ISSN (Print) : 2320–3765
ISSN (Online): 2278 –8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 2, Issue 8, August 2013

GRID INTEGRATED SOLAR PHOTOVOLTAIC SYSTEM USING MULTI LEVEL INVERTER

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ABSTRACT: In any PV based system, the inverter is a critical component responsible for the control of electricity flow between the dc source, and loads or grid. This paper presents a solar PV generation system integrated to the grid. The results of matlab modeling of the system detail the comparative operation of inverter topologies which are the conventional two level inverters and multilevel inverter topology to reduce total harmonic distortions in grid voltage and electromagnetic interference. The proposed control scheme to mitigate the power quality issues for power quality improvement in grid integrated DER simulated using MATLAB/ SIMULINK in power system block set.

Keywords: Solar Photovoltaic (SPV), Boost converter, Neutral point clamped (NPC), Multi level inverter (MLIs), Total Harmonic Distortions (THD), Voltage sources inverter (VSI).

I. INTRODUCTION

In recent years, there has been an increasing interest in electrical power generation from renewable-energy sources, such as photovoltaic (PV) or wind-power systems [1], [2]. The benefits of power generation from these sources are widely accepted. They are essentially inexhaustible and environmentally friendly. Among the different renewable-energy sources possible to obtain electricity, solar energy has been one of the most active research areas in the past decades, both for grid-connected and stand-alone applications [3]–[9]. The exponential rate of growth in the worldwide cumulative PV capacity is mainly due to enhancement in grid-connected inverter topologies. The PV array and the battery are connected to the AC grid via a common DC/AC inverter. AC output voltage is created by switching the full bridge in an appropriate sequence [10]-[11]. The inverter topologies can be divided with two types, that are single and multi stage inverter. The single stage inverter has advantage such as low cost, high efficiency, robust performance, high reliability and simple structure. On the other hand, the multi stage inverter accept a wide range of input voltage variations, high cost, low efficiency, complicated structured and isolated topologies with high frequency transformers can extract power from the source even when DC voltage is very low [12]. [13] present the comparison of expense of power semiconductors and passive components of a (2.3 kV, 2.4 MVA) two-level, three-level NPC, three-level flying capacitor, four-level flying-capacitor, and five-level series connected H-bridge voltage source converter on the basis of the state-of-the-art insulated gate bipolar transistors for industrial medium-voltage drives. And illustrate that in three level inverter topology net total harmonics distortion is reduced in the output wave form without decreasing in inverter output power [14-18].

Photovoltaic systems require interfacing power converters between the PV arrays and the grid. These power converters are used for two major tasks. First, is to inject a sinusoidal current in to the grid. And second is to reduce the harmonics content in the grid injected voltage and current. Normally there are two power converters [19]. The first one is a DC/DC power converter that is used to operate the PV arrays at the maximum power point. The other one is a DC/AC power converter to interconnect the photovoltaic system to the grid. As shown in fig.1

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The classical single or three-phase two level VSIs is normally used for this power converter type [13]. However, other topologies have been proposed is the multi level VSI. Multilevel converter topologies are a very interesting choice for realizing this objective.
Multilevel power converters present several advantages over a conventional two level converter such as:

- Reducing switching frequency
- Output voltage with very low distortion and
- Reduced dv/dt stress [14-18].

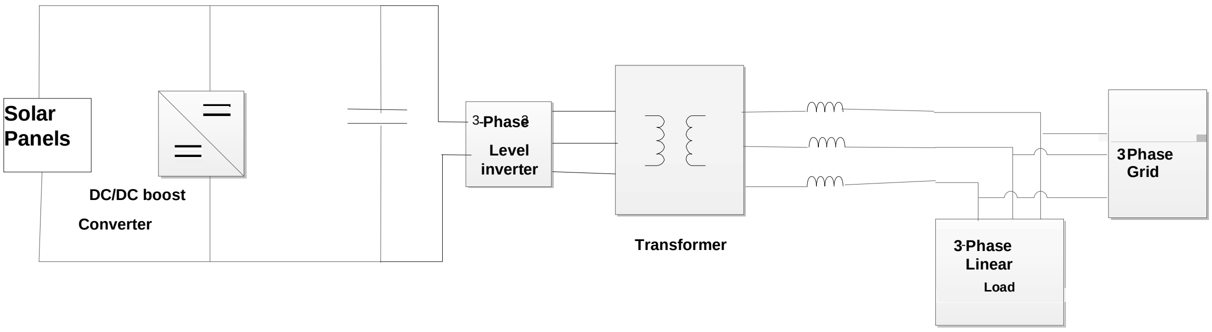

Fig.1: Grid connected solar panels with two stage inversion process

In order to obtain a galvanic connection between the grid and the PV generator many PV systems use a power transformer, avoiding that a leakage current may flow through the capacitance between PV generator and ground. Some systems use a transformer embedded in a high-frequency DC/DC converter. Others use a line frequency transformer at the output of the inverter as presented in the proposed model.

Related to these developments, this paper presents a new power converter structure for SPV systems. The proposed structure uses twin configured three-phase three levels NPC VSIs and a line transformer. This structure is specially developed to use with the central -string technology. A control system for the MLI is also proposed. This control system is based on a voltage oriented controller with a pulse width modulator (PWM). Several experimental results are presented in order to confirm the characteristics of the proposed system against the conventional two level inverters topology.

II. CONTROL STRATEGIES

Among multiple functions of grid connected systems, the current control plays one of the most important roles. The performance of the complete system largely depends on the quality of the applied current control strategy. It has to fulfill basic requirements, such as low harmonic distortion of the output current, high dynamic response, regulation of the dc-link voltage and, in a number of cases, provide bi-directional power flow. The desire to propose a current control strategy which combines most of these requirements has encouraged many researches in the last two decades [12] [14].

A. Controller of Proposed dc/dc converter

The DC to DC boost converters is shown in fig.2 is an important component to reach the desire voltage level in grid connected system so as to reduce the complexity and rating of the required PV modules. The voltage source provides the input DC voltage to the switch control, and to the magnetic field storage element.

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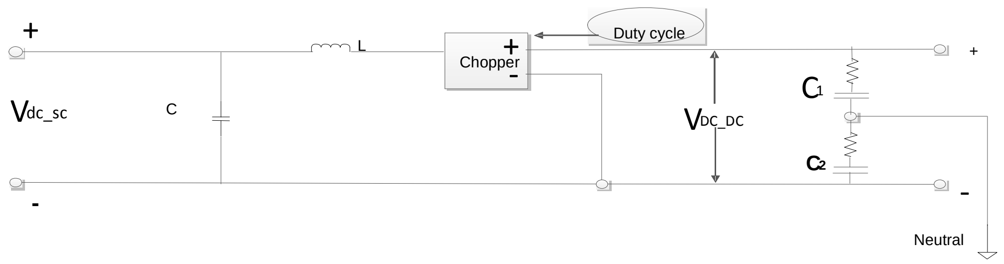

Fig.2: DC/DC boost converter with neutral point clamping

The control signal or duty cycle is given by open loop switch control that directs the action of the switching element, while the output rectifier and filter deliver an acceptable DC voltage at the output. The input of 200 volts represented by $V_{dc\ sc}$ is given at the input terminal converter and in the control circuit the reference voltage which is required is given as input signal i.e. 400 volts is represented by symbol V_{ref} as shown in fig.3. These two signals are compared in the PI controller and the controlled output is given to the signal generator. And required dc output voltage is given by equation (1).

$$V_{ref} = \sqrt{2V_{LL}/M} \qquad (1)$$

V_{LL} = the line to line voltage of the AC-grid
M = modulating index

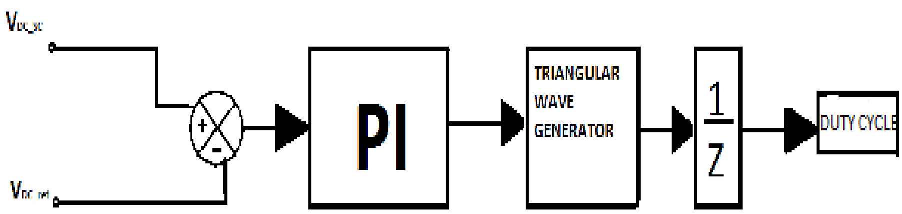

Fig.3: DC/DC converter controller

B. Controller of Proposed multi level PV inverter

In multilevel inverter we will use an fast switching control mechanism i.e. the voltage oriented control approach as shown in fig.4 we have to use the active power feedback from grid to control the active and reactive power flow in the grid and to maintain the grid current sinusoidal and within specified limits. In controller the active power from grid is compared with the reference power and the error signal is then fed to the power controller which extracts the reference current signal in direct and quadrature axes through synchronous reference frame theory. This again converted into three phase component and this reference voltage Vref is compared with the direct axis component of the grid voltage V_{abc_IB}. From which the error signal is computed and further transform into phased components and the supplied to the PWM generator which will produce the controlled pulses for controlling the inverter switching state.

The control strategy uses a PLL based unit vector template for extraction of reference signal from the distorted output supply. To get unit vector templates of voltage, the output voltage is sensed and multiplied by gain equal to $1/V_p$, where V_p is peak

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amplitude of fundamental output voltage. These unit vector templates are then passed through a PLL for synchronization of signals. The unit vector templates for different phases are obtained as follows:

$$V_a = \sin(\omega t) \quad (2)$$
$$V_b = \sin(\omega t - 120^0) \quad (3)$$
$$V_c = \sin(\omega t + 120^0) \quad (4)$$

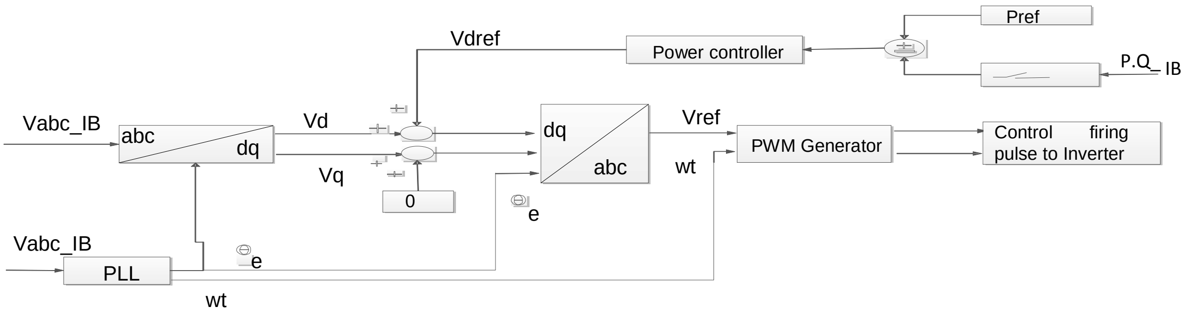

Fig.4: voltage oriented control for three level inverters

C. Controller design for dc/ac two levels inverter

The controller plays an important role in controlling and maintaining the proper functioning of the whole system by limiting the system parameter in specified ranges. Here in fig.5 the controller of grid connected two levels PV inverter is presented. As shown in the fig.5 we have to use the power feedback from grid to control the active and reactive power flow in the grid and to maintain the grid current sinusoidal and within specified limits. In controller the grid power is compared with the reference power and the resultant signal is then fed to the power controller which extracts the reference current signal in dq axes. Which again converted into three phase component and this reference current is compared with the gird current and the error signal fed to the hysteresis controller which directly generates the control signals or firing pulse for the inverter to maintain the gird current within specified limits.

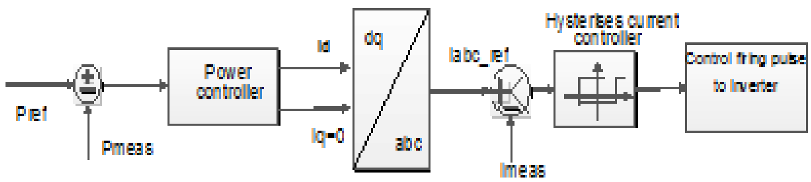

Fig.5: Controller design of two levels inverter

III. SIMULATION STUDY OF GRID CONNECTED THREE LEVEL PV INVERTER

The role of three level grid connected PV inverter is to improve power quality of grid tied solar powered system by reducing THDs, increasing the voltage level.

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A. Proposed grid integrated PV system with three level inverters

The base configuration of the proposed grid connected photovoltaic system is presented in Fig.6 This system consists of PV module as a DC source, DC/DC power converters, a multilevel DC/AC power converter, a power transformer, resistive load and an AC grid. The input supply is feed through PV module a dc source and this output voltage magnitude is boost to require level to obtain the line voltage the dc/dc boost converter is employed. The output of DC/DC boost converters is the DC power supplied to the multilevel DC/AC power converter.

In this system the balanced voltage feed to the three phases of grid is given as:

$$Va = V_m\ Sin(\omega t) \quad (5)$$

$$Vb = V_m\ Sin(\omega t - 120) \quad (6)$$

$$Vc = V_m\ Sin(\omega t\ + 120) \quad (7)$$

$$V_m = V_p * \sqrt{2}/\sqrt{3} \quad (8)$$

Where V_p is the peak amplitude voltage.

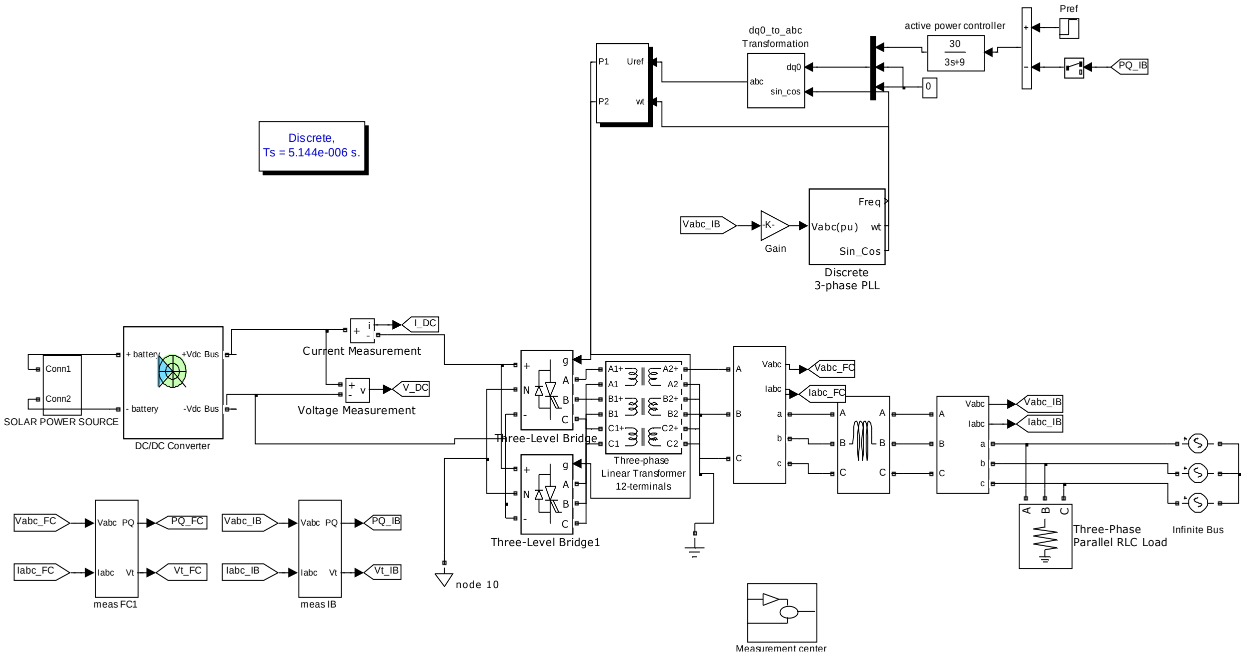

Fig.6: MATLAB Simulink model of grid connected PV system with three levels inverter

IV. RESULTS AND DISCUSSIONS

The three levels inverter generates three-phase voltages and currents which are sinusoidal and balance. The total harmonic distortion of voltage and current in grid tie three level inverter system in reduced to a large extent than the two level one. And they provide reactive power compensation at PCC and reduced electromagnetic emission. The results demonstrate the effectiveness of the proposed MLI based grid connected PV system.

Fig.8 (a) shows dc source voltage and current in three levels inverter based grid connected SPV system. Fig.8 (b) shows dc source voltage and current in two levels inverter based grid connected PV system. And it is clear from both the result that the

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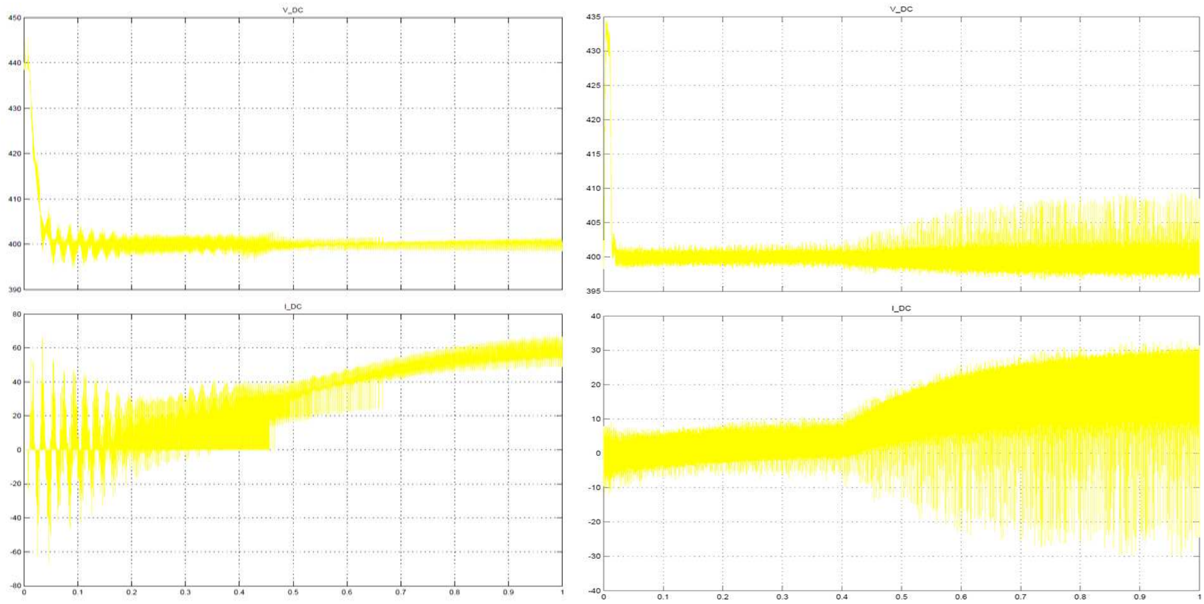
Vol. 2, Issue 8, August 2013

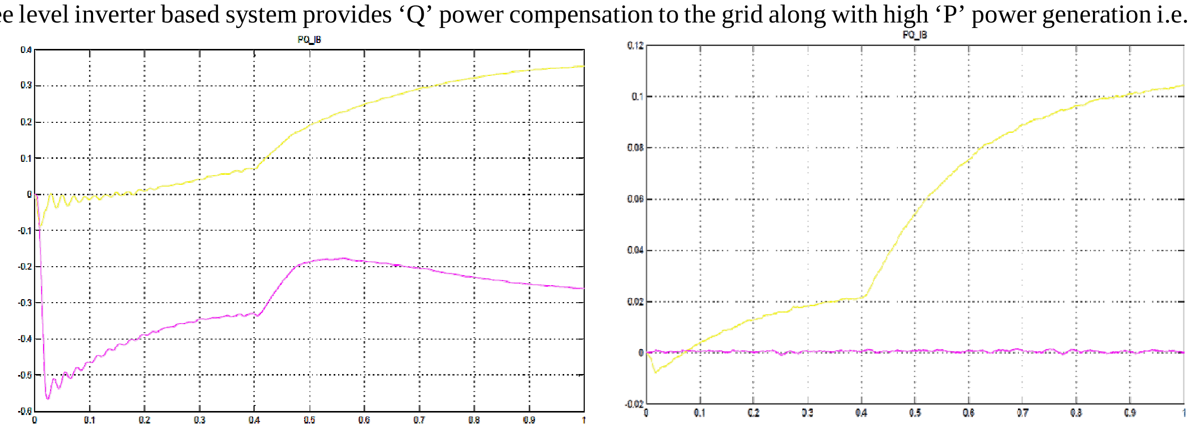
magnitude of voltage and current generation at the dc boosting stage in two levels that generates 400 volts, 20 amperes is less than the three level one which generates approximate sharp 400 volts, 50 amperes and high distortion it contains.



(a) (b)

Fig.8 (a) & (b): DC voltage and current output from dc/dc boost converter in 3 levels & 2 levels inverter based grid connected SPV system.

Fig. 9(a) shows the flow of active and reactive power in per unit with three level inverter model. And Fig. 9(b) shows the flow of 'P' and 'Q' power in p.u with two level inverter models at inverter and grid. The difference is clearly evaluated that the three level inverter based system provides 'Q' power compensation to the grid along with high 'P' power generation i.e. about



(a) (b)

Fig. 9(a) & (b): Active and Reactive power of infinite bus in 3 level & 2 level inverter based grid connected SPV.

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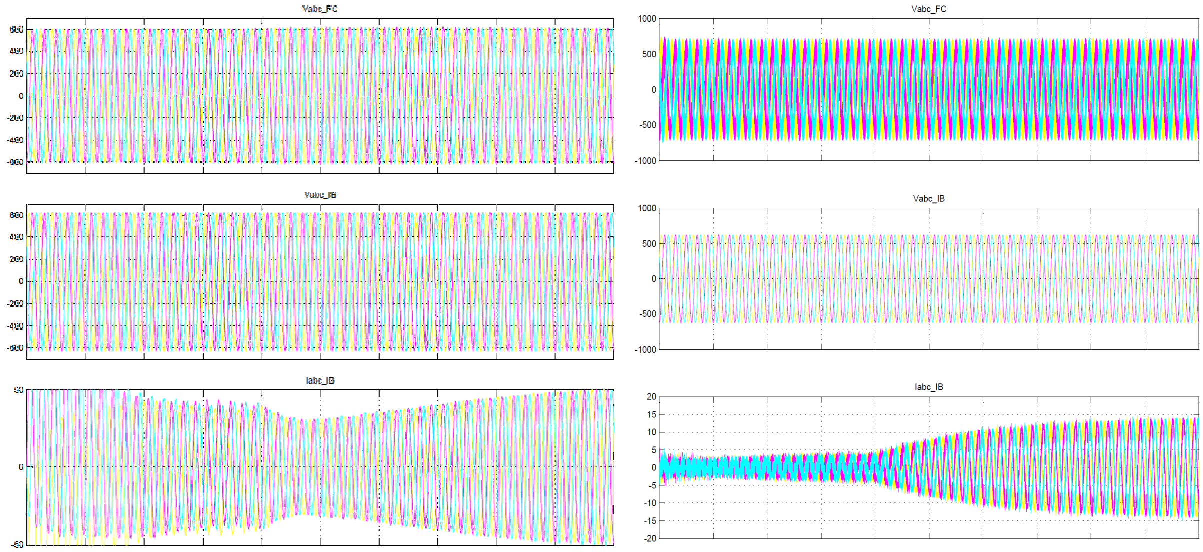
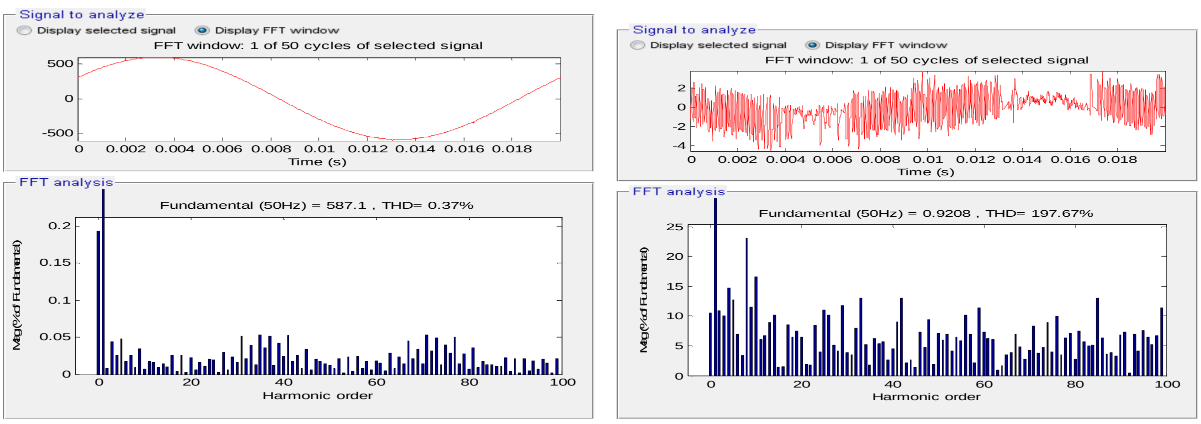
Fig.10 (a) & (b) consists three phase voltage and current waveforms of three level & two level inverter and grid. And it is clearly shown from the waveforms of both figures that the three levels inverter gives highly sinusoidal waveform of current and voltage with higher magnitude and lower fluctuation level.



(a) (b)

Fig. 10(a) & (b): Three phase voltage and current of inverter and infinite bus in three levels & two level inverter based grid connected SPV system.

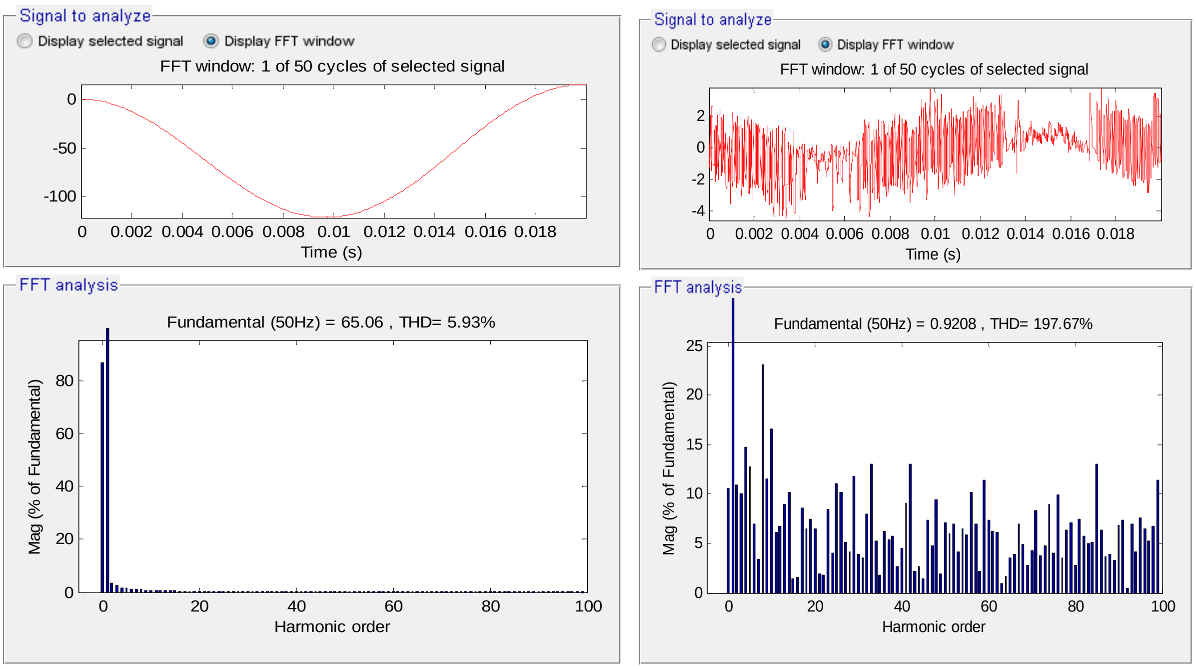
Fig.11 (a) & (b) clarify the difference in THD level of the two proposed system that in three level inverter system it is 0.37% in the inverter output voltage and in two level inverter system the output voltage distortion level is 38.51% which is too high that inversely effects the quality of power in the grid interacted DER's that is not permissible according to IEEE standards.



(a) (b)

Fig.11 (a) & (b): Total harmonic distortion level in three level & two level inverter voltages

Fig.12 (a)&(b) the THD content in the grid or infinite bus current in three level inverter based system it is 5.93% while in two level inverter system it is 197.67% a large difference in the level of distortion at same input provided to the system.



(a) (b)

Fig.12 (a) & (b): Total harmonic distortion level in three & two level inverter currents

TABLE I
Comparison between THD level of two and three level inverter based system

	THD_i (grid)	THD_v (inv)
Two Level Inverter	197.67%	38.51%
Three Level Inverter	5.93%	0.37%

V. CONCLUSION

The MLIs are very beneficial as the number of switches in inverter increases this increases the level of inverter the harmonics distortion in AC output voltage and current decreases, it also provide reactive power compensation to the AC grid and reduction in electromagnetic emissions because they operate on lower switching frequency.

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