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Solar PV based switched reluctance motor drive for low power medium speed applications

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Solar Photovoltaic (SPV) is the most important renewable energy source which is gaining importance in all fields of electrical utility. Utilization of SPV source in electrical drives applications can bring about a considerable change in the present day energy crisis. Here an SPV based Switched Reluctance motor (SRM) drive is presented which can be utilized in low power high speed and medium speed applications. SRMs have inherent advantages of low inertia, low rotor losses, robustness and simple construction. The operation of the converter circuit is with respect to the reluctance variation of the rotating machine which makes it different from other drives. Here a converter circuit is designed for the operation of SRM from SPV source. The SPV characteristics are different from a constant DC source since the output power and voltage varies with insolation and temperature. The proposed system is verified using LabVIEW™ Simulation and the results are discussed.

Keywords: *Solar Photovoltaic (SPV), Switched reluctance Motor (SRM), LabVIEW™, Reluctance*

1.0 INTRODUCTION

The emphasis on replacing conventional energy sources with renewable energy sources is increasing day by day due to the rising energy crisis. Solar Photovoltaic (SPV) is the most important among them and various researches are going on for the better utilization of SPV sources. Large scale generating stations are being commissioned for supplying power to the grid which requires a vast design and forecasting. Small standalone SPV systems are widely used for domestic and commercial applications. Small scale grid connected SPV power plant are also gaining importance through the concept of micro grids. Since machines constitute an important part of electrical utility, stand alone SPV based machine drives can bring about considerable amount of energy saving.

Various studies are going on for utilizing SPV for electrical machines. Many systems are developed with Induction motors, brushless DC machines, and permanent magnet synchronous machines etc for specific applications [1]. Switched reluctance motor is another special electrical machine which is still under research for performance improvement. The features of switched reluctance motors and the converters can be modified to suit the SPV operation [2-5]. For this initially a proper design of the SPV system is required for which there are many modeling techniques according to the application [6-8].

The working principle of SRM is based on shortest reluctance path. High magnetic saturation and non-linear characteristics of SRM bring great difficulty in the motor design and performance evaluation [9-10]. The simulation of a system is important in view of its design and experimental

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realization [11-14]. Studies concerning dynamic simulation of switched reluctance machines have been achieved using non linear simulations and programming

2.0 SOLAR PV DRIVES

The general schematic of an SPV system is shown in Figure 1. The output of Solar panel will be DC of an ideal open circuit voltage of 24 V. The panels are connected in series and parallel to obtain the required voltage level and power level. The converter and power conditioning circuit is the most important part of the system which is designed according to the application.

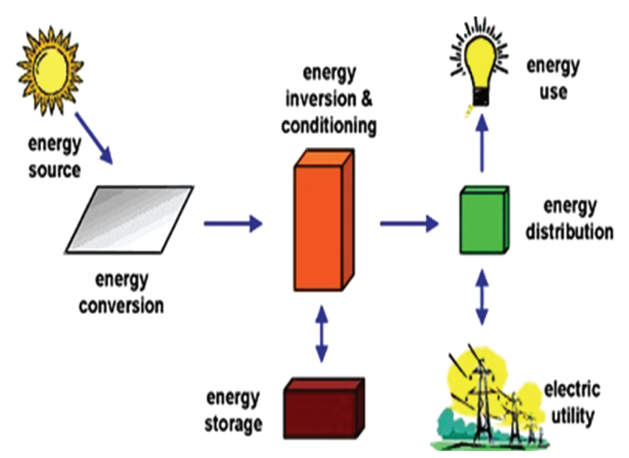

FIG. 1 GENERAL SCHEMATIC OF A SOLAR PV BASED POWER GENERATION SYSTEM.

For grid connected and stand alone SPV system for utility, the converter supplies sinusoidal AC in such a way that there is maximum power tracking and minimum harmonics at any point of time [6-8]. But when it comes to drives applications, various other factors are also to be considered because the speed control and torque change of the machine brings about dynamic changes in the voltage and power requirements which further depend upon the application of the machine. Here an efficient design of converter for PV based drive system is attempted using switched reluctance motor.

3.0 SWITCHED RELUCTANCE MOTOR

With the advent of modern control technology and power electronics, switched reluctance motor drives are becoming increasingly popular. Because of high efficiency over wide operating range, the absence of rotor windings, and the maintenance free operation, SRMs are advantageous over other types of electrical machines in some applications.

3.1 Features

The switched reluctance motor both stator and rotor have salient poles. Only the stator has windings, while the rotor is made of steel laminations without any permanent magnets. The construction is shown in Figure 2. Compared with the ac and dc machines, shows two main advantages [9]. It is a very reliable machine since each phase is largely independent physically, magnetically, and electrically from the other machine phases. It can also achieve very high speeds (20000—50000 rev/m) because of the lack of conductors or magnets on the rotor.

One limitation of SRM is that, it must always be electronically commutated and thus cannot run directly from a DC bus or an ac line. Also, the double salient structure causes strong nonlinear magnetic characteristics, complicating its analysis and control, resulting in torque ripple and harmonics.

3.2 Working Principle

The motion in SRM is produced because of the variable reluctance in the air gap between the rotor and the stator. When a stator winding of opposite phases are energized, producing a single magnetic field, reluctance torque is produced by the tendency of the rotor to move to its minimum reluctance position. When a rotor pole is aligned with a stator pole, the field lines are orthogonal to the surfaces and there is no torque In this position, the reluctance is minimum. If there is a displacement the rotor of its position, there will be torque production that will tend to bring back the rotor toward the aligned position. So the converter should operate according to the position of the rotor [9-10].

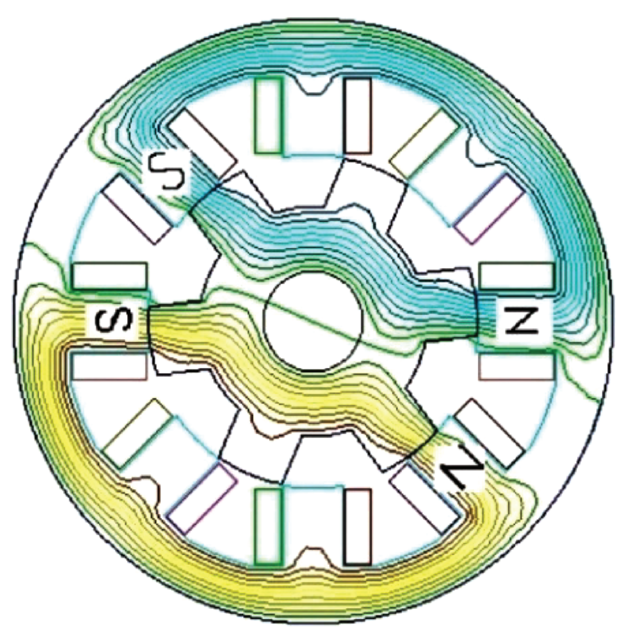

FIG. 2 CONSTRUCTION AND FIELD ORIENTATION OF SRM.

The equations related to the above explained operations are given below

$$V = iR_a + \frac{d\psi}{dt} \quad ....(1)$$

$$\psi = Li \quad ....(2)$$

$$\Rightarrow V = iR_a + \frac{\partial\psi}{\partial i}\frac{di}{dt} + \frac{\partial\psi}{\partial i}\frac{d\theta}{dt}. \quad ....(3)$$

$$\Rightarrow V = iR_a + L\frac{di}{dt} + i\omega\frac{dL}{d\theta} \quad ....(4)$$

$$Torque = \frac{i^2}{2}\frac{dL}{d\theta} \quad ....(5)$$

Where V is the dc voltage applied to a phase, and I is the current flowing. Ra is the winding resistance of one phase. Ψ indicates the flux linkage, L is the inductance per phase and dθ is the elementary angle [9].

3.3 Switching Scheme

There are several possible configurations to energize an SRM from a converter depending upon the number of semiconductors and passive components, number of phases and the way the stator coils are connected. The maximum control and flexibility is obtained, with the H-bridge asymmetric type converter [11-15]. A general topology is shown in Figure 3. Each phase has two insulated gate bipolar transistors (IGBTs) and two diodes.

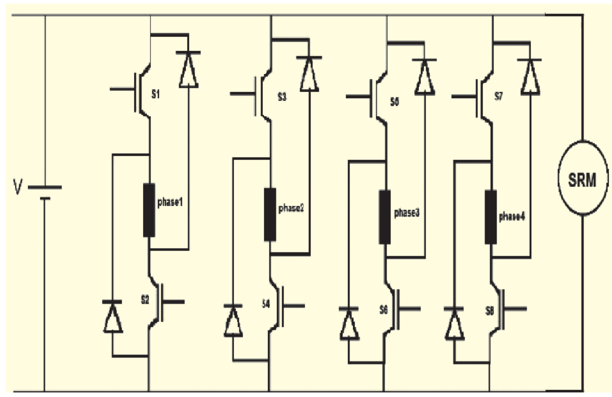

FIG. 3 CONVERTER CONFIGURATION.

4.0 PROPOSED SYSTEM

The block diagram of the proposed system is shown in Figure 4. The most important part of the system is the converter which includes a boost converter to obtained the required DC voltage and the H bridge converter for the operation of the machine. The ripples in current due to the back feeding by the machine driver are also taken in to consideration when designing the boost converter. A feed back of the position and current are given for calculation of firing angle and closed loop control respectively. In hardware implementation, the switching signal logic can be achieved using microcontroller.

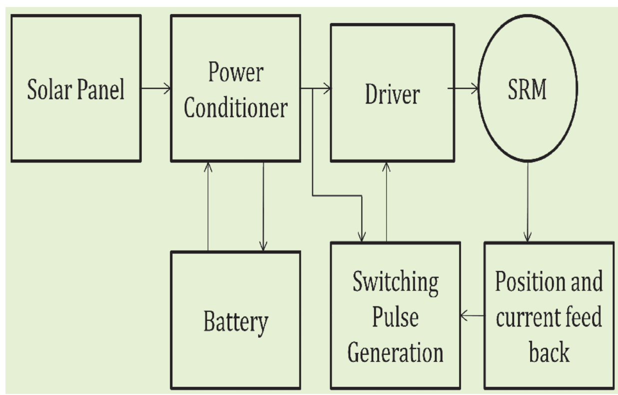

FIG. 4 BLOCK DIAGRAM OF PROPOSED SYSTEM.

5.0 SIMULATION STUDIES

5.1 Solar PV Modeling

The New designs of Stand alone and grid connected SPV power generation systems are under development in all fields of electrical utility. Many models have been developed to simulate the PV cell and module behavior that provides the experimental curves of the solar panel. The commonly used single diode model is shown in Figure 5 which is utilized for the simulation study of the proposed system.

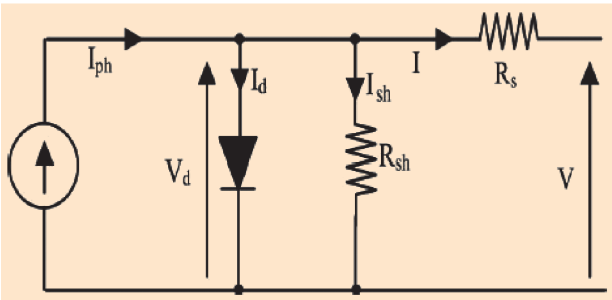

FIG. 5 MODELING OF SOLAR PV.

The working equations of this circuit are obtained using KCL and KVL for obtaining the simulation model. The simulation model of solar module is developed using LabVIEW™ simulation platform based on this. The variation of Voltage, Current and output power for various radiation and temperature can be analyzed using this model. Figure 6 shows the Simulation diagram and Figure 7 shows the VI characteristics of solar PV cell for various incident radiations using simulation.

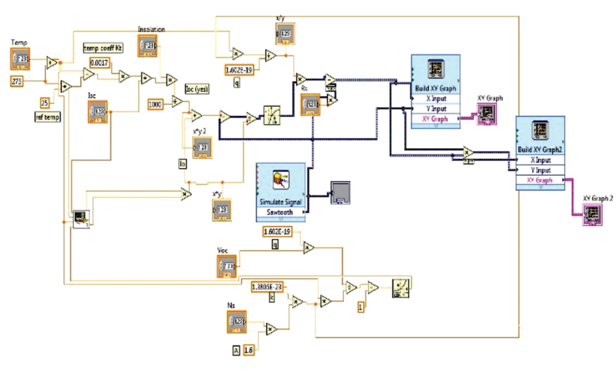

FIG. 6 SOLART PV SIMULATION MODEL IN LAB VIEW

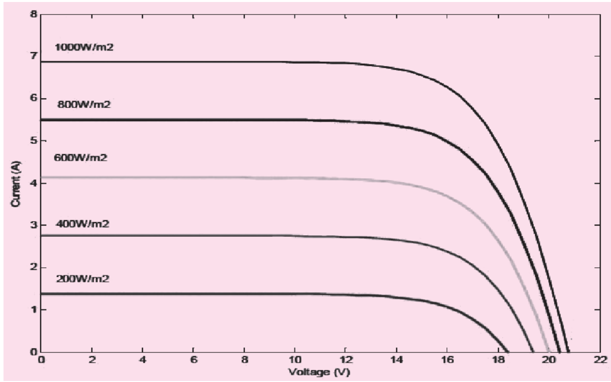

FIG. 7 PV CELL SIMULATION OUTPUT

5.2 Motor modelling

The machine inductance of SRM is a function of both rotor position and current. So the control strategy development of SRM is more complicated compared to other type of machines. The basic block diagram of simulation model is shown in Figure 8. [12-17]. The parameters used to simulate the mechanical part of 8/6 SR motor are to be previously obtained by a Finite Element Analysis (FEA).

We have stroke angle,

$$\Theta s = 2\Pi \ ((1/Nr)-(1/Ns)) \qquad \text{....(6)}$$

Where N_r and N_s are the number of rotor and stator poles, respectively. The profile is obtained by preparing a look up table.

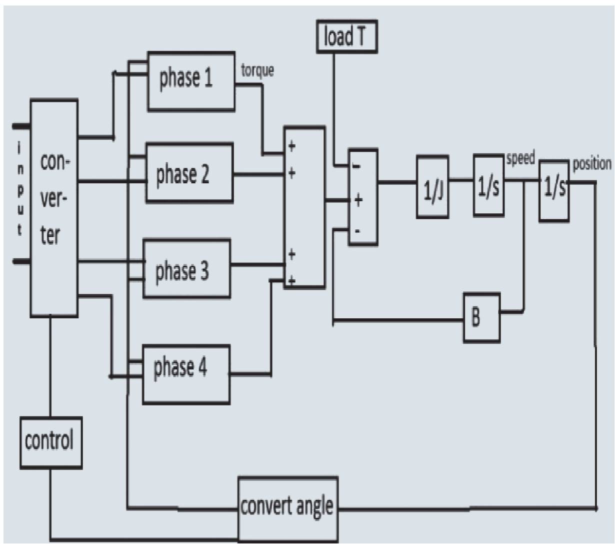

FIG. 8 BLOCK DIAGRAM OF SIMULATION MODEL

5.3 Switching Control

The schematic representation of the switching scheme is shown in Figure 9 is used. Voltage is applied during the positive slope of inductance profile to get a positive torque. A negative voltage is applied for making the current fall to zero before the negative slope so as to avoid the production of negative torque. In the scheme used here, voltage control strategy is followed. The switch ON angle and switch OFF angle are kept constant and the average dc applied voltage level is varied [11]. To obtain the gate signals for the buck converter, speed controller and current controller were used. Various types of controllers were experimented and best results were obtained for PI speed controller and hysteresis current controller [14].

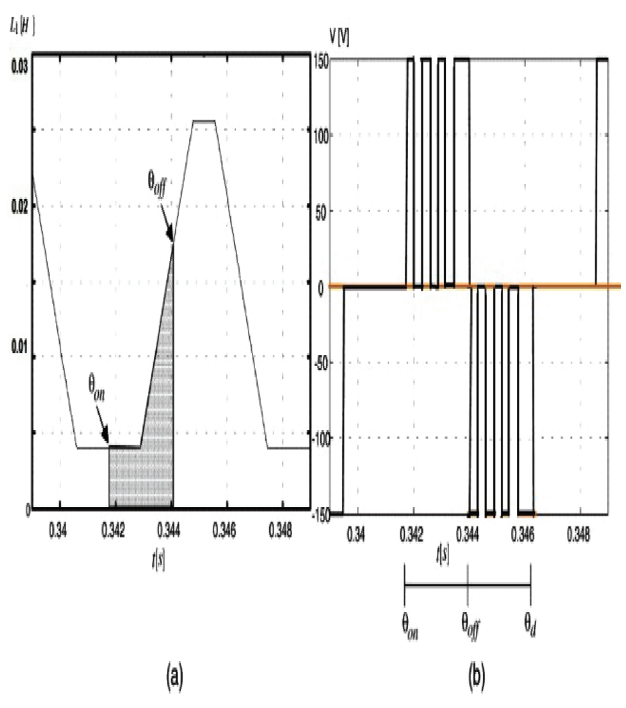

FIG. 9 SWITCHING SCHEME

6.0 RESULTS AND DISCUSSIONS

Simulation is done for a machine of power rating as shown in the Table 1. Other parameters like frictional coefficients, winding resistance, winding inductance etc used for the simulation studies are taken from the machine data sheet. This will require a solar panel area of around 6.5 m^2.

TABLE 1

DESIGN PARAMETERS

Sl. No.	Parameters	Value	unit
1	Rated Power	500	W
2	Rated DC Link Voltage	110	V
3	Rated Current	4.5	A
4	Rated Seed	4000	rpm

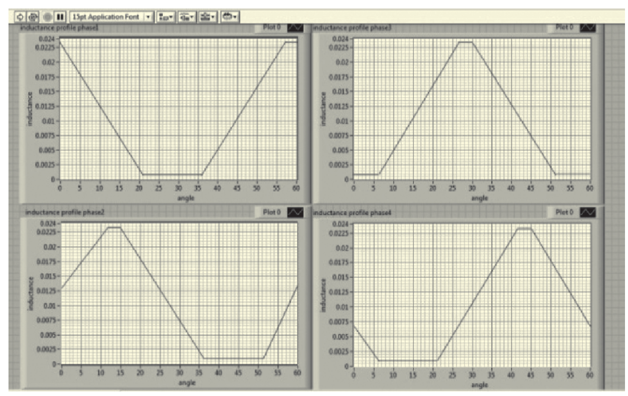

FIG. 10 INDUCTANCE VARIATION

When rated voltage is applied, the rated speed is obtained. The parameters including temperature, incident radiation, advance angle, conduction angle, load torque and constants J and B can be given as inputs through the user interface. Figure 10 shows the inductance profile generated using lookup table values. The inductance at every rotor position was obtained using Finite element analysis of the designed machine. The firing angle is calculated using this inductance profile.

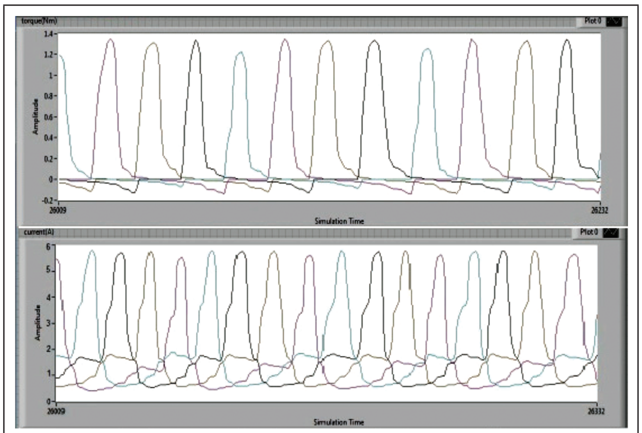

FIG. 11 DEVELOPED TORQUE AND CURRENT WAVEFORMS FOR FOUR PHASES OF SRM

Figure 11 shows the torque and current waveforms for each phase of the machine. The dc link current will be the sum of the current drawn by each of the 4 phases at any instant. Similarly the total torque output is the sum of the torque developed in individual phases. Figure 12 shows the total output torque and speed of the machine at rated load condition. Even though the torque is slightly pulsating, the machine speed will not be much affected due to inertia. The control is done for a speed set point of 3000 rpm that is 314 rad/s.

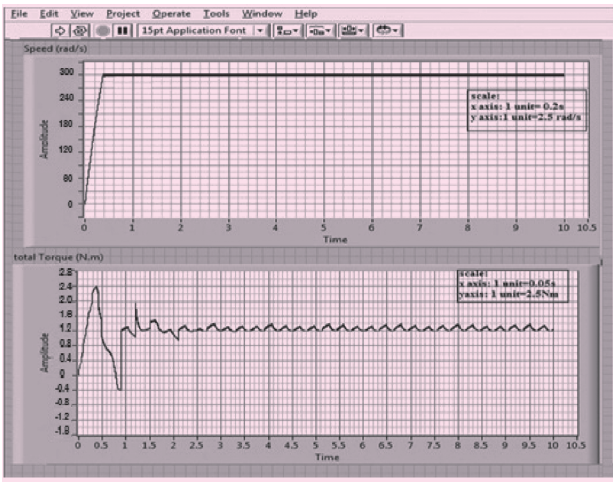

FIG. 12 SPEED SETPOINT AT 3000 RPM FOR RATED TORQUE OUTPUT

7.0 CONCLUSIONS

Switched reluctance motor comes under special machines which are mainly used for fractional power applications. The design, modeling and simulation of the proposed drive system is done for low power application with rated speed of 4000 rpm. The machine can be operated from solar PV source for speed above 10000 rpm without much variation in the average torque. The operation can be verified for various values of radiation and temperature using this model. Even though Switched reluctance motors are cheap, efficient and has higher power to weight ratio, harmonics is one of the inherent disadvantage due to the converter switching. For a standalone Solar PV based SRM drive system, this disadvantage will not affect the utility grid and the advantages of the machine can be utilized. The system can be used in high speed low power drive applications like drilling, centrifugal separation, and aero space applications.

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