overcomes the disadvantages of the conventional multi level inverter. The proposed inverter has reduced harmonics in the output voltage. Moreover, the implemented topology reduced THD. The performance of the inverter is studied in terms of spectral quality of the output and it is analyzed for various modulation indices and the results are discussed. MATLAB/SIMULNK software is employed to carry out the simulation of the proposed inverter structure [9].

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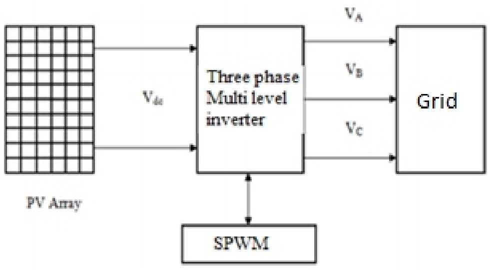

Fig.1.General Diagram of Proposed System.

The traditional inverters are Voltage Source Inverter (VSI) and Current source Inverter (CSI), which consist of diode rectifier front end, DC link and Inverter Bridge. In order to improve power factor, either an AC inductor or DC inductor is normally used. The DC link voltage is roughly equal to 1.35 times the line voltage and the Voltage source inverter is a buck converter that can only produce an AC voltage limited by the dc link voltage. Because of this nature, the Voltage source inverter based PWM VSI and CSI are characterized by relatively low efficiency because of switching losses and considerable Electromagnetic Interference (EMI) generation [10-11].

II.GRID CONNECTED SOLAR PVSYSTEM:

The general grid connected SPV system is shown in Fig.2. First stage PV array or module is connected with the system which connects the input to the inverter. The 3-phase VSI is used to convert DC voltage to AC voltage and feeds the energy to the load and grid [2] through LC filter circuit. The inverter has to be controlled in order to obtain harmonic less voltage to achieve good power quality. Various PWM techniques are used to switch the inverter circuit. A PLL is used for proper synchronization

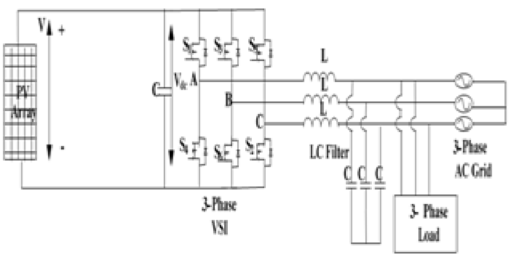

Fig.2. General Block Diagram of Grid Connected SPV system.

A. Modeling of Solar PV :

The Solar-PV cells are used to produce electricity by directly converting solar energy to electrical energy. Each solar cell is basically a p-n diode. As sunlight strikes a solar cell, the incident energy is converted directly into electrical energy without any mechanical effort. The voltage and current levels are produced from PV cells are very less, thus these PV cells are connected in series and parallel called modules and arrays to produce required voltage and current levels. The solar PV array is modeled by considering the output characteristics of PV panel which directly have relation with power converters which exists in the system. The solar PV cell is a non linear device which can be represented by a current source connected parallel with diode as shown in Fig.2. The characteristics of equivalent solar cell circuit are given in (1).

$$I_{PV} = N_P * I_{Ph} - N_P * I_0[\exp\{\frac{q*(V_{PV}+I_{PV}R_s)}{N_s AkT}\}-1] \qquad (1)$$

Where Ipv is the PV array output current, Vpv is the PV array output voltage, Ip his module photo current, R s is the series resistance, k is the Boltzmann constant (138e-23 J/K), A is the ideal factor, N sis the series no of cells and Np is parallel number of cells. T is the operating temperature [2]. The equation (1) is simulated using MATLAB/Simulink and P-V and I-V characteristics are obtained. The operating curves shows that solar PV output power is function of solar irradiation.

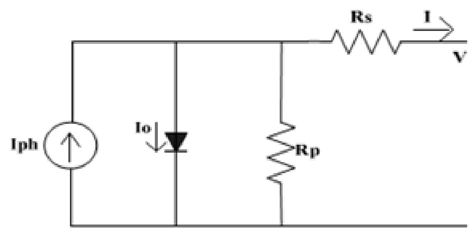

Fig.3. PV Module.

B.3-Phase VSI and Filter :

A 3-phase VSI is used to convert DC voltage into AC voltage and feeds power to consumer loads and utility grid. The 3-phase inverters are used in grid connected SPV systems. A 3-phase inverter is a six step bridge inverter. It uses a minimum of six devices. As stated earlier, the transistor family of devices is now very widely used in inverter circuits. Presently the use of IGBT in three-phase inverter is on the rise. A capacitor connected at the input terminals tends to make the the input dc voltage constant. This capacitor also suppresses the harmonics fed back to the source. In inverter terminology,

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a step is defined as a change in the firing from one IGBT to the next IGBT in proper sequence. For one cycle of 360, each step would be of 60 intervals for a six step inverter. This means that the IGBT would be gated at regular intervals of a six step inverter. There are two possible patterns of gating the switches. In one pattern, each switch conducts for 180 and in the other each switches conducts for 120. But in both these patterns gating signals are applied and removed at 60 intervals of the output voltage [3]. A LC type filter is used to provide 50Hz frequency output to consumer loads and electric grid. There are various factors which decide the selection of filter capacitor and inductor. Generally in order to eliminate the higher order harmonics, the resonant frequency of the filter should be greater than 6 times of desired output frequency [4].

III. MATHEMATICAL MODEL OF LC FILTER:

The mathematical model of LC filter circuit has been derived using state space analysis [5]. LC output filter circuit for voltage and current equations is shown in Fig.4. Kirchhoff's current law is applied to the nodes a, b, c shown in Fig.4.

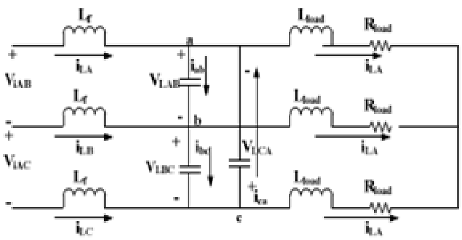

Fig.4. LC Filter Circuit.

At node a,

$$i_{iA}+i_{ca}=i_{ab}+i_{LA}\Rightarrow i_{iA}+C_f\frac{dV_{LCA}}{dt}=C_f\frac{dV_{LBC}}{dt}+i_{LB} \quad (2)$$

At node b,

$$i_{iB}+i_{ab}=i_{bc}+i_{LB}\Rightarrow i_{iB}+C_f\frac{dV_{LAB}}{dt}=C_f\frac{dV_{LBC}}{dt}+i_{LB} \quad (3)$$

At node c,

$$i_{iC}+i_{bc}=i_{ca}+i_{LC}\Rightarrow i_{iC}+C_f\frac{dV_{LBC}}{dt}=C_f\frac{dV_{LCA}}{dt}+i_{LC} \quad (4)$$

To make state equations, Kirchhoff's voltage law is applied to inverter side and load side and finally state space equation for LC filter circuit is given in (5).

$$\dot{X}(t)=AX(t)+Bu(t) \quad (5)$$

$$X=\begin{bmatrix}V_L\\ I_i\\ I_L\end{bmatrix}_{9\times1},\quad A=\begin{bmatrix}0_{3\times3} & \frac{1}{3C_f}I_{3\times3} & \frac{-1}{3C_f}I_{3\times3}\\ \frac{-1}{L_f}I_{3\times3} & 0_{3\times3} & 0_{3\times3}\\ \frac{1}{L_{load}}I_{3\times3} & 0_{3\times3} & \frac{-R_{load}}{L_{load}}I_{3\times3}\end{bmatrix}_{9\times9}$$

$$B=\begin{bmatrix}0_{3\times3}\\ \frac{1}{L_f}I_{3\times3}\\ 0_{3\times3}\end{bmatrix}_{9\times3},\quad u=[V_i]_{3\times1}$$

Where $V_L=[V_{LAB}\ V_{LBC}\ V_{LCA}]^T$, $Ii=[i_{iAB}\ i_{iBC}\ i_{iCA}]^T$, $Vi=[V_{iAB}\ V_{iBC}\ V_{iCA}]^T$, $I_L=[\ i_{LAB}\ i_{LBC}\ i_{LCA}]^T$

(6)

IV. PWM TECHNIQUES FOR 3-PHASE VSI:

This section describes two types of PWM techniques used to control the 3-phase VSI of a grid connected SPV system.

A. Sinusoidal PWM (SPWM) :

The SPWM technique is very simple and very easy to implement. This method produces a sinusoidal waveform by filtering an output pulse waveform by varying width. The required output voltage is achieved by varying the amplitude and frequency of modulating voltage. The pulse width can be changed by changing the amplitude and frequency of reference or modulating voltage. In Fig.5, modulating wave is compared with high frequency triangular wave from. The high switching frequency leads better output sinusoidal wave from. The switching state is changed when sine waveform is intersects with high frequency triangular waveform.

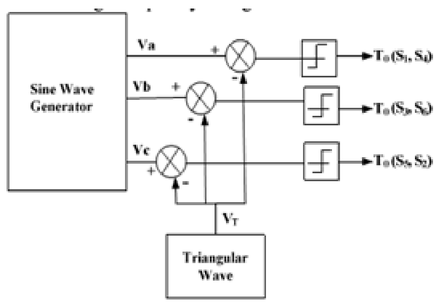

Fig.5. SPWM Control signal Generation.

In 3-phase VSI, the SPWM is achieved by three sinusoidal voltages (Va, Vb, Vc) which are 120 • out of phase with each other are compared with high frequency triangular waveform(VT), and relative levels of the waveforms are used to control the switching the devices in each phase leg of the inverter.

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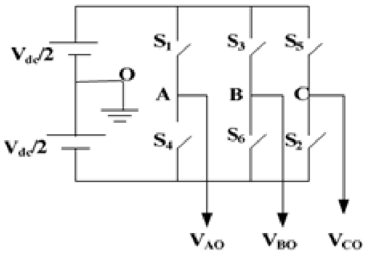

Fig.6. SPWM Inverter.

3-phase VSI having six switches (S1-S6) with each phase output is connected to middle of the each inverter leg is shown in Fig.6. The output of the comparator forms the control signal for each leg of the inverter. In one lag, two switches makes a phase and these two switches open and close in a complementary fashion.

The total voltage is Vdc, therefore the each pole voltage Vao, Vbo,Vco of the inverter varies between –Vdc/2and +Vdc/2. If the sine wave is greater than triangular wave, then upper switch is getting turned ON and lower switch is turned OFF. Based on switching states, positive or negative half DC link voltage is applied to each phase. Usually the switches are controlled in pairs (S1,S4),(S3,S6) and (S5,S2) and the logic is shown in Table I.

TABLE.I SWITCHING STATES:

S1 is ON when $V_a > V_T$	S4 is ON when $V_a < V_T$
S3 is ON when $V_b > V_T$	S6 is ON when $V_b < V_T$
S5 is ON when $V_c > V_T$	S2 is ON when $V_c < V_T$

V. MULTILEVEL INVERTER:

Fig.7.shows a five-level diode-clamped converter in which the dc bus consists of four capacitors, C1, C2, C3, and C4. For dc-bus voltage Vdc, the voltage across each capacitor is Vdc/4, and each device voltage stress will be limited to one capacitor voltage level Vdc/4 through clamping diodes.

To explain how the staircase voltage is synthesized, the neutral point n is considered as the output phase voltage reference point. There are five switch combinations to synthesize five level voltages across a and n.

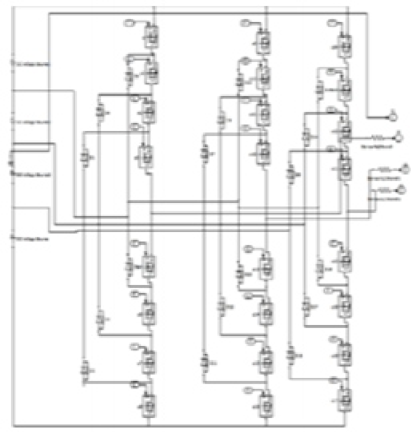

Figure.7. Five level diode clamped multilevel inverter circuit topologies.

1) For voltage level Van = Vdc/2, turn on all upper switches S1– S4.
2) For voltage level Van = Vdc/4, turn on three upper switches S2– S4 and one lower switch S1'.
3) For voltage level Van = 0, turn on two upper switchesS3 and S4 and two lower switches S1' and S2'.
4) For voltage level Van = –Vdc/4, turn on one upper switch and three lower switches S1'– S3'.
5) For voltage level Van = –Vdc/2, turn on all lower switches S1'– S4'.

Four complementary switch pairs exist in each phase. The complementary switch pair is defined such that turning on one of the switches will exclude the other from being turned on. In this example, the four complementary pairs are (S1, S1'), (S2, S2'), (S3, S3'), and (S4, S4').

TABLE.II. SWITHCING STATES OF THE FIVE LEVEL INVERTER:

V_{a0}	S_1	S_2	S_3	S_4	$S_{1'}$	$S_{2'}$	$S_{3'}$	$S_{4'}$
V5=Vdc	1	1	1	1	0	0	0	0
V4=3Vdc/4	0	1	1	1	1	0	0	0
V3=Vdc/2	0	0	1	1	1	1	0	0
V2=Vdc/4	0	0	0	1	1	1	1	0
V1=0	0	0	0	0	1	1	1	1

Although each active switching device is only required to block a voltage level of Vdc/ (m-1), the clamping diodes must have different voltage ratings for reverse voltage blocking. Using D1'of Fig.7. as an example, when lower devices S2' ~ S4' are turned on, D1' needs to block three capacitor voltages, or 3Vdc/4. Similarly, D2 and D2' need to block 2Vdc/4, and D3 needs to block 3Vdc/4.

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Assuming that each blocking diode voltage rating is the same as the active device voltage rating, the number of diodes required for each phase will be (m-1) (m-2). This number represents a quadratic increase in m. When m is sufficiently high, the number of diodes required will make the system impractical to implement. If the inverter runs under PWM, the diode reverse recovery of these clamping diodes becomes the major design challenge in high voltage high-power applications.

VI.MATLAB/SIMULINK RESULTS:

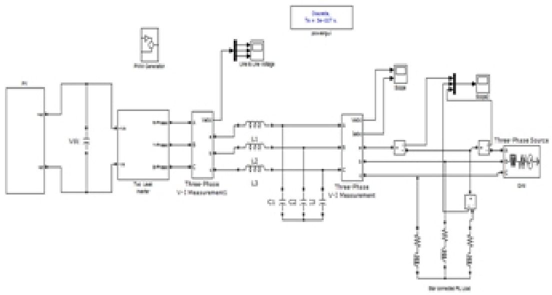

Figure.8.Matlab/Simulink Circuit diagram Grid Connected PV system with Two Level Inverter.

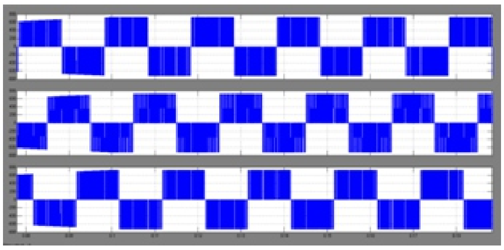

Figure.9. Two level Inverter line to line Voltages of before filter (ViAB,ViBC,ViCA).

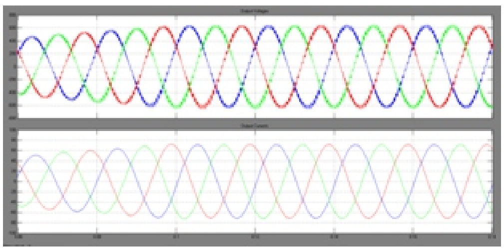

Fig.10.Inverter Voltages After Filter.

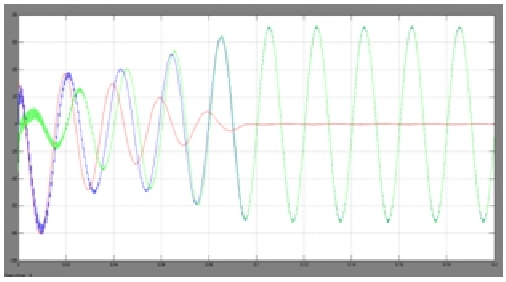

Fig.11.Grid Currents in Phase A, B, C.

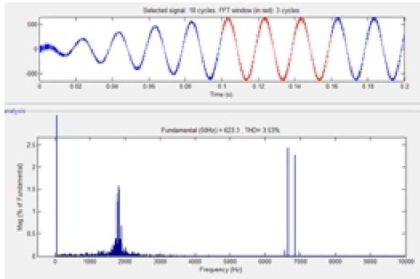

Fig.12.THD for Output Current after Filter for Two Level Inverter.

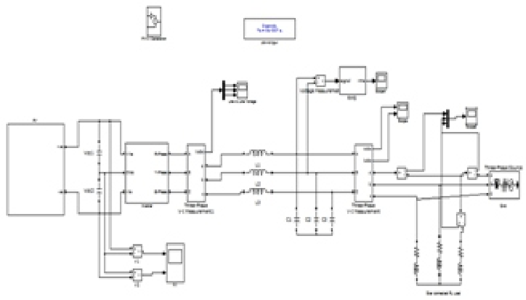

Figure.13.Matlab/Simulink Circuit diagram Grid Connected PV system with three Level Inverter.

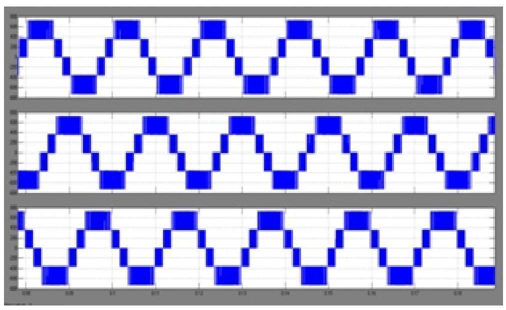

Figure.14. three level Inverter line to line Voltages of before filter (ViAB, ViBC, ViCA).

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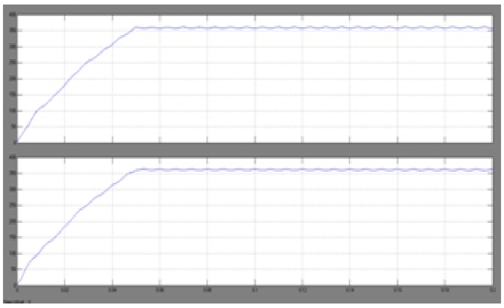

Fig.15.Capacitors Voltages

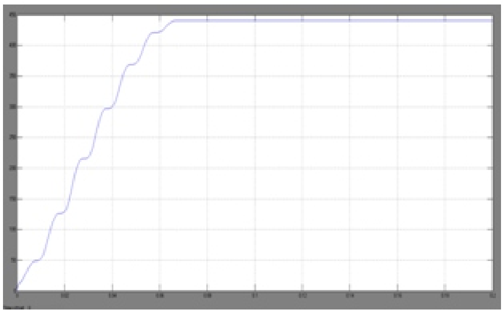

Fig.17.RMS Voltage.

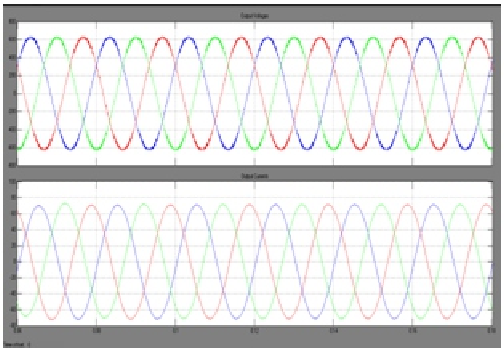

Fig.18.Grid Voltage and Current.

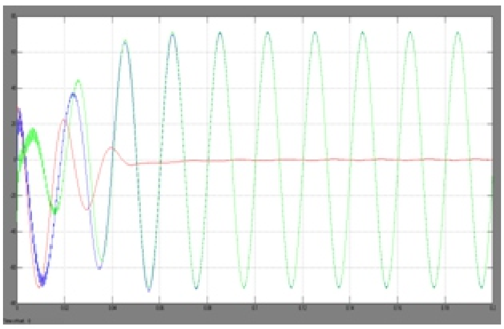

Fig.19.Line Currents in Grid Systems

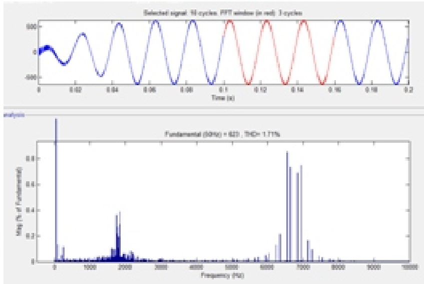

Fig.20.THD for Output Current after Filter for three Level Inverter.

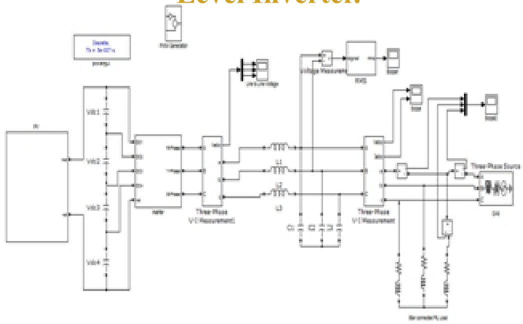

Figure.21.Matlab/Simulink Circuit diagram Grid Connected PV system with five Level Inverter.

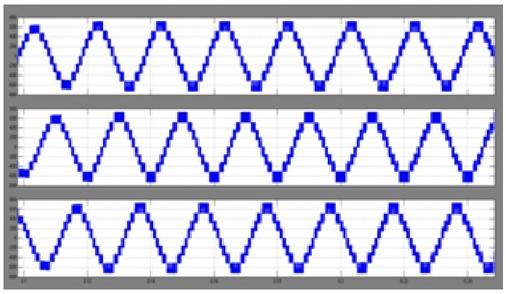

Figure.22. five level Inverter line to line Voltages of before filter (ViAB, ViBC, ViCA).

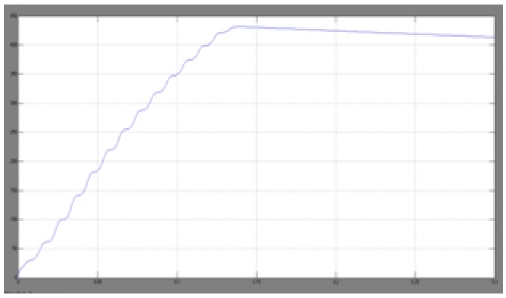

Fig.23.RMS Voltage.

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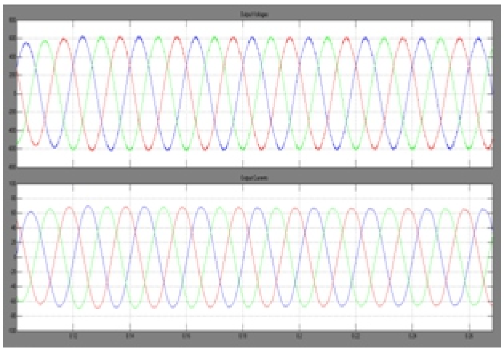

Fig.24.Grid Voltage and Current.

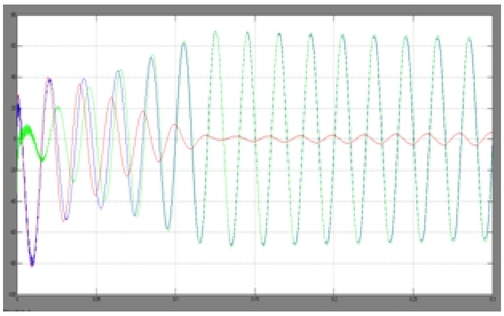

Fig.25.Line Currents in Grid Systems.

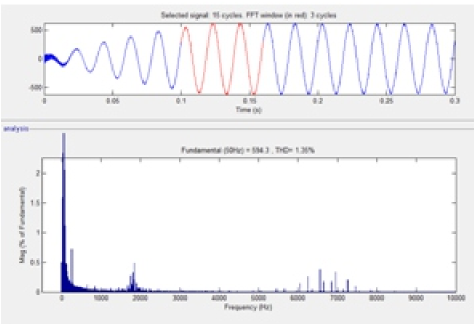

Fig.26.THD for Output Current after Filter for five Level Inverter.

VII.CONCLUSION:

The investigation of the grid-connected three-phase inverter for the PV applications has been presented. The developed inverter control system modeling is carried out in MATLAB/SIMULINK environment with different load power demands and grid voltage and frequency disturbance scenarios. The presented results showed that the inverter control algorithm is successful in converting PV dc power to ac power with acceptable THD level for supplying power to the load and grid as well.

In addition, the system manages to regulate the 50Hz sinusoidal output voltage and response to the grid voltage and frequency disturbances effectively. Increasing demand on energy efficiency and power quality issues, grid connected solar PV systems is taking a good place. In this paper SPWM and SVPWM techniques have been discussed for 3-phase grid connected VSI. The LC filter circuit is used in the proposed system. This filter circuit is mathematically modeled by using state space analysis and complete state space equation is obtained. Multilevel inverters are very useful in high power and power quality application. Modulation method are getting trend on multilevel inverter for better performance.

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