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A Single-Phase Bidirectional Inverter with Two Buck/Boost MPPTs for DC- Distribution Applications

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Abstract: ***An integration and operation of a single-phase bidirectional inverter with two buck/boost maximum power point trackers (MPPTs) for dc-distribution applications. In a dc-distribution system, a bidirectional inverter is required to control the power flow between dc bus and ac grid, and to regulate the dc bus to a certain range of voltages. A droop regulation mechanism according to the inverter inductor current levels to reduce capacitor size, balance power flow, and accommodate load variation is proposed. Since the photovoltaic (PV) array voltage can vary from 0 to 5000 V, especially with thin-film PV panels, the MPPT topology is formed with buck and boost converters to operate at the dc-bus voltage around 4000 V, reducing the voltage stress of its followed inverter. Additionally, the controller can online check the input configuration of the two MPPTs, equally distribute the PV-array output current to the two MPPTs in parallel operation, and switch control laws to smooth out mode transition. A comparison between the conventional boost MPPT and the proposed buck/boost MPPT integrated with a PV inverter is also presented. A single-phase bidirectional inverter with two buck/boost maximum power point trackers (MPPTs) by using the closed loop circuit. This project is workout by simulink using mat lab.***

Keywords: Bidirectional inverter, buck/boost maximum power point trackers (MPPTs), dc-distribution applications.

1. Introduction

Many types of renewable energy, such as photovoltaic (PV), wind, tidal, and geothermal energy, have attracted a lot of attention over the past decade [1]–[3]. Among these natural resources, the PV energy is a main and appropriate renewable energy for low-voltage dc-distribution systems, owing to the merits of clean, quiet, pollution free, and abundant. In the dc-distribution applications, a power system, including renewable distributed generators (DGs), DC loads (lighting, air conditioner, and electric vehicle) in which two PV arrays with two maximum power point trackers (MPPTs) are implemented.

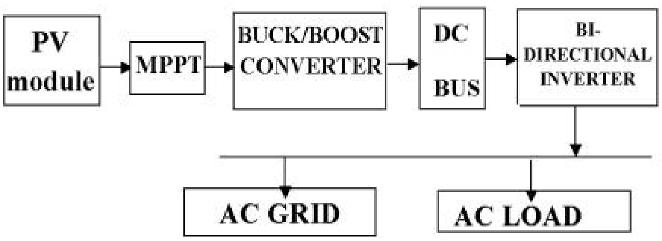

Figure 1: Block Diagram

However, the *i*–*v* characteristics of the PV arrays are nonlinear, and they require MPPTs to draw the maximum power from each PV array. Moreover, the bidirectional inverter has to fulfill grid connection (sell power) and rectification (buy power)with power-factor correction (PFC) to control the power flow between dc bus and ac grid, and to regulate the dc bus to a certain range of voltages, such as 230 ± 10 V. Nowadays, a conventional two-stage configuration is usually adopted in the PV inverter systems [4]–[8].

This objective of this research is to quantify the increase in efficiency of a multiple-panel PV system by allocating individual MPPTs with DC converters to each panel.

Applications best suited for multiple MPPTs are also considered and recommendations for usage based on present and near-future technologies are provided. Finally, the possibility of integrating MPPTs with converters for each individual solar cell in a system will be analyzed, and recommendations to achieve optimal efficiency in a cost efficient and realistic manner will be provided.

The goals of this research are:
1) To simulate and analyze the typical power in PV array.
2) Basic overview of MPPTs to include tracking algorithms.
3) Perturbation and observation tracking method.
4) To simulate and analyze the methodology chosen for MPPTs.
5) Building the case for the usage of multiple MPPTs.
6) To determine the best control mode for proposed buck/boost.
7) To implement a single-phase bidirectional inverter using AC and DC power supply unit.

2. PV Inverter System with the Buck/Boost

2.1 MPPT Systems

A conventional two-stage configuration is usually adopted in the PV inverter systems. Each MPPT is realized with a boost converter to step up the PV-array voltage close to the specified dc-link voltage. The boost converter is operated in by-pass mode when the PV-array voltage is higher than the dc-link voltage, and the inverter will function as an MPPT. The characteristics of PV arrays are different from each other, the inverter operated in by-pass mode cannot track each individual maximum power point accurately, and the

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inverter suffers from as high-voltage stress as the open voltage of the arrays. To release the abovementioned limitation, an MPPT topology, which combines buck and boost converters is proposed in this project, in which the control algorithm for tracking maximum power points is based on a perturbation and observation method. The MPPT will switch operation modes between bucks and boost when the output voltage of a PV array is close to the dc-bus voltage. The designed controller can switch control laws to achieve smooth mode transition and fulfill online configuration check for the MPPTs, which can be either separate or in parallel connection, to draw the maximum power from the PV arrays more effectively. Additionally, a uniform current control scheme is introduced to the controller to equally distribute the PV-array output current to the two MPPTs in parallel operation.

To eliminate leakage ground current circulating through PV arrays and ground, several transformers less inverter topologies were proposed. Even though they can achieve high efficiency, they require more components than the conventional full-bridge topology.

The bidirectional full bridge inverter is operated with bipolar modulation to avoid leakage ground current and to save power components while still sustaining high efficiency. Note that a full-bridge inverter operated with bipolar modulation can achieve only low frequency common-mode voltage (=(−)/2), resulting in low leakage ground current.

To regulate the dc-bus voltage for the grid-connected inverter, the controls, such as robust, adaptive, and fuzzy, were adopted. When adopting these controls for the studied dc-distribution system, a heavy step-load change at the dc-bus side will cause high dc-bus voltage variation and fluctuation, and the system might run abnormally or drop into under or over voltage protection. Bulky dc-bus capacitors can be adopted to increase the hold-up time and suppress the fluctuation of the DC-bus voltage, but it will increase the size and cost of the system significantly.

The MPPT topology is formed from a buck converter and a boost converter but with a shared inductor to accommodate wide PV-array voltages from 0 to 600 V. For various PV-array applications, the two MPPTs will be connected separately or in parallel. The MPPT senses PV voltage, dc-bus voltage, and inductor current into the single chip PIC microcontroller to determine operational mode and duty ratio for tracking the maximum power point accurately. When voltage is higher than , the MPPT is operated in buck mode, and switch is turned ON to magnetize inductor and thus increase inductor current . While switch is turned OFF, inductor releases its stored energy through diodes and.Thus, the control laws can be expressed as follows:

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= — (for buck mode)

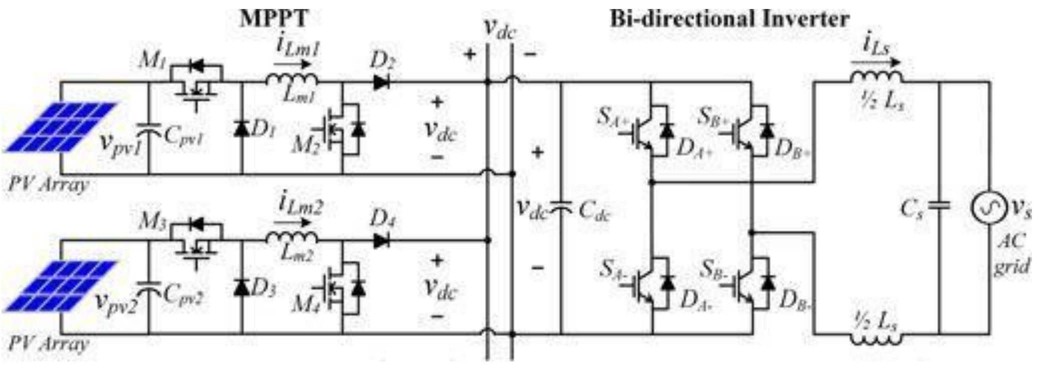

Figure 2: Circuit diagram for PV Inverter System with the Buck/Boost MPPT Systems

The MPPT is operated in boost mode when voltage , is lower than , and switches and are turned ON to magnetize inductor . While switch M2 is turned OFF, inductor releases its stored energy through diode . Thus, the control laws can be expressed as follows:

= (for boost mode)

Maximum power from PV arrays, a perturbation and observation control algorithm for tracking maximum power points is adopted. If the maximum power level of a PV array is higher than the power rating of an MPPT, the two MPPTs will be in parallel operation to function as a single MPPT. Thus, it requires an online configuration check to determine the connection types of the two MPPTs, separately or in parallel. Moreover, if the two MPPTs are in parallel operation, a uniform current control scheme is introduced to equally distribute the PV-array output current to the two MPPTs. The operational-mode transition control between buck and boost is also used. Combines buck and boost converters is proposed in this project, in which the control algorithm or tracking maximum power points is based on a perturbation and observation method. The MPPT will switch operation modes between buck and boost when the output voltage of a PV array is close to the dc-bus voltage. The designed controller can switch control laws to achieve smooth mode transition and fulfill online configuration check for the MPPTs, which can be either separate or in parallel connection, to draw the maximum power from the PV arrays more effectively. Additionally, a uniform current control scheme is introduced to the controller to equally distribute the PV-array output current to the two MPPTs in parallel operation. To eliminate leakage ground current circulating through PV arrays and ground, several transformer less inverter topologies are proposed.

3. Analysis of Tracking

3.1 Algorithms

A. Perturb and Observe

The most common MPPT algorithm utilized is the perturb and observe (P&O) this is due to its simplicity and ease of implementation. The basic premise behind P&O is the algorithm's constant comparison of the array's output power after a small, deliberate perturbation in the array's operating voltage is applied. If the output power is increased after the perturbation, then the array's operating point is now closer to the MPP, and the algorithm continues to "climb the hill" towards the MPP. If the power is decreased, then the operating point is further from the MPP, and the algorithm reverses the algebraic sign of the perturbation in order to "climb the hill." To better illustrate this point, a family of power curves as a function of voltage (P-V curves) at different irradiance levels *G*.

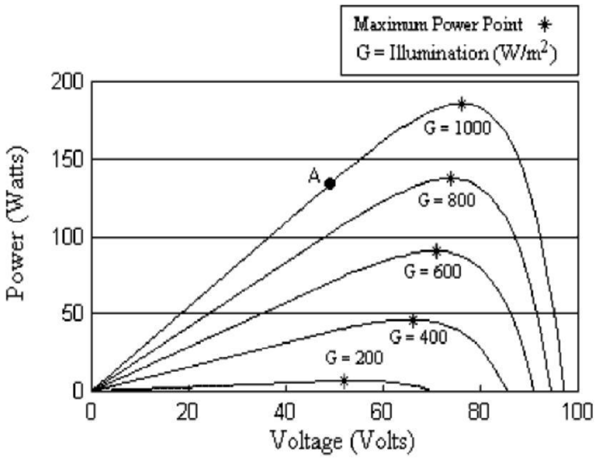

Figure 3: The P-V relationship at different irradiance levels

The other major solar input variable, temperature, is held constant. If an array is operating at point A as shown in Figure 3, the P&O algorithm incrementally increases the array's operating voltage until the MPP is reached at the global maxima (i.e., G = 1000 W/m2).

B. MPPT Design Principles

The wide-spread adoption of the utilization of solar energy as a renewable resource is severely limited by the relatively low conversion efficiency from solar to electrical power. A general guideline for most PV systems corresponds to an overall efficiency of less than 17% and is significantly less under low irradiation conditions. This low conversion attribute requires an almost disproportionate quantity of solar cells to generate a modest amount of useful electrical power. Therefore, any device, technique, or advance in technology that increases the energy conversion efficiency of a PV system by even a small amount has a large impact in reducing the quantity of cells and the physical size of the array. Other benefits of optimizing the conversion efficiency include a significant reduction in cost or a substantial increase in the power available to the user. A common method of maximizing the efficiency of a PV system is the detection and tracking of an array's MPP under varying conditions overall operating 20 voltage of the system is determined by the intersection of the load line and I-V curve as shown in Figure .4.

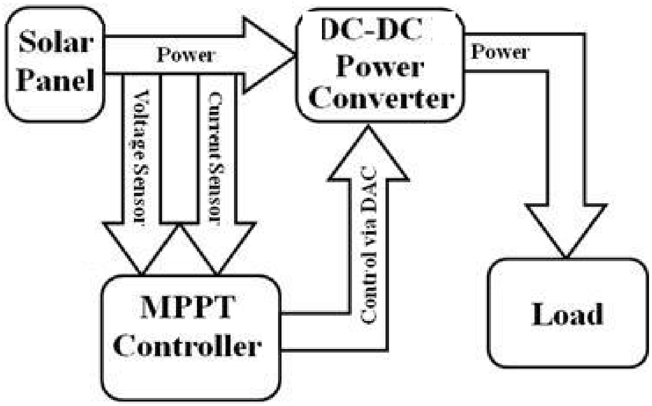

Figure 4: Block Diagram of MPPT

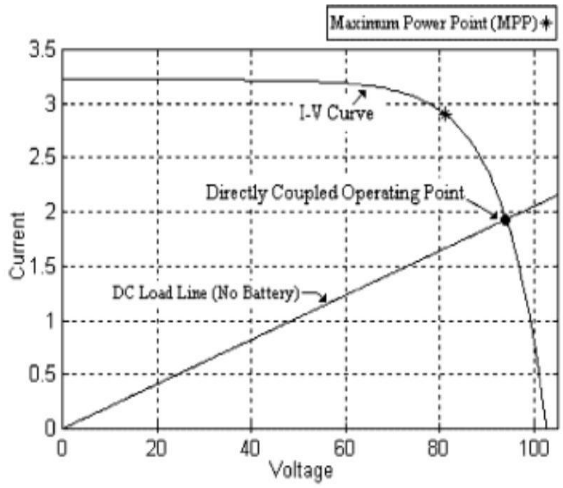

Figure 5: Operating Point of a Directly-Coupled PV

Array and Load

A fluctuating level of irradiance is one of the many nonlinear variables that influence the I-V curve of a PV array. As shown in Figure 5, the intersection of the load line and varying I-V curves due to fluctuating irradiance levels significantly impacts the operating voltage and power output available to the load. The typical solution to account for this nonlinear relationship is to oversize the PV array to ensure the load's power requirements are always met.

The MPP is not constant or easily known; this is due to the nonlinear relationship between a cell's output and input variables (i.e., solar irradiation and temperature) which results in a unique operating point along the I-V curve where maximum power is delivered. When a PV array is connected directly to the load, referred to as a directly-coupled system, the

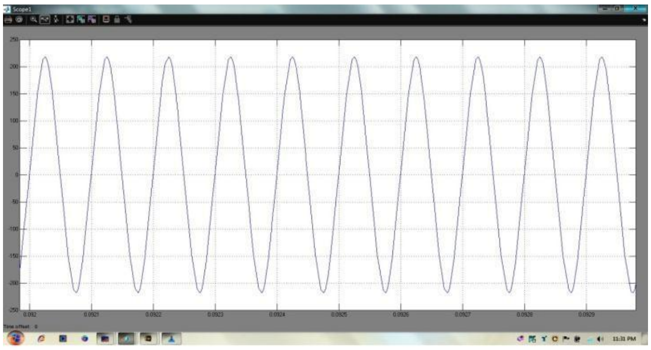

Figure 6: AC Output Voltage (V_{out})

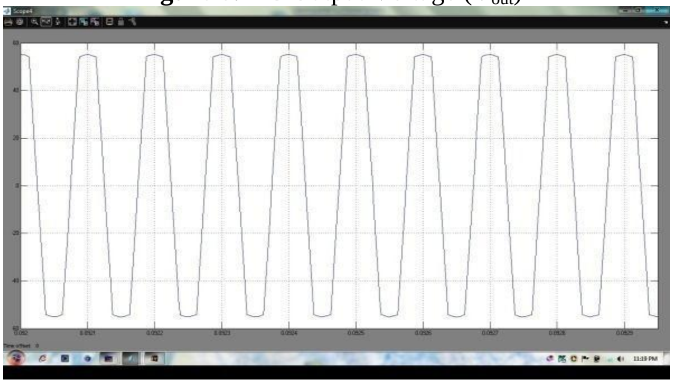

Figure 7: AC Output current (I_o)

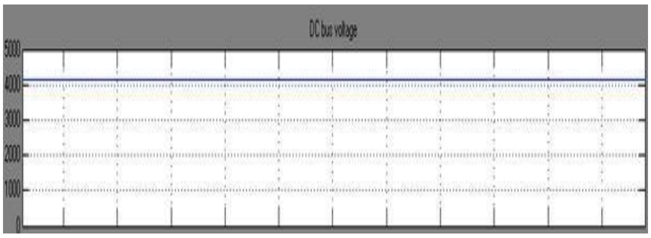

Figure 8: Output Voltage In Dc Bus

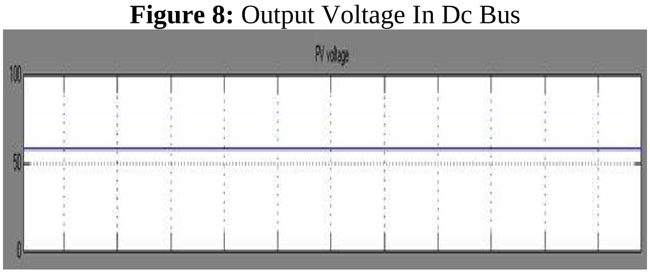

Figure 9: PV output voltage

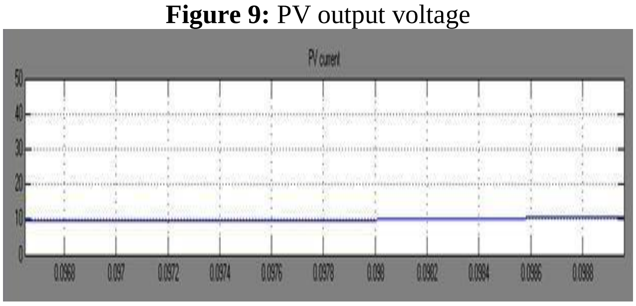

Figure 4.10: PV output current

4. Implementation

The MPPT topology, which combines buck and boost converters is proposed in in which the control algorithm for tracking maximum power points is based on a perturbation and observation method. The MPPT will switch operation modes between buck and boost when the output voltage of a PV array is close to the dc-bus voltage. The designed controller can switch control laws to achieve smooth mode transition and fulfill online configuration check for the MPPTs, which can be either separate or in parallel connection, to draw the maximum power from the PV arrays more effectively. Additionally, a uniform current control scheme is introduced to the controller to equally distribute the PV-array output current to the two MPPTs in parallel operation. To eliminate leakage ground current circulating through PV arrays and ground, several transformer less inverter topologies were proposed [9]–[11]. Even though they can achieve high efficiency, they require more components than the conventional full-bridge topology. Thus, in this study, the bidirectional full bridge inverter is operated with bipolar modulation to avoid leakage ground current and to save power components while still sustaining comparatively high efficiency to those in [9]–[11]. Note that a full-bridge inverter operated with bipolar modulation can achieve only low frequency common-mode voltage (vCM = ($v$dc − vs)/2), resulting in low leakage ground current [9]. To regulate the dc-bus voltage for the grid-connected inverter, the controls, such as robust, adaptive, and fuzzy [12]–[14], were adopted. When adopting these controls for the studied dc-distribution system, a heavy step-load change at the dc-bus side will cause high dc-bus voltage variation and fluctuation, and the system might run abnormally or drop into under or over voltage protection. Bulky dc-bus capacitors can be adopted to increase the hold-up time and suppress the fluctuation of the dc-bus voltage [15], but it will increase the size and cost of the system significantly. Additionally, even though there are approaches to achieving fast dc-bus voltage dynamics, the systems with load connected to the dc bus have not been studied yet [16]-[17]. Therefore, to operate the dc-distribution system efficiently while reducing the size of dc-bus capacitors, a droop regulation mechanism according to the inverter current levels is proposed in this study. In this paper, operational principle and control laws of the system are first described, and the MPPT control algorithm, online configuration check, uniform current control, buck/boost mode transition, and dc-bus-voltage regulation mechanism are then addressed.

5. Experimental Results

The PV inverter system performance and control algorithm, a 5-kW, single-phase bidirectional inverter with two buck/boost MPPTs was designed and implemented. The solar panels used in the experiments are YPY200-24, of which the maximum power of each panel is 200 W and its open-circuit voltage is 43 V. Each MPPT is connected to an array of 13 panels in series and the rated power is totally around 2.5 kW. The 5-kW PV inverter system is started up by a built-in fly back power supply. The minimum start-up voltage is 100 V, since the output power of the PV array is very low when the PV voltage is lower than 100V. It can only provide the power for starting up the control board. Therefore, in fact, the designed input voltage range is 100–600 V. This range of PV voltage is suitable for single-phase power applications, such as a 5-kW home-use system. Moreover, when an inverter is operated with 5 kW, inductor current will vary from 0 to 32 A in one line cycle. This will result in wide inductance variation from 3 mH to 650 μH when the inductor is constructed with a molybdenum permalloy powder (MPP) core. Before time $t1$, the two MPPTs are separated. The controller can determine that the PV1 array is removed from or plugged into the MPPT at time $t1$ and $t2$, respectively. Similarly, the PV2 array has the same operation at time $t3$ and $t4$. Moreover, the MPPTs can be controlled in parallel operation When vPV1 and vPV2 are lower than the minimum start up voltage (100 V) of the power supply, the controller determines that PV1 and PV2 arrays are removed from the MPPTs. Since the two capacitors were not fully discharged yet, there exist nonzero voltages.

6. Conclusion

A single-phase bidirectional inverter with two buck/boost MPPTs has been designed and implemented. The inverter controls the power flow between dc bus and ac grid, and regulates the dc bus to a certain range of voltages. A droop regulation mechanism according to the inductor current levels has been proposed to balance the power flow and accommodate load variation. Since the PV-array voltage can vary from 0 to 600 V, the MPPT topology is formed with buck and boost converters to operate at the dc-bus voltage around 230 V, reducing the voltage stress of its followed inverter.

The controller can online check the input configuration of the MPPTs, equally distribute the PV-array output current to the two MPPTs in parallel operation, and switch control laws to smooth out mode transition. Integration and operation of the overall inverter system have been discussed in detail, which contributes to dc-distribution applications significantly. The output voltage is 230 V amplitude in volts and output current is 55A current in amps. The output of PV voltage is 55 V in constant value DC and the output of PV current is 10 amps. A single-phase bidirectional inverter with two buck/boost maximum power point trackers (MPPTs) by using the closed loop circuit. This paper is workout by simulink using matlab and hardware.

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