An improved energy management control strategy for a standalone solar photovoltaic/battery system

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ABSTRACT

This paper proposes efficient energy management in hybrid microgrid-comprising of photovoltaic (PV) and battery storage systems. The proposed technique. The hybrid system's power balance is based on smart control to meet the demands of isolated off-grid direct current (DC) loads as well as to stabilize the voltage to DC Bus. The Perturb and Observe technique (P&O) is used to achieve maximum power point tracking by adjusting the duty cycle of the Bidirectional converter, which links the Li-ion battery to the DC Bus of stand-alone power systems (SPS). The proposed controller regulates the power flow of the battery for efficiency voltage control in a microgrid. The energy management system proposed has been approved using MATLAB/Simulink under variable solar irradiation conditions. The simulation results show that the technique used increases the battery cycle-life and better energy management and voltage control performance compared with previous examples.

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1. INTRODUCTION

Stand-alone power systems (SPS) or islanded microgrids are remote power systems that are not linked to the main grid and are used to provide high-quality energy to individual clients, households, or small businesses. Today, the power grid is supported by a smart grid, which is an intelligent electrical network, to increase electrical power stability, efficiency, and sustainability [1]. An intelligent grid concept combines information and communication technologies with power system engineering to achieve real-time supply and demand balance and communication amongst all grid components [2]. An intelligent a microgrid is a network on a small scale designed to provide intermittent demands. Microgrids are powered by distributed generation (DG). Consumption and production must be balanced in order to control energy flow reliably. Microgrids (MGs) are medium or low voltage hybrid power generation systems that combine small-scale energy producers and renewable energy sources as primary energy sources to provide high-quality electricity to a small number of customers [3]. A common connection point can connect the microgrid to the major grid (PCC) or it can run entirely autonomously or in isolated mode. Due to the lack of grid connectivity in SPS, battery energy storage ensures that the electricity supply is reliable and stable [4]. SPSs often combine energy sources such as solar panels, wind turbines, and diesel generators to provide load power and energy storage for system balance. As a result, an appropriate control approach is required to deliver power stability and transition in SPS [5].

As a result, island residents often rely on off-grid solar or diesel generator systems to meet load needs [6], [7], which are more valued and efficient than the island's primary grid system. Additionally, an effective control approach improves the system's power quality and keeps voltage variation below acceptable limits. Conventional methodologies have been utilized to ensure both kinds of MG systems [8]. Consequently, energy storage systems (ESS) are utilized to ensure the system's stability and availability. As a result, Li-ion batteries are the most common, ESS are utilized to ensure the system's stability and availability. In the SPS system, the most common type of battery is lithium-ion. As a result, to ensure the safe operation of these batteries, a safety system and a control system are necessary. Thus, a bidirectional direct current (DC/DC) converter is used to link Li-ion batteries to the DC bus for charging and discharging in order to adjust the DC bus's voltage [9]. Konara *et al*. [10] proposes. Han *et al*. [11] Suggested a direct current (DC) microgrid control approach dependent on the level of charge of the battery, which divides the battery's operating state into various portions, preventing deep charge and battery drain, and extending the ESS's life. Rajasekaran and Rani [12] presented a microgrid energy management system that comprised a photovoltaic (PV) array, a DC-DC bidirectional converter, and an ESS to regulate battery charge/discharge operations based on load needs. [5] proposes using a proportional integral (PI) and an artificial neural network (ANN), energy management and voltage control in an isolated system that relies on DC-DC bidirectional converter control to satisfy all load power needs and stabilize the DC bus voltage value in [13], a novel strategy for active Bridges with bidirectional traffic is presented.

The PI controller is used to control converters for energy management in a microgrid based on solar PV panel ESS. Under the day, batteries are charged, and during cloudy weather, they are drained. In the standalone system, this work provides a new energy management strategy based on PI control and reference current. The suggested method for controlling to be durable in the face of weather changes, the DC-DC bidirectional converter must cover full load power. as well as for the most efficient use of energy.

The following is a breakdown of the paper's structure: Section 2 discusses the planned power system configuration. Section 3 then presents the recommended strategy to energy management. The simulation results and remarks are presented in section 4. Finally, in section 5, there is a conclusion.

2. PROPOSED CONFIGURATION

The recommended design of a freestanding microgrid is depicted on Figure 1. To meet the load requirement, the proposed microgrid consists of a solar panel and battery energy storage coupled to DC Bus through bidirectional DC-DC converter. Consequently, ESS are utilized to ensure the system's stability and availability. Because of their advantages over other battery models, Li-ion batteries are one of most typically utilized in the Stand-alone power (SPS) system. Therefore, to maintain a safe operation. The PV generator employed in this research is made up of linked modules that combine to generate a high-constant-energy-production unit compatible with ordinary electrical equipment [14].

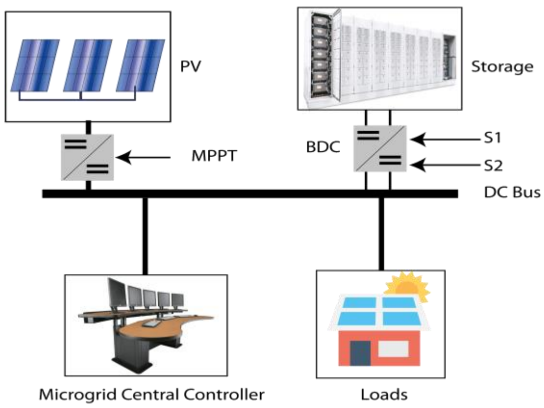

Figure 1. Proposed standalone system with storage battery

2.1. Modeling of the photovoltaic generator

A similar electric circuit depicted in Figure 2 can be used to simulate a solar cell. The PV The following equations [14] reflect the PV array mathematical model:

$$I = I_{ph} - I_d - I_r \tag{1}$$

with,

$$I = \frac{V_{pv} + R_S\, I}{R_{sh}} \quad (2)$$

$$I_d = I_0\left(exp^{\frac{V_{pv} + R_S\, I}{V_T}} - 1\right) \quad (3)$$

As shown in (4) relates the current delivered by a PV module comprised of the Ns series of cells to the PV voltage.

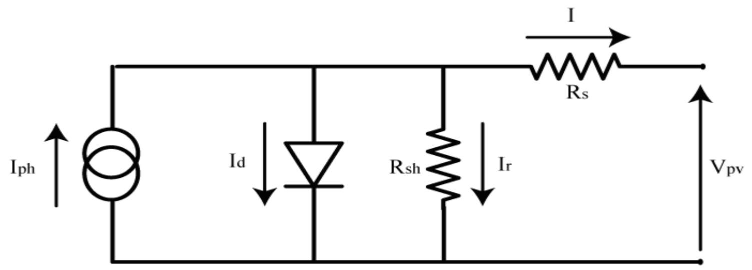

Figure 2. Model of a PV cell

$$I_d = I_{ph} - I_0\left(exp^{\frac{V_{pv} + R_S\, I}{V_T}} - 1\right) - \frac{V_{pv} + R_S\, I}{R_{sh}} \quad (4)$$

$$V_T = \frac{N_S\, n\, k\, T}{q}$$

VT: the thermal voltage; Ns series cells; n: a diode ideality constant; k: the Boltzmann constant; q: the electron charge; The temperature of the p-n junction is denoted by T. Iph: The photocurrent; I0: The diode's reverse saturation currents.

The main characteristics of the PV module 1STH-215-P used in this study are presented in Table 1 [15]. This module consists of two series-connected monocrystalline silicon solar cells and two monocrystalline Silicon solar cells arranged in parallel can provide 852 W of power. The solar cell's performance is generally assessed using the standard test condition (STC), which uses an average solar spectrum at 1.5 AM, normalizes solar radiation to 1000 W/m2, and defines the cell temperature at 25 °C.

Table 1. The electrical properties of the SW 255 PV module at STC

Parameter	Name	Value
P_{max}	Maximum power voltage	213.15 W
V_{mp}	Maximum power current	29V
I_{mp}	Current at maximum power	7.35A
V_{oc}	Voltage across an open circuit	36.3V
I_{sc}	Current in a short circuit	7.84A
N_s	The number of cells in each module	60
T_r	Temperature of reference	298.15K
E	Solar irradiation as a reference	1000W/m^2
I_0	Saturation current at Tr	2.9259e-10
a	The ideality factor of the diode	0.98117
R_{sh}	Shunt resistance	313.3991Ω
R_s	Series resistance	0.39383Ω
K_i	Isc temperature coefficient	0.102%/K
FF	Forme factor	0.749

Irradiance and temperature have a direct impact on photovoltaic cell performance. Figure 3 depicts the effect of radiation at 25 °C on a solar cell's current-voltage characteristics. Each radiation value corresponds to the maximum amount of power that the solar cell can produce.

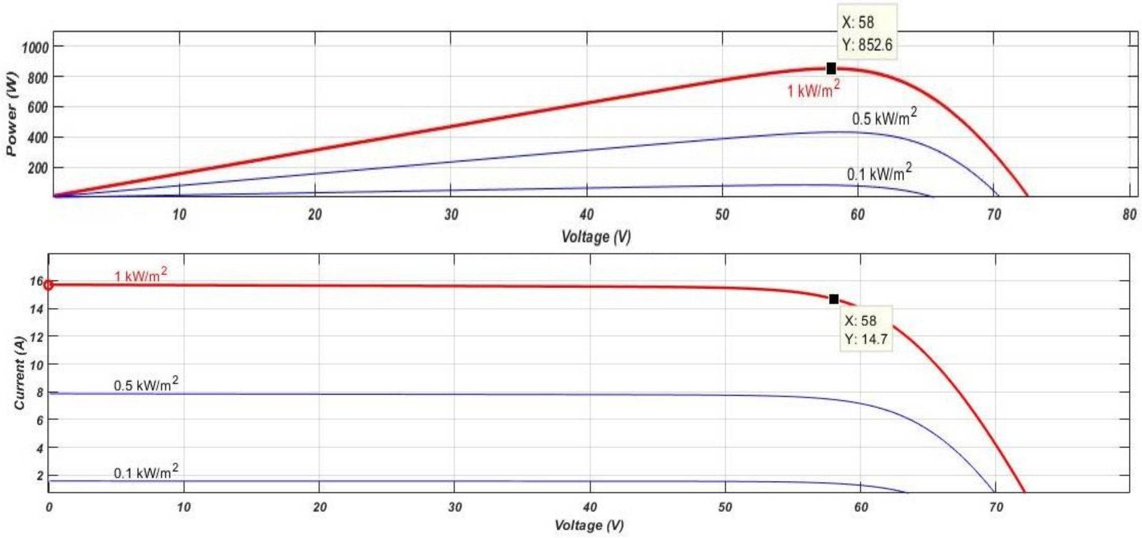

Figure 3. I-V and P-V characteristics of the PV module

2.2. MPPT algorithms for the PV system

Optimum processing points over varying solar radiation and temperature conditions. Inserting an electronic device, it is required to have a connection between the PV generator and the electrical load. for impedance adaptation [16]. This is a static maximum power point tracking converter (MPPT) command. to create a more effective power interface. The Boost converter (voltage boosting chopper) is utilized in this study because of its simple structure and high voltage transformation ratio in comparison to other topologies. To extract (transfer) the maximum power generated, a stationary converter (DC/DC power converter) (Figure 4) is used as an adapter between the PV generator and the load. An MPPT is a PV generator's nonlinear I-V characteristics allow for a single regulator to be accustomed to regulate the boost converter so that maximum energy efficiency is achieved at all times.

There are numerous approaches to determining the maximum power point of PV modules [17]. There are two types of algorithms: direct algorithms and indirect algorithms. Indirect approaches rely on databases including photovoltaic (PV) panel parameters that are dependent on metrological variables (temperature, irradiance) and empirical mathematical calculations to find the highest power point. The generator open-circuit voltage approach [18] and the short-circuit technique [19] are two examples. Direct techniques are those that employ voltage and current measuring panels and have an algorithm based on the fluctuation of these values. These algorithms have the benefit of not requiring PV properties. Perturbation and Observation (P&O) [20], incremental conductance [21], and algorithm for climbing hills [22] are among these approaches. To in this suggested system the P&O In the study, a technique-based MPPT controller is used to harvest power under variable irradiance. This software applies an iterative technique based on an algorithmic procedure to obtain the maximum power offered by the Photovoltaic generator (PVG).

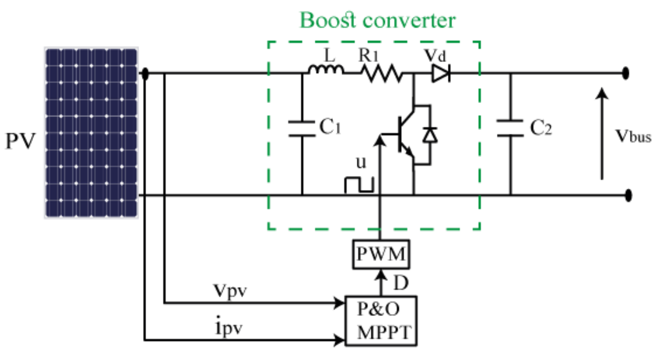

Figure 4. Circuit diagram of a boost converter

The operational voltage V(k) is disturbed for this approach (Figure 5), and the fluctuation in PV panel electrical power P(k) is detected. The voltage disturbance pushes the operating point closer to the MPPT if P(k) is positive. If P is negative, the operating point shifts away from the MPPT, requiring the voltage disturbance V to be reversed to bring the operating point back to the MPPT. Figure 6 depicts the voltage and power profile of a PV array when the solar irradiation is constant. The extracting power changes as a result of variations in voltage. When dP/dV=0, the PV array outputs the most power.

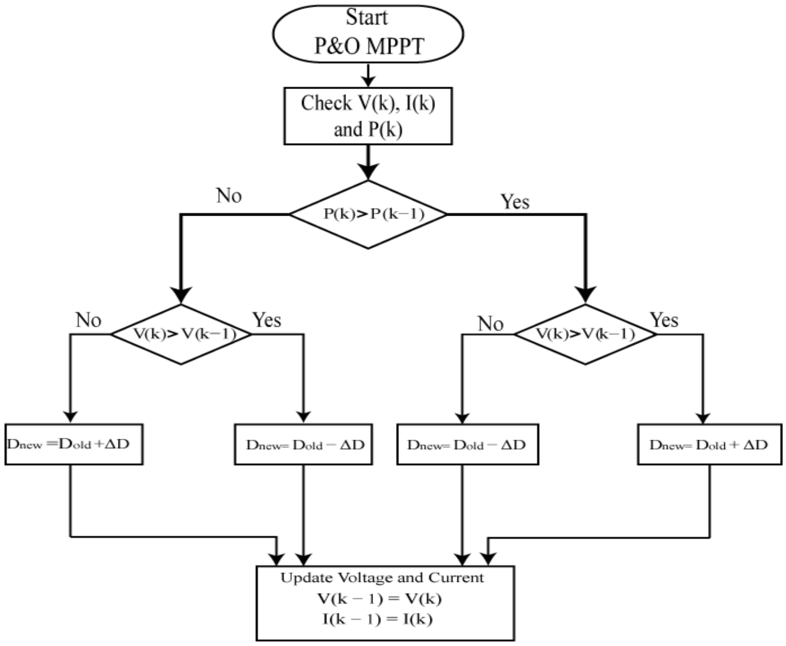

Figure 5. Flowchart of the P&O method

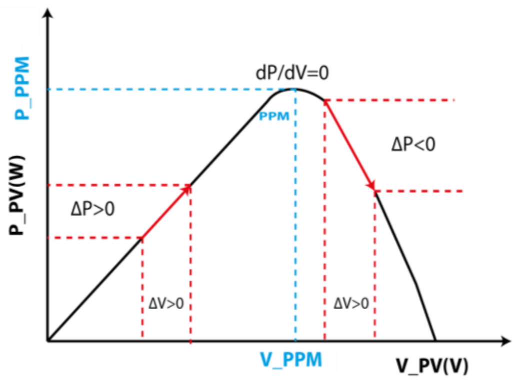

Figure 6. The P&O method's operating power (P) and voltage (V) curve of the P&O method

2.3. Battery storage system

The increased growth of RES necessitates the use of storage units to lessen the intermittent nature of renewable energy sources (PV, wind). Storage units are essential components of insulated microgrids. Energy storage is the process of storing an amount of energy for later use [23]. In comparison to all stored energy, batteries are required in a narrow range of charge states (SOC). As a result, their safety may be ensured by avoiding reaching extreme charging states, which are largely responsible for early battery aging. In a genuine system, the safety of the batteries is generally provided by controlling their voltage. If their voltage exceeds the maximum or minimum voltage terminals, they are disconnected. This strategy necessitates a study of their tension at all times. As a result, Check the appropriate operation of the batteries by applying state-of-charge thresholds that must not be exceeded. The basic dynamics of the batteries are represented as [24]:

$$\mathrm{SOC_{batt}} = 100\ \left[1 - \left(\frac{1}{Q_{bat}} . \int_0^t i_{bat}(t)\ dt\right)\right] \quad (7)$$

where $\mathrm{SOC_{batt}}$ is the battery state of charge (%), Q_{bat} is the maximum battery capacity (Ah), and i_{bat} is the battery current.

2.4. Bidirectonel DC-DC converter

The bidirectional DC-DC converter is seen in Figure 7. The DC-DC converter is an insulated gate bipolar transistor (IGBT) half-bridge architecture powered by a battery bank and operating in continuous conduction mode (CCM). The converter functions in two ways: S2 and D1 are engaged in boost mode, and current flows to the DC connection to discharge the battery. S1 and D2 are active in buck mode, and the power flow is reversed to charge the battery [25]. For battery charging and discharging, a buck-boost DC-DC converter is used in this study. After multiple testing, the settings of the bidirectional DC-DC converter parameters (L and C) are chosen to ensure the system's great performance.

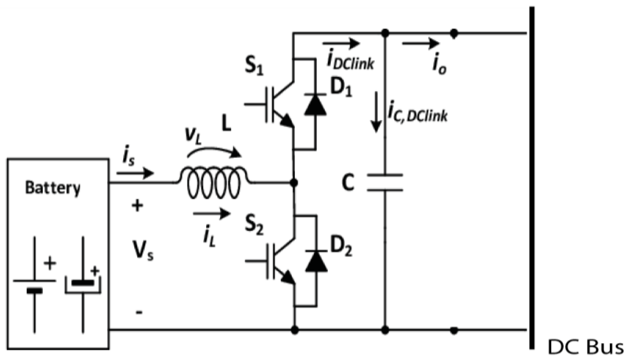

Figure 7. Schematic of the bidirectional DC-DC converter

3. THE PROPOSED TECHNIQUE FOR ENERGY MANAGEMENT

The major goal is to use PI to present a novel strategy to the efficient management of energy transferred between all microgrid components. The investigated microgrid is modeled in MATLAB/Simulink by taking into account the computations of all mathematical parameters. The electricity in the microgrid must be balanced under the various PV source circumstances. As a result, regulating the level of charge of the battery is critical for safe battery operation. As a consequence, in our study, we used the SOC level in energy management. Figure 8 depicts the suggested control strategy's flowchart. The battery-based storage system is used for energy supply as well as storage.

In islanded mode, when there is an excess of energy, the algorithm instructs the battery to be charged at a rate that does not exceed the battery's maximum current, and the SOC of the storage system is checked at all times. The extra energy is then injected into the network via PCC regulated by PI as soon as it occurs. When PV production is inadequate, the storage system will provide the energy to fulfill load demand, and the EMS will continue to operate to monitor the SOC until it is discharged.

Because the microgrid is linked to the battery bus via a bidirectional DC/DC converter, the PI controller's primary job is to operate the Bidirectional converter between the battery and DC BUS. The PI-based reference current is used to establish the right duty cycle for the PWM block to regulate the buck and boost converter, as shown in Figure 9.

The PV energy flow supplies to the DC charge and the battery to manage the current and voltage of the converter and guarantee correct balance, as a result of which the PV system's electricity is beneficial and the battery will be operated well into the charge and discharge. The DC-DC bidirectional converter and control circuit based on two integral proportional PI compensators are shown in Figures 10 and 11. The reference current (IBref) is the voltage control PI's output to follow the reference voltage (Vref=220V). This current (IBref) is utilized in the current control PI to obtain the right duty cycle value for controlling battery charging and discharging. After multiple iterations, the values of the PI parameters (Kp and ki) are chosen. The system's great performance is tested.

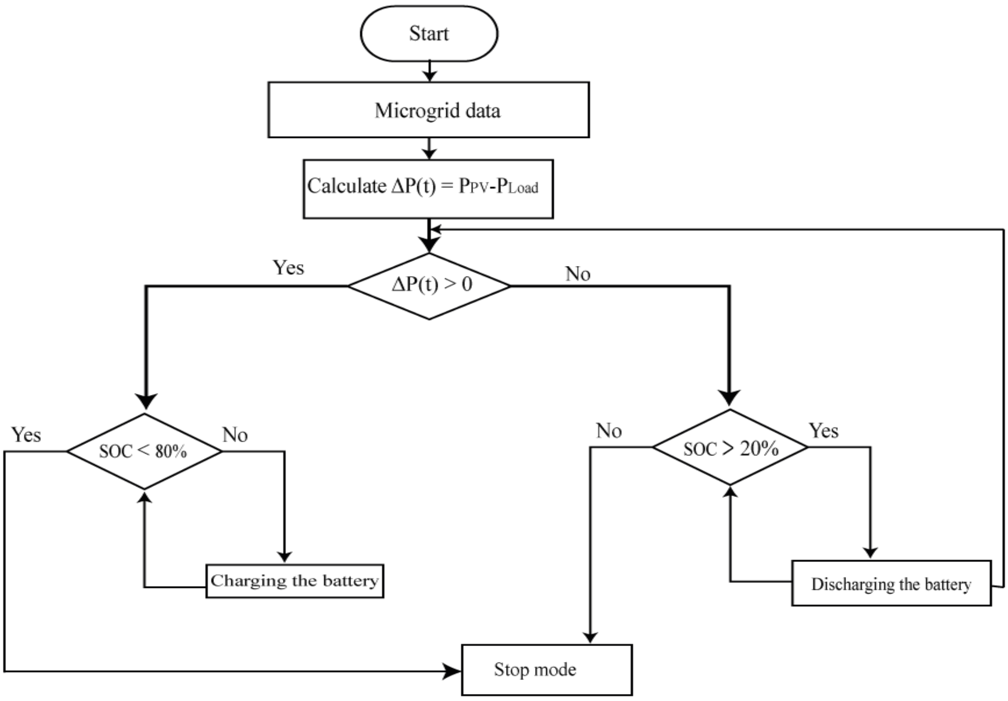

Figure 8. Strategy for energy management

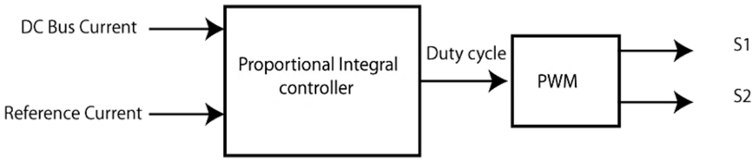

Figure 9. Schema of PI controller implementation

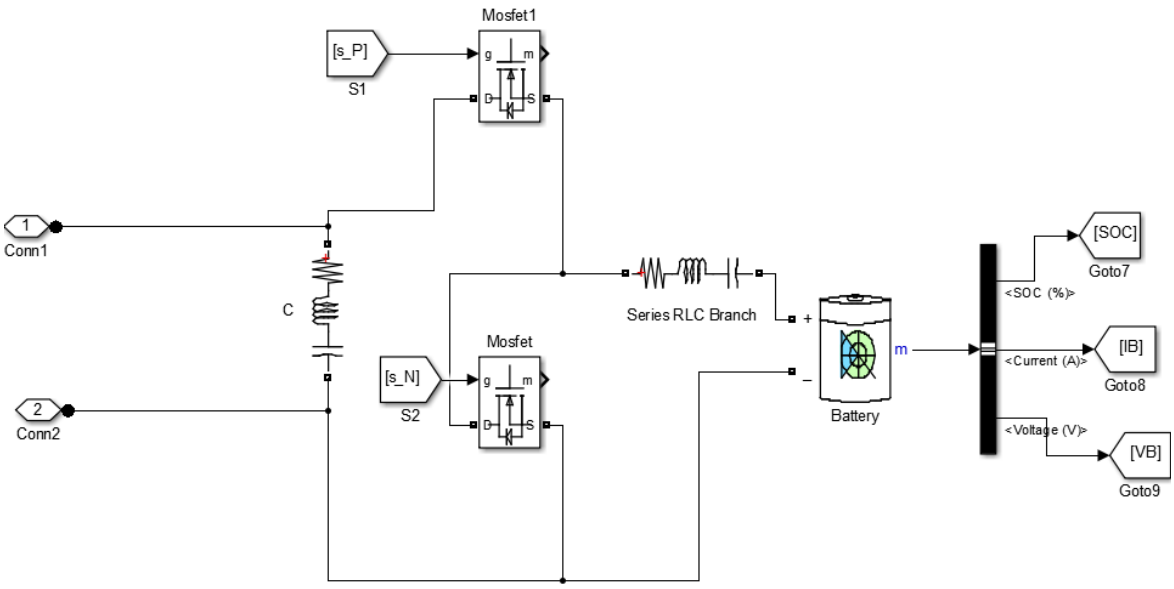

Figure 10. DC-DC bidirectional converter model

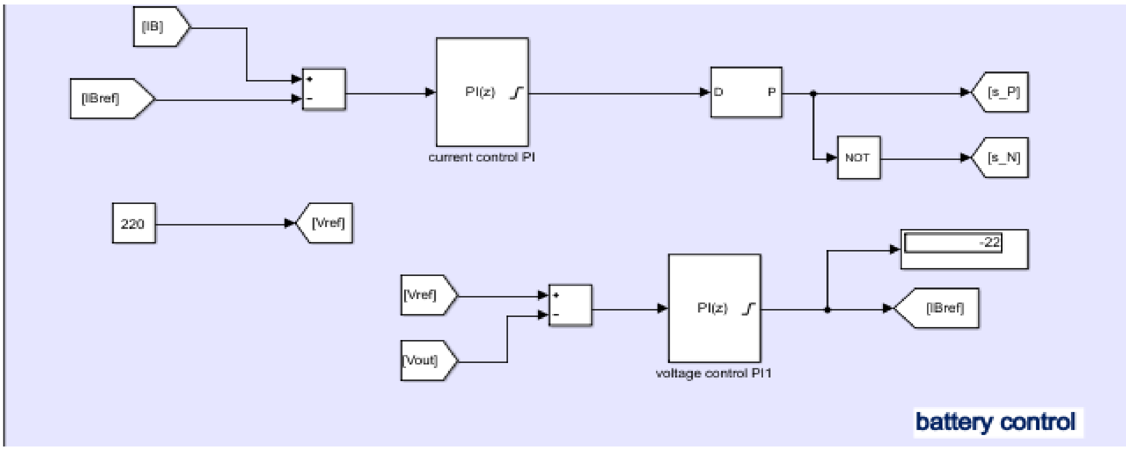

Figure 11. Proposed controller for DC-DC bidirectional converter

4. RESULTS AND DISCUSSION

The standalone PV system generates electricity from the sun's varying irradiation to supply DC a resistive load with 10 kW. To boost the working voltage, 36 solar panels are linked in series, delivering 14 kW of power at maximum irradiance. A bidirectional DC/DC converter connects Lithium-Ion battery packs to the system to strengthen the reliability of the supplied electricity.

The simulation runs for 10 seconds with 125e-6 sampling time, presents a scenario containing several irradiations as shown Figure 12, and the results are presented over a time of 10 s. We can notice that the PV generator operates practically in MPPT mode throughout the simulation. Figure 13 shows several changes in irradiation. We set up the system with varying levels of solar radiation and a temperature of 25 °C, because the latter has a negligible impact on PV power. In contrast, PV is directly affected by sun radiation power fluctuation. This is why the temperature is set at 25 °C.

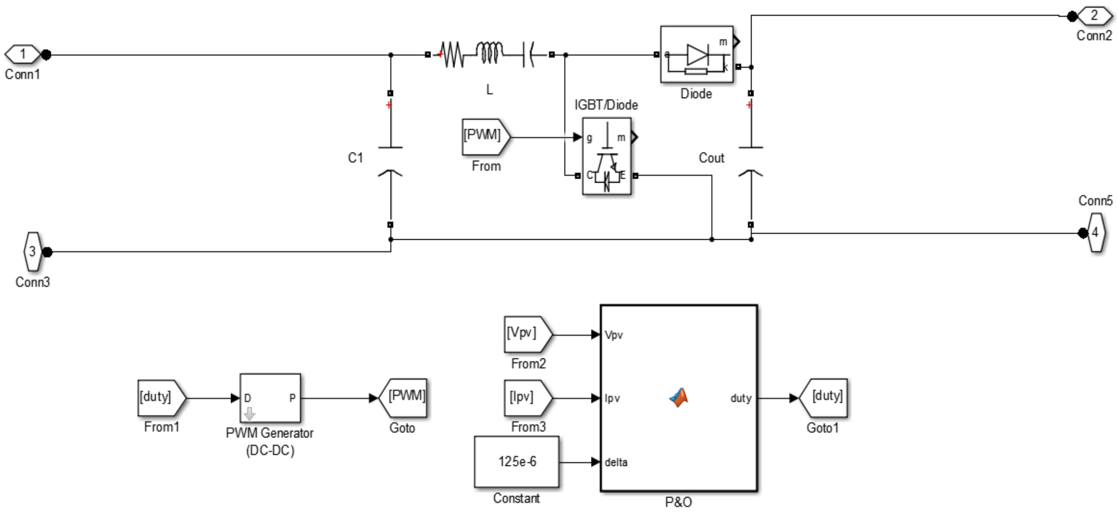

Figure 12. PV boost converter

Figure 14 shows the PV voltage variation, and the Figure 15 shows the PV current variation, we know that the power is the multiplication of the voltage of PV and the current of PV, therefore, Figure 16 indicates the PV power; at the beginning of the simulation, the power is more significant than 10 kw, which means there is a surplus from the power sent to the DC bus. Therefore, as previously stated, the balance of the power at the DC bus will cover with the battery. As we can see from Figure 17, the battery state of charge increases to store the surplus power at t=0.5 s the power of the solar panel system decreases to 7 kw, which means there is a need for more energy at the bus DC to cover the load demand. Figure 18 displays the change in battery voltage, which remains practically constant at 214 V during the draining mode of operation and rises to 216 V during the charging mode.

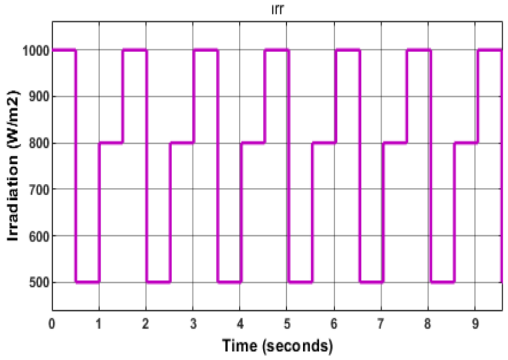

Figure 13. Solar irradiation (w/m²)

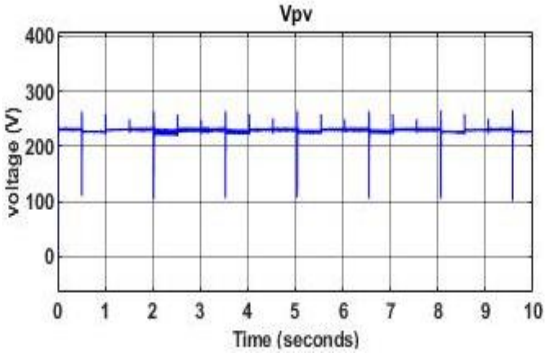

Figure 14. Voltage of PV

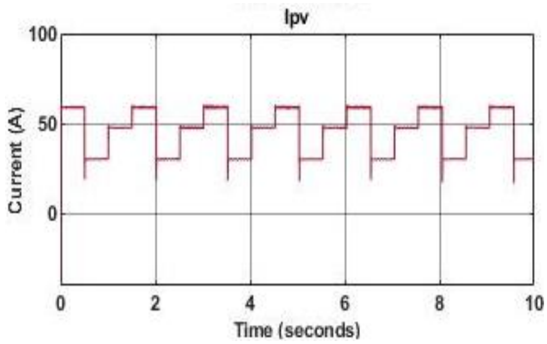

Figure 15. Current of PV

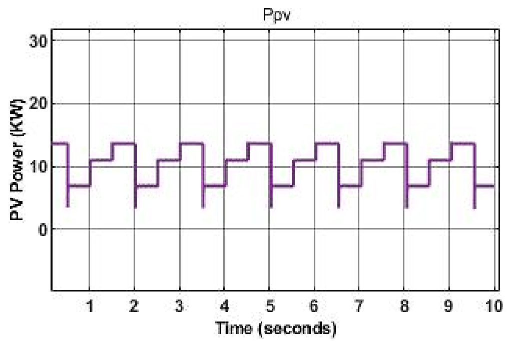

Figure 16. Power of PV

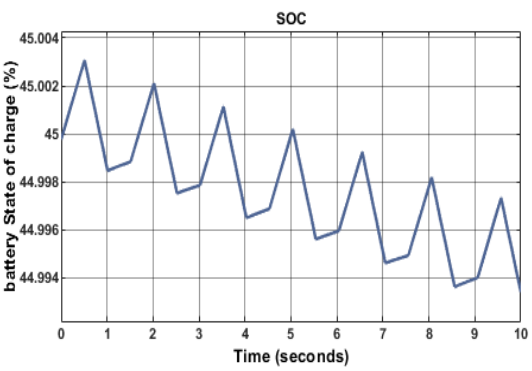

Figure 17. Battery state of charge

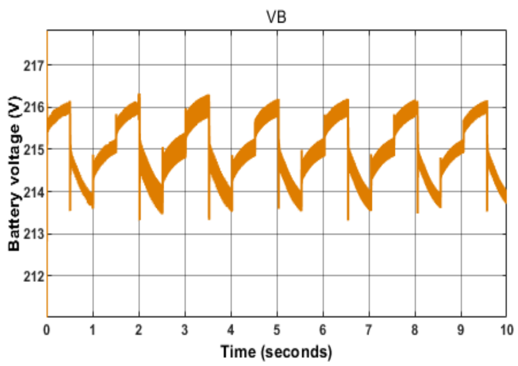

Figure 18. Battery voltage

Figure 19 shows the battery current, which depends on the battery's charging and draining. Figure 14 depicts the photovoltaic power drops suddenly due to a decrease in solar irradiation during the period from t=0.5s to t=1s as shown in Figure 13. Therefore, the battery will be covered with energy and meet the charging needs, bringing a slight VB lowering. Currently, the battery current IB is positive. When the battery is in state charging, the current IB will be negative and such for all the periods of change of the irradiation. The current IB is negative when the battery is charged. When the battery is discharged, on the other hand, the current IB is positive.

Figure 20 shows employing the PI control technique, the voltage variance in the DC bus As we can see from the simulation of the method's efficiency for DC bus voltage stabilization, it's clear that the voltage is stable at 220 V. This demonstrates that the DC bus voltage stabilizes rapidly and voltage overshoot is low, indicating that the DC bus's safety is not jeopardized.

This paper studied the energy management between sources to satisfy the load using a stand-alone PV/battery system. The energy management control proposed forces the battery to be considered as a pressure source of energy for system balance and voltage control. Moreover, the controller system proposed is used for the voltage control in DC Bus. It protects the battery in all conditions, including normal, overcharging, and over-discharging depending on the bidirectional bidirectional DC-DC converter. The output power, according to the simulation findings is varies each time the radiation changes. Nevertheless, the battery tries to compensate for the power during the decrease in radiation. This article's scientific contribution is the application of an optimal energy management approach using PI, which demonstrates the robustness and reliability of this approach despite various changes in irradiation and the protection of the battery against deep discharge, which has a positive effect on the battery life.

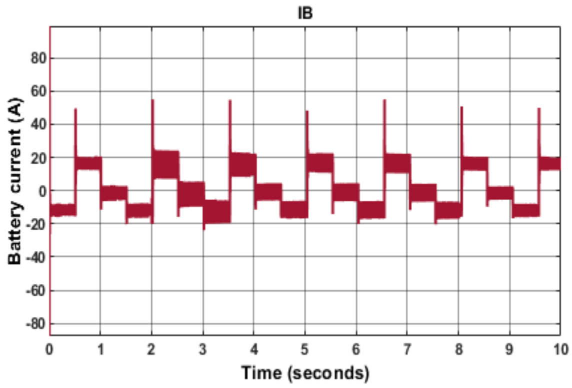

Figure 19. Battery current

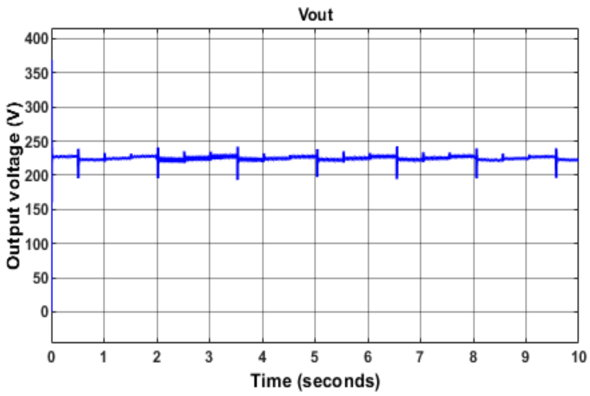

Figure 20. DC Bus voltage

5. CONCLUSION

A new robust control approach and power management plan for a stand-alone PV/battery hybrid power system are proposed in this paper. The Perturb and Observe (P&O) approach has been used by the MPPT controller to achieve a maximum power from the PV generator under all weather conditions situations. In contrast, the DC-DC bidirectional inverter controller is employed for optimal energy management and voltage control. The bidirectional DC-DC converter serves as a connection between the battery and the energy management DC bus in various irradiance states and the SOC. An energy management system is described in this work that allows it to adapt to load demand and maintain power balance at the DC Bus while calculating the voltage difference between the DC Bus and the reference voltage. The battery, on the other hand, can maintain the voltage in the vicinity of the required value by using a bidirectional DC-DC converter to charge and discharge it the simulation results indicate that the suggested controller outperforms others in a variety of settings.

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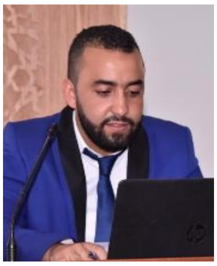

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