ISSN: 2581-3404 (Online)
International Journal of Innovative Research in Technology and Management, Vol-4, Issue-5, 2020.

PVA Fed Sensor Less Fuzzy Logic Speed Control of Induction Motor For Water Pumping Application

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ABSTRACT

In this paper a fuzzy structure sensor less vector controller of induction motor is proposed fed with PVA. The speed of the induction motor is estimated by speed estimator with three phase voltages and currents inputs. The induction motor is controlled by six switch inverter for which the pulses are generated by hysteresis current loop controller. The speed is estimated through estimated stator flux. The proposed system includes solar photovoltaic (PV) array, a threephase voltage source inverter (VSI) and a motor-pump assembly. An incremental conductance (InC) based MPPT (Maximum Power Point Tracking) algorithm is used to harness maximum power from a PV array. The controller includes speed regulator with PI controller which is later replaced with fuzzy logic controller with 49 rule base. The speed of the induction motor is more stable with reduced peak value and settling time when operated with fuzzy logic controller. The Model is developed using MATLAB Simulink software with results generated by power gui tool.

Keywords: PV array, vector control, speed estimator, pi controller, fuzzy logic controller.

INTRODUCTION

In the modern era of development, renewable resources of energy are being advocated by many countries to meet the increasing demand of electrical energy due to rapid depletion of non-renewable resources [1]-[2]. Solar PV based energy generation, has come up as an important alternative for many purposes [3]. The irrigation sector is one of the major sectors where solar PV power is extensively used for water pumping [4-5]. Solar PV water pumping has been initially realized using the DC motor. However, with all due virtues associated with the induction motor in terms of mechanical simplicity, ruggedness, reliability, low cost, higher efficiency and lower maintenance than the DC motors, it has replaced DC motors. Here, a solar PV array fed induction motor drive using vector control is used [6]-[7] As one knows that solar PV power depends on solar insulation and temperature. The characteristic of PV module exhibits a single power peak. An extraction of maximum power is very important part of the PV system. Therefore, various MPPT (Maximum Power Point tracking) techniques have been developed and explained in the literature. These algorithms vary in their speed, range of effectiveness and complexities [8]. Here, an incremental conductance (InC) based MPPT algorithm is used to track MPPT. This algorithm is developed to overcome some drawbacks of perturb and observe (P&O) algorithm. InC algorithm improves the tracking time and to produce increased energy on a vast irradiation changes. Moreover, it has advantage over P&O method, which increases losses in slow varying atmospheric condition as it oscillates around MPP [9]-[10].

Most of the existing induction motor drives (IMDs) incorporate one DC-DC converter and a

VSI (Voltage Source Inverter) for achieving MPPT and maximum efficiency of the motor [11].

Moreover, the DC link voltage regulation is achieved by VSI itself. However, the system requires at least seven power converter switches and hence switching losses are increased. This further includes a DC-AC conversion with a VSI feeding a vector-controlled three-phase IMD. Therefore, there is a need to use single stage controlled drive for water pumping and thereby decreasing number of switches and losses. In single stage system, a VSI has to maintain the MPP as well as DC link voltage is also controlled by it. Therefore, variable DC link voltage cannot be achieved as explained in [12]-[13].

The vector control strategy is superior to scalar control in terms of speed of response and accuracy as explained in [14]-[16]. In the vector control technique, an AC motor is operated in such a manner to behave dynamically as a DC motor by using feedback control [16]. This technique enables to vary the speed over the wide range. Hence with the advancement of power electronics and by using powerful microcomputer and DSPs, the vector control ousts scalar control [17]-[19].

In this vector control scheme, the stator flux is estimated in stationery αβ frame, which is used to estimate the slip speed (ωsl), synchronous speed (ωe) and the motor speed as explained in Fig.1 shows the configuration of a single stage solar PV array fed speed sensor less induction motor drive incorporating vector control for water pumping. This proposed system constitutes PV array followed by a VSI fed three-phase induction motor drive operated pump. The motor speed is estimated by stator fluxes, which is estimated by DC link voltage and motor currents. Three-phase VSI switching is controlled by hysteresis-band controller. An incremental conductance (InC) control algorithm is used for MPPT to generate switching pulses for the VSI.

II PROPOSED METHODOLOGY

2.1photo voltaic fed induction motor drive

Fig 2.1 shows the configuration of a single stage solar PV array fed speed sensor less induction motor drive incorporating vector control for water pumping. This proposed system constitutes PV array followed by a VSI fed three-phase induction motor drive operated pump. The motor speed is estimated by stator fluxes, which is estimated by DC link voltage and motor currents. Three-phase VSI switching is controlled by hysteresis-band controller. An incremental conductance (InC) control algorithm is used for MPPT to generate switching pulses for the VSI. The proposed circuit diagram is shown

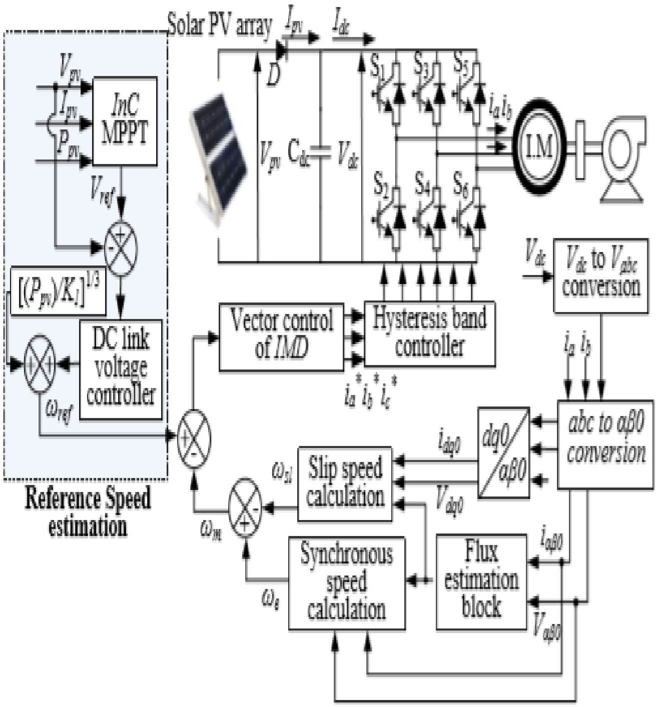

Fig. 2.1: Photo voltaic fed induction motor drive.

2.2 SYSTEM DESIGN PARAMETER

Fig. 2.1 shows a basic schematic of a three-phase induction motor of a 7.5 kW (10 HP), 400V, used to drive the pump powered by a 8.7 kW maximum power solar PV array. The various stages of system have been designed here and the

performance of overall system is shown in subsequent sections under various conditions.
Design of Solar PV Array A 8700 W PV array is designed to drive a 7.5kW induction motor drive. The rating of PV array is selected more than the motor rating so that the performance of the motor remains unaffected by the losses incurred in the motor and converter.

2.2.1 Calculation of DC Link Voltage

In order to control the output current of VSI, the voltage of the DC link should be more than as compared to the peak amplitude of line voltage given to the motor [13].

$$V_{dc} = \sqrt{2} \times V_L = \sqrt{2} \times 230 = 325\ V$$

Hence the value of DC link voltage is kept as325 V.

2.2.2 Design of DC Link Capacitor:

The value of DC link capacitor is estimated by using fundamental frequency component as [13]

$$w_{rated} = 2 \times \pi \times 50 = 314\ rad/s$$

$$\frac{1}{2} \times C_{dc} \times \left(V_{dc}^2 - V_{dc1}^2\right) = 3aV_p It = 3 \times 1.2 \times 239.6 \times 13.5 \times 0.005$$

Hence, Cdc= 2509µF where Vdc is the DC link voltage and Vdc1 is the minimum allowable DC link voltage during transient condition, t is the time required for the voltage to recover minimum allowable DC-link voltage, I is the motor phase current and Vp is the phase voltage. Therefore, capacitor value is selected as 2500 µF.
D. Design of Water Pump Water pumps have non-linear relationship between load torque and motor speed [21] i.e. load torque (TL) is directly in proportion to the square of the rated rotor speed. Hence

$$T_L = K_1 w_m^2$$

Where K1 is the proportionality constant of the pump.

2.3 CONTROL OF RECOMMENDED SYSTEM

The control of overall system includes MPPT of solar PV array to extract maximum power through three phase VSI, control of three-phase VSI switching by using hysteresis-band controller for vector-controlled IMD and speed estimation for speed sensorless vector control of an induction motor drive.

2.3.1. PROPORTIONAL-INTEGRAL CONTROL SYSTEM

Proportional-integral-derivative (PID) controllers are widely used in industrial control systems because of the reduced number of parameters to be tuned. They provide control signals that are proportional to the error between the reference signal and the actual output (proportional action), to the integral of the error (integral action) and to the derivative of the error (derivative action) [13]. The corresponding equation is given as:

$$u(t) = K_p e(t) + K_i \int_0^t e(t)dt + K_d \frac{d}{dt} e(t)$$

Where u(t) is the actuating signal, e(t) is the error signal, Kp is the proportional gain constant, Ki is the integral gain constant and Kd is the derivative gain constant. The PID control offers the simplest and yet most efficient solution to many real-world control problems by means of its three-term functionality covering treatment to both transient and steady-state responses. Shown in fig. 2.2 is schematic diagram of PI proposed control system.

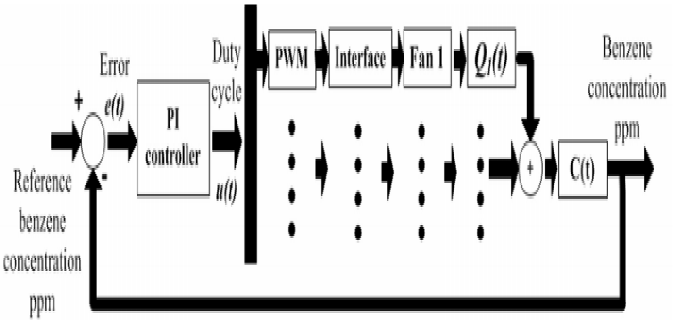

Fig. 2.2: Proposed PI control system.

2.4 FUZZY LOGIC CONTROLLER

The fuzzy controller has four main components: The rule-base, which holds the knowledge, in the form of a set of rules, describing the best way to control a system. The membership functions are used to quantify knowledge. The inference mechanism evaluates which control rules are relevant at the current time and then decides what input of the plant should be enabled.

The fuzzification interface modifies the inputs, so that they can be interpreted and compared to the rules in the rule-base. The defuzzification interface transforms the conclusions reached by the inference mechanism into the inputs of the plant. Shown in fig. 2.3 is schematic diagram of fuzzy logic controller.

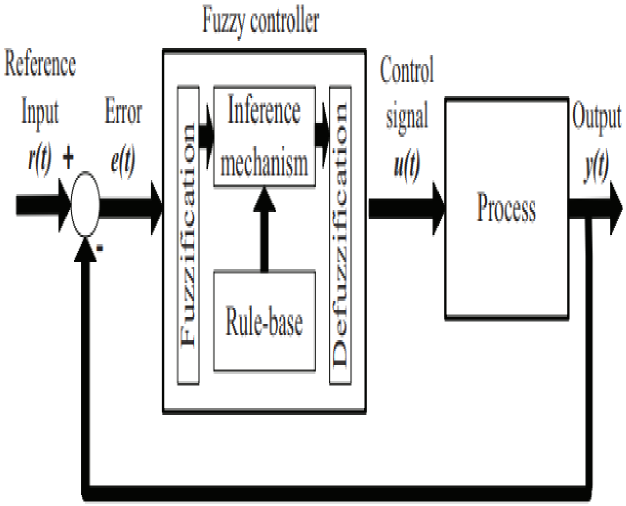

Fig. 2.3: Scheme of a fuzzy logic controller.

2.4.2 Description of fuzzy logic tools

Fuzzy logic unlike Boolean or crisp logic, deal with problems that have vagueness, uncertainty or imprecision and uses membership functions with values varying between 0 and 1. Figure 2.3 shows a schematic block diagram of fuzzy inference system or fuzzy controller.

It consists of following working blocks

- Fuzzification Interface
- Knowledge base
- Decision making logic
- Defuzzification

As it is a two dimensional fuzzy control, a fuzzy logic controller should posses proportional integral control effects. An integral action is normally needed to achieve the best performance in practical situation.

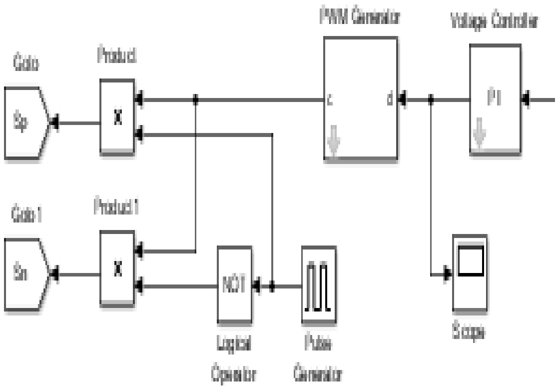

Fig. 2.4: PWM pulse generator.

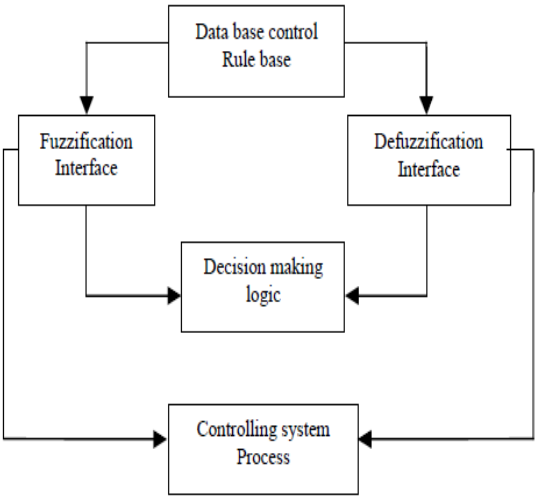

Fig. 2.5: Fuzzy Inference System.

2.4.3 Design of Control Rules

The fuzzy control rule design involves defining rules that relate the input variables to the output model properties. As fuzzy logic controller is independent of system modal, the design is mainly based on the intuitive feeling for, and experience of, the process. The rules are expressed in English like language with syntax such as If {error e is A and change of error $\Delta e$is B} then {control output is C}For better control performance finer fuzzy petitioned subspaces(NL, NM, NS, ZE, PS, PM, PB) are used, and summarized in table 5.1. These seven membership functions are same for input and output and characterized using triangular membership functions.

The output membership functions are of triangular format.

III SIMULATON RESULT AND DISCUSSION

The implementation of the proposed algorithm is done over MATLAB (R2016). The signal processing toolbox helps us to use the functions available in MATLAB Library for various methods like Windows, shifting, scaling etc.

3.1 SYSTEM PARAMETER

Parameter	Value
Temperature of PV	35°
Irradiation (maximum)	1000 w/m^2
Irradiation (minimum)	500 w/m^2
DC link capacitor	2500μF
IGBT Internal Resistance	0.001 ohm
Rating of induction motor (power)	10(HP) or 7.5Kw
Lint to line voltage	400V
Frequency of IM for 1440 rpm	50Hz
Proportional Gain	0.1
Integral Gain	2
Stator resistance (Rs)	0.7384 ohm
Stator inductance(Ls)	0.003045 henry
Rotor resistance (Rs)	0.7402 ohm
Rotor inductance(Ls)	0.003045 henry
Mutual inductance (Lm)	0.1241 henry
Pole pairs	2

Table 3.1: Parameter used in simulation.

3.2 Simulation result and discussion:

PVA fed Sensor less speed control of induction motor using vector control technique.The proposed model is shown in fig. no.3.1 The proposed model is consisting of seven major component .such as photo voltaic array ,dc link capacitor connected with voltage source inveter, speed estimator(MRAS) speed controller, PI controller, fuzzy logic controller.

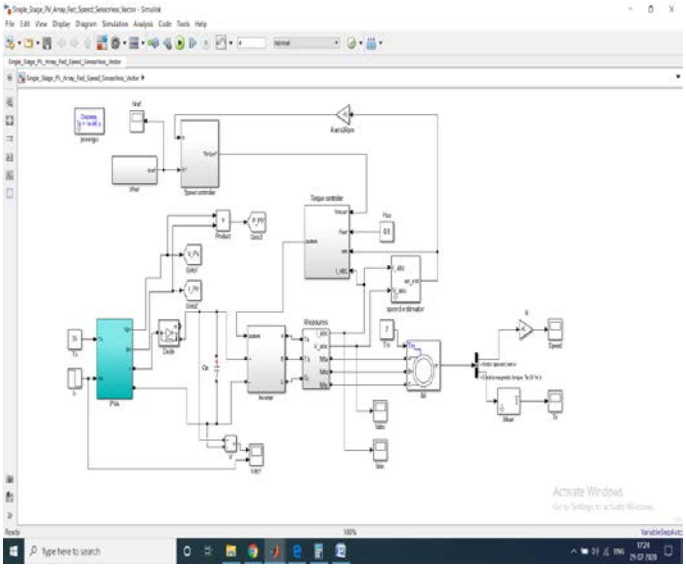

Fig. 3.1: Proposed system with PVA fed to induction motor.

In a Fig. 3.1 is the three phase induction motor connected to six switch converter fed by PVA with variable solar irradiation. The converter is controlled by vector control with speed and torque individual controllers. The below are the speed regulator and torque controller with PI controller. The internal sub system of speed regulator of pi controller is shown in figure 3.2.

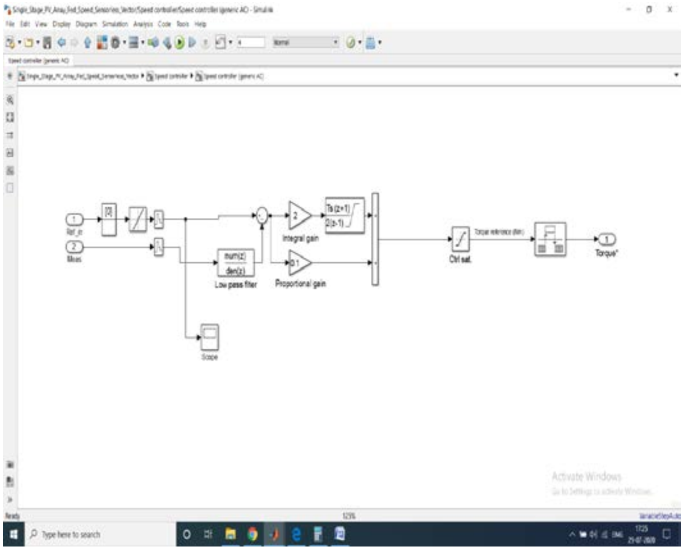

Fig. 3.2: Speed regulator with PI controller.

Fig. 3.3: Speed of induction motor with pi controller.

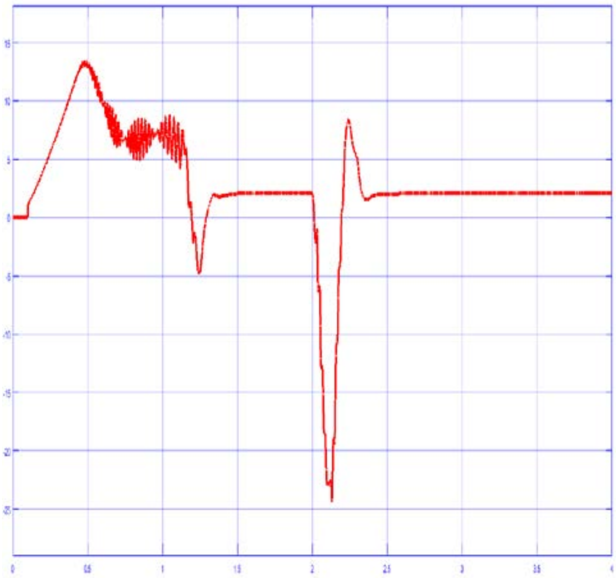

Fig. 3.3: Electromagnetic torque with PI Controller.

The below (fig.3.4) is the speed regulator with fuzzy logic controller connected by two input variables and one output variable. Each variable comprises of 7 membership functions with 49 rule base.

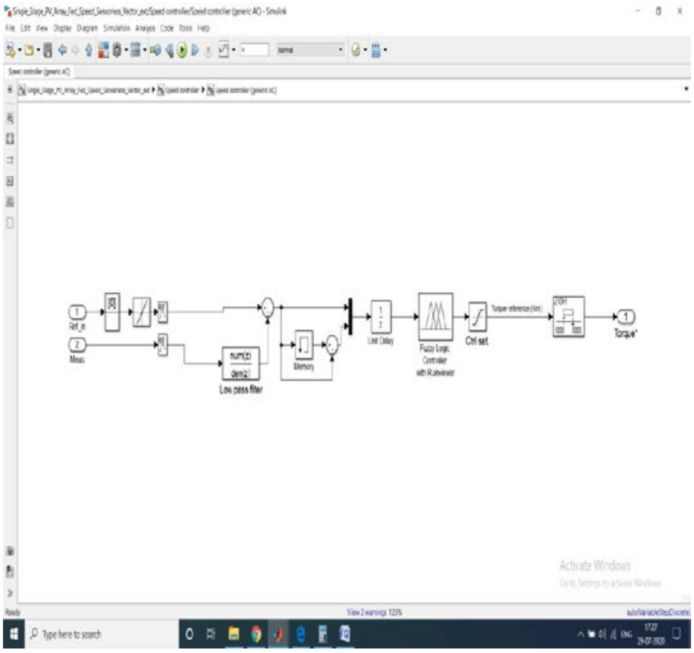

Fig. 3.5: Speed regulator with fuzzy controller.

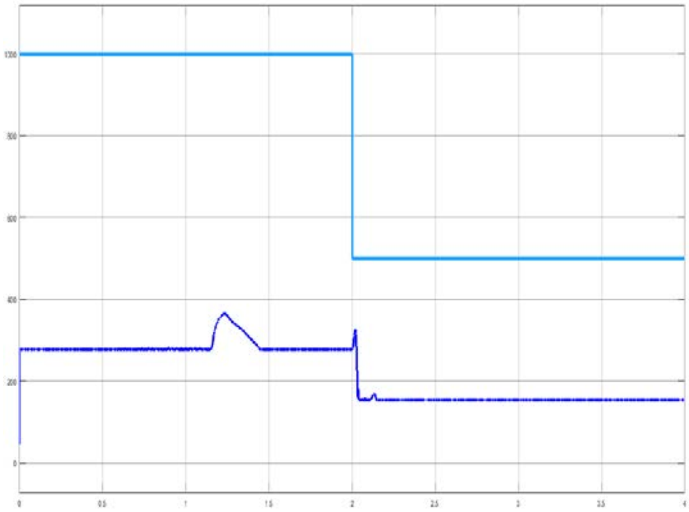

Fig. 3.6: Solar irradiation and voltage output of PVA.

The above (fig. no 3.5) are the graphs of solar irradiation and PVA voltage changing with respect to time. The solar irradiation is changed from 1000W/mt2 to 500W/mt2 at 2secs. The total simulation time is 4secs. The below (fig. 6.12) are the three phase currents of induction machine for the same change in solar irradiation.

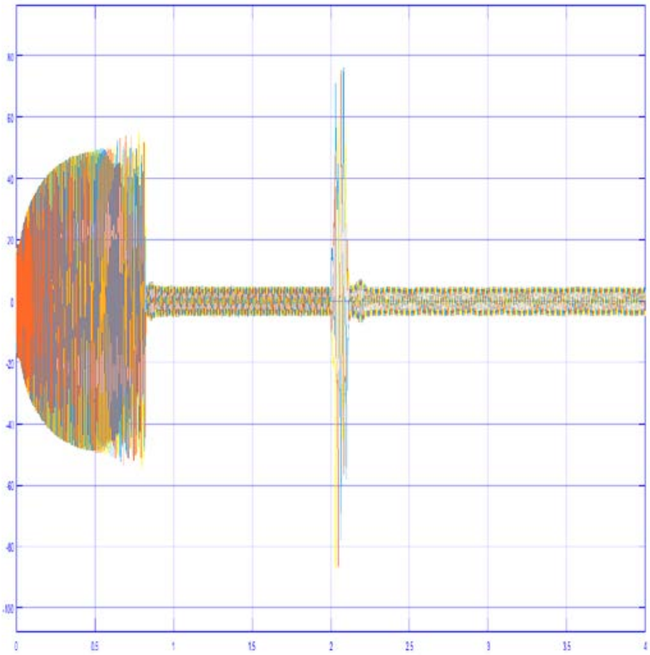

Fig. 3.7: Induction motor three phase currents.

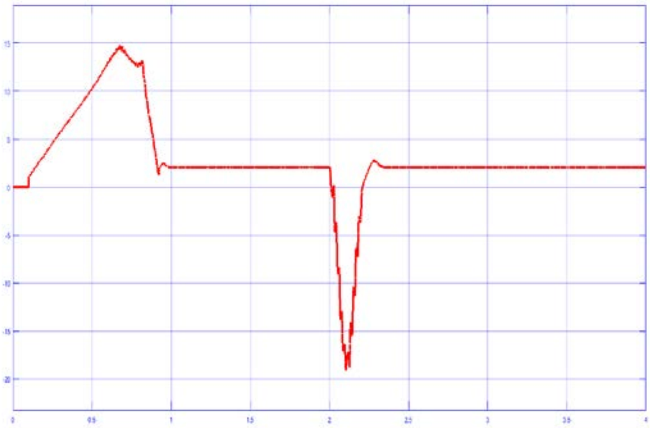

Fig. 3.8: Electromagnetic torque of induction motor.

3.2 Comparative induction motor speed analysis between pi and fuzzy logic controller

The below (fig. no. 6.14) graph is the induction motor speed comparison with PI and fuzzy logic controller. The speed is changed from 1500rpm to 825rpm when the solar irradiation is changed at 0.2secs. The below is the electromagnetic torque of the motor for the same change.

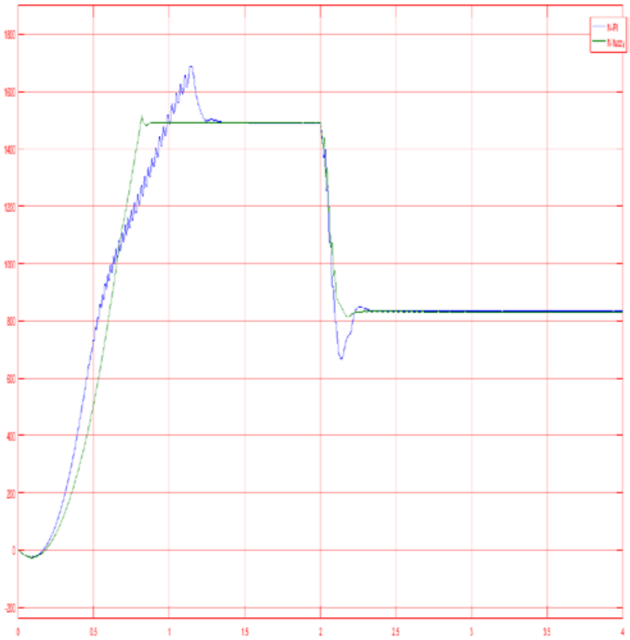

Fig. 3.9: Speed comparison of induction motor with PI and fuzzy controller.

IV CONCLUSION AND FUTURE SCOPE

4.1 Conclusion

With the above results it can be concluded that the speed of the induction motor is more stable with less peak value generation and less settling time. The motor controlled with fuzzy controller of 49rules has better performance as compared to PI controller. The torque and stator flux, have been controlled independently. The motor is started smoothly. The reference speed is generated by DC link voltage controller controlling the voltage at DC link along with the speed estimated by the feed forward term incorporating the pump affinity law. The power of PV array is maintained at maximum power point at the time of change in irradiance. This is achieved by using incremental conductance based MPPT algorithm. The model is run by Simulink modelling generating graphs with respect to time.

4.2 Future Scope

The input source PVA can be replaced with fuel cell or wind farm (connected to controlled rectifier) for multiple renewable source feeding the converter. The speed regulator can be updated with neuro fuzzy controller for faster response of speed with reduced settling speed and ripple in the value.

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