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Two Stage Permanent Magnet Synchronous Motor Driven Solar Water Pumping System

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***Abstract:** This paper proposes a standalone two stage solar photovoltaic (PV) water pumping system. This system utilizes a solar PV array, boost dc-dc converter, Utility grid, three-phase voltage source converter; three phase VSI (Voltage Source Inverter), PMSM (Permanent Magnet Synchronous Motor).*

The boost converter used between PV array and VSI, serves the purpose of MPP (Maximum Power Point) tracking by adjusting the duty ratio using an INC (Incremental Conductance) method in order to extract optimum power from the PV array. In this way, the purpose of effective and efficient water pumping is achieved.

The proposed system is modelled using MATLAB/ Simulink environment and its performance is simulated to study its behaviour under varying insolation level.

***Keywords:** PV array; Utility grid; Voltage Source Inverter; Voltage Source Converter; Permanent Magnet Synchronous Motor; Incremental Conductance Algorithm.*

I. INTRODUCTION

With the ever increasing energy demand and depleting conventional energy sources, renewable energy sources offer a promisable alternative for fulfilling the rapidly increasing gap between demand and supply.

With the advancement of semiconductor technology, the steadfast improvement in PV array technology has improved its efficiency and effectiveness.

Amongst various sectors where solar PV energy is being utilized, water pumping for domestic as well as irrigation processes is seemingly one of the best and economically viable applications of PV energy generating system.

Two types of topologies are mostly used for utilizing PV energy.

The conventional two stage topology has first stage to extract the maximum power and second stage for maintaining DC link voltage. However, a single stage topology is more effective as the first stage DC-DC Converter is completely eliminated and thereby the losses associated with it are reduced.

Despite this, two stage topology has better control on DC link voltage even at lower insolation level. Moreover, the presence of DC-DC Converter eases the burden on VSI as it has to maintain only the power flow to the load.

Mostly induction motors are used to drive the pump with advantages such as low cost, robustness, ability to operate under adverse environment, easy availability and need for low maintenance but some of their limitations like low efficiency, complex control, overheating at lower voltages make them feasible for solar PV pumping.

In the last few decades, extensive research in permanent magnet (PM) technology has led to the development of PMs of considerably high energy density.

This advancement has contributed to the development of Permanent Magnet Brushless ac and dc motors. Permanent Magnet ac motors are generally known as PMSM (Permanent Magnet Synchronous Motor) whereas permanent magnet brushless dc motor as BLDCM (Brushless DC Motor).

It has an advantage of high efficiency, large torque to weight ratio, long life, low noise, low torque ripples, high reliability and low maintenance and hence best suited for Solar PV array water pumping.

A three phase Voltage Source Inverter (VSI) is widely used to feed the PMSM which is controlled using high frequency PWM signals.

II. PROPOSED SYSTEM ARCHITECTURE AND DESIGN

The system presented in this work comprises of solar PV array, dc to dc boost converter, three phases VSI, PMSM and a centrifugal pump. An INC method is utilized for extracting optimum power from solar PV array.

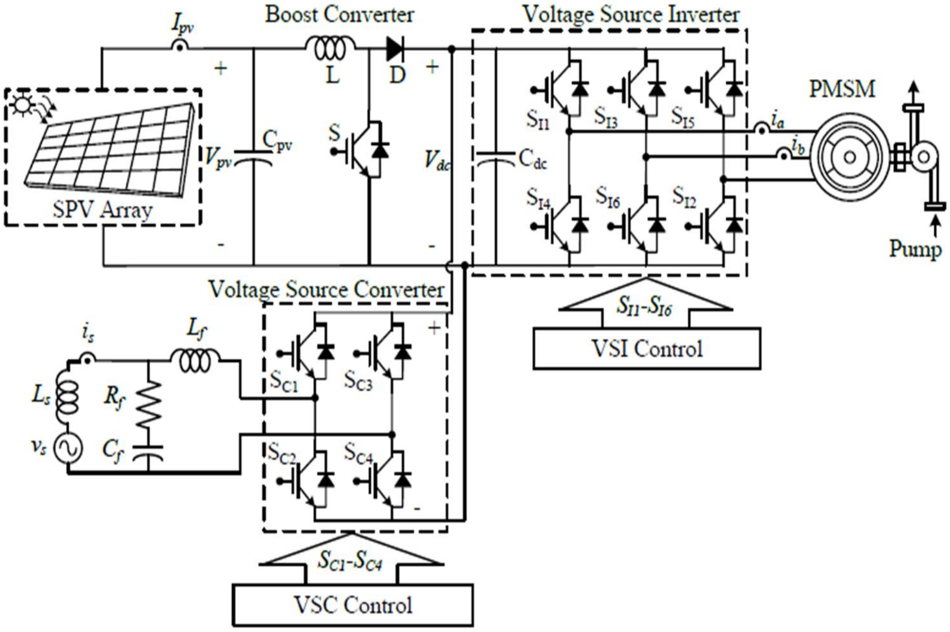

Fig.1 Architecture and design

Solar cells are fundamental building block of solar PV array. PV cells are combined in order to make a solar PV module. These modules are of standard power rating. Series combination of these PV modules increases the voltage level whereas parallel combination increases the current level. Depending upon the power required, the numbers of solar PV modules are decided. These modules are further arranged in series and parallel depending upon system voltage and current requirement respectively.

A. Design Of Solar PV Arrray

For the design of a solar PV array, the most important aspect to be considered is the load power requirement. The power rating of the solar PV array is selected somewhat higher as compared to the load power. Since the actual system is never lossless, this excess power would feed the losses of converter used for power processing at intermediate stages and load would get rated power at standard solar irradiation.

B. Design Of Boost Dc-Dc Converter

The voltage available at the input of the boost dc-dc converter is the solar PV MPP voltage (V_{vp}). This voltage is considered as 230V. VSI dc link terminal voltage (V_{dc}) which is the output voltage of boost converter and it is considered as 300V. Hence the duty ratio, D of the boost converter can be calculated as,

$$D = V - V_{pv}V_{dc}$$

III. CONTROL OF PROPOSED SYSTEM

This system configuration proposes an INC method of MPPT. This method controls the duty ratio of boost converter in such a way that an optimum power is extracted from a solar PV array. The three phases VSI switching is controlled using hysteresis current control in vector control of PMSM drive. Two PI (Proportional Integral) controllers are utilized in the system. First PI controller serves the purpose of regulating the DC link terminal voltage whereas the second PI controller serves the purpose of stator current control of PMSM. A power feed – forward term is also utilized which provides the system a smooth response under varying insolation conditions and also reduces stress on dc link PI controller.

A. Speed Control Of Pmsm Drive

The speed control of PMSM is achieved by FOC which represents the schematic of FOC implemented for the speed control of PMSM. The FOC involves the control of phase as well as magnitude of phase current and voltage applied to the motor. The speed control of PMSM comprises of three steps viz generation of reference speed, generation of reference voltage vectors and generation of switching signals for VSI. Under this situation, reference speed selector is put at position 1 and reference speed is set at its rated value. In the absence of grid, Vs is zero. In such a situation, WPS is operating in standalone mode and selector switch automatically shifts to position 2. The reference speed is generated by reference speed generator.

$$\omega_{rated} \qquad ; \; V_S \neq 0$$

$$\omega_{ref} = (K_{p\omega r} + \frac{K_{i\omega r}}{S})\{V_{dcref}(k) - V_{dc}(k)\} \qquad ; \; V_S = 0$$

Where V_s is the rms value of the grid voltage.

B. Bidirectional Power Flow Control

It enables the pump to operate at its full capacity by ensuring the power flow maintained in a way that the rated power is fed to the pump. Moreover, the power should be fed to utility grid when pumping is not required. This bidirectional power flow is possible by a unit vector control theory. The reference DC link voltage (V_{dcref}) is compared with the sensed DC link voltage and DC link voltage error is generated.

This error is fed to the DC link voltage controller and obtained output is the weight of the reference current. A unit vector template is generated by dividing the grid voltage by its peak amplitude. The product of weight of reference grid current and unit template, gives the reference grid current.

$$V_{dc\,er}(k) = V_{dcref}(k) - V_{dc}(k).$$

C. Maximum Power Point Tracking (MPPT)

For the purpose of optimizing the output power from the solar PV array, the MPP tracking techniques are mostly utilized. An INC method of MPP tracking is used in this work for its capability of highly accurate tracking even under rapidly changing insolation conditions. The MPP tracking method adjusts the duty ratio of dc-dc boost converter in small step size. Smaller step size gives good MPP tracking.

The disadvantage of the perturb and observe method to track the peak power under fast varying atmospheric condition is overcomes by IC method. The IC can determine that the MPPT has reached the MPP and stop perturbing the operating point. If this condition is not met, the direction in which the MPPT operating point must be perturbed can be calculates using the relationship between Di/Dv and –i/v. This relationship is derived from the fact that dp/dv is negative when the MPPT is to the right of the MPP and positive when it is to the left of the MPP. This algorithm has advantages over P and O in that it can determine when the MPPThas reached the MPP, where P and O oscillates around MPP. Also, incremental conductance can track rapidly increasing and decreasing irradiance condition with higher accuracy than P and O.

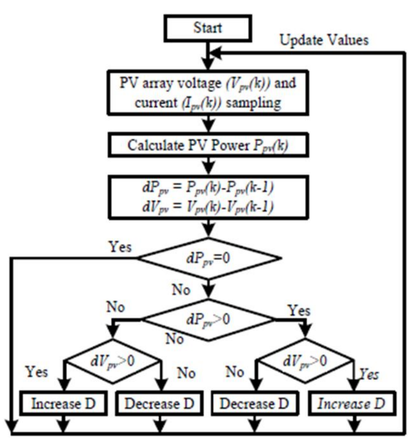

Fig.2 Flowchart

IV. PERFORMANCE OF THE SYSTEM

A solar PV array fed water pumping system utilizing PMSM has been modelled and analysed using MATLAB/Simulink. For good understanding of the system, performance during starting as well as steady state performance is shown together and dynamic performance is shown separately.

A. ABC Current

It takes the measurement of a three phase sytem and leads it to a two axes coordinate frame of reference, obtaining the two dimension pattern. Fig.3 shows the abc currents, the αβ currents and the generated patterns of a three phase load without unbalances, neither harmonics nor reactive power.

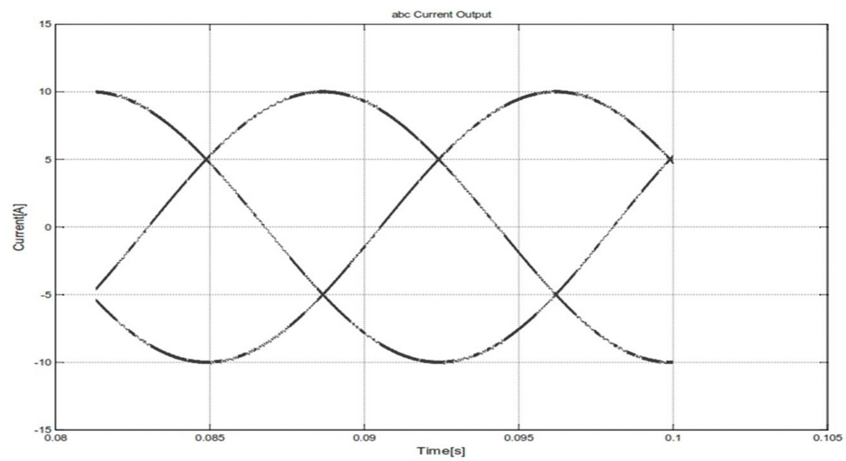

Fig.3 abc current output

B. DQ Current

The direct axis inductance(Ld) and quadrature axis inductance (Lq) with respect to star wound rotor is studied. Fig.4 show the dq current output with current in the Y-axis and time at the X-axis.

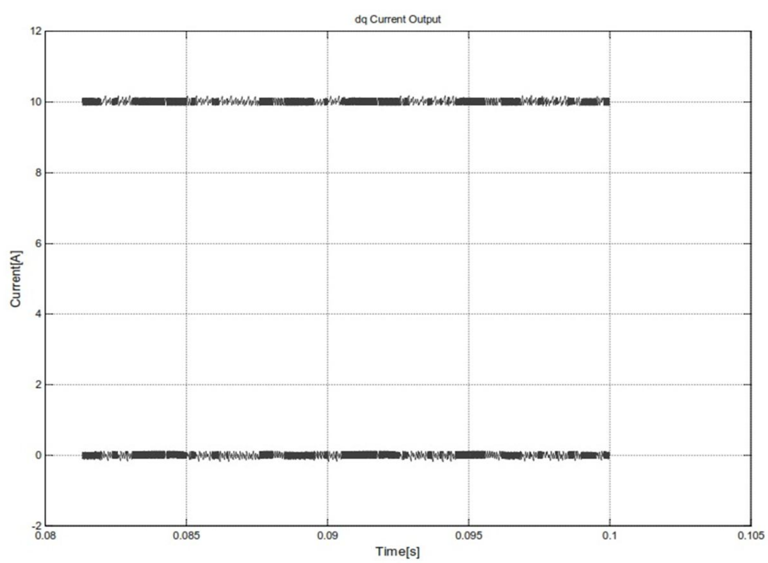

Fig.4 dq current output

C. Torque Output

The output torque of a three phase motor is calculated from the output power and the mechanical angular velocity. PMSM torque is -60N/M. Rotor angle of PMSM is plotted at -30deg. The PMSM current is -10 to +10A

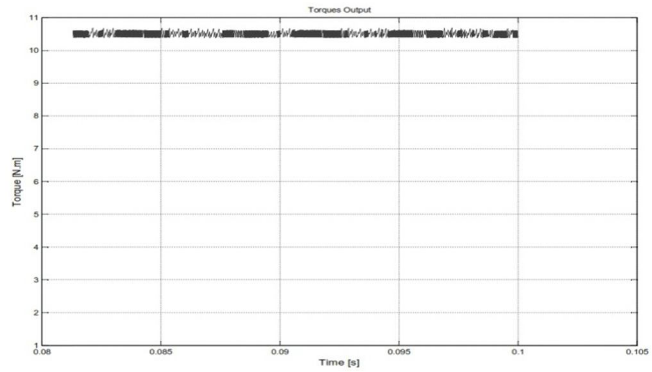

Fig.5 Torque output

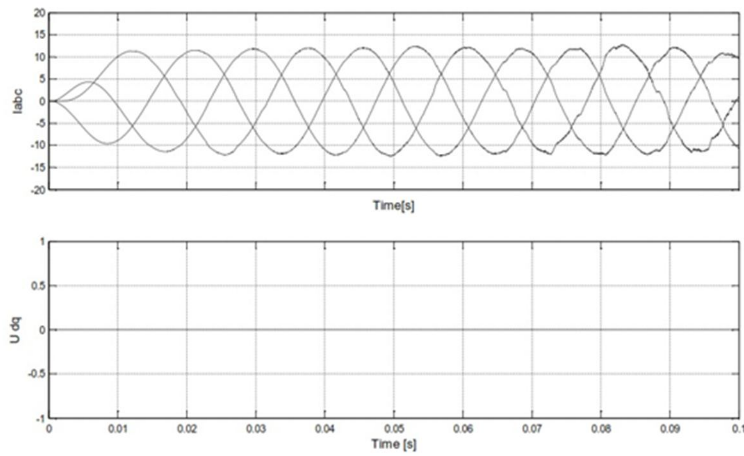

Fig.6

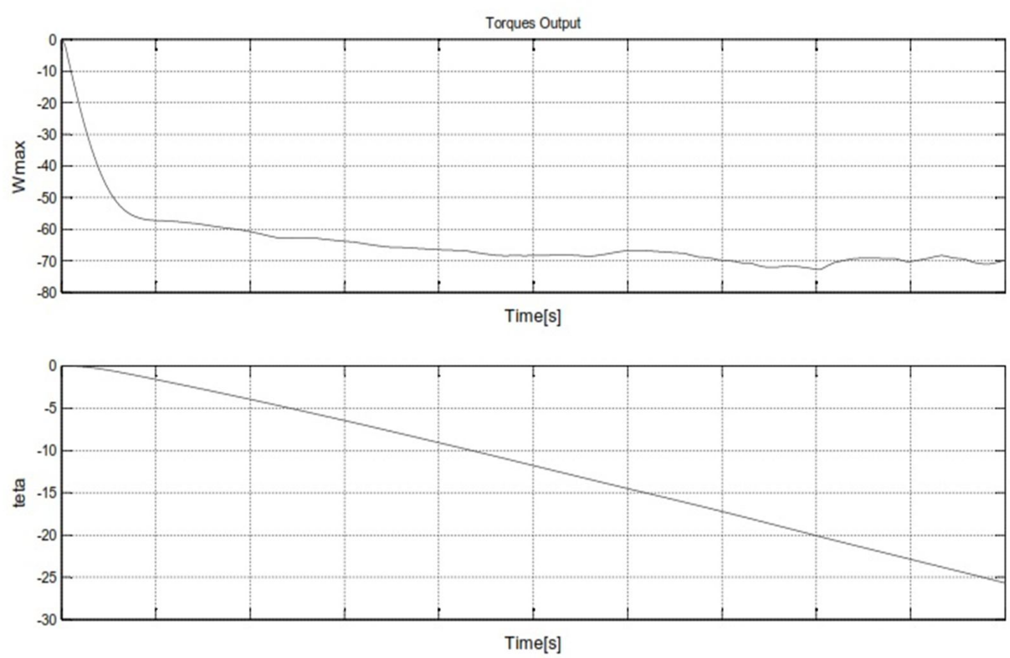

Fig.7

V. CONCLUSION

A double stage solar PV water pumping system driven by PMSM has been designed modeled and simulated using MATLAB/Simulink. The performance of the system has been analyzed under wide range of insolation. The system has demonstrated a satisfactory performance under both steady and dynamic conditions. The incorporated novelty such as MPPT using a boost converter, proper design of solar PV array, power fed-forward term and vector controlled PMSM driven pump has enhanced the system performance making it best suited for pumping application. Hence the proposed system gives a simple, reliable, economical, efficient, robust and compact solution which is highly feasible for solar water pumping.

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