

Four Quadrant Operation and Control of three Phase BLDC Motor for Electric vehicles

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Abstract:

This paper proposes bidirectional power flow control of a grid interactive solar photovoltaic (PV)-fed water pumping system. A brushless DC (BLDC) motor drive without phase current sensors is used to run a water pump. This system enables a consumer to operate the water pump at its full capacity for 24 hours regardless of the climatic condition and to feed a single-phase utility grid when water pumping is not required. The full utilization of a PV array and motor pump is made possible in addition to an enhanced reliability of the pumping system. A single-phase voltage source converter with a unit vector template generation technique accomplishes a bidirectional power flow control between the grid and the dc bus of the voltage source inverter (VSI), which feeds a BLDC motor. The VSI is operated at fundamental frequency, which minimizes the switching loss. The maximum power point operation of a PV array, and power quality improvements, such as power factor correction and reduction of total harmonic distortion of grid, are achieved in this system. Its applicability and reliability are demonstrated by various simulated results using MATLAB/Simulink platform and hardware implementation.

INTRODUCTION:

Rising carbon emissions and depleting fossil fuel supplies are pushing customers to switch to renewable energy sources immediately. One of the most promising alternatives to traditional energy sources for home appliances is solar photovoltaic (PV) production. Before switching to an AC induction motor, the water was pumped using DC motors. Permanent magnet brushless DC (BLDC) motors are popular as of the previous decade owing to their compact size, low electromagnetic interference (EMI), minimal maintenance requirements, extended service life, and high-power density. It has been calculated that by including this motor, not only will PV panels perform better and need less maintenance, but they will also be smaller in size. When coupled with a bidirectional control, the battery is charged during times of high solar radiation and drained when there is little to no solar radiation, guaranteeing a constant supply of fresh water. On the other hand, adding a battery energy storage to a PV-based water pumping system not only raises the total cost and maintenance but also shortens the lifespan of the system. The typical lead acid battery only lasts two to three years before it has to be replaced. The primary focus is on constantly

pumping water at maximum capacity, day or night, without interruption. A water pump and controller are wired onto the DC bus shared by the PV array and the grid-tied inverter. Since there is no need for battery storage, the system's useful life is extended, and both the maintenance and production costs are minimized. It is not immediately obvious that this is a PV pumping system linked to the electric grid. In [15], a hybrid PV water pumping system is described in which a battery is charged by a PV array via a charge controller and then discharged to supply the water pump using an inverter.

The system's price increases because of the high initial and ongoing costs associated with the battery storage. In cases where no water pumping is necessary, the proposed system would allow power to flow from the PV array to the single-phase utility grid, and vice versa when the PV array's power is insufficient (or at night) to run the BLDC motor-pump at full capacity. According to the IEEE-519 standard [19], the suggested system also satisfies the power quality requirements of a utility grid. In [20], it is stated that some of the aforementioned capabilities have been implemented in a grid-interfaced PV-based water pumping system. Here we offer in-depth discussions of our strategy for design, our control methods, our simulation analysis, and the hardware implementation. Maximum Power Point Tracking (MPPT) is accomplished using a DC-DC boost converter and an incremental conductance (Inc.) approach for a PV array [21-25]. By running the VSI (Voltage Source Inverter) in PWM (Pulse Width Modulation) mode for a set amount of time, the beginning stator current of a BLDC motor may be modulated. After the motor has been started, however, the VSI is run on fundamental-frequency pulses, reducing switching loss and improving conversion efficiency. Another cost-saving feature of BLDC motor control is that no phase current sensor is required. To back up the assertions made, a MATLAB/Simulink platform-based design, modelling, and simulation of a PV-based water-pumping system with a BLDC motor drive is shown, with the results of the simulation being compared with those obtained from a subsequent hardware implementation.

Inverters that use a three-phase voltage source:

The power range for single-phase VSIs is modest, whereas the power range for three-phase VSIs is significant. The primary function of these topologies is to provide a three-phase voltage where the amplitude, phase, and frequency may be adjusted as needed. Emerging applications, such as active filters and voltage compensators, need arbitrary voltages in addition to sinusoidal voltages (e.g., ASDs, UPSs, FACTS, var compensators). Figure 14.13 depicts the typical three-phase VSI structure, while Table 14.3 lists the eight possible switch configurations. Switches S1 and S4, S3 and S6, or S5 and S2 of the inverter's legs cannot be turned on at the same time, since this would induce a short circuit across the dc link voltage supply, same as in single-phase VSIs. In a similar vein, it is not possible to turn off the switches of both legs of the inverter at the same time, since this would lead to an output line voltage that vary depending on the polarity of the line current. Two of the eight possible states (7 and 8 in Table 14.3) result in a 0 V ac line voltage. Here, the currents in the AC lines may freely flow via either the top or bottom parts. The ac output voltages are not zero for the remaining states (1–6 in Table 14.3). The inverter transitions between states in order to produce a specified voltage waveform. For the structure shown in Fig. 1, the resultant ac output line voltages have the discrete values of v_i , 0, and $-v_i$. The modulating method is responsible for selecting the states necessary to create the specified waveform, and it must make sure that only legitimate states are used.

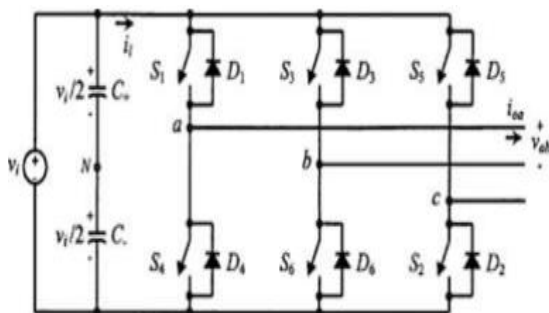


Fig. 3.1 three phase voltage source inverter

PROPOSED SYSTEM CONFIGURATION:

In Fig. 1 we see a diagram of the suggested water pumping system's layout, in which a BLDC motor drives the water pump. A BLDC motor-pump is powered by photovoltaic cells with a boost converter and VSI. While the VSI takes care of the electrical commutation of the BLDC motor, the boost converter handles the maximum power point

tracking (MPPT) of the PV array using the Inc. algorithm [5, 26]. Three Hall Effect signals are produced by an internal encoder, allowing an electrical commutation to take place. VSI relies on a single-phase power grid to power its DC bus. A voltage source converter (VSC) allows for reversible power flow through a DC bus capacitor. When water pumping is not needed, the PV array may provide power to the grid. To facilitate power transfer between the grid and VSC while reducing harmonic current in the supply, an interface inductor is installed in the line. Supply voltage harmonics are kept under control using a built-in RC ripple filter. In the Appendices, we provide a comprehensive mathematical model of the system as a whole.

BLDC MOTOR SPEED CONTROL:

The phase current sensors are unnecessary for the BLDC motor drive that has been suggested. The BLDC motor pump should be run at its rated speed in all save the most extreme weather. The VSI DC bus voltage is maintained at the BLDC motor's rated DC voltage to accomplish this. By controlling the DC bus voltage and, in turn, the operating speed, a bidirectional power flow control ensures that the entire amount of power necessary to operate the water pumps is delivered. If there is no access to the grid or if the DC bus voltage drops below the rated DC voltage of the BLDC motor due to weather or other environmental factors, the speed will be controlled by the DC bus voltage.

CONTROL OF THE TWO-WAY FLOW OF POWER:

Grid-interactive PV production allows for the construction of a trustworthy water pumping system and the optimal use of available resources. As can be seen in Fig. 2, a bi-directional power control is implemented using a UVT generation [20, 27-28] to enable power flow in both directions. The lack of a complicated mathematical model or procedure makes this the simplest method, making it the quickest and easiest to apply. The utility grid voltage and current are synchronized using a Phase Locked Loop (PLL) with a single phase. It creates a fundamental-frequency sinusoidal supply voltage, represented by the unit vector \sin . However, by controlling the voltage on the DC bus (v_{dc}), the fundamental component of the supply current (ISSP) may be retrieved. To regulate the supply voltage, a proportional-integral (PI) controller is implemented. The ripple information in the measured v_{dc} is filtered out using a first-order low pass filter. The filtered v_{dc} is then compared to a predetermined threshold. Multiplying ISSP by \sin yields i_s^* , a crucial part of supply current. The gating pulses for VSC are generated by a current controller, which

compares the measured supply current, with i_s^* and error. The voltage regulator produces a positive i_{sp} while utility electricity is being drawn. Therefore, a supply current with the correct phase is taken from the grid. Similarly, when PV arrays are used to feed the utility, negative i_{sp} is produced, leading to an asynchronous supply current. By switching the current's direction, power flow may be directed in whatever direction is most convenient. Total harmonic distortion (THD) and power factor are both reduced thanks to the implemented control method, guaranteeing better power quality from the utility grid. If the power grid goes down, it will be impossible to control the DC bus voltage. Despite the PV array's sensitivity to weather, it can provide power to the water pump in autonomous mode. In the Appendices, we provide a comprehensive evaluation of the proposed bidirectional power flow regulation.

A MODEL CIRCUIT FOR:

Through the use of simulated results in the MATLAB/Simulink platform, the suggested system is examined in a number of different operational contexts. Starting, dynamic, and steady-state operations are tested on the designed system and its control. A 1.5 kWp (under typical test circumstances) PV array and a single phase 180 V, 50 Hz utility grid are used to power a 4-pole, 3000 rpm @ 270 V (DC), 1.3 kW motor pump. In the Appendices, you'll find the system's detailed requirements. For example, the water pump may be powered solely by a PV array, the grid alone, a combination of the two, or not at all. For the purpose of demonstrating the proposed system, all of these operational circumstances are taken into account.

A. Acceleration and Maintaining a Constant Speed

The primary goals of these performance experiments are to show that BLDC motors may be started gently under a variety of situations, and that motor-pump systems can run steadily in the steady state. When the BLDC motor-pump is supplied only by the PV array: In Fig. 3, we see many indices for the PV array and the BLDC motor-pump combination. As can be shown in Fig. 3(a), a 1000 W/m² radiation intensity is needed to run a PV array at its MPP. That's why in Fig. 3(b), the BLDC motor pump is likewise being driven at its maximum possible speed of 3000 rpm, right at its rated capacity. The PV array provides enough electricity to operate the pump at full capacity without drawing any power from the grid. Back-EMF (e_a), Stator Current (i_s), Nominal Velocity (N), Electromagnetic Torque (T_e), and Load Torque (T_L) are the different indices. These findings show that the motor-pump may be started

gently and run reliably in a steady condition. When a water pump is needed at night, and only the utility grid can provide power, we have operating situation number two. Fig. 4(a) shows that a DC bus voltage of 270 V is maintained when an in-phase sinusoidal supply current of 8.3 A (rms) is drawn. As can be seen in Fig. 4(b), the motor is able to operate at full load since it is drawing enough power from the utility. This scenario exemplifies the full potential of the pumping mechanism. When Water Pumping Is Not Necessary (Step 3), the PV Array's Produced Electricity Is Sent into the Mains Supply? Figure 5(a) depicts the 1000 W/m² MPP functioning of the PV array. The utility is being supplied by a PV array, as shown in Fig. 5(b), and the power flow is being reversed while the DC voltage is being held constant at 270 V.

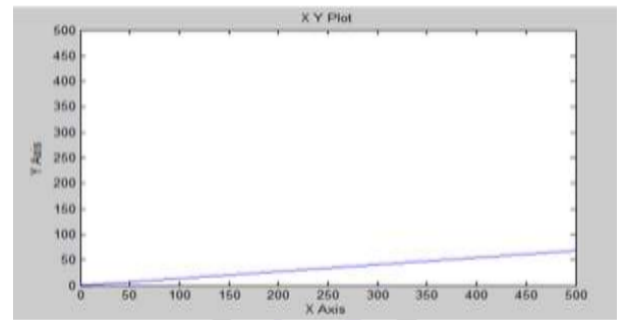
A. Performing Dynamically

A dynamic situation is one in which there is a quick shift in the prevailing weather patterns or the need for an immediate reversal in the direction of electricity transmission. It has been shown that the suggested system works well when the relevant dynamics are taken into account. This research assumes that the water pump is first run via the utility grid when electricity from the PV array is unavailable. Considering that water pumping is no longer necessary but that electricity from PV arrays is still accessible prompts a drastic shift in operating mode. As a result, supplying the utility with a PV array is a current goal. The results under such dynamic conditions are shown in Fig. 6. In about 0.3 seconds, the mode of operation shifts. The PV array index, utility grid index, and BLDC motor pump index are shown in Figs. 6(a), 6(b), and 6(c), in that order. Current flow direction flips within a half cycle, as seen in Fig. 6(b). As can be seen in Fig. 6(c), the DC bus voltage is maintained at 270 V. Decreases in the It is expected that initially just the PV array is feeding the pump since it is adequate to operate the water pump at full capacity. However, as time progresses, both the PV array and the grid will be feeding the pump. At 0.3 s, the radiation level drops from 1000 W/m² to 500 W/m². It is wanted to tap into the utility network since the PV array cannot provide enough electricity to operate the water pump at full capacity (500 W/m²). Fig. 7 depicts this situation. Figure 7(a) illustrates how a radiation intensity of 500 W/m² causes a decrease in the maximum power output of a PV array. The absence of utility power use prior to 0.3 s is seen in Fig. 7(b). After 0.3 s, a 4.3 A (rms) in phase supply current flows from the utility to meet the remaining power demand. The motor pump is run at full capacity in all-weather situations, as shown in Fig. 7(c). The DC

bus voltage is maintained at 270 V, allowing the motor to spin at 3000 rpm.

Aspects of Power Quality, Part B

The suggested solution guarantees enhanced power factor and THD on the electric grid. In case the water pump is powered only by the utility grid, the THD and harmonics spectrum of supply current is shown in Fig. 8(a). If the radiation level is 600 W/m² and the remaining power is needed from the utility grid, the THD and harmonics spectrum of is illustrated in Fig. 8(b). In each case, the THD of the supply current is less than 5%, which is within the tolerances set by the IEEE519 standard. Additionally, a unity power factor is maintained under all operational scenarios.

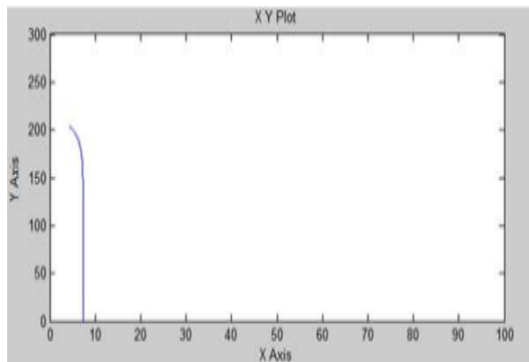


Stator current

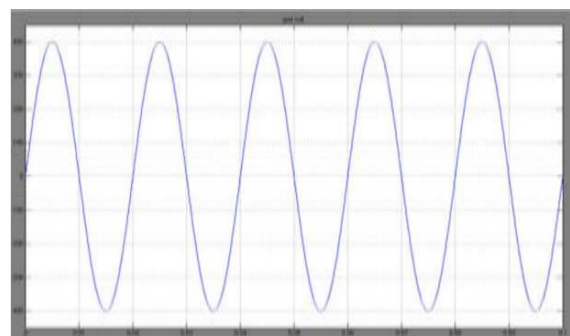


Rotor speed

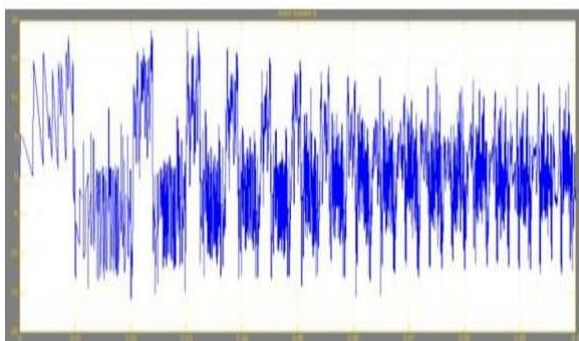
SIMULATION AND RESULTS:



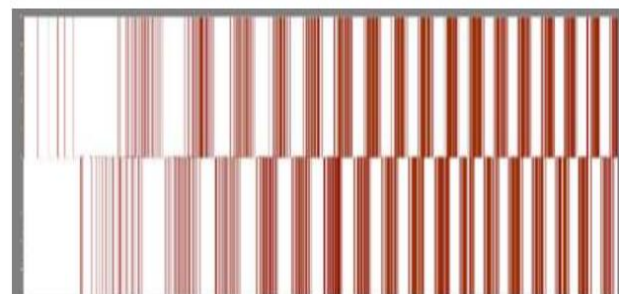
Solar IV characterizes



Grid input voltage



Solar PV characterizes



VSI output

CONCLUSIONS:

A BLDC motor drive-based PV array water pumping system has been suggested and proven. VSC's ability to regulate electricity in both directions has allowed for the most efficient use of available resources for water pumping under all weather conditions. To regulate the current as needed, a simple UVT generating method has been implemented. The IEEE-519 standard for power quality has been fully implemented. Without the use of current sensing devices, BLDC motor pump speed control has been realized. To improve the entire system's efficiency, fundamental frequency VSI switching has been used. When water pumping is not necessary, the suggested technology may be used to generate income by selling power to the utility. APPENDIX: The Solar Array's Settings Short circuit current = 8.15 A, maximum power point voltage = 200 V, open circuit current = 254.8 V, and maximum power point current = 7.5 A. Peak power = 1.5 kW. Motor specifications: Voltage constant = 68 V/kept; speed = 3000 rpm; stator resistance = 3.58 ; stator inductance = 9.13 mH. Parts for Interfacing with a Grid The values for the DC bus capacitor are 4700 F, 3.3 mH for the interface inductor, and 5, 5 F for the R-C filter.

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