PV Fed Three-Level CascadeInverter

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Abstract

This paper presents a two-state power conversion of renewable energy (solar energy) to useful electrical applications with low harmonic content in the output voltage. In this two-state conversion PV-array, boost converter and inverter are connected in series to obtain required output power. In this paper cascade three-level inverter is used. This inverter is simple because it is obtained by cascading two two-level inverters. This inverter uses the Space Vector PWM control algorithm, which gives maximum DC utilization. To validate the proposed topology MATLAB/Simulation studies are carried and compared with the existing topologies.

Keywords:*Photovoltaicarray; multilevel inverter;SVPWM.*

I. INTRODUCTION

In recent has years, there has been an increasing interest in electrical power generation from renewable-energy sources, such as photovoltaic (PV) or wind power system. Among the different renewable-energy sources, solar energy has been one of the most active research areas in the past decades, both for grid-connected and Stand-alone application. The basic concept of PV array is to collect solar energy from sun and transfer it for distribution as electrical power [1]-[2]. However this collected solar energy requires conversion techniques to make them usable to the end users. Basically the output of PVarray is DC form.For commercial purpose it needs to convert to AC form because most of the loads are AC loads.

A power electronic device which converts DC power to AC power at required output voltage and frequency level is known as inverter. Two categories into which inverters can be broadly classified are two level inverters and multi-level inverters. The conventional two-level inverter can only create two different output voltages for the load, In order to obtain the controlled (variable output voltage) and variable frequency the pulse width modulation techniques (PWM) are employed for an inverter. There is a large number of control techniques are developed so for to control the operation of an inverter. With these different PWM techniques the harmonics are minimized, but the switching losses are more. Though this conventional two-level inverter method is effective it creates harmonic distortions in the output voltage, EMI, high switching losses and high dv/dt (compared to MLIs).To obtain low switching losses and low harmonics in waveforms, the advanced PWM technique i.e.; SVPWM control technique and multi-level inverters are used.In this project the gate pulses of an inverter is generated by comparing the modulating waveform with the two triangular carrier waveforms. The concept of MLIs is introduced since 1975.The term multi-level began with the three-level converter. Subsequently, different topologies MLIs for the conversion from DC to AC are available such as Neutral point clamped MLI (NPC-MLI),Flying capacitorMLI (FC-MLI), Cascaded H-bridge MLI(CHB-MLI) .The advantages of MLIs are, reduced total harmonic distortion (THD),since the dv/dt is low, the EMI from the system is low, lower switching frequencies can be used and hence reduction in switching losses.These types of MLI topologies having disadvantages. InNeutral point clamped MLI (NPC-MLI) required excessive clamping diodes, therefore the inverter control can be very complicated. InFlying capacitor MLI (FC-MLI) requiredexcessive storage capacitors; therefore the inverter control can be very complicated. In Cascaded H-bridge MLI(CHB-MLI) required more isolated DC sources for real power conversion and neutral point fluctuations are not eliminated.

To overcome these disadvantages of MLIs, Cascading of two two-level inverters are proposed. In this paper cascade three-level inverter is used. This inverter is simple because it is obtained by cascading two two-level inverters. This inverter uses the Space Vector PWM control algorithm, which gives maximum DC utilization. And also the Neutral point fluctuations are absent, and fast recovery neutral clamping diodes are not needed.

This paper presents a simulation analysis cascading of two two-level inverters for PV applications with the svpwm control technique to achieve 3 level output voltage.

II. PHOTOVOLTAIC SYSTEM:

A photovoltaic (PV) system directly converts solar energy into electrical energy. The basic device of a PV system is the PVcell. Cells may be grouped to form arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and dc motors or connect to agrid by using proper energy conversion devices.

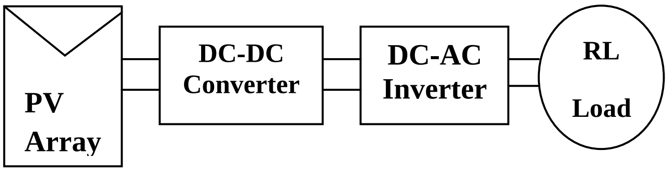

Fig1: Block diagram representation of proposed system

This PV system consists of three main parts which are PV module, balance of system and load. The major balance of system components in this systems are charger, battery and inverter. The block diagram of the PV system is shown in fig.1

The simplest equivalent circuit of a PV cell is a current in parallel with a diode [1]-[2]. The output of the current source is directly proportional to the light falling on the cell. During darkness, the PV cell is not an active device; it works as a diode, i.e, a p-n junction .It produce neither a current nor a voltage. However, if it is connected to an external supply (large voltage) it generates currentI_d, called dioded current or dark current.The diode determines the V-I characterstics of the PV cell.

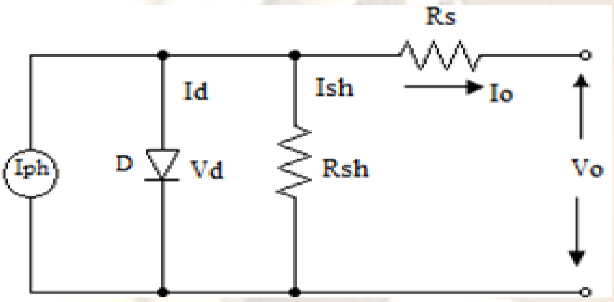

Fig2: Equivalent circuit of PV cell

Fig 2 shows the equivalent circuit of PV cell; whereR_s is the very small series resistance and R_{sh} is the quite large shunt resistance.D is the ideal p-n diode,Thephoto current (Iph) source generated proportionally by the surface temperature and insulation.V_OAndI_O represent the output voltage and output current of PV cell.

According to the physical property of p-n semiconductor, the V-I characteristics of PV module could be expressed.

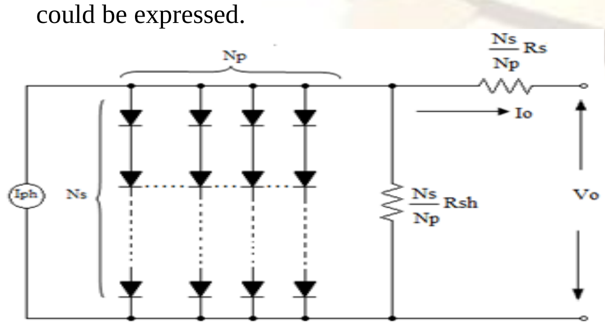

Fig3: General model of PV Array

The I_{ph} is expressed in equ (1) represents photo current proportionally produced to the level of cell temperature and radiation, where I_{scr} is the short-circuit current, K_i is the short-circuit current temperature coefficient, and rad is the solar radiation in W/M^2.

$$I_{ph} = \left(I_{scr} + K_i * (T - T_r) * (rad/100)\right) \text{---------- (1)}$$

In addition, the module reverse saturation current I_{rs} is,

$$I_{rs} = I_{rr} * ((T/T_r)^3) * \exp\left(q * \frac{E_g}{(K*A)}\right) * \left(\left(\frac{1}{T_r}\right) - \left(\frac{1}{T}\right)\right) \text{------- (2)}$$

$$I_o = (N_p * I_{ph}) - (N_p * I_{rs}) * \left(\exp\left(\frac{q}{(K*T*A)}\right) * Vo/Ns - 1 \right) \text{-------- (3)}$$

The PV power can be calculated using above equations as follows:

$$P = I_o V_o = n_p I_{ph} V_o \left[\left(\frac{q}{(K*T*A)} * V_o/N_s\right) - 1\right] \text{------ (4)}$$

III. DC-DC BOOST CONVERTER

The PV modules are always used with DC to DC converters to get the maximum output voltage. The types of converters used are buck, boost and buck-boost. For battery charging applications buck-boost configuration is preferred whereas boost converters are used for grid connected applications. DC-DC boost converters are used often in PV systems to step up the low module voltage to higher load voltages.

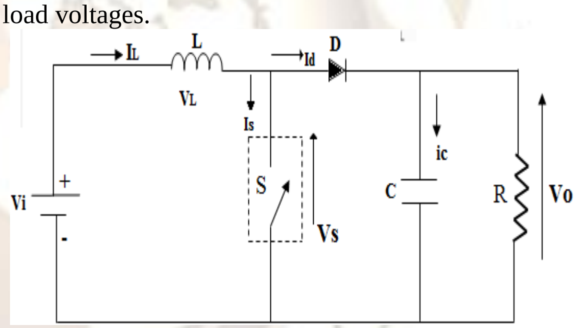

Fig4: Boost converter schematic

Fig. 4 shows the basic design - of a step up converter. As the name implies, the output voltage is always greater than the input voltage. The operation of the converter depends on the state of the switch. For better understanding the operation of the converter, the operation of the switch is examined circuit when the switch is opened or closed.

(a). Mode1

When the switch is on as shown in fig.5 the diode becomes reversed biased and the output stage is isolated. At this point the input is supplying energy to the inductor.

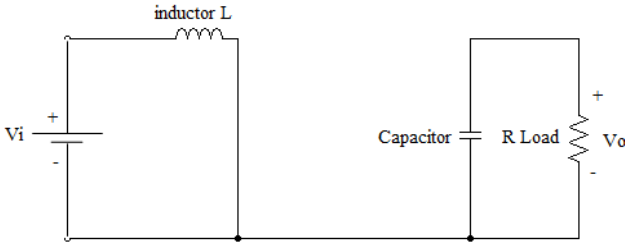

Fig5: Boost converter switch ON

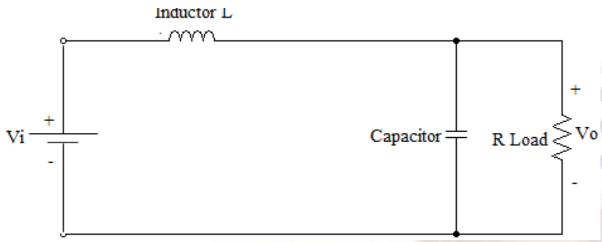

Fig6: Boost converter switch OFF

(b). Mode2

When the switch is off as shown in fig.6 the output stage receives energy from the inductor as well as from the input. In the steady-state analysis, the output filter capacitor is assumed to be very large to ensure a constant output voltage $v_{0(t)} = v_0$.

Fig.7 shows the switch state, voltage and current waveforms. when the dc-dc converter operates in continuous conduction mode, the inductor current flows continuously when$[i_L(t) > 0]$.

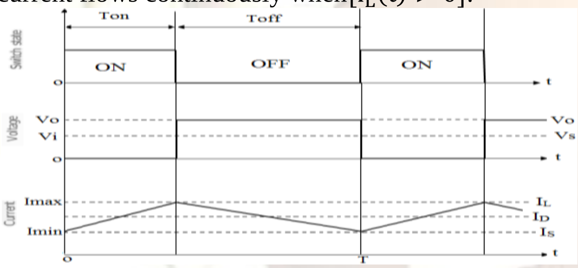

Fig7: Boost converter switch state and voltage and current waveforms

In steady state, the time integral of the inductor voltage over one time period must be zero. Thus

$$V_i t_{on} + (V_i - V_0) t_{off} = 0 \ .$$

Dividing both sides by the switching time, TS and rearranging terms, the equation obtained describes the relationship between the input and output voltages, switching time and duty cycle.

$$\frac{V_o}{V_i} = \frac{T_s}{T_{off}} = \frac{1}{(1-D)}$$

IV. PROPOSED THREE – LEVEL INVERTER CONFIGURATION

Fig 8 depicts the proposed three-level inverter topology. In this circuit configuration, three level inversions are achieved by connecting two two-level inverters cascade [3]-[6]. From fig 8, it may be seen that the output phases of inverter-1 are connected DC-input points of the corresponding phase in inverter-2.Each inverter is operated with an isolated DC power supply, with a voltage of $V_{dc}/2$(fig 8).The present power circuit can be operated as a two-level inverter in the range of lower modulation, by clamping one inverter to a zero state and by switching the other inverter.

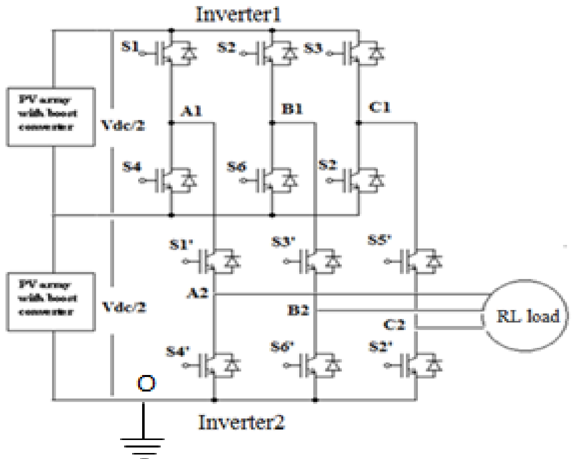

Fig8: The power circuit configuration of the proposed PV fed three-level inverter

The output pole voltages of inverter-1(the voltages of the individual phases A1,B1 and C1 of inverter-1),with respect to the point O, are denoted as V_{a1o}, V_{b1o} and V_{c1o} respectively (fig 8). The output pole voltages of inverter-2(the voltages of the individual phases A2, B2 and C2 of inverter-2),with respect to the point O, are denoted as V_{a2o}, V_{b2o} and V_{c2o} respectively (fig 8).

(a). The pole voltage of any phase for inverter-2 attains a voltage of $V_{dc}/2$, ifthe switches of $S_4$and S1' is turned ON.

(b). The pole voltage of any phase for inverter-2 attains a voltage of Vdc, ifthe switches of $S_1$and S_1' is turned ON.

(c). And Similarly, the pole voltage of any phase for inverter-2 attains a voltage of zero(0), ifthe switch of S_4' is turned ON.

Thus, the DC-input points of individual phases of inverter-2 may be connected to a DC voltage of either V_{dc} or $V_{dc}/2$ by turning on the top switch or the bottom switch of the corresponding phase leg in inverter-1.

Thus, the pole voltage of a given phase for inverter-2 is capable ofassuming one of the three possible values 0, $V_{dc}/2$ and V_{dc}, which are the characteristics of a three-level inverter.

V. SIMULATION STUDY

Three-level inverter configuration cascading two two-level inverters are simulated in MATLAB/SIMULINK and the THD of the current and in the voltage are analyzed by taking a inductive load. The modeling of PV cell is done based on related electrical parameters and Simulinkmodel of

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PV is developed with irradiation and temperature as two input parameters. The photo voltage, current I_{pv} and diode current I_d are modeled using equations (1),(2) and (3).The V-I characteristics and P-V characteristics of PV array is shown in fig.9,fig.10,fig.11 and fig.12 respectively.

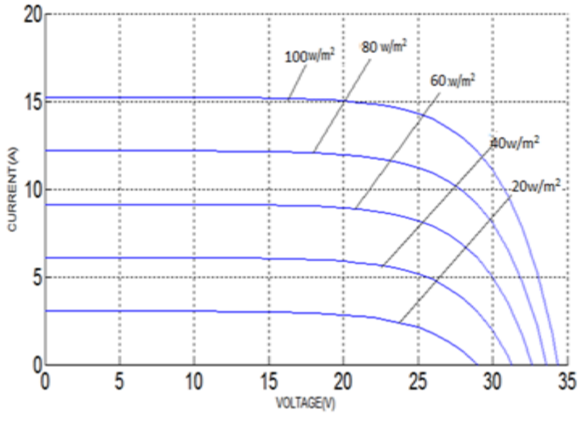


Fig 9: V-I characteristic of a solar array with different irradiance

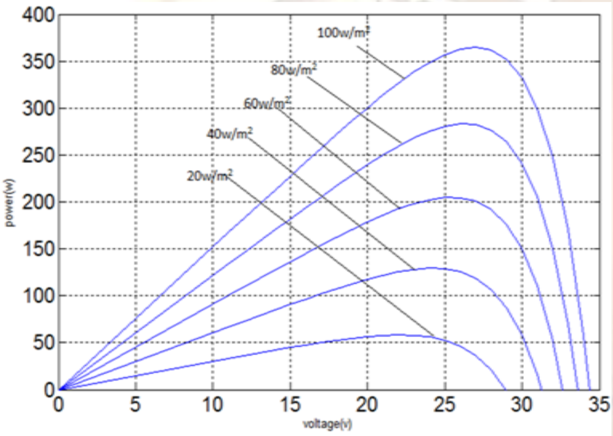


Fig10: P-V characteristic of a solar array with different irradiance

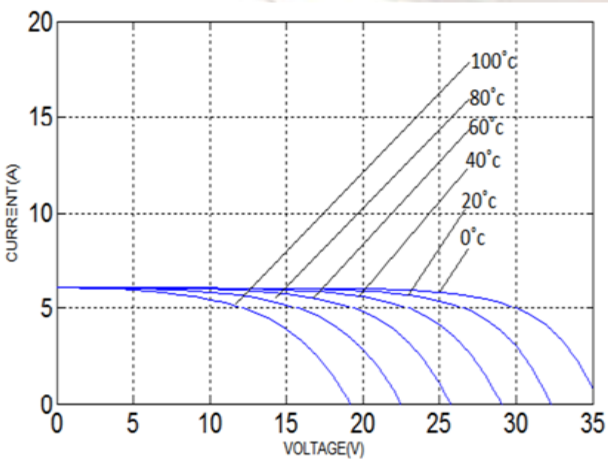


Fig11: V-I characteristic of a solar array with different temperatures.

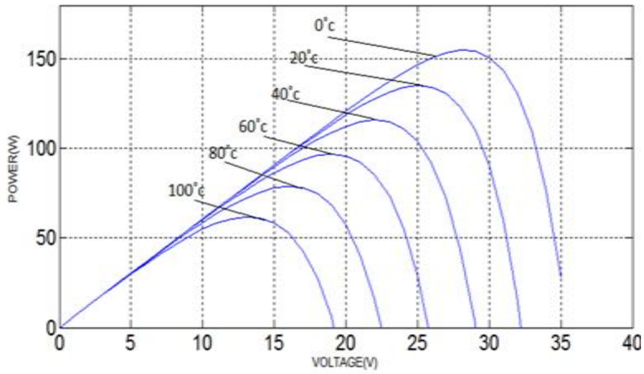


Fig12: P-V characteristic of a solar array with different temperatures.

It can be observed from figures that as the irradiation increases the maximum power level also increases. Similarly the curves will effect to the changes in temperature, series resistance and diode reverse saturation current.

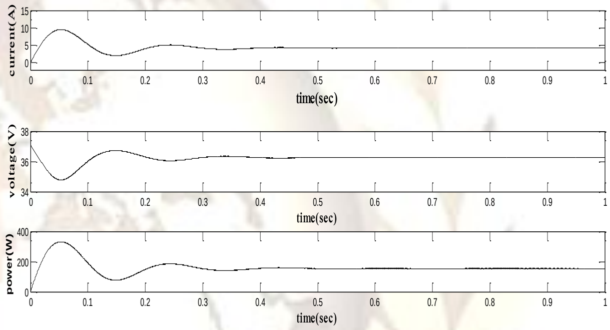


Fig13: Simulation Results of PV Array

Fig13 shows the output waveforms of a PV array. It shows the voltage, current and power characteristics with respect to time for a PV system. From the obtained results it is found that the average value of voltage is 36.26V, current is4.09A and power is 152.6W.

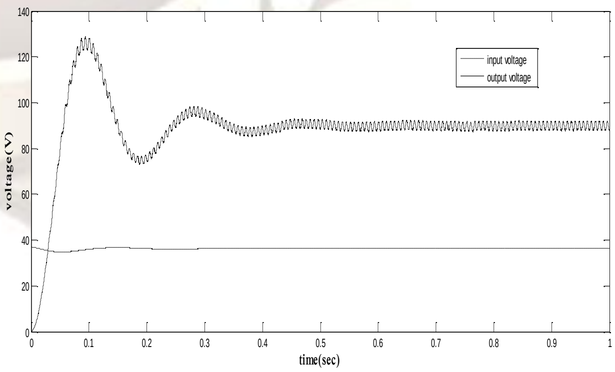


Fig14: Simulation results of PV Array with Boost converter for constant insulation input

Fig.14 shows the output waveforms of a PV array fed with boost chopper.The input given to the boost chopper is 36.26V and boosted to an average output of 88.01V.

SIMULATION RESULTS OF PV FED CASCADING OF TWO TWO-LEVEL INVERTERS FOR RL-LOAD

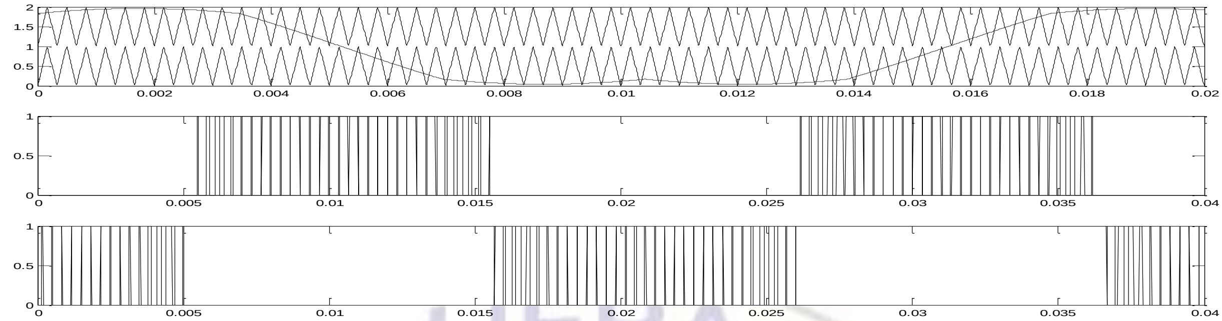
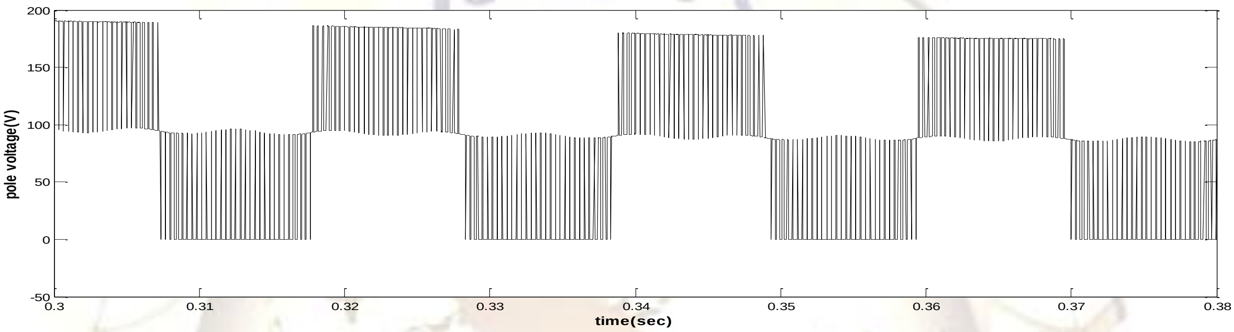
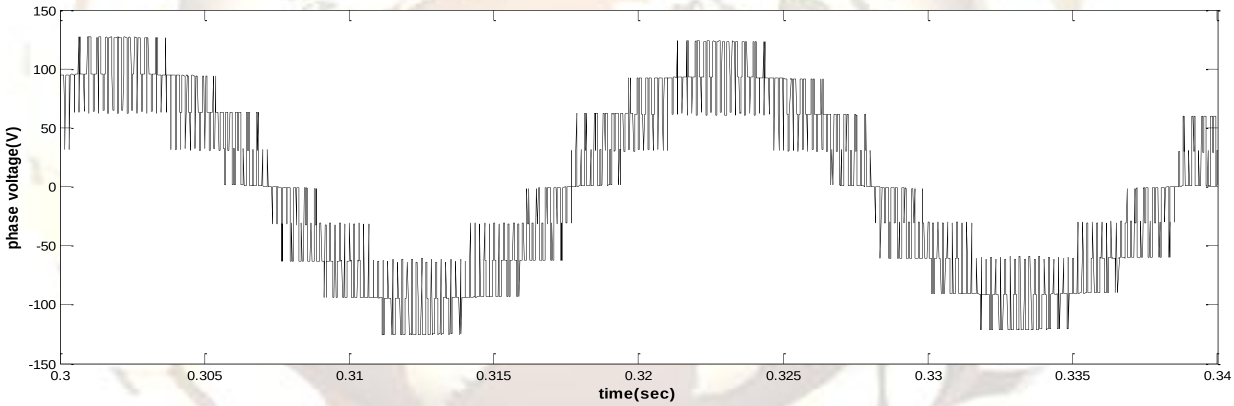
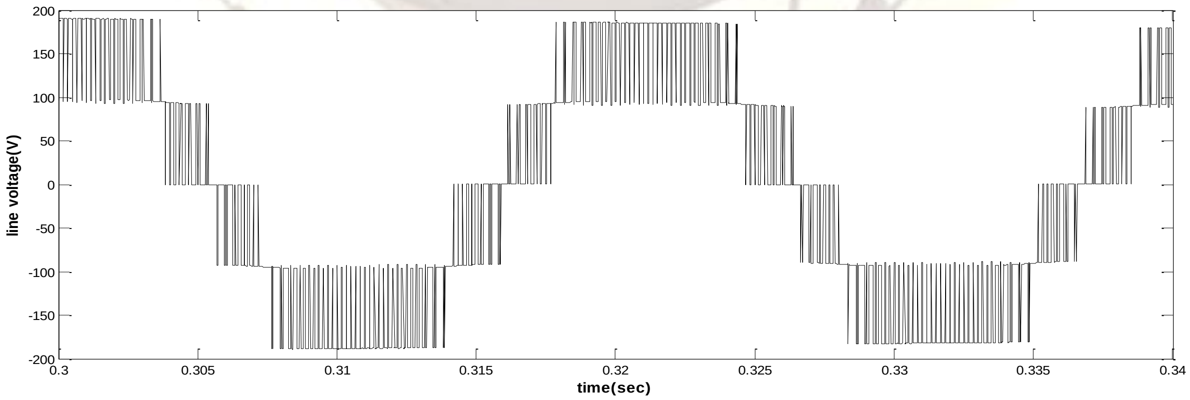


Fig15: Switching pulses for Inverter.







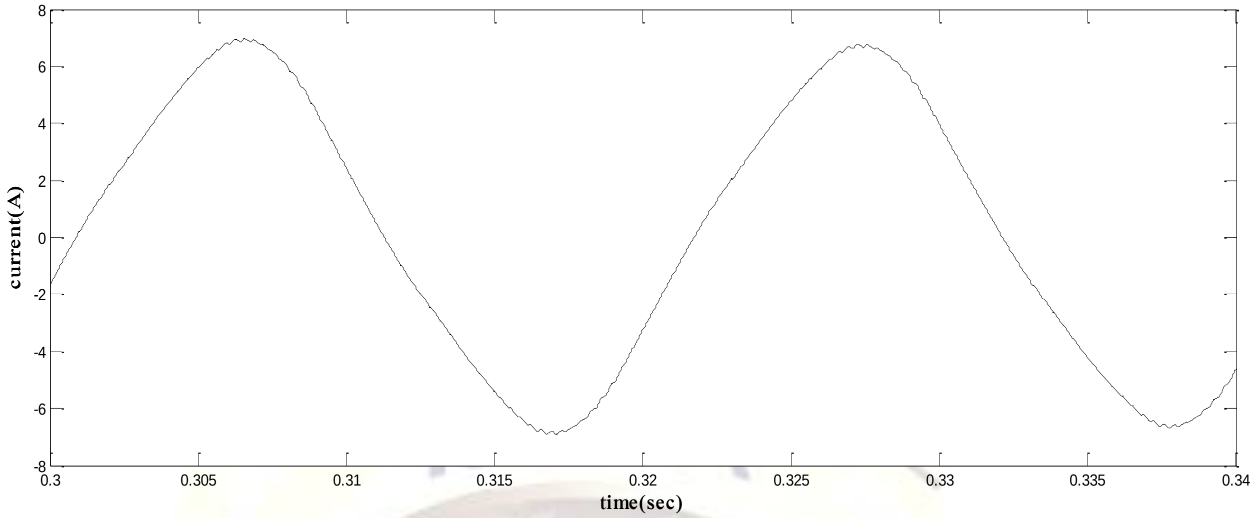


Fig16: the experimental waveforms of pole, phase and line voltage and current.

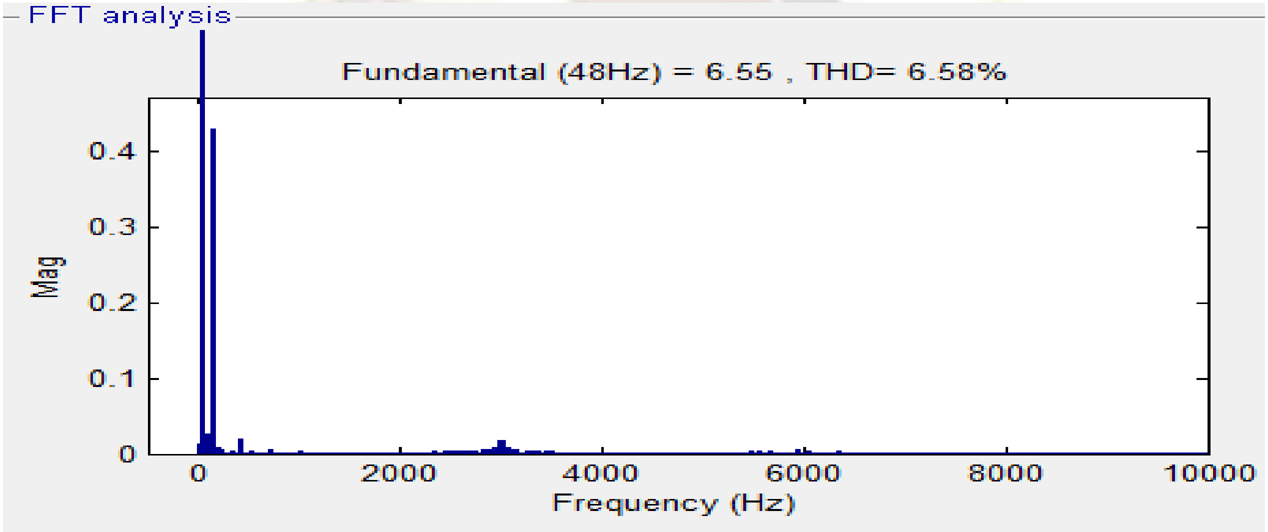


Fig 17: THD for current of a 3-level inverter

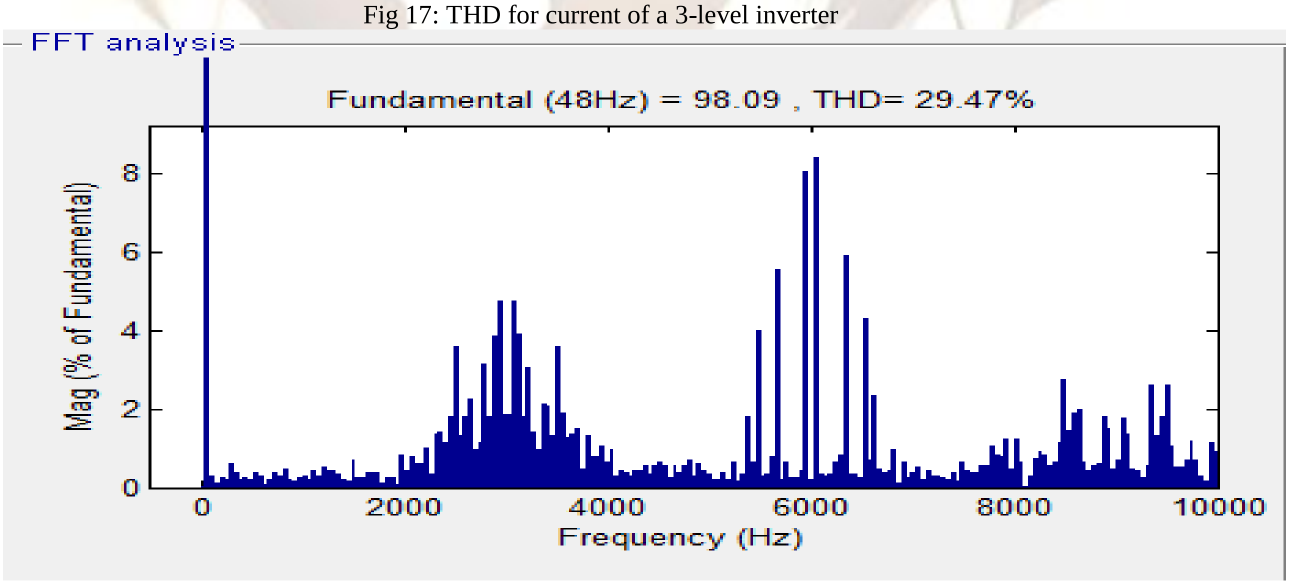


Fig 18: THD for line voltage of a 3-level inverter

TABLE.1
COMPONENT VALUES OF DC-DC BOOST CONVERTER

Description	Rating
Inductor	120 mH
Capacitor	1000µF
Switching Frequency	5KHz
R,L (at load side)	5Ω,50 mH

VI. CONCLUSION

In the proposed scheme, two two-level inverters connected in cascade to achieve three-level inversion. This proposed configuration needs two isolated power supplies when compared to an H-bridge topology, which needs three isolated DC links. Thus, the voltage fluctuations of the neutral point are avoided. Two existing two-level inverters are retrofitted to realize three-level inversion. The neutral clamping diodes are not needed in this topology, when compared to conventional NPC three-levelinverter. The THD of the both voltage and current of the three-level inverter is less than that of conventional two-level inverter. The stresses on the switching devices are in a MLI system is lesser compared to a two-level inverter.

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