CHAPTER – 7

PHOTO-VOLTAIC ENERGY GENERATION

SCHEME FED SRM DRIVE SYSTEM FOR

IRRIGATION APPLICATION
7.1 INTRODUCTION

Irrigation system is a well-developed process on many farms and is practised on several levels around the world. It allows the diverse crops which in turn increase size of fields. The automated solar powered irrigation systems support a sustainable solution to improve the efficiency [92]-[94]. In irrigation fields, use of renewable energy system is required primarily for flooding irrigated scheme. The main utilization of this PV-irrigated system will be able to contribute to socio-economic development. Since, several electric motors are used for water pumping applications, proposed SRM drive are quite popular in this sector.

The contemporary vast proliferation of electric motor drives in domestic irrigation applications with advanced schemes are in high demand for efficient adjustable speed operations [95]-[101]. The precise demand for full control of drive speed with good transient stability, attain incredible efficiency. 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. Advancements in the technology and rise in manufacturing units with ease of operation motivate many users to employ PV systems for their applications. Photovoltaic power is environmental friendly in which sun is the main source [102].

Though PV system was developed several decades ago, advances in PV technology divert many users towards use of PV systems where sun light is the main source. 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 [103]-[105].

When 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 for feeding the Switched Reluctance Motor. 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. In many agricultural applications, motor plays a vital role for driving mechanical loads [106]-[109]. To drive these mechanical loads many motors are available which take electrical energy as input and deliver mechanical output. Pumping systems are used for lifting water for drinking and irrigation purpose.

7.2 PV MODEL

Fig.7.1 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:

$$I = I_L - I_0 \left( e^{\frac{q(Y+IR_s)}{nRT}} - 1 \right) - \frac{V+IR_s}{R_{sh}}$$  \hspace{1cm} (7.1)

The value of $R_s$ varies as reciprocal of solar irradiance. The value of $R_{SH}$ which is leakage resistance, typically large, is greater than 100$k\Omega$ in most of the cases. From the current equation of PV model we can say the total current delivered is algebraic sum of currents passing through diode, shunt branch and incoming source current $I_L$. As we know, in the power-voltage curve of solar panel there is an optimal
operating points such that PV cell delivers the maximum possible power to the load [110]. Maximum power point tracking (MPPT) is employed to achieve or draw more power from the system and thus this MPPT can deliver more power to the point of application. Various MPPT methods are available to attain maximum power from the PV system varying from simple voltage relations to complex multiple sample based analysis.

Fig.7.1 Simple PV Model

Keeping in mind the solar irradiance and the end user application, different MPPT methods are available and it’s the choice of power engineers to select optimal method to draw maximum amount of power from the PV system. The problem which is considered by MPPT methods is automatically finding the current $I_{MP}$ and voltage $V_{MP}$ 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 method is employed in this chapter 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 [111]-[113]. 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 prior 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 MPP and smaller step size might slow down the process resulting in sluggish response to the changes in irradiance. Fig.7.2 shows the block diagram of PV fed SRM model containing of PV system, boost converter, SRM motor with converter. Boost converter is controlled by controlling the duty cycle produced from the MPPT algorithm.

7.3 PROPOSED PV FED SRM DRIVE SYSTEM FOR IRRIGATION APPLICATION

Switched Reluctance Motor is obtaining rehabilitated notice as an erratic applicant for different variable speed and torque applications. 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. For any application, the motor torque must match the load 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. Thus, SRM drives requires only one 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 [99]-[105].
The torque expression requires the small relation between rotor position and the 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 [108]. 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 chapter, asymmetrical configuration of the converter is employed for the drive system, which was explained, in detail, in chapter 5 (Section 5.4.4).

Fig.7.4 shows the open loop speed control scheme. In open loop control, the feedback errors were not sensed and there might be errors at the output side, where as in closed
loop speed and torque control, speed and torque are sensed at the output level and the error signal is fed back to the input such that more effective speed and torque are 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 chapter both closed loop PI and fuzzy controllers were discussed to reduce the error signal.
Fig. 7.4 Block Diagram representation of speed control of SRM Drive in Open Loop Control system.
Fig. 7.5 shows the closed loop speed control block diagram with PI controller. In PI controller, the error signal is reduced by reducing present error by proportional controller and the past errors were reduced by integral controller.
Fig. 7.6 shows the close loop speed control block diagram with fuzzy control with some of the fuzzy space divisions mentioned in block diagram in Fig. 7.7. Here the maximum value of dc link voltage obtained from the PV system decides minimum voltage rating of the 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 chapter mainly 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 fuzzy technique, the error signal is fed to the fuzzy controller where the error signal is reduced by fuzzy control strategy which uses fuzzy rule base 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 Fig. 7.6 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 $I_{\text{ref}}$. 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 is the current controller to control the current [111]. The rules generated like this are “and” rules, we can say these rules are implemented so the IF part meets simultaneously with the result of THEN part.
Fig. 7.6 Block Diagram representation of Speed Control of SRM Drive with Fuzzy Controller
Fig. 7.7 Division of Input And Output Spaces into Fuzzy Regions, (a) $m(X_1)$, (b) $m(X_2)$, (c) $m(Y)$

### Table 7.1 Fuzzy Rule Structure

<table>
<thead>
<tr>
<th>X1</th>
<th>X2</th>
<th>S2</th>
<th>S1</th>
<th>CE</th>
<th>B1</th>
<th>B2</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2</td>
<td>S2</td>
<td>S2</td>
<td>S2</td>
<td>S1</td>
<td>CE</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>S2</td>
<td>S2</td>
<td>S1</td>
<td>CE</td>
<td>B1</td>
<td></td>
</tr>
<tr>
<td>CE</td>
<td>S2</td>
<td>S1</td>
<td>CE</td>
<td>B1</td>
<td>B2</td>
<td></td>
</tr>
<tr>
<td>B1</td>
<td>S1</td>
<td>CE</td>
<td>B1</td>
<td>B2</td>
<td>B2</td>
<td></td>
</tr>
</tbody>
</table>
7.4 RESULTS AND DISCUSSION OF PROPOSED IRRIGATION APPLICATION

Table –III: Parameters of Proposed Asymmetric Converter Fed SRM Drive System for Irrigation System are shown in APPENDIX-I. The chapter was discussed for both open loop and closed loop operation of SRM Drive. 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. Fig.7.8 shows the Voltage – Current (VI) characteristics of photo-voltaic system, Fig.7.9 shows the power – Voltage (PV) characteristics of photo-voltaic system while using the MPPT controller for obtaining the maximum power from PV strings.

Fig. 7.8 PV Characteristics

Fig.7.9 VI Characteristics
7.4.1 RESULTS WITH OPEN LOOP CONTROL FOR DIFFERENT SPEEDS

Based on the simulation analysis we found out simulation results of 6/4 asymmetric converter fed SRM drive with different control objectives for irrigation application such as open-loop/PI controller/ Fuzzy controller schemes, in that (a) Phase Current response of SRM Drive, (b) Electromagnetic Torque response of SRM Drive, (c) Speed response of SRM Drive. A typical analysis is carried out by different control objectives; in open loop system gives various concerns. In SRM drive system main concerns are better speed regulation with high stability factor and another concern is minimization of torque ripples. These concerns are minimized by effective proposed control objectives, the torque ripples are low compared to open loop system which is
moderate in fuzzy control objective. Coming to speed, in open loop system there is no required speed point but reaches the certain speed limit with high peak over shoots. In PI controller speed reaches steady state at a moderate time over the open loop system with better peak over shoots with moderate stability factors and in fuzzy controller speed reaches steady state at very low time with greater stability index as shown in respective simulation results. The torque ripples are very high in open loop system and when using the closed loop PI controller the torque ripples may goes on decreasing and when using the closed loop Fuzzy controller the torque ripples are very less over other control schemes under several speed ranges.

(a) Phase Current response of SRM Drive

(b) Electromagnetic Torque response of SRM Drive
7.4.2 RESULTS WITH PI CONTROLLER FOR DIFFERENT SPEEDS

Fig. 7.12 Results of 6/4 Asymmetric Converter Fed SRM Drive System

Fig. 7.13 Results of 6/4 Asymmetric Converter Fed SRM Drive System for Rated Speed (2500 rpm)
Fig. 7.14 Simulation Outcomes of 6/4 Asymmetric Converter Fed SRM Drive System for Below Rated Speed (2000 rpm)

(a) Phase Current response of SRM Drive

(b) Electromagnetic Torque response of SRM Drive

(c) Speed response of SRM Drive
7.4.3 RESULTS WITH FUZZY CONTROLLER FOR DIFFERENT SPEEDS
Fig. 7.16 Results of 6/4 Asymmetric Converter Fed SRM Drive System for Rated Speed (2500 rpm)

(a) Phase Current response of SRM Drive

(b) Electromagnetic Torque response of SRM Drive

(c) Speed response of SRM Drive

Fig. 7.17 Results of 6/4 Asymmetric Converter Fed SRM Drive System for Below Rated Speed (2000 rpm)
Table 7.3 represents the comparative analysis of the different control schemes fed SRM drive system under different speed ranges such as, open loop system, PI controller, Fuzzy controller with rated speed (2500 rpm), below rated speed (2000 rpm), above rated speed (3000 rpm).
Table 7.3 Comparative Analysis of the Different Control Schemes Fed SRM Drive System for Different Speeds

<table>
<thead>
<tr>
<th>Control Strategy</th>
<th>Settling Time ($T_s$)</th>
<th>Under Rated Speed (2500 rpm)</th>
<th>Under Below Rated Speed (2000 rpm)</th>
<th>Under Above Rated Speed (3000 rpm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open-Loop System</td>
<td>0.18 sec ↑</td>
<td>0.15 sec ↑</td>
<td>0.24 sec ↑</td>
<td></td>
</tr>
<tr>
<td>With PI Controller</td>
<td>0.17 sec</td>
<td>0.12 sec</td>
<td>0.23 sec</td>
<td></td>
</tr>
<tr>
<td>With Fuzzy Controller</td>
<td>0.1 sec</td>
<td>0.08 sec</td>
<td>0.13 sec</td>
<td></td>
</tr>
</tbody>
</table>

The above performance analysis is useful for selection of control objective for speed regulation of SRM drive in an irrigation application. A typical analysis is carried by different control objectives.

The open loop system reaches a rated speed of 2500 rpm in 0.18 sec and 2000 rpm in 0.15 sec. For speeds above 3000 rpm the accelerating time is 0.24 sec.

The PI controller reaches 0.17 sec at rated speed 2500 rpm, 0.13 sec at below rated speed 2000 rpm and 0.23 sec at above rated speeds 3000 rpm.

The Fuzzy controller reaches 0.1 sec at rated speed 2500 rpm, 0.08 sec at below rated speed 2000 rpm and 0.13 sec at above rated speeds 3000 rpm.

The low settling time is required for better speed regulation with high stability factor in an irrigation application. In that fuzzy controller requires low settling time over other control objectives by attaining better speed regulation at 0.1 sec over other schemes.
CONCLUSION

The PV systems are commonly designed for power generation to SRM based irrigation applications in areas where there are no electricity mains. The main feature is that, they utilize sun energy directly from the periods of maximum demand for coinciding water with the period of maximum solar radiation. Compared to fuel-fired pumping system, the cost of PV based water pumping system is 64.2% acute of fuel-fired pumping systems, over a life of 15 years as more. Economically PV systems are more perfect up to approximate of 3 KW for village water supply and 1.5 KW for irrigation system. PV stacks illustrates an eco-friendly, low maintenance, alternative cost function to irrigation system, greater flexibility, high speed regulation. This chapter highlights the PV fed SRM drive using several control objectives for irrigation application. Both open loop and closed PI/Fuzzy control objectives were discusses and the results prove that the SRM drive is more suitable for agriculture-irrigation application with better speed regulation. The proposed Fuzzy controller can controls the speed of PV fed SRM in less very time thus improving the system performance, obtain the high stability index.