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Research Article

VCS control by Hysteresis of an Inverter with P&O MPPT and Battery Storage for Optimal Management of Photovoltaic Energy in the Electrical Grid

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ABSTRACT

In this work, a solar system with battery storage that is integrated into the electrical grid is designed and modeled. In spite of changes in irradiance, it maximizes the power from solar panels using an MPPT algorithm based on the perturbation and observation P&O method. With a considerable decrease in harmonics and an enhancement in power quality, the hysteresis current technique (VCS) is used to operate the inverter, guaranteeing accurate and dynamic tracking of the current injected into the grid. By providing constant energy needs and mitigating production swings, the incorporation of a battery enhances network stability and dependability. To verify the system's performance, MATLAB/SIMULINK is used to model and simulate it. The results show a reliable and effective method for the ideal integration of PV energy into contemporary grids.

Keywords: Maximum power point (MPPT), Perturb and observer (P &O), hysteresis current technique (VCS), Battery, Voltage inverter Control, boost converter, State of charge (SOC), buck-boost converter.

1. Introduction

Photovoltaic solar energy has become one of the key renewable sources for the generation of clean power, helping to the reduction of greenhouse gas emissions and the energy transition [1], [2]. The components of a typical photovoltaic system include solar panels that convert sunlight into direct current, an inverter that converts this current into grid-compatible alternating current, and a control system that maximizes the power extracted [3],[4]. By guaranteeing a steady and uninterrupted energy supply, the use of battery storage devices helps to mitigate the intermittent nature of solar production. This work focuses on controlling a battery storage system that includes a hysteresis inverter (VCS) and an integrated perturbation and observation (P&O) type MPPT algorithm [5]. Through efficient management of energy production and storage, the goal is to optimize the injection of 30 KW of photovoltaic energy into the electrical grid while preserving quality, stability, and service continuity [6]. This method may be validated and shown to be resilient to changes in the environment and the demands of the contemporary grid through the modeling and simulation of the system using MATLAB/SIMULINK.

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2. Photovoltaic system architecture

2.1. photovoltaic Generator

In order to maximize energy extraction from solar irradiation, the photovoltaic generator (PVG) uses photovoltaic modules, which are frequently installed in series-parallel configurations, a DC-DC converter, typically a Boost converter, and a Maximum Power Point Tracking (MPPT) algorithm of the Perturbation and Observation (P&O) type to manage the generated DC power [7], [8].

2.2 Parameters for photovoltaic system (PVS)

In order to shield the system's performance from the losses associated with the converters, the network's power (PVS) is marginally greater than the power used by the three loads and the network. Table 2 guides the selection of the network's (PVS) settings. The (PVS) module's comparable characteristic model is displayed in Figure 5 [9], [10]. The following formula is used to represent a photovoltaic cell's output current:

$$I_{pv} = I_{ph} - I_d - I_p \tag{1}$$

$$I_d = I_0 (e^{\frac{V_d}{nV_t}} - 1) \tag{2}$$

$$I_{pv} = I_{ph} - I_0 (e^{\frac{V_d}{nV_t}} - 1) - \frac{V_d}{R_p} \tag{3}$$

$$I_{pv} = I_{ph} - I_0 (e^{\frac{V_{pv} + R_s I_{pv}}{nV_t}} - 1) - \frac{V_{pv} + R_s I_{pv}}{R_p} \tag{4}$$

$$V_t = \frac{kT}{q} \tag{5}$$

I_{pv}: The current produced by the solar cell;

I_{ph}: Photocurrent generated by the cell (proportionate to the radiation exposure);

I_d: Flowing current through the diode

V_t: Represents the thermal voltage, as determined by the following;

$k = 1.38 \times 10^{-23} J / K$:is the Boltzmann constant;

$q = 1.6 \times 10^{-19} C$: is the electronic charge;

T : is the absolute temperature (K)

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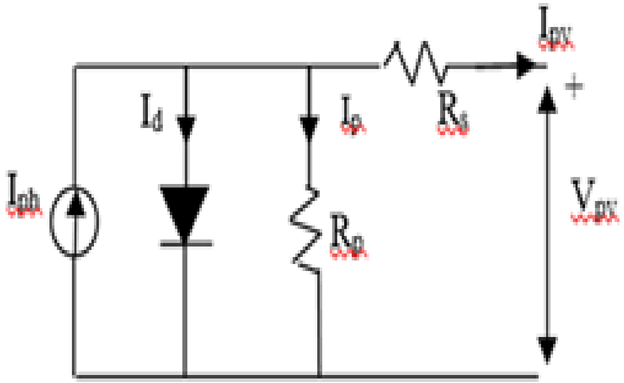

Fig.1. Equivalent circuit of a photovoltaic Cell

Tabl 2. Solar PV array parameters

PV module	PV Array
Number of cells 60	Number of series module10
Number of parallel cells 15	Number of parallel module 2
Series resistance 0.39381Ω	Open circuit voltage 36.3V
Parallel resistance313.0553Ω	Short circuit current 7.84A

2.3. Tracking Maximum Power Point (MPPT)

The operating point of the system depends on the properties of the solar array and the load when a photovoltaic generator is connected to a boost converter, a current hysteresis-controlled inverter. The operating point of the system in this scenario is often not at the maximum power point of the photovoltaic array. The DC-DC boost converter, which serves as an appropriate interface between the solar generator and the load, can be used to achieve maximum power. By regulating the duty cycle of the boost converter, the equivalent impedance of the load seen from the generator side is adjusted and synchronized with the maximum power point of the generator. The maximum power transfer from the PV generator side to the load side and the grid.

A number of maximum power point tracking (MPPT) strategies have been proposed. The most commonly used approach, however, is Perturb and Observe (P&O), particularly for low-cost implementations [11]. Therefore, this article suggests using the Perturb and Observe (P and O) approche [12], [13]. The flowchart of the MPPT technique based on the P&O technique is given by figure 2.

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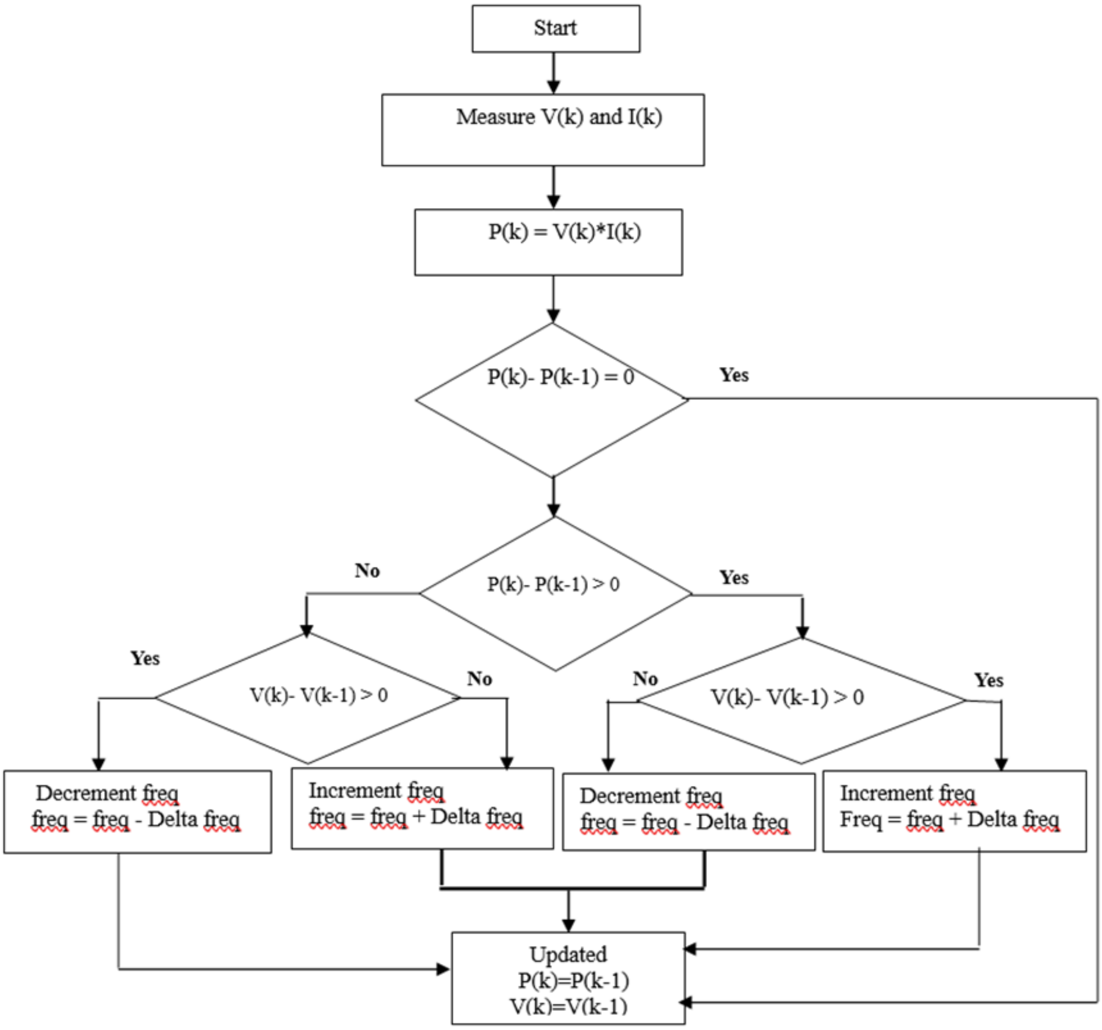

Fig.2. MPPT algorithm for perturbation and observation (P&O)

2.4. Boost converter

In hybrid photovoltaic systems that guarantee energy storage in a battery and injection into the electrical grid, the boost converter is essential. It serves as an interface for voltage and power adaption between the photovoltaic generator (PVG) and the inverter and battery, which are other parts of the system. In order for the battery to store surplus energy and the inverter to convert DC/AC and inject it into the grid, the boost converter increases the voltage to a level that is compatible with the DC bus voltage. Usually based on the Perturb and Observe (P&O) technique, the MPPT (Maximum Power Point Tracking) algorithm regulates the converter's duty cycle [14], [15].

$$V_L(t) = L\frac{dI_L}{dt} \tag{6}$$

$$V_L(t) = V_i(t) - V_0(t) \tag{7}$$

BOOST converter parameters:

- Inductance: L = 0.04H;
- IGBT is a power diode;
- Capacitance C_1 = 700e-5 F, C_2 =1000e-5 F

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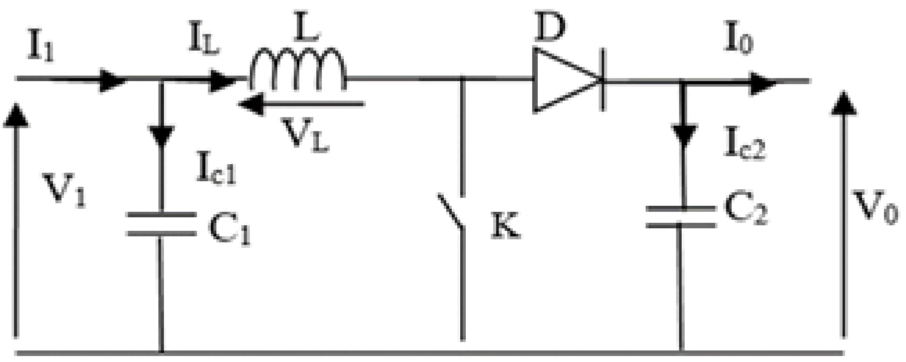

Fig.3. Model of a boost converter

3. Voltage inverter Control

In renewable energy systems, especially solar systems, the inverter is a crucial electronic converter that transforms direct current (DC) electricity into alternating current (AC) voltage that is in sync with the electrical grid. The control method that is employed has a significant impact on the quality of this conversion. Hysteresis control in conjunction with the VCS (Voltage Control Strategy) has become a highly effective method among the others [16], [17].
The control scheme of the inverter by VCS is given by the figure 4.

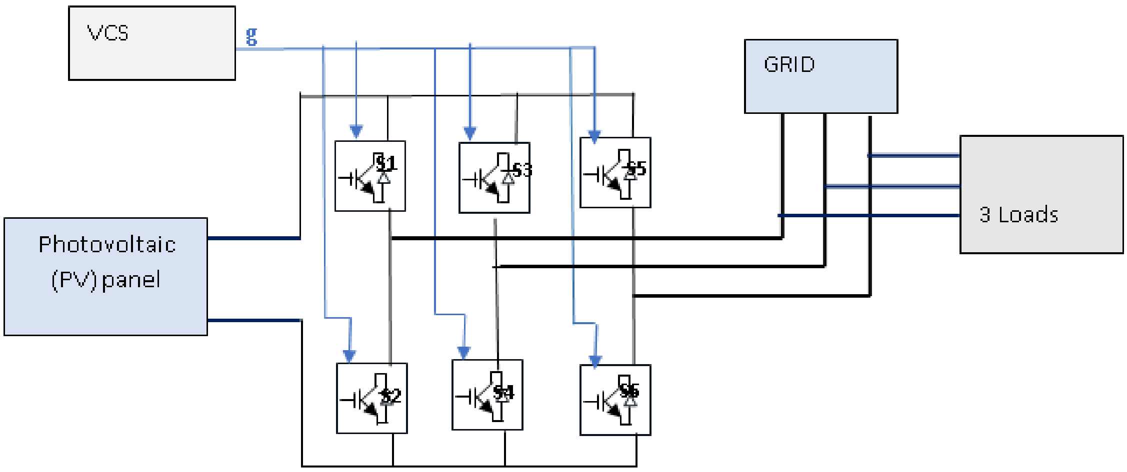

Fig.4. Voltage Control Strategy

4. Hysteresis current control technique

In contrast to traditional current loop controls, the VCS technique focuses on the injected volt age, allowing for better quality of the injected wave, a rapid dynamic response, and direct con trol of injection into the grid. The benefitsof using the VCS technique by hysteresis include a quick response time to load or PV source variations,
ease of implementation (no need for a PWM generator), and the ability to directly inject into the grid without a
transformer. The technique is used in grid-connected photovoltaic systems, with or without sto rage, in hybrid PV-battery systems, and in microgrids that require dynamic regulation [18],[19]
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The diagram of the current control technique by hysteresis using Simulink is represented by a figure 5.

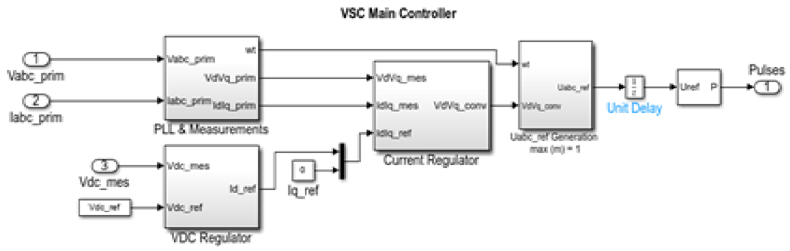

Fig.5. Diagram of the current control technique by hysteresis VCS

5. Controller configurations

In this design, a 30-kW solar array is often connected to an upstream boost converter with M PPT of the
(P&O) type. The inverter controls the VCS technique, which converts direct current to alternati ng current,
using hysteresis. While the inverter optimizes and synchronizes this energy with the grid, the MPPT draws the greatest power possible from the solar generator to power three loads: P_1 = 5 kW, P_2 = 7.5 kW, and P_3 = 10 kW. Constant energy requirements are satisfied and producti on fluctuations are minimized by the addition of a battery.

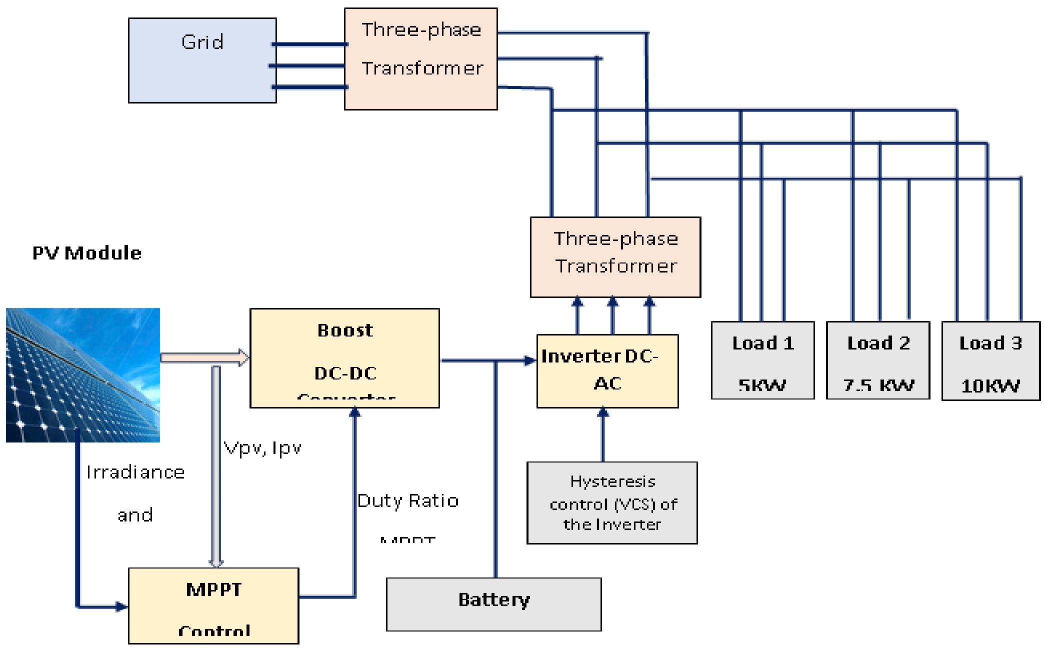

Fig.6. Diagram of the current control technique by hysteresis VCS

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6. Modeling Micro-grids

MATLAB/Simulink software, which is the most popular among engineers and researchers due to its efficacy, was used to model micro-grid components. This modeling makes use of mathe matical modeling formulae.
The Simulink model of an electrical network is shown in Figure 7.

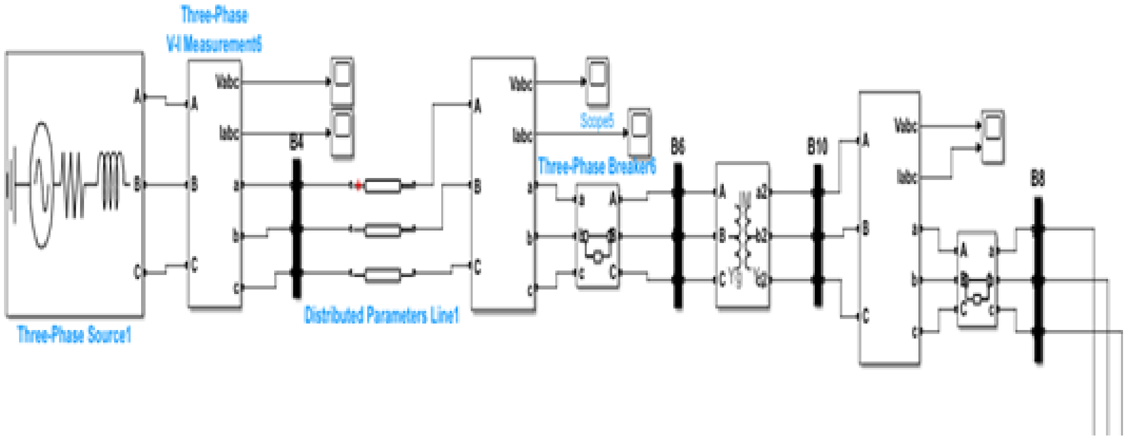

Fig.7. Simulink model of the Micro-grid system

7. Energy storage system modeling

One important way to maximize the usage of electricity generated by photovoltaic solar panels is through battery energy storage. When the panels produce more energy than is immediately needed, the extra energy is chemically stored in the battery and can be released when solar production isn't enough (during peak consumption periods, at night, or on overcast days). Based on the charge/discharge principle, a solar battery charges when production is in excess and discharges when demand outpaces immediate production. To prevent deep discharges or overcharges that could harm the battery, a charge controller must be integrated [20]. By adding a storage system, the rate of self-consumption may be increased, energy autonomy can be enhanced, and reliance on the electrical grid can be decreased. Lithium-ion, lead-acid, and other battery technologies are available; each has pros and downsides with regard to cost, longevity, and capacity [21].

7.1. Modeling of the energy storage system

Equation 8 for the charge (+) and discharge (-) states is used to get the current battery voltage in the generic battery model.

$$V = V_{co} \mp IR \qquad (8)$$

Where I is the battery charging current from an external load that is about zero at rest, V is the battery's current voltage, VOC is its open-circuit voltage, and R is its internal resistance.

Equation (9) is used to determine the battery's state of charge.

$$SOC = Q - QdiscCbat \qquad (9)$$

Where SOC is the state of charge of the battery, Q is the actual charge of the battery, $Qdisc$ is the actual discharge rate of the battery and $Cbat$ is the battery capacity.

The Simulink model of battery is shown in Figure. 8.

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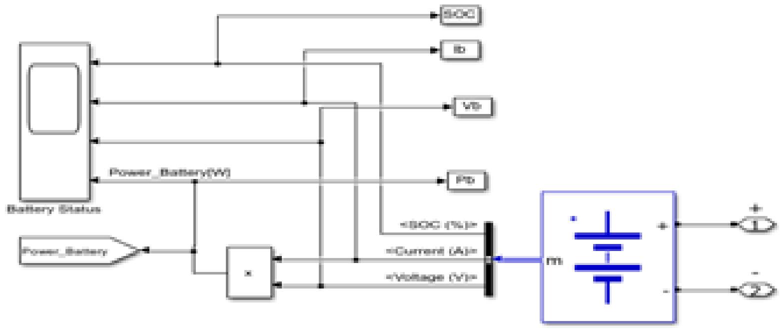

Fig.8. Simulink model of the energy storage system

8. DC buck-boost converter:

A common method for connecting the battery storage unit to the DC side is the buck-boost DC converter, often known as a bidirectional converter. Two IGBT switches make up the majority of the bidirectional DC converter; one of these switches permits the battery to run in buck mode while charging, and the other in boost mode when discharging [22] [23].
The battery unit's bidirectional converter was thought to function in this suggested model at a voltage level of roughly 200 V on the buck side and 440 V on the boost side [24] . The battery's charging and discharging operation in this study is determined by central energy management based on the battery's state of charge (SOC) and the grid's photovoltaic energy generation and charging circumstances. Monitoring the state of charge (SOC) in energy management enables the battery to function within a safe SOC operating range (40–80%) to prevent overcharging and undercharging. The Simulink model of buck-boost DC converter in Figure 9

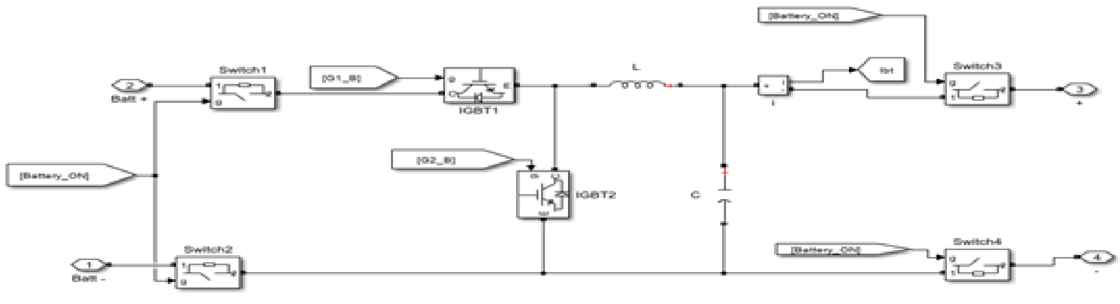

Fig.9. Simulink model of buck-boost DC converter

9. Simulation resultants and discussion

MATLAB/Simulink software was used to simulate the entire model of Figure 6, with the powe rgui simulation type
set to discrete. A temperature of 25°C and a variable irradiance [500 700 800] W/m² were u sed to simulate the
model. The figures below display the outcomes of the simulation. As shown in figure.10, the ir radiation variation.

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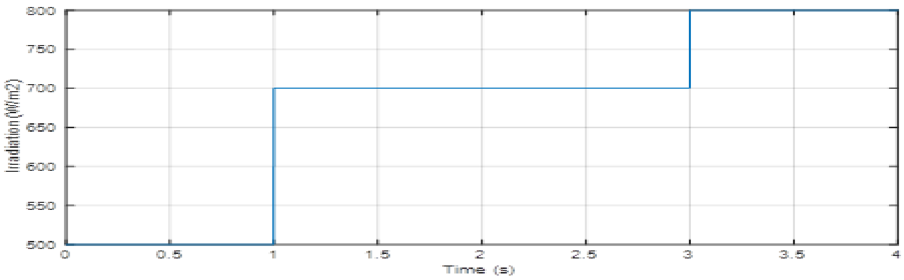

Fig.10. Solar irradiation

From Figure 11, we observe that the MPPT generates the maximum power regardless of the illumination value. Moreover, with each change in illumination, It quickly finds the maximum power point without going thru the zero point, unlike the MPPT method using the P&O algorithm.

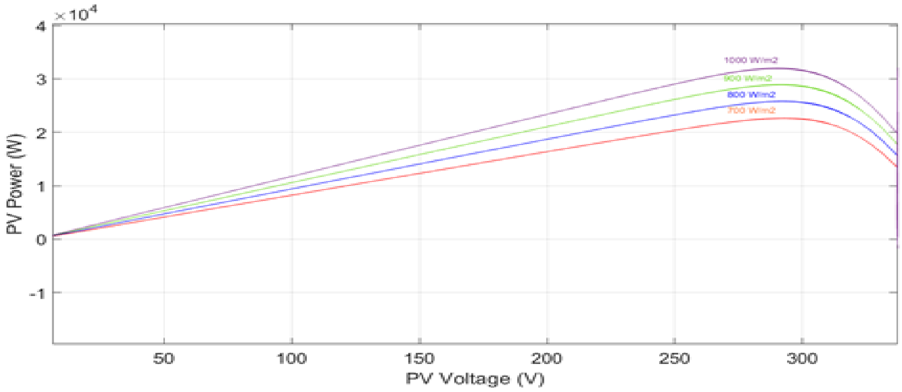

Fig 11. Characteristic PV and MPPT control curves.

The PV voltage is shown in Figure 12. We can observe that the solar generator's voltage sta bilizes at 335V at t=2.1s when the irradiance exceeds 700 w/m2. We note, particularly for syst ems operating under conditions of frequent changes in irradiance and a module temperature o f 25°C, the photovoltaic network maintained optimal power production by continuously adjusti ng the duty cycle of the Boost converter to keep the voltage and current at a maximum powe r point.

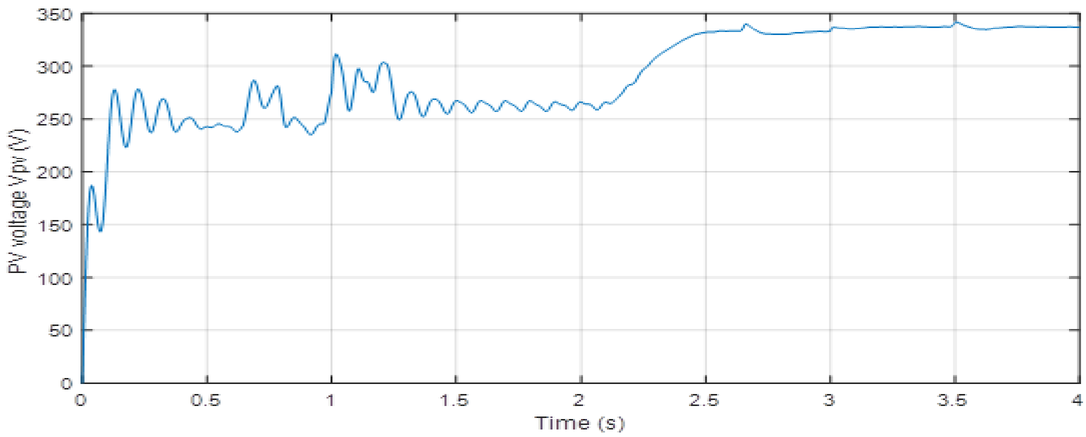

Fig.12. Responses of PV voltage

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The converter elevator's variation is displayed in Figure 13, and it is evident that the tension stays constant at 710V in a permanent regime. We observe that the boost converter voltage is larger than the solar panel voltage value, yet it still follows the panel voltage. As seen in figure 14, this variation results from changes in the duty cycle and irradiance.

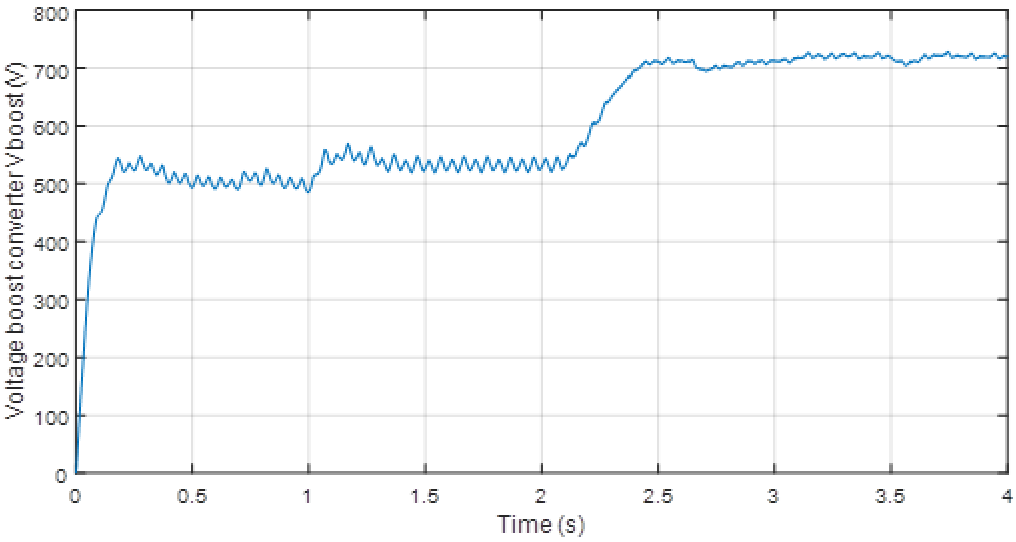

Fig.13. Responses of the boost converter voltage

The duty cycle fluctuation is shown in Figure 13. Figure 14 shows how the duty cycle fluctuates to maintain the DC-DC boost converter's output voltage as stable as feasible. It demonstrates how the MPPT control operates as intended.

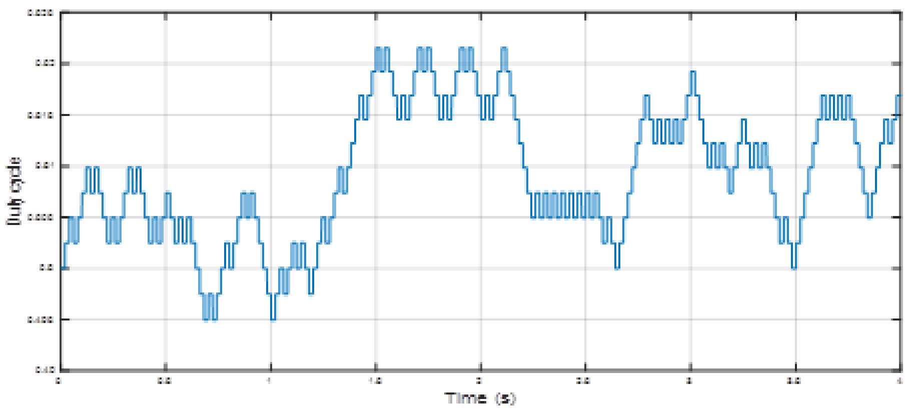

Fig.14. Variation of the duty cycle

We can observe that the three phase-to-phase voltages in Figure (15), which depicts the inverter voltage variation, are sinusoidal. The hysteresis-controlled inverter is an easy, quick, and effective way to regulate the current that is fed into the grid. Because of its accuracy and resilience, this technique is still frequently employed for renewable energy conversion applications even though it produces a variable switching frequency.

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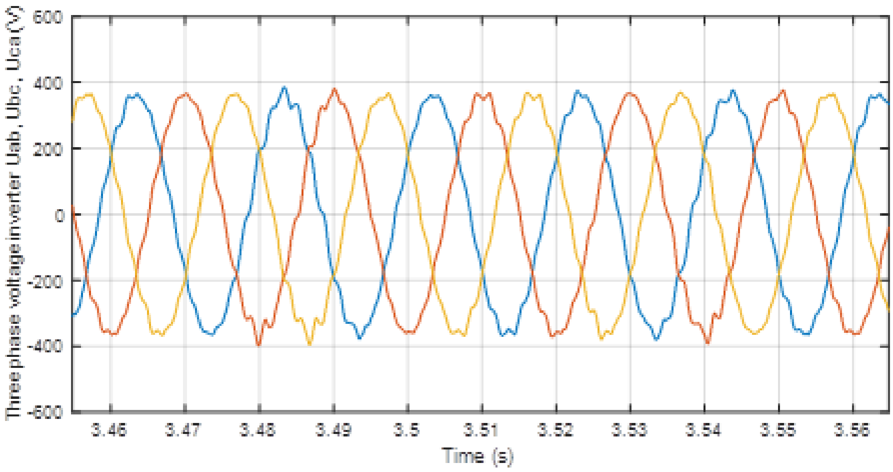

Fig.15. Three phase inverter voltage U_{ab}, U_{bc}, U_{ca}

The battery is 80% charged, as seen in the figure (16). We observe that the entire status of accessible energy is expressed by SOS. To guarantee the storage system's sustainability, performance, and safety, their cooperative management is crucial.

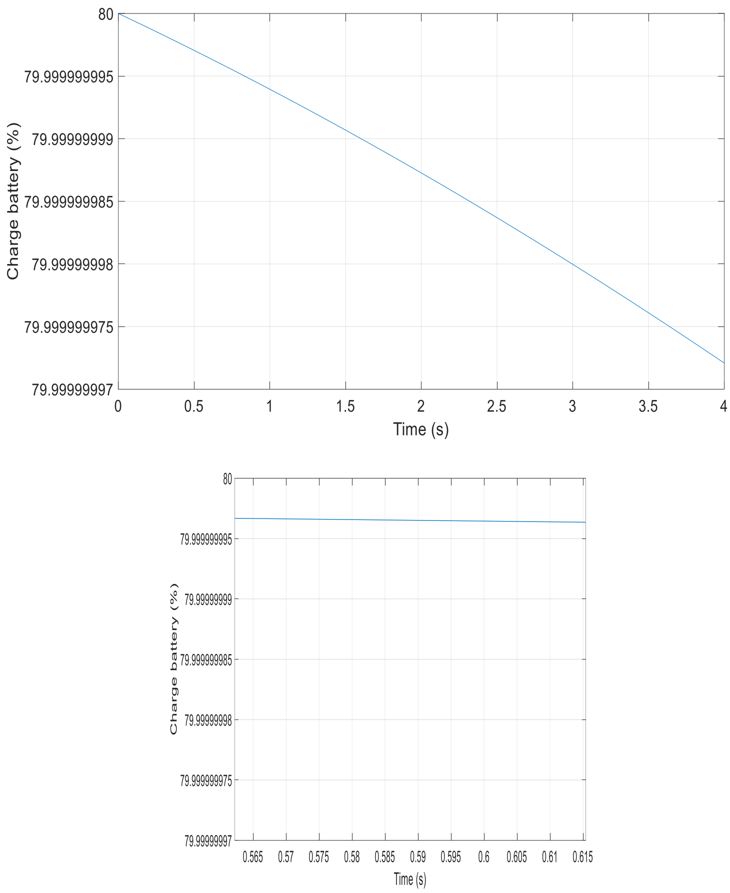

Fig.16. Responses charge battery SOS (%)

Electrical systems can be stabilized and optimized through the use of batteries for energy sto rage. Figure (17) illustrates how the battery voltage, which is 200V, directly reflects its insta

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ntaneous behavior.

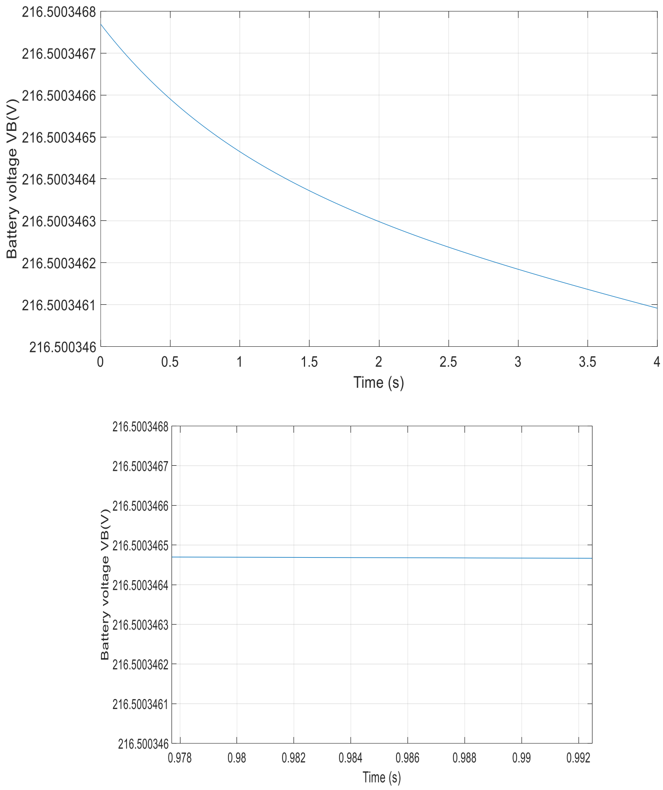

Fig.17. Responses battery voltage

The figure (18) represents The variation of the network voltage shows that the three voltages Va, Vb, Vc are sinusoidal in shape and well-shifted by 120° with an effective value of 50 KV without oscillations due to the use of filters and transformers (220V/50KV**)**

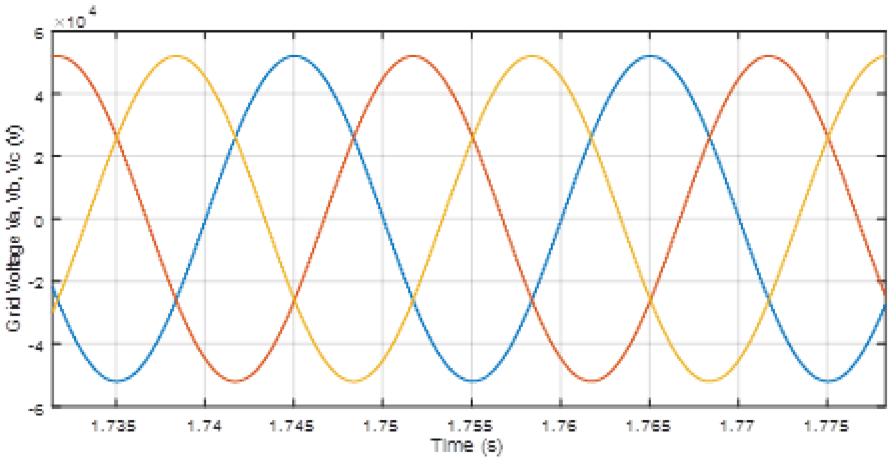

Fig.18. Responses of voltage grid-connected and PV-connected inverters under MPPT control

The figure (19) represents The variation of the network voltage shows that the three voltages Ia, Ib, Ic are sinusoidal in shape and well-shifted by 120° oscillations due to the use of filters and transformers

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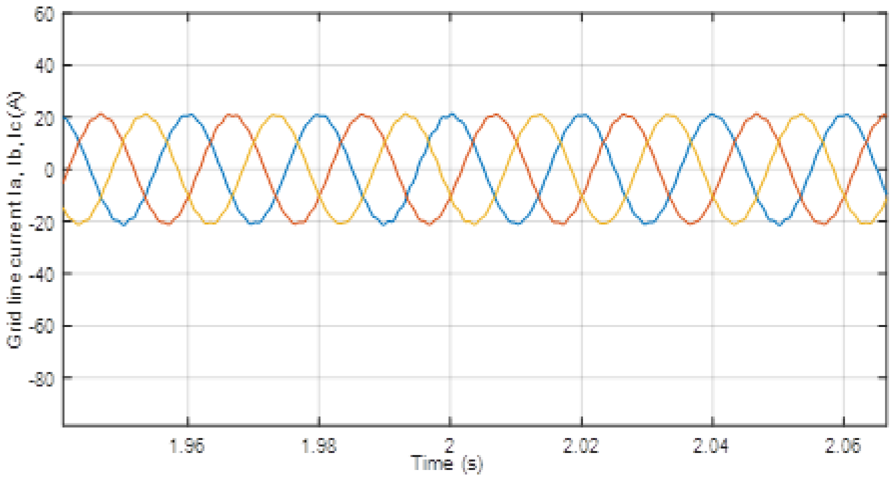

Fig 19 Responses of current grid-connected and PV-connected inverters under MPPT control

Conclusion

In order to assess the efficacy of control strategies under fluctuating conditions, the paper models and simulates a 30-kW photovoltaic system that is connected to the electrical grid and powers three distinct power demands using MATLAB/Simulink. We demonstrate the solar generator using a single-diode model. The output voltage is variable because the P&O type MPPT device, in conjunction with a Boost converter, adjusts the duty cycle to maximize the recovered power in response to variations in temperature and irradiance. A battery storage device is included to make up for low irradiances. Lastly, the inverter's use of VCH hysteresis current regulation guarantees strong stability and prompt system reactions.

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