International Journal of Research in Engineering, Science and Management
Volume-3, Issue-7, July-2020
journals.resaim.com/ijresm | ISSN (Online): 2581-5792

Modelling and Simulation of Perturb and Observe Algorithm on Solar PV Water Pumping System using Different Controllers in MATLAB/Simulink

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***Abstract*: This paper deals with the Perturb and Observe algorithm on a Photovoltaic System using different Controllers in MATLAB/Simulink. The Photovoltaic System is depends on the mathematical equations. The P & O algorithm is the Maximum Point Tracking Technique (MPPT) to track the maximum power point. A high level boost converter is used between solar panel and the PWM inverter. The DC voltage is maintained constant by controlling the duty cycle of boost converter. Three phase Voltage Source Inverter (VSI) is maintain constant supply to PMSM under change in solar irradiation to regulate discharge of water. The performance of system employing PMSM drive with PI controller and fuzzy logic controller is analyzed. The current and voltage ripple harmonics will be reduced and THD (total harmonic distraction) also reduced. The Modelling and Simulation of Perturb and Observe Algorithm is done by using Different Controllers in MATLAB/Simulink.**

***Keywords*: Maximum Power Point Tracking (MPPT), Vector Oriented Control(VOC), Voltage Source Inverter (VSI), Photo Voltaic (PV) Array, DC to DC Boost Converter.**

1. Introduction

Renewable energy penetrations are increased in power sector to reduce dependency on fossil fuels [1]. Solar PV (Photo-Voltaic) systems are now well recognized for trapping solar energy. Solar energy has the greatest availability compared to other energy sources. It has been estimated that the amount of energy supplied to the earth in one day is sufficient to cater energy needs of the earth of one year [2]. For such solar PV systems, maximum power point tracking control is preferred for efficient operation [3]-[5]. Matsui et. al have presented a MPPT control system for solar PV system by utilizing steady state power balancing condition at DC link [6]. It has further improved by Mikihiko for sensorless application [7]. Integration of PV system with the grid fulfil standard power quality requirements and it have been reported in [8]-[10].

The solar PV system has found many potential applications such as residential, vehicular, space air craft and water pumping system [11]. PV water-pumping is highly competitive compared to traditional energy technologies and best suited for remote site applications that have small to moderate power requirements. Most of the existing photovoltaic irrigation systems offer a mechanical output power from 0.85 kW up to 2.2 kW. The efficiency of Induction motors is less compared to permanent magnet motors, whereas DC machines are not suitable for submersible installations [12].

In recent years, the use of PMSM (Permanent Magnet Synchronous Motors) are increased for drives applications due to its high efficiency, large torque to weight ratio, longer life and recent development in permanent magnet technologies [13]-[15]. It need power processor for effective control [16]. PMSM become a serious challenger of induction motors in hybrid electric vehicle applications [17]-[18].

This paper presents a standalone solar PV supplied PMSM drive for water pumping system. Pumping water is a universal need for agriculture and the use of PV panels is a natural choice for such applications. The performance of photovoltaic pumping system employing PMSM drive with proportional integrator controller and fuzzy logic controller is analyzed.

2. System Configuration and Principle of Operation

Fig. 1 shows schematic diagram for the stand-alone solar PV based PMSM drive for water pumping system. The proposed system consists of solar PV panel, a boost converter, a three phase VSI (Voltage Source Inverter) and a PMSM coupled with a centrifugal water pump.

A PV or solar cell is the basic building block of a PV system. An individual PV cell is usually quite small, typically producing about 1 or 2W of power. To increase the power output of PV cells, these cells are connected in series and parallel to assemble larger unit called PV module. The paragraphs. PV array is connected to the DC to DC boost converter to increase the output voltage level. An IGBT (Insulated Gate Bipolar Transistor) based VSI is used for DC to AC conversion and connected to the PMSM drive. The constant DC voltage is converted to the AC output using a VSI. Reference speed of PMSM is a function of solar irradiation.

The continuation of this article is made up of the following sections: Section III discusses the modeling of the system topologies of photovoltaic water pumping system, the MPPT based on P&O algorithm, Boost converter and VSI. Section IV discusses the The performance of photovoltaic pumping system employing PMSM drive with proportional integrator controller and fuzzy logic controller is analyzed.

3. Modeling of System

The structure of photovoltaic water pumping system considered in this work is illustrated by Fig. 1.

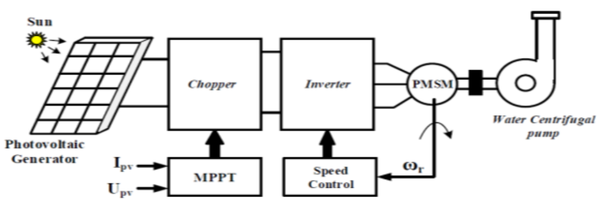


Fig. 1. Synoptic block of photovoltaic water pumping system

A. Design of PV Array

Cell photovoltaic is component the most elementary of a module PV [16], the current generated by these cells is very weak. A solar module is a combination amongst solar cells, which are joined in series NS or shunt NP in order to increase the power of a PV module, it is modelled as a power current (Ph)with diode (D) in parallel, shunt and series resistance designed respectively by R_{sh} and R_s. The model circuit of PV array is indicated in Fig. 2.

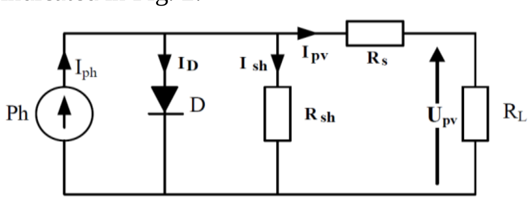


Fig. 2. Equivalent circuit for PV array

The PV Array is design by using equation (1), q is the unit charge, k is the Boltzman's constant, A is the p-n junction ideality factor, and T_c is the cell temperature, i_{scr} is the Current cell reverse saturation current, which varies with temperature according to,

$$I_{pv}=0.01[i_{scr}+K_v(T_c-T_{ref})]S \quad (1)$$

i_{scr} the cell short-circuit current at the reference temperature and radiation, a temperature coefficient, and the insolation level in kW/m. The power delivered by the PV array is calculated by multiplying both sides of equation (1) by V_{pv}

$$P_{pv}=n_p i_{ph} v_{pv}-n_p i_{rs} v_{pv} \exp\left(\frac{q}{kAT_c}\frac{v_{pv}}{n_s}\right)-1$$

It is evident that the power delivered by the PV array is a function of insolation level at any given temperature.

B. Perturb and Observe (P&O) MPPT techniques

In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented. A scheme of the algorithm is shown in fig. 3.

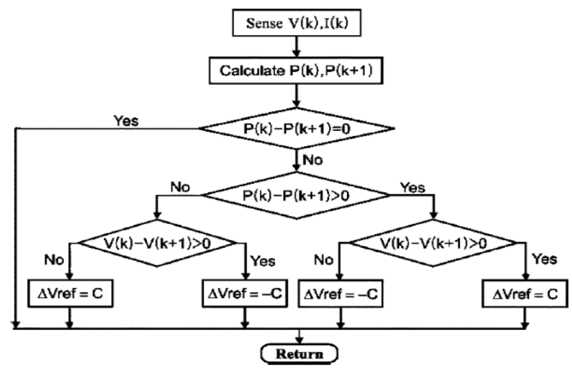


Fig. 3. MPPT (P&O) algorithm

C. Design of Boost Converter

The boost converter is used to feed the active power from PV array to the DC link capacitor connected VSI fed PMSM. The design parameters of the boost converter are given as,

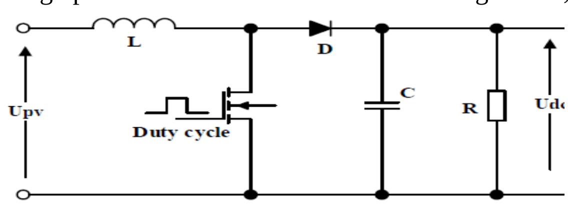


Fig. 4. Equivalent circuit of Boost converter

$$L=V_{pv}D_2*\Delta i*F_{sw} \quad (3)$$

Where D is duty cycle, V_{pv} is output voltage of PV array, f_{sw} is switching frequency, Δi is ripple in output current of PV array. Considering V_{pv}=198.99V, Δi=10% of PV current and f_{sw} = 15 kHz, the value of L is obtained as 2.67 mH.

The maximum current through boost converter IGBTs is obtained as 1.25 (i_{pp}+ I_{pv}) where i_{pp} is peak to peak ripple current considering 10% ripple 25 A, 600 V IGBT is used for boost converter.

D. Voltage Source Inverter

The apparent power rating of a VSI is given as,

$$S_{VSI}= P_2+Q_2 \quad (4)$$

It is obtained as 1500 VA. The rms current through a VSI is given as,

$$I_{VSI}=kw*10^{3}/(V_m 3) \quad (5)$$

Where V_m is stator voltage of PMSM. The maximum current through IGBTs is obtained as 1.25 (i_{pp}+ I_{VSI}) [20]. Considering 7.5% peak-peak ripple current, 25 A, 600 V IGBTs are used in a VSI.

4. Control Scheme

Fig. 1 shows the comprehensive control scheme for a speed controller of solar PV based PMSM drive. The control scheme is discussed in two parts, i.e. control of boost converter to maintain constant DC link voltage and control of VSI in vector oriented mode to achieve fast dynamic response under change in solar irradiances and load conditions. Basic equations. used in control algorithms are as follows.

A. Control of Boost Converter

The DC bus voltage and the output of the DC PI controller is used to estimate the DC voltage error at the kth sampling instant is as,

$$V_{dce}K=V_{dc*}(K)-V_{dc}(K) \quad (6)$$

Where V_{dc} and V_{dc*} are sensed and reference DC bus voltages respectively. The output of the DC PI controller at the kth sampling instant is expressed as,

$$I_{pv*}k=I_{pv*}k-1+k_{pa}v_{dce}k-V_{dce}k-1+k_{ia}V_{dce}(k) \quad (7)$$

Where k_{pa} and k_{ia} are the proportional and integral gain constants of the PI controller. V_{dce} (k) and V_{dce} (k-1) are the DC bus voltage errors in the kth and (k-1)th sampling instant and $I_{pv*}k$ and $I_{pv*}k-1$ are output of DC PI controller in the kth and (k-1)th instant needed for voltage control. The reference and actual PV bus current are used to estimate the PV bus current error at the kth sampling instant as,

$$I_{pv}k=I_{pv*}k-I_{pv}(k) \quad (8)$$

The PV bus current error (Ipve) is amplified using gain K and compared with fixed frequency carrier signal to generate switching signals for IGBT used in boost converter.

B. Control of VSI

For the VSI, a VOC (Vector Oriented Control) scheme is used. Two Hall effect current sensors are used to sense two phase motor currents i_a, i_b and third phase source current i_c is estimated considering that instantaneous sum of three-phase currents is zero. Reference motor speed (ω*r) is the function of solar irradiation and used to track the maximum power.

Irradiation sensor transducer gives the output in the form of voltage signal which is fed to the look up table. Reference speed is compared with the measured rotor speed (ω_r) and it provided speed error ω_e. The speed error at the k_{th} sampling instant is given as,

$$\omega_{re}k=\omega_{r*}k-\omega_r(k) \quad (9)$$

Speed error is processed using the speed PI controller, which provide the reference electromagnetic torque (T^*_{ref}). The reference torque (T^*_{ref}) is used to generate reference qaxis current (i^*_q) as follows,

$$i_{q*}(k)=i_{q*}k-1+k_{pa}[\omega_e k-\omega_e(k-1)]+k_{ia}\omega_e(k) \quad (10)$$

Where k_{pa} and k_{ia} are the proportional and integral gain constants of the PI controller. $\omega_e k$ and ω_e(k-1) are the speed errors in the kth and (k-1)th sampling instant and $i_{q*}k$ and $i_{q*}k-1$ is the output of speed PI controller in the kth and (k-1)th instant needed for speed control. Similarly, from the sensed rotor speed of the PMSM, magnitude of d-axis PMSM current (i^*_d) is obtained which is consider zero below rated speed.

$$i_{d*}=0 \quad (11)$$

For the estimation of three phase PMSM currents the transformation angle (θ_{re}) is obtained as,

$$\theta_{re}=\frac{P}{2}\theta_r \quad (12)$$

Where P is the number of poles of the PMSM. Three-phase reference PMSM currents (i_{a*}, i_{b*}, i_{c*}) are obtained using i^*_d and i^*_q and the rotor angular position in electrical rad/sec by inverse park transformation. Three-phase reference PMSM currents are as [13],

$$i_{a*}=i_{d*}\cos\theta_{re}-i_{q*}\sin\theta_{re} \quad (13)$$
$$i_{b*}=i_{d*}\cos(\theta_{re}-\frac{2\pi}{3})-i_{q*}\sin(\theta_{re}-\frac{2\pi}{3}) \quad (14)$$
$$i_{c*}=i_{d*}\cos(\theta_{re}+\frac{2\pi}{3})-i_{q*}\sin(\theta_{re}+\frac{2\pi}{3}) \quad (15)$$

Three phase reference currents (i_{a*}, i_{b*}, i_{c*}) are compared with sensed PMSM currents (i_a, i_b, i_c) and resulting current errors are fed to the PWM current controller for generating the switching signals.

C. Speed Controller

The photovoltaic water pumping system according to the speed rotation of the PMSM motor which drives the centrifugal pump, then the speed of motor control is add to the speed controller returns to the start of water constant. In this work we consider two types of controllers: proportional integral (PI) controller and fuzzy logic controller (FLC).

1) Proportional Integral Regulator

The traditional regulator PI is the most used in regulation because it is simple and reliable in operation. So in this the PI is used for speed control of PMSM, so the rotor speed (ω_r) and compared with the reference speed (ω_{r*}). As shown in the following equations.

$$e_r x=\omega_r x-\omega_r(x-1) \quad (16)$$
$$\Delta e_r x=e_r x-e_r(x-1) \quad (17)$$

The quadrate current reference is given by:

$$I_{q-ref}x=I_{q-ref}x-1+K_p.\Delta e_r(x)+K_i.e_r(x) \quad (18)$$

Table 1
Fuzzy rules

Δe/e	NB	NM	NS	Z	PS	PM	PB
NB	NB	NM	NS	NS	NS	NS	Z
NM	NB	NM	NS	NS	NS	Z	Z
NS	NM	NS	NS	NS	Z	NS	PM
Z	NS	NS	NS	Z	PS	PM	PM
PS	NS	NS	Z	PS	PS	PS	PS
PM	NS	Z	NS	PM	PS	PM	PM
PB	Z	PS	PM	PB	PB	PB	PB

Where,

$e_r(x)$: speed error of working interval,

$e_r(x-1)$: speed error of previous interval,

K_p and K_i: proportional and integrator speed controller gains, respectively.

2) Fuzzy Logic Controller

The fuzzy controller is an intelligent controller defines the laws of control of all the system from adopting rules, he composed two inputs: error and variation in the error rate as expressed in equation (20):

$$e_r x = \omega_r x - \omega_r(x-1) \quad (19)$$

$$\Delta e_r x = e_r x - e_r(x-1) \quad (20)$$

It involves three steps: fuzzification, inference and defuzzification. The fig. 5 presents the diagram of fuzzy logic controller.

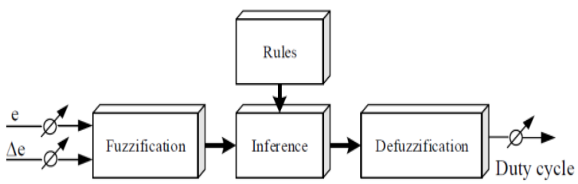
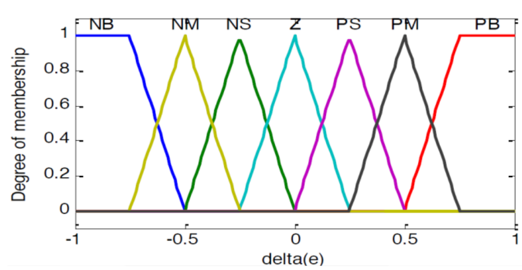
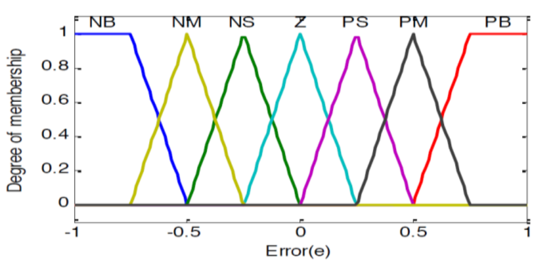


Fig. 5. Structure of fuzzy logic controller

In the fuzzification stage, variable digital inputs are converted into linguistic variable in our case with the seven values NB: Negative big; NM: Negative medium NS: Negative small; Z: Zero; PS: Positive small; PM: Positive medium; PB: Positive big, as seen in fig. 6.





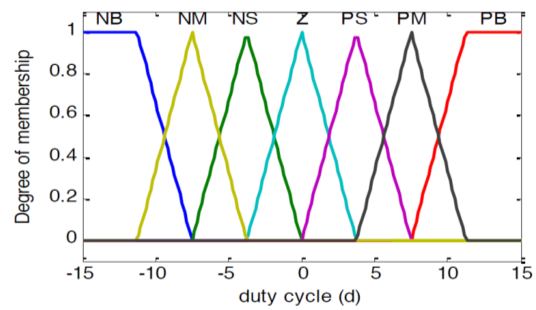


Fig. 6. Rules of fuzzy logic controller

The inference rules will be illustrated in table 1 with two input variables as (e) and (Δe) where (d) as the output.

5. Results and Discussion

The simulation results of the speed control of PV water pumping system employing PMSM drive are developed using MATLAB/ Simulink R2010. The performance of the PV based PMSM drive system for water pumping application is evaluated under various operating conditions and observed in terms of PV voltage (V_{PV}), PV currents (I_{PV}), PMSM currents (I_{mabc}), PMSM speed (N), electromagnetic torque and load torque (T, T_l), DC link voltage (V_{dc}) and mechanical power (P_m) is presented. Fig. 8 presents the simulation diagram.

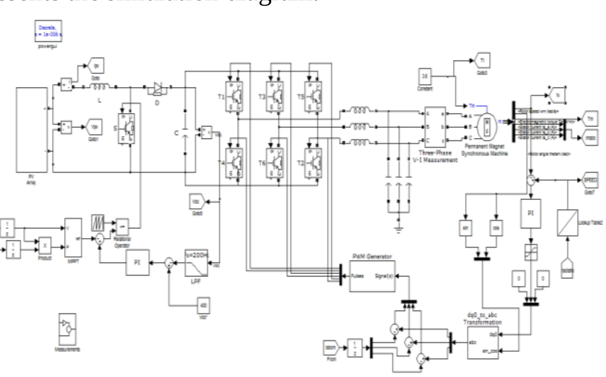


Fig. 7. Simulation block

A. Performance of PV based PMSM Drive under Starting

Fig. 9 shows the performance of the PV based PMSM drive under starting. During starting of a PMSM drive, it is observed that the DC link voltage is maintained constant and motor allows developing rated torque. The PMSM achieves the reference speed in a 50 ms. The observed performance of proposed drive establishes the efficacy of proposed system.

B. Transient Performance of PV based PMSM Drive

Fig. 10 shows the performance of solar PV based PMSM drive under step change in irradiation. At 0.6s, a step change in PV radiation from 1000 to 900 W/m2. It leads to instantaneous change in electromagnetic torque of PMSM due to which the PMSM starts deaccelerate and it is achieved the desired speed within 20 ms. The time require to achieve steady state point is reasonably small. However, under such transient conditions, the DC link voltage remains fairly constant and necessary changes in stator currents are also monitored to maintain power balance between input supply and load.

C. Steady State Performance of the PV based PMSM Drive

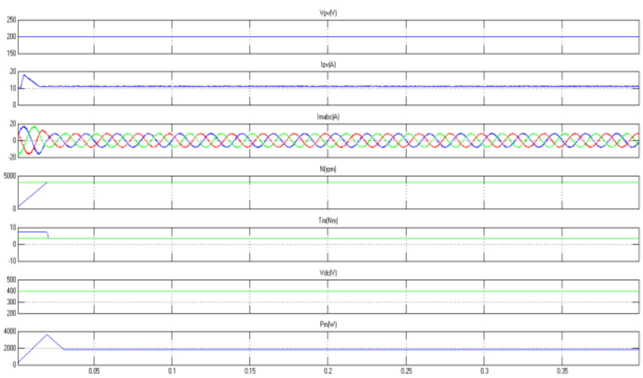


Fig. 8. Performance of PV based PMSM drive during starting

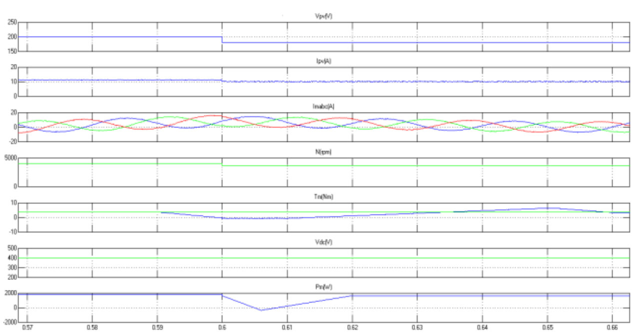


Fig. 9. Performance of the PV based PMSM drive under change in solar irradiation

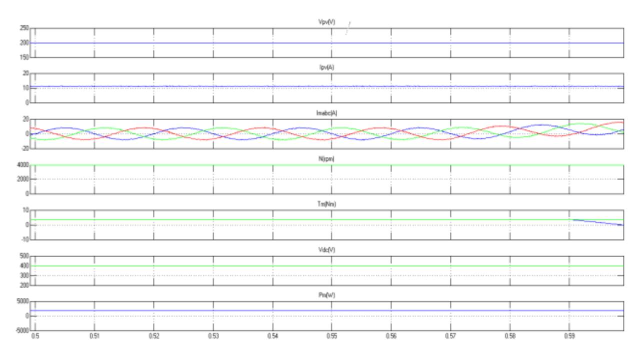
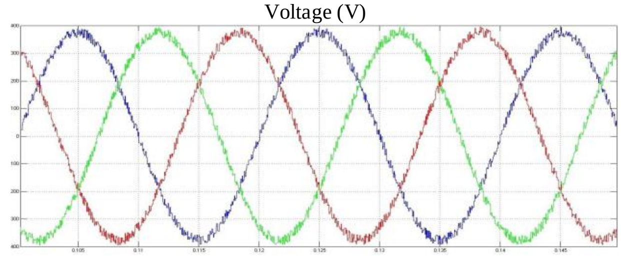


Fig. 10. Performance of the solar PV based PMSM drive under constant solar irradiation

Fig. 11 shows the performance of the solar PV based PMSM drive under steady state operation at the rated condition. The PMSM drive is running at 4000 rpm which is the rated reference speed. The electromagnetic torque (Te) developed by PMSM, coincides with the load torque (TL) which is the function of speed as evident from obtained results. A centrifugal pump load is considered in this study. The DC link voltage is maintained at its reference value and three phase PMSM stator currents are observed balanced and sinusoidal.

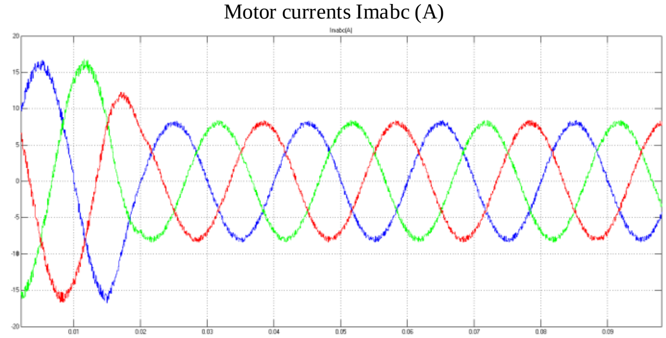
Voltage (V)



Time(sec)

Fig. 11. Inverter voltages (V)

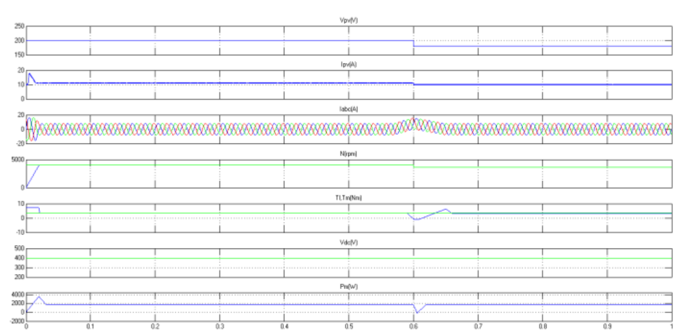
Motor currents Imabc (A)



Time(sec)

Fig. 12. PMSM Motor currents Imabc(A)

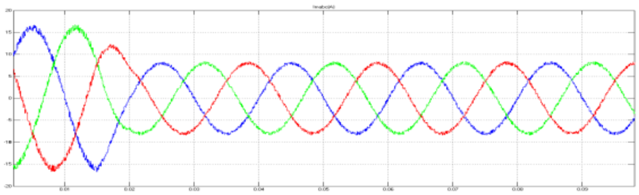
The performance of photovoltaic pumping system employing PMSM drive with proportional integrator controller and fuzzy logic controller is analyzed. Performance of the solar PV based PMSM drive with fuzzy logic controller is shown in Fig.14. Performance of PV based PMSM drive - during starting is from time 0 to 0.4 sec, under change in solar irradiation is from 0.55 to 0.65 sec and under constant solar irradiation is from 0.5 to 0.6 sec.



Time(sec)

Fig. 13. Performance of the solar PV based PMSM drive with Fuzzy logic controller

Motor Currents with PI controller:



Motor currents with Fuzzy logic controller:

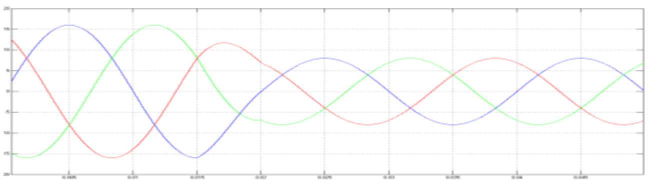
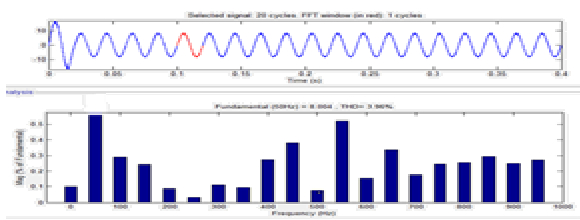


Fig. 14. Comparison of motor currents with PI controller and Fuzzy logic controller

Motor Currents THD (3.96%) with PI controller:



Motor currents THD (0.45%) with Fuzzy logic controller:

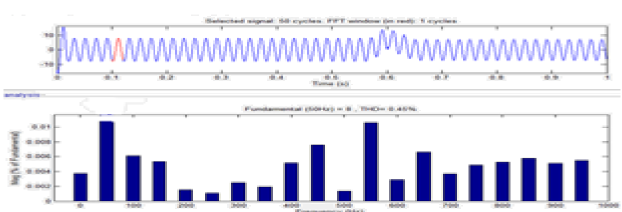


Fig. 15. Comparison of THD in motor currents with PI controller and Fuzzy logic controller

6. Conclusion

The objective of this paper is to tracking the current and voltage of solar array to get the maximum power possible of the Photo Voltaic Generator (PVG) regardless of the different climatic conditions such as solar radiation and temperature.

The artificial intelligence controllers can give more accurate results than traditional controllers for non-linear systems. The performance of Perturb and Observe Algorithm is done by using Different Controllers with proportional integrator controller and fuzzy logic controller is analyzed. The speed is controlled by fuzzy controller. To compare the both test results indicates the acceptability of fuzzy logic controller performance in the proposed work. There was a greater speed, a good rejection of load disturbance.

Appendix

Specifications of Boost converter	Interface inductor- 2.67 mH, DC link capacitor- 1800µf, DC PI gain Kp=0.289, Ki=1.8
PV system parameters	Pv cell per string(ns)=1500 , Pv strings (np) =176, Ideality factor(A)=1.92, Cell reference temperature(Tref)=300K,Temperature coefficient(Kv)=0.0017A/K, Cell short circuit current(Iscr)=8.03A, Reverse saturation current(Irs)=1.2*10-7 A.

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