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Hybrid Fuzzy Logic Controller Using Photovoltaic Based Push Pull Converter and Three Phase Inverter Fed Induction Motor Drive

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Abstract - in 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 can do justice by giving a high power throughout. The harmonics content of the output signals are analyzed. A sinusoidal Pulse Width Modulation (SPWM) method for a multilevel inverter that supplied an induction motor is developed. This converter has high voltage gain, in addition the input current having its current ripple amplitude halved and minimizes the oscillations at the module operation point. A hybrid Fuzzy Logic Controller (HFLC) is used as a speed control for Induction Motor. A three phase Induction motor connected to Voltage Source Inverter (VSI), which in turn runs the centrifugal pump. The whole system is controlled using Matlab/Simulink environment. The dynamic performances of an Induction Motor (IM) drive is controlled in the presence of fuzzy logic controller, which increases the overall efficiency of the system. The effectiveness of hybrid fuzzy system and energy storage management in water pumping system are demonstrated and implemented.

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

I. INTRODUCTION

The water access either for individual needs in a community, or for irrigation, presents one of the main factors for the development of remote area in developing countries Since the connectivity to the national electric grid presents an expensive investment in such isolated area, the PV pumping system is one of the most economical and efficient ways [1]. Although this solution is applied and commercialized since the last decade, it is still taking a considerable focus in order to reduce the cost and to improve its efficiency, effectiveness and robustness [1, 3]. The use of electrical motor is the most popular solution to convert the electrical energy generated by the PV Generator PVG to a mechanical energy used to train pumps. The use of DC motors was incorporated with the first generation of PV pumping system. In such configuration, the direct connection between PVG and the motor is the main advantage [4]. However, the maintenance issue remains the major drawback. With the development of power electronics, the use of AC Motors was widely deployed. Nevertheless a
DC/AC inverter has to be added to the installation. Comparing to the synchronous motor, the IM presents an attractive and competitive technical choice in such application thanks to its low cost and its performances in terms of reliability, rigidness and robustness [5, 6]. Taking into consideration the high investment on the PV pumping system, an imperative consideration of the optimization of the end to end system have to be taken. Thus, several optimization strategies and algorithms were developed to maximize the ratio of pumped water to generated energy.

The PV pumping systems using AC motors were generally accompanied by an energy system storage. We note that PV pumping systems with a lead acid battery were the subject of many studies [7]. This storage system improves the efficiency of the water pump. In addition, it enhances the stability of the global system while decoupling the dynamics the PVG and the IM. Indeed, through a bidirectional DC-DC converter, the energy balance between the PVG, the battery and the motor is ensured. Furthermore, a constant dc-link peak voltage is guaranteed. However, the use of battery bank implies a lot of drawbacks: 1) an additional installation expensive cost, 2) an additional maintenance effort and cost, 3) a decrease of the overall system lifetime, 4) an environmental impact. These drawbacks have to be considered especially for remote area in developing countries were individual incomes is too low and government and public investment are too limited [8].

The purpose of the actual study is to design an HFLC controller that ensures both the control of dc-link voltage and optimization of IM efficiency. The dc-link voltage is controlled through an energy balance between the PVG, the IM and the capacitor of the dc-bus. The control objective consists on maintaining the dc-bus voltage constant following any change of the transited power. The

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IM efficiency is improved by a fuzzy control of the speed level in case of sensor less.

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]:

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

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

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

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.

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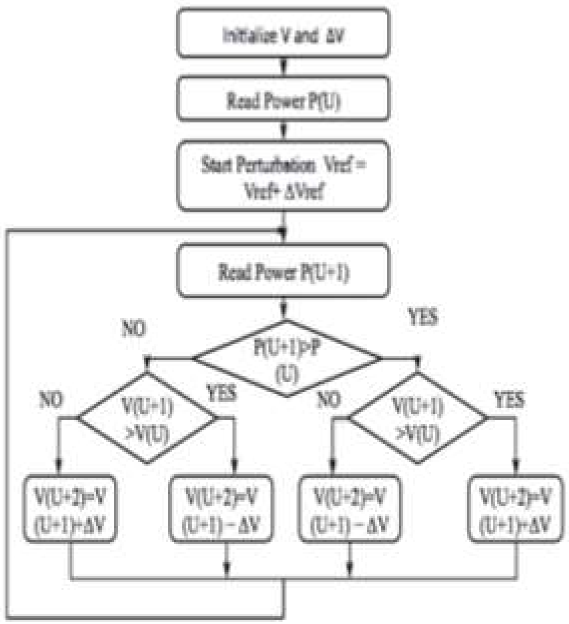

Fig.1.MPPT, P&O algorithm flow chart.

C. 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],

$$E = \frac{n}{1-D} V \quad (4)$$

$$D = \frac{t_{on}}{T} \quad (5)$$

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.

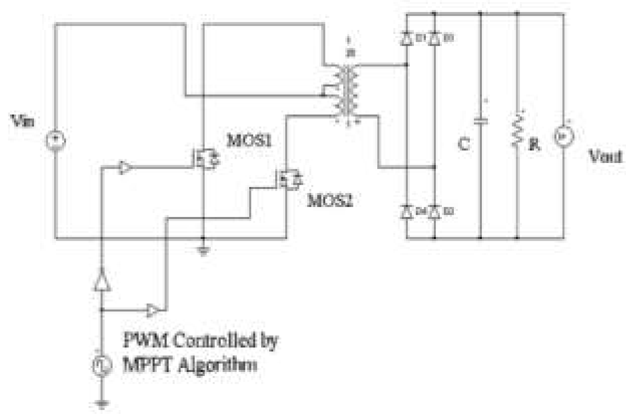

Fig.2. Push-Pull Converter Circuit

D. 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,

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

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

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.

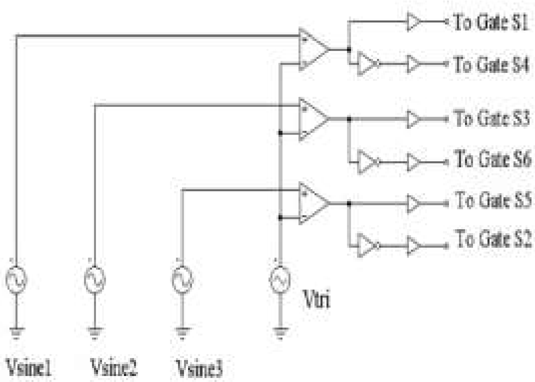

Fig.3. Control circuit of SPWM technique.

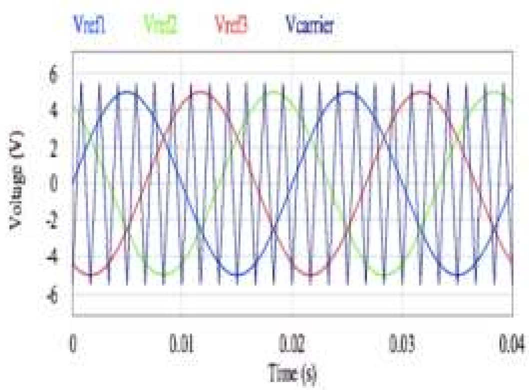

Fig.4.Carrier signal vs. reference voltage.

E.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.

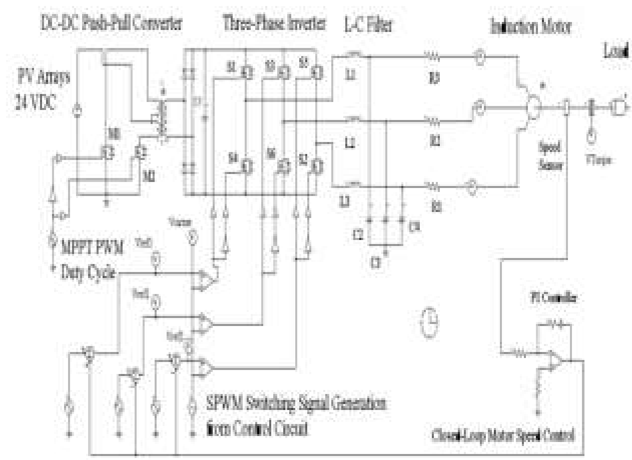

Fig.5. Complete schematic diagram of proposed design in PSIM.

III. INDUCTION MOTOR

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,

$$n_s = \frac{120f}{P} \quad (8)$$

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.HYBRID FUZZY CONTROLLER

The objective of the hybrid controller is to utilize the best attributes of the PI and fuzzy logic controllers to provide a controller which will produce better response than either the PI or the fuzzy controller. There are two major differences between the tracking ability of the conventional PI controller and the fuzzy logic controller. Both the PI and fuzzy controller produce reasonably good tracking for steady-state or slowly varying operating conditions. However, when there is a step change in any of the operating conditions, such as may occur in the set point or load, the PI controller tends to exhibit some overshoot or oscillations. The fuzzy controller reduces both the overshoot and extent of oscillations under the same operating conditions. Although the fuzzy controller has a slower response by itself, it reduces both the overshoot and extent of oscillations under the same operating conditions. The desire is that, by combining the two controllers, one can get the quick response of the PI controller while eliminating the overshoot possibly associated with it. Switching Control Strategy the switching between the two controllers needs a reliable basis for determining which controller would be more effective. The answer could be derived by looking at the advantages of each controller. Both controllers yield good responses to steady-state or slowly changing conditions. To take advantage of the rapid response of the PI controller, one needs to keep the system responding under the PI controller for a majority of the time, and use the fuzzy controller only when the system behaviour is oscillatory or tends to overshoot. Thus, after designing the best stand-alone PI and fuzzy controllers, one needs to develop a mechanism for switching from the PI to the fuzzy controllers, based on the following two conditions:

1) Switch when oscillations are detected;
2) Switch when overshoot is detected.

The switching strategy is then simply based on the following conditions: IF the system has an oscillatory behaviour THEN fuzzy controller is activated, Otherwise PI controller is operated. IF the system has an overshoot THEN fuzzy controller is activated, Otherwise PI controller is operated. The system under study is considered as having an overshoot when the error is zero and the rate of change in error is any other value than zero. The system is considered oscillatory when the sum of the absolute values of the error taken over time does not equal the absolute values of the sum of the error over the same period of time. Since the system is expected to overshoot during oscillatory behavior, the only switching criterion that needs to be considered is overshoot. However, in practice, it is more convenient to directly implement the control signal according to the control actions delivered by the controller. Consequently, the fuzzy controller can be designed so that normal behavior (no oscillations or overshoot) results in a null fuzzy action. Accordingly, the switching between the two controllers reduces to using PI if the fuzzy has null value; otherwise, the fuzzy output is used. In particular, the fuzzy controller can be designed so that a normal behavior.

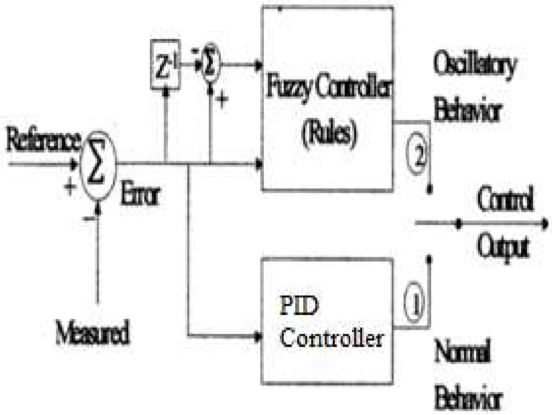

Fig.6. Structure of switching strategy results in a null fuzzy action.

V.MATLAB/SIMULINK RESULTS

Case 1: Performance of Proposed System by Using PI Controller

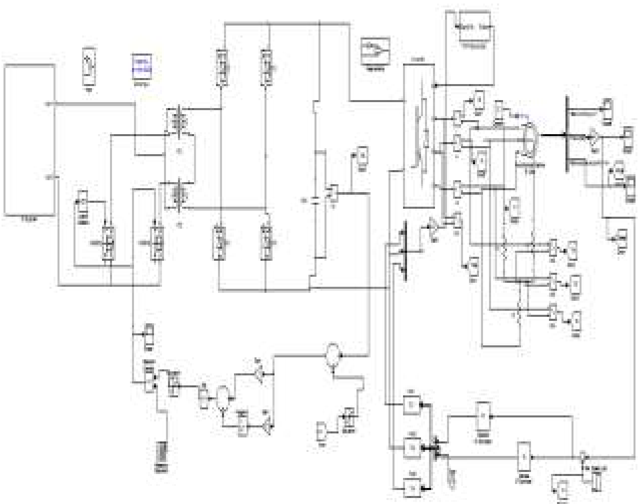

Fig.7.Simlink Circuit for Proposed System by Using PI Controller.

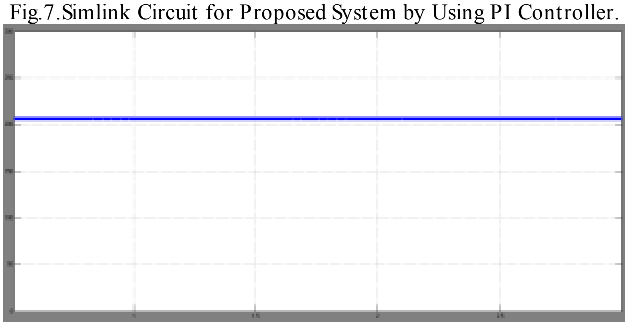

Fig.8.Simulation Result for Output Power of Solar Cell

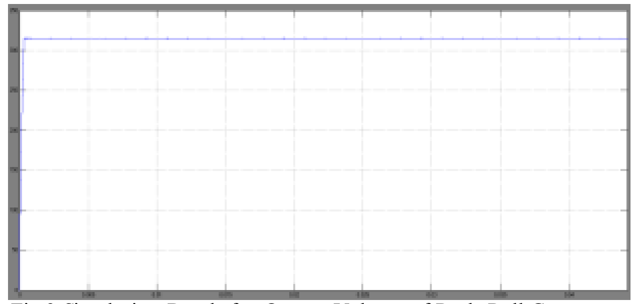

Fig.9.Simulation Result for Output Voltage of Push-Pull Converter.

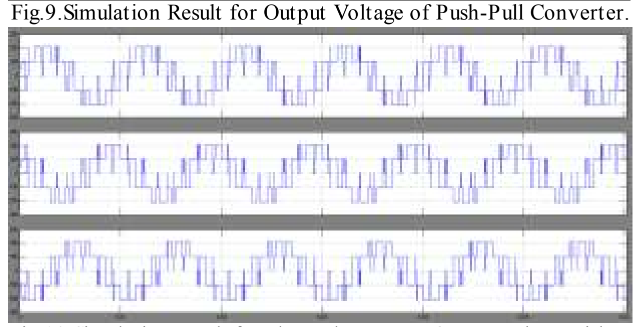

Fig.10.Simulation Result for Three-Phase PWM Output Voltage without Filtering.

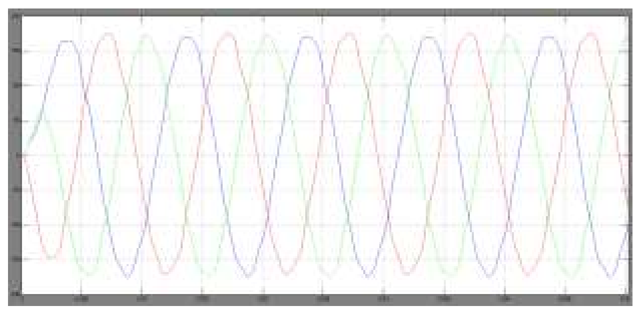

Fig.11.Simulation Result for Inverter Output Voltage with filter.

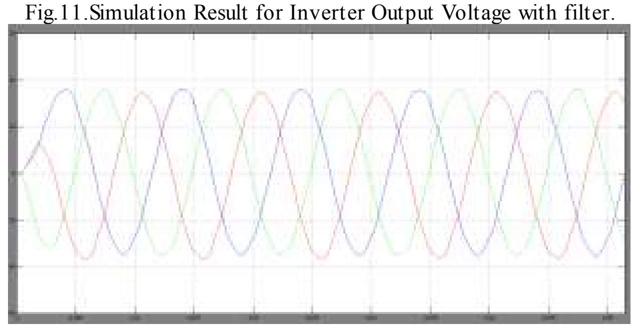

Fig.12.Simulation Result for Inverter Output Current with filter.

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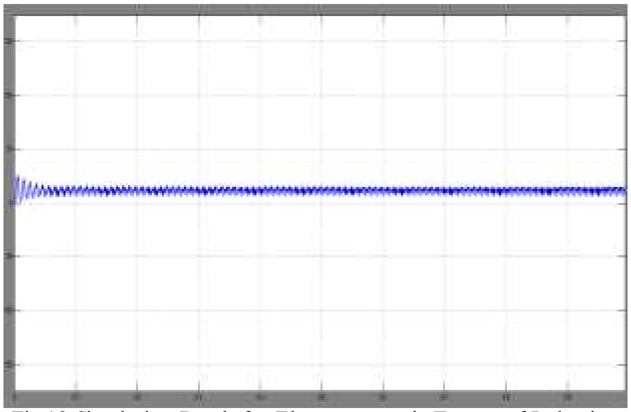

Fig.13.Simulation Result for Electromagnetic Torque of Induction Motor.

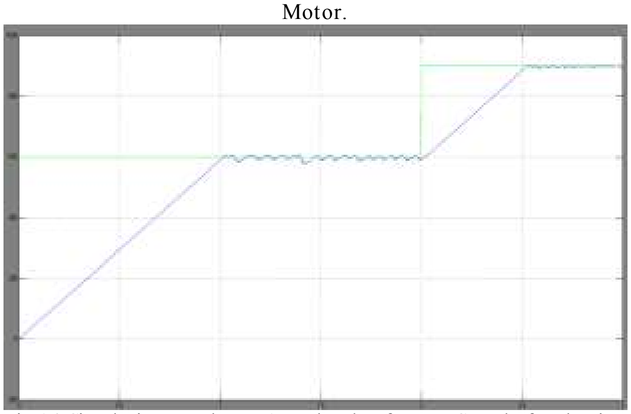

Fig.14.Simulation Result For Actual and Reference Speed of Induction Motor in Closed Loop PI System.

Case 2: Performance of Proposed System by Using Hybrid fuzzy logic (PI+Fuzzy) Controller

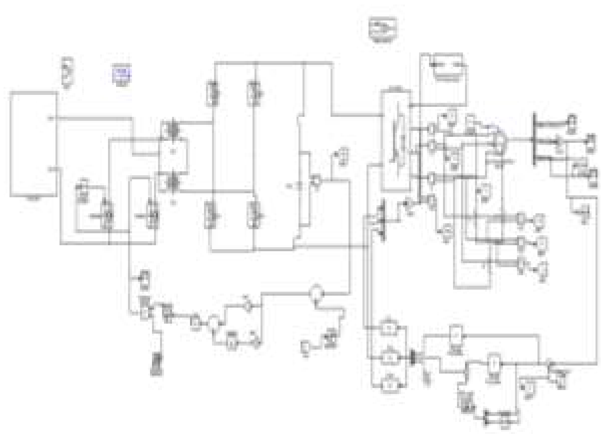

Fig.15.Simulink Circuit for Proposed System by Using PI+ Fuzzy logic Controller.

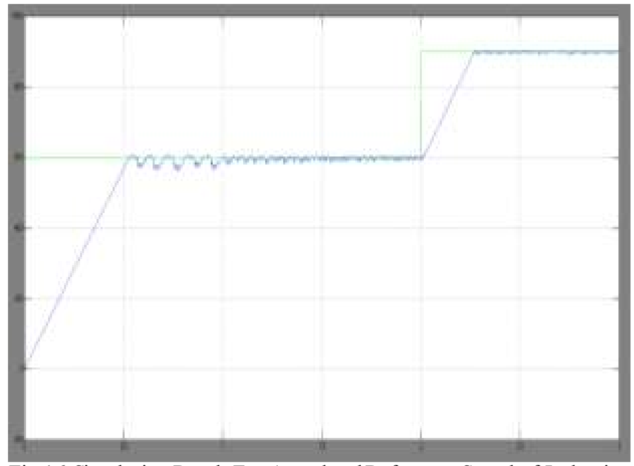

Fig.16.Simulation Result For Actual and Reference Speed of Induction Motor in Closed Loop PI+ Fuzzy System.

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. The converter was designed to drive a three phase induction motor directly from PV solar energy, and was conceived to be a commercially best solution having low cost, high efficiency, and robustness. The simulation results suggest that the proposed solution could be a viable option after more reliability tests are performed to guarantee its robustness. The modified energy storage system with hybrid fuzzy logic controller provides reliable performance and it provides better and quick response than any other controllers. Also, the speed can be controlled through hybrid fuzzy system very efficiently. The physical fabrication and test of the proposed design is yet to be done and will be implemented in future.

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