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Design and Analysis of Standalone Solar Assisted Switched Reluctance Motor Drives

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***Abstract*—Switched Reluctance Motor (SRM) is a simple, low cost, robust structure, reliability, controllability and high efficiency, So that it is used in variable speed and high speed applications. Renewable energy sources are a great improvement in many applications. In this paper, a switched reluctance motor with PV modeling is introduced. The implemented design is based on the optimization of solar PV modules arranged in array, integrated with rechargeable battery with existing converter models to drive the switched reluctance motor. The results of the investigations compare with SRM driven by DC source offers superior performance in terms of simulation analysis.**

***Index Terms*—Battery, Charger, Converter, PV Panel, Switched Reluctance Motor**

I. INTRODUCTION

Following the wide application, Researchers are putting more and more efforts on the study of SRM and renewable energy sources. Besides assisting in the reduction of emission of green house gases, they add the much needed flexibility to the energy resource mix by decreasing the dependence of fossil fuels [1]. Among the renewable resources, solar energy is most essential resource of sustainable energy because of abundance, everlasting. No potential damage to the environment. It is a very large source of energy. The power from the sun intercepted by earth is about 1.8 x 10^{11}MW which is 1000 times larger than our current power consumption from all the sources [2].

The converter implementation to drive the SRM is not standard. Numerous converters for SRM drives were proposed, developed and used in industrial applications. Among these asymmetric bridge converter is most popular and best performed one, in which each phase is controlled by power semiconductor devices such as IGBT and Diode in the form of bridge as shown in Fig.1.

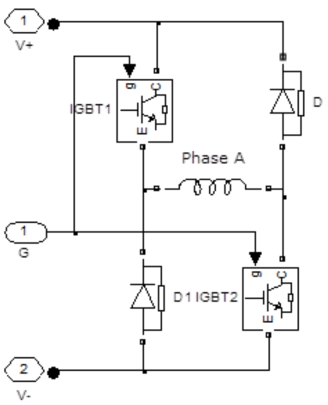

Fig.1 Asymmetric Bridge converter for one phase of SRM

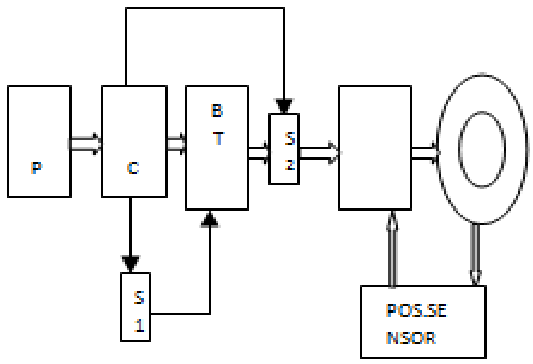

Fig.2 Structural Design – PV Integrated SRM Drive

This paper is organized as follows. The PV concept is applied according to the design of interface with grid connected standalone and hybrid PV systems which consist of PV generator will be analyzed in detail in section II. In section III the energy storage devices such as batteries is modeled for both charging and discharging concepts with truth table. The SRM drive along with existing asymmetric converter for three phases is implemented in section IV. The simulation results will be shown in section V to verify the proposed integrated concept of SRM driven by regenerative source of PV modules. Finally, the conclusions and effectiveness of this research is discussed in section VI. The overall structural design is shown in Fig.2.

II. SOLAR PV GENERATOR

The simplest model of solar cell is designed using the MATLAB/ SIMULINK based on the mathematical expression.

$$I = I_L - [\, I_0\, e^{\,q(V+ I R_s)/nkT\, -1}] \qquad (1)$$

$$V_{oc} = kT/q\ (\ln [(I_L/I_0) +1) \qquad (2)$$

V_{oc} depends on short circuit current (Isc $=I_L$) and saturation current (I_0).Where I_L is current generated due to light, R_s is series resistance of PV modules, n is ideality factor, I_o is reverse saturation current, T is temperature and k is the Boltzmann constant, q is the charge of the electron. The current source represents the current generated by the PV cell due to photons received by it and is constant with reference to constant irradiance and temperature [3]. During cloudy and in nights solar cell performance is poor it denotes that it works as a normal diode. It is known fact that the current output of solar cells is a linear function of solar irradiation. Also, the current output of solar cell does not depend strongly on the temperature of the solar cell. Therefore solar cell current can be used as a measure of solar irradiation at a given time.

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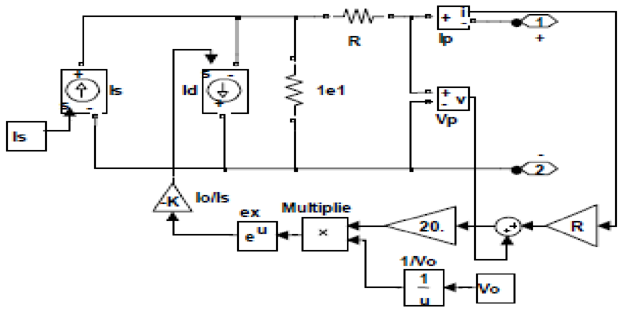

Fig.3 MATLAB/SIMULINK PV Model

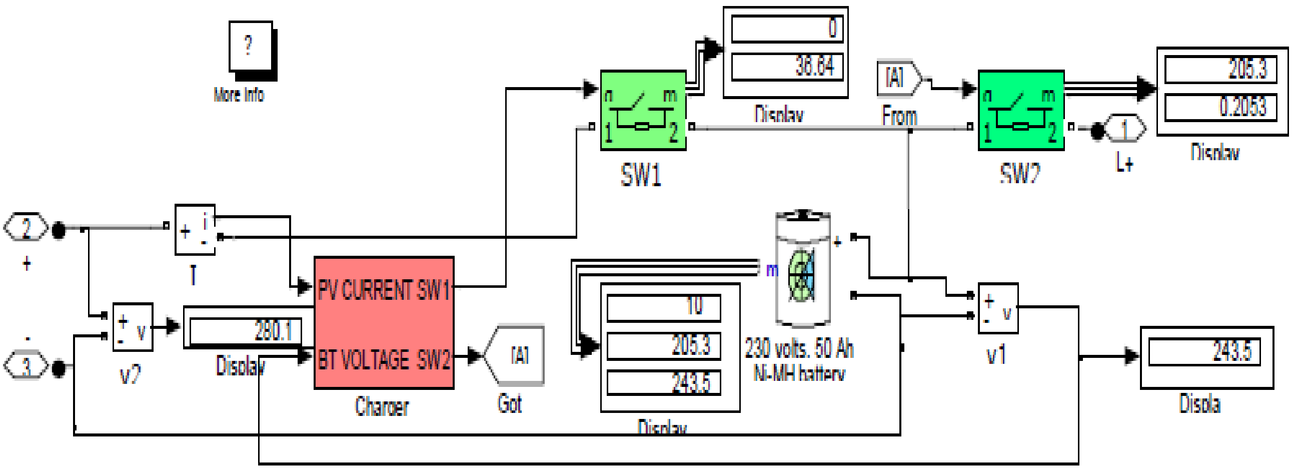

Fig.4 MATLAB/SIMULINK – Battery Charger Model

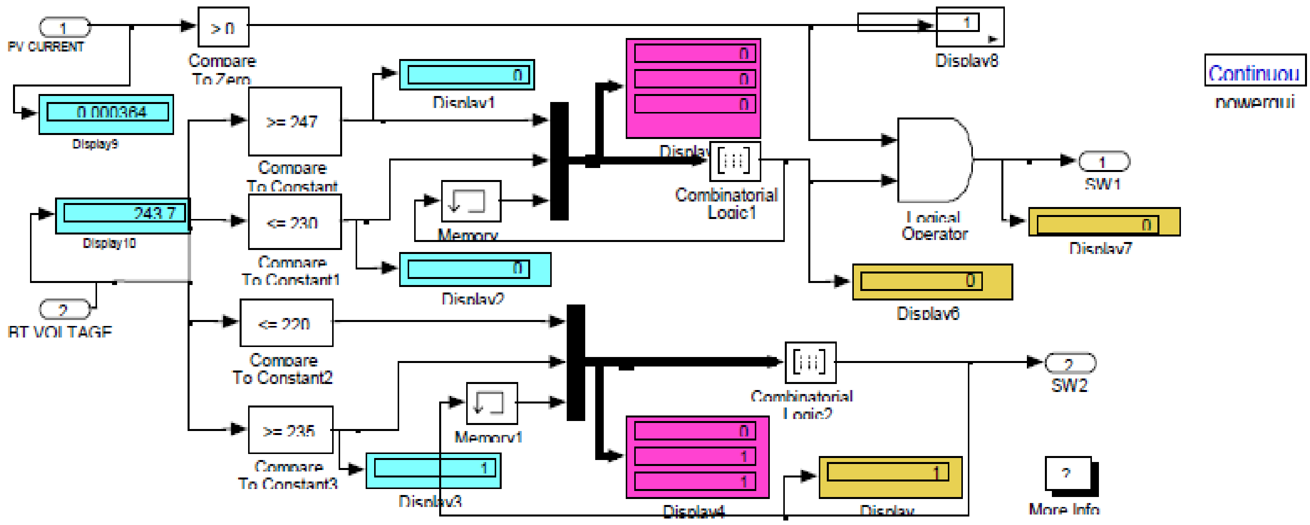

Fig.5 MATLAB/SIMULINK Charger Model

Solar Irradiation (W/m^2) = K* Cell current (A) (3)

Here K is the proportionality constant (=2175). The main elements in PV Cell are short circuit current ISC and open circuit voltage VOC and irradiance Wp. In this research part, the PV modules comprises short circuit current of 2.855 A and open circuit voltage of 279.8 V for corresponding irradiation of 600 W/m2 and temperature of 30o C are modeled. Such 18 PV cells are arranged in single parallel module to generate a Short circuit current of 51.39 A.

For an ideal cell, series resistance is zero and shunt resistance is infinite [4]. The net current of PV cell is the difference between the output current from PV cell and diode current. By Using MATLAB/SIMULINK, the above expression can be simulated numerically as shown in Fig.3 to obtain the PV Cell model in order to implement this application to drive the Switched reluctance Motor.

III. BACKUP DEVICE

Though abundant, solar insolation is unreliable source of energy. It fluctuates as a function of time and is not available during nights and in cloudy sky. Therefore, when PV systems are used for standalone applications, a backup source of energy is necessary to compensate for balance power demand of load. For such cases, batteries are used as backup source. The drawback for using storage device alone is such that it is critical to prevent over charging or deep discharging of batteries [7]. In order to overcome this, effective charging techniques are implemented along with battery modeling to preserve their life and ensure good performance. This can be done by chargers.

Table 1. Set points of battery voltage used for charge controllers

S.No	Parameter	Threshold Value
1	Voltage Regulation limit [VR]	247
2	Low voltage Hysteresis [VRH]	235
3	Low Voltage Disconnect [LVD]	220
4	LVD Hysteresis [LVDH]	230

In this, shunt type charge controller is implemented. Fig.4 shows that switch S1 is connected in parallel to the PV panel which is turned ON, when the battery voltage reaches it's over voltage limit [VRL]. The PV array is short circuited and it no more feeds the battery. Also it is designed to open the switch 1, if the current in PV module is less than or equal to zero [6]. This prevents the battery to discharge through PV panel during nights and insolation periods.

The switch S2 allows the battery to discharge through any one phase of 6/4 pole SRM which acts as load for solar source in this research. When the battery reaches the threshold value [LVD], the switch S2 turned off to prevent deep discharging of battery. The charge controller senses the voltage of the battery or state of charge [SOC] and decides either to disconnect it from PV array to prevent it from over charging or to disconnect the load to prevent deep discharging of battery. The control modeling of the charger to a battery is shown in Fig. 5.

The charge control formulation has threshold values depend upon which it take decisions [5]. The threshold set in values for charge controller to drive the SRM is shown in table 1.

A. Voltage Regulation limit [VRL]

It is the maximum voltage up to which the battery can charged. If this point is reached, the charger disconnects the battery from PV array. The set in points derived from the characteristics of the battery shown in Fig. 6.

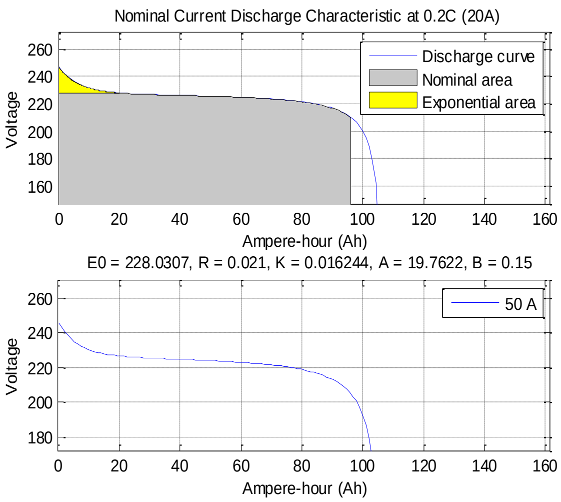

Fig.6 Battery Threshold Set points

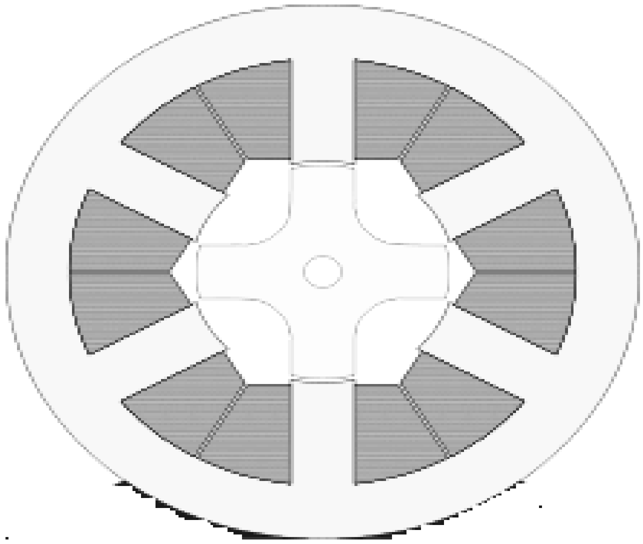

Fig. 7- 6/4 pole SRM Model

B. Low voltage hysteresis [VRH]

It is the difference between Voltage Regulation Limit value and the voltage at which the charger reconnects the battery to the PV source and starts charging. It also determines how effectively the charger can control the battery.

C. Low Voltage Disconnect [LVD]

It is the minimum voltage up to which the battery can be allowed to discharge, without getting deep discharged. Also it is defined as maximum Depth of discharge [DoD] of battery. The charger disconnects SRM from battery as soon as it reaches LVD to prevent it from over discharging.

D. LVD Hysteresis [LVDH]

It is the difference between LVD value and the battery voltage at which the SRM can be reconnected to battery terminals.

The switch SW1 is modeled to OFF state for any value of the battery voltage above VR value (100% Charged). Similarly the switch SW2 is designed to OFF state once the battery voltage drops and reaches LVD (20% charge left). The truth table for charge control states for both the switches is given in Table 2 and Table 3. The value one represents closed switch and zero represents open switch.

***Table 2.* Truth table used for controlling SW1**

S.No	Battery Voltage	>=VR	<=LVDH	Previous state SW1	Present state SW1
1	Between VR and LVDH	0	0	0	0
		0	0	1	1
2	Less than or equal to LVDH	0	1	0	1
		0	1	1	1
3	Greater than *or equal to* VR	1	0	0	0
		1	0	1	0
4	None	1	1	0	0
		1	1	1	0

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Table 3. Truth table used for controlling SW2

S.No	Battery Voltage	<=LVD	>=VRH	Previous state SW2	Present state SW2
1	Between VRH and LVD	0	0	0	0
		0	0	1	1
2	Greater than or equal to VRH	0	1	0	1
		0	1	1	1
3	Less than or equal to LVD	1	0	0	0
		1	0	1	0
4	None	1	1	0	0
		1	1	1	0

IV. CONVERTER MODEL FOR SRM

SRM with Asymmetric bridge converter is integrated to PV system in this proposed research. The most common SRM converter requires two switches for a single phase [8]-[10]. The merit of this asymmetric bridge converter is independent control for each phase and moreover the effective IGBT Modules are used as switches which are suitable for high voltage and high power applications. While considering the converter for one phase, the switching technique of the circuit is given and the same concept is applicable for all the phases.

- When both IGBT Switches conduct, the phase A is in energizing mode.
- When both are not conducting, the phase A is in de energizing mode.
- When any one of the IGBT is not conducting and other is not conducting, then the phase A is in current regulating mode.

The Model of 6/4 pole SRM is shown in Fig.7. It is a doubly salient single excited motor that is rotor has no magnets or windings. Only excitation is given to stator windings based on the position or speed of the rotor. This can be achieved by the position feedback sensor which compares and control the excitation sequence given to stator windings.

In this standalone PV integrated SRM analysis, the computation modeling of PV panel with battery and charging mode, position feedback sensor and converter are designed and analyzed using MATLAB / SIMULINK. Fig.8 shows the developed block diagram in MATLAB / SIMULINK.

V. VERIFICATION

In order to verify this standalone PV integrated SRM drive, the simulation based on MATLAB / SIMULINK was carried out. The gate signal given to IGBT Modules present in the asymmetric bridge converter is also analyzed. The Schematic arrangement of Position feedback sensor is also analyzed.

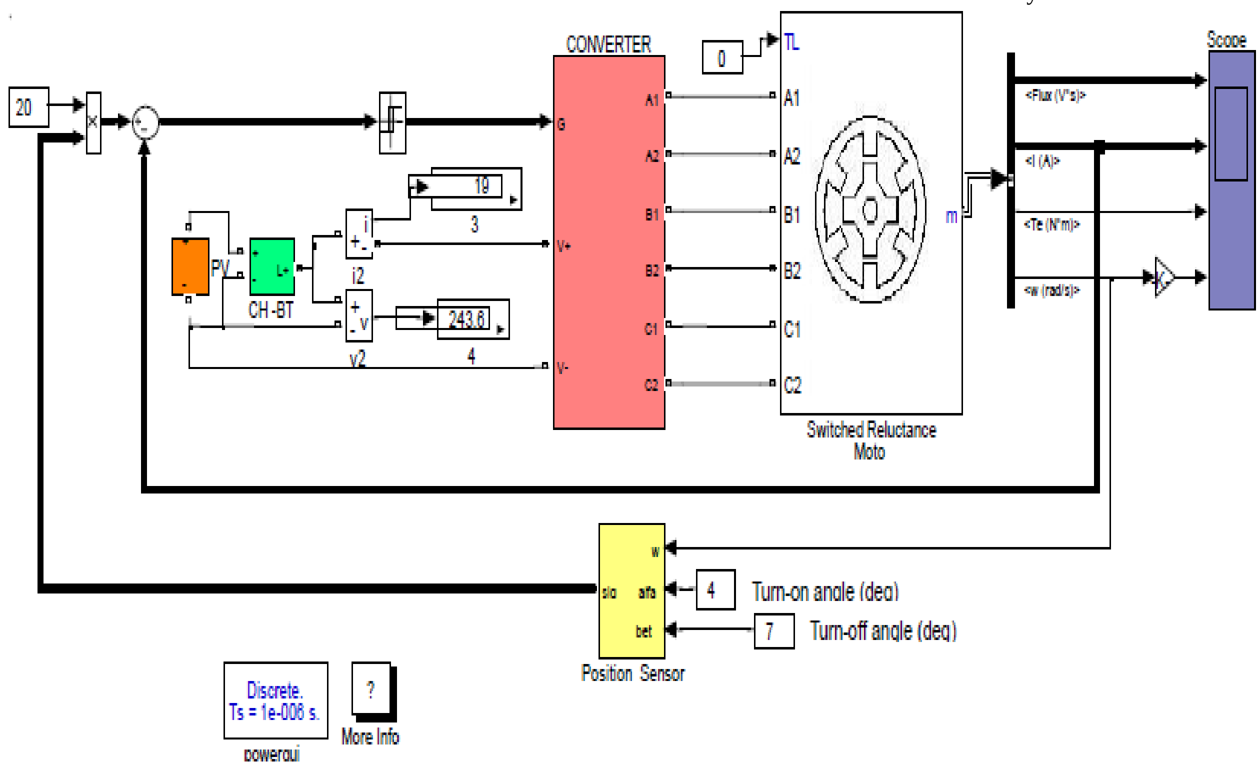

Fig.8 MATLAB/SIMULINK Block diagram model for solar assisted SRM drive

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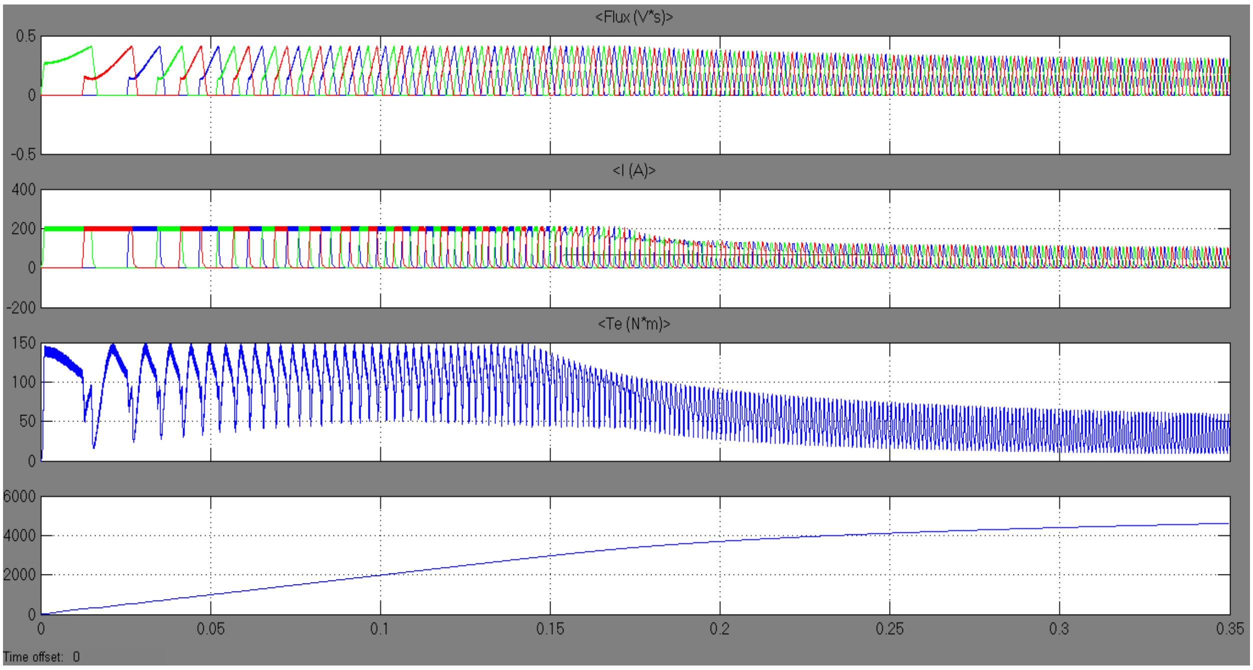

Fig.9 Simulation Results Showing Stator current and Speed of SRM

From this it can be observed and analyzed at simulation that the measured and theoretical current waveform demonstrates the proposed standalone SRM can be used to implement practically. The simulation waveform corresponding to flux linkage of Stator windings to the current and angular Speed of SRM driven by PV integration is shown in Fig. 9.

VI. CONCLUSIONS

In this paper, A new standalone PV integrated SRM drive has been implemented. This scheme of research part may be proposed for industrial drive application, locomotives, automobiles, aircrafts where sufficient solar source is required. Once implemented the maintenance cost is reliable and effective since charging controllers are used to extend and maintain the battery life. Also this arrangement is very much flexible to initiate at any weather conditions and also different user application. The completed model shows to evaluate the efficiency of PV system, performance of Charger and battery and efficiency of SRM

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