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Grid Interactive Solar PV Based Water Pumping using BLDC Motor Drive

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ABSTRACT

This study proposes a method for controlling the bidirectional power flow in a solar Photo Voltaic (PV) driven water pumping system connected to the grid. It employs a brushless DC (BLDC) motor drive for the pump, eliminating the need for phase current sensors. This setup allows the pump to operate at full capacity round the clock regardless of weather conditions and can also feed excess power back into the grid when pumping is unnecessary. By utilizing a single-phase Voltage Source Converter (VSC) with a Unit Vector Template (UVT) generation technique, power flow between the grid and the VSI's DC bus is managed. The Voltage source inverter (VSI) operates at the fundamental frequency to minimize switching losses. The system achieves Maximum Power Point (MPP) operation of the PV array and improves power quality by correcting the power factor and reducing Total Harmonic Distortion (THD) on the grid. The effectiveness and reliability of the system are validated through simulations using MATLAB/Simulink and hardware implementation.

KEYWORDS: Solar Photo Voltaic, Brushless DC Motor, Voltage source converter (VSC), Unit Vector Template (UVT), Voltage source inverter(VSI), Maximum power Point, Power Quality, Power Factor, Total Harmonic Distortion (THD).

1. INTRODUCTION

Over the last several years, both in Australia and across the globe, there has been an increase in the penetration of renewable energy sources (RESs) into the current electricity system. Due to their unique characteristics, such as their accessibility from nature and ease of installation, solar and wind energy systems have become the most popular RESs. One of the most well-known and fastestgrowing RESs is the solar photovoltaic (PV) system. Based on the ratio of installed rooftop PV units to the total number of residential buildings, Australia is regarded as the nation with the biggest number of rooftop solar PV systems. The intermittent nature of solar PV systems and the necessity to convert DC power generated by them into AC via power electronic interfaces provide a number of difficulties for their grid integration. One of the biggest problems with grid-connected PV (GCPV) systems is getting the necessary real and reactive power—that is, electricity with the predicted power factor—into the grid. The continual changes in the environment's temperature and sun irradiation have an impact on maintaining the anticipated power factor or providing the intended amount of electricity. Additionally, loads that are linked to the main grid are constantly changing. To ensure the supply of the necessary power, the switching signals of power electronic interfaces (such as DC-DC converters and voltage source inverters (VSIs) for PV systems) must be continually modified to coincide with these changes. Another significant issue with GCPV systems is power quality, which is measured by total harmonic distortion (THD). These distortions are brought on by the switching operations of power electronic interfaces. According to IEEE Standard 1547, in order to successfully integrate PV systems with the primary power grid, the value of the THD in the grid current must be kept below a predetermined threshold of 5%. To lower the THD in the grid current, several filter types primarily first order (L), second order (LC), and third order (LCL) is utilized. In three-filter GCPV systems, the goal of this study is to provide a linear switching control approach for the VSI. To construct the switching control actions, the comprehensive dynamic models of VSIs with various kinds of filters will be employed. The functioning of the system under various power factor and environmental circumstances is taken into account while analyzing the performance of the suggested linear switching controllers. To show the value of the suggested CTMPC strategy for GCPV systems, the improvements in the THD will also be severely examined.

The continuously increasing carbon emission and diminishing of fossil fuels encourage the instant consumers to adopt the renewable energy. A solar photovoltaic (PV) generation is emerging as the best alternative of conventional sources for various appliances. With reference to this, the water pumping has gained a broad attention in last few decades as a crucial application of PV energy. The DC motors have been used initially to pump the water followed by an AC induction motor. An innumerable research has been carried out on electric motor drives to improve the performance and efficiency of PV fed pumping systems with cost benefit.

A permanent magnet brushless DC (BLDC) motor, due to its high efficiency, high power density, no maintenance, long service life, low electromagnetic interference (EMI) issues and small size, is being opted from last decade. It has been determined that introducing this motor reduces the cost and size of PV panels in addition to improved performance and maintenance free operation. Being a grid-isolated or standalone system, the existing BLDC motor driven water pumps fed by a PV array rely only on solar PV energy. Due to its intermittency, the solar PV generation exhibits its major drawbacks, which results in an unreliable water pumping systems. In the course of bad climatic condition, 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 shutdown of the water pumping system [1].

2. LITERATURE SURVEY

A. K. Gupta, P. Kumar and A. K. Singhal et. al. Among the non-conventional energy sources, solar energy, specifically photovoltaic energy, is considered the most promising. This is because it has the potential to meet the energy requirements of remote rural regions. This research discusses the design and implementation of an improved control approach for a single-stage photovoltaic-based water pumping system. The system is efficient and dependable thanks to the innovative scheme of basic switching of the SRM drive across its maximal operating period. The MATLAB Simulink program is used to do the simulation. The results of the simulations reveal a considerable increase in the current model's performance compared to the performance of the existing model. The solar power is increase 20%, RPM enhance is approx 3 times than previous work [2].

R. K. Gaddala and B. R. Kumar et. al. A grid interactive solar PV-fed BLDC motor using non-linear based model predictive current controller is implemented at PV side DC-DC converter and grid side single phase voltage source inverter (SPVSI). For this application, linear based propotional integral (PI) control structures are used in several articles which are designed at single operating point. In most of the literature, authors have not been considered when DC loads are present and their changes occur suddenly, when irradiation suddenly absent or available or changes time to time, when water pump is suddenly present during the operation, and when grid is absent and there is no sufficient PV power. For all this cases, the controller should react very fast to achieve better dynamics of the system. So, grid connected solar PV-fed BLDC motor with non-linear based controller is required. The proposed system achieves (i) Better dynamics during the changes in system, (ii) Unity power factor at grid side, (iii) PV array is operating at its maximum power point (MPP) mode at all the conditions, (iv) Able to supply the power to water pump in most of the cases. Finally, the overall system with controller structure is validated through MATLAB/SIMULINK results [3].

M. Kondalu, S. Uday, C. R. Reddy, O. C. Sekhar, A. Pandian and C. N. Sai Kalyan et. al. Bidirectional power flow here between renewable energy sources (RES) and also the load is implemented in this work. Renewable energy (RES) is generated using solar photovoltaic (PV) cells and a BLDC motor load is linked to the water pump via a single stage bi-directional converter & voltage source inverter (VSI) in the system to power the water pump Fusing in the solar generating framework allows the solar power generation system to extract maximum power while reducing grid losses and enabling consumers to run their motors and loads at their maximum efficiency all day long. Adaptive neuro-fuzzy interface system (ANFIS) in the Photovoltaic reduces switching costs, total harmonic distortion of the grid, etc. while preserving the system's power factor, quality of power and system stability [4].

S. Dinesh and S. A et. al. This paper introduces a grid interactive solar water pumping system. This system utilizes a new non-isolated boost DC-DC converter with SPV array as input in the first stage, a three phase voltage source inverter (VSI) is used to drive the permanent magnet synchronous motor to which the centrifugal pump is coupled as the second stage and a voltage source converter is used for effective power transfer between the grid and the system. An extended topology for boost DC-DC converter based on voltage lifting technique is used here. A perturb and observer MPPT algorithm control the duty ratio of the converter and extract the maximum energy from the PV array. A Sine PWM based Field Oriented Control technique is implemented for driving the PMSM coupled water pumping the bidirectional power flow between the common DC link of the system and the grid is controlled with unit vector template scheme. This system is modeled and operation is verified through simulation studies using MATLAB/Simulink [5].

A. K. Mishra and B. Singh et. al. This paper proposes a single-stage grid interactive solar powered switched reluctance motor (SRM) driven water pumping system with an efficient control technique. The control of the proposed system provides the proficient maximum power point technique (MPPT) tracking and motor drive control with bidirectional power flow between the photovoltaic (PV) array and single-phase grid. It has harmonics components elimination, improved dynamic performance, and a dc offset rejection capability compared to other control. A PV feed-forward term is also incorporated in developed control to enhance the dynamic performance of the system and to minimize the size of dc link capacitor with improved MPPT performance. The novel scheme of fundamental switching of SRM drive over its maximum operational time (when the grid is present) makes system efficient and reliable. An improved perturb and observe based MPPT algorithm is used in this system to minimize the undesirable losses in a PV array especially under varying insolation levels. The proposed control is tested on a developed prototype and its suitability is authenticated through simulated and test results under various conditions [6].

M. Kashif and B. Singh et. al. An interactive solar water pumping unit (SWPU) with enhanced frequency locked loop (FLL) based synchronization to ensure uninterrupted power for smart residential prosumers is presented in this paper. Enhanced FLL ensures rejection of both DC-offset and selected harmonics unlike conventional FLL, thereby improving performance of interactive SWPU, and hence power quality of prosumers' residential environment. A photovoltaic (PV) array, battery storage system (BSS), motor-pump unit (MPU) and power electronics interface consisting of synchronization unit (SynU), grid-connected voltage source converter (GC-VSC) and motor-connected VSC (MC-VSC) qualifies as main components of interactive SWPU. Besides, current control and voltage control for operating GC-VSC are developed under presence and absence of grid. Even a sensorless control to remove motor position sensor from MPU is developed for reducing cost of SWPU. Test performances of interactive SWPU in different operating modes including synchronization with grid are reported to demonstrate effectiveness of enhanced FLL [7].

3. METHODOLOGY

Several significant technologies that interact with converters and inverters will make MGs possible. Figure 1 illustrates this. The voltages and currents generated by the energy source are converted by these inverters, which are power electronic equipment, into the sinusoidal voltages and frequencies required for grid connection. Insulated gate bipolar transistors (IGBTs) and metal oxide semiconductor field effect transistors (MOSFETs) are examples of these semiconductor devices. For various energy sources, such as batteries, fuel cells, and photovoltaic (PV) arrays, direct current (DC) to alternating current (AC) conversion is only required once.

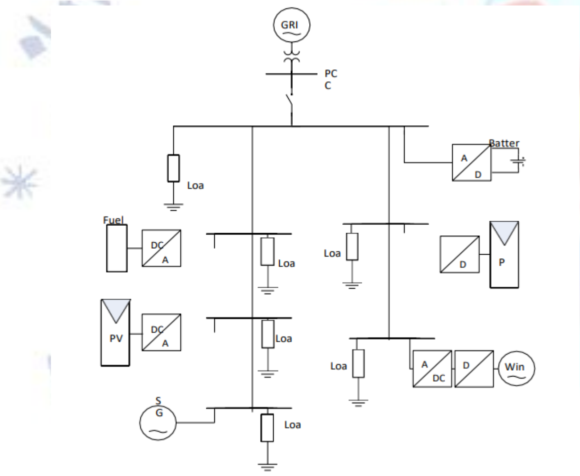

Figure 1: Possible MG configuration

Other energy sources that have the potential to produce high frequency voltages, such wind turbines and micro turbines, need a two-step conversion. Then back to AC after going from AC to DC. There are two common utility frequencies: 50Hz and 60Hz. The voltage will normally be at MV (1kV to 35kV) or LV (1kV or less) levels, however it may fluctuate. It is possible to categories the two operational modes of voltage source inverters (VSIs), sometimes known as inverters PQ or V-f.

In the BLDC motor control system using a cascade control structure, a controller is usually adopted in the inner current loop to make sure the output parameters of the motor can meet the requirements of stable operation. Additionally, the outer speed loop generally controls the speed through adjusting the voltage or pulse-width modulation (PWM) regulation. Thus, the BLDC motor operation performance is mainly determined by the inner current loop controller and the outer speed loop controller o further improve the stability of the BLDC motor and reduce the torque ripple, many scholars have carried out various in-depth research. In a Zeta converter is used to control the speed of the BLDC motor; hence, the motor speed is relatively constant under static or dynamic conditions. The inner current loop mainly adopts proportional integral differential (PID) control, and the literature combines the basic theory of fuzzy control with traditional PID control to design a fuzzy automatic adjustment PID controller. Compared with a traditional PID control method, the fuzzy automatic adjustment controller has a faster response speed and higher accuracy.

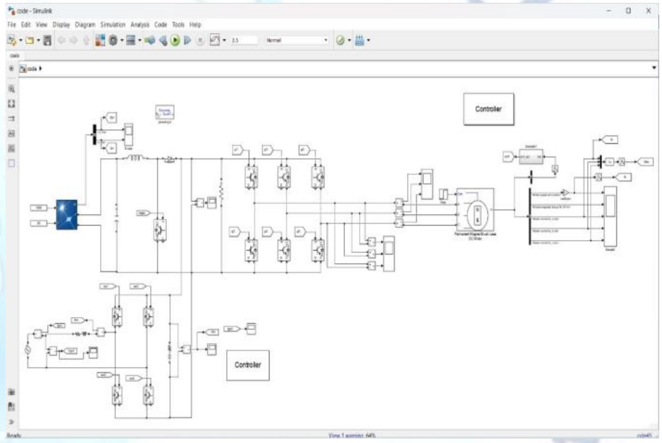

Figure 2: control circuit

In the BLDC motor was controlled through self tuning PID parameters. This method aims to use the collected data of detected back electromotive force (EMF) and rotor position information as feedback for the control algorithm to achieve self-tuning control. In a new three-effective vector (TEV) current control scheme was proposed, which overcomes the current distortion that may be caused by the reverse magnetic field of phase C, resulting in small output current ripple and a faster response speed. The robust control algorithm has also been applied in motor control. An improved infinite norm (H∞) strategy was proposed in and the improved controller can reduce the torque ripple and improve the dynamic response performance. The above control strategies can improve the operation performance of the BLDC motor partly, but the influence of parameter perturbation and sensor noise is ignored. Therefore, the change in the motor system working conditions will deteriorate the influence of the parameter perturbation. In order to improve the dynamic response performance of the BLDC motor control system and enhance the robustness of the uncertain system under the parameter perturbation condition, a current control method that includes PI control and the H∞ mixed sensitivity robust control algorithm is proposed in this paper to optimize the operation of the BLDC motor system. Firstly, according to the circuit topology and the differential equations of the BLDC motors, the current loop transfer functions of the BLDC motors are derived. Then, according to the possible changes during the whole operating process, an uncertainty model of the BLDC motors control system is established. In addition, the optimal weighting function is calculated based on the mixed sensitivity theory, and a generalized feedback system augmented matrix is established to solve the ideal controller. Finally, the effectiveness of the proposed algorithm is verified through comparing with traditional PI controller.

Droop control

By looking at a two bus example of a synchronous generator linked to a transmission network, it is possible to understand the connection between active power and frequency and reactive power and voltage. For a two-bus system, the power generated at the generator's terminal may be stated as:

$$P = \frac{E}{R^2 + X^2}(XV\sin\delta + R(E - V\cos\delta)) \quad (1)$$

$$Q = \frac{E}{R^2 + X^2}(-RV\sin\delta + X(E - V\cos\delta)) \quad (2)$$

The voltage angle, also known as the power angle, is represented by the symbol in the formulae. When using the generator terminal as the reference, which has a voltage angle of zero, the equations are most straightforward to construct. Only the angle difference between the two buses, however, is significant. A positive number for implies that the voltage on the generating bus is higher than the voltage at the receiving end.

4. RESULTS

Solar cell is the basic unit of solar energy generation system where electrical energy is extracted directly from light energy without any intermediate process. The working of a solar cell solely depends upon its photovoltaic effect hence a solar cell also known as photovoltaic cell. A solar cell is basically a semiconductor device. The solar cell produce electricity while light strikes on it and the voltage or potential difference established across the terminals of the cell is fixed to 0.5 volt and it is nearly independent of intensity of incident light whereas the current capacity of cell is nearly proportional to the intensity of incident light as well as the area that exposed to the light. Each of the solar cells has one positive and one negative terminal like all other type of battery cells. Typically a solar or photovoltaic cell has negative front contact and positive back contact. A semiconductor p-n junction is in the middle of these two contacts.

While sunlight falling on the cell the some photons of the light are absorbed by solar cell. Some of the absorbed photons will have energy greater than the energy gap between valence band and conduction band in the semiconductor crystal.

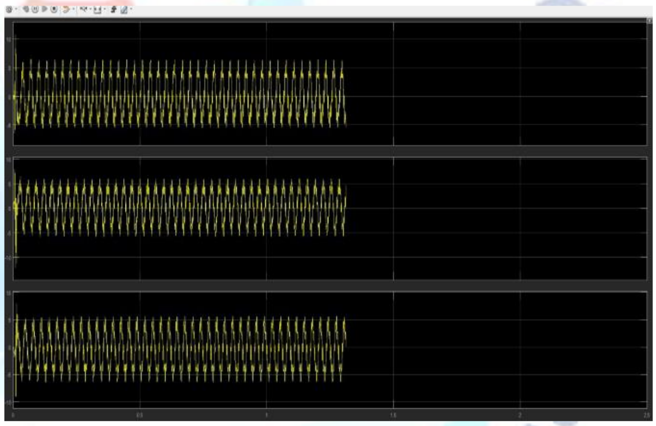

Figure 3: solar characteristics using matlab simulation

Hence, one valence electron gets energy from one photon and becomes excited and jumps out from the bond and creates one electron-hole pair. These electrons and holes of e-h pairs are called light- generated electrons and holes. The light-generated electrons near the p-n junction are migrated to n-type side of the junction due to electrostatic force of the field across the junction. Similarly, the light-generated holes created near the junction are migrated to p-type side of the junction due to same electrostatic force. In this way a potential difference is established between two sides of the cell and if these two sides are connected by an external circuit current will start flowing from positive to negative terminal of the solar cell. This was basic working principle of a solar cell now we will discuss about different parameters of a solar or photovoltaic cell upon which the rating of a solar panel depends.

Grids are mainstream technologies that do not have a clear and complete definition in the literature. Establishing a complete grid definition is considered an important goal in order to allow determining the limits of the grid research field as well as exploring new fields of application in grid computing.

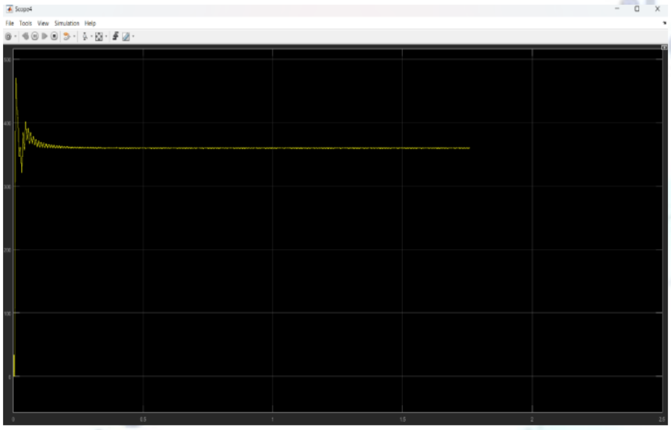

Figure 4: Grid characteristics using matlab simulation

To tackle this problem, ten definitions extracted from main literature sources have been studied allowing the extraction of the ten main characteristics of grids. In addition, grid uses have been defined in terms of the different types of application support provided by grids according to the literature. Both grid characteristics and uses have been used to build a grid definition. The establishment of a grid definition in this paper is not an isolated effort.

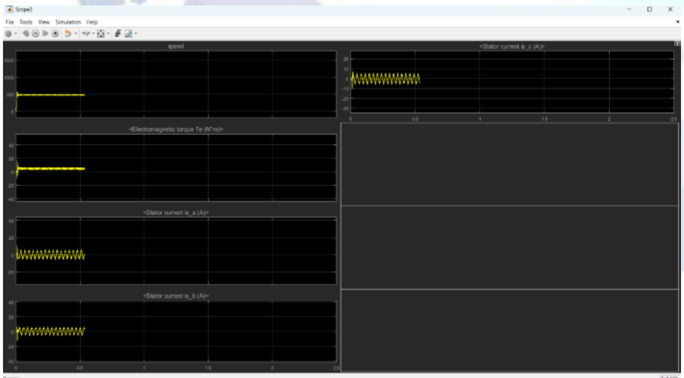

Figure 5: BLDC motor characteristics using matlab simulation

The DC motor has a number of advantageous characteristics including small size and power, ability to begin rotating when simply connected to a DC power supply, ease of speed and positioning control, and so forth. However, the use of brushes and a commentator create a number of disadvantages including increased wear and electrical noise, etc. Due to this, a brushless motor that has the advantages of a DC motor is required. The biggest feature of brushless DC motors is that they are maintenance-free. There are a number of differences from DC motors. One of these differences is their small size, a high-performance brushless DC motor accommodates high-performance magnets in a space smaller than that for the rotor of conventional DC motors. Thanks to this space efficiency, the rotor has no magnets, allowing the corresponding space to be downsized. A higher magnetic flux density provides higher motor efficiency and suppresses heat generation. Among all the motor parts, the coil generates the greatest amount of heat. And since the coil of a DC motor is located inside the motor, it is enveloped by air in the motor, which prevents heat in the coil from dissipating. In comparison, since the coil of a brushless motor is positioned on the stator side, the motor's heat radiation performance is enhanced. The decisive advantage of brushless motors is their high degree of freedom of design. For instance, you can design a flat rotor, place the rotor in the outer part of the motor, or choose an elongated shape depending on how the motor is to be used. Even while operating at extremely high speeds, brushless DC motors achieve a long, trouble-free life, as there is no mechanical commutation. They have mainly linear motor characteristics, with excellent speed and position control. In brushless motors, static windings are attached to the motor housing, resulting in improved heat dissipation and overload capability. Brushless motors are high efficiency.

5. CONCLUSION

The system uses a YAML based templating engine to search for regex in the raw text extracted from the image processing libraries. A flexible YAML based templating system allows us to match content pdf files precisely. It also enables us to define static fields that are identical for every invoice. It provides enough flexibility to an organization to define custom fields or to have multiple regex per field based on requirements. The templating system has plugins available to match line items and tables in an invoice. Using YAML templating allows flexibility for users to quickly add new invoice templates to the system by quickly creating a template for it and the system can process invoices based on the new templates immediately. This templating system results searches for regex in the raw text and helps return accurate results from an invoice.

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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