A Fuzzy Algorithm Based Photovoltaic System Fed Novel Three Phase Boost Inverter

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***Abstract*—Recently inverters demand is in high due to its advantages of reduced part counts like diodes, capacitors, and switches. This paper investigates the fuzzy algorithm based PV system with a novel 3-phase single stage inverter. In this topology, the harmonic content at grid side is low compared to conventional inverters. And also, the switching pattern of proposed inverter is developed by sliding variable structure control (SVSC). The foremost design is maximum power point tracking (MPPT) to track peak powers of PV in varying. So, the MPPT is attained by Fuzzy Logic Controller (FLC) with a fast response in operation and stability in outputs. Furthermore, authors analyzed the performance of proposed system with conventional multilevel inverters.**

Keywords: MPPT Controller, Sliding Variable Structure Control, Single Stage Power Conversion, Total Harmonic Distortion, Induction Motor, Multi Level Inverter.

Nomenclature:

SVSC	: Sliding Variable Structure Control
H-bridge	: Hybrid-Bridge
MPPT	: Maximum Power Point Tracking
THD	: Total Harmonic Distortion
PV	: Photovolatic
SPWM	: Sinusoidal Pulse Width Modulation
FLC	: Fuzzy Logic Controller

I. Introduction

The increasing population in our country has imposed increased demand for power generation. The increased demand cannot be accomplished with the available fossil fuels. This has imposed more responsibility on the researchers to focus on non-renewable energy sources. The solar energy obtained abundantly and is environmental friendly, cost effective and feasible. Also solar power can be easily connected to the power converters. The growing demand for solar renewable energy has resulted in rapid evolution of power converters and their integration with the grid. The photovoltaic renewable energy has become a significant part in energy production.

In present modern society the electrical energy has become very vital in every aspect of human life. The objective of power electronics has a broad range from improving efficiency to minimizing power quality issues , from effective transmission to utilization. Power electronics and Information electronics has become brain and muscle of modern society.

The unreliable nature of photovolatic systems always require a Maximum power point tracker to extract maximum power under all circumstances. MPPT techniques are already available. P&O method is the most frequently used algorithm. Also with the recent advancements a Fuzzy MPPT technique has been introduced in this paper for improved maximum power extraction.

The dc output from solar module is stored in a battery. The battery voltage is fed to a three phase boost inverter , converting low Dc output of battery into high AC voltage with the fundamental frequency without a DC-DC Converter in a single stage and hence the name Boost inverter.

This paper mainly focused on controllers such as MPPT, SVSC and Dual Leg DC-AC Converter and its control topology due to its boosting and inverting property which is achieved in a single stage. The Fuzzy based MPPT technique is considered for regulating the PV module output voltage. To maintain the invariant output voltage , SVSC technique is being implemented to meet the three phase load demands.

Due to the climatic changes, the performance of the solar energy is not able to give constant voltage and give less efficiency [2]. In addition, the DC battery acts as an energy storage systems and more number of solar cells will lead to a hike in investment of the solar power plant. In this paper ,the proposed single stage dual leg three phase inverter is analysed with variable load conditions and the performance is compared with multilevel inverter to prove the productiveness of the proposed approach in terms of losses, cost of inverter, complexity, efficiency. The pictorial representation of the proposed system is as in Figure:1

The paper is arranged as follows: Fuzzy MPPT is discussed in section 2, while control implementation is analysed in section 3. The simulation results are discussed in section 4. Finally, conclusions are in section V.

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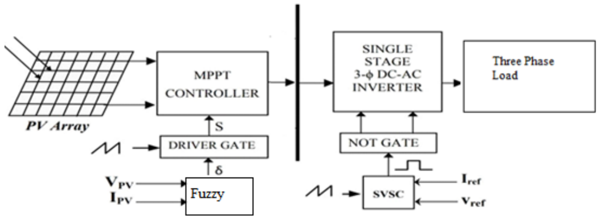

Fig.1: Block Diagram of the Proposed System.

II. Fuzzy MPPT

The simple and popular MPPT technique is P&O MPPT algorithm is very simple to be realized. The main concept is to always push the system to the direction where the power obtained from the PV system increases. This method is preferable for the systems with gradual variations in temperature and radiation.. The response of P&O method for rapid variations in temperature or irradiance is very slow. For such variations, the fuzzy control algorithm can be considered for retrieving improved tracking performance. A Fuzzy Logic Controller allows for rapid prototyping and also can handle the systems with non-linearity. Also the exact mathematical model of the system is not required for FLC and it is more robust than conventional non-linear controllers.

A. Fuzzy Logic Controller

The functioning of FLC can be easily explained in four steps namely Fuzzification, Rule-Base, Inference Engine and finally Defuzzification as shown in Figure: 2.

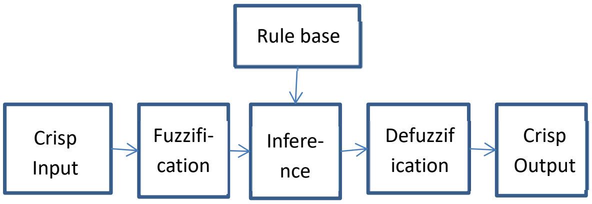

Fig. 2(a): Components of FLC

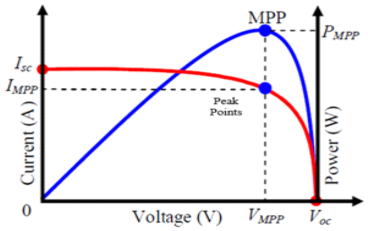

Fig. 2(b): Graphical Representation of Maximum Power Point

It is very easy to construct FLC and rules are designed based on error e and change in error signal de/dt[6]. The following equations are used for designing the Fuzzy MPPT algorithm.

$$E= V_{max}- V_{PV} \tag{1}$$

$$\Delta E(k)= E(k)=E(k-1) \tag{2}$$

Triangular Membership shapes are used with five membership functions for variable errors of input FL and output FL controllers, and notations are negative big (NB), negative small (NS), zero (Z), positive small (PS) and positive big (PB). Using the notations and following Fuzzy frameworks, rules are framed with five capacities and are used to filter the execution of the fuzzy. Table.1 represents the fuzzy rule base for the membership functions considered. Figure.2 graphically represents the maximum power point.

Table 1: Fuzzy Rule Base for Fuzzy MPPT Algorithm

E/(DE/DT)	NB	NS	Z	PS	PB
NB	NB	NB	NB	NS	Z
NS	NB	NB	NS	Z	PS
Z	NB	NS	Z	S	PB
PS	NS	Z	PS	PB	PB
PB	Z	PS	PB	PB	PB

III. Single Stage (Boost) Inverter

The proposed three phase boost inverter gives dc biased voltage in each phase using four switches per phase. The output voltage of each converter has a phase shift of 1800 delivering maximum differential voltage across the load [1]. The neutral terminal of each phase is commonly connected and the three phase variable load is connected at each phase terminal. The circuit of three phase boost inverter is shown in Figure.3.

The advantage of Boost converter is to convert low DC photovoltaic voltage to high ac utility voltage in a single stage without using step up converter. Number of switches requirement is also less as compared with CHB multilevel inverter. Also we obtain a distortion less sinusoidal voltage waveform without using filters.

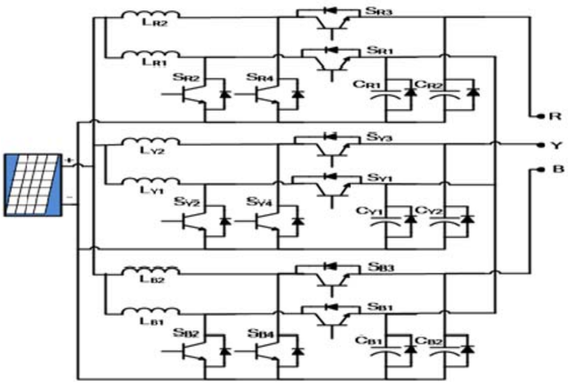

Fig. 3: Schematic Diagram of Three Phase Boost Inverter

A. Working of Single Stage Inverter

The proposed DC-AC Inverter has two modes of operation per phase. Consider the circuit of R-phase as in Figures. 4 and 5, the analysis can be understood in two modes.

Mode: 1 The S1R (switch) is open and S2R is closed in the first interval of positive half cycle. The charging current of inductor L2 increases the loop current as in Figure(4). The switch S2R is open and S1R is closed in the next interval. The capacitor C1 supplies to load and the voltage across the load is VC1.

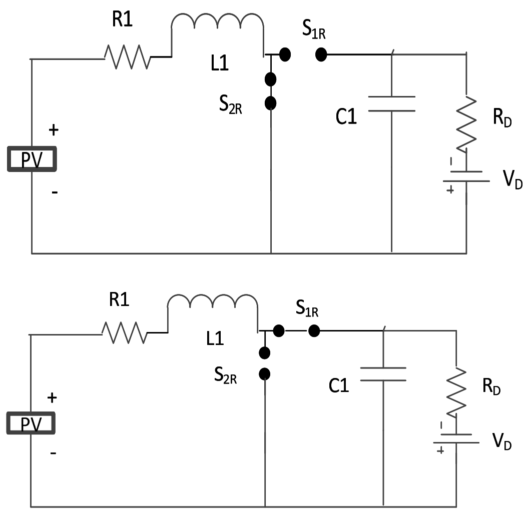

Fig. 4: Circuit of Converter in Positive Half Cycle (R-Phase, is Mode-1)

Mode: 2 In the first interval of negative half cycle, with S_{3R} is open and the switch S_{4R} is closed, then the inductor L_1 charges as in Figure(5). In the next interval the switch S_{4R} is open and the switch S_{3R} is closed, the capacitor C_2 supplies the load with the voltage V_{C2}.

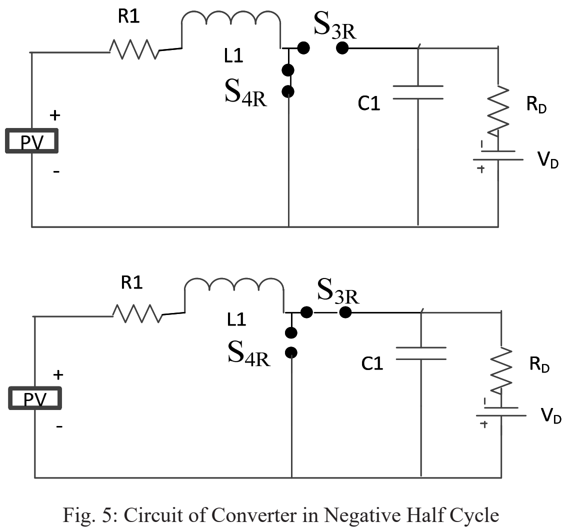

Fig. 5: Circuit of Converter in Negative Half Cycle (R-Phase, is Mode-1)

The mode of operation of converter in the positive half cycle is given by the following equation

$$\frac{V_{C1}}{V_{PV}} = \frac{1}{1-D} \tag{3}$$

The mode of operation of converter in the negative half is given expressed by the equation

$$\frac{V_{C2}}{V_{PV}} = \frac{1}{D} \tag{4}$$

The functionality of the converter (R-Phase) can be easily evaluated with the equations given below

$$V_R = V_{C1} - V_{C2} = \frac{VDC}{1-D} - \frac{VDC}{D} \tag{5}$$

$$V_R = V_{pv} * \frac{2D-1}{(1-D)\,D} \tag{6}$$

B. Sliding Variable Structure Controller (SVSC)

Variable Structure System (VSS) was first realized in USSR. VSS is a class of nonlinear systems for analyzing specific control tasks in systems either linear or non-linear. VSS is more crucial as the system is totally insensitive to external variations and to all uncertainties. The robustness and the invariance property of VSS has improved its application in the field of control for Induction motors, DC servomotors, robotic manipulators.

Also the parametric differentiations, external disturbances and variable payloads can be easily handled by SMC (sliding mode control) based on VSS. The Sliding mode control can limit the drawbacks of PI control which is subject to conflict between the steady state perfection and dynamic response speed [5].

In the recent research, SVSC theory has been developed into discrete complex systems. The SVSC is an advanced nonlinear control approach in which structure can be changed automatically after attaining a switching plane. This approach is considered to gain the exact system dynamic properties. This method is known for its robust control strategy for treating system parameter perturbation and any external variations.

In variable structure systems the control is allowed to change its structure, that is, to switch at any instant from one to another member of a set of possible continuous functions of the state. The variable structure design problem is then to select the parameters of each of the structures and to define the switching logic[5]. The operation of SVSC in the two modes is shown in Figures:6(a) and 6(b).

A sliding variable structure control method is proposed to control the output of the single stage dual leg dc-ac converter. Sum of the error values of the state variables of the proposed converter with proper gains [6] are given to

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the hysteresis current controller. There are two bands are formed in the hysteresis current controller which is lower and upper band based on the ripple of the error signals[6]. A continuous pulse signal is produced with unequal width by cutting the ripples on the edges of lower and upper bands with the frequency range is up to 400KHz.

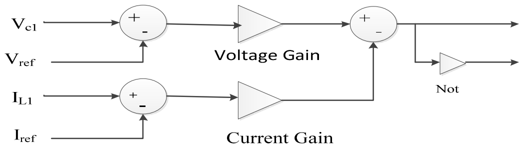

Fig. 6(a): Mode 1 Operation of SVSC Scheme

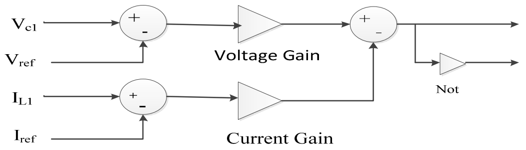

Fig. 6(b): Mode 2 Operation of SVSC Scheme

IV. Simulation Results

The design and modelling of single stage three phase dual leg DC-AC inverter and control techniques are developed by MATLAB/Simulink environment as shown in Figure:7. Consider the circuit parameters to be ideal. The parameters are: V_{DC} = 100V, L_1, L_2 = 750µH each, C_1, C_2 = 20µF each and F_{sw} = 400KHz (Variable). SVSC Controller for the proposed Single stage Inverter has been simulated in the Matlab / Simulink environment.

The cascaded five level inverter has been simulated using the circuit as shown in Figure:8 with a total of 24 Switches in the inverter, eight switches in each phase.

The Solar panel output voltage of 100v is shown in Figure:9, the three phase single stage inverter output voltage of around 400V is obtained as shown in Figure:10. The Dc-AC inverter output voltage with variable R-load is given in Figure:11

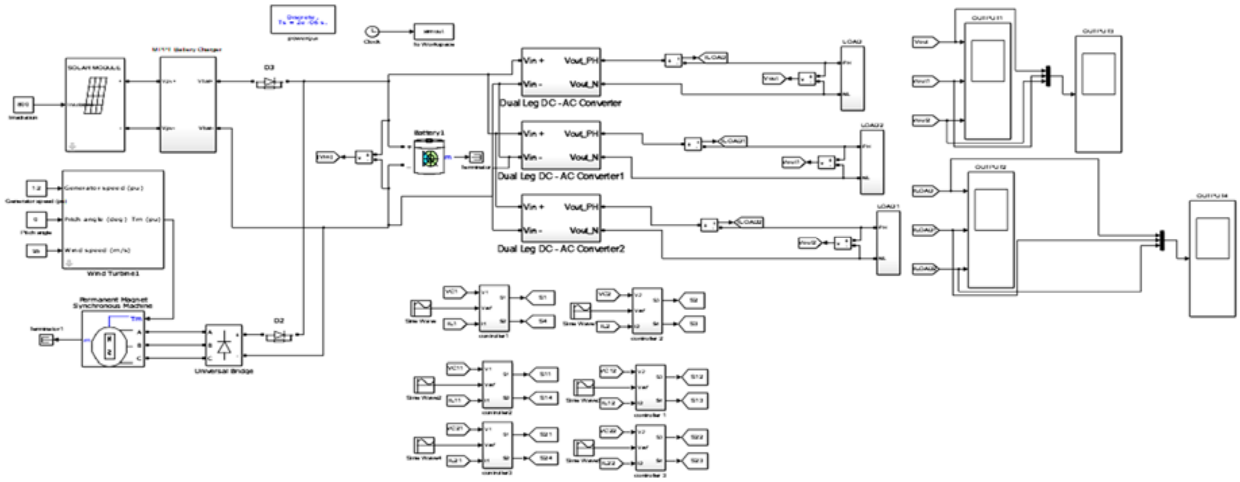

Fig. 7: Simulation Model of the Proposed System with Three Phase Load

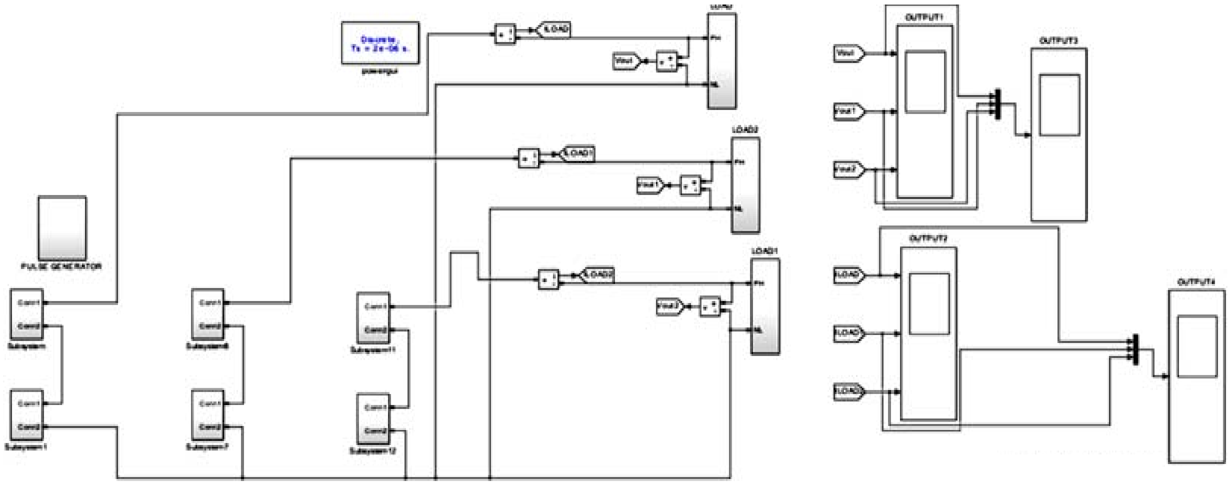

Fig. 8: Simulation Diagram of Five Level Multilevel Inverter with Three Phase Load

The Inductor currents ILR1 and ILR2 in single stage inverter and the Capacitor voltages VCR1 and VCR2 in single stage inverter are as shown in Figures 12 and 13. The inductor currents and capacitor voltages are used for obtaining the switching pulses for the switches of the boost inverter using SVSC scheme.

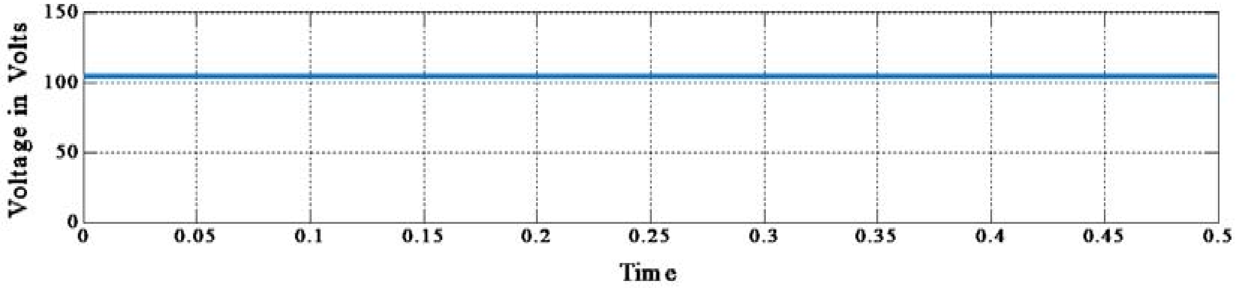

Fig. 9: Solar Panel Output Voltage

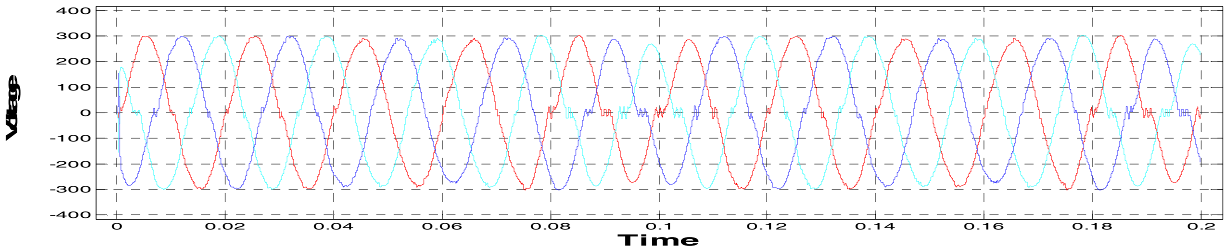

Fig. 10: Single Stage Inverter Output Voltage With Variable R-Load

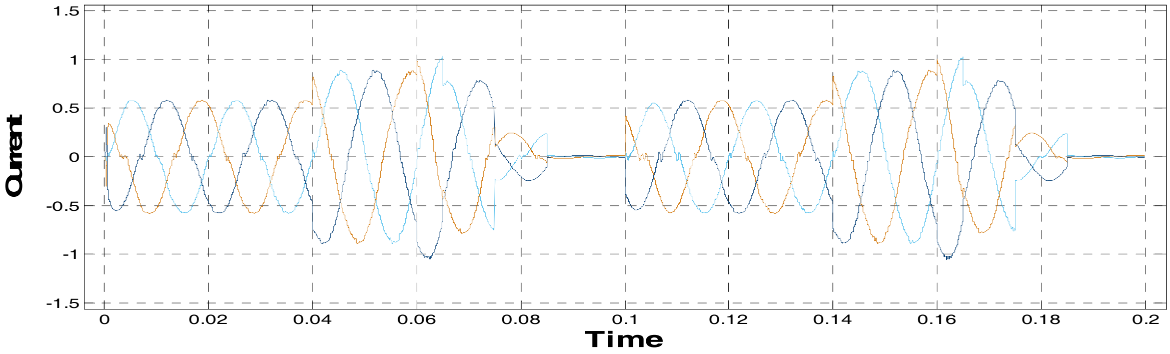

Fig. 11: Single Stage Inverter Output Current With Variable R-Load

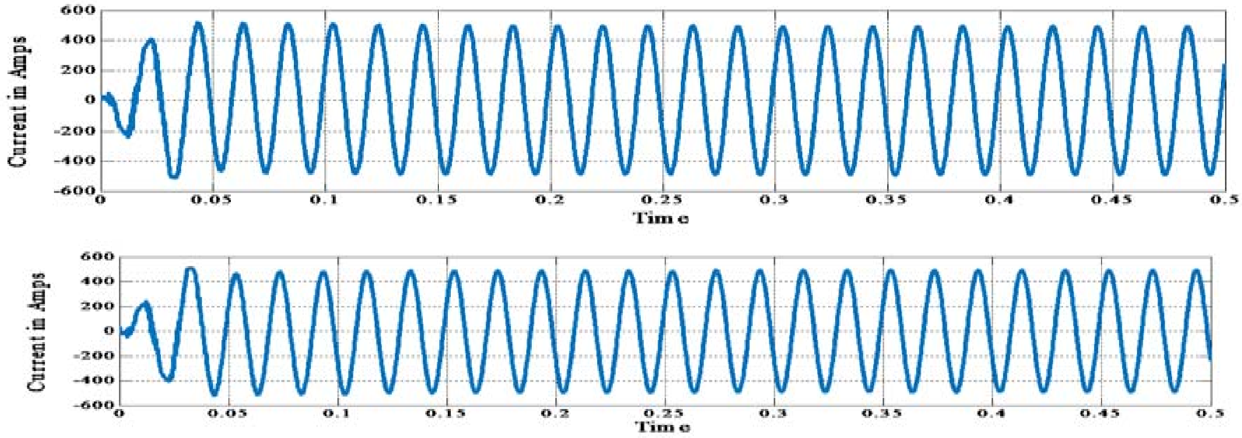

Fig. 12: Inductor Currents ILR1 and ILR2 in Single Stage Inverter

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The Cascaded H-Bridge five level inverter output voltage of 400v with variable resistive load has been obtained as shown in Figure: 14. Also the varying load current of five level bridge inverter is as shown in Figure:15.

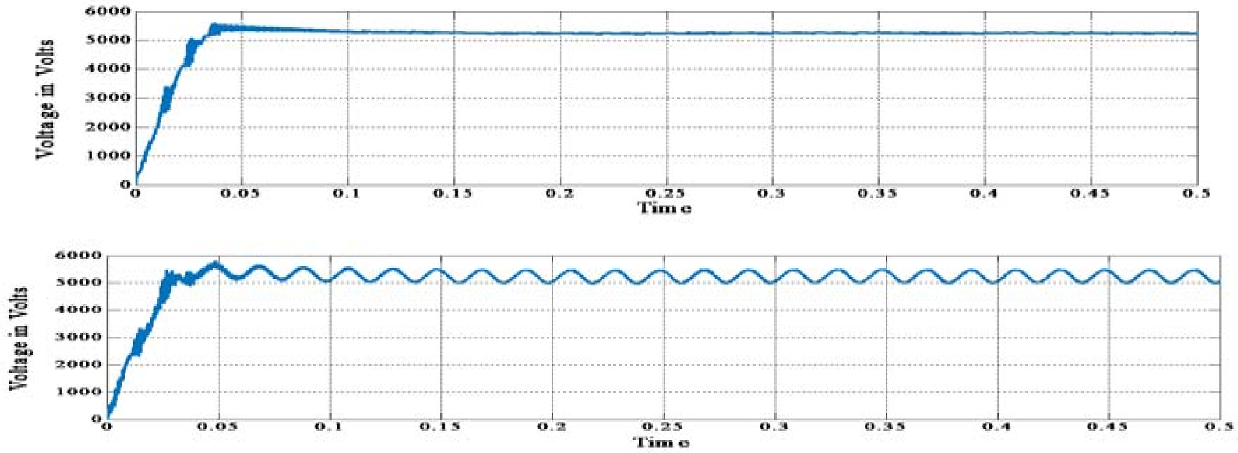

Fig. 13: Capacitor Voltages VCR1 and VCR2 in Sngle Stage Inverter

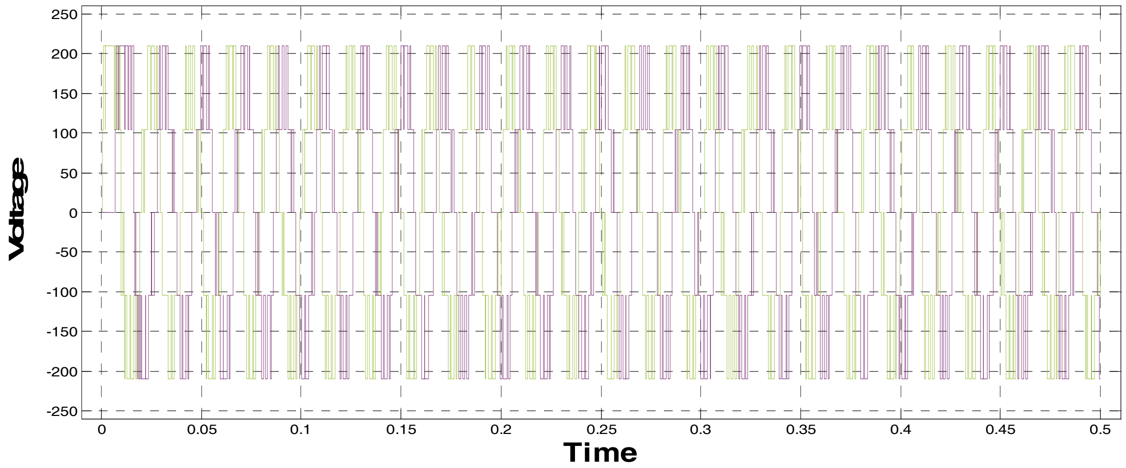

Fig. 14: Output Voltage of Five Level H-Bridge Inverter

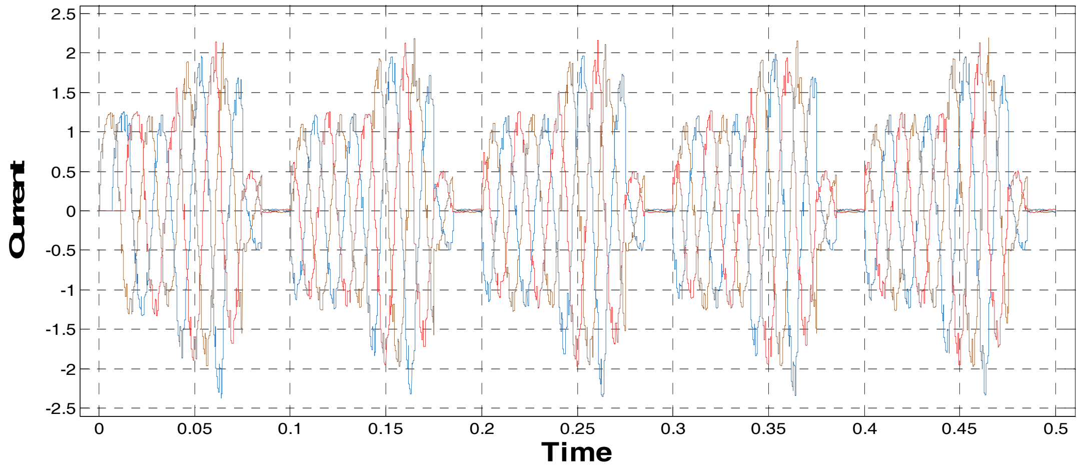

Fig. 15: Load Current of Five Level H-Bridge Inverter

A Total Harmonic Distortion of 5.96% in load current with R- Load is obtained with the single stage inverter & THD of 36.89% is obtained with Multilevel inverter as shown in Figure:16.The performance of Single stage inverter for variable loads is compared with that of five level H-ridge inverter in terms of THD, the number of switches used, number of sources considered has been tabulated in Table 2.

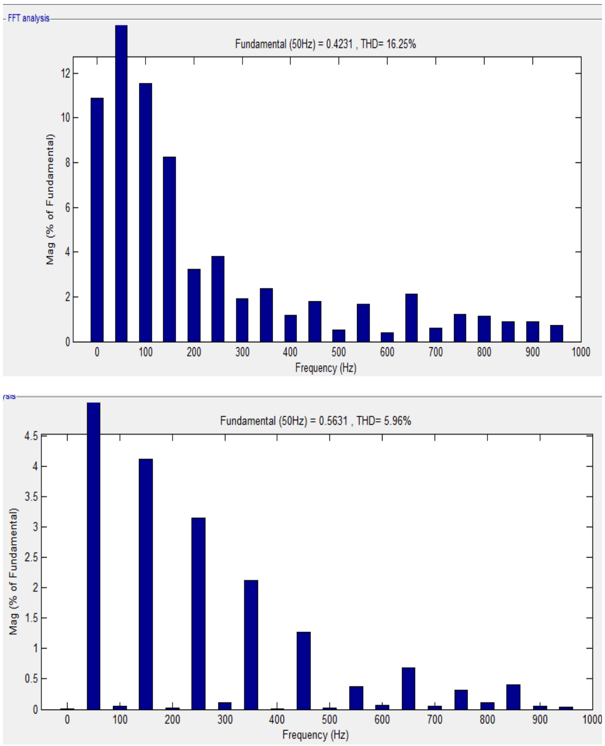

Fig. 16: THD Values of Five Level Inverter and Single Stage Inverter.

Table 2: Comparison of Single Stage Inverter and Multilevel Inverter

Parameter	Single stage inverter	Multilevel inverter
Number of switches	12	24
Number of PV sources	One source	Two sources
Output voltage	415V	415V
THD(R-Load)	5.96%	36.89%
THD(RL-Load)	0.62%	17.93%
THD(RLC-Load)	5.39%	16.25%

V. Conclusion

A Novel three phase single stage inverter has been simulated and the performance is compared with that of Multilevel inverter with variable loads. It can be concluded that with the proposed system only 12 switches are enough to supply a voltage of 415V but with the multilevel inverter 24 switches are to be used. Also with the proposed system the distortion produced is less as compared with the multi level inverter.The proposed single stage inverter can further be used to drive a three phase Induction Motor and its performance can also be analysed. Futher the proposed inverter can be implemented with Solar -Wind hybrid energy system.

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