Performance Analysis of DC-DC Converters for Solar Water Pumping System Employing Switched Reluctance Motor Drive

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Abstract: *The grail of this paper is to investigate the performance of various DC-DC converters for solar based water pump system incorporating switched reluctance motor drive. The Converters used are CUK converter, Buck-Boost converter and Boost converter respectively. The speed of the switched reluctance motor is regulated by the mid-point converter along with the various DC-DC converters. The Switched reluctance motor is adopted over other motors because of its low inertia, ease of control, speed range is wide, less losses as there is no windings nor permanent magnets Present on the rotor. In order to operate the solar PV array at its optimum level we employ maximum power point tracking (MPPT) and specifically Perturb and Observe control method is employed in this project. The proposed system deals with the design, modeling and simulation of three different types of converters using MATLAB/Simulink environment. The applicability of this system can be analyzed by the simulated results.*

Keywords: *Maximum power point tracking (MPPT), Photovoltaic System, Switched Reluctance Motor (SRM).*

I. INTRODUCTION

India is one of the subtropical countries which have about 2000 hours to 3000 hours of sunshine throughout the year; these lands can use the solar energy for generation of power. The solar water pump is one of the applications of solar energy which is very useful for agriculture. The continuity of water supply is difficult in areas where there is no pipe line but has water underground in deep wells. Solar water pump is one of the most preferred applications of solar energy. Profuse motors are used so far in water pumping system using solar energy. There are lot of complications in using direct current and alternating current motors among which dc motors usage involves lot of maintenance of brushes along with commutators, whereas ac motors face difficulties to run

at low speeds and has complex control. The Switched reluctance motor has elementary construction [12].

The SRM has low inertia,ease in control, extended speed range and less overall cost. The other advantage of SRM is that the stator windings are separated electrically which makes the converter topology and controlling flexible when compared with other drives.

The two conventional topologies of solar powered water pump system is by employing boost converter along with battery and the other one is battery voltage regulator. Both of these methods have drawbacks like reduce efficiency, reliability due to the change in operating voltage level due to the battery regulation. The proposed system deals with the inquiry of various types of DC-DC converters suitable for solar water pump application. The performance is inquired by using MATLAB /Simulink environment.

II. FRAME WORK OF PROPOSED SYSTEM

The proposed topology of solar powered water pump system is shown in Fig.1, which is basically the block diagram. Three different DC-DC converters used namely Boost, Buck-Boost, CUK. The midpoint converter feeds the SRM which is intern coupled to a centrifugal pump. The performance of various converters is discussed elaborately.

III. CONTROL TECHNIQUES OF THE SYSTEM

In this system perturb and observe is the algorithm used for tracking the maximum amount of power from the photovoltaic array and the converter which the SRM is controlled by using electronic commutation which is by using hall sensors.

A. MPPT Control Technique

The MPP always varies with the changes in the temperature and irradiance levels. These changes need to be tracked time to time, therefore different algorithms need to be used for this process among which in this system Perturb and Observe technique is employed [7].

 This method is usually preferred because of its less complexity for implementation.

This method varies the duty ratio of the converters through the MPPT control algorithm and thus generates the PWM pulses which are required for switching on the switches of the converter.

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B. SRM Conduction Angle Control

The method used to get the smooth control, ripple free torque and improved efficiency is by using control techniques on to the rotor position. It is done by using position sensors.

The control happens mainly with the help of two angles namely turn-on angle (θ_α) and turn-off angle (θ_β) [9].

The switches of each phase need to be turned on once for every 45 degrees. The θ_α should be chosen in such a way that it allows the growth of the current which intern reduces the inductance value to a minimum level.

Fig. 1. The proposed topology block diagram

IV. PROPOSED SYSTEM DESIGN

In the proposed system designing consists of components design of the Boost, Buck-Boost and Cuk converters. It also contains design of PV array and SRM.

A. Solar PV Array

The system peak power rating is 4.5 kW. The short circuit current of the module is 8.5 A (I_{sc}) and open circuit voltage of the module is 30 V (V_{ocm}).

The current and voltage values per module are 7.5 A (I_{MP}) and 25V (V_{MP}) respectively. The open circuit array voltage of PV panel is 310 V (V_{OCP}). The strings to be connected in series is given by the following equation,

$$V_{OCP} = n_s * V_{ocm} \qquad (1)$$

Thus there are 15 modules per series string. The strings that are connected in parallel is given by

$$I_{MP} = n_p * I_{sc} \qquad (2)$$

Thus there are 2 modules per each parallel string. Thus the PV array totally contains 2*15 modules [3-5].

B. CUK Converter Design

The CUK converter basically has two inductors along with a capacitor. The schematic diagram of CUK converter based water pump is shown in Fig.2.

The duty ratio is calculated by the following equation as,

$$\frac{V_{dc}}{V_{MPP} + V_{dc}} = 0.659 \qquad (3)$$

Input inductance is as follows,

$$L_1 = \frac{V_{MPP} * D}{\Delta I_1 * f_{SW}} = 4.5397 \text{mH} \qquad (4)$$

Output inductance is as show below,

$$L_2 = \frac{V_{dc} * (1 - D)}{\Delta I_2 * f_{SW}} = 9.742 \text{mH} \qquad (5)$$

The value of capacitance is estimated as,

$$C_1 = \frac{I_1 * (1 - D)}{\Delta V_{C1} * f_{SW}} = 2.89 \mu\text{F} \qquad (6)$$

f_{SW} denotes the switching frequency which is chosen to be 15 KHz.

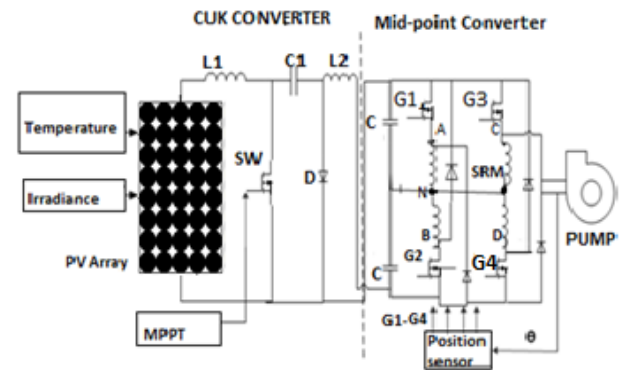The $\Delta V_{C1}, \Delta I_1, \Delta I_2$ are the respective allowable voltage and current ripples.

Fig. 2. Schematic Diagram of CUK Converter Based Water Pump

C. Buck-Boost and Boost Converter Design

The Buck-Boost converter and the boost converter has same design parameters which consists of inductor and capacitors and the Fig.3 and Fig.4 represents the schematic diagram of the two converters based water pump.

The duty ratio is as shown below,

$$\frac{V_{dc}}{V_{MPP} + V_{dc}} = 0.659 \qquad (7)$$

The inductor value is estimated as

$$L = \frac{V_{MPP} * D}{\Delta I_L * f_{SW}} = 5.4477 \text{mH} \qquad (8)$$

The capacitance value is given as,

$$C_1 = C_2 = \frac{I * (30 - \alpha)}{2 * \Delta V_{dc} * w} = 3.21 \mu\text{F} \qquad (9)$$
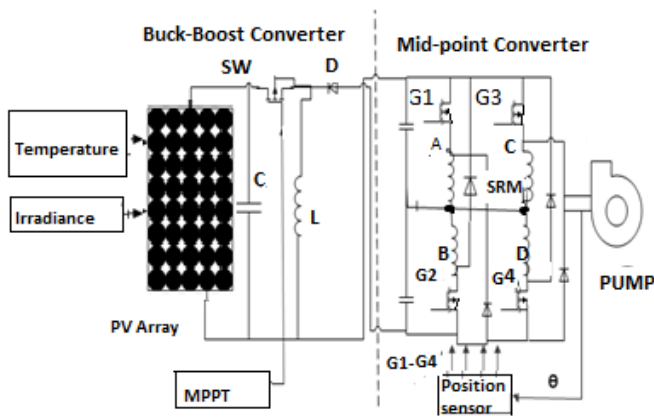
Fig. 3. Schematic Diagram Representation of Buck-Boost Converter Based Water Pump
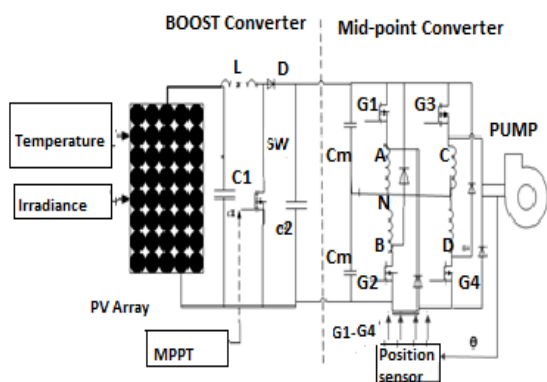

Fig. 4. Schematic Diagram Representation of Boost Converter Based Water Pump

D. Modeling and Design of SRM

The basic equivalent circuit of SRM is shown in Fig.5 which is modeled by considering current-controlled voltage source. The specifications of SRM are 3.5kW, 8/6 pole, 1500rpm.

The following equation gives the KVL equation of SRM in the conducting phase as,

$$V = R*I + \frac{d\Psi}{dt} \qquad (10)$$

$$V = R*I + L*\frac{di}{dt} + w_m*i*\frac{di}{dt} \qquad (11)$$

Where the term V represents the voltage at terminals .

Generally the last term in the above equation can be also given as,

$$E = w_m*i*\frac{di}{d\theta} \qquad (12)$$

By interpreting the instantaneous electrical and mechanical powers we can obtain the torque developed across the terminals of the motor.

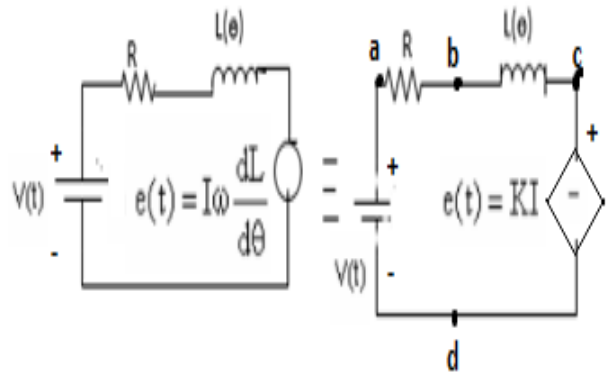$$T = \frac{1}{2}*I^2*\frac{dL}{d\theta} \qquad (13)$$

Fig. 5. Equivalent circuit of SRM

V. PROPOSED SYSTEM DESIGN

The solar powered water pump system using three different converters is designed as discussed in the above sections and it is simulated using MATLAB/Simulink.

The performance is analyzed based upon the speed of the SRM and the torque developed in the SRM. The solar panels are operated at a fixed irradiance of 1000W/m^2 and the operating temperature is 25°C.

A. Performance of solar powered Water Pump using CUK Converter

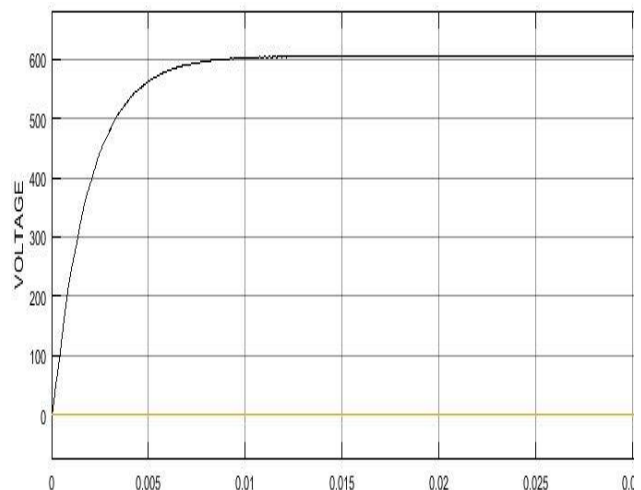Fig.6 shows the voltage waveform of Cuk converter which is 605V.

Fig. 6. Voltage Waveform of CUK converter

Fig.7 shows the speed with the SRM is operating which is given as the input to centrifugal pump and it also shows the developed torque in the motor. The speed value is 1500 rpm and the torque obtained is 24N-m.
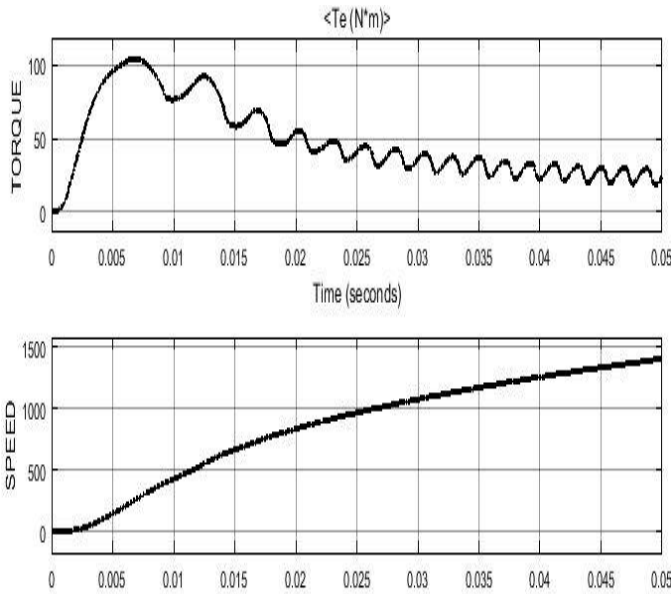
Fig. 7. Speed and Torque of SRM Employing CUK Converter

B. Performance of solar powered Water Pump using Boost Converter

Fig.8 denotes the terminal voltage of the Boost converter whose value is 600V.
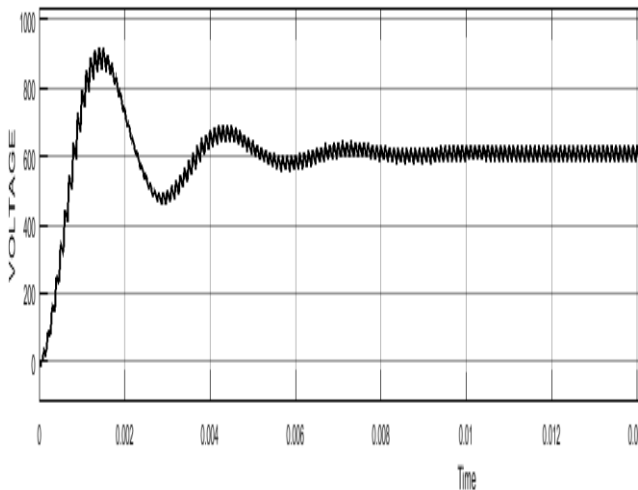

Fig. 8. Voltage Waveform of Boost Converter

Fig.9 shows the speed with which the SRM is operating and also it gives us the developed torque value. The speed with the SRM is running is 1280 rpm and the torque developed in the motor id 20N-m.

C. Performance of solar powered Water Pump using Buck-Boost Converter

Fig.10 represents the terminal voltage of buck-boost converter and its voltage value is 600V.
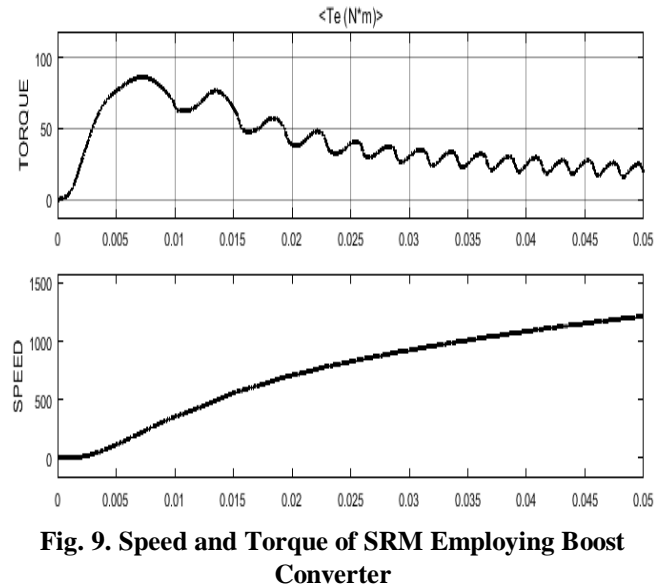

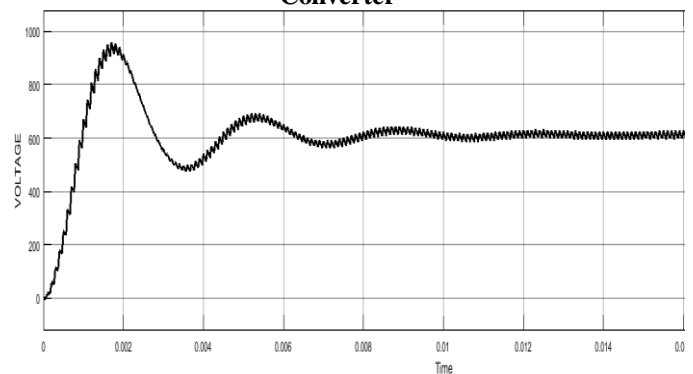**Fig. 9. Speed and Torque of SRM Employing Boost Converter**

Fig. 10. Voltage Waveform of Buck-Boost Converter

Fig.11 shows the speed with which the SRM is operating and also the torque developed in the motor. The speed with which the SRM is operating is 1270 rpm and the torque developed is 19.7 N-m.

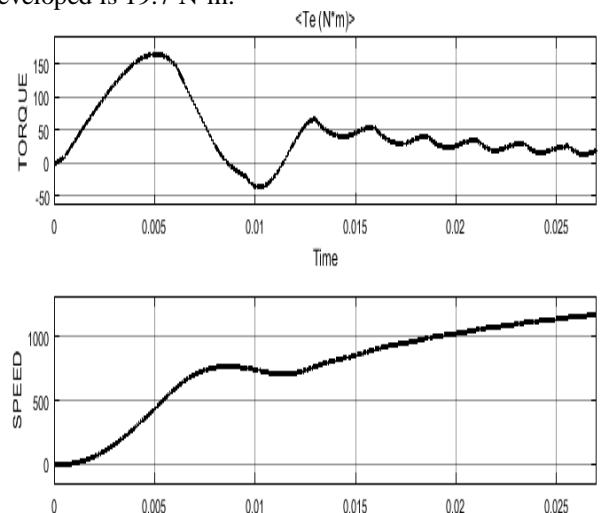

Fig. 11. Speed and Torque of SRM Employing Buck-Boost Converter

VI. CONCLUSION

The solar powered water pump system incorporating SRM along with three different converters is simulated using MATLAB/Simulink.
Following are the conclusions

and observations obtained from the results:

▪ The operation of switches in the mid-point converter employing electronic commutation results in the improvement of efficiency.

▪ The below table gives the comparison of the performance between the three different converters with respect to speed and torque:

Converter	Speed (rpm)	Torque (N-m)
CUK	1500	24
BOOST	1280	20
BUCK-BOOST	1270	19.7

▪ From the above table it is observed that the CUK converter is operated at almost the rated speed and torque irrespective of the changes in the input solar energy as the Cuk converter has wide MPPT operating range.

▪ The boost converter has voltage as well as current ripples due to which the speed and torque is not as desired. The other drawback is that it doesn't have wide operating range of MPPT.

▪ The buck-boost converter has voltage as well as current ripples due to which the control in the voltage across the bus is difficult and employing the MPPT control algorithm is also difficult due to the input current ripples.

Therefore from the above discussion it can be concluded that among these three different converters CUK converter is more advantageous. Employing the CUK converter makes the system reliable and also efficient.

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