Induction Motor Drive system using Push-Pull Converter and Three Phase Inverter

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Abstract: The paper deals with the study of an Induction Motor drive system integrating Push-Pull Converter and three phase inverter using a single solar photovoltaic panel. To step-up the voltage from the panel to drive motor a push-pull converter is used. To obtain better motor performance, to reduce harmonic content of the inverter output waveform and to increase the efficiency of the system, we use Space Vector Pulse Width Modulation(SVPWM) Technique for inverter switching. Closed-loop speed control is developed by Fuzzy Logic Controller to regulate the motor speed to desired value. Maximum Power Point Tracking (MPPT) is employed to obtain maximum power from the PV panel. Lastly simulation results are discussed and analysed.

IndexTerms **-Photovoltaic; Power Electronics; DC-DC Push-Pull Converter; Maximum Power Point Tracking; SVPWM; Three-Phase Inverter; Induction Motor; Fuzzy Logic Controller.**

I. INTRODUCTION

Excessive use of fossil fuels in present scenario leads to environmental pollution and mainly affects the global climate and temperature. These problems can be solved by the use renewable energy sources (AswathiUnni et al. 2015). Solar energy is most available in nature and PV panels are used to convert solar energy into electricity. Power electronics interface is required to drive the motor from the panel. Hence, a DC-DC Push-Pull Converter merge with DC-AC three phase inverter, it is possible to transfer power efficiently from panel to the motor with the help MPPT Technique. Here, Perturb and Observe MPPT Technique is used to obtain maximum power from panel (ZenguriYeng et al. 2017).

Pulse Width Modulation Technique is used for inverter switching and controlling motor (N. Mendez-Gomez et al. 2012). But, these techniques leads to drawbacks such as low fundamental output voltage, excessive amount of harmonic content and higher value of total harmonic distortion. These drawbacks can be solved by the use of space vector pulse width modulation technique and finally leads to increase in the efficiency of the system. Closed-loop speed control is done to achieve maximum motor efficiency in which it controls both voltage magnitude and frequency (M.A. Vitorino et al. 2011). Fuzzy Logic controller is employed to control the speed of the motor by determining the error in the speed of motor (VaruneetVarun et al. 2012). The main objective is to design and integrate series of power electronics converters, in order to run an induction motor efficiently using the power from the solar PV panel as cost efficient as possible.

II. PROPOSED SYSTEM

The block diagram of the proposed system is shown in Fig.1. The block diagram mainly consists of PV panel, DC-DC Push-Pull converter, Three Phase Inverter and Induction Motor. The PV panels mainly consist of cells which are connected in series or parallel and the electrical power from the panel mainly depends on the solar irradiance, panel temperature and operating current and voltage relationship. Thus I-V characteristics of PV array, is complex and non-linear function. The following equations are important in determining the power from the panel (N. Mendez-Gomez et al. 2012).

$$Pmax = \frac{\mathrm{Vop} * \mathrm{Isc}}{1-\exp(-1/b)} * \left[1 - \exp\left(\frac{Vop}{bVoc} - \frac{1}{b}\right)\right] \qquad (1)$$

$$b = \frac{\left(\frac{\mathrm{Vop}}{\mathrm{Voc}} - 1\right)}{\ln\left[1 - \frac{\mathrm{pmax}}{\mathrm{Vop} * \mathrm{Isc}}\right]} \qquad (2)$$

$$Rop = \frac{\mathrm{Vop} - \mathrm{Vop} * \exp\left(-\frac{1}{b}\right)}{\mathrm{Isc} - \mathrm{Isc} * \exp\left(\frac{\mathrm{V}}{\mathrm{bVoc}} - \frac{1}{b}\right)} \qquad (3)$$

Where, Isc is the short circuit current, Voc is the open circuit voltage, lop is the optimal current and V_{op} is the optimal voltage. The value of b is very small and it is distinct and unique for every solar panel and does not vary with changes in irradiance and solar cell temperature.

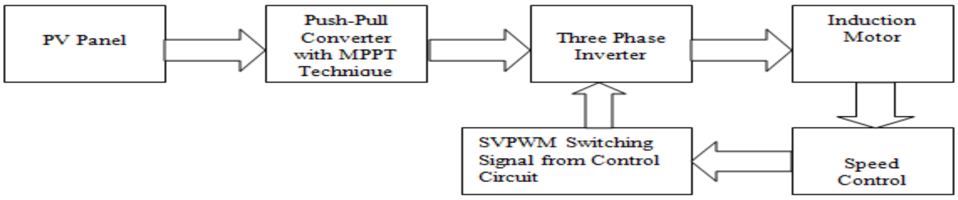

Fig.1: Block diagram of the proposed system

Maximum power point tracking technique is used to extract maximum power from the panel. Since, it minimizes the solar array cost by decreasing the number of solar modules required to achieve the desired output power. Due to variation in climate there will be changes in the power from the panel. Hence, MPPT Techniques are used to gain more power from panel (ZenguriYeng et al. 2017). We use Perturb and Observe Technique to achieve maximum power from panel due to its simplicity and ease of implementation. This technique is easily implemented by an algorithm using power-voltage characteristics of PV module. Fig.2 shows P&O, MPPT algorithm varying the push-pull converter duty cycle to obtain the maximum power delivered by PV panel (E.I Ortiz-Rivera et al. 2008). 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+1 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 Fig.3 shows Perturb and Observe MPPT circuit.The maximum power achieved after MPPT is about 277W.

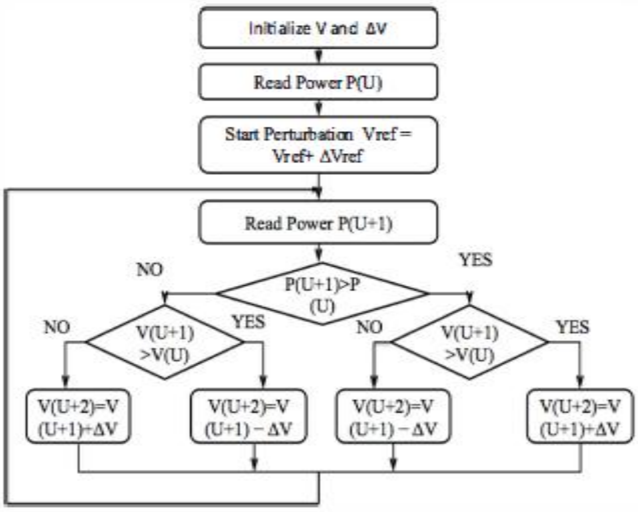

Fig.2: MPPT, P&O algorithm flow chart

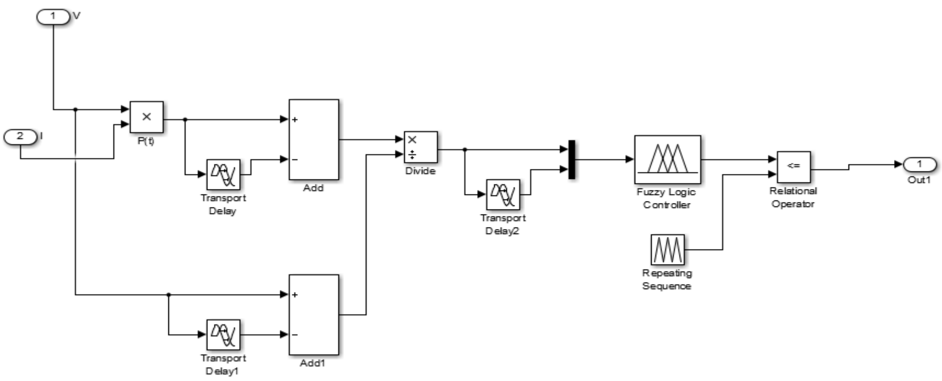

Fig.3: MPPT, P&O with FLC circuit

DC-DC converters are used to convert the unregulated DC to regulated DC. Compared to linear power supply, switching power supply provides more efficiency and power density. The push-pull converter is used to increase voltage level of 24V from panel to the 312V by selecting suitable turns ratio of the transformer (E.I Ortiz-Rivera et al. 2008).. It is convenient to select transformer turns ratio n such that duty cycle D does not vary in wide range (S. Abe et al. 2012). At the same time, high values for n should be avoided to ensure that the voltage inverter operates with low modulation index.. The push-pull output voltage (E) depends on the input voltage (V), the duty cycle (D), and the high frequency transformer turns ratio (n), (D. Holmes et al. 2006)

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

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

Where, D defines the duty cycle and ton corresponds to the total time interval when both switches conduct (ton= DT). Fig.4 shows Push-Pull Converter with PV panel. Here the Push-Pull converter mainly consists of two switches on primary side of transformer. The output of the converter is connected as input to the three phase inverter.

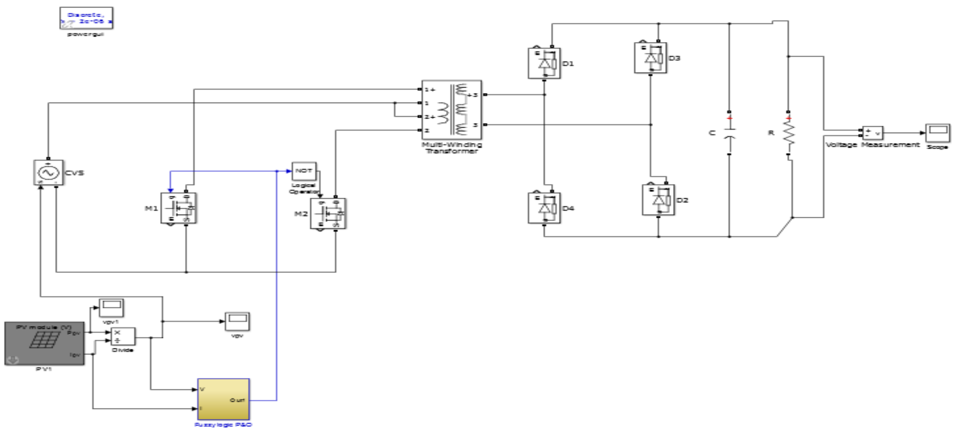

Fig.4: Push-Pull Converter with PV Panel

Three phase inverter is employed to convert regulated DC to AC. Here, the inverter is selected operated in 180 degree mode of conduction (M.H. Rashid, 2007). This inverter consists of three half-bridge units the upper and lower switches are controlled complementary. In a cycle six modes of operation exist and each has duration of 60 degrees. The switching of the inverter is necessary to control the motor. Hence, PWM techniques are used. But these methods suffer from drawbacks like low fundamental output voltage, contains excessive amount of harmonics, higher THD value and lower efficiency. In order to overcome these drawbacks space vector pulse width modulation technique is employed. Fig.5 shows SVPWM technique with Fuzzy Controller.

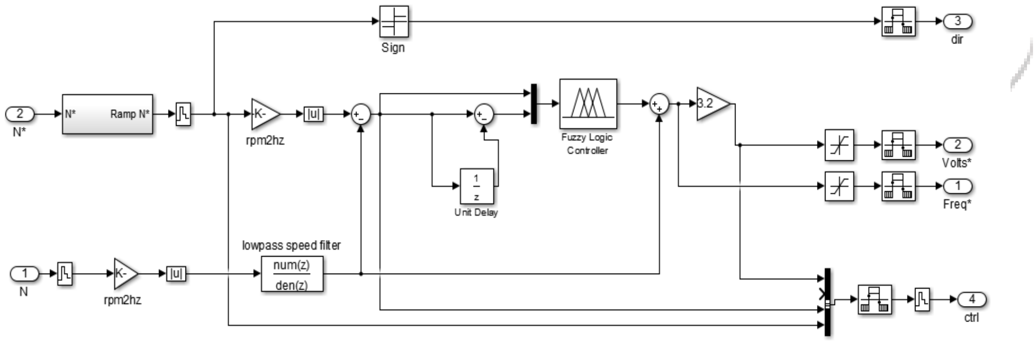

Fig.5: SVPWM technique with Fuzzy Controller

In the proposed system Induction motor is used because of its wide applications and reasonable cost. A sinusoidal voltage is applied to the stator, in the induction motor which results in an induced electromagnetic field (A Santiago-Gonzalez et al. 2011). A current in the rotor is induced due to this field, which creates another field that tries to align with the stator field, causing 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 start voltage controls the synchronous speed (Joseph Peter et al. 2015). Thus, induction motor synchronous speed is defined by following equation.

$$ns = \frac{120f}{p} \qquad (6)$$

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.

Fuzzy logic control (FLC) is a control algorithm based on a linguistic control strategy which tries to account the human's knowledge about how to control a system without requiring a mathematical model. The approach of basic structure of the fuzzy logic controller system is illustrated in Fig.6. Fuzzy controller mainly consists of Fuzzifier, Inference Engine, knowledge base and Defuzzifier (VaruneetVarun et al. 2012).

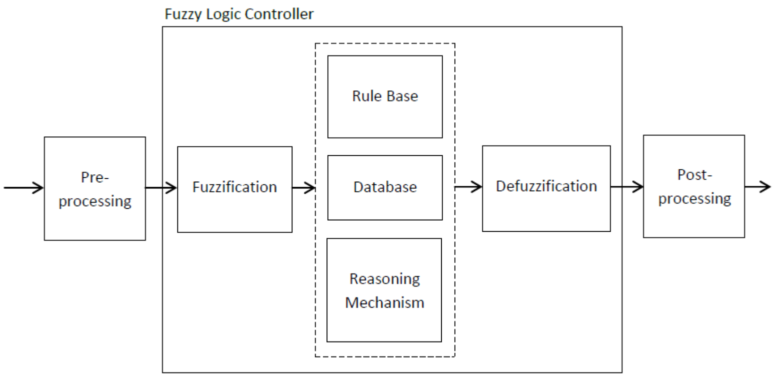

Fig 6: Structure of fuzzy logic controller

The design of a Fuzzy Logic Controller requires the choice of Membership Functions. The membership functions should be chosen such that they cover the whole universe of discourse. It should be taken care that the membership functions overlap each other. This is done in order to avoid any kind of discontinuity with respect to the minor changes in the inputs. To achieve finer control, the membership functions near the zero regions should be made narrow. Wider membership functions away from the zeroprovide faster response to the system. After the appropriate membership functions are chosen, a rule base should be created. It consists of a number of Fuzzy If-Then rules that completely define the behaviour of the system. Fig.7 represents membership function plots. The range for these functions is from -1 to +1. The number of membership functions selected for error and change error are seven and for the output we select eleven (VaruneetVarun et al. 2012).

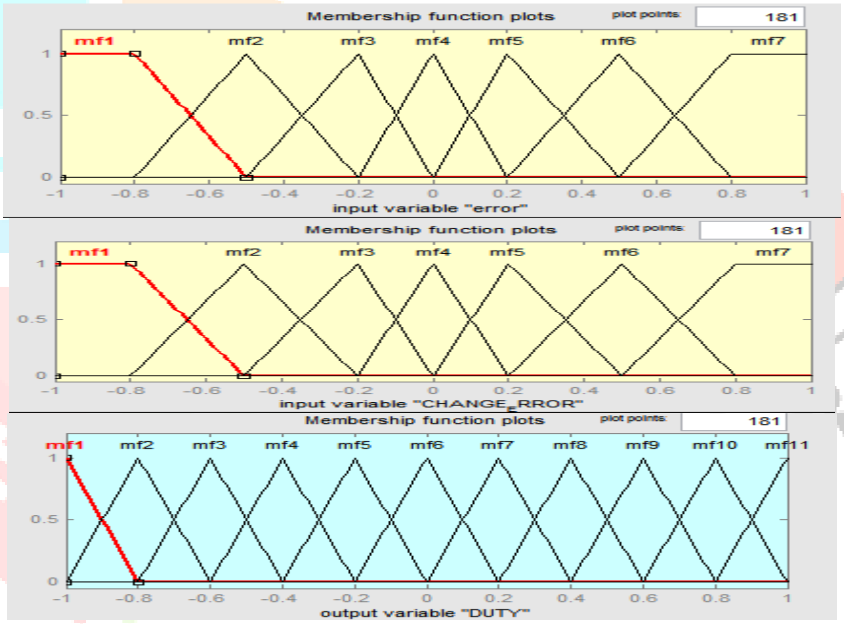

Fig.7: Membership Function Plots (Error, Change error and Duty)

Fuzzy rule table is also necessary to give rules for the output function. Table.1 show below represents the rule table for output. According to rules provided for the output function there will changes in the output.The FLC is therefore designed and using the rule viewer the outputs are verified. By changing the input variables the output can be varied. Hence, the V/f ratio is maintained constant and motor speed control is achieved by FLC. The better performance of the proposed system is obtained by controlling the speed of the motor in wide range. In coming chapter the simulation circuits and the results are discussed.

Table 1: Fuzzy Rule Table for Output

Δe\e	**NL**	**NM**	**NS**	**ZE**	**PS**	**PM**	**PL**
NL	NL	NL	NLM	NM	NMS	NS	ZE
NM	NL	NLM	NM	NMS	NS	ZE	PS
NS	NLM	NM	NMS	NS	ZE	PS	PMS
ZE	NM	NMS	NS	ZE	PS	PMS	PM
PS	NMS	NS	ZE	PS	PMS	PM	PLM
PM	NS	ZE	PS	PMS	PM	PLM	PL
PS	ZE	PS	PMS	PM	PLM	PL	PL

Where,

NL – Negative Large NLM – Negative Large Medium NM – Negative Medium
NMS – Negative Medium Small NS – Negative Small ZE – Zero
PS – Positive Small PMS – Positive Medium Large PM – Positive Medium PLM – Positive Large Medium PL – Positive Large

III. SIMULATION RESULTS

The circuit of the proposed system built in MATLAB is show in Fig.8. The proposed system design consists of a solar panel followed by a series of power electronics interface that controls the speed of an induction motor. At first, Sanyo HIP-210HKHA6 panel with 210 watts maximum power output under Standard Test Condition (STC) is used. At STC condition of 25-degree temperature and irradiance of 1000 W/m2 the panel is stimulated. Fig 9(a) shows output voltage from converter at 600rpm speed. We can observe from the waveforms that the converter output voltage varies when speed of the motor varies. The push-pull converter is connected to the solar panel which efficiently steps-up PV panel 24V DC into 312V DC and then fed into three-phase SVPWM inverter. To keep push-pull converter duty cycle optimal for maximum power extraction, the P&O method is used. The parameters of the three phase induction motor are shown in table 2.

Table 2: Parameters of Induction Motor

Parameter	Value
Nominal Power	3HP
Voltage (line – line)	400V
Frequency	50Hz
Stator Resistance	0.435Ω
Stator Inductance	0.002H
Rotor Resistance	0.816Ω
Rotor Inductance	0.002H
Mutual Inductance	0.1722H
Number of Poles	4

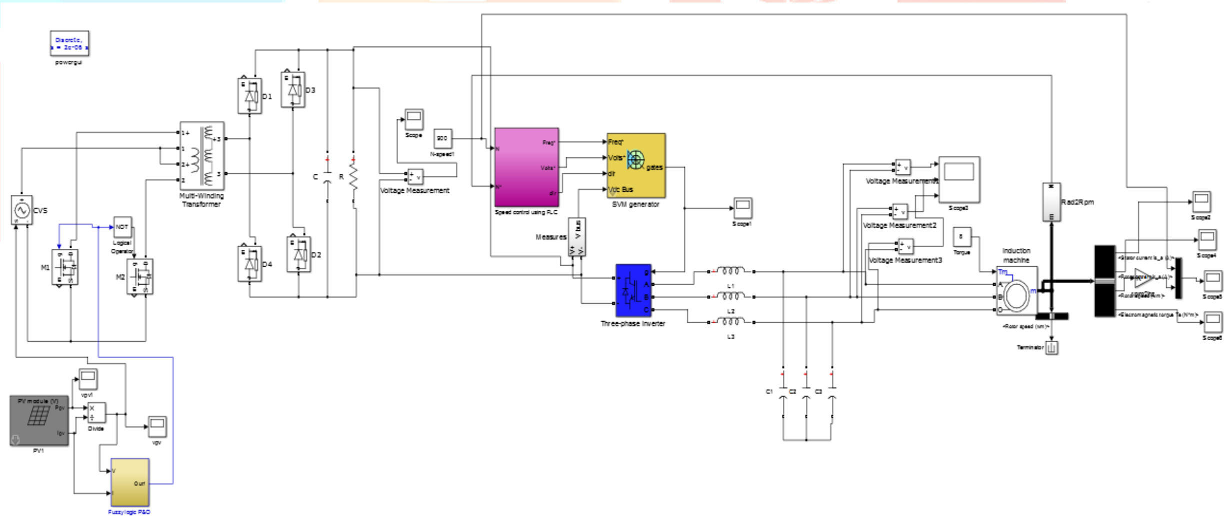

Fig.8: The proposed model built in MATLAB

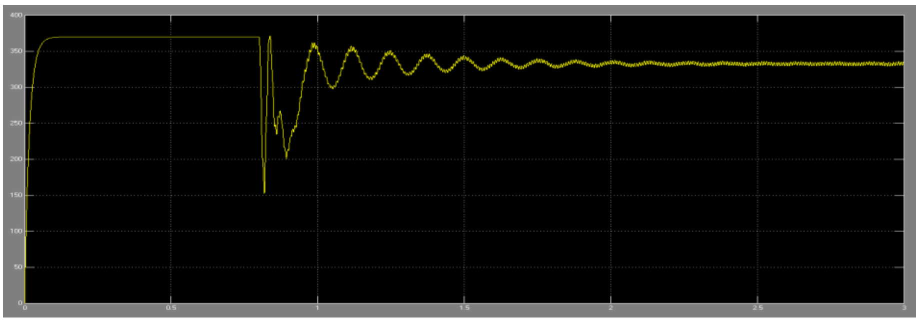

Fig 9(a): converter output voltage at 600rpm speed

When the motor speed speed increases the output voltage of the converter varies. Fig 9(b) represents the converter output voltage when motor is running at 900 rpm speed. We can say that the converter voltage varies when motor speed changes.

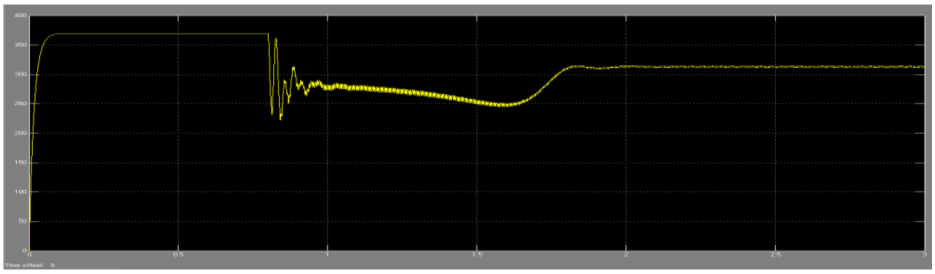

Fig 9(b): converter output voltage at 900 rpm speed

The inverter used converts the 312V DC to AC which is useable for the machine. Initially the simulated waveform is distorted, non-sinusoidal and contains harmonics. Then, it's converted to pure sine wave by using low pass LC filter circuit, the values being L= 60.6mH and C= 0.159mF. Fig 10(a) represents the line voltages of inverter at 600rpm speed.When motor is running at 900 rpm speed the line voltages of the three phase inverter changes and these voltage waveforms are shown in Fig 10(b).

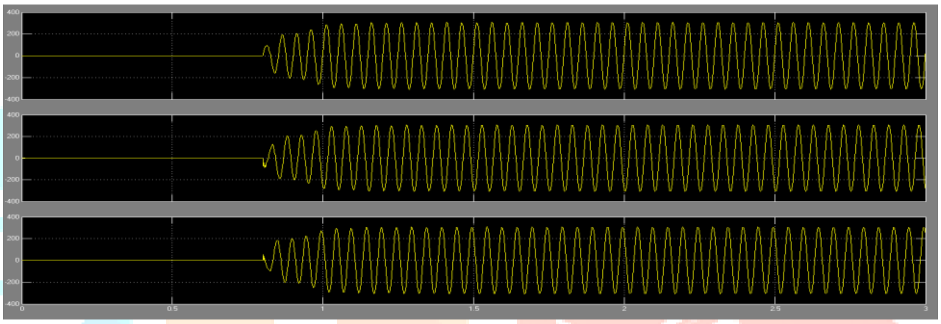

Fig.10(a): line voltages at 600rpm speed

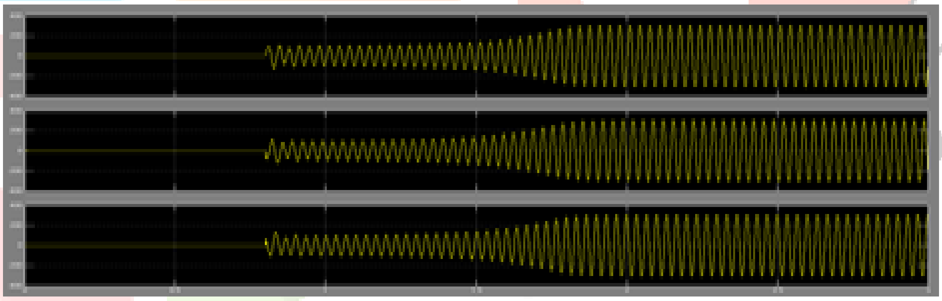

Fig.10(b): line voltages at 900rpm speed

When the speed of the motor varies the stator and rotor current profile also changes. The waveforms of stator current, rotor current and speed of the motor which is maintained at 600rpm is shown in Fig 11(a).When the motor is running at 900rpm the current in the stator and rotor varies compared to those currents when motor is operating at 600rpm. The waveforms of stator current, rotor current and speed of the motor which is running at 900 rpm is shown in Fig 11(b).

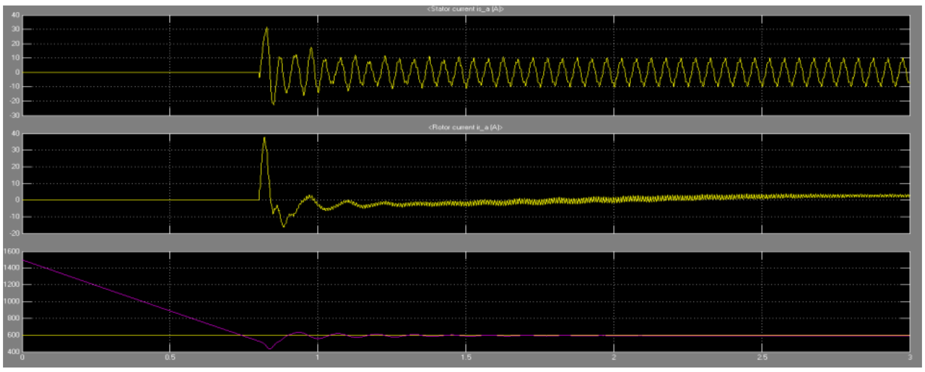

Fig 11(a): Stator current, Rotor current and Speed curves at 600rpm

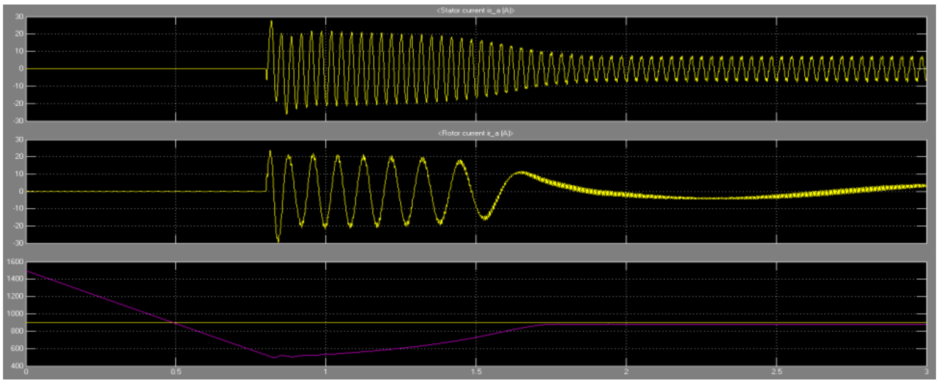

Fig 11(b): Stator current, Rotor current and Speed curves at 900 rpm

Table 3 shows the values converter output voltage, line voltage, stator current and rotor current at 600rpm reference speed and load 8Nm and also at 11Nm load torque. The Table 4 shows output results of the proposed system at 900rpm reference speed and the load 8Nm and also at 11Nm load torque.

Table 3: Results of the proposed system at 600 rpm reference speed

Parameter	At reference speed 600rpm and 8Nm torque	At reference speed 600rpm and 11Nm torque
Converter output voltage	345V	330V
Line voltage	320V	305V
Stator current	10A	10A
Rotor current	3A	2.5A

Table 4: Results of the proposed system at 900rpm reference speed

Parameter	At reference speed 900rpm and 8Nm torque	At reference speed 900rpm and 11Nm torque
Converter output voltage	330V	315V
Line voltage	320V	300V
Stator current	8A	7.5A
Rotor current	2A	2A

By observing the results and also the waveforms, the induction motor speed control is achieved. Hence, the induction motor is effectively driven by the panel by the use of push-pull converter and 3-Φ inverter. The simulation results can also be done with varying reference speed in wide range and also by changing the mechanical load provided to the motor. With the use of FLC, the motor speed reaches the reference speed in less time and also the overshoot is also very less. Finally the results are analysed and the induction motor is driven efficiently by the panel. In coming chapter the hardware development of the system is discussed.

IV. CONCLUSION

It is concluded that the Induction Motor is effectively driven by a PV panel. Maximum power is extracted from the panel by use of P&O Technique with push-pull converter. By selecting suitable turns ratio of push-pull converter transformer offers an additional voltage step-up to reach higher than a boost converter. By maintaining voltage to frequency ratio constant the speed of the motor is controlled through three phase inverter by SVPWM Technique.

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