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Three Phase Five Level Inverter with SPWM fed from Hybrid Renewable Energy Based Induction Motor Drive

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ABSTRACT

This paper describe the control of a multilevel inverter fed with an Induction motor supplied by a Photovoltaic (PV) panel and wind energy based hybrid generation smart grid. With the increase in number of levels the power quality of multilevel inverter signal may depends. However, during this paper solve the problem of how many number of levels necessary to increase for harmonic reduction. Thus a new push pull converter which is two switch topology will do justice by giving a high power throughout. Three, three level and five-level converters are studied. The harmonics content of the output signals are analyzed. A simplified Pulse Width Modulation (SPWM) technique for a multilevel inverter that supplied an induction motor is developed. The controller equations are such that the SPWM pulses are generated automatically for any number of levels. The Induction Motors are the AC motors and hence from converter, an inverter system is also required to obtain an AC voltage. This inverter is chosen based on its advantages and it is fed to induction motor. In order to maximize the power output the system components of the Hybrid (PV and WIND) system should be optimized. The proposed system performance can be improved by five level inverter and is implemented MATLAB/ SIMULINK software for performance of Induction Motor.

KEYWORDS: *Photovoltaic; Power Electronics; DC-DC Push-Pull Converter; SPWM; Three-Phase Inverter; Induction Motor.*

I. INTRODUCTION

Multilevel inverters have been gained more attention for high power application in recent years which can operate at high switching frequencies while producing lower order harmonic components [1]. 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. There are several topologies such as diode clamped multilevel inverter or neutral point clamped inverter, flying capacitor based multilevel inverter, and cascaded multilevel inverter [2]. The main disadvantage still exists in diode clamped multilevel inverter topology, which restricts the use of it to the high power range of operation. Moreover flying capacitor based multilevel inverter also exhibits a disadvantage including more number of capacitors [3]. The first topology introduced is the series H-bridge design, in which several configurations have been obtained. This topology consists of series power conversion cells which form cascaded H- bridge multilevel inverter and power levels will be scaled easily. An apparent disadvantage of this topology is large number of controlled switches.

Two level inverter output has high harmonic distortion content and cannot be used for high power applications and drive systems. Multi level inverters can be used to replace the two level inverters. For a particular switching frequency, compared with a two level inverter, the harmonic content is less in case of MLI [4,5].Multi Level Inverter topologies have been widely used in the drives industry to run induction machines for high power configurations. Three major topologies are available for MLI namely: Cascaded H Bridge, Diode clamped, Flying Capacitor. The Cascaded H Bridge MLI is probably the only kind of multi level inverter wherein the inputs can be individual isolated energy sources (capacitors, batteries, PV arrays, etc) and is best suited for renewable energy systems.

The main advantage of multilevel inverters is that the output voltage can be generated with a low harmonics. Thus it is admitted that the harmonics decrease proportionately to the inverter level. For these reasons, the multilevel inverters are preferred for high power applications [6]. However, there is no shortage of disadvantages. Their control is much more complex and the techniques are still not widely used in industry. In this paper, modeling and simulation of a multilevel inverter using Neutral Point-Clamped (NPC) inverters have been performed with motor load using Simulink/ MATLAB program. In the first section multilevel inverter control strategies are presented before to detail a study of seven-level inverter in the second section. Total Harmonic Distortion (THD) is discussed in the third section. The aim is to highlight the limit at which the multilevel inverters are no longer effective in reducing output voltage harmonics [7, 8].

II. METHODOLOGY

A.Photovoltaic Panel

PV array is a p-n junction semiconductor, used to convert sunlight into electrical energy. When the incoming solar energy exceeds the band-gap energy of the module, photons are absorbed by materials to produce electricity. The cells in the PV array are tied in series or parallel and the electrical power of the PV array depends upon the solar irradiance, panel temperature and the operating current and voltage relationship. The current voltage relationship, which is the I-V characteristic of the PV array is a complex and non-linear function. The following exponential model is used to describe and predict the behavior of our proposed photovoltaic module. According to this model, maximum power, P_{max} equals [8]:

$$P_{\max} = \frac{V_{op} * I_{sc}}{1-\exp\left(-1/b\right)} * \left[1-\exp\left(\frac{V_{op}}{b.V_{oc}} - \frac{1}{b}\right)\right] \tag{1}$$

$$b \cong \frac{\left(\frac{V_{op}}{V_{oc}} - 1\right)}{\ln\left[1 - \frac{P_{\max}}{V_{op} * I_{sc}}\right]} \tag{2}$$

$$R_{op} = \frac{V_{op} - V_{op} * \exp\left(\frac{-1}{b}\right)}{I_{sc} - I_{sc} * \exp\left(\frac{V}{b.V_{oc}} - \frac{1}{b}\right)} \tag{3}$$

Where I_{SC} is the short circuit current, V_{OC} is the open circuit voltage, I_{OP} is the optimal current and I_{OP} is the optimal voltage. Solving equation (1) for b and taking into account that b is very small; b can be estimated by equation (2). This value is distinct and unique for every solar panel and does not fluctuate with changes in irradiance and solar cell temperature. Thus for a particular irradiance level and cell temperature, if $I_{SC,}$ $V_{OC,}$ I_{OP} and V_{op} are found for a given solar panel, the value of b can be achieved. By using the value of b in the exponential model, an accurate representation of the voltage and current characteristics of the panel can be obtained. Using the value of b, the optimal resistance R_{op} can also be found, which is the load resistance at which the photovoltaic panel transfers P_{max} to the load.

B. Maximum Power Point Tracking (MPPT)

Maximum Power Point Tracking (MPPT) is very important in solar power system because it minimizes the solar array cost by decreasing the number of solar modules required to achieve the desired output power. MPPT is a device that looks for the maximum power point of a source and keeps it operating in that point. Since, the PV is not always operating in its maximum power point, but with the use of an MPPT it is possible to force the PV to extract the maximum power at the given irradiance level. We used P&O MPPT algorithm due to its simplicity and easy of implementation [2]. This technique is easily implemented by an algorithm using the power-voltage characteristics of the PV module. Knowing that at the right and the left of the maximum power point the power decrease, the converters duty cycle is changed depending on the last change in power and if the duty cycle was increased or decreased. To implement the P&O the power needs to be read at a time U, afterwards the voltage is changed. Next the power in time U+ I is read, if this power is incrementing we increment the duty ratio and by consequence the voltage in the PV. In the case that the power in the U+1 is lower than in the U time we decrement the duty ratio and by consequence the voltage. This technique operates in the boundaries of the MPP. The MPPT algorithm developed for this application is responsible for deploying the necessary adjustment in the Push-Pull Converter's duty cycle so that the optimum voltage is achieved, thus allowing maximum power delivery to the load [3]. Fig. 1 shows the P&O, MPPT algorithm varying the push-pull converter duty cycle to obtain the maximum power delivered by PV panel.

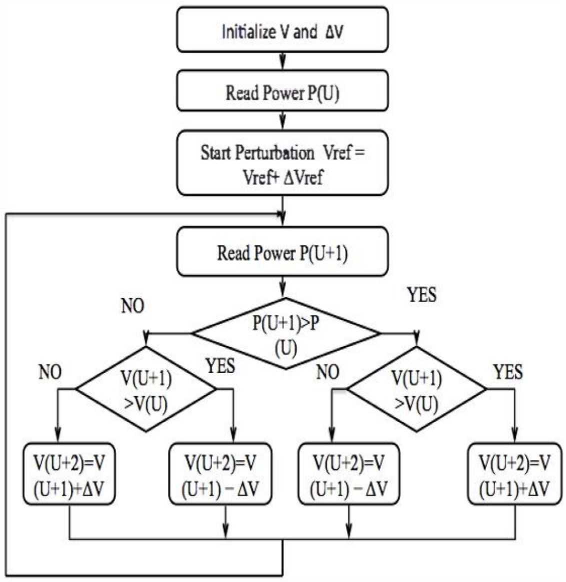

Fig.1 MPPT, P&O algorithm flow chart.

C. *Wind Energy Based System*

Wind is abundant almost in any part of the world. Its existence in nature caused by uneven heating on the surface of the earth as well as the earth's rotation means that the wind resources will always be available. The conventional ways of generating electricity using non renewable resources such as coal, natural gas, oil and so on, have great impacts on the environment as it contributes vast quantities of carbon dioxide to the earth's atmosphere which in turn will cause the temperature of the earth's surface to increase, known as the green house effect. Hence, with the advances in science and technology, ways of generating electricity using renewable energy resources such as the wind are developed. Nowadays, the cost of wind power that is connected to the grid is as cheap as the cost of generating electricity using coal and oil. Thus, the increasing popularity of green electricity means the demand of electricity produced by using non renewable energy is also increased accordingly.

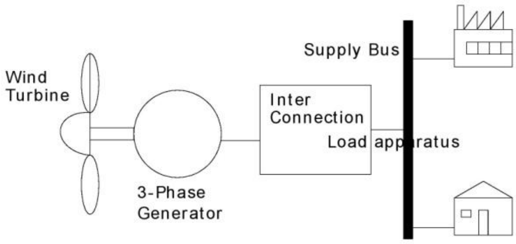

Fig.1.1. Structure of a typical wind energy system.

The major components of a typical wind energy conversion system include a wind turbine, generator, interconnection apparatus and control systems, as shown in Figure 6. Wind turbines can be classified into the vertical axis type and the horizontal axis type. Most modern wind turbines use a horizontal axis configuration with two or three blades, operating either down-wind or up-wind. A wind tur-bine can be designed for a constant speed or variable speed operation generator is coupled to the rotor of a wind turbine directly, offers high reliability, low maintenance, and possibly low cost for certain turbines , power electronic converters to provide a fixed frequency and fixed voltage power to their loads.

D. *DC-DC Push-Pull Converter*

To achieve maximum power point tracking of the photovoltaic panel, the DC-DC push-pull converter topology is implemented in this project [3]. Switch mode DC-DC converters efficiently convert an un-regulated DC input voltage into regulated DC output voltages. Compared to linear power supply, switching power supply offers much more efficiency and power density. Switching power supply includes solid-state devices such as transistors and diodes to operate as a switch: either completely turn-on or completely turn-off. The basic push-pull converters consist of inductors, capacitors, diodes, transistors and transformer to step-up or step-down a voltage input. The Fig. 2 shows the push-pull converter circuit. When designing a push-pull converter, it is convenient to select the transformer turns ratio n such that duty cycle D does not vary in wide range [4]. At the same time, high values for n should be avoided to ensure that the SPWM voltage inverter operates with low modulation index. The push-pull input voltage is the MPPT panel array voltage. Thus given the motor output power, it is possible to numerically search the push-pull input voltage. The push-pull output voltage (E) depends on the input voltage (V), the duty cycle (D), and the high frequency transformer turns ratio (n), [5],

$$E = \frac{n}{1-D} V \tag{4}$$

$$D = \frac{t_{on}}{T} \tag{5}$$

Where, D defines the duty cycle and ton corresponds to the total time interval when both switches conduct (ton= D7). Thus, our design we implemented a DC-DC push-pull converter, that successfully steps-up PV arrays 24V DC output voltage into 312V DC in case of steady environmental condition.

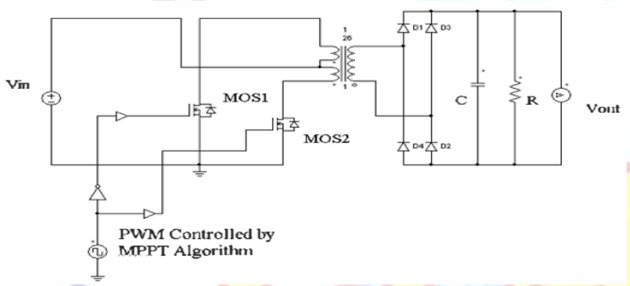

Fig.2. Push-Pull Converter Circuit

E. Sinusoidal Pulse Width Modulation (SPWM)

PWM technique is most commonly used in conventional inverter switching, which suffers from various drawbacks such as low fundamental output voltage, higher THD level and contains excessive amount of harmonics at inverter output waveform. However, an alternatives modulation technique such as SPWM is used in order to mitigate this problem. In SPWM switching control, for three-phase inverter; three sinusoidal modulation signals (called as reference signals) of 50Hz are generated that are delayed by 120 degree with respect to each other [6]. Then it is compared with high frequency triangular wave in order to get the resulting switching gate pulses for inverter MOSFET switch [7]. Fig. 4 shows the schematic diagram of SPWM control circuit. However, the two key factors that influence the performance of the three-phase inverter, one of them is modulation index Ma that is defined by the ratio between reference signal (sine wave), Vref and the carrier signal (triangular wave), Vcarrier and another one is frequency modulation, Ma defined by the ratio between the frequency of carrier signal and reference signal.

Thus, these two terms are also described by following mathematical equations,

$$M_a = \frac{V_{ref}}{V_{carrier}} \tag{6}$$

$$M_f = \frac{f_{triangular}}{f_{ref}} \tag{7}$$

The value of Ma is important to find output voltage of inverter though theoretically if Ma decreases inverter AC voltage increases. From equation (6) Ma should be less than 1, in order to achieving high voltage gain with fewer harmonics content at inverter output. So filter design is easy if Ma is in between 0.9 and 1. For Ma greater than 1, the harmonics will decrease and this condition is known as over modulation. Fig.5 shows the reference signal of each phase with the carrier signal.

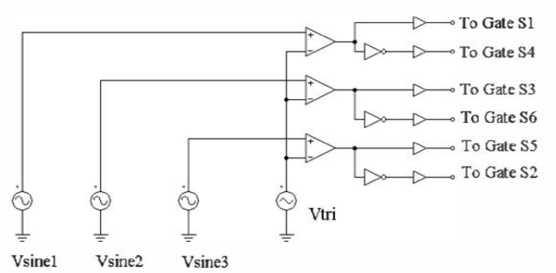

Fig.3. Control circuit of SPWM technique.

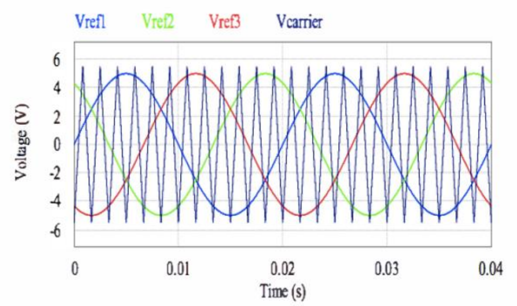

Fig.4.Carrier signal vs. reference voltage.

F.DC-AC Three-Phase Inverter

Inverter is a device used to convert direct current to alternate current. By using proper switching and control technique the alternate current can be any required voltage or frequency. The three-phase inverter is commonly used to transform direct current to alternate current in high power application. This inverter consists of three half-bridge units; the upper and lower switches are controlled complementarily, which means that when the upper one is turned on, the lower one must be turned off and vice versa [6]. Gating signals are delayed by 120 degrees with respect to each other for three phase inverters. A common type of control signals (SPWM) used to switch the six transistors in three-phase inverter is the ISO-degree conduction mode. In a cycle six modes of operation exist and each has duration of 60 degrees. Each gate signal is shifted by 120 degrees between each phase and respective complementary signals. Thus as a result the three phase voltages lag by 120 degrees. However, the output of an inverter, when it is not connected to a transformer, is a square waveform due to the on/off states of the switches. Later it is converted to sine waveform by employing low pass LC filter.

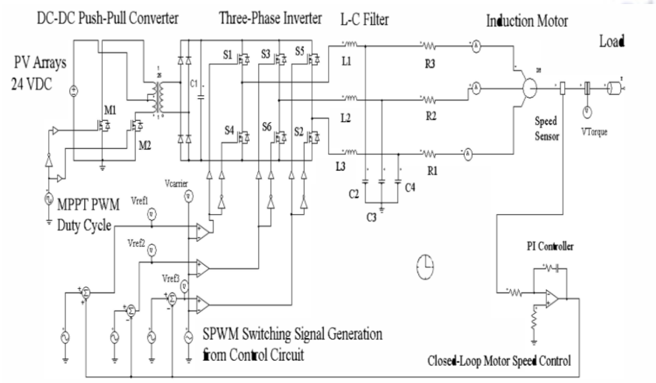

Fig.5. Complete schematic diagram of proposed design in PSIM.

III. INDUCTION MOTOR (IM)

An induction motor is an example of asynchronous AC machine, which consists of a stator and a rotor. This motor is widely used because of its strong features and reasonable cost. A sinusoidal voltage is applied to the stator, in the induction motor, which results in an induced electromagnetic field. A current in the rotor is induced due to this field, which creates another field that tries to align with the stator field, causing the rotor to spin. A slip is created between these fields, when a load is applied to the motor. Compared to the synchronous speed, the rotor speed decreases, at higher slip values. The frequency of the stator voltage controls the synchronous speed. The frequency of the voltage is applied to the stator through power electronic devices, which allows the control of the speed of the motor. The research is using techniques, which implement a constant voltage to frequency ratio. Finally, the torque begins to fall when the motor reaches the synchronous speed. Thus, induction motor synchronous speed is defined by following equation,

$$n_s = \frac{120 f}{P} \tag{8}$$

Where f is the frequency of AC supply, n, is the speed of rotor; p is the number of poles per phase of the motor. By varying the frequency of control circuit through AC supply, the rotor speed will change.

A. Control Strategy of Induction Motor

Power electronics interface such as three-phase SPWM inverter using constant closed loop Volts l Hertz control scheme is used to control the motor. According to the desired output speed, the amplitude and frequency of the reference (sinusoidal) signals will change. In order to maintain constant magnetic flux in the motor, the ratio of the voltage amplitude to voltage frequency will be kept constant. Hence a closed loop Proportional Integral (PI) controller is implemented to regulate the motor speed to the desired set point. The closed loop speed control is characterized by the measurement of the actual motor speed, which is compared to the reference speed while the error signal is generated. The magnitude and polarity of the error signal correspond to the difference between the actual and required speed. The PI controller generates the corrected motor stator frequency to compensate for the error, based on the speed error.

IV. MULTILEVEL INVERTER

Fig.6.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.

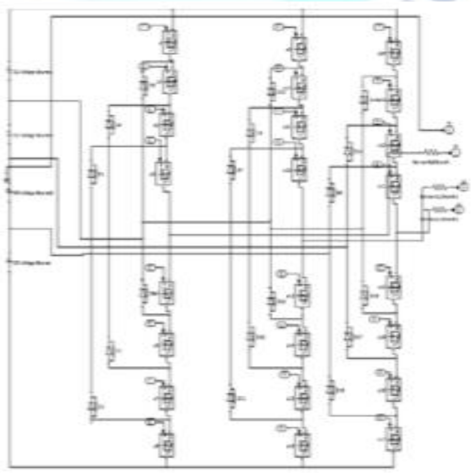

Figure.6. Five level diode clamped multilevel inverter circuit topologies.

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. Switching 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.6. 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. 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.

V.MATLAB/SIMULINK RESULTS

Case 1: Performance of Proposed System by Using SPWM Controller

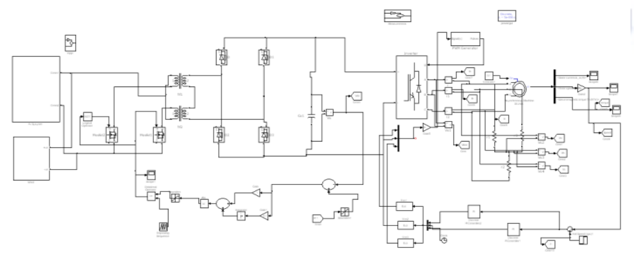

Fig.7.Simlink Circuit for Proposed System by Using PI Controller.

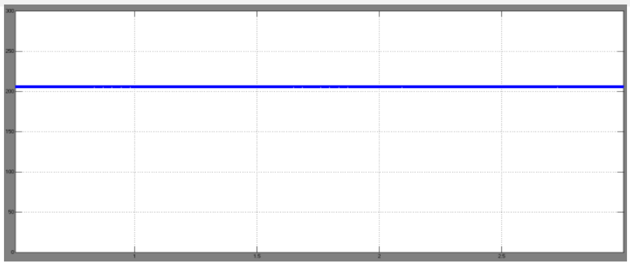

Fig.8.Simulation Result for Output Power of Solar Cell

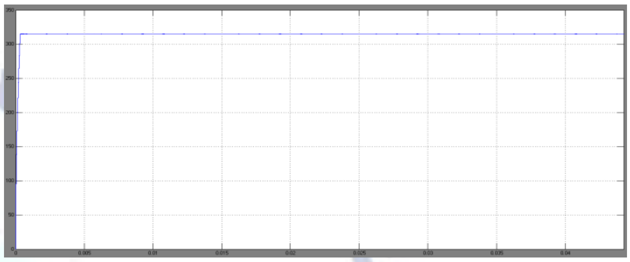

Fig.9.Simulation Result For Output Voltage Of Push-Pull Converter.

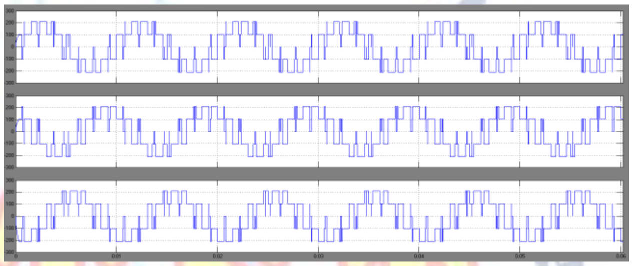

Fig.10.Simulation Result for Three-Phase PWM Output Voltage without Filtering.

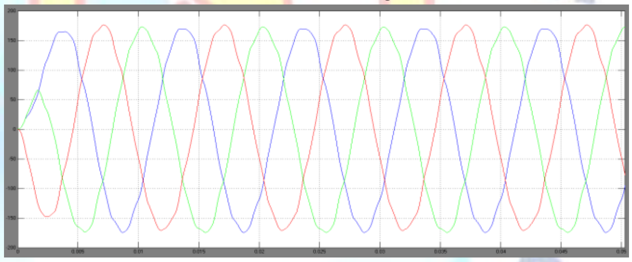

Fig.11.Simulation Result for Inverter Output Voltage.

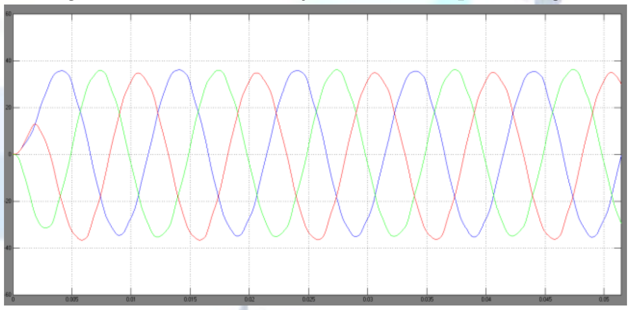

Fig.12.Simulation Result for Inverter Output Current.

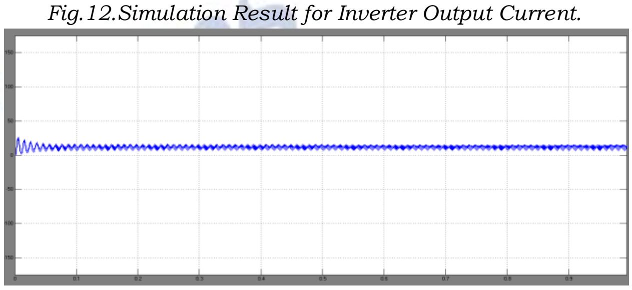

Fig.13.Simulation Result for Electromagnetic Torque of Induction Motor.

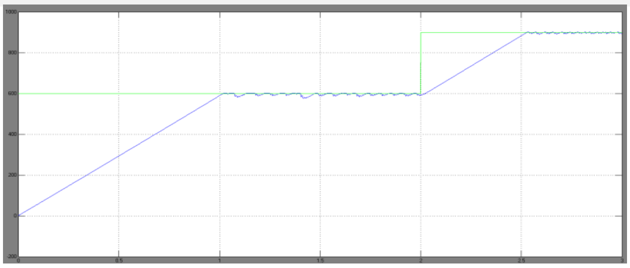

Fig.14.Simulation Result For Actual and Reference Speed of Induction Motor in Closed Loop PI System.

Case 2: Performance of Proposed System by Using SPWM Controller five level inverter.

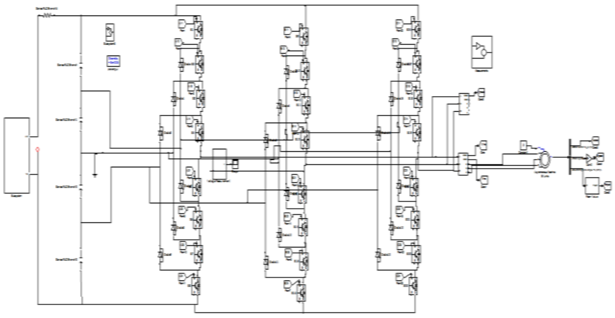

Fig.15.Simulink Circuit for Proposed System by Using SPWM Controller with Five Level Inverter.

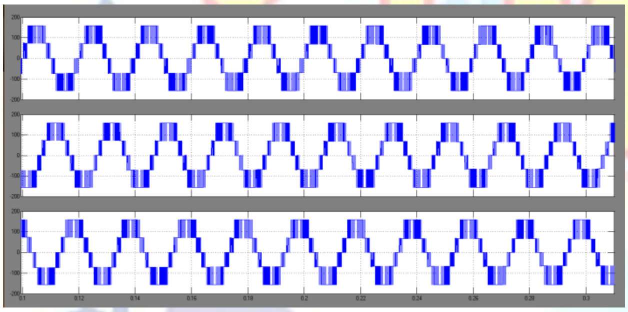

Fig.16.Simulation Result for Three-Phase five level inverter PWM Output Voltage without Filtering.

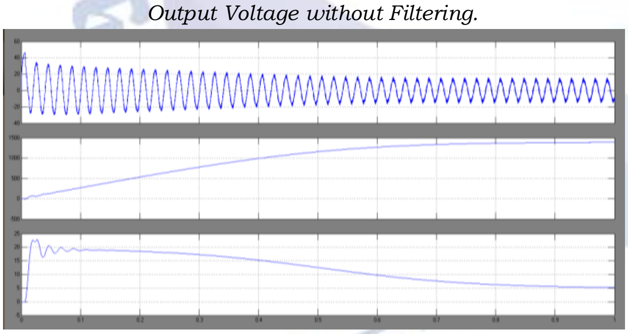

Figure.17. Stator Current, Speed and Torque Waveform of Modified Five Level Inverter Fed Induction Motor Drive.

VI.CONCLUSION

In this paper, a general multilevel SPWM control algorithm for multi level inverter has been modeled and simulated using Matlab/Simulink. This algorithm can generate automatically SPWM pulses for any level of inverter by changing only a parameter n which is the number of inverter level. Simulation of three and five level inverter connected to induction motor has been performed and the generated signals THD are analyzed. Maximum power is extracted effectively from panel using MPPT (P&O) technique with push pull converter. The turn ratio of push-pull transformer offered an additional voltage step-up to reach higher voltages than a single boost converter could. By keeping voltage to frequency ratio constant the speed of the motor is controlled through the three-phase inverter by SPWM technique. Research has to be done to understand the complexity of this work of integrating power electronics converter into the system. This paper might help us to understand the benefits that this kind of research can bring to the worldwide crisis of global warming. The physical fabrication and test of the proposed design is yet to be done and will be implemented in future.

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