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GRID INTERACTIVE SOLAR PV-BASED WATER PUMPING USING PMSM MOTOR DRIVE

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ABSTRACT

This study focuses on a power transfer strategy that efficiently feeds a field-oriented controlled (FOC) permanent magnet synchronous motor (PMSM) drive into a water pumping system (WPS) from a solar photovoltaic (PV) array and a single-phase grid. The need for a consistent water supply cannot be met by a standalone system due to the intermittent nature of photovoltaic (PV) systems. A grid intergraded WPS is suggested here to lessen this. The consumer can operate their water pump continuously regardless of the amount of solar insolation thanks to grid integration. Additionally, when water pumping is not necessary, the PV power can be sent into the utility grid. The shared DC link between the solar PV system and utility grid is controlled by switching pulses produced by the VSC using the unit vector template theory. To power the PMSM connected to the water pump, a sensor-less FOC is used. Under fluctuating insolation, the best power can be extracted from solar PV arrays using an intermediate stage boost converter. For maximum power point (MPP) operation, the duty ratio is generated using a perturb and observe approach. The suggested system is validated using a lab-developed prototype after being simulated in the MATLAB/Simulink environment with the SIM Power system toolkit. The system prototype is put to the test under a variety of solar insolation conditions as well as grid anomalies including voltage sag and voltage swell.

Keywords: PMSM Motor, Maximum Power Point (MPP), Power Factor, Power Flow Control, Power Quality, Solar Photovoltaic (PV), Total Harmonic Distortion (THD), Unit Vector Template (UVT), Voltage Source Converter (VSC), Voltage Source Inverter (VSI).

I. INTRODUCTION

A multifunctional system, which may enable a bidirectional power flow depending on the operating circumstances such that both PV installation and pumping system are fully utilized, is yet to be developed. This paper presents a suchlike system employing a PMSM motor drive for the first time. As mentioned, the proposed system deals with the development of a bidirectional power flow control, enabling the flow of power from PV array to the single-phase utility grid in case water pumping is not required, and from the grid to PMSM motor pump in case the PV array power is not sufficient (or at night) to run the pump at its full capacity. This practice offers a source of earning to the consumers by sale of electricity to the utility. A unit vector template (UVT) generation, due to its simplicity and ability to serve the objective, is applied to perform a bidirectional power transfer. The proposed system also meets the power quality standards required by a utility grid. A grid-interfaced PV-based water pumping system, incorporating some of the features, has been reported. A detailed design approach, control methodology, simulation analysis, and hardware implementation are added here.

Being a grid-isolated or standalone system, the existing PMSM motor-driven water pumps fed by a PV array rely only on solar PV energy. Due to its intermittency, solar PV generation exhibits its major drawbacks, which results in unreliable water pumping systems. During bad climatic conditions, water pumping is severely interrupted, and the system is underutilized as the pump is not operated at its full capacity. Moreover, an unavailability of sunlight (at night) leads to the shutdown of the water pumping system. These shortcomings are required to be overcome to acquire a reliable PV-based pumping system. Few attempts in this connection are found, although not with PMSM motor drives, which deploy a battery as an energy storage. Associated with a bidirectional control, the battery is charged and discharged during full and poor solar radiation (or no radiation), respectively; thus, it ensures full water delivery continuously. Contrary to this, introducing battery energy storage in PV-based water pumping not only increases the overall cost and maintenance but also reduces its service life.

II. PROPOSED SYSTEM ARCHITECTURE & DESIGN

The system that is being presented in this study includes a centrifugal pump, three stages of VSI, a dc-to-dc boost converter, and a solar PV array. To get the most power out of a solar PV array, an INC approach is used.

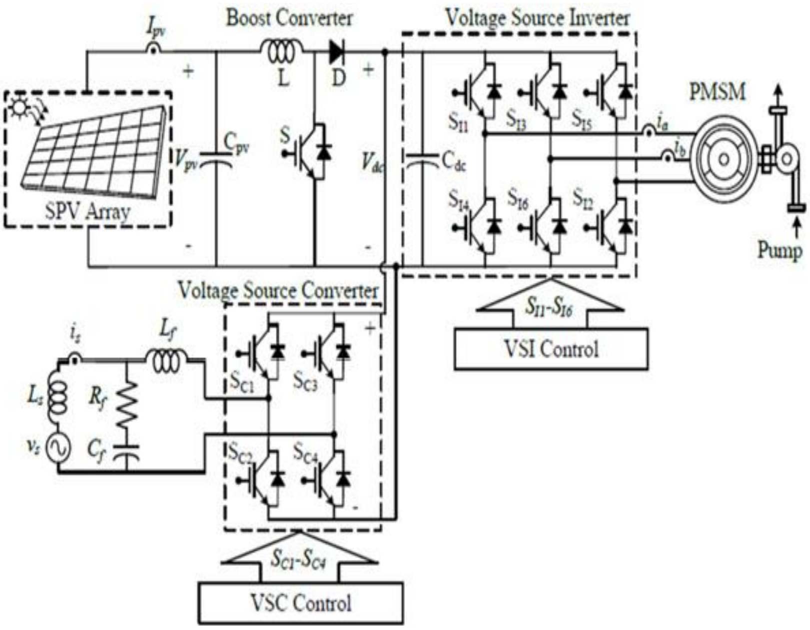

Fig. 1 Architecture & Design

A solar PV array's essential component are solar cells. A solar PV module is created by combining PV cells. This module's power rating is standard. While combining these PV modules in parallel will increase current, combining them in series will boost voltage. The quantity of solar PV modules is chosen based on the electricity needed. Depending on the system voltage and current requirements, these modules are then arranged in series and parallel, accordingly.

A. Design of solar PV Array

The most crucial factor to consider when designing a solar PV array is the load power needs. In comparison to the load power, the solar PV array's power rating is chosen to be a little bit greater. This surplus power would feed the losses of the converter used for power processing at intermediate stages because the actual system is never lossless, and the load would get rated power at standard solar irradiation.

B. Design of Boost Dc-Dc converter

The solar PV MPP voltage (Vvp) is the voltage that is available at the boost dc-dc converter's input. This voltage is taken to be 230V. The boost converter's output voltage, known as the VSI dc link terminal voltage (Vdc), is 300 volts. Consequently, the boost converter's duty ratio, D, can be computed as,

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

III. PERFORMANCE OF THE SYSTEM

Using MATLAB/Simulink, a solar PV array fed water pumping system utilizing PMSM has been simulated and examined. Performance while startup as well as steady state performance and dynamic performance are shown separately for better system knowledge.

A. ABC Current

The two-dimensional pattern is obtained by taking the measurement of a three-phase system and guiding it to a coordinate frame of reference with two axes. Figure 2 displays the generated patterns, abc currents, and currents of a three-phase load without unbalances, harmonics, or reactive power.

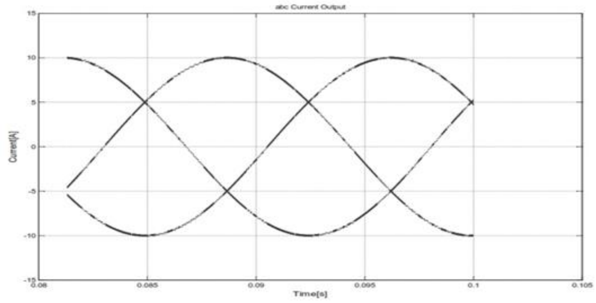

Fig. 2 ABC Current Output

B. DQ Current

Regarding a star wound rotor, the direct axis inductance (Ld) and quadrature axis inductance (Lq) are investigated. The dq current output is displayed in Fig. 3 with time on the X-axis and current on the Y-axis.

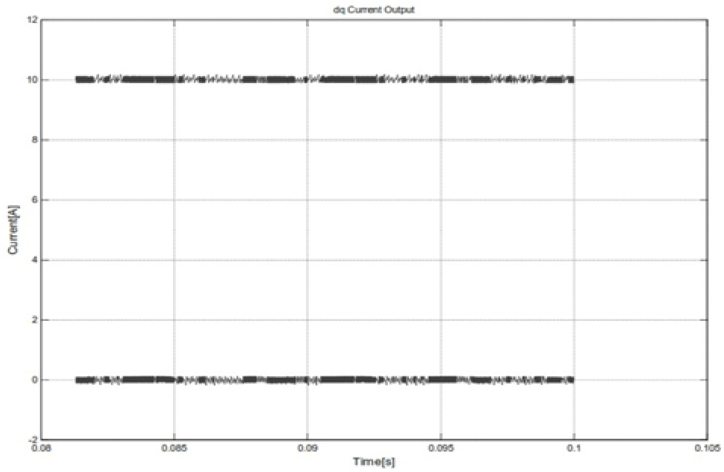

Fig. 3 DQ Current Output

C. Torque Output

A three-phase motor's output torque can be computed using its mechanical angular velocity and output power. -60N/M is the PMSM torque. The PMSM's rotor angle is depicted at -30 degrees. The present PMSM

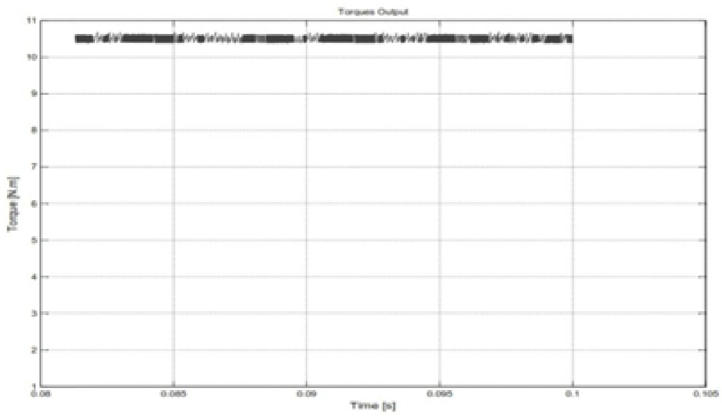

Fig. 4 Torque Output

IV. CONTROL PROPOSED SYSTEM

This design of the system suggests using the INC method of MPPT. With the use of this technique, the boost converter's duty ratio is adjusted to maximize the amount of power that can be drawn from a solar PV array. In vector control of PMSM drive, hysteresis current control is used to regulate the three phases of VSI switching. The system makes use of two PI (Proportional Integral) controllers. The first PI controller is used to regulate

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the DC link terminal voltage, while the second PI controller is used to control the PMSM stator current. Additionally, a power feed-forward term is used, which lessens strain on the dc link PI controller and gives the system a smooth response under a range of isolation conditions.

A. Speed control of PMSM Drive

$$\omega_{ref} = \begin{cases} \omega_{rated} & ; V_S \neq 0 \\ \left(K_{p\omega r} + \frac{K_{i\omega r}}{s}\right)\{V_{dcref}(k) - V_{dc}(k)\} & ; V_S = 0 \end{cases}$$

Where is the grid voltage's root mean square value

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.

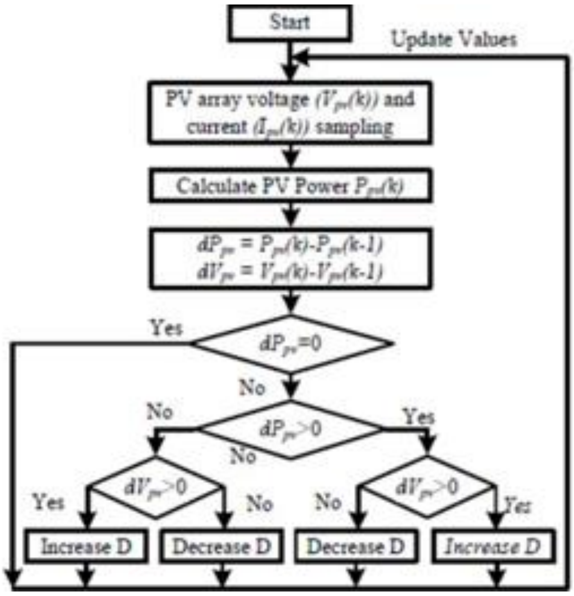

Fig. 5 Flowchart

V. CONCLUSION

A single-phase grid-interactive PV array-based water pumping system using a PMSM motor drive has been proposed and demonstrated. A bidirectional power flow control of VSC has enabled the full utilization of resources and water pumping with maximum capacity regardless of the climatic conditions. A simple UVT generation technique has been applied to control the power flow as desired. All the power quality aspects have been met as per the IEEE-519 standard. The speed control of BLDC motor pump has been achieved without any current sensing elements. A fundamental frequency switching of VSI has contributed to enhance the efficiency of the overall system by reducing the switching losses. The proposed solution has emerged as a reliable water pumping system, and as a source of earning by sale of electricity to the utility when water pumping is not required

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