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Multiple Controller Design and Implementation of Solar Power Generation System with Power Smoothing Function

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ABSTRACT

This project presents a solar power generation system with a power smoothing function achieved through the control of the DC-link voltage, implementation of a current controller, and utilization of a Phase-Locked Loop (PLL) for frequency control. The system aims to mitigate power fluctuations caused by variations in solar irradiance and other factors, ensuring a stable and constant power supply.The proposed SPGS consists of a solar cell array, a battery set, a dual-input buck-boost DC-AC inverter (DIBBDAI) and a boost power converter (BPC).The DIBBDAI combines the functions of voltage boost, voltage buck and DC-AC power conversion. The BPC acts as a battery charger between the solar cell array and the battery set. For the proposed SPGS, the DC power that is provided by the solar cell array or the battery set is converted into AC power through only one power stage. The solar cell array also charges the battery set through only one power stage. This increases the power conversion efficiency for the solar cell array, the battery set and the utility. The battery set is charged/discharged when the output power of the solar cell array changes drastically, in order to smooth the output power from the SPGS. The DC-link voltage control is responsible for regulating the voltage level within the system, ensuring it remains within a specified range for optimal operation. This control is achieved using a DC-DC converter, which adjusts the voltage level based on system requirements and solar panel output. The current controller plays a crucial role in regulating the current flow from the solar panels to the DC-link. By operating at the maximum power point (MPP), the current controller optimizes power generation. The PLL frequency control ensures synchronization between the generated power and the utility grid. By monitoring the grid frequency and adjusting the frequency of the generated power accordingly, the system seamlessly integrates with the grid and facilitates efficient power transfer.

Keywords : DC-link, Maximum Power Point, PLL, Boost Power Converter, DIBBDAI, SPGS

I. INTRODUCTION

Extreme climate change has created global warming. In order to prevent irreversible climate change, the United Nations promotes the international convention on greenhouse gas emission reduction. Most countries are actively developing renewable power generation to reduce the environmental impact of greenhouse gas emissions. Renewable energy from solar energy and wind energy involves mature technology and is widely used to generate electricity. In the past, renewable power generation was expensive and depended on government subsidies but the cost of renewable power generation has decreased rapidly due to developments in manufacturing technology. The cost of renewable energy power generation in many countries is close to or less than the price of electricity that is generated using fossil fuels so an increasing number of renewable power generation systems are being integrated into the grid to generate electricity.

The output power from a solar power generation system (SPGS) changes significantly due to environmental factors. These environmental factors change with the weather and seasons and cannot be controlled. As the penetration of SPGSs increases, drastic changes in their power generation will affect the voltage and frequency of distribution power system and can cause power outages. This reduces the power quality of distribution power systems. Several control strategies for the power conversion interface are used to alleviate the fluctuation in the output power from a SPGS. However, these control strategies only limit the increase in power from the SPGS by giving up maximum power tracking, and they only suppress the upward power fluctuations for the SPGS. In addition, the power that is generated by the SPGS is also decreased. To suppress upward and downward fluctuations of the SPGS, the rapid power regulation technology is required to temporarily store and release power to stabilize the power output from the SPGS. Since battery set has the advantages of small size, quick absorption and release of electrical energy and flexible operation, it has considerable potential as a power regulation device for the SPGS. In general, the control concept for smoothing the output power of SPGS is that the battery energy storage system supplies the difference between the average value and the instantaneous value for the output power of SPGS. The average value for the output power of SPGS can be calculated by low-pass filters, moving average filters, Saviztky–Golay filtering and moving regression filter. Since the instantaneous value for the output power of SPGS is rare equal to its average value, the charging/discharging time of the battery set is long.

The output from a solar cell array is DC power and the battery set stores power in DC form, so a power conversion interface is needed for integrating solar cell array or battery set into the power grid for DC-AC power conversion. The configuration of SPGS and battery energy storage system can be divided into AC coupling and DC coupling. For the AC coupling configuration, the SPGS and the battery energy storage system (BESS) are respectively connected to the grid. Therefore, the SPGS and the BESS have their own DC-AC power converter and the circuit structure is more complicated. For the DC coupling configuration, the SPGS and the BESS share a common DC-AC power converter so the circuit structure is relatively simple.

II. EXISTING SYSTEM

A solar power generation system with power smoothing function typically consists of a solar panel array, a battery, a power converter, and a controller. The solar panel array converts sunlight into DC power, which is then stored in the battery. The power converter converts the DC power from the battery into AC power that can be used to power a load or to feed into the grid. The controller regulates the output of the solar panel array and the battery to ensure that the desired power output is maintained. The power smoothing function is typically implemented using the battery. When the solar panel array is producing more power than is needed, the excess power is stored in the battery. When the solar panel array is producing less power than is needed, the battery provides the missing power. This helps to smooth out the fluctuations in solar power output and to provide a more stable power supply.There are a number of different ways to implement the power smoothing function. One common approach is to use a proportional-integral-derivative (PID) controller. The PID controller monitors the output of the solar panel array and the battery and adjusts the power output of the solar panel array accordingly.

2.1 Disadvantages

- Complex and difficult to install.
- More expensive.
- The system can be less efficient than other types of solar power systems
- Time-consuming process

III. PROPOSED SYSTEM

The proposed SPGS uses a dual-input buck-boost DC-AC inverter and a BPC to integrate a solar cell array and a battery set to generate power injecting into the grid. For the proposed SPGS, the DC power that is provided by the solar cell array or the battery set. The solar cell array also charges the battery set through only one power stage. This increases the power conversion efficiency for the solar cell array, the battery. The DC-link voltage control is responsible for regulating the voltage level within the system. The current controller plays a crucial role in regulating the current flow from the solar panels to the DC-link. A solar power generation system with power smoothing function can be achieved by incorporating various control techniques to regulate the DC-link voltage, implement a current controller, and employ a Phase-Locked Loop (PLL) for frequency control. Let's discuss each component and its role in achieving power smoothing.

3.1 Advantages

- Improved efficiency
- Increased reliability
- Reduced fluctuations in power output
- Increased lifespan of solar panels
- Reduced maintenance costs

BLOCK DIAGRAM

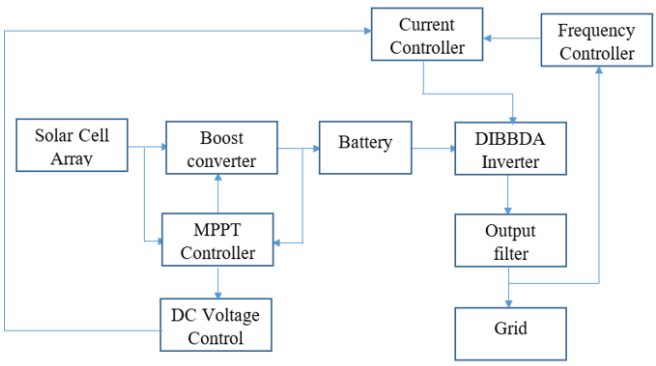

Fig 2.1 Block Diagram

3.1.1 DC-LINK VOLTAGE CONTROL:

The DC-link voltage control regulates the voltage level in the system. It ensures that the voltage remains within a specified range, which is crucial for the stable operation of the solar power generation system. This control is typically achieved using a DC-DC converter, such as a boost converter or a buck-boost converter. The converter adjusts the voltage level based on the system's requirements and the output from the solar panels.

3.1.2 CURRENT CONTROLLER:

The current controller is responsible for regulating the amount of current flowing from the solar panels to the DC-link. It ensures that the power generation system operates at its maximum power point (MPP), which is the point where the solar panels produce the maximum power for a given irradiance level. The current controller adjusts the duty cycle of a switching device, such as a pulse-width modulation (PWM) controller, to maintain the desired current level and extract maximum power from the solar panels.

3.1.3 POWER SMOOTHING:

Power smoothing is the process of mitigating power fluctuations caused by variations in solar irradiance and other factors. It involves controlling the power output to ensure a relatively constant power supply. Power smoothing techniques can include energy storage systems, such as batteries, or using control algorithms to manage the power flow.

3.1.4 PHASE-LOCKED LOOP (PLL) FREQUENCY CONTROL:

A PLL is a control mechanism used to synchronize the frequency of the generated power with the grid frequency. It ensures that the solar power generation system operates in sync with the utility grid, allowing for the efficient transfer of power. The PLL monitors the grid frequency and adjusts the frequency of the generated power accordingly. This control technique is particularly important for grid-connected systems, where synchronization is required for seamless integration.

By integrating these control techniques, the solar power generation system can achieve power smoothing by regulating the DC-link voltage, maintaining the current at the maximum power point, and synchronizing the frequency with the grid. These control mechanisms help optimize power generation, minimize power fluctuations, and ensure the stability and reliability of the solar power system.

3.2 CIRCUIT DIAGRAM

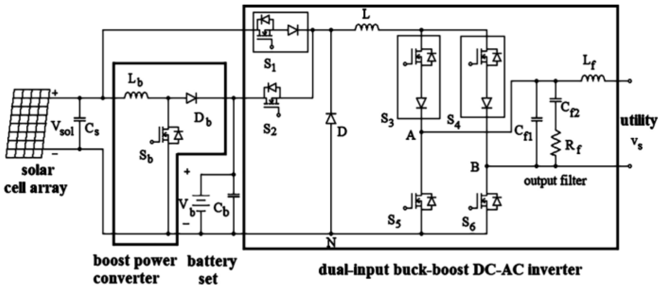

Fig. 2.2 Circuit diagram

The circuit configuration for the proposed SPGS is shown in Fig. 3.2. The DC coupling configuration is used for the proposed SPGS. As seen in Fig. 3.2, the proposed SPGS is composed of a solar cell array, a battery set and the power conversion interface. The power conversion interface consists of a DIBBDAI and a BPC. The BPC is connected between the solar cell array and the battery set to control the power from the solar cell array that charges the battery set. In order to reduce the capacity of battery set, the battery set only operates when the power variation for the solar cell array exceeds the specified range. The battery set is only charged by the solar cell array so the power flow of BPC is unidirectional.

The DIBBDAI performs the functions of voltage boost, voltage buck and DC-AC power conversion. The DIBBDAI BPC operate at the same time to convert the power from the solar cell array for injecting into the grid and for charging the battery set, respectively

IV. PROPOSED DESIGN

4.1.1 OPERATION OF DIBBDAI

The two input terminals of the DIBBDAI are respectively connected to the solar cell array and the battery set. The operation of the DIBBDAI can be divided into the boost mode and the buck mode. The two input terminals of the DIBBDAI are respectively connected to the power electronic switches S_1 and S_2. Since the voltage of the solar cell array is lower than that of the battery set, S1 should further contain a diode to form a unidirectional switch to prevent the battery voltage from affecting the voltage of the solar cell array. Power electronic switches S_1 and S_2 are used as switches during the buck mode.

For the proposed SPGS, the solar cell array and the battery set will not release the power at the same time; hence, the power electronic switches S_1 and S_2 will not operate at the same time. The DIBBDAI also includes a bridge structure that is composed of S_3-$S_6$for commutation, in order to generate an AC output current. Among them, $S_3$and S_4further contain a diode to form a unidirectional switch to avoid short circuit in the grid. S_3 or $S_4$are also used as switches during the boost mode. $C_{f1}, C_{f2}, R_f\ and\ L_f$ create a damped second-order lowpass filter.

If the solar cell array is operating and the battery set is disabled, $S_1$is activated and S2 is turned off. If the grid has two DC input terminals, which are respectively connected to battery set and the solar cell array, and both the battery set and the solar cell array can directly use the DIBBDAI to convert DC power into AC power for supplying to the grid.

When the output power from the solar cell array is stable, the DIBBDAI converts the power from the solar cell array to the grid, so the BPC is disabled and the battery set is in standby mode. The DIBBDAI converts the power from the battery set to the grid when the power of solar cell array suddenly decreases, and the BPC tracks the maximum power of solar cell array to charge the battery set. When the power of solar cell array suddenly increases, the DIBBDAI and voltage is lower than the voltage of the solar cell array, the DIBBDAI is operated in the buck mode. At this time, S1 is operated in pulse width modulation (PWM) switching and S_3-$S_6$are operated in accordance with the polarity of the grid voltage. The operation of buck mode can be divided into four modes.

Mode Bk-1: During the positive half cycle of the grid voltage, S_1, S_3, and $S_6$are turned on, and S_4 , S_5 and D are turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = \frac{V_{sol} - v_s}{L}$$

where v_s and V_{sol} are the grid voltage and the voltage of the solar cell array, respectively. The solar cell array releases energy to the inductor and the grid. Mode Bk-2: During the positive half cycle of the grid voltage, S_3, $S_6$and D are turned on, and S_1 , S_5 , and S_5 are turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = -\frac{v_s}{L}$$

The inductor releases energy to the grid.

Mode Bk-3: During the negative half cycle of the grid voltage, S1, S4 and S5are turned on, and S_3, $S_6$and D are turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = \frac{V_{sol} + v_s}{L}$$

The solar cell array releases energy to the inductor and the grid. Mode Bk-4: During the negative half cycle of the grid voltage, S_4 , S_5 and D are turned on, and S_1, S_3 and S_6 are turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = -\frac{v_s}{L}$$

The inductor releases energy to the grid. The equivalent circuit for the DIBBDAI in the buck mode is shown in Fig. 2, where S is S_1. The grid voltage is converted to its absolute value by the operation of S_3-S_6 and then added to the output of conventional buck power converter. As a result, the DIBBDAI operates as a conventional buck power converter, and the inductor current can be controlled by the switching of S.

If the grid voltage is higher than the voltage of the solar cell array, the DIBBDAI operates in the boost mode. At this time, S_1 is always on, S_4 and S_3 are respectively operated in PWM switching during the positive and negative half cycles for the grid voltage and S_6 and S_5 are operated in accordance with the polarity of the grid voltage. The operation of boost mode can also be divided into four modes.

Mode Bt-1: When the grid voltage is in the positive half cycle, S_3, S_4 and $S_6$are turned on and S_5 is turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = \frac{V_{sol}}{L}$$

The solar cell array releases energy to the inductor.

Mode Bt-2: When the grid voltage is in the positive half cycle, $S_3$and $S_6$are turned on and S4 and S5 are turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = \frac{V_{sol} - v_s}{L}$$

Both the solar cell array and the inductor release energy to the grid.

Mode Bt-3: When the grid voltage is in the negative half cycle, S_3, S_4 and S_5 are turned on and S_6 is turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = \frac{V_{sol}}{L}$$

The solar cell array releases energy to the inductor.

Mode Bt-4: When the grid voltage is in the negative half cycle, $S_4$and $S_5$are turned on and $S_3$and $S_6$are turned off. The change rate for the inductor current is:

$$\frac{di_L}{dt} = \frac{V_{sol} + v_s}{L}$$

Both the solar cell array and the inductor release energy to the grid.

The equivalent circuit for the DIBBDAI operating in the boost mode is shown in Fig. 3. The grid voltage is converted to its absolute value and then added to the output of conventional BPC by the operation of S_3-S_6. In Fig. 3, switch S is S_4or $S_3$and the diode is the body diode of S_3or S_4depending on the polarity of the grid voltage. The DIBBDAI operates as a conventional BPC and the inductor current is controlled by switching S.

When the DIBBDAI is powered by the battery set, S2 is activated and S_1 is turned off. At this time, the DIBBDAI operates similarly to when the solar cell array is operated, and it is not repeated.

The operation of S_1-$S_6$is summarized where PHC and NHC mean the positive half cycle and negative half cycle. The control signals S_1-$S_6$and operation voltage during a grid cycle when the solar cell array supplies power to the DIBBDAI. As can be seen in only one power electronic switch is operated in PWM switching at any time, and VAN and VBN are close to the positive cycle voltage and the negative cycle voltage of grid, respectively.

The equivalent circuit of the DIBBDAI for the leakage current analysis, Cpv and Rg are the stray capacitor for the solar cell array and ground resistor for the grid, respectively. VAN and VBN are the voltages from terminals A and B to the negative terminal N of the solar cell array, respectively. Since C_{f1}, C_{f2} and R_f are connected across terminals A and B, these components do not affect the leakage current. $S_5$and $S_6$are switched synchronously with the grid voltage. S_6 is turned on and $S_5$is turned off when the grid voltage is in the positive half cycle, and:

$$V_{AN} = v_s + v_{Lf}$$

$$V_{BN} = 0$$

where vL_f is the voltage of L_f . Since VBN is equal to 0, the voltage across the loop of CPV and Rg is 0 and the leakage current is 0. When the grid voltage is in the negative half cycle, $S_5$is turned on and S_6 is turned off and

$$V_{AN} = 0$$
$$V_{BN} = -(v_s + v_{Lf})$$

The voltage across the loop of CPV and Rg is $-(v_s + v_{Lf})$. Since vs is a sinusoidal voltage of 60Hz and the impedance of the stray capacitor is very large at 60Hz, the leakage current induced by vs is very small. v_{Lf}contains a switching-frequency component, which is caused by the switching-frequency ripple in the output current. However, the switching-frequency component of v_{Lf} is effectively suppressed by C_{f1}, C_{f2} and R_f . VAN and VBN are respectively close to the positive cycle voltage and the negative cycle voltage of grid, and it is consistent with the analysis. Accordingly, the leakage current induced by v_{Lf} is still small even the impedance of the stray capacitor at the switching frequency is small. Therefore, the leakage current contains a small switching-frequency component and a small fundamental component during the negative half cycle.

4.1.2 OPERATION OF BPC

The BPC is inserted between the solar cell array and the battery set and is used when the battery set is charged by the solar cell array. The BPC is disabled when the power variation for the solar cell array is within the specified range. The BPC performs maximum power tracking (MPPT) for the solar cell array if the power variation for the solar cell array exceeds the specified range. The BPC is designed to be operated in continuous-conduction mode, and the relationship between the voltage of the solar cell array and the voltage of the battery set is:

$$\frac{V_{sol}}{V_{bat}} = \frac{1}{1 - D_{Sb}}$$

where D_{Sb} is the duty cycle for S_b.

4.1.3 SMOOTHING OPERATION

If the output power of the solar cell array is stable, the output power from the solar cell array is converted into AC power by the DIBBDAI. At this time, the DIBBDAI performs MPPT using the perturbation and observation (P&O) method. The output voltage from the solar cell array is disturbed, and then the change in the power from the solar cell array is observed to determine the direction in which the output voltage from the solar cell array is disturbed until the maximum power point is tracked. The output power smoothing mechanism is activated when the power variation for the solar cell array significantly exceeds the specified range. The state of charge (SOC) of the battery set is specified as between 30% and 90% to avoid over-charging or over-discharging, which decreases the life of the battery set. Considering the upward and downward power fluctuations of SPGS, the desired SOC of the battery set is at 60% when the battery set is in the stand-by mode. Since this study concerns the smoothing operation for the output power from the SPGS, the SOC of the battery set is estimated simply using the terminal voltage. The output power from the SPGS is smoothed when the power variation (1PPV) for the solar cell array exceeds the specified value P_1. P_1 is determined by the power variation of regulation. The DIBBDAI is still powered by the solar cell array but MPPT is performed by the BPC using the P&O method. Consequently, the output current amplitude of DIBBDAI is controlled to be increased linearly along a specified gradient, driving the output power (Pout) from the SPGS also linearly increases along the specified gradient. The specified gradient for the output current amplitude depends on the allowable maximum power variation for Pout. At this time, the difference between the P_{PV} and P_{out} is positive. This power difference is automatically injected into the battery set through the BPC and the SOC of battery set is increased. When Pout exceeds P_{PV} by P_2, the DIBBDAI controls the output current amplitude to be a fixed value. The BPC still performs MPPT. At this time, the difference between P_{PV} and

P_{out} becomes negative and the power difference is automatically supplied from the battery set to decrease the SOC of the battery set. If P_{PV} remains stable, the BPC stops operating when the SOC of the battery decreases to 60%. The DIBBDAI performs MPPT. At this moment, the power variation in Pout is P_2. P_2 must be less than or equal to P_1 to avoid exceeding the power variation of regulation. When the output power Pout is still less than P_{PV} and the SOC of the battery set has been equal to 90%, the BPC stops and the power smoothing function is disabled, in order to prevent the battery set from over-charging.

The output power from the SPGS is also smoothed when 1PPV for the output power from the solar cell array decreases to less than the specified value –P1. At this time, the DIBBDAI is powered by the battery set and the BPC performs MPPT. The solar cell array charges the battery set through the BPC. The DIBBDAI decreases the amplitude of the output along the specified gradient, so Pout also linearly decreases along the specified gradient. At this time, the difference between Pout and P_{PV} is automatically supplied from the battery set and the SOC of the battery set is decreased. When Pout is P1 less than P_{PV}, the DIBBDAI maintains the output current amplitude at a fixed value. The BPC continuously performs MPPT. P_{PV} is greater than Pout so the battery set is charged instead and the SOC of the battery set is increased. If P_{PV} remains stable, the BPC stops operating when the SOC of the battery is increased to 60%. The DIBBDAI is powered by the solar cell array and performs MPPT. At this moment, the power variation in P_{out} is P_2. If Pout is not less than P_{PV} and the SOC of the battery set has been equal to 30%, the BPC stops smoothing the power output of the SPGS, in order to prevent the battery set from over-discharging. The DIBBDAI is powered by the solar cell array and performs MPPT.
The operation flowchart for the proposed SPGS with power smoothing function. No matter P_{PV} increases or decreases drastically, P_{out} increases or decreases linearly along the specified gradient to smooth the output power from the SPGS. Since the battery set is actuated only when the absolute value of power variation (1PPV) for the solar cell array exceeds the specified value P_1, the charging/discharging time of the battery set is much less than other smoothing methods. Moreover, regardless of whether the battery set is charged or discharged to smooth the output power from the solar cell array, the battery set will immediately discharge or charge to maintain its SOC close to 60% when Pout catches up with P_{PV}. As a result, the capacity of battery set can be reduced.

4.1.4 CONTROL BLOCK

The output voltage and the output current from the solar cell array are sent to the MPPT block to calculate PPV and to generate a predicted voltage for the solar cell array. The predicted voltage and the detected voltage for the solar cell array are sent to a proportional integral (PI) controller to generate a MPPT control signal. The power variation (ΔP_{PV}) for the solar cell array is also calculated in the MPPT block. ΔP_{PV} is sent to comparison block I and compared with (P_1, $-P_1$) to generate an amplitude gradient control signal, Ssl. When PPV > P_1, Ssl is +Vsl. S_{sl} is $-V_{sl}$ when $\Delta P_{PV} < -P1$. When $\Delta P_{PV}$is between P_1 and $-P_1$, S_{sl} is 0. Ssl is sent to an integrator. When S_{sl} is $+V_{sl}$, a linearly increasing signal is generated. A linearly decreasing signal is generated if S_{sl} is $-V_{sl}$. Therefore, V_{sl} controls the gradient of the amplitude control signal for the output current to determine the gradient in Pout when the smoothing function is actuated. When P_{PV} is stable, S_{sl} is 0 and the amplitude control signal is determined by the MPPT control signal. The MPPT control signal remains unchanged and Vsl controls the gradient of the amplitude control signal for the output current if P_{PV} changes significantly. The amplitude control signal and a unity sinusoidal signal are sent to a multiplier and an absolute value block to generate the output current reference signal. The unity sinusoidal signal is generated by a phaselocked loop (PLL) and a sinusoidal table to ensure the unity sinusoidal signal is a sine-wave and in phase with the grid voltage. Because the DIBBDAI can be operated in the buck mode and the boost mode, the current control involves two parts. The detected output current is sent to an absolute value block. In buck mode, the detected absolute output current is compared with the output current reference signal and sent to the current controller. The output from current controller is added to the feedforward control signal $v_{f,bk}$ to generate a buck modulation signal and then sent to the PWM block I. to generate a buck PWM signal PWMbk. The carrier based PWM technology is used in the PWM block I. The buck modulation signal is compared with a triangle carrier in the PWM block I to generate a buck PWM signal PWM_{bk}. The feedforward control signal $v_{f,bk}$ is:

$$v_{f,bk} = \frac{|v_s|}{k_{pwm1}}$$

and,

$$k_{pwm1} = \frac{V_{dc}}{V_{tri}}$$

where V_{tri} is the peak value for the triangular carrier and V_{dc} is the input voltage for the DIBBDAI, which is the voltage of either the solar cell array or the battery set.

Since the output current from the DIBBDAI contains large high-frequency switching harmonics in the boost mode, the detected absolute output current is sent to an extra low-pass filter. The output from the low-pass filter is compared with the output current reference signal and then sent to the current controller. The output from the current controller is added to the feedforward control signal vf,bt to generate a boost modulation signal and then sent to the PWM block. The carrier based PWM technology is also used in the PWM block. The boost modulation signal is compared with a triangle carrier in the PWM block to generate a boost PWM signal PWM_{bt}. The feedforward control signal vf,bt is:

$$v_{f,bt} = \frac{|v_s| - V_{dc}}{|v_s|} V_{tri}$$

The feedforward control signals $v_{f,bk}$ and $v_{f,bt}$ will generate the major part of modulation signal, and the current controller and the current controller are used to fine tune the modulation signal to ensure that the detected absolute output current can trace the output current reference signal to be an absolute sine-wave. The grid voltage is sent to the comparison block and compared with 0 to generate a control signal, S_p. S_p is 1 and 0 during the positive and negative half cycles of the grid voltage, respectively. The absolute value of the grid voltage is also compared with V_{dc} to generate a control signal, Sb. When the absolute value of the grid voltage is greater than V_{dc}, S_b is 1, and the DIBBDAI operates in the boost mode. On the contrary, S_b is 0, and the DIBBDAI operates in the buck mode. Finally, S_p, S_b, PWM_{bk} and PWM_{bt} are sent to the logic processing block to create the control signals for S_1-S_6. The control signals for S_1-S_6 are:

$$S_1 = (\bar{S}_b PWM_{bk} + S_b) \cdot S_o$$
$$S_2 = (\bar{S}_b PWM_{bk} + S_b) \cdot \bar{S}_o$$
$$S_3 = \bar{S}_p \cdot S_b \cdot PWM_{bt} + S_p$$
$$S_4 = S_p \cdot S_b \cdot PWM_{bt} + \bar{S}_p$$
$$S_5 = \bar{S}_p$$
$$S_6 = S_p$$

where S_o depends on the input source for the DIBBDAI. S_o is 1 if the solar cell array provides power and 0 if the battery set provides power. The BPC is controlled by current control, which uses the MPPT control signal from the solar cell array and the current from the inductor Lb, and the output of current control is sent to the PWM block to create the control signal for SD.

V. CONCLUSION

This project proposes a SPGS with a power smoothing function. The proposed SPGS uses a DIBBDAI to integrate the solar cell array and the battery set for outputting a smoother power. The proposed SPGS has the following innovative features. The SPGS integrates two input power sources, solar cell array and battery set, which can be changed seamlessly. The battery set acts as an energy buffer to smooth the power variation from the SPGS. The proposed SPGS using only two power stages, hence, the power circuit is simplified. Regardless of whether the input power source is the solar cell array or the battery set, only one power stage is required to convert DC power to AC power. Besides, the power for charging the battery set from the solar cell array is only through one power stage. The leakage current induced by the stray capacitance of the solar cell array is suppressed due to the use of the proposed SPGS. The experimental results show that the proposed SPGS outputs a sinusoidal current in phase with the utility voltage and smooth the power variation caused by the power fluctuation from the solar cell array. In addition, the leakage current of solar cell array is effectively suppressed. Therefore, it verifies that the major concerns of power fluctuation and leakage current can be solved by using the proposed SPGS.

VI. REFERENCES

[1]. Q. Peng, A. Sangwongwanich, Y. Yang, and F. Blaabjerg, "Grid-friendly power control for smart photovoltaic systems," Sol. Energy, vol. 210, pp. 115–127, Nov. 2020.

[2]. D. Cheng, B. A. Mather, R. Seguin, J. Hambrick, and R. P. Broadwater, "Photovoltaic (PV) impact assessment for very high penetration levels," IEEE J. Photovolt., vol. 6, no. 1, pp. 295–300, Jan. 2016.

[3]. J. Martins, S. Spataru, D. Sera, D.-I. Stroe, and A. Lashab, "Comparative study of ramp-rate control algorithms for PV with energy storage systems," Energies, vol. 12, no. 7, p. 1342, Apr. 2019.

[4]. D. Lin and N. Normal University, "Strategy comparison of power ramp rate control for photovoltaic systems," CPSS Trans. Power Electron. Appl., vol. 5, no. 4, pp. 329–341, Dec. 2020.

[5]. H. Nazaripouya, C.-C. Chu, H. R. Pota, and R. Gadh, "Battery energy storage system control for intermittency smoothing using an optimized two-stage filter," IEEE Trans. Sustain. Energy, vol. 9, no. 2, pp. 664–675, Apr. 2018.

[6]. K. Koiwa, K.-Z. Liu, and J. Tamura, "Analysis and design of filters for the energy storage system: Optimal tradeoff between frequency guarantee and energy capacity/power rating," IEEE Trans. Ind. Electron., vol. 65, no. 8, pp. 6560–6570, Aug. 2018.

[7]. M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, "A novel approach for ramprate control of solar PV using energy storage to mitigate output fluctuations caused by cloud passing," IEEE Trans. Energy Convers., vol. 29, no. 2, pp. 507–518, Jun. 2014.

[8]. A. Atif and M. D. Khalid, "Saviztky-Golay filtering for solar power smoothing and ramp rate reduction based on controlled battery energy storage," IEEE Access, vol. 8, pp. 33806–33817, 2020.

[9]. M. A. Syed and M. Khalid, "Moving regression filtering with battery state of charge feedback control for solar PV firming and ramp rate curtailment," IEEE Access, vol. 9, pp. 13198–13211, 2021.

[10]. M. J. E. Alam, K. M. Muttaqi, and D. Sutanto, "Battery energy storage to mitigate rapid voltage/power fluctuations in power grids due to fast variations of solar/wind outputs," IEEE Access, vol. 9, pp. 12191–12202, 2021.

[11]. A. Makibar, L. Narvarte, and E. Lorenzo, "Contributions to the size reduction of a battery used for PV power ramp rate control," Sol. Energy, vol. 230, pp. 435–448, Dec. 2021.

[12]. M. Combe, A. Mahmoudi, M. H. Haque, and R. Khezri, "Optimal sizing of an AC-coupled hybrid power system considering incentive-based demand response," IET Gener., Transmiss. Distrib., vol. 13, no. 15, pp. 3354–3361, Jul. 2019.

[13]. V. T. Tran, M. R. Islam, D. Sutanto, and K. M. Muttaqi, “Mitigation of solar PV intermittency using ramp-rate control of energy buffer unit,” IEEE Trans. Energy Convers., vol. 34, no. 1, pp. 435–449, Mar. 2019.

[14]. S. Kumar, L. N. Patel, B. Singh, and A. L. Vyas, “Self-adjustable stepbased control algorithm for grid-interactive multifunctional single-phase PV-battery system under abnormal grid conditions,” IEEE Trans. Ind. Appl., vol. 56, no. 3, pp. 2978–2987, May 2020.

[15]. R. K. Dhar, A. Merabet, A. Al-Durra, and A. M. Y. M. Ghias, “Power balance modes and dynamic grid power flow in solar PV and battery storage experimental DC-link microgrid,” IEEE Access, vol. 8, pp. 219847–219858, 2020.

[16]. N. Vazquez, S. S. Yu, T. K. Chau, T. Fernando, and H. H.-C. Iu, “A fully decentralized adaptive droop optimization strategy for power loss minimization in microgrids with PV-BESS,” IEEE Trans. Energy Convers., vol. 34, no. 1, pp. 385–395, Mar. 2019.

[17]. C. M. Nirmal Mukundan, P. Jayaprakash, U. Subramaniam, and D. J. Almakhles, “Binary hybrid multilevel inverter-based grid integrated solar energy conversion system with damped SOGI control,” IEEE Access, vol. 8, pp. 37214–37228, 2020.

[18]. J. Wu, H. Jou, and X. Wu, “Power conversion interface with harmonic suppression for a DC grid and single-phase utility,” IET Power Electron., vol. 13, no. 7, pp. 1302–1310, May 2020.

[19]. D. Ghaderi, G. Bayrak, and J. M. Guerrero, “Grid code compatibility and real-time performance analysis of an efficient inverter topology for PVbased microgrid applications,” Int. J. Electr. Power Energy Syst., vol. 128, Apr. 2021, Art. no. 106712.

[20]. E. Kabalcè, “Review on novel single-phase grid-connected solar inverters: Circuits and control methods,” Sol. Energy, vol. 198, pp. 247–274, Mar. 2020.

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