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Comparison of PI and Fuzzy Controllers for Closed Loop Control of PV Based Induction Motor Drive

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Abstract:

Then performances of both the controller are simulated and compared. For controlling speed here scalar control method is employed, where magnitude of the stator voltage and frequency is changed proportionately. For this V/F control, a reference speed is chosen and controller is designed as such, it can provide that desired (reference) speed in case of frequent load changes. The major merit of Fuzzy controller over PI controller is use of linguistic variable and user defined rule base that makes it possible to incorporate human intelligence in the controller. system is also required to obtain an AC voltage. This inverter is chosen based on its advantages and it is fed to induction motor. To obtain optimum motor performance and to reduce total harmonic distortion of the inverter output waveform, we employed sinusoidal pulse width modulation (SPWM) technique for switching of inverter power circuit. In order to maximize the power output the system components of the photovoltaic system should be optimized. Maximum power point tracking algorithm (Perturb & Observe) is used to extract maximum power from photovoltaic panel. The proposed system performance can be improved by using fuzzy controller and is implemented MATLAB/SIMULINK software for better control of motor.

Keywords:

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

I. INTRODUCTION:

Induction motor has achieved popularity in motoring application due to its low cost, reliability, low maintenance, no brushes to wear out, very simple rotor assembly and no magnets to add to the cost. Squirrel cage induction machine when operated constant line voltage (50Hz) it operates at constant speed. However in industries we have variable speed applications of Induction motors. This can be achieved by Induction motor drives [1]. Main application of Induction Motor drives are Fans, blowers, Compressor, Pumps [2], machine tools like lathe, drilling machine, lifts, and conveyer belts etc. Induction motor is widely used to drive the industrial pump loads. Centrifugal pump are the most common type of kinetic pump, and it is widely used in the field of irrigation and industrial fluid pumping applications. Centrifugal pumps are more economical to operate and require lesser maintenance than other types of pumps. There are several control schemes devised for the control Induction motor both in open loop as well as closed loop vector control of Induction motor is widely accepted control scheme due to its better dynamic response. Vector control scheme is more popular due to its better dynamic performance.Multilevel inverters are suitable for high voltage and high power applications due to their ability to synthesize waveforms with better harmonic spectrum, reduced filter requirements, suitable for renewable and distributed generation system.

Using multilevel technique, the amplitude of the output voltage is increased, switching stress in the devices is reduced and the overall harmonic profile is improved. 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.

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To maximize motor efficiency, a closed loop motor speed control technique is implemented in our system, which controls both the voltage magnitude and voltage frequency [11]. The prime objective of this research is to design and integrate a series of power electronics converters, in order to run an induction machine effectively using the power from a solar photovoltaic panel as cost efficient as possible.

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, Pmax equals [8]:

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

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

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

Where ISC is the short circuit current, VOC is the open circuit voltage, IOP is the optimal current and IOP 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 ISC, VOC, IOP and Vop 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 Rop can also be found, which is the load resistance at which the photovoltaic panel transfers Pmax 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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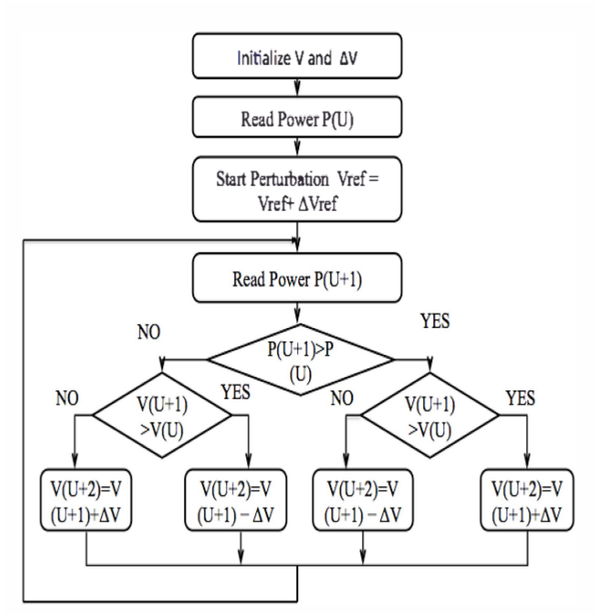

Fig.1 MPPT, P&O algorithm flow chart.

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],

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

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

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.

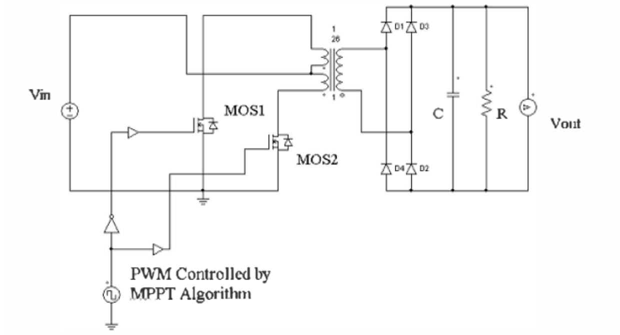

Fig.2. Push-Pull Converter Circuit

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,

$$M_a = \frac{V_{ref}}{V_{carrier}} \qquad (6)$$

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$$M_f = \frac{f_{triangular}}{f_{ref}} \quad (7)$$

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.

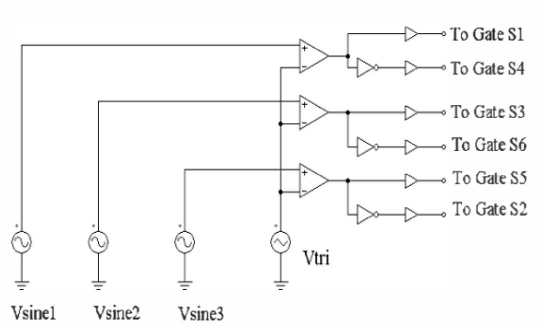

Fig.3. Control circuit of SPWM technique.

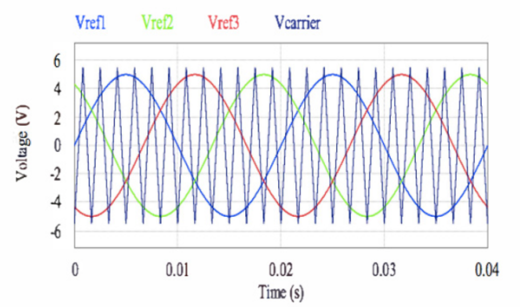

Fig.4.Carrier signal vs. reference voltage.

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..

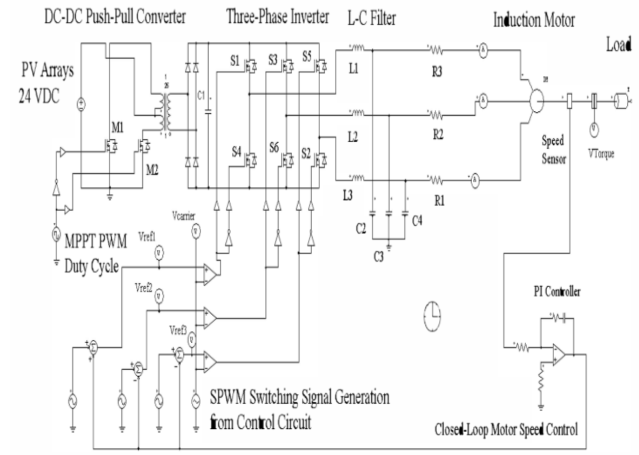

Fig.5. Complete schematic diagram of proposed design in PSIM.

III. INDUCTION MOTOR (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,

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

(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. INTRODUCTION TO FUZZY LOGIC CONTROLLER:

A new language was developed to describe the fuzzy properties of reality, which are very difficult and sometime even impossible to be described using conventional methods. Fuzzy set theory has been widely used in the control area with some application to dc-to-dc converter system. A simple fuzzy logic control is built up by a group of rules based on the human knowledge of system behavior. Matlab/Simulink simulation model is built to study the dynamic behavior of dc-to-dc converter and performance of proposed controllers. Furthermore, design of fuzzy logic controller can provide desirable both small signal and large signal dynamic performance at same time, which is not possible with linear control technique. Thus, fuzzy logic controller has been potential ability to improve the robustness of dc-to-dc converters.

The basic scheme of a fuzzy logic controller is shown in Fig 5 and consists of four principal components such as: a fuzzy fication interface, which converts input data into suitable linguistic values; a knowledge base, which consists of a data base with the necessary linguistic definitions and the control rule set; a decision-making logic which, simulating a human decision process, infer the fuzzy control action from the knowledge of the control rules and linguistic variable definitions; a de-fuzzification interface which yields non fuzzy control action from an inferred fuzzy control action [10].

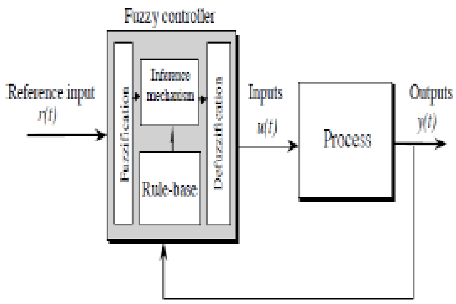

Fig.6. General structure of the fuzzy logic controller on closed-loop system

The fuzzy control systems are based on expert knowledge that converts the human linguistic concepts into an automatic control strategy without any complicated mathematical model [10]. Simulation is performed in buck converter to verify the proposed fuzzy logic controllers.

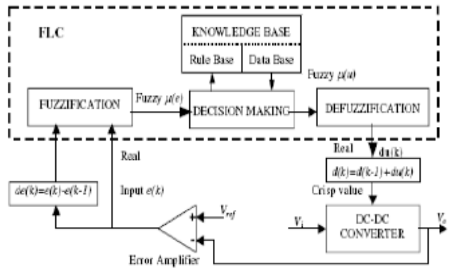

Fig.7. Block diagram of the Fuzzy Logic Controller (FLC) for dc-dc converters

A. Fuzzy Logic Membership Functions :

The dc-dc converter is a nonlinear function of the duty cycle because of the small signal model and its control method was applied to the control of boost converters. Fuzzy controllers do not require an exact mathematical model. Instead, they are designed based on general knowledge of the plant. Fuzzy controllers are designed to adapt to varying operating points.

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Fuzzy Logic Controller is designed to control the output of boost dc-dc converter using Mamdani style fuzzy inference system. Two input variables, error (e) and change of error (de) are used in this fuzzy logic system. The single output variable (u) is duty cycle of PWM output.

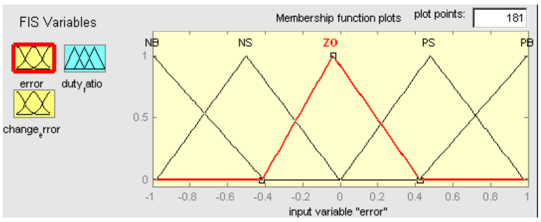

Fig. 8.The Membership Function plots of error.

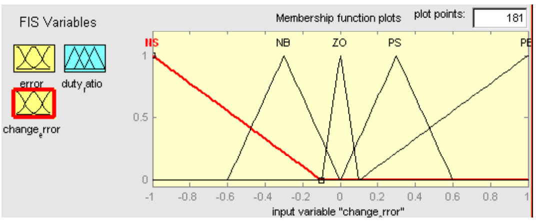

Fig.9. The Membership Function plots of change error.

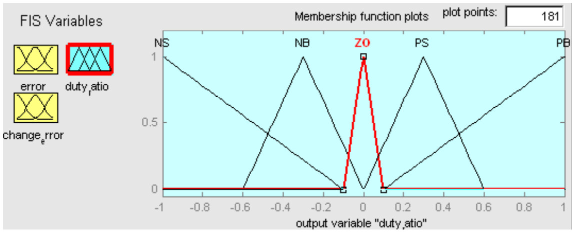

Fig.10. The Membership Function plots of duty ratio

B. Fuzzy Logic Rules:

The objective of this dissertation is to control the output voltage of the boost converter. The error and change of error of the output voltage will be the inputs of fuzzy logic controller. These 2 inputs are divided into five groups; NB: Negative Big, NS: Negative Small, ZO: Zero Area, PS: Positive small and PB: Positive Big and its parameter [10]. These fuzzy control rules for error and change of error can be referred in the table that is shown in Table II as per below:

Table II: Table rules for error and change of error

(de) \ (e)	NB	NS	ZO	PS	PB
NB	NB	NB	NB	NS	ZO
NS	NB	NB	NS	ZO	PS
ZO	NB	NS	ZO	PS	PB
PS	NS	ZO	PS	PB	PB
PB	ZO	PS	PB	PB	PB

V.MATLAB/SIMULINK RESULTS

Case 1: performance of proposed system by using PI controller:

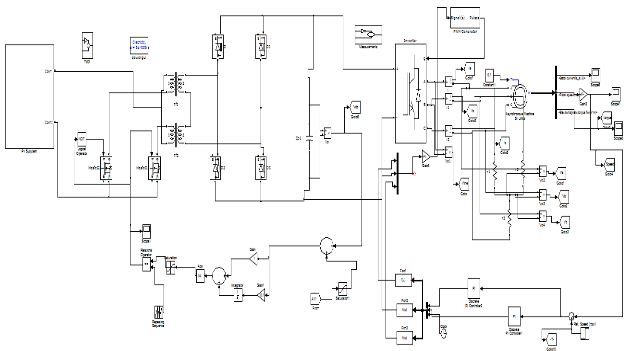

Fig.11.Simlink circuit for proposed system by using PI controller

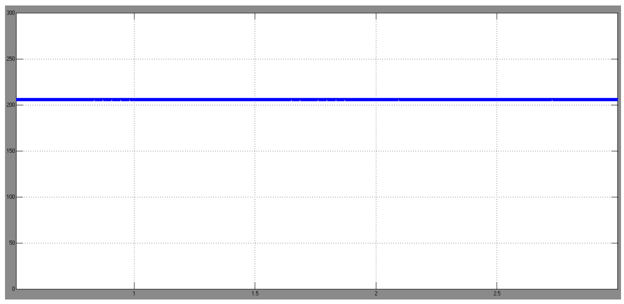

Fig.12.Simulation result for output power of solar cell

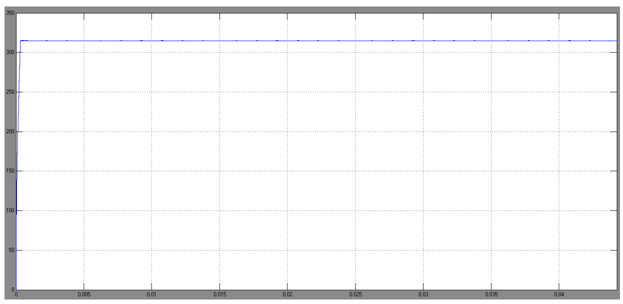

Fig.13.Simulation result for Output voltage of push-pull Converter.

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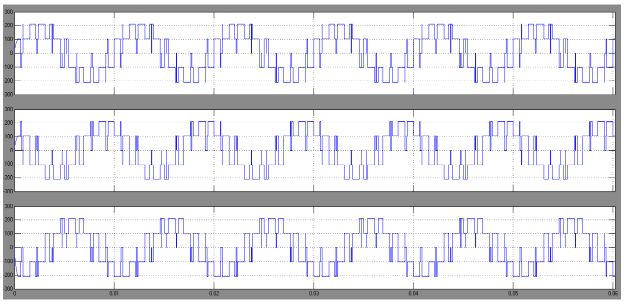

Fig.14.Simulation result for Three-phase PWM output voltage without filtering.

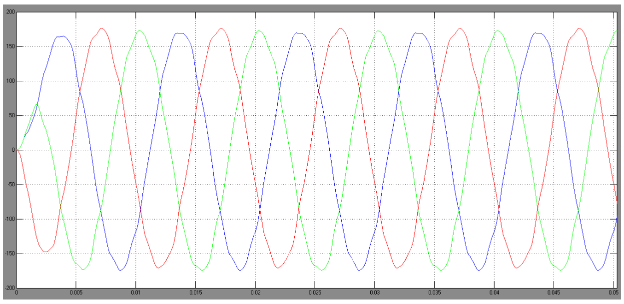

Fig.15.Simulation result for inverter output voltage

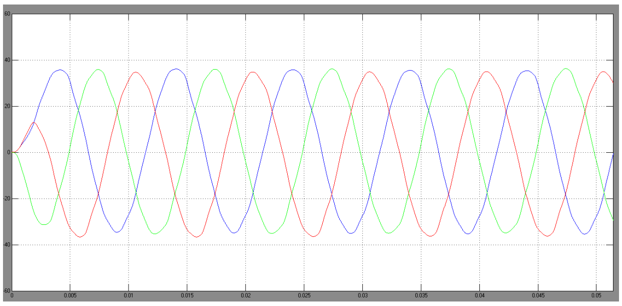

Fig.16.Simulation result for inverter output current

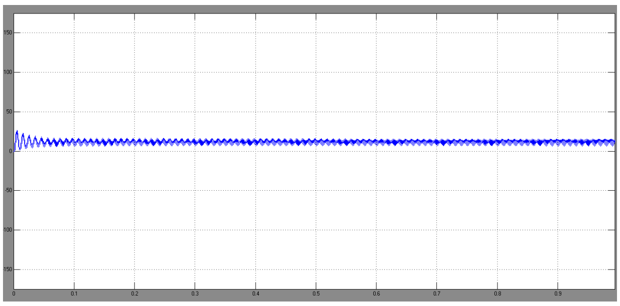

Fig.17.Simulation result for electromagnetic torque of induction motor

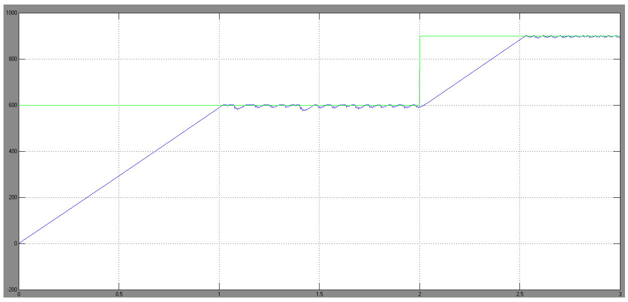

Fig.18.Simulation result for actual and reference speed of induction motor in closed loop PI system

Case 2: performance of proposed system by using fuzzy controller:

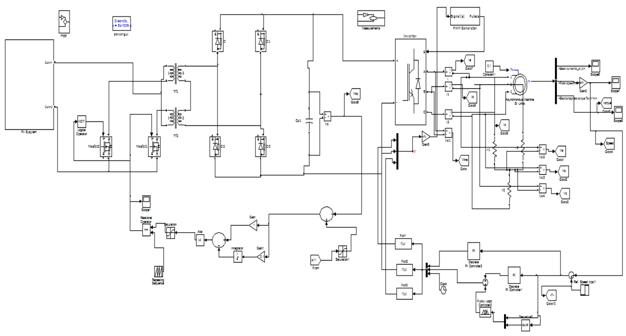

Fig.19. Simulink circuit for proposed system by using fuzzy controller.

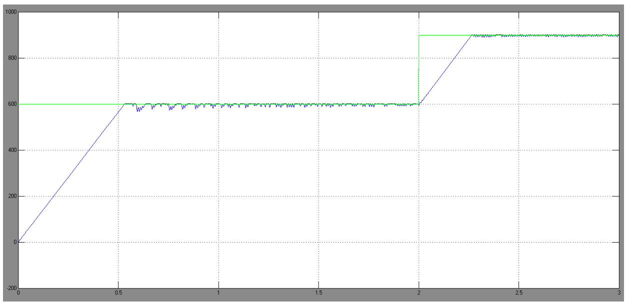

Fig.20. Simulation result for actual and reference speed of induction motor in closed loop fuzzy system

From fig.19 we conclude that by using PI controller in the control strategy speed reaches steady state at 0.25 sec means response is slow. So we go for another control strategy i.e. Fuzzy controller, by using fuzzy controller the speed response is fast shown in fig.20. compared to previous topology.

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VI.CONCLUSION:

In this paper we present an effective method to drive a three-phase squirrel cage induction motor fed from a single solar PV panel. Based on simulation result we demonstrate that the induction motor can be effectively driven by a PV panel. 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 The fuzzy controller controlled drive is providing better results in improving the performance of the induction motor than PI controller. Whenever the machine is loaded, the speed of the machine fell to some extent but this fall in speed is very less in case of fuzzy controller controlled drive. So we can say that overshoot is more in case of PI controller. And overall we can say that Fuzzy controller is proving better result than PI controller This project 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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