A THREE PORT CONVERTER INTEGRATED HYBRID ENERGY STORAGE SYSTEM

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Abstract - *Photovoltaic (PV)/battery hybrid power units have attracted vast research interests in recent years. For the conventional distributed power generation systems with PV/battery hybrid power units, two independent power converters, including a unidirectional dc-dc converter and a bidirectional converter, are normally required. Aim of our paper is energy management and control strategy for the PV/battery hybrid distributed power generation systems with only one integrated three-port power converter. As the integrated bidirectional converter shares power switches with the full-bridge dc–dc converter, the power density and the reliability of the system is enhanced. The corresponding energy management and control strategy are proposed to realize the power balance among three ports in different operating scenarios, which comprehensively takes both the MPPT benefit and the battery charging/discharging management into consideration.*

Key words: PWM, MPPT, ESS, SOC, PV,

1.INTRODUCTION

With the development of the power electronic technology, a larger amount of PV panels are integrated as power sources in to the distributed power generation systems For example, renewable energy consumption (excluding hydro) of the world grew by 17% in 2017, and the solar energy contributed more than a third of the total renewables growth despite accounting for just 21% of the total renewables power generation. The energy storage system (ESS) technology is undoubtedly the key solution to the intermittent nature of the renewable energy sources.

A PV/battery hybrid power unit forms the most basic topology among various distributed power generation systems. Normally the conventional PV/battery hybrid power unit based on the DC/AC microgrids includes at least two independent power converters with a unidirectional DC-DC conversion stage and a bidirectional conversion stage (the DC microgrid based system for example). The unidirectional DC-DC converter interfaces the PV with the DC bus, and the bidirectional converter interfaces the ESS such as the battery with the DC bus. Literatures focus on the improvement of the control and power management scheme based on the DC/AC hybrid microgrids, AC microgrid and DC microgrid, either in the grid-connected or the islanded operating mode. Some literatures focus on the application of the PV/battery hybrid power system based on the DC microgrid alone. Normally, a comprehensive control strategy for the PV/battery hybrid power system incorporates the PV array controller for MPPT purpose, the battery controller for charging/discharging management and SOC control purpose, the inverter controller (for the system based on the AC microgrid).

1.1 NEED OF HYBRID SYSTEM

A hybrid energy system or hybrid power, usually it consists of two or more renewable energy sources used together to provide increased system efficiency as well as greater balance in energy supply.

The hybrid solar energy systems have various advantages.

1. **Continuous power supply -**The hybrid solar systems provide power continuously, without any interruption, as the batteries connected to them store the energy. So, when there is an electricity outage, the batteries work as inverter to provide you backup. This is also the case during the evening or night time when there is no sun and energy is not being generated; batteries provide the back-up and life goes on without any interruption.

2. **Utilize the renewable sources in best way -** Because the batteries are connected to the system to store the energy, there is no waste of the excess energy generated on bright sunny days. So, these systems make use of the renewable in best way, storing energy on a good day and utilize the stored power on a bad day. The balance is maintained.

3. **Low maintenance cost -** The maintenance cost of the hybrid solar energy systems is low as compared to the traditional generators which use diesel as fuel. No fuel is used and they do not require frequent servicing.

4. **High efficiency -**The hybrid solar energy systems work more efficiently than your traditional generators which waste the fuel under certain conditions. Hybrid solar systems

work efficiently in all types of conditions without wasting the fuel.

5. **Load management** - Unlike traditional generators, which provide high power as soon as they turned on, most of hybrid solar power systems manage load accordingly. A hybrid solar system may have technology that adjusts the energy supply according to the devices they are connected to, whether it's an air conditioner requiring high power or a fan which requires less. This is one of the essential needs of hybrid energy storage system.

Like all things, hybrid solar energy systems also have few disadvantages.

2.OBJECTIVE

To develop PV/battery hybrid distributed power generation system interfacing a 3-port network. To analyse different operating scenarios of the system under various power conditions. A comprehensive energy management and control strategy accordingly.

3.BLOCK DIAGRAM

The proposed PV/battery hybrid distributed power generation system is shown in Fig 1. This is a three-port system interfacing a PV, an ESS unit (a battery for example) and a DC load. The battery serves as an energy buffer, which means it can be charged or discharged to balance the power flow in the PV/battery hybrid power system.

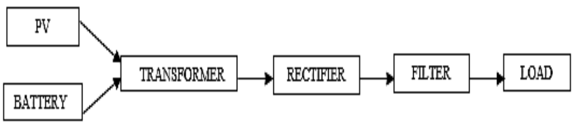

Fig -1: Block diagram of system

The phase-shift full-bridge DC-DC converter interfacing the PV and the load shares power switches with the integrated bidirectional buck/boost converter interfacing the battery, based on which the power density of the system is enhanced compared with the conventional topology consisting of the independent phase-shift full-bridge DC-DC converter and bidirectional converter.

A modified phase-shift modulation scheme is adopted for the primary full bridge is used. Two switching legs of the primary full bridge are phase shifted by the angle ϕ. In addition, the duty cycle of switches Sp1 and Sp2

on leg A can be regulated, while the duty cycle of the other two switches is fixed at 50%. The battery, capacitor C_b, inductor L_b, two power switches of the leg A and the PV side bus form a bidirectional buck/boost topology inherently. When the battery is charged with $i_b > 0$, the topology operates in the buck mode. When the battery is discharged with $i_b < 0$, then the topology operates in the boost mode. Therefore, the bidirectional power flow can be achieved for the battery with the charging/discharging management requirement.

According to the buck/boost operating principle, since the battery voltage V_b can be considered as almost constant during the normal SOC period, the PV output voltage V_{pv} can be regulated to achieve MPPT by control of the duty cycle D. Assuming that the inductor L_b is large enough, V_{pv} is derived as

$$V_{pv} = \frac{v_b}{D} \qquad (1)$$

In addition, the phase shift angle ϕ is adopted as another control variable to obtain the required DC bus voltage V_{bus}. Due to the asymmetric modulation with two legs of the full bridge, V_{AB} contains a DC component, which can compromise the normal operation of the HF transformer. In this paper, a DC blocking capacitor C_p is incorporated to prevent the HF transformer from saturation. According to the volt-second balance principle for the inductor L_p and the HF transformer, the DC blocking capacitor C_p voltage V_{cp} is derived as

$$V_{cp} = V_{pv}\left(D - \frac{\phi}{2\pi} \right) \qquad (2)$$

Based on the volt-second balance principle for the inductor L_o and assuming L_o is large enough, the DC bus voltage Vbus can be expressed as

$$V_{bus} = N\{\frac{\phi}{2\pi}(V_{pv} - V_{cp}) + \left(\frac{1}{2} + \frac{\phi}{2\pi} + D\right)(V_{pv} + V_{cp}) + [1 - \left(\frac{1}{2} + \frac{\phi}{2\pi} - D + \frac{\phi}{2\pi}\right)] |V_{cp}|\} \qquad (3)$$

where the turns ratio of the transformer is defined as 1:N. Then the DC bus voltage V_{bus} can be derived as

$$V_{bus} = \{ N V_{pv} \frac{\phi}{\pi}\left(\frac{3}{2} - D\right) \} \qquad D > \frac{1}{2} \qquad (4)$$

$$V_{bus} = \{ N V_{pv} [\frac{\phi}{\pi}\left(\frac{3}{2} - D\right) + \frac{1}{2} - 2D^2] \qquad D < \frac{1}{2} \qquad (5)$$

According to fig, the following constraints need to be applied for the modulation scheme as

$$\frac{\phi}{2\pi} < D < \frac{\phi}{2\pi} + \frac{1}{2} \qquad (6)$$

3.1 CONTROLLER

Phase shift angle ϕ of the full bridge is used to control the load side DC bus voltage V_{bus} through a PI controller. The PV reference voltage V_{ref} is obtained by the basic incremental conductance MPPT algorithm. In addition, a low SOC detecting part is incorporated in the control system to temporarily halt the operation of the system (such as setting the phase shift angle ϕ as zero) when the battery voltage V_b drops to a low value V_{SL}.

The duty cycle D serves as the key control variable to achieve the power balance and automatic control in different operation scenarios of the whole power generation system. There are three control loops competing to take charge of the duty cycle D, namely the constant voltage (CV) charging loop, charging current loop and MPPT loop. The priority controller determines which control loop to enable. The overall objective is to achieve the power balance of the whole power system and automatic battery charging/discharging management, while have the PV to operate at the maximum power point, if possible, here, the priority controller is to obtain the minimum value among three control loop outputs. For example, when the load power PL is larger than the PV maximum output power PMPP but within the most power that the PV and battery can supply in combination, the battery would operate in the discharging mode, and therefore the battery charging current i_b would turn negative, which results in the saturation for the output of the charging current loop. Then in this case the MPPT control loop would be enabled (assuming the battery voltage Vb is lower than the CV charging voltage V_{bH} and the CV charging loop is disabled), and the duty cycle D would be regulated until the PV operates near the maximum power point. It is noted that the battery serves as a power balance port in this case.

When the load power is relatively small, there can be much surplus power from the PV supposing the MPPT control loop is enabled, which can cause high battery charging power beyond the specific battery charging requirements. In this case the input error signal of the charging current control loop would turn negative, which means the corresponding loop would take charge over the duty cycle D (assuming the battery voltage V_b is lower than the CV charging voltage V_{bH} and the CV charging loop is disabled). Therefore the battery would operate in the constant current (CC) charging mode at a preset level of i_b^*.

It is noted that the PV serves as a power balance port in this case and the operating point of the PV would be regulated accordingly to achieve the power balance of the system. For the CV charging loop, when the battery voltage V_b reaches the preset CV charging voltage V_{bH}, the CV charging loop is enabled and the battery would operate in the CV charging mode. Since the charging power is unstable and uncontrollable for the CV charging mode, the operating point of the PV would change through the CV charging process to achieve the power balance.

This is all about controlling of buck and boost operation.

4.OPERATION SCENARIOS

1. Scenario 1: The load power is larger than the most power that the PV and battery can supply in combination. In this case either the whole system needs to be halted, or measures such as the load shedding needs to be taken.

2. Scenario 2: The load power is larger than the PV maximum output power PMPP, but within the most power that the PV and battery can supply in combination. In this case the MPPT control loop would be enabled to utilize the most of the solar energy under the specific irradiance and temperature conditions. In the meantime, the battery would operate in the discharging mode and supply a part of the load power, which achieves the power balance for the system.

3. Scenario 3: The PV maximum power PMPP just equals to the load power. In this case the battery would not be charged or discharged and the PV supplies the load power solely at the maximum power point.

4. Scenario 4: The PV maximum power PMPP is larger than the load power, and the surplus power from the PV is within the maximum charging power of the battery. In this case, the MPPT control loop would be enabled and the PV would supply the load and charge the battery in the meantime. The battery serves as the power balance port of the system in this case.

5. Scenario 5: The PV maximum power PMPP is larger than the total of the load power and the maximum charging power of the battery under the specific irradiance and temperature conditions. In this case the battery charging current ib control loop would be enabled and the MPPT control loop would be disabled. The battery would operate in the constant current charging mode at a preset level of i_b^*. In the meantime, the operating point of the PV would be regulated accordingly until the power balance of the system can be achieved.

6. Scenario 6: The PV output power is near zero (for example in the evening) and the load power is larger than the maximum discharging power of the battery. In this case either the whole system needs to be halted, or measures such as the load shedding needs to be taken.

7. Scenario 7: The PV output power is near zero and the load power is within the maximum discharging power of the battery. In this case the battery would operate in the discharging mode as the only power source

5.MATLAB AND SIMULATION

5.1 HYBRID DISTRIBUTED POWER SYSTEM

The simulation of the proposed PV/battery hybrid distributed power generation system are conducted using the Matlab/Simulink software. The PV array model is built of strings of PV modules connected in

parallel and each string consists of modules connected in series.

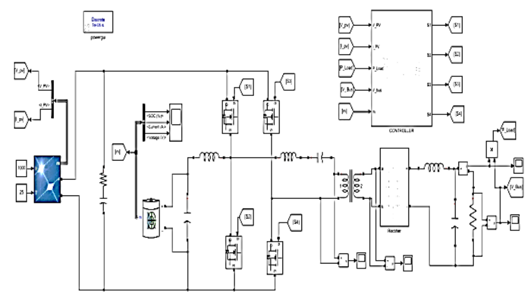

Fig-2: Simulation of hybrid distributed power system

5.2 SIMULATION OF CONTROLLER

The simulation of the controller of the PV/battery hybrid distributed power generation system are conducted using the Matlab/Simulink software.

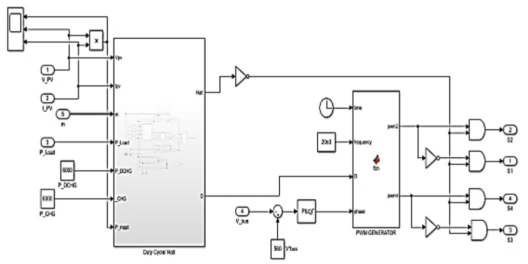

Fig-3: Simulation of controller

5.3 SIMULATION OF DUTY CYCLE/HALT

The simulation of duty cycle of the PV/battery hybrid distributed power generation system is shown in fig 4. It consist of 3 loops. MPPT enable, constant voltage loop, constant current loop. These 3 loops are enabled accordingly.

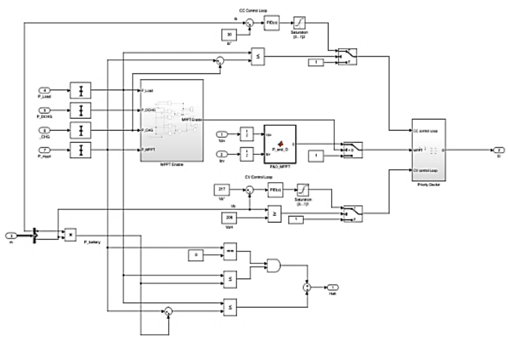

Fig-4: Simulation of duty cycle/halt

5.4 SIMULATION OF PRIORITY DETECTOR

The 3 loops of the controller is enabled accordingly

with respect to priority detector. output is taken as the duty ratio.

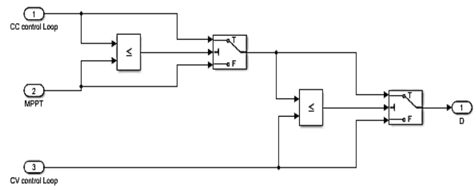

Fig-5: Simulation of priority detector

5.5 SIMULATION OF MPPT ENABLE

MPPT enable operates in 3 conditions. These three conditions are shown in the above simulation. Accordingly, MPPT is enabled.

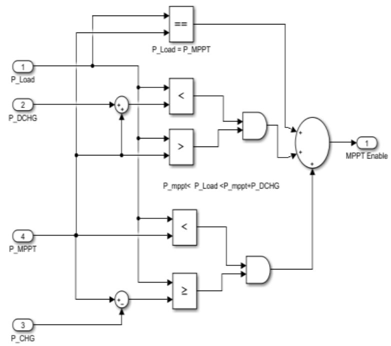

Fig-6: Simulation of MPPT enable

6.RESULTS AND DISCUSSION

Matlab /Simulink has been chosen to carry out the computer simulation studies in this project. Simulation model of hybrid distributed power generation system were developed using Matlab. The simpower Toolbox of Matlab is used for the development of the simulation model.

6.1 PV PANEL OUTPUT

Maximum power obtained from the PV panel is 9.6KW. Maximum voltage and current obtained from PV is 39V and 7.35A respectively. Different irradiances are considered here.

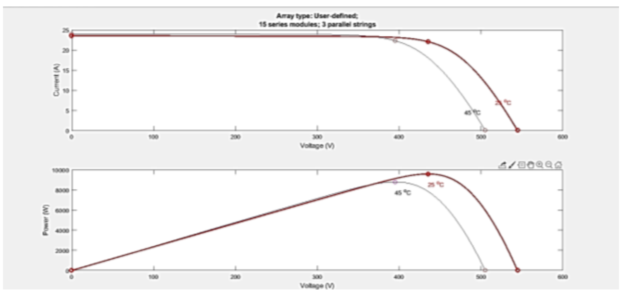

Fig-7: PV, VI characteristics

6.2 BATTERY CHARGING

This is the case of battery charging. Here soc increases from 60% to 60.0027%. Value of current is negative which is -30A. Battery voltage is about 201V. Battery is charged at higher irradiance. At low level of irradiance battery is discharged. At higher irradiance battery is charged and if there is more than enough power, then remaining power is used to charge the battery.

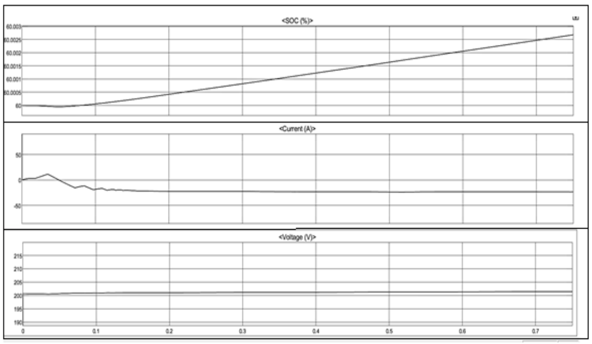

Fig-8: Battery charging

6.3 BATTERY DISCHARGING

This is the case of battery discharging. Here soc decreases from 60% to 59.994%. Value of current is positive which is 25A. Battery voltage is about 200.1V. Fig 9 shows the simulation of battery discharging at 10 irradiance.

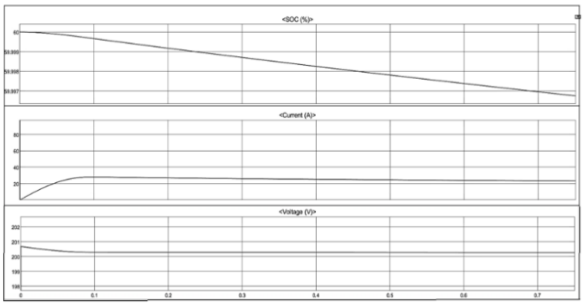

Fig-9: Battery discharging at 10 irradiance

6.4 BATTERY DISCHARGING

This is the case of battery discharging. Here soc decreases from 60% to 59.995%. Value of current is positive which is 20A. Battery voltage is about 200.1V. Below is battery discharging at 100 irradiance.

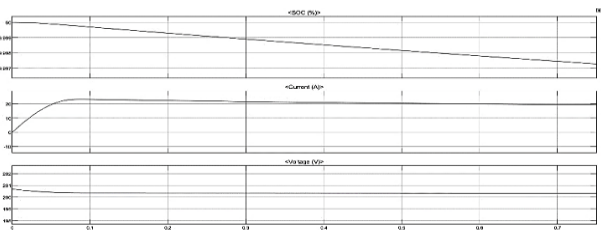

Fig-10: Battery discharging at 100 irradiance

6.5 BATTERY OUTPUT

Here, battery voltage obtained is 220V which is the required voltage. Battery is charged and discharged. Battery voltage is constant.

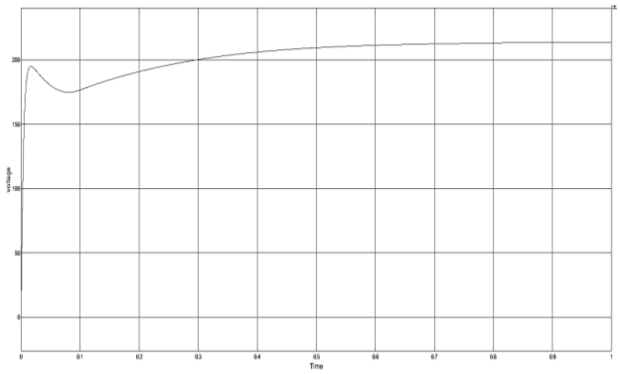

Fig-11: Battery voltage

6.6 OUTPUT CURRENT

Current obtained at the load is 5.6A. Required current is obtained.

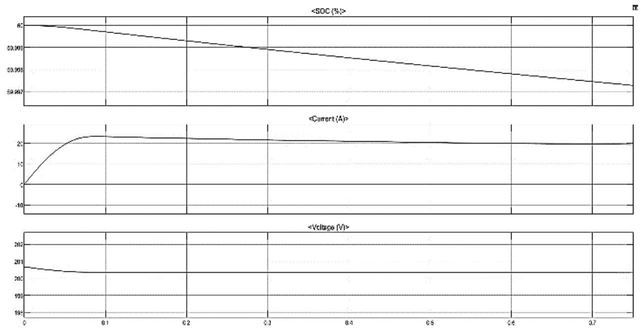

Fig-12: Output current

6.7 OUTPUT VOLTAGE

Voltage obtained at the load is 560V. Required voltage is obtained

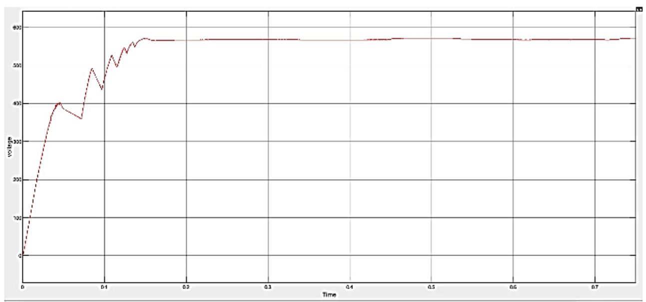

Fig-13: Output voltage

7.CONCLUSION

An integrated three-port power converter as the interface for the PV/battery hybrid distributed power generation system is proposed. Compared with the conventional system topology containing an independent DC-DC unidirectional conversion stage and a bidirectional conversion stage, the proposed system has advantages in terms of higher power density and reliability. The phase shift angle of the full bridge and the switch duty cycle are adopted as two control variables to obtain the required DC bus voltage and realize the power balance among three ports.

Different operating scenarios of the system under various power conditions are discussed in detail and a comprehensive energy management and control strategy is proposed accordingly. The priority controller can enable one of the control loops in different scenarios to optimize the whole system performance, taking both the MPPT benefit and the battery management requirements into consideration. Constant dc voltage is obtained.

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