

# PV-Fed Switched Reluctance Motor For Agricultural Needs

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**Abstract**—In the recent technology, PV systems are the most commonly used sources in many applications. The electrical energy which is generated by the PV cell can feed loads. In agricultural field applications electrical motors are required to feed water for the field. Many motors compete for this kind of application in agricultural fields but switched reluctance motor (SRM) has many advantages over other motors. In this paper, application of SRM for agricultural fields with closed loop operation is discussed. The maximum available power at any moment can be extracted by using maximum power point tracking (MPPT) algorithm. MPPT with perturb and observe (P&O) method is used for extracting the maximum power. The Models discussed here are simulated using MATLAB/SIMULINK and the results are critically analyzed.

**Keywords**—Switched reluctance motor, PV cell, MPPT, Perturb & Observe, agricultural field.

## I. INTRODUCTION

Widespread use of solar energy for domestic and agricultural activities is being practiced since many decades. In recent era, the use of photovoltaic system is used in many applications. Progress in the technology and rise in manufacturing techniques in photovoltaic systems(PV)units with ease of operation gives photovoltaic (PV) systems motivate users to employ PV systems extensively for their applications. In PV cells, sun radiation is converted to electrical energy at sub-atomic level which in turn can drive load. Silicon is mainly used as the base material in the production of PV cells and by adding trivalent and pentavalent elements to the pure silicon structure, n-type material and p-type material can be formed respectively. PV cells are formed by layering n-type and p-type semiconductor materials together [2]. The photons emitted by the sun radiation fall on p-n junction semiconductor device, the valence electrons which are in the outer most shell escape to conduction zone. Movement of these free electrons causes current to flow producing potential difference at the terminals. The electrical energy generated by PV cells can be used at user end.

Switched Reluctance Motor is a very common device for most of the applications due to its unique advantages over many other AC and DC motors. There are many advantages and some of them are stated in this paper. Construction of

SRM is simple and cost of the machine construction is low due to the absence of rotor windings and permanent magnets. Because of series connected stator windings with converter switches, the problem of shoot-through faults are eliminated in SRM drive system. Unidirectional current requirement by the SRM drive makes drive circuit very reliable and simple. SRM motor has low rotor inertia and has high torque to inertia ratio. SRM is more robust than other machines since the stator phases are controlled independently and failure of any one phase does not influence the drive operation. SRM motor can be operated in insensitive environment.

## II. PV SYSTEM MODEL

Figure – 1 shows simple PV model consisting of a current source, anti-parallel diode, parallel resistor  $R_{SH}$  and a series resistor  $R_s$ . PV output current is given by:

$$I = I_L - I_0 \left( e^{\frac{q(V+IR_s)}{nkT}} - 1 \right) - \frac{V + IR_s}{R_{sh}}$$

The value of  $R_s$  varies as reciprocal of solar irradiance.  $R_{sh}$ , which is the leakage resistance, is typically large having a value normally greater than 100k. The value of  $R_{SH}$  which is leakage resistance typically large and is greater than 100kilo ohms. From fig.1, it can be seen that, the total current delivered is algebraic sum of currents passing through diode, shunt branch and incoming source current  $I_L$ .

In the power-voltage curve of solar panel the selection of an optimal operating point gives the information about maximum power delivered by the PV cell to the load [3]. Maximum power point tracking (MPPT) is employed to extract maximum power from the system. Several MPPT methods are available to attain maximum power from the PV system varying from simple voltage relations to complex multiple sample based analysis.

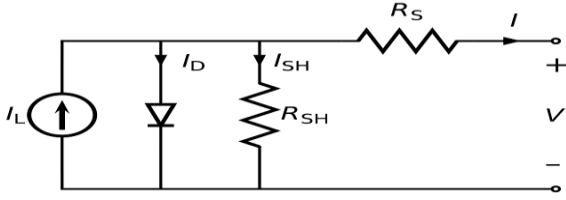


Figure – 1: Simple PV model

The problem which is considered by MPPT methods is to find automatically the current  $I_{MPP}$  and voltage  $V_{MPP}$  at which an array of PV cells can deliver maximum power from the given temperature and solar irradiance.

Many MPPT techniques like fractional open-circuit voltage, fractional short circuit current, Perturb and Observe, Incremental conductance and temperature parametric methods are available. Out of which Perturb and Observe (P & O) method is employed in this paper to attain maximum power from the PV arrays. Perturb and Observe algorithm seeks the power output and searches for maximum power by adjusting the PV current and voltage [4]. The tracking is done periodically by increasing or decreasing the array voltage. By adjusting the voltage periodically if the perturbation results in increasing output power then the succeeding perturbation is continued in the same manner. Conversely if the perturbation leads to decrease in the power output, the next successive perturbation is generated in the opposite direction to that of earlier case. So, the duty cycle of the buck converter changes and the course is continued until maximum power point is reached.

In this process, the system oscillates about maximum power point (MPP) and the oscillations can be minimized by reducing the perturbation step size. But, with small step size of the perturbation the process might become slow. So the selection of step size of the perturbation is exceptionally significant where large step size might create oscillations about maximum power point and smaller step size might slow down the process resulting in sluggish response to the changes in irradiance.

Figure-2 shows the block diagram of PV fed SRM model containing PV system, boost converter, SRM motor with converter. Boost converter is controlled by controlling the duty cycle produced from the MPPT algorithm.

### III. SRM MODEL

Switched Reluctance Motor is obtaining rehabilitated notice as an erratic applicant for different variable speed and torque applications.

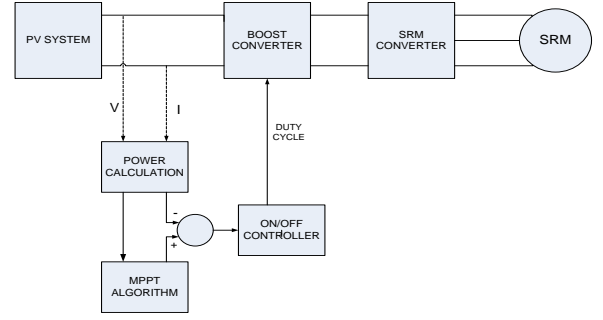


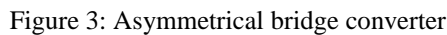
Figure 2: Block diagram of PV fed SRM Model

Having the unique characteristics in terms of simplicity and effective power converter results, SRM drive system is most preferred over other AC and DC motor drives. SRM is a doubly-salient machine consisting of independent phase windings on both rotor and stator. Diagrammatically opposite pole windings are connected in series to form a phase of motor. When stator pole windings are excited the very near rotor pole gets attracted towards the energized stator having low magnetic reluctance. By switching the respective stator phases rotor tends to rotate developing torque. Each phase winding is excited separately with increasing inductance for positive torque and vice-versa [5].

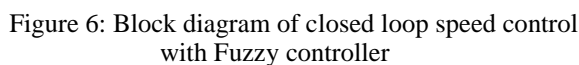
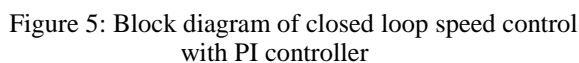
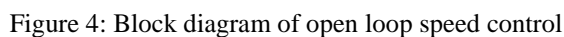
Torque indicates the motor characteristics and application of any motor depends on the torque. In SRM, since the torque is directly proportional to the square of the current we can say torque has no relation with the polarity of the current and thus, SRM drives requires only a single switch per phase which is not the case in AC motors where for the control of current they require at least two switches per phase winding. The torque expression requires relation between rotor position and flux linkage [6]. Torque can be controlled by the flux linkage magnitude control and also by change in speed of stator flux vector [7]. SRM drives give us complete autonomy over the control and generation of torque since SRM have negligible mutual coupling between the phase windings. But careful handling of phase windings is necessary since the energy is stored in the form of magnetic energy [8]. The way we handle this stored energy in the phase windings makes us the way to design number of topologies for SRM drive systems. This stored energy, sometimes returned to the DC source by means of electromagnetic or electronic means, sometimes freewheeled; sometimes energy is converted to electrical/mechanical energy and also partially dissipated in the phase windings. Generally for SRM converters, the DC source may be from batteries or usually from the rectified source.

In this paper, asymmetrical configuration of the converter is employed for the drive system. Figure-3 shows the asymmetrical converter configuration, switching-ON transistors  $T_1$  and  $T_2$  will cause a current to flow in phase A and similarly in other two phases by switching  $T_3$ ,  $T_4$  and  $T_5$ ,  $T_6$  respectively [9-10]. If the current reaches its final value then transistors  $T_1$  and  $T_2$  are turned-OFF allowing the current to flow in the same direction though diodes  $D_1$  and  $D_2$  until the energy stored in the phase-A winding is dissipated. Diodes  $D_1$  and  $D_2$  will be in forward bias in this

switching devices but to decide the current rating is not as simple as voltage rating. Proper switching strategy is to be selected to provide equal rms current in the power switches and average current in the diodes.



The paper discusses both open loop and closed loop speed and torque control methods. In open loop speed and torque control technique, the reference speed and torque are set and the current controller produces pulses accordingly and controls the speed and torque. In open loop control, the feedback errors were not sensed and there might be errors at the output side. Whereas in closed loop speed and torque control, speed and torque are sensed at the output level and the error signal is feedback to the input such that more effective speed and torque was obtained. The error signal along with the reference signal is fed to the speed controller where the error signal is reduced by using any of the control strategy. To improve the system performance closed loop control strategy is also discussed with the proposed system which can also improve voltage frequency and magnitude. In this paper both closed loop PI and fuzzy controllers were discussed to reduce the error signal. In PI controller the error signal is reduced by reducing present error by proportional controller and the past errors were reduced by integral controller. In fuzzy technique, the error signal is fed to the fuzzy controller where the error signal is reduced by fuzzy control strategy which uses fuzzy rules for its controller operation.



Fuzzy rule based control system is a method combining both linguistic information and numerical information into a common framework. This type of control strategy mainly excludes the task of human beings in the control environment where complex control systems are involved. The figure-6 shows close loop fuzzy control for SRM drive system. Here, the actual speed is sensed and is compared with the reference speed signal and this error signal is sent to fuzzy controller producing reference current  $I_{ref}$ . The current signals are sensed from the machine windings and are now compared with the reference current producing hysteresis window thus giving out gate pulses to the converter, also included current controller to control the current [11].

$$(X_1^{(1)}, X_2^{(1)}, Y^{(1)}), (X_1^{(2)}, X_2^{(2)}, Y^{(2)}), \dots$$
$$(X_1^{(1)}, X_2^{(1)}, Y^{(1)}) \rightarrow [X_1^{(1)}(B1, \max) X_2^{(1)}(S1, \max); Y^{(1)}(CE, \max)] \rightarrow \text{Rule 1};$$
$$(X_1^{(2)}, X_2^{(2)}, Y^{(2)}) \rightarrow [X_1^{(2)}(\text{B1, max}), X_2^{(2)}(\text{CE, max}); Y^{(2)}(\text{B1, max})] \rightarrow \text{Rule 2};$$

If X1 is B1 and X2 is CE, THEN Y is B1.

The rules generated like this are “and” rules, we can say these rules are in which condition of IF part must meet simultaneously for the result of THEN part.

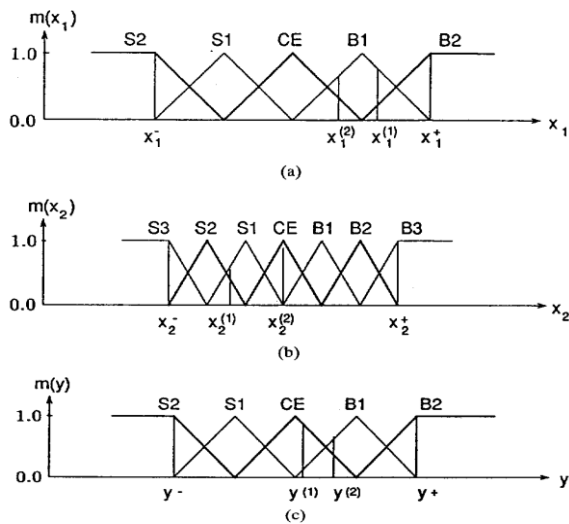


Figure 7: Division of input and output spaces into fuzzy regions, (a)  $m(X1)$ , (b)  $m(X2)$ , (c)  $m(Y)$ .

#### IV. MATLAB MODEL AND SIMULATION RESULTS

The paper was discussed for both open loop and closed loop operation of SRM with PI and Fuzzy control techniques. Here in this paper the Matlab models and simulation results were shown for 6/4 pole SRM both in open loop mode of operation and closed loop mode of operation with PI and fuzzy controllers.

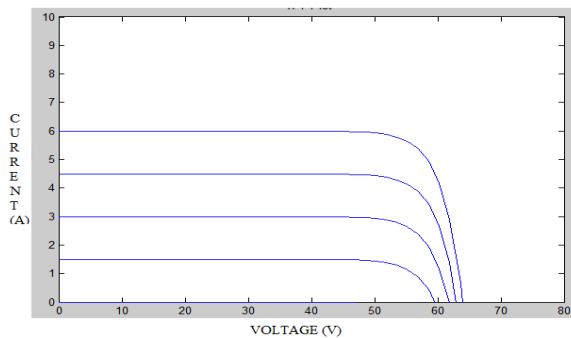


Figure 8: V-I characteristics PV system

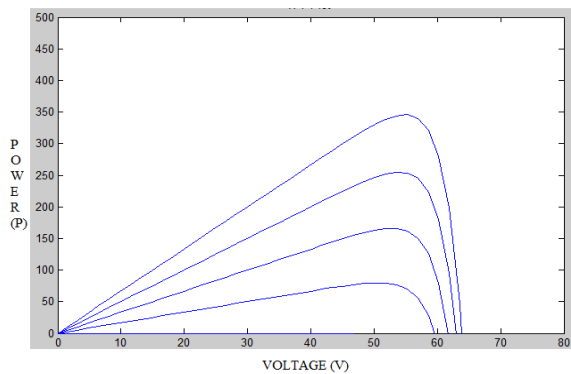


Figure 9: P-V characteristics of PV system

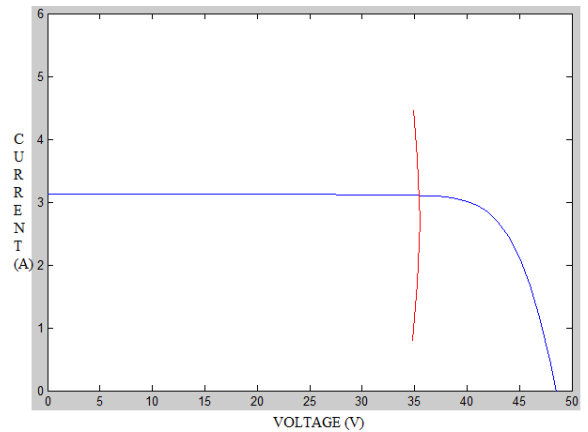


Figure 10: MPPT extracted from PV system

Figure-8 shows the Voltage - current characteristics of PV system and figure-9 shows the power – voltage characteristics of PV system while figure-10 gives us the maximum power point obtained from the PV system.

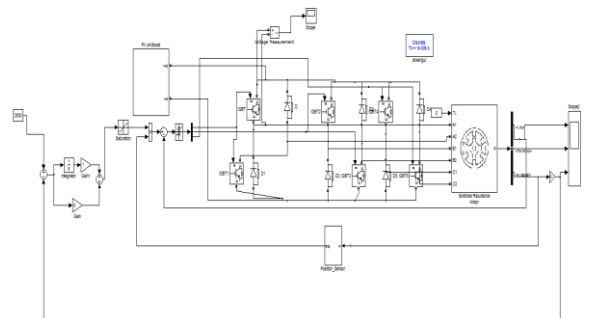


Figure 11: Matlab model of PV fed SRM with closed loop control

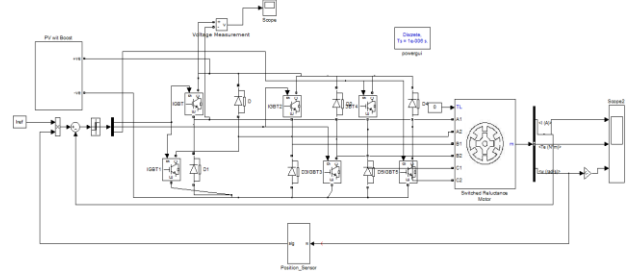


Figure 12: Matlab model of PV fed SRM with open loop control

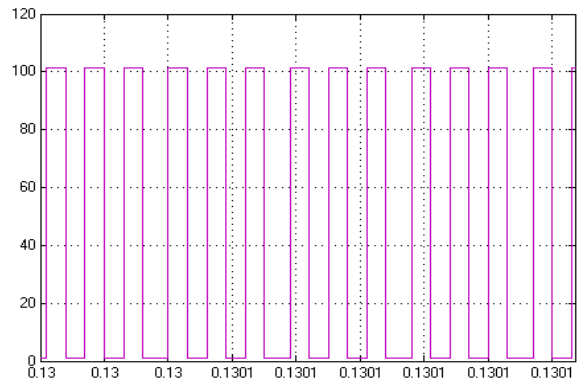


Figure 13: Boost output of PV fed SRM

Figure 11 and figure 12 shows the Matlab models of PV fed SRM with closed loop and open loop control respectively while figure 13 shows the boost converter output of PV fed SRM system where we can observe that the voltage is increased to 100V from nearly 60V produced at the output of PV array.

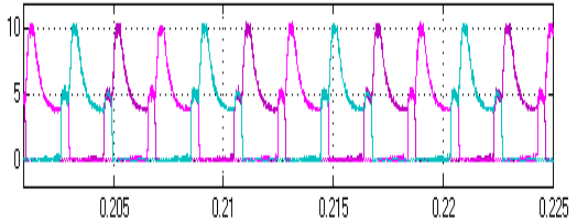


Figure 14: Phase Currents of PV fed 6/4 pole SRM with closed loop PI control

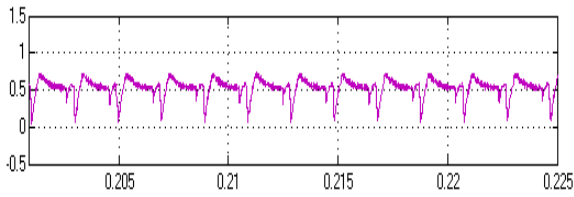


Figure 15: Torque of PV fed 6/4 pole SRM with closed loop PI control

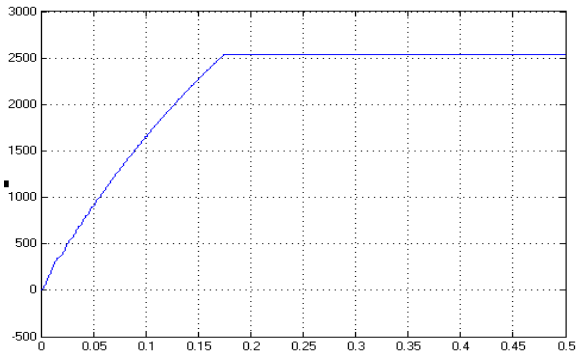


Figure 16: Speed of PV fed 6/4 pole SRM with PI closed loop control

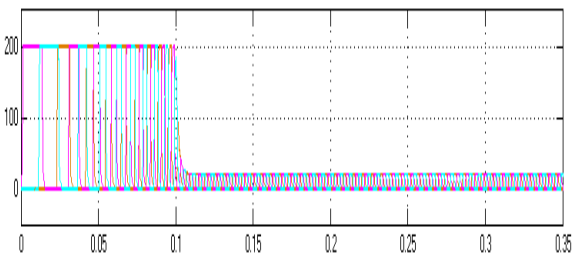


Figure 17: Phase Currents of PV fed 6/4 pole SRM with closed loop with fuzzy control

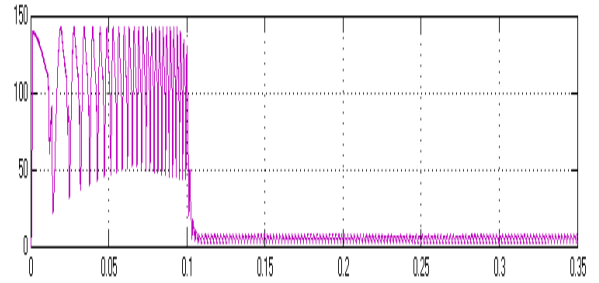


Figure 18: Phase Torque of PV fed 6/4 pole SRM with closed loop with fuzzy control

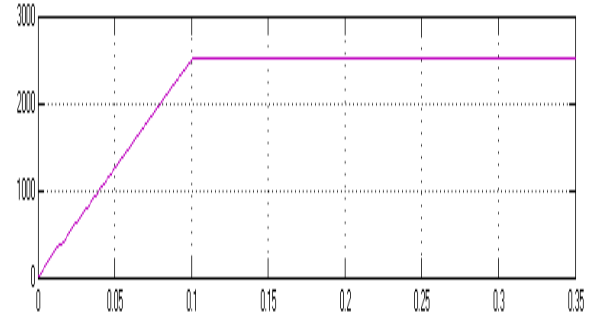


Figure 19: Speed in closed loop speed control of PV fed SRM with closed loop fuzzy controller.

Figure 14 and figure 15 show the current in a phase winding of SRM and torque respectively for PV fed 6/4 pole SRM with closed loop operation with PI controller. Figure 16 shows the speed for closed loop PV fed 6/4 pole SRM PI controller. Figure 17 and figure 18 show the current in a phase winding of SRM and torque respectively for PV fed 6/4 pole SRM with closed loop operation with fuzzy controller. Figure 19 shows the speed for closed loop PV fed SRM fuzzy controller. We can observe that the time taken by the speed to reach its desired value is 0.1 seconds approximately in closed loop operation with fuzzy controller which is less when compared to closed loop speed controller with PI scheme. We can also observe that the torque fluctuates and comes to a steady state value after 0.1 seconds using fuzzy control which is less time compared to PI controller.

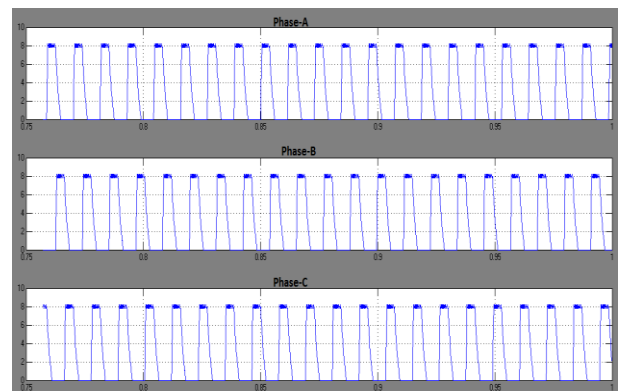


Figure 20: Phase currents in 6/4 pole open-loop SRM

Figure-20 shows the phase currents in 6/4 pole open loop speed control of SRM and the torque is shown in figure-21. Figure-22 shows the output result of speed in 6/4 pole open loop PV fed SRM where we can observe the speed reaches its final value at 0.4 seconds which is more when compared to both closed loop PI and fuzzy controls.

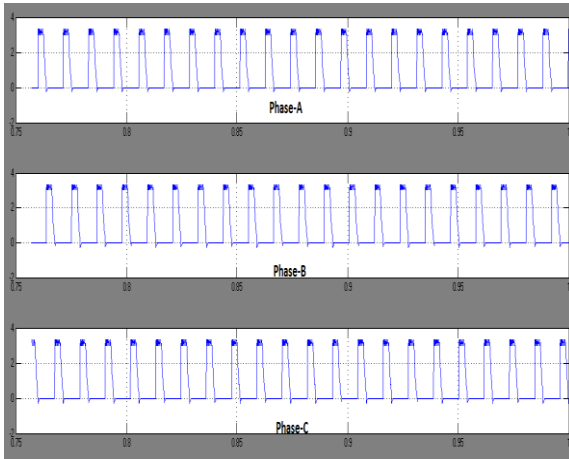


Figure 21: Phase torques in 6/4 pole open-loop SRM

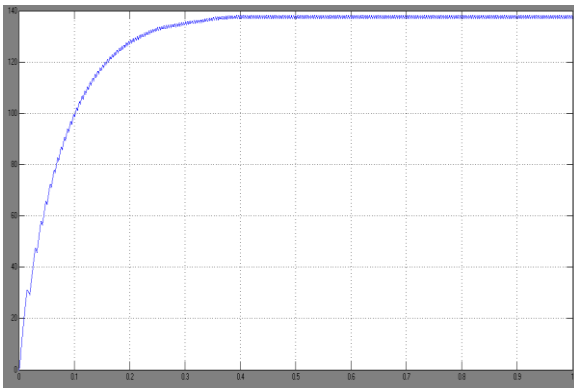


Figure 22: Speed in 6/4 pole open-loop SRM

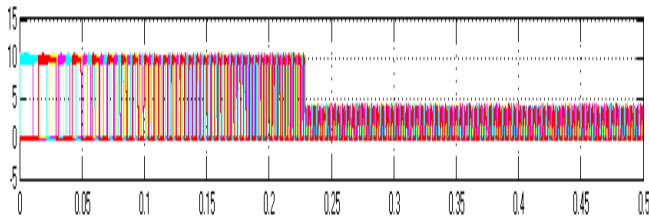


Figure 23: Phase Currents of PV fed 8/6 pole SRM with closed loop PI control

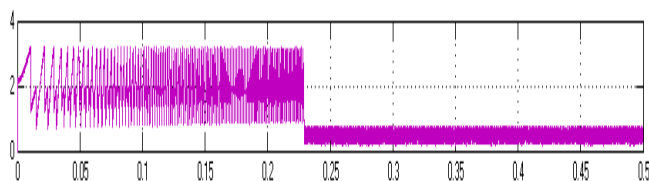


Figure 24: Torque of PV fed 8/6 pole SRM with closed loop PI control

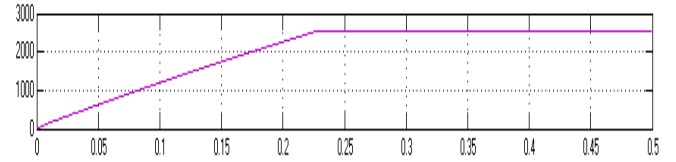


Figure 25: Speed of PV fed 8/6 pole SRM with PI closed loop control

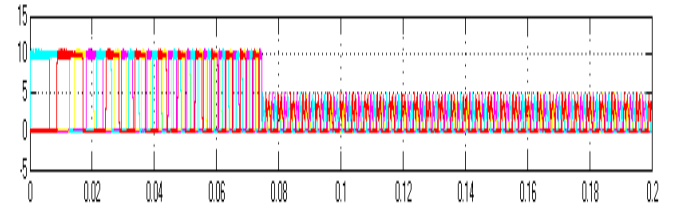


Figure 26: Phase Currents of PV fed 8/6 pole SRM with closed loop fuzzy control

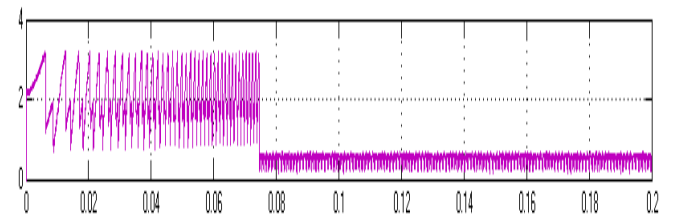


Figure 27: Torque of PV fed 8/6 pole SRM with closed loop fuzzy control

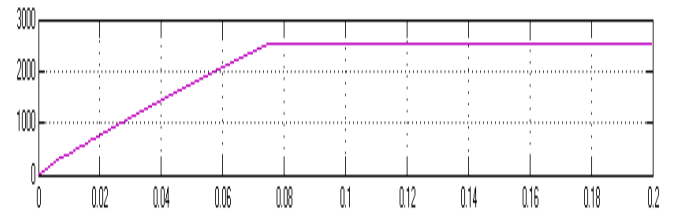


Figure 28: Speed of PV fed 8/6 pole SRM with fuzzy closed loop control

Figure 23 and figure 24 show the current in a phase winding of 8/6 pole SRM and torque respectively for PV fed SRM with closed loop operation with PI controller. Figure 25 shows the speed for closed loop PV fed 8/6 pole SRM PI controller. Figure 26 and figure 27 show the current in a phase winding of SRM and torque respectively for PV fed 8/6 pole SRM with closed loop operation with fuzzy controller. Figure 28 shows the speed for closed loop PV fed SRM fuzzy controller. We can observe that the time taken by the speed to reach its desired value is 0.075 seconds approximately in closed loop operation with fuzzy controller which is less when compared to closed loop speed controller with PI scheme. We can also observe that the torque fluctuates and comes to a steady state value after 0.075 seconds using fuzzy control which is less time compared to PI controller.



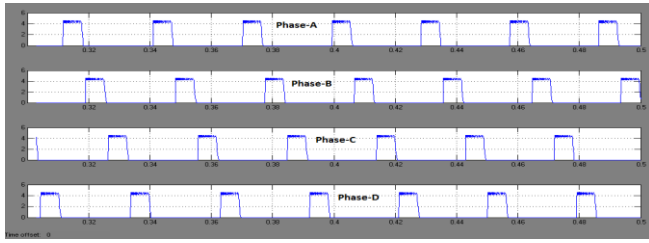


Figure 29: Phase currents in 6/4 pole open-loop SRM

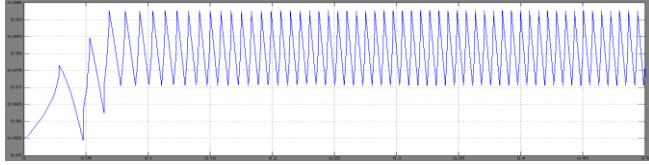


Figure 30: Phase torque in 6/4 pole open-loop SRM

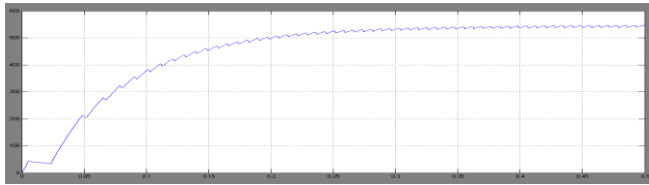


Figure 31: Speed in 6/4 pole open-loop SRM

Figure-29 shows the phase currents in 8/6 pole open loop speed control of SRM and the torque is shown in figure-30. Figure-31 shows the output result of speed in 6/4 pole open loop PV fed 8/6 pole SRM where we can observe the speed reaches its final value at 0.3 seconds which is more when compared to both closed loop PI and fuzzy controls.

Table 1 shows us the settling time taken by the closed loop operation of PV fed SRM employing both PI and fuzzy controllers for both 6/4 pole and 8/6 pole SRM. We can clearly observe from the results that the time taken by the drive system to reach its final speed is less when using fuzzy controller than that of using PI controller.

Table 1: Comparison of settling time with different control techniques

Converter		Settling Time (Sec)
Configuration	Controller	
Asymmetrical 6/4 pole SRM	Open loop	0.4
	Closed loop with PI	0.175
	Closed loop with Fuzzy	0.1
Asymmetrical 8/6 pole SRM	Open loop	0.3
	Closed loop with PI	0.23
	Closed loop with Fuzzy	0.075

## V. CONCLUSION

This paper discusses the SRM drive fed with PV system with boost converter in the intermediate stage between PV system and the drive system. This paper proves the possibility of driving SRM with PV system as input used for agricultural field applications. Both open loop control and closed loop control strategies were discussed and the results prove SRM is well suited in agricultural field applications. Models were simulated for both open loop and closed loop control techniques of both 6/4 pole and 8/6 pole SRM. Closed loop speed control is achieved by using PI controller and Fuzzy controller. From the output results we can say fuzzy controller takes less time of 0.1 seconds to attain set speed for 6/4 pole SRM when compared to PI controller taking 0.175 seconds for its drive system to reach its final value. Similarly fuzzy controller takes less time of 0.075 seconds to attain set speed for 8/6 pole SRM when compared to PI controller taking 0.23 seconds for its drive system to reach its final value. We can conclude, fuzzy can control the speed of PV fed SRM in less time thus improving the system performance.

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