Switched Reluctance Motor Driver Based Solar Power Water Pumping Systems

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Abstract- Solar power is a non-polluting source of energy. It has lower efficiency and it's dependent on irradiance level, array temperature. This deteriorates if maximum power transfer theorem is not fulfilled. A solar photovoltaic array can be used to feed water pumping system employing a switched reluctance motor (SRM) drive. The pumping system works without batter storage. This system is simple and consists of a switched reluctance motor driving a pump powered by a PV array. This motor is cheaper, efficient and reliable than conventional AC and DC electrical machines used in this application. Cuk converter operating in continuous conduction mode decreases losses in converter. To deliver smooth input / output current it drives the motor with considering maximum power point of generator.

Keyword- *Switched reluctance motor (SRM), Cuk converter, Continuous conduction mode (CCM), Solar Photo Voltaic (SPV) system, Solar Water Pump, Maximum Power Point (MPPT)*

I. INTRODUCTION

Solar power is an attractive sources of energy, free, abundant and non-polluting the atmosphere. However, due to the lower efficiency of current photovoltaic cells, conversion of sunlight into electrical power is very poor and its irradiance level, array temperature dependents, this efficiency further decreases if there is no impedance matching between photovoltaic panels output and the load ensure that the maximum power transfer theorem is fulfilled. This paper presents a solar photovoltaic (SPV) array fed water pumping system employing a switched reluctance motor (SRM) drive. The aim of this paper is to show how to achieve an effective photovoltaic pumping system without batter storage this system is simple and consists of a switched reluctance motor driving a pump powered by a PV array. This motor is cheaper, efficient and reliable than conventional AC and DC electrical machines used in this application. This is because of its simple construction.[1] The SRM drive at fundamental frequency offers reduced switching losses in the mid-point converter and increases the efficiency of the proposed system. A DC-DC Cuk converter operating in continuous conduction mode (CCM). The CCM operation decreases the losses of DC-DC converter. For smooth input/output current Cuk converter of SRM drive with the region for maximum power point tracking (MPPT).[2] By adjusting the step size of an incremental conductance MPPT algorithm can facilitate the soft starting of SRM drive. The system under study shows the effectiveness and robustness of the proposed method for increasing pumping performance.

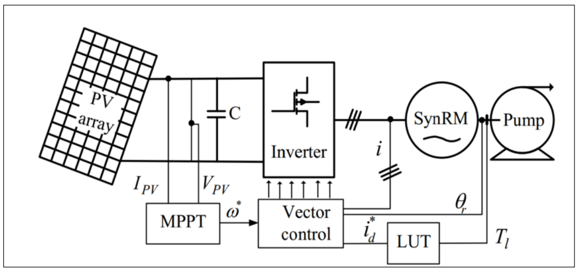

Fig 1– Basic form of solar PV – SRM pump system

The solar water pumps are gaining the popularity in rural areas, where the electricity is not available. Moreover, solar PV fed water pumps are the favoured in remote areas for irrigation, water treatment plant, and agriculture purpose. Country like India, where 70 percent population depends upon agriculture, therefore, and irrigation is necessary for good yield.[3] There is large number of water pumps in the world running with electricity or with non-renewable energy sources. The acquisitions of solar PV based water pumping systems are more convenient as compared to diesel based water pumping systems in respect to the cost and pollution.

II. SYSTEM CONTROL OPERATIONS

The configuration of SPV array fed water pumping system using SRM drive is shown in figure. The system is competent enough to work smoothly in critical environment. The system is controlled effectively near solar maximum power point through effective control mechanism. It consists of The SPV array, the Cuk converter, the mid-point converter feeding the SRM coupled to a centrifugal water pump. The SPV array output power is optimized by P&O MPPT technique.[4]

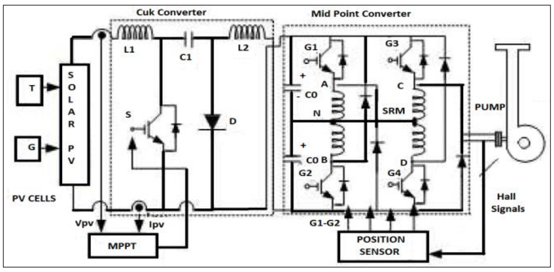

Fig 2- System Configuration [4]

a) MPPT Technique

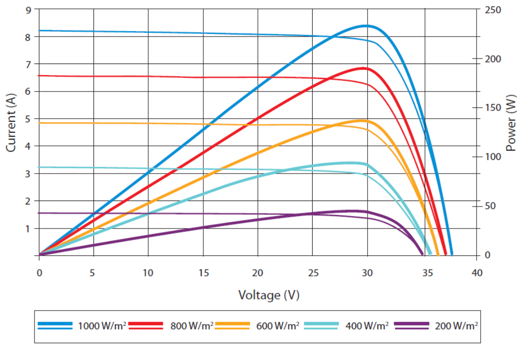

Fig 3- MPPT points at various power levels

The maximum power point in the I-V characteristics of SPV array is not predicted beforehand but it always varies dynamically with irradiance and temperature. There are observable voltage shifts, where the MPP occurs [5]. So, MPP needs to be located by tracking algorithms. The P&O method of MPPT tracking, which is very advantageous and implementation is easy. It is also called three step operations method. The duty ratio of Cuk converter is routinely regulated through this MPPT controller. Thus MPPT produces PWM pulses for the switch of Cuk converter.

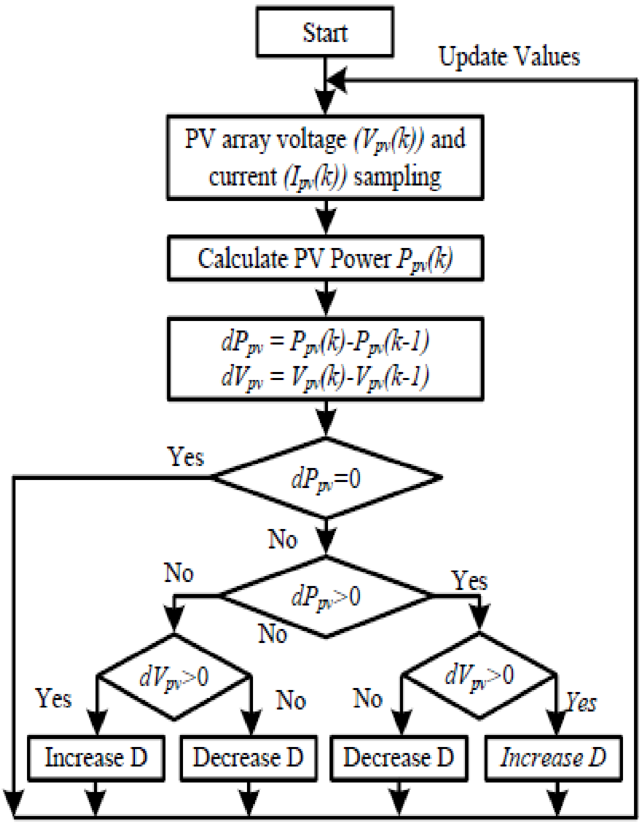

Fig 4- P&O Algorithm [8]

b) Conduction Angle Control of SRM

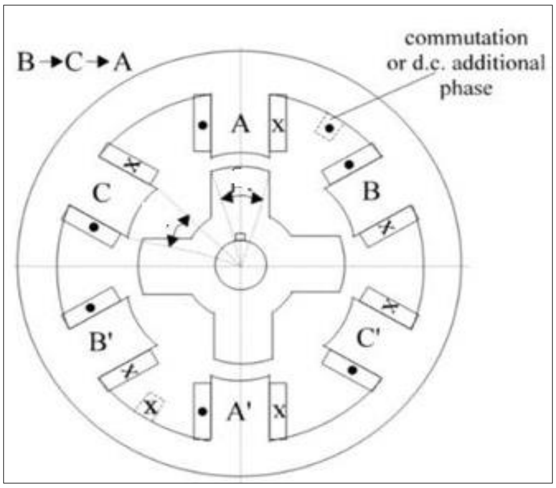

Fig 3- SRM configuration

The method under study gives out smooth, continuous torque and high efficiency is by using Rotor position information to control phase energization of SRM drive. The conduction angle for phase currents of stator is controlled and synchronized with the rotor position usually by means of shaft position sensor. The SRM is integrated with a closed loop control circuit, which is essential to run the machine. The main function of the control circuit is to optimize the switching angles of the applied phase voltage to make the current pulse coincide with the active interval of the motoring inductance profile. The whole switching of converter is control by three parameters [7]:

- *The Turn-on angle), θα*
- *The Turn-off angle, θβ*
- *The effective supply voltage*

The switching angles are defined for each phase based on the rotor position information provided by a position sensor located on the shaft. The value of *θα* is chosen to permit the current to grow to an adequate level while the inductance is at its minimum value.

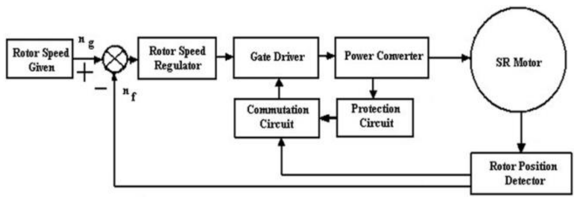

Fig 4– Motor control signal flow

To avoid the generation of a reverse or braking torque in the motoring mode that results in reduction of total average torque, the current pulse duration must be confined to half of the rotor pole pitch. The mechanical stroke-angle, € is given as,[10]

$$€ = \frac{2\pi}{N_{ph}N_r}$$

c) Control of Mid-point Converter

Excitation pattern and ON-OFF switching of SRM phase winding are carried out using a combination of semiconductor switches connected in a predefined configuration. The mid-point converter is selected for SRM whose phases are in even number. Unlike the other converters it requires less number of switches equal to the number of phases. The mid-point converter contains two DC-link capacitors Because of less number of switches and absence of PWM switching, operation of this converter results in a lower switching losses compared to other converters.

III. MODELLING OF PROPOSED SYSTEM

The design of SPV array fed water pumping system employing SRM drive consist of SPV array, DC-DC Cuk converter, a midpoint converter and the SRM coupled with a water pump. The designs procedures of the components are shown below:

a) Design of SPV Array

The proposed system is designed for the peak power capacity of 4.8 kW. A solar PV module has short circuit module current (I_{sc}) of 8.21A and open circuit module voltage (V_{ocn}) of 32.9 V. The maximum power for SPV array is given as,

$$P_{mp} = n_s n_p \times V_{mp} I_{mp}$$

Where n_s and n_p represent series and parallel strings of PV module, V_{mp} is the voltage of a module at MPPT, Imp is the current of a module at MPPT and P_{mp} is the nominal power of a module at MPPT.

b) *Design of Cuk Converter*

The Cuk converter transfers the active power from PV array to the DC link capacitor of mid- point converter feeding SRM pump system. The Cuk converter is so designed that it always operates in continuous conduction mode (CCM) regardless of the atmospheric conditions.

The value of duty cycle, D is estimated as,

$$D = V_0 / (V_{mpp} + V_0)$$

The value of input inductor, L_1 is given as,

$$L_1 = V_{mpp} D / (\Delta i_1 f_{sw})$$

The value of output inductor, L_2 is given as,

$$L_2 = V_0 (1-D) / (\Delta i_2 f_{sw})$$

The value of energy transfer capacitor, C_1 is given as:

$$C_1 = I_1 (1-D) / (\Delta V_c 1 f_{sw})$$

Where, D is the duty cycle, f_{sw} is the switching frequency, I_1 is the input current of the Cuk converter, Δi_1 is permitted ripple in the current flowing through L_1, Δi_2 is permitted ripple in the current flowing through L_2, ΔVc_1 is permitted ripple in the voltage across C_1 (10% of Vc_1), V_0 is the output voltage of the Cuk converter.

c) Design of Centrifugal Water Pump

In general, pumps are classified as centrifugal pumps (or rotor-dynamic pumps) and positive displacement pumps. In displacement pumps, the water output is directly proportional to the pump speed, but independent of head. The centrifugal pumps produce a head and a flow by increasing the velocity of the liquid through the machine with the help of a rotating vane impeller and its water output is directly proportional to the square of pump speed. It is generally used where water pump is directly interfaced with the SPV array. The characteristics of the centrifugal water pump are well matched with the characteristics of SPV array. The Centrifugal water pump is designed using its torque-speed relationship as,

$$T_p = K\omega^2$$

IV. CONCLUSION

The SPV array fed SRM driven water pumping system can be designed, modelled into an effective system and its various starting, dynamic and steady state performances can be drafted into demonstration model or simulation. Following merits can be derived from the system under study:

- *SPV array is forced to operate at its MPP resulting in the efficiency optimization of the proposed system regardless of the operating conditions.*
- *The mid- point converter losses are reduced due to its operation with electronics commutation which results in an overall efficiency improvement of the proposed water pumping system.*
- *The proposed system is reliable, simple and requires less maintenance.*
- *It has been revealed that the proposed water pumping system exhibits satisfactory performance under the change in solar irradiation which verifies its suitability for SPV array fed water pumping.*
- *The system is reliable, simple and requires less maintenance.*

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