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Performance Improvement and Speed Control Of PMSM and IM for Water Pumping Applications

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Abstract: ***In this paper a PVA fed Induction machine (IM) and PMSM inverter drive circuit is proposed with vector control to maintain speed of the motor with respect to solar irradiation. The speed of the IM &PMSM is controlled by feedback from the sensor of machine. The speed controller is upgraded with MPPT reference speed estimation which generates required speed with respect to voltage and current feedback from PVA.The speed controller of PMSM is updated with 49 rule based fuzzy interface system with 7 membership functions. The circuit is modelled in MATLAB Simulink environment with results and graphs generated with respect to time.***

Keywords : PVA (Photo Voltaic Array), PMSM,MPPT, FuzzyLogic Controller and MATLAB/Simulink.

I. INTRODUCTION

In future era with huge advancement in electrical consumption the load demand increases which needs to be met with supply generation. The supply generation from conventional sources leads to increase in global warming and also increase in pollution. These conventional sources include thermal coal plants or nuclear power plants which generate hazardous gases danger for human civilization and also environment. These ways of conventional power generation need to be replaced with renewable source power generation like solar panels, wind farms, bio gas plants, tidal energy sources. In the available renewable sources [1] solar panel renewable energy generation is considered as the best source with easy installation and operational maintenance. Solar panels can be used in any place even in remote areas without any hazard to human civilization. Other renewable source needs specific places like wind farms need to be installed far away from human interference, tidal renewable source is to be installed only in seas or oceans, bio gas plants need to be installed deep into the ground. All these sources need specific space and the cost of installation is also very high. On the other hand, solar panels (PVA) can be placed on the roof tops of urban buildings, empty uncultivated barren lands far or near the load consumptions. The PVA arrangement [2] can also be done in movable applications like electric vehicles to charge the battery or run the motor directly or water pumping system to transfer water to higher position for later use. The only issue with the solar renewable energy source is it generates power only in the day time and will be completely dead during the night time. Application which have secondary source backup like batteries or applications which needs only day time operation can be installed with solar panels. The power from the solar panel is also not constant as the solar irradiation (Ir) is not constant. During variation of solar irradiation, the voltage output of the PVA varies which changes the current flow changing the power output from the panel. For the considered application of water pumping system, it is viable to use solar panels with variable voltage and also operation during only day time.

For the proposed application of water pumping system constant power supply is not necessarily needed, and speed of the machine need not to be constant for pumping the water [3]. This ability of variable supply qualifies PVA as source with variable output power. To run the motor at different speeds with different speed reference generation vector controller is used to operate the voltage source inverter (VSI). To compare two machines working using vector controllers, induction machine and permanent magnet synchronous machine are considered. The vector control of VSI and solar input with PMSM drive water pumping system along with sensor less vector control of induction machine is shown below.

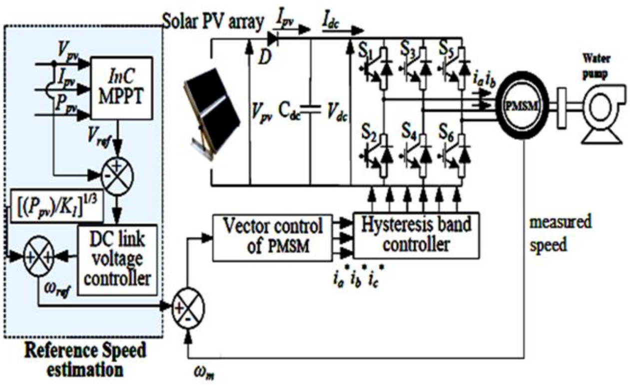

Fig. 1. Proposed circuit topology with vector controller of PMSM and PVA input.

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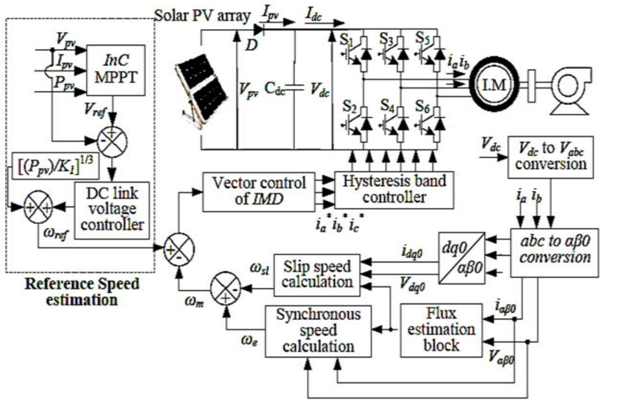

Fig. 2. Proposed circuit topology with vector controller of IM and PVA input.

II. SYSTEM CONFIGURATION

In the proposed circuit topology specific PVA arrangement is used with rating of the PMSM are taken with respect to it. In the proposed topology the voltage rating of the PVA is taken at 300V during optimal solar irradiation (Ir) of 1000W/mt^2. The voltages vary with respect to change in solar irradiation. The rating of the solar panel is given below in table I

TABLE I

Name of the parameter	Parameter value
Each cell voltage Vc	0.42V
Each cell minimum current Ic	10mA
Number of series cells Ns	715 Nos.
Number of parallel cells Np	33333 Nos.
Benchmark solar irradiation Sc	1000 W/mt^2
Benchmark ambient temperature Tc	20^{0}C
Short circuit current Isc	5amp

As mentioned in the parameter table of PVA configuration [2] the number of series cells Ns connected are 715 with each cell voltage Vc of 0.42V. Therefore, the total voltage output of the PVA is calculated as

$$Vpva = Ns \times Vc \ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$= 715 \times 0.42$$

$$= 300.3V$$

With number of parallel cells Np connected are 33333 the total current output of the PVA is calculated as

$$Ipva = Np \times Ic \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

$$= 33333 \times 0.01$$

$$= 333.33 \text{ A}$$

The total power output of the PVA is calculated as

$$Ppva = Vpva \times Ipva \ldots\ldots\ldots\ldots\ldots..(3)$$

$$= 300.3 \times 333.33$$

$$= 100kW$$

The maximum power output of the PVA during optimal solar irradiation of 1000W/mt^2 is 100kW. So, a three-phase salient pole PMSM of 100kW rating is connected to VSI for water pumping system which can run at different speeds. The rating of PMSM is given in table II.

TABLE II

Name of the parameter of PMSM	Parameter value
Nominal Power Pn	100kW
Nominal Voltage Vph	122Vrms
Nominal frequency f	50Hz
Stator resistance Rs	8.296m ohms
d-axis inductance Ld	0.1741mH
q-axis inductance Lq	0.2926mH
Inertia J	0.089kg.m^2
Number of poles P	4

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A. *Design of water pump:*

A Centrifugal pump is attached to the motor shaft which pumps the water and it is designed to operate at its rated power and speed and it has non-linear relationship between motor torque and motor speed.

III. CONTROL STRUCTURE

The controller of PMSM has speed sensor measuring the speed of the machine given as a feedback to the vector control. The reference speed is generated by the MPPT algorithm [4] and DC link voltage controller. The controller comprises of Parks and Clarks transformations for reduction of complex format signals to simple d-q axis components. The d-qaxis components in stationary reference frame can be used for arithmetic calculations for generation of reference values fed to sinusoidal pulse width modulation. The MPPT algorithm used for generation of reference speed is incremental conductance method which is one of the fastest converging algorithms in MPPT techniques. The below is the flow chart of incremental conductance algorithm applied in the controller.

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	Table column subhead	***Subhead***	***Subhead***
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[a] Sample of a Table footnote. (*Table footnote*)

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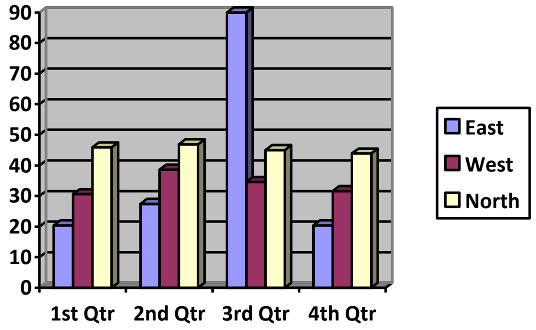

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B. *Design of water pump:*

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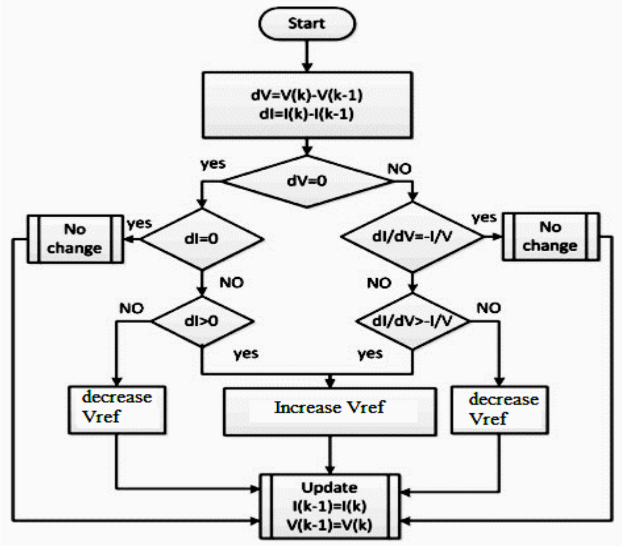


Fig. 3.Incremental conductance MPPT algorithm

The MPPT algorithm [5] takes voltage and current measurements [6] of PVA with present and past value generation. The comparison of these values will generate change in voltage current of PVA with change in solar irradiation. The reference voltage (Vref) is increased or decreased with respect to change in current by voltage ratio. The generated reference voltage value is compared to measured voltage of PVA generating voltage error. The voltage error is fed to DC voltage PI controller generating reference speed for the vector controller. The vector controller implemented [7] for the PMSM is shown below.

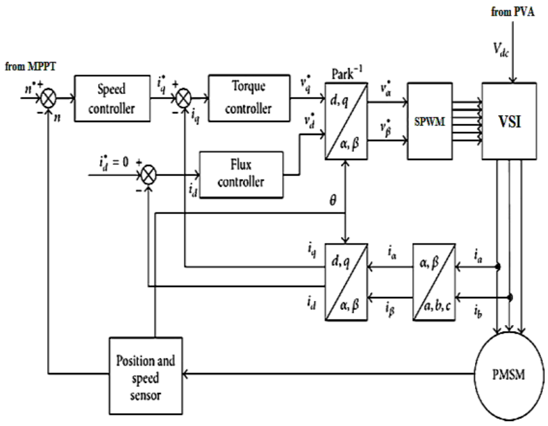


Fig. 4. Vector control of PMSM

The speed, torque and flux controllers have PI controllers with specific Kp and Ki values for generation of reference voltage d-q axis components. The Clarks and Parks transformation are given below.

$$\begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} = \begin{bmatrix} \frac{2}{3} & \frac{-1}{3} & \frac{-1}{3} \\ 0 & \frac{1}{\sqrt{3}} & \frac{-1}{\sqrt{3}} \end{bmatrix} \begin{bmatrix} ia \\ ib \\ ic \end{bmatrix} \text{..................(4)}$$

$$\begin{bmatrix} id \\ iq \end{bmatrix} = \begin{bmatrix} \cos\Theta & \sin\Theta \\ -\sin\Theta & \cos\Theta \end{bmatrix} \begin{bmatrix} i\alpha \\ i\beta \end{bmatrix} \text{............(5)}$$

To generate reference values for sinusoidal pulse width modulation inverse Clarks and Parks transformation are used which are given below.

$$\begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} = \begin{bmatrix} \cos\Theta & -\sin\Theta \\ \sin\Theta & \cos\Theta \end{bmatrix} \begin{bmatrix} vd \\ vq \end{bmatrix} \text{.......(6)}$$

$$\begin{bmatrix} va \\ vb \\ vc \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ \frac{-1}{2} & \frac{\sqrt{3}}{2} \\ \frac{-1}{2} & \frac{-\sqrt{3}}{2} \end{bmatrix} \begin{bmatrix} v\alpha \\ v\beta \end{bmatrix} \text{..............(7)}$$

The reference voltage values are compared to high frequency triangular waveform generating pulses for six switches of VSI [9]. The control of the voltage from VSI controls the PMSM speed at the given reference value from MPPT controller.

The same MPPT speed reference is also used for vector control of induction machine without speed sensors. The vector control of induction machine alsoincluding parks and Clarkes transformations. The estimated rotor speed (w_m) of the IM is given as

$$w_m = w_e - w_{sl} \text{ ....(8)}$$

here, we is electrical synchronous speed; w_{sl} is slip speed of the machine

The w_e and w_{sl} are give as

$$w_e = \frac{(V_\beta - R_s \times i_\beta)\psi_\alpha - (V_\alpha - R_s \times i_\alpha)\psi_\beta}{\psi_s^2} \text{.....(9)}$$

In the above equation the flux components are given as

$$\frac{d}{dt}(\psi_\beta) = V_\beta - R_s \times i_\beta \text{................(10)}$$

$$\frac{d}{dt}(\psi_\alpha) = V_\alpha - R_s \times i_\alpha \text{................(11)}$$

$$\psi_s = \sqrt{\psi_\alpha^2 + \psi_\beta^2} \text{........................(12)}$$

The slip speed estimation of the IM is given as

$$w_{sl} = \frac{(1+\sigma S\tau_r)L_s i_{qs}}{\tau_r(\psi_d - \sigma L_s i_{ds})} \text{.....................(13)}$$

Here σ, τ_r is given as

$$\sigma = \frac{1-L_m^2}{Ls \times Lr} \text{.............................(14)}$$

$$\tau_r = \frac{Lr}{Rr} \text{.................................(15)}$$

Lr=rotorinductance, Ls = stator inductance, Lm=magnetizing inductance, Llr= rotor leakageinductance, Lls= statorleakage inductance, Rr=stator referredrotor resistance, Rs=stator resistance.

The vector control of induction machine is given below

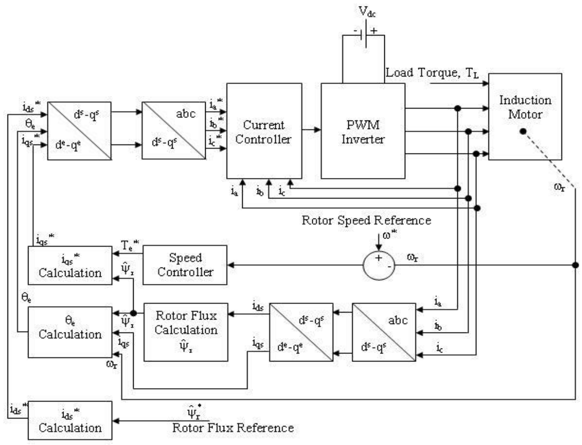


Fig. 5. Vector control of induction machine

After the estimation of required reference stator current values, the reference values are compared to measured values with hysteresis band generating pulses for the VSI.

***Speed control of pmsm using fuzzy system*:**

The speed controller of pmsm with PI controller is now replaced with fuzzy logic controller to improve the performance of the motor .The fuzzy logic controller with seven membership functions in each variable which is 49 rule base is implemented[10].The input membership functions are speed error and change in speed error and output membership function is current and rule base are shown below

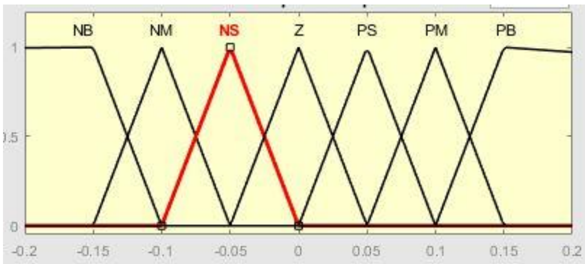


Fig. 6: Membership function speed error

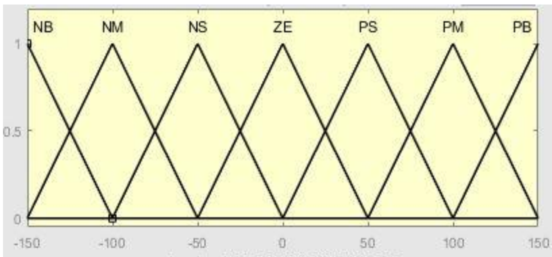


Fig. 7. input membership function change in speed error

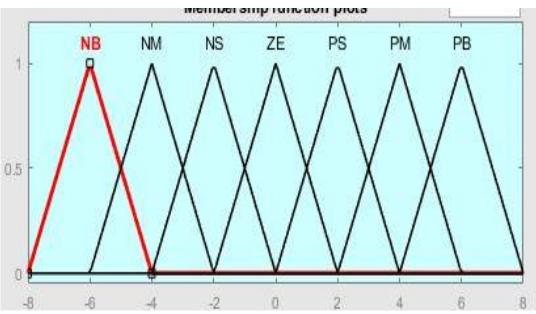


Fig. 8: Membership function

		←		e		→		
		NB	**NM**	**NS**	**EZ**	**PS**	**PM**	**PB**
	PB	Z	PS	PM	PB	PB	PB	PB
↑	**PM**	NS	Z	PS	PM	PB	PB	PB
	PS	NM	NS	Z	PS	PM	PB	PB
de	**EZ**	NB	NM	NS	Z	PS	PM	PB
	NS	NB	NB	NM	NS	Z	PS	PM
↓	**NM**	NB	NB	NB	NM	NS	Z	PS
	NB	NB	NB	NB	NB	NM	NS	Z

Fig. 9. Fuzzy rule base system is shown

IX. RESULTS AND DISCUSSION

The PVA integrated VSI with PMSM drive controlled by MPPT speed reference vector-oriented control is modelled in MATLAB Simulink and simulation is carried out for 4secs.

The results generated from the model are graphs with respect to time. The solar irradiation is varied from 1000W/mt^2 to 500W/mt^2 at 2sec

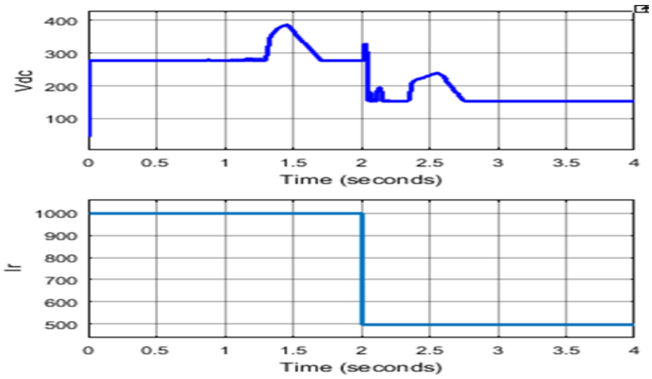
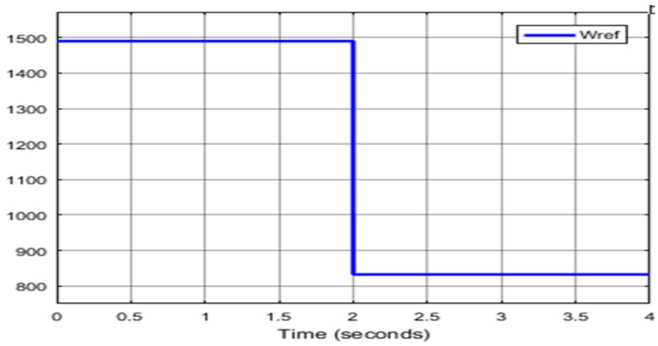


Fig. 10. Voltage of PVA with respect to variable solar irradiation



e **Fig. 11.Speed reference generation from MPPT controller**

In the above graphs the PVA voltage (Vpva) and speed reference (Nref) generation are changed with respect to change in solar irradiation (Ir) at 2sec. The speed reference is changed from 1500rmp to 820rpm at 2sec by the MPPT controller

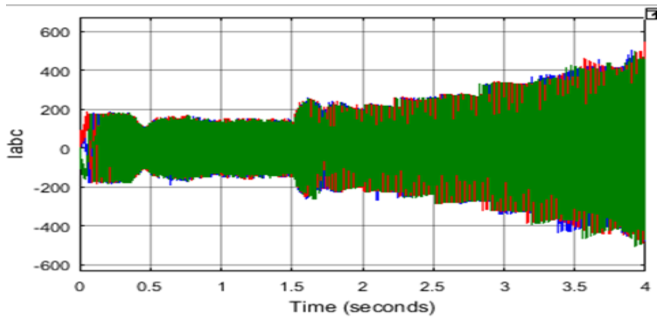


Fig. 12. Current input to PMSM

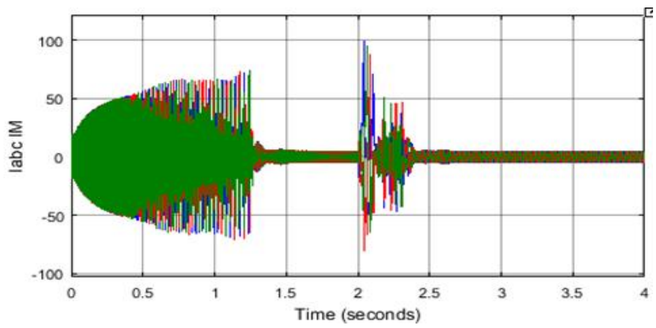


Fig. 13. Current input to IM

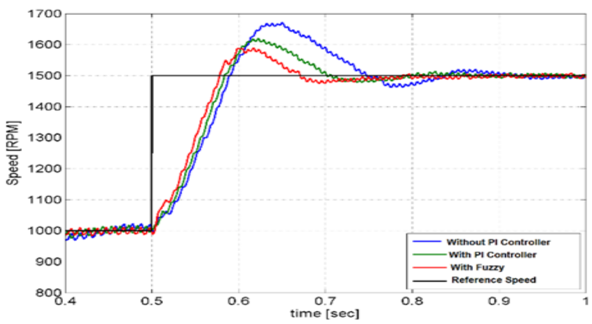


Fig. 14. Speed comparison of PMSM with PI and Fuzzy.

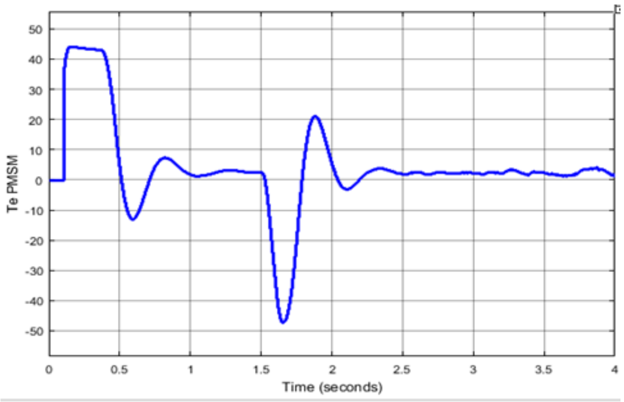


Fig. 15. Electromagnetic torque of PMSM

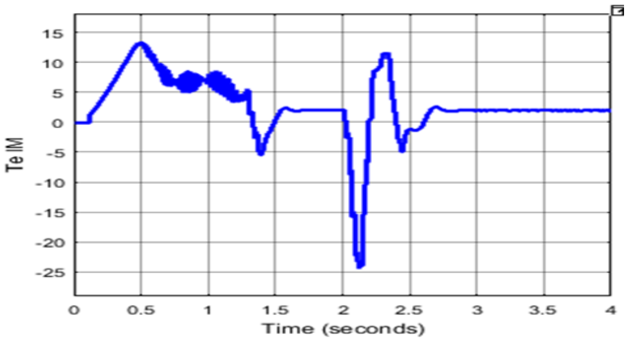


Fig. 16: Electromagnetic torque of IM

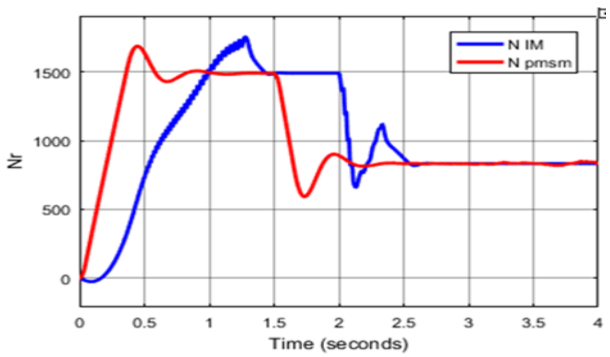


Fig. 17.Speed comparison of PMSM and IM

The above are the graphs of PMSM and IM characteristics with measurement of speed, currents and electromagnetic torque of the machines changing with respect to the refence speed generation from MPPT controller.

X. CONCLUSION

With the above modelling of PVA integrated vector controlled VSI for PMSM and IM drive with MPPT speed reference controller the PMSM and IM is changing its speed with respect to change in solar irradiation. The speed of the motors is changing from 1500rpm to 820 rpm as per the reference speed given by the MPPT controller. The motor now is operating in required speed with change in solar irradiation for pumping water and will be stopped when there is no PVA power input during night time. The settling of speed in PMSM is faster and has reduced disturbance as compared to IM. The PMSM speed controller with fuzzy system has better speed response than the PI controller.

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