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Performance and Analysis of Hybrid Multilevel Inverter fed Induction Motor Drive

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ABSTRACT

This paper presents the Five level inverter with single DC source which is used to generate a five level output with two bridges and six switches and performance of three phase induction motor is analyzed when connected to PV array For this two identical dc sources of 50V each for two bridges in five levels using Multi level inverter and five level output is obtained by using a single DC source of 100V with six switches. A virtual DC source (charged capacitor acts as virtual DC source) is used for getting the output. The same technique is implemented for three-phase circuit i.e. by using single DC source. An asynchronous motor (three-phase) is connected as load and its performance characteristics are analyzed. And further the DC source is replaced by a renewable resource such as solar panels, fuel cell etc. and DC voltage is obtained. Performance characteristics of three-phase asynchronous motor are analyzed with PV array connected. The method can be easily extended to an m-level inverter. The cascaded inverter is subjected to other modulation scheme. Simulations have been carried out in MATLAB–Simulink to study the performance of the proposed prototype.

KEYWORDS: Cascaded H Bridge inverter, Induction motor, PV array, THD, Virtual DC source.

I. INTRODUCTION

A multilevel inverter 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, which can be easily interfaced to a multilevel inverter system for high power applications The topologies of multilevel inverters are classified in to three types the Flying capacitor inverter, the Diode clamped inverter and the Cascaded bridge inverter.

The proposed prototype use of r multilevel inverter has five level associated with a six number of power switches [1-3] with the use of single dc source In normal five level inverter use of this two identical dc sources of with two bridges in five levels using Multi level inverter and five level output is obtained in proposed circuit by using a single DC source. The same technique is implemented for three-phase circuit i.e. by using single DC source. An asynchronous motor (three-phase) is connected as load and its performance characteristics are analyzed. And further the DC source is replaced by a renewable resource such as solar panels, fuel cell etc. and DC voltage is obtained. Performance characteristics of three-phase asynchronous motor are analyzed with PV array connected. To develop the model of hybrid multilevel inverter, a simulation is done based on MATLAB/SIMULINK platform

II. PV ARRAY

Photons of light with energy higher than the band-gap energy of PV material can make electrons in the material break free from atoms that hold them and create hole-electron pairs. These electrons however, will soon fall back into holes causing charge carriers to disappear. If a nearby electric field is provided, those in the conduction band can be continuously swept away from holes toward a metallic contact where they will emerge as an electric current. The electric field within the semiconductor itself at the junction between two regions of crystals of different type, called a p-n junction. [4]

The PV cell has electrical contacts on its top and bottom to capture the electrons. When the PV cell delivers power to the load, the electrons flow out of the n-side into the connecting wire, through the load, and back to the p-side where they recombine with holes [4]. Note that conventional current flows in the opposite direction from electrons.

2.1MATHEMATICAL MODEL OF THE PV ARRAY

2.1.1. SIMPLIFIED EQUIVALENT CIRCUIT:

A solar cell basically is a p-n semiconductor junction. When exposed to light, a current proportional to solar irradiance is generated. The circuit model of PV cell is illustrated in Fig.1. Standard simulation tools utilize the approximate diode equivalent circuit shown in Fig. 4 in order to simulate all electric circuits that contain diodes. The model is based on two-segment piecewise linear approximation. The circuit consists of R_{on} in series with voltage source $V_{on.}$

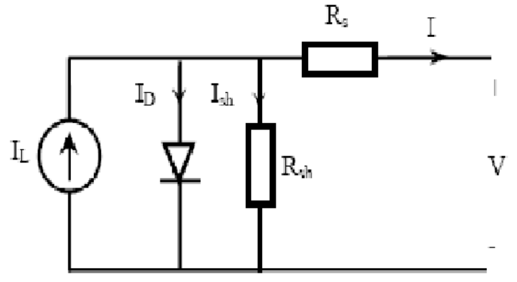

Fig. 1: Circuit model of PV solar cell

2.2. THEORETICAL MATHEMATICAL MODEL:

The equation [1] & [2] that are used to solve the mathematical model of the solar cell based on simple equivalent circuit shown in Fig. 1, are given below;

$$I_D = I_O \left[e^{\frac{q(V+IRs}{KT}} - 1\right] \quad \text{.............................. (1)}$$

$$I = I_L - I_O \left[e^{\frac{q(V+IRs}{KT}} - 1\right] - \frac{V+IRs}{Rsh} \quad \text{........................ (2)}$$

Where:

I is the cell current in (A).
q is the charge of electron = 1.6x10-19 (coul).
K is the Boltzmann constant (j/K).
T is the cell temperature (K).
IL is the light generated current (A).
Io is the diode saturation current.
Rs , Rsh are cell series and shunt resistance (ohms).
V is the cell output voltage (V).

2.3. PV CHARACTERISTICS:

2.3.1 CURRENT VS VOLTAGE CHARACTERISTICS:

Equation (1) was used in computer simulation to obtain the output characteristics of a solar cell, as shown in the figure4. This curve clearly shows that the output characteristics of a solar cell are non linear and are crucially influenced by solar radiation, temperature and load condition

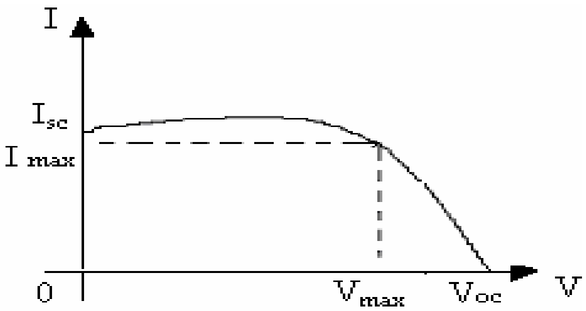

Fig. 2: Output Characteristics Of Solar Cell

2.3.2 POWER VS VOLTAGE CHARACTERISTICS: Figure 3 shows the typical Power versus Voltage curve of the PV array. In this figure, P is the power extracted from PV array and V is the voltage across the terminals of the PV array [7].

The characteristics have different slopes at various points. When maximum power is extracted from PV array the system is operating at MPP where slope is zero. The PV curve varies according to the current insolation and temperature. When insolation increases, the power available from PV array increases whereas when temperature increases, the power available from PV Array decreases.

2.3.3 VARIATION IN AVAILABLE ENERGY DUE TO SUN'S INCIDENT ANGLE:

PV cell output with respect to sun's angle of incidence is approximated by a cosines function at sun angles from 0° to 50° .Beyond the incident angle of 50° the available solar energy falls of rapidly as shown in the figure 4. Therefore it is convenient and sufficient within the normal operating range to model the fluctuations in photocurrent (Iph) verses incident angle is given by Eq(3). [8].

$$Iph = Imax \cos\theta \quad \text{........................ (3)}$$

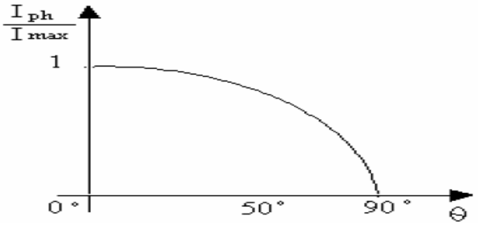

Fig 3: Power Vs Voltage

The graph shown in fig.4 is used to find the maximum power extracted from the sun when the PV arrays are inclined a different angles. From the figure we observe that Max power is obtained when the slope of the PV array is equal to zero.

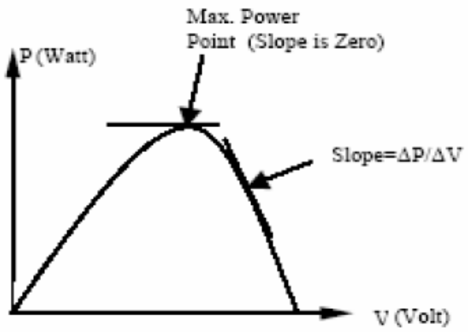

Fig. 4: Variation In Available Energy Due Sun's Incident Angle Variation.

III .CASCADED MULTILEVEL INVERTER

In this paper the use of one half bridge and one full bridge to get five level output wave as output.

3.1 VIRTUAL DC SOURCES

Virtual DC sources are nothing but charged capacitors. These charged capacitors are used to get the required output voltage with changing in levels. The main advantage of using the virtual dc source is to minimize the voltage sources (PV arrays) which results in decreasing of installation cost.

3.2 MULTI-LEVEL INVERTER

Three different major multilevel converter structures have been applied in industrial applications cascaded H-bridges converter with separate dc sources, diode clamped, and flying capacitors. Before continuing discussion in this topic, it should be noted that the term multilevel converter is utilized to refer to a power electronic circuit that could operate in an inverter or rectifier mode. The cascaded h bridge multilevel inverter focused on this paper.

3.3.1 Cascaded H-Bridges: A single-phase structure of an m-level cascaded inverter is illustrated in Figure 10. Each separate dc source (SDCS) is connected to a single-phase full-bridge, or H-bridge, inverter. Each inverter level can generate three different voltage outputs, $+V_{dc}$, 0, and $-V_{dc}$ by connecting the dc source to the ac output by different combinations of the four switches, S_1, S_2, S_3, and S_4. To obtain $+V_{dc}$, switches S_1 and S_4 are turned on, whereas $-V_{dc}$ can be obtained by turning on switches S_2 and S_3. By turning on S_1 and S_2 or S_3 and S_4, the output voltage is 0. The ac outputs of each of the different full-bridge inverter levels are connected in series such that the synthesized voltage waveform is the sum of the inverter outputs. The number of output phase voltage levels m in a cascade inverter is defined by m = 2s+1r. The phase voltage $v_{an} = v_{a1} + v_{a2} + v_{a3} + \ldots\ldots + V_{an}$

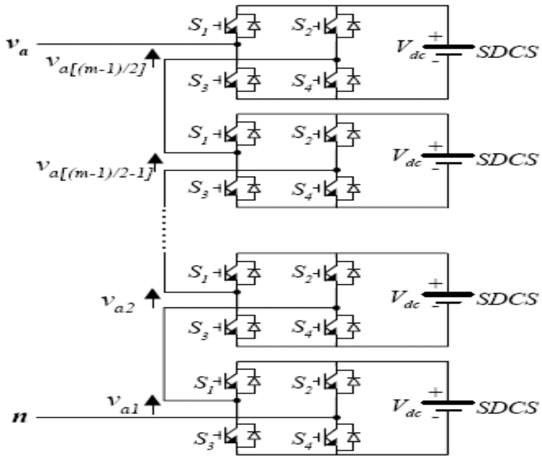

Fig.5. Single-phase structure of a m level multilevel cascaded H bridge inverter.

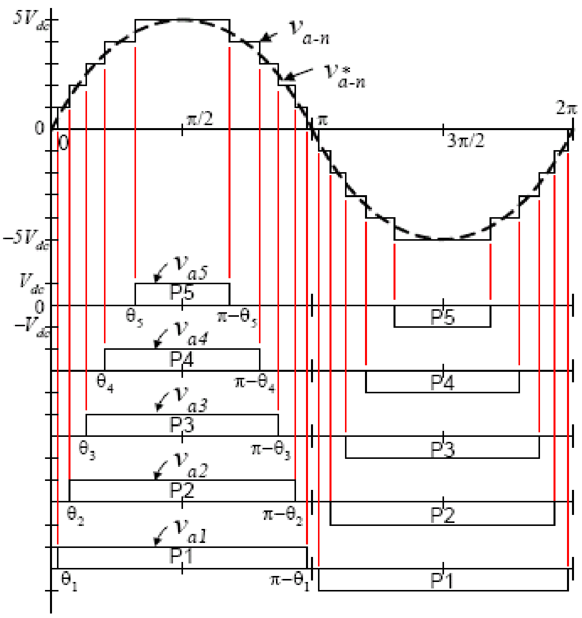

Fig.6 Output phase voltage waveform of an 11-level cascade inverter with 5 separate dc sources

Multi level inverters divide the main DC supply voltage into several smaller DC sources which are used to synthesize an AC voltage into a stair case, or stepped, approximation of the desired sinusoidal waveform. A waveform generated with five DC sources each one with one volt magnitude approximates the desired sinusoid, as shown in figure 11. The five DC sources (five steps) produced peak to peak voltage of 10V using eleven discrete levels

3.4 MLI WITH SINGLE DC SOURCE:

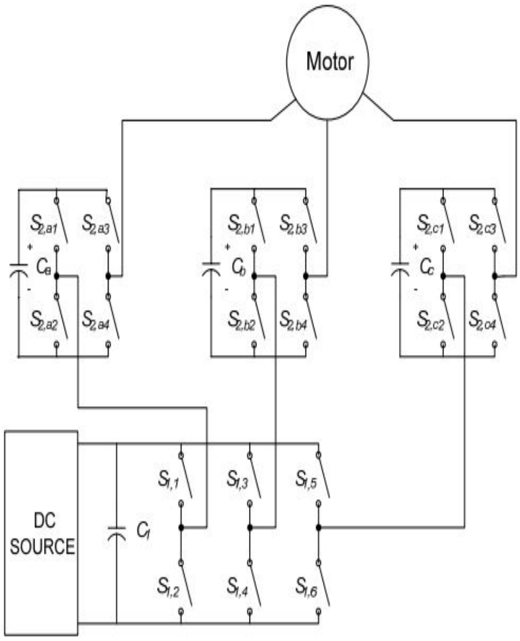

Fig.7. Topology of the hybrid multilevel inverter.

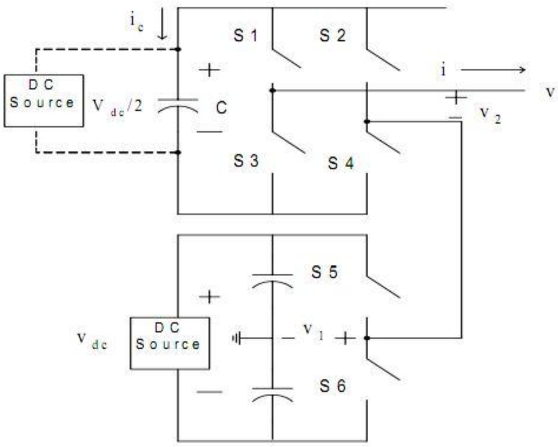

Fig.8. Simplified single-phase topology of the hybrid multilevel inverter.

Fig. 7 shows the topology of the proposed hybrid shows the topology of the proposed hybrid multilevel inverter. A simplified single-phase topology is shown in Fig.8. The bottom is one leg of a standard 3-leg inverter with a dc power source. The top is an H-bridge in series with each standard inverter leg. The H-bridge can use a separate dc power source or a capacitor as the dc power source [5][6].

The output voltage v_1 of this leg (with respect to the ground) is either $+V_{dc}/2$ (S_5 closed) or $-V_{dc}/2$ (S_6 closed). This leg is connected in series with a full H-bridge which in turn is supplied by a capacitor voltage. If the capacitor is kept charged to $V_{dc}/2$, then the output voltage of the H-bridge can take on the values $+V_{dc}/2$ (S_1, S_4 closed), 0 (S_1, S_2 closed or S_3, S_4 closed), or $-V_{dc}/2$ (S_2, S_3 closed). An example output waveform that this topology can achieve is shown in the top of Fig. 14. When the output voltage $v = v_1 + v_2$ is required to be zero, one can either set $v_1 = +V_{dc}/2$ and $v_2 = -V_{dc}/2$ or $v_1 = -V_{dc}/2$ and $v_2 = +V_{dc}/2$. It is this flexibility in choosing how to make that output voltage zero that is exploited to regulate the capacitor voltage

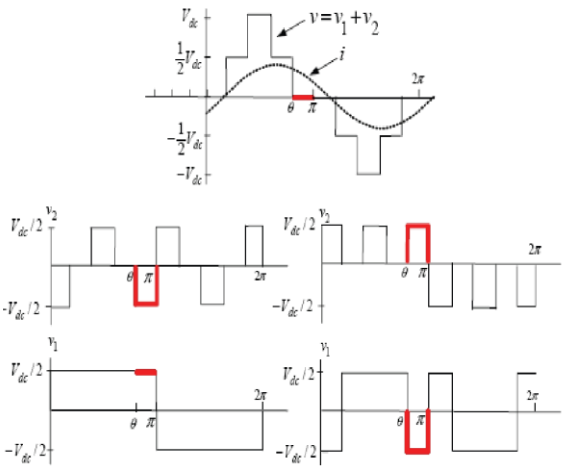

Fig.9. Capacitor voltage regulation process.

When only a dc power source is used in the inverter, that is, the H-bridge uses a capacitor as the dc power source, the capacitor's voltage regulation control details are illustrated in Fig.9. During $\theta_1 \le \theta \le \pi$, the output voltage in Fig.9 is zero and the current $i > 0$. If S_1, S_4 are closed (so that $v_2 = +V_{dc}/2$) along with S_6 closed (so that $v_1 = -V_{dc}/2$), then the capacitor is discharging ($i_c = -i < 0$ see Fig. 14) and $v = v_1 + v_2 = 0$. On the other hand, if S_2, S_3 are closed (so that $v_2 = -V_{dc}/2$) and S_5 is also closed (so that $v_1 = +V_{dc}/2$), then the capacitor is charging ($i_c = i > 0$ see Fig. 14) and $v=v_1+v_2=0$. The case $i < 0$ is accomplished by simply reversing the switch positions of the $i > 0$ case for charge and discharge of the capacitor. Consequently, the method consists of monitoring the output current and the capacitor voltage so that during periods of zero voltage output, either the switches S_1, S_4, and S_6 are closed or the switches S_2, S_3, S_5 are closed depending on whether it is necessary to charge or discharge the capacitor.

As Fig.9 illustrates, this method of regulating the capacitor voltage depends on the voltage and current not being in phase. That means one needs positive (or negative) current when the voltage is passing through zero in order to charge or discharge the capacitor. Consequently, the amount of capacitor voltage the scheme can regulate depends on the phase angle difference of output voltage and current.

IV. INDUCTION MOTOR:

In recent years the control of high-performance induction motor drives for general industry applications and production automation has received widespread research interests. Induction machine modeling has continuously attracted the attention of researchers not only because such machines are made and used in largest numbers but also due to their varied modes of operation both under steady and dynamic states. Traditionally, DC motors were the work horses for the Adjustable Speed Drives (ASDs) due to their excellent speed and torque response. But, they have the inherent disadvantage of commutator and mechanical brushes, which undergo wear and tear with the passage of time. In most cases, AC motors are preferred to DC motors, in particular, an induction motor due to its low cost, low maintenance, lower weight, higher efficiency, improved ruggedness and reliability. All these features make the use of induction motors a mandatory in many areas of industrial applications. The advancement in Power electronics and semiconductor technology has triggered the development of high power and high speed semiconductor devices in order to achieve a smooth, continuous and low total harmonics distortion (THD).

Three phase induction motors are commonly used in many industries and they have three phase stator and rotor windings. The stator windings are supplied with balanced three phase ac voltages, which produce induced voltages in the rotor windings due to transformer action. It is possible to arrange the distribution of stator windings so that there is an effect of multiple poles, producing several cycles of magneto motive force (mmf) around the air gap. This field establishes a spatially distributed sinusoidal flux density in the air gap.

In this paper three phase induction motor as a load. The equivalent circuit for one phase of the rotor is shown in figure. 10(a).

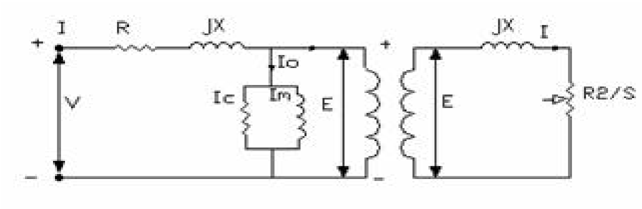

Fig. 10 (a). Steady state Equivalent circuit of an induction motor

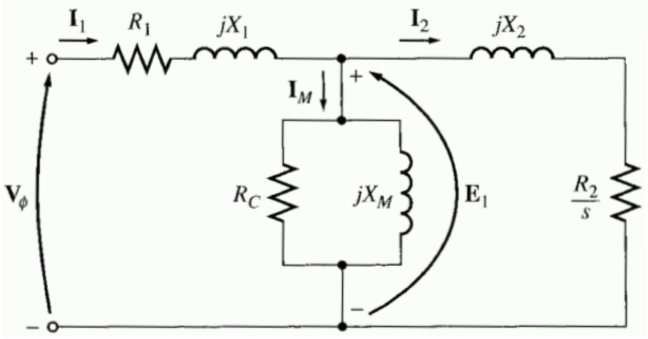

Fig.10 (b). Equivalent circuit refer to stator

The rotor current is

$$I_r = \frac{sE_r}{R_r + jX_r} \ldots\ldots\ldots (4)$$

$$= \frac{E_r}{\frac{R_r}{s} + jX} \ldots\ldots\ldots\ldots (5)$$

The complete circuit model with all parameters referred to the stator is in figure. Where R_s and X_s are the per phase resistance and leakage reactance of the stator winding. X_m represents the magnetizing reactance. R'_r and X'_r are the rotor resistance and reactance referred to the stator. I'_r is the rotor current referred to the stator. There will be stator core loss, when the supply is connected and the rotor core loss depends on the slip.

V. PROPOSED CIRCUIT:

The proposed prototype consists of three phase five level inverter interfaced with a PV module is as shown in the fig.11.This paper deals with a asymmetrical inverter so that the use of virtual DC with that the method of using a singled source the required five level output is achieved The combination of multi level inverter with a single DC source and PV arrays will reduce the initial cost of the circuit and also maintenance cost of the circuit

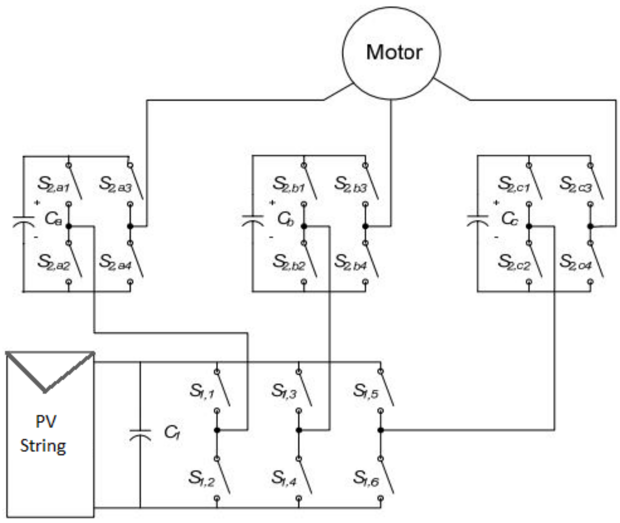

Fig.11 proposed circuit with PV array

An asynchronous motor is connected to the circuit as load. And the performance characteristics are obtained for the connected motor.

VI. SIMULATION RESULTS

A single phase five level inverter with single DC source simulated and as shown in fig.12. and corresponding five level output with the use of a single DC source shown in fig.13.Similarly three phase five level inverter simulated as shown in figure.14. and corresponding the three phase line to ground voltages separately shown in fig.15.The proposed PV module is shown in the figure 16 .It is worth mentioning that the output voltage of the PV string arrays should be chosen based on the grid nominal voltage and the minimum desired operating power of each cell. If the power generated by all strings is equal, the output voltage of all cells will be equal..A PV Array contains six series-connected 100-V 1000-Wp PV panels Simulations have been carried out in MATLAB–Simulink

A three phase asynchronous motor is connected to the proposed circuit shown in fig 17. The circuit is simulated to show the performance characteristics of motor. Fig.18 Shows the stator currents, all the values are variable in nature up to 0.8 sec and then rated stator current are become stable in nature. The rotor currents of an asynchronous motor had shown in fig.19 the frequency of stator currents generally much higher than to the rotor currents. The speed of rotor is nearly 152.2rad/sec as per the results of speed-time curve, shown in fig.20.The torque of motor was calculated by using the equations [7] & [8] and the calculated torque will be equal to the obtained torque during simulation as shown in fig.21

$$S = \frac{N_S - N}{N_S} \ldots\ldots\ldots (7)$$

$$T = \frac{V_2^2 * SR_2}{\sqrt{R_2^2 + (SX_2)^2}} \ldots\ldots\ldots (8)$$

The THD of inverter output voltage and Harmonic spectrum of the simulation system is as shown in the fig. 22 which shows the results are well within the specified limits of IEEE standards. The experimental and simulated results are show satisfactory results in term of total harmonic distortion and output voltage and current waveform shapes To verify the validity of the proposed Hybrid Five level inverter fed induction motor drive The results of both output voltage and FFT analysis are verified by simulating the main circuit using MATLAB

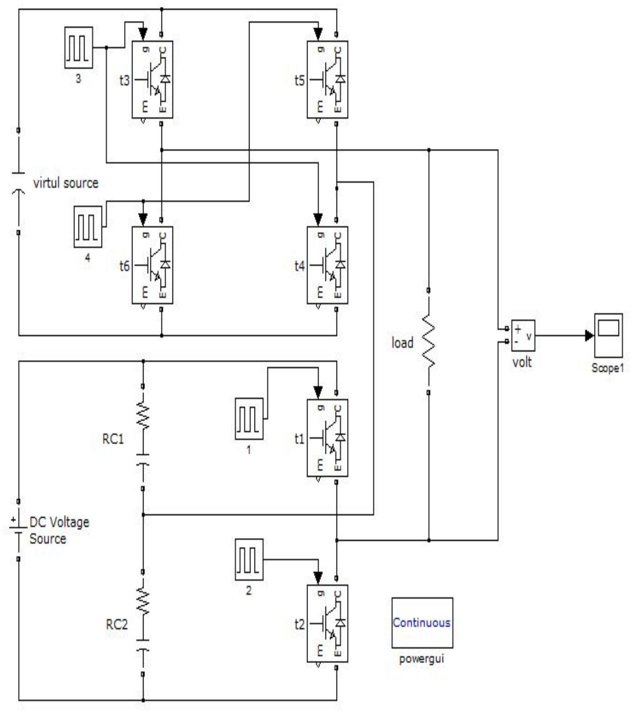

Fig.12 single phase five level inverter with a single DC source

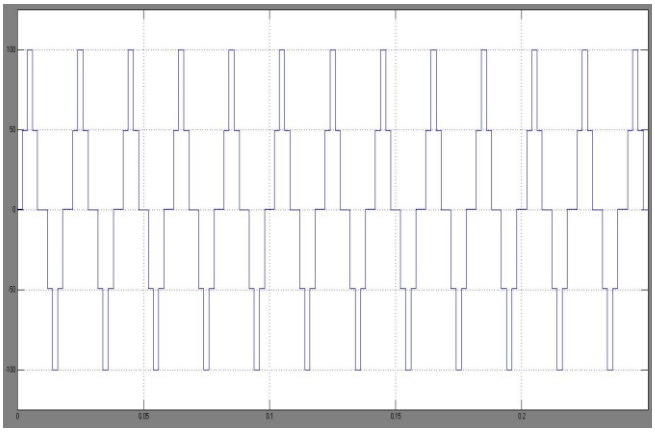

Fig.13 Five Level Inverter output Voltage with a single DC source.

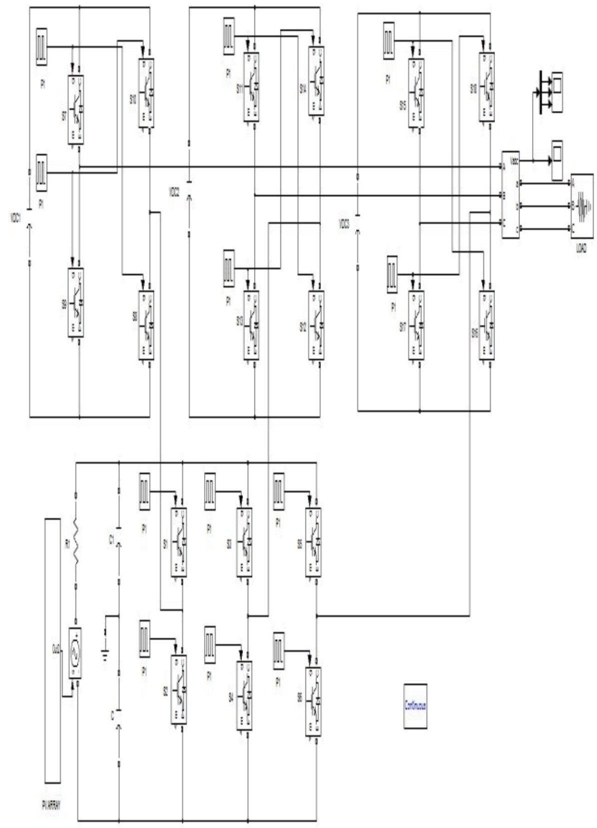

Fig. 17: Schematic of proposed of three phase Five level Inverter

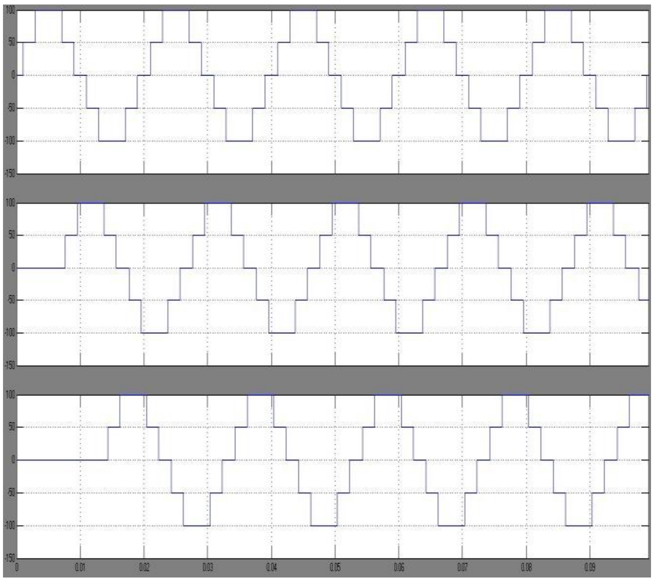

Fig.15. Three phase Line to ground voltage

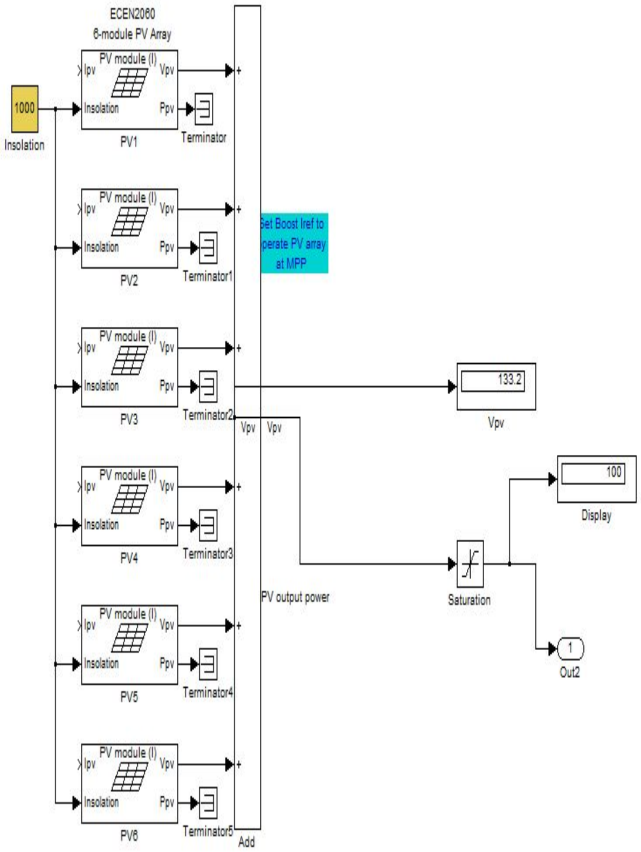

Fig.16: PV array module

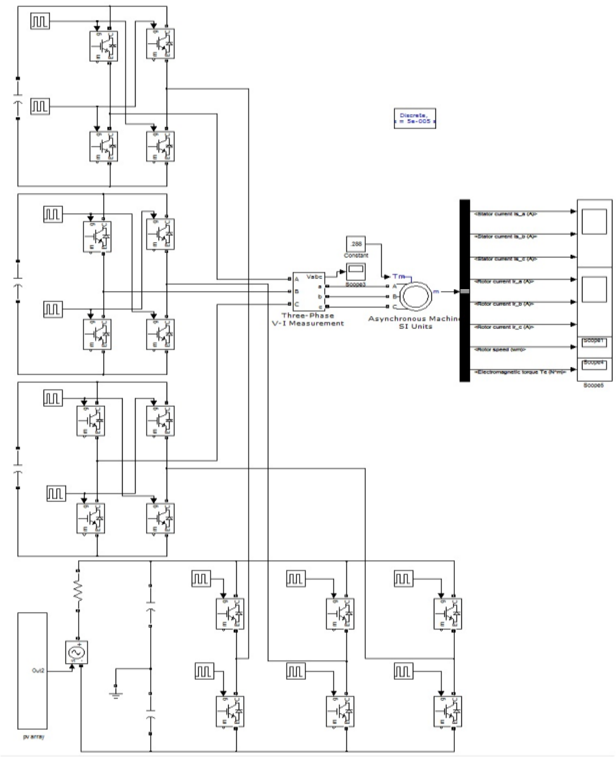

Fig.17 .Schematic of proposed Prototype

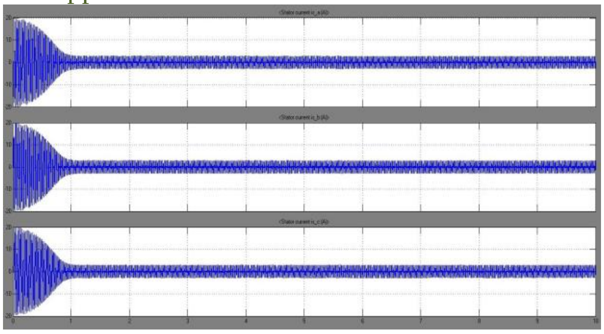

Fig.18 stator currents of asynchronous motor

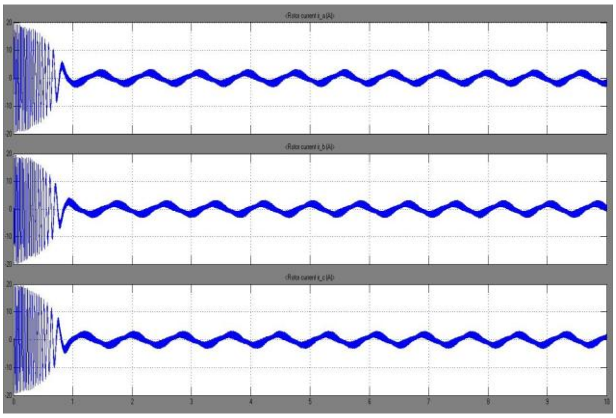

Fig.19 rotor currents of asynchronous motor

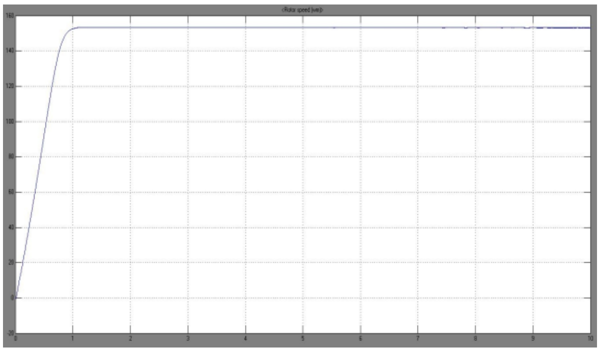

Fig.20 speed- time curve

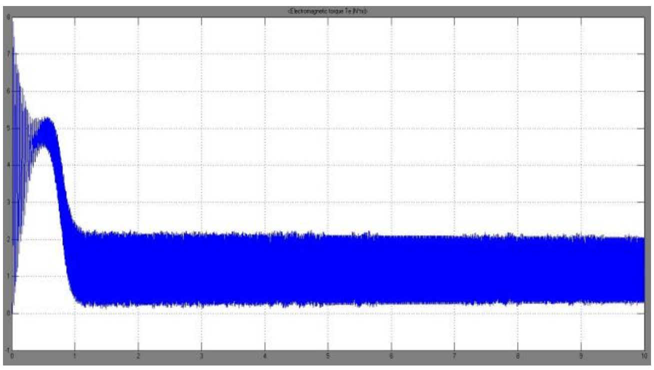

Fig.21 torque with respect to time

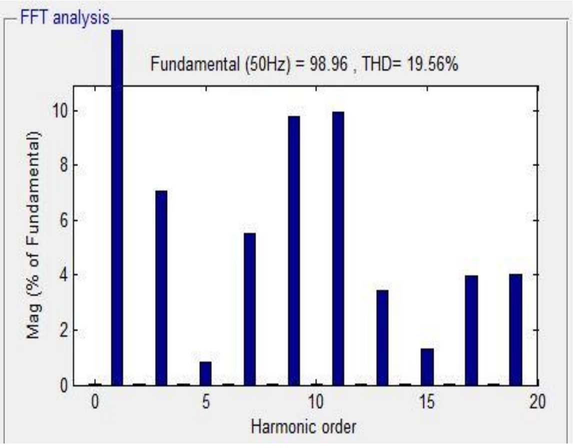

Fig. 22. FFT analysis

VII. CONCLUSION

This paper presented an Three phase five-level cascade H-bridge Inverter, which uses single DC source and PV system as DC source and connected to three phase induction motor is used as load to observe the performance characteristics of the motor. The proposed Multilevel Inverter fed Induction Motor FFT Analysis THD value is 19.56 voltage of 98..2 V. The method can be easily extended to an m-level inverter. The cascaded inverter is subjected to other modulation scheme. Simulations have been carried out in MATLAB–Simulink to study the performance of the proposed prototype

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