



# Power Smoothing Capable Solar Power Generation System

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**ABSTRACT:** Environmental conditions have a significant impact on the output power of solar power generation systems (SPGS), which in turn impacts the stability and dependability of power distribution networks. This paper suggests using the power smoothing function in an SPGS. A solar cell array, a battery set, a dual-input buck-boost DC-AC inverter (DIBBDI), and a boost power converter (BPC) make up the suggested SPGS. The DIBBDI integrates the DC-AC power conversion, voltage buck, and voltage boost capabilities. Between the battery set and the solar cell array, the BPC functions as a battery charger. There is just one power stage needed to convert the DC electricity from the solar cell array or the battery set into AC power for the proposed SPGS. Additionally, the battery set is charged by the solar cell array using a single power stage. This improves the solar cell array's, the battery set's, and the utility's power conversion efficiency. In order to stabilize the output power from the SPGS, the battery set is charged or discharged when the solar cell array's output power fluctuates significantly. Furthermore, the leakage current caused by the solar cell array's parasitic capacitance can be suppressed by the DIBBDI. The suggested power conversion interface for an SPGS reduces leakage current, smoothes power fluctuations, and boosts power efficiency. To confirm the suggested SPGS's functionality, a hardware prototype is finished.

**INDEX TERMS:** buck-boost DC-AC inverter, power smoothing, and solar power generating.

## I. INTRODUCTION:

Global warming is the result of extreme climate change. The United Nations advocates the international treaty on greenhouse gas emission reduction as a means of averting irreversible climate change. To lessen the negative effects of greenhouse gas emissions on the environment, the majority of nations are aggressively developing renewable power generation. Electricity is frequently produced using renewable energy sources like solar and wind energy, which require sophisticated technology. Renewable power generation used to be costly and dependent on government subsidies, but because to advancements in manufacturing technology, its cost has dropped significantly. An increasing number of renewable power production systems are being connected into the grid to create electricity since the cost of producing electricity using renewable energy is often comparable to or lower than the cost of producing electricity using fossil fuels. Environmental conditions have a significant impact on a solar power generating system's (SPGS) output power [1]. Never the less, these control tactics simply suppress the upward power fluctuations for the SPGS and limit the growth in power from the SPGS by giving up maximum power tracking. Furthermore, the power produced by the SPGS is also reduced. Rapid power regulation technology is needed to temporarily store and release power in order to stabilize the power output from the SPGS and reduce

upward and downward fluctuations in power. Given that battery sets have the benefits of compact size, rapid electrical energy absorption and release, and flexible functioning. It has a great deal of potential for use as an SPGS power regulation device [2]. Generally speaking, the battery energy storage system is used as the control idea to smooth the output power of SPGS.

System provides the variation in the SPGS output power between the average and instantaneous values. By using low-pass filters [3] [6], moving average filters [3], [4], [7], Savitzky-Golay filters [8], and moving regression filters [9], one may get the average value for the output power of SPGS. The battery set takes a long time to charge and discharge since the immediate output power of the SPGS is rarely equal to its average value.

A power conversion interface is required to integrate a solar cell array or battery set into the power grid for DC-AC power conversion because solar cell arrays produce DC power and batteries store DC power [1]. There are two types of configurations for SPGS and battery energy storage systems: AC coupling [9] and DC coupling [4], [8]. The battery energy storage system (BESS) and the solar power generation system (SPGS) are connected to the grid, respectively, for the AC coupling configuration. As a result, the circuit configuration of the SPGS and BESS is more intricate and each has a separate DC-AC power converter. Because the SPGS and the BESS share a DC-AC power converter for the DC coupling configuration, the circuit construction is rather straightforward.

Because they use fewer solar modules or batteries, small capacity SPGSs and BESS have lower DC voltages. The DC bus voltage of a DC-AC power converter with a classic bridge architecture or multi-level architecture must be higher than the peak grid voltage since these converters are derived from buck power converters [1]. The solar cell array or battery set and the DC-AC power converter must be connected via a boost power converter (BPC), and two power conversion stages must be used to process all of the power from the solar cell array or battery set. Four power stages are required for power conversion in the battery energy storage system and SPGS AC connection configuration. For the battery energy storage system and SPGS DC coupling configuration, there are only three power processing stages remaining. As a result, the power circuit becomes more intricate, leading to a decrease in power efficiency. Furthermore, two DC-DC power converters should be used to process the charging power from the solar cell array to the battery set in order to integrate the BESS and carry out the power smoothing function for an SPGS.

A buck-boost converter is implemented into the AC side of the bridge architecture. The buck-boost converter is used to step up or down the voltage and manage the output current. The bridge architecture is switched in synchronization with the grid voltage to provide a square voltage. Cascaded bridge architecture is an alternative to the current bridge architecture. Bidirectional power electronic switches, which are made up of two regular power electronic switches connected in series, are what the buck boost converter should employ. It is also possible to integrate the buck-boost converter into the bridge architecture's DC side. However, because all of the conversion power needs to be stored in and subsequently released from the inducer, the buck-boost converter's power efficiency is reduced. Additionally, these DC-AC power converters only handle a single DC power supply.

An SPGS with a power smoothing function is suggested in this paper. The proposed SPGS integrates a solar cell array and a battery set to create power injecting into the grid using a dual-input buck-boost DC-AC inverter (DIBBDAI) and a BPC. Two DC power sources are integrated by the DIBBDAI. In the proposed SPGS, only the DIBBDAI is used to convert DC power from the solar cell array or the battery set into AC power, and only the BPC is used to charge the battery set from the sun cell array. In order to stabilize the output power from the SPGS, the battery set is charged or discharged whenever there is a significant variation in

the solar cell array's output power. Because there aren't many high frequency components in the solar cell array's negative terminal voltage, the parasitic capacitance of the array causes less leakage current to occur

## II. CIRCUIT DEFINITIONS

Fig. 1 depicts the circuit configuration for the suggested SPGS. For the suggested SPGS, the DC coupling configuration is employed. The suggested SPGS consists of a battery set, a solar cell array, and a power conversion interface, as shown in Fig. 1. A BPC and a DIBBDAI make up the power conversion interface. To regulate the electricity from the solar cell array that charges the battery set, a BPC is linked between the solar cell array and the battery set. The battery set only works when the power fluctuation for the solar cell array above the specified range, which lowers the battery set's capacity.

The BPC's power flow is unidirectional since the solar cell array is the primary source of power for the battery set. Voltage bucking, DC-AC power conversion, and voltage boost are all handled by the DIBBDAI. In order to transform the power from the solar cell array for both charging the battery set and injecting it into the grid, the DIBBDAI BPCs run simultaneously.

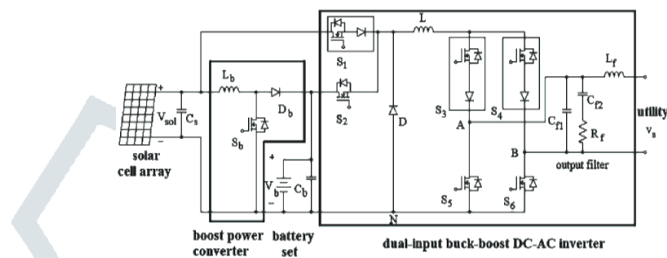


Fig1: Circuit configuration for the proposed SPGS

## III. DIBBDAI OPERATION

The battery set and the solar cell array are linked to the DIBBDAI's two input terminals, respectively. There are two modes of operation for the DIBBDAI: boost mode and buck mode. The power electronic switches S1 and S2 are connected to the DIBBDAI's two input terminals, respectively. S1 should further include a diode to form a unidirectional switch as the voltage of the sun cell array is lower than the voltage of the battery set. This will stop the battery voltage from influencing the voltage of the solar cell array. During the buck mode, power electronic switches S1 and S2 are utilized as switches.

S1 is turned on and S2 is turned off when the battery set is disengaged and the solar cell array is working. The grid can directly use the DIBBDAI to convert DC power into AC power for delivering to the grid if it has two DC input terminals that are connected to the battery set and the solar cell array, respectively.

The BPC is turned off and the battery set is placed in standby mode when the output power from the solar cell array reaches a stable level and is converted to the grid via the DIBBDAI. When the power of the solar cell array abruptly drops.

The DIBBDAI operates in the buck mode when the power of the solar cell array increases abruptly and the voltage is lower than the voltage of the solar cell array. S1 is currently operated via pulse width modulation (PWM) switching, while S3 through S6 are currently operated based on the grid voltage's polarity.

There are four ways that the buck mode operates.

Mode Bk-1: S1, S3, and S6 are on and S4, S5, and D are off throughout the grid voltage's positive half cycle. The inductor current's changing rate is  $V$ .

$$\frac{di_L}{dt} = \frac{V_{sol} - v_s}{L} \quad (1)$$

where  $v_s$  and  $V_{sol}$  stand for the solar cell array's voltage and the grid voltage, respectively. The grid and the inductor receive energy releases from the solar cell array.

Mode Bk-2: S3, S6, and D are switched on and S1, S4, and S5 are turned off during the grid voltage's positive half cycle. The inductor current's changing rate is  $V$ .

$$\frac{di_L}{dt} = -\frac{v_s}{L} \quad (2)$$

Energy is released into the grid by the inductor.

Mode Bk-3: S1, S4, and S5 are switched on and S3, S6, and D are turned off during the grid voltage's negative half cycle. The inductor current's changing rate is  $V$ .

$$\frac{di_L}{dt} = \frac{V_{sol} + v_s}{L} \quad (3)$$

The grid and the inductor receive energy from the solar cell array.

Mode Bk-4: S4, S5, and D are switched on and S1, S3, and S6 are turned off during the grid voltage's negative half cycle. The inductor current's changing rate is  $V$ .

$$\frac{di_L}{dt} = -\frac{v_s}{L} \quad (4)$$

Energy is released into the grid by the inductor.

Fig. 2 depicts the corresponding circuit for the DIBBDAI in the buck mode, where S is S1.

After S3–S6 complete their function, the grid voltage is converted to its absolute value and added to the output of a traditional buck power converter. The inductor current can therefore be adjusted by switching S, and the DIBBDAI functions as a typical buck power converter.

When the voltage of the grid surpasses that of the solar cell array, the DIBBDAI functions in the boost mode. S4 and S3 are currently operating in PWM switching throughout the positive and negative half cycles of the grid voltage, S1 is always on, and S6 and S5 are operating in accordance with the polarity of the grid voltage. Four modes can also be distinguished in the way that boost mode operates.

Mode Bt-1: S3, S4, and S6 are on while S5 is off when the grid voltage is in the positive half cycle. For the inductor current, the change rate is  $V$ .

$$\frac{di_L}{dt} = \frac{V_{sol}}{L} \quad (5)$$

The inductor receives energy from the solar cell array.

Mode Bt-2: S3 and S6 are switched on and S4 and S5 are turned off when the grid voltage is in the positive half cycle. The inductor current's changing rate is  $V$ .

$$\frac{di_L}{dt} = \frac{V_{sol} - v_s}{L} \quad (6)$$

Energy is released to the grid by the inductor and the solar cell array

Mode Bt-3: S3, S4, and S5 are switched on and S6 is turned off when the grid voltage is in the negative half cycle. For the inductor current, the change rate is  $V$ .

$$\frac{di_L}{dt} = \frac{V_{sol}}{L} \quad (7)$$

The inductor receives energy from the solar cell array.

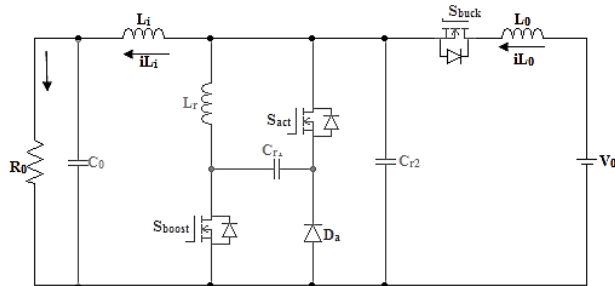


Fig 2: Equivalent circuit for the DIBBDAI in the buck mode.

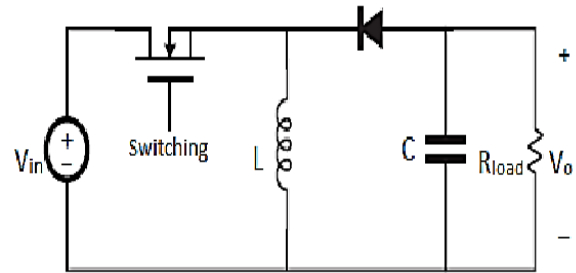


Fig 3: Equivalent circuit for the DIBBDAI in the boost mode.

Mode Bt-4: S4 and S5 are switched on while S3 and S6 are turned off when the grid voltage is in the negative half cycle.

The inductor current's changing rate is  $V$ .

$$\frac{di_L}{dt} = \frac{V_{sol} + v_s}{L} \quad (8)$$

The inductor receives energy from the solar cell array.

Fig. 3 depicts the analogous circuit for the DIBBDAI when it is in the boost mode. S3-S6 operate to convert the grid voltage to its absolute value, which is then added to the traditional BPC's output. Depending on the way the grid voltage is polarized, switch  $S$  in Figure 3 is either S4 or S3, and the diode is either S3 or S4's body diode. The inductor current is managed by switching  $S$ , and the DIBBDAI functions as a typical BPC.

S2 turns on and S1 turns off when the battery-operated DIBBDAI is powered. Currently, the DIBBDAI functions in a manner consistent with that of the solar cell array and does not repeat itself.

Tab. 1 provides an overview of how S1–S6 operate. The terms PHC and NHC refer to the positive and negative half cycles, respectively.

Figure 4 displays the operation voltage and control signals S1–S6 during a grid cycle when the DIBBDAI is powered by the solar cell array. As shown in Fig. 4, there is only one power electronic switch operating in PWM switching at any given moment, and VAN and VBN are in close proximity to the grid's positive and negative cycle voltages, respectively.

The analogous circuit of the DIBBDAI for the leakage current analysis is displayed in Fig. 5. The ground resistor for the grid and the stray capacitor for the solar cell array are represented by  $C_{pv}$  and  $R_g$ , respectively, in Figure 5.

The components Cf1, Cf2, and Rf have no effect on the leakage current because they are linked across terminals A and B.

The grid voltage is used to synchronously switch S5 and S6. When the grid voltage is in the positive half cycle, S6 turns on and S5 turns off.



$$V_{AN} = v_s + v_{Lf} \quad (9)$$

$$V_{BN} = 0$$

where  $v_{Lf}$  denotes  $L_f$ 's voltage. Given that  $V_{BN}$  is equal to 0, there is no leakage current and no voltage across the CPV and  $R_g$  loop.

when  $S_5$  turns on,  $S_6$  turns off, and the grid voltage is in the negative half cycle.

$$V_{AN} = 0$$

$$V_{BN} = -(v_s + v_{Lf}) \quad (10)$$

The voltage between  $R_g$ 's and CPV's loop is  $\pi(v_s C v_{Lf})$ . Because  $v_s$  is a 60Hz sinusoidal voltage and the stray capacitor has a very large 60Hz impedance, there is relatively little leakage current caused by  $v_s$ .

The switching-frequency ripple in the output current is what causes the switching-frequency component of  $v_{Lf}$ . However,  $C_{f1}$ ,  $C_{f2}$ , and  $R_f$  effectively suppress the switching-frequency component of  $v_{Lf}$ .

	power source	voltage range	$S_1$	$S_2$	$S_3$	$S_4$	$S_5$	$S_6$
PHC	solar cell array	$v_s < V_{sol}$	PWM	off	on	off	off	on
		$v_s > V_{sol}$	on	off	on	PWM	off	on
	battery	$v_s < V_b$	off	PWM	on	off	off	on
		$v_s > V_b$	off	on	on	PWM	off	on
NHC	solar cell array	$ v_s  < V_{sol}$	PWM	off	off	on	on	off
		$ v_s  > V_{sol}$	on	off	PWM	on	on	off
	battery	$ v_s  < V_{sol}$	off	PWM	off	on	on	off
		$ v_s  > V_{sol}$	off	on	PWM	on	on	off

Table 1: Operation of  $S_1$  to  $S_6$

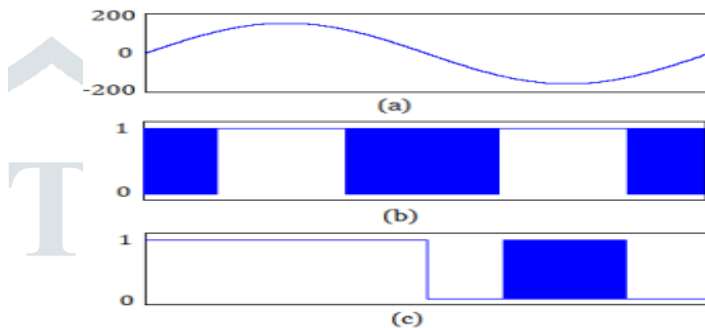


Fig 4: Control signals  $S_1$ - $S_6$  and operation voltage in a power grid cycle, (a) utility voltage, (b)  $S_1$ , (c)  $S_3$

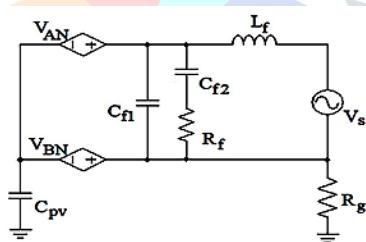


Fig 5. Equivalent circuit of the DIBBDAI for the leakage current analysis.

#### IV. BPC OPERATION

When the battery set is being charged by the solar cell array, the BPC is placed between the battery set and the solar cell array. When the solar cell array's power variation falls within the designated range, the BPC is deactivated. If the solar array's power variation goes beyond the predetermined range, the BPC tracks the solar array's maximum power (MPPT). The relationship between the voltage of the battery set and the voltage of the solar cell array is such that the BPC is intended to function in continuous-conduction mode.

$$\frac{V_{sol}}{V_{bat}} = \frac{1}{1 - D_{sb}} \quad (11)$$

here  $D_{sb}$  represents  $S_b$ 's duty cycle.

## V. SMOOTHING OPERATION

In case the solar cell array's output power remains constant, the DIBBD AI transforms the output power into AC power. At the moment, the perturbation and observation (P&O) approach is used by the DIBBD AI to perform MPPT. The solar cell array's output voltage is disrupted, and the direction in which the output voltage is disrupted until the maximum power point is tracked is then determined by observing the change in the solar cell array's power.

The output power smoothing mechanism comes into play when the solar cell array's power variance considerably beyond the designated range. The battery set's state of charge (SOC) is regulated between 30% and 90% to prevent overcharging or over discharging, which shortens the battery set's lifespan. When the battery set is in the stand-by mode, the intended SOC is 60% due to the upward and downward power swings of SPGS.

Since the smoothing operation for the output power from the SPGS is the focus of this study, estimating the SOC of the battery set only requires utilizing the terminal voltage.

The difference between  $P_{out}$  and PPV at this point is good. The BPC automatically injects this power differential into the battery set, increasing its state of charge (SOC).

The output current amplitude is fixed by the DIBBD AI when  $P_{out}$  exceeds PPV by  $P_2$ . The BPC continues to use MPPT. When the difference between PPV and  $P_{out}$  turns negative, the battery set automatically supplies the difference in power to lower the battery set's state of charge. When the battery's state of charge (SOC) drops to 60%, the BPC ceases to function if the PPV stays constant.

In MPPT, the DIBBD AI operates. The power variation in  $P_{out}$  at this time is  $P_2$ . To prevent going over the regulated power variation,  $P_2$  needs to be less than or equal to  $P_1$ . In order to keep the battery, set from overcharging, the BPC shuts off and the power smoothing feature is turned off when the output power  $P_{out}$  is still less than PPV and the SOC has reached 90%.

When the solar cell array's 1PPV output power falls below the designated value  $-P_1$ , the output power from the SPGS is additionally smoothed. Currently, the BPC uses MPPT whereas the DIBBD AI is powered by the battery set.

The battery installed through the BPC is charged by the solar cell array.  $P_{out}$  falls linearly along the designated gradient in response to the DIBBD AI's reduction of the output's amplitude along the gradient. At this point, the battery set automatically supplies the difference between  $P_{out}$  and PPV, lowering the battery set's state of charge.

The output current amplitude is maintained at a constant value by the DIBBD AI when  $P_{out}$  is  $P_1$  smaller than PPV. The BPC executes MPPT constantly. Because the PPV exceeds the  $P_{out}$ , the battery set's SOC is raised and it is charged instead.

When the battery's state of charge (SOC) reaches 60%, the BPC ceases to function if the PPV stays constant. The solar cell array provides power to the DIBBD AI, which carries out MPPT. The power variation in  $P_{out}$  at this time is  $P_2$ .

In order to keep the battery, set from over-discharging, the BPC ceases smoothing the power output of the SPGS if  $P_{out}$  is greater than PPV and the SOC is equal to 30%. The DIBBD AI is a MPPT is carried out and the solar cell array provides power.

Fig. 6 displays the operation flowchart for the suggested SPGS with power smoothing feature. Pout grows or drops linearly along the designated gradient to smooth the output power from the SPGS regardless of sharp changes in PPV.

The battery set's charging and discharging times are significantly shorter than those of other smoothing techniques since it is only activated when the solar cell array's absolute value of power variation (1PPV) surpasses the predetermined value P1 [3]–[9].

Furthermore, when Pout catches up with PPV, the battery set will instantly discharge or charge to maintain its SOC close to 60%, regardless of whether it is charged or drained to smooth the output power from the solar cell array. Consequently, the battery set's capacity may be lowered.

## VI. MONITOR BLOCK

The DIBBDAI control block is depicted in Fig. 7. The MPPT block receives the output voltage and output current from the solar cell array in order to compute PPV and provide an expected voltage for the solar cell array. A proportional integral (PI) controller receives both the anticipated and observed voltages for the solar cell array in order to produce an MPPT control signal. The MPPT block additionally computes the solar cell array's power variation (1PPV). 1PPV is routed to comparison block I, where it is compared to (P1, -P1) in order to produce a Ssl (amplitude gradient control signal).  $PPV > P1$  causes Ssl to be  $+V_{sl}$ . If  $1PPV < -P1$ , then  $S_{sl} = -V_{sl}$ .

Ssl equals 0 when 1PPV falls between P1 and -P1. An integrator receives the SSL. A signal that increases linearly is produced when Ssl equals  $+V_{sl}$ . If Ssl is less than  $V_{sl}$ , a signal with a linear decrease is produced.

Consequently, when the smoothing function is activated,  $V_{sl}$  regulates the gradient of the amplitude control signal for the output current to ascertain the gradient in Pout.

$S_{sl}$  is 0 and the MPPT control signal determines the amplitude control signal when PPV is stable. If PPV fluctuates significantly,  $V_{sl}$  regulates the gradient of the amplitude control signal for the output current while the MPPT control signal stays the same.

To create the output current reference signal, a multiplier and an absolute value block receive the amplitude control signal and a unity sinusoidal signal.

To guarantee that the unity sinusoidal signal is a sine-wave and in phase with the grid voltage, a phase locked loop (PLL) and a sinusoidal table are used to generate the signal. The current control is bifurcated since the DIBBDAI has two operating modes: boost and buck. The output current that has been identified is routed to an absolute value block.

When operating in buck mode, the current controller I receives the detected absolute output current after it has been compared to the output current reference signal. In order to create a buck modulation signal, the output from current controller I is added to the feed forward control signal  $v_{f,bk}$ . This signal is then delivered to PWM block I, which creates a buck PWM signal  $PWM_{bk}$ .

PWM block I uses the carrier based PWM technology. In PWM block I, the buck modulation signal is compared to a triangle carrier to produce the buck PWM signal  $PWM_{bk}$ . The control signal  $v_{f,bk}$  that is feed forward is:

$$v_{f,bk} = \frac{|V_s|}{K_{pwmI}} \quad (12)$$



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

The detected absolute output current is routed to an additional low-pass filter because the output current from the DIBBDAI in the boost mode contains substantial high-frequency switching harmonics. After being compared to the output current reference signal, the low-pass filter's output is forwarded to the current controller II.

After creating a boost modulation signal by adding the output from the current controller II to the feed forward control signal  $v_{f,bt}$ , the signal is transferred to the PWM block II.

In PWM block II, the carrier-based PWM technique is also employed. In the PWM block II, the boost modulation signal is compared to a triangle carrier to produce a boost PWM signal, or  $PWM_{bt}$ . The control signal  $v_{f,bt}$  that is feed forward is:

$$V_{f,bt} = \frac{|V_s| - V_{dc}}{|V_s|} V_{tri} \quad (13)$$

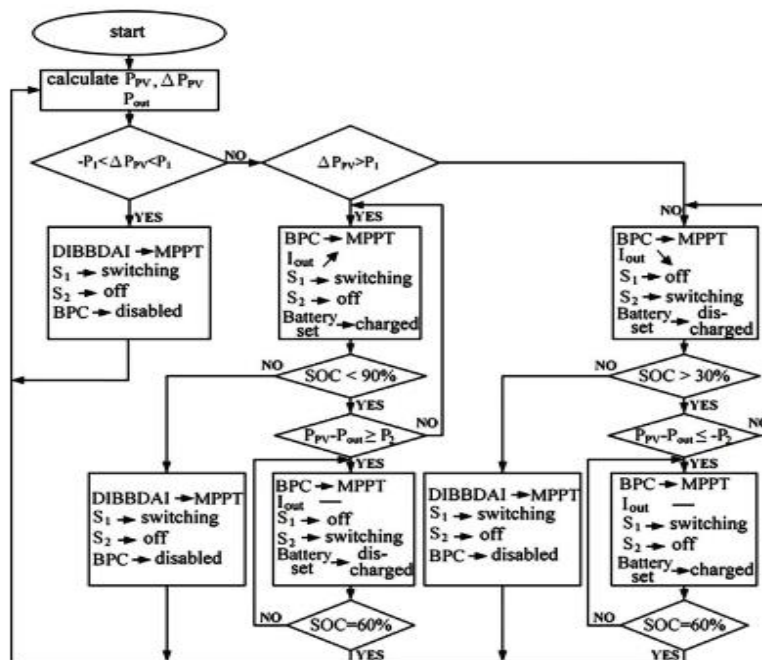


Fig 6: Operation Flowchart for the Proposed SPGS with Power Smoothing Function.

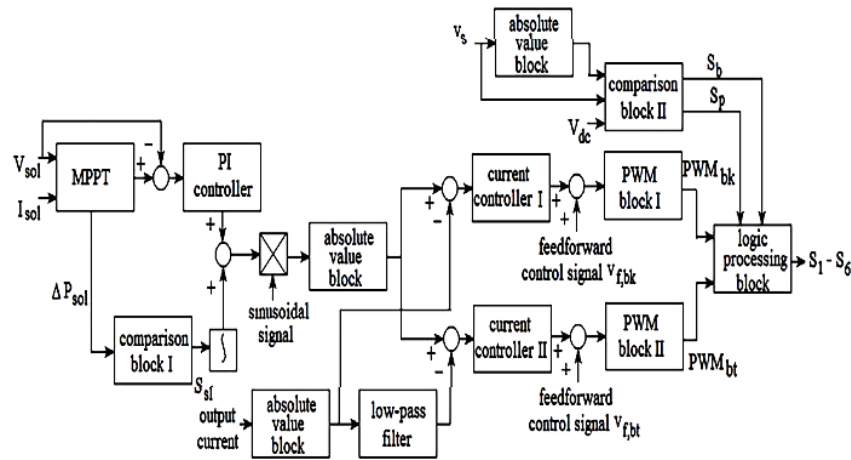


Fig7: Control block for the DIBBDAl.

The majority of the modulation signal will be produced by the feed forward control signals  $V_{f,bk}$ , and  $V_{f,bt}$ . The modulation signal is then fine-tuned by current controllers I and II to guarantee that the detected absolute output current may follow the output current reference signal. to have a perfect sine wave.

BPC			
$L_b$	1mH	switching frequency	20kHz
DIBBDAl			
$L$	1mH	switching frequency	20kHz
$C_{\pi}, C_{\alpha}$	9.4μF	$L_r$	0.5mH
$C_b, C_s$	1000μF		

Table 2: The Prototype's Circuit Specifications.

In order to produce a control signal,  $S_p$ , the grid voltage is passed to comparison block II where it is compared to 0. During the grid voltage's positive and negative half cycles, respectively,  $S_p$  is 1 and 0. To create a control signal,  $S_b$ , the grid voltage's absolute value is also compared to  $V_{dc}$ .  $S_b$  equals 1 and the DIBBDAl runs in boost mode when the grid voltage is greater than  $V_{dc}$  in absolute terms.

Conversely,  $S_b$  is 0, and the buck mode is used by the DIBBDAl. Ultimately, the logic processing block receives  $S_p$ ,  $S_b$ ,  $PWM_{bk}$ , and  $PWM_{bt}$  in order to generate the control signals for  $S_1$ – $S_6$ . For  $S_1$ – $S_6$ , the control signals are:

$$S_1 = (\bar{S}_h PWM_{bk} + S_b). S_0 \quad (14)$$

where thus, it depends on the DIBBDAl's input source.

Similarly, 1 indicates electricity from the solar cell array, and 0 indicates power from the battery set.

The MPPT control signal from the solar cell array and the current from the inductor  $L_b$  are used by current control to operate the BPC. The output of current control is transmitted to the PWM block to generate the control signal for SD.

## VIII. CONCLUSION

The suggested SPGS integrates the battery set and solar cell array using a DIBBDAl to produce power that is more evenly distributed. The following novel features are present in the suggested SPGS.

1. The solar cell array and battery set, which can be easily replaced, are integrated into the SPGS as two input power sources. By acting as an energy buffer, the battery set evens out power variations from the SPGS. Because the suggested SPGS only uses two power stages, the power circuit is made simpler.
2. To convert DC power to AC power, only one power stage is needed, regardless of whether the input power source is a battery set or a solar cell array. Furthermore, only one power stage is used to charge the battery set using the solar cell array.

According to the experimental findings, the suggested SPGS smoothes the power variation brought on by the solar cell array's power fluctuation and outputs a sinusoidal current that is in phase with the utility voltage.

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