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A Comparison Between CCCV and VC Strategy for the Control of Battery Storage System in PV installation

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ABSTRACT

To meet demand with unpredictable daily and seasonal variations, the power grid faces significant hurdles in transmission and distribution. Electrical Energy Storage (EES), in which energy is stored in a specific state, depending on the technology utilized, and is converted to electrical energy, is acknowledged as a technology involved with significant potential for solving these difficulties. This paper deals with the modeling and control of a renewable energy production system based on solar panel. To improve the performance of the investigated power generation system, a lithium-ion battery storage system and bidirectional converter are associated to a solar panel that is unable to compensate for rapid variations in load power demand. In this situation, to meet load power demand, a rule-based energy management algorithm is used to share energy between the grid and the energy production system. Furthermore, two solutions are developed and compared: VC (Variable Current) and CC-CV (Constant Current Constant Voltage). The VC approach is used in conjunction with an energy management and protection system, whereas the CC-CV method is used in conjunction with an artificial neural network (ANN). The simulation results show that the VC control strategy give greater energy performance and installation stability compared to the CC-CV strategy, but not improved safety and protection of lithium-ion batteries.

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1. INTRODUCTION

The storage of electrical energy is increasingly exploited, due to the intermittence of renewable energies such as photovoltaic and wind energy and the increase in consumption. The use of batteries allows for the stability and continuity of operation of the energy production system, to achieve this objective, an adequate and efficient charging system is necessary [1].

There are several types of battery charging system, such as the constant current constant voltage (CC-CV) charging and discharging method, which ensures battery safety and extends battery life. In fact, the operating principle of this control strategy is divided into two stages: the battery charges with a constant current, and the voltage gradually increases until reaching a maximum value. Then, the second stage begins at this point, with the battery charge current starting to decrease and the battery now being charged at a steady voltage [2].

In reference [3] the CC-CV control strategy of the lithium-Ion batteries is used to implement a wireless charging system in an electric vehicle. In fact, a voltage control loop (CV) is combined with a wireless system based on two nRF24L circuits that provides communication between the electric vehicle and the wireless charging system. The simulation findings are very satisfactory, with a 97.95 % efficiency.

Indeed, the constant current and constant voltage (CC-CV) charge method is simple and offers great robustness. It is widely used in the industry, because it offers the advantage of having a guarantee of a maximum charge state of 100%. However, there is a major drawback of this method in a transient state with each change in charging mode [4].

In particular, compared to other types of storage systems, lithium-ion batteries offer high performance, as they have a high energy density and low self-discharge effects, and their price is becoming increasingly lower. This type of battery is suitable for storing electrical energy in a stationary system [4].

Research [5] discusses a new method of charging lithium-ion batteries that provides more protection, this method consists of varying the charge current according to the SOC (State of Charge). Then, the obtained result by the proposed method is compared to the conventional CC-CV strategy.

Usually, the battery charging technology is obtained by cascading two loops, an internal current loop and a external voltage loop, using PI regulators. This method can allow variable currents (VC) to obtain the required power. The advantage of this method is to maintain a constant voltage on the DC bus [6].

Paper [7] presents a smart charging device for electric vehicle using the dual closed-loop control, which can be divided into a current loop and a voltage loop. The simulation results show a reduction in charging time and an improvement in charging efficiency. It can also be seen that the CC-CV strategy ensures efficient batteries operation.

In reference [8], an ANN controller is applied to the bidirectional vehicul to grid (V2G) charger. The proposed system allows to vary the batteries current in order to regulate the grid voltage in various modes of charging and discharging operations. Simulation of the system under several scenarios shows that the batteries current follows the reference with great accuracy and stability.

Paper [9] presents a management system based on fuzzy logic adopted for charging batteries supplied by a PV system. The proposed fuzzy logic system can effectively charge and protect the batteries from overcharge and deep discharge, with an energy efficiency of 95% compared to other existing methods.

A simple fuzzy controller is proposed in the research work [10] for the regulation of the charging current of a battery storage system and compared to the CCCV strategy. The controller is improved by a genetic algorithm (GA) in order to ensure a better charging time and a lower temperature compared to the CCCV strategy.

In fact, without an effective control approach, the installation of a battery system could have very modest effects on peak load reduction, the economy and the environment [11]. Also, it is critical that the connected grid manage the distribution of power based on load requirements and the need to recharge the batteries or provide excess power to the grid. The backup system for solar generation will need to maximize energy production while also helping to maintain battery charge levels and reduce the need to buy power from the grid [12].

In this study, we will compare two control strategies for a storage system consisting of a bidirectional converter and lithium-ion batteries. In fact, to achieve this objective, we will set up two electrical installations connected to the grid containing solar panels, batteries and a three-phase inverter controlled by the VSC (Voltage Source Converter) strategy. Both installations produce the same amount of power and feed the same load.

The first part of this research is devoted to the configuration of the two installations, and then the second part is devoted to the modeling of the installation system using the VC approach of charge and discharge. In addition, an energy management algorithm is created, which allows to connect or disconnect the storage system, as well as to control the flow of energy exchange with the electrical grid and to protect the batteries against overcharge and deep discharge. In the third section, an installation based on the CC-CV approach is presented, along with a management algorithm based on artificial neural networks (ANN). PV power is increased using the MPPT perturb and observe (P&O) power maximization technique, and the VSC control strategy is utilized to manage each bidirectional three-phase inverter. Finally, the results of simulations obtained by the two control strategies are compared and discussed.

2. CONFIGURATION OF THE INSTALLATION USING THE VC/CCCV STRATEGY

The two proposed system consists of a photovoltaic installation, lithium-Ion batteries connected to a DC bus via the DC-DC biderectional converter, the power available on the line is transferred to the three-phase load using a biderectional inverter. Also, when the power generated by the PV system becomes insufficient for the proper functioning of the load, the electrical grid compensates for the lack of energy. The configuration of the two proposed installations is shown in Figure 1.

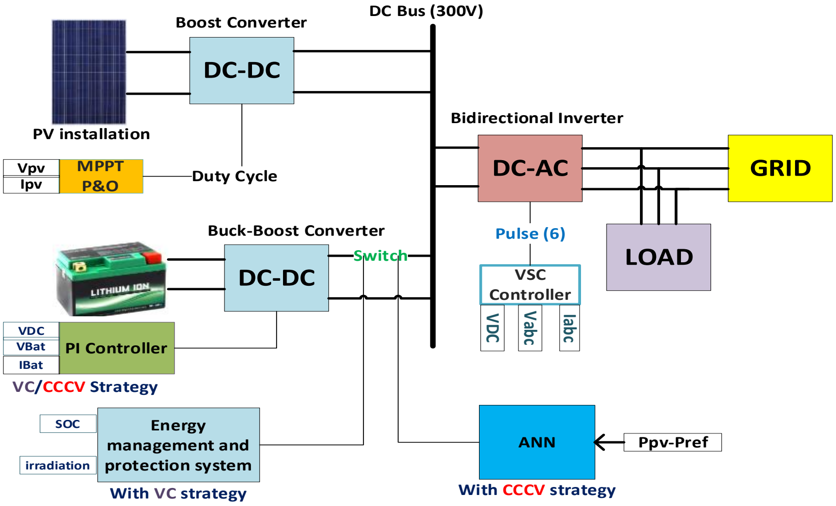

Figure 1. Design of the proposed installation using the VC/CCCV strategy.

3. VC CONTROL STRATEGY

Figure 2 shows the use of bidirectional converter. It allows energy transfer from the battery to the DC bus and vice versa. Switching is ensured by using the transistors Q_1 and Q_2 [13].

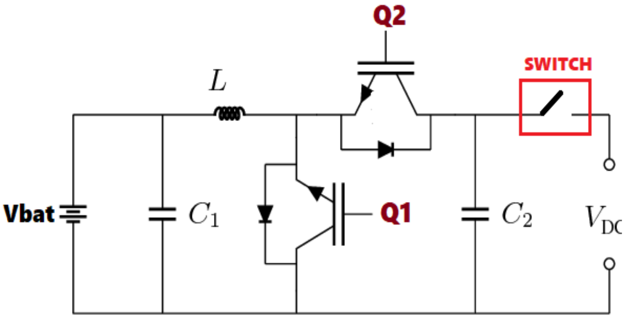

Figure 2. Topology of the bidirectional converter.

The objective of the VC control system is to regulate the batteries current to obtain the required power. For that, we use two cascaded loops: a voltage loop (external) which compares the DC bus voltage to a reference voltage to generate a reference current using the PI voltage regulator and a current loop (internal) which consists of comparing the reference current to the actual battery current according to the error duty cycle is generated by the PI current regulator. The duty cycle is converted to a PWM signal using a PWM generator. The PI controller parameters are determined by using the Ziegler-Nichols method. Schematic diagram for the proposed VC controller is given by Figure 3 below.

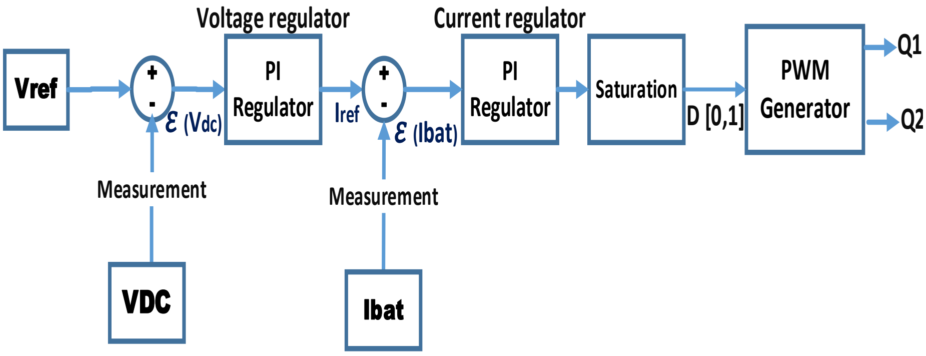

Figure 3. Schematic diagram of the proposed VC controller.

Energy Management and Protection System

A power management system is required when using a VC method to control the flow of energy exchanged with the electrical grid and to maintain battery life by protecting against overloads and deep discharges, The energy management and protection algorithm is shown in Figure 4.

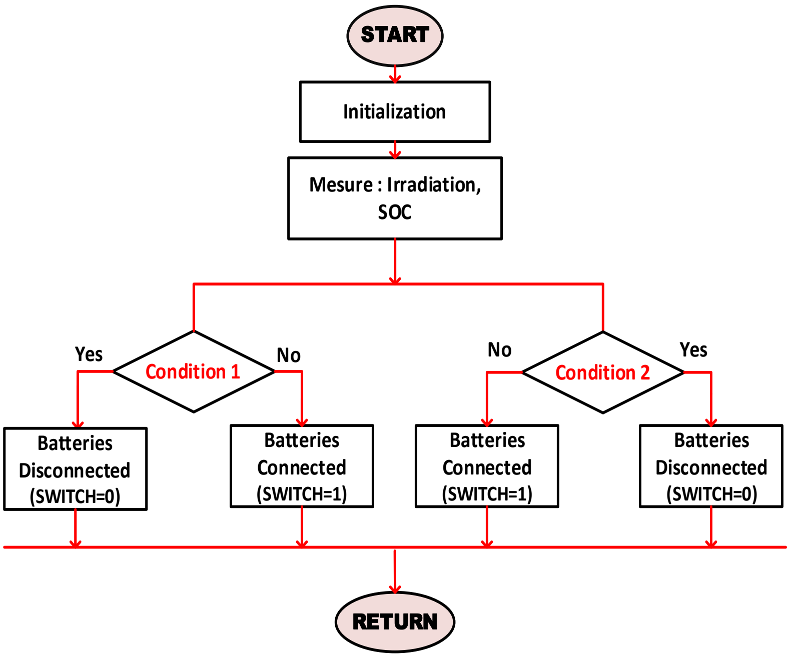

Figure 4. Energy management and protection system flowchart.

Condition 1: (SOC>=94) and (Irradiation >800), Condition 2: (SOC<=4) and (Irradiation<=500).
If condition 1 or 2 is true, then the batteries are disconnected and the SWITCH =0, otherwise the batteries are connected with SWITCH =1. The energy management system ensures optimal control of the power supplying the load and increases the lifetime of the batteries system.

4. CC-CV CONTROL STRATEGY

The CC-CV technology for charging and discharging lithium-ion batteries is the most recommended by manufacturers. It consists of three modes of operation, charge, discharge, and standby [14]. The charging modes are shown in Figure 5.

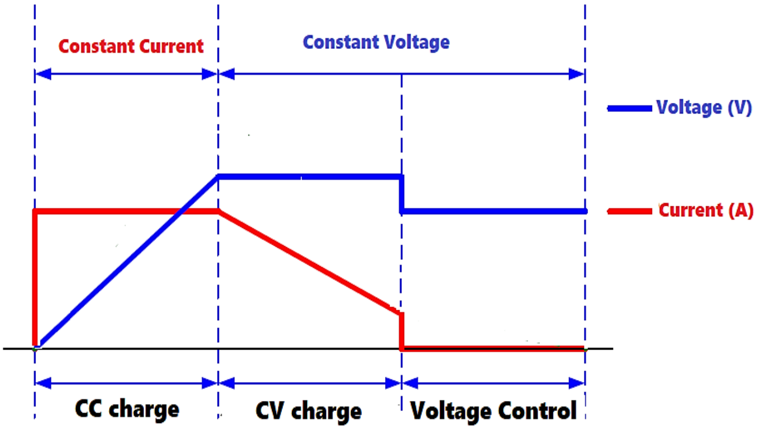

Figure 5. The three stages of the charging mode [14].

The voltage control mode is activated when the battery is close to full charge and the state of charge is maintained at full charge state (SOC_{Max}). The CC-CV controller sets the charging or discharging current using the PI regulator. In our case, we chose the charge current -87 A and the discharge current 87 A, this allows a protection of the battery since whatever the case, the battery current does not exceed the nominal operating current, and limits the battery temperature. This represents an advantage over the VC strategy. The battery current adjustment system consists of three loops, two voltage loops (V_{DC} is the voltage of the DC bus is compared to the voltage bus reference and the voltage of the battery is compared to the reference V_{Bref}), which generates the reference current in charge and discharge, which is compared to the actual battery current. The current regulator generates the corresponding duty cycle for the PWM generator.

The control signals S of the CC-CV controller and of the switch of the bidirectional converter are generated by the ANN system. The PI controller parameters are determined using the Ziegler-Nichols method. The schematic diagram for the proposed CC-CV controller is given in Figure 6.

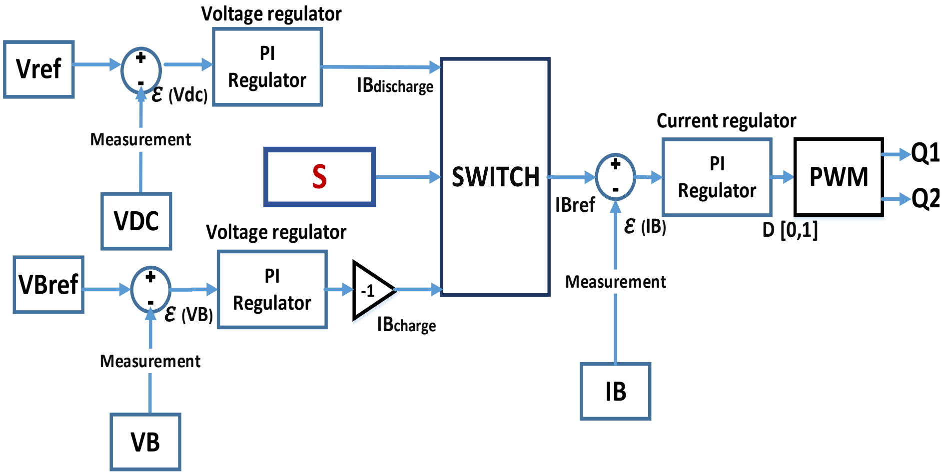

Figure 6. Schematic diagram of the proposed CC-CV controller.

Artificial neural networks (ANN), constitute an approach to solving the problems of perception, memory, learning, and reasoning. ANN is inspired from human nerve cells (neurons). ANNs are used in several applications such as engineering, medicine, etc.[15]. It consists of an input layer, hidden layers and an output layer. In our case, we use Feed-Forward Backpropagation network and the activation function is TANSIG [15]. The proposed ANN algorithm is shown in Figure 7.

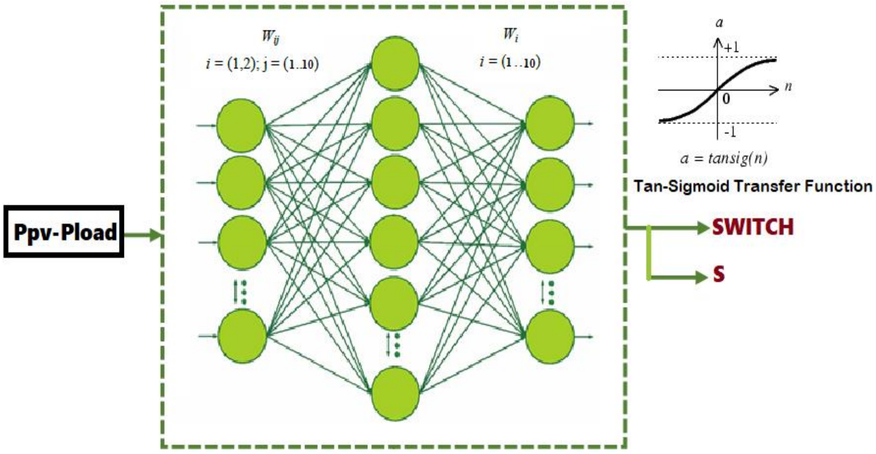

Figure 7. The ANN proposed model.

The power of the PV solar panels is compared to the power of the load, depending on the difference the ANN system generates a signal in charge or in discharge or does nothing. If P_{pv}- $P_{load} > 0$, then the battery is in charge mode or If P_{pv}-$P_{load} < 0$, then the battery is in discharge mode or If P_{pv}-$P_{load} = 0$, then the current of the battery is around 0.

5. SIMULATION RESULTS

In this section, the two installations are simulated under variable irradiation conditions. The power produced by the photovoltaic installation using the power maximization algorithm P&O under variable irradiation conditions is given by Figure 8.

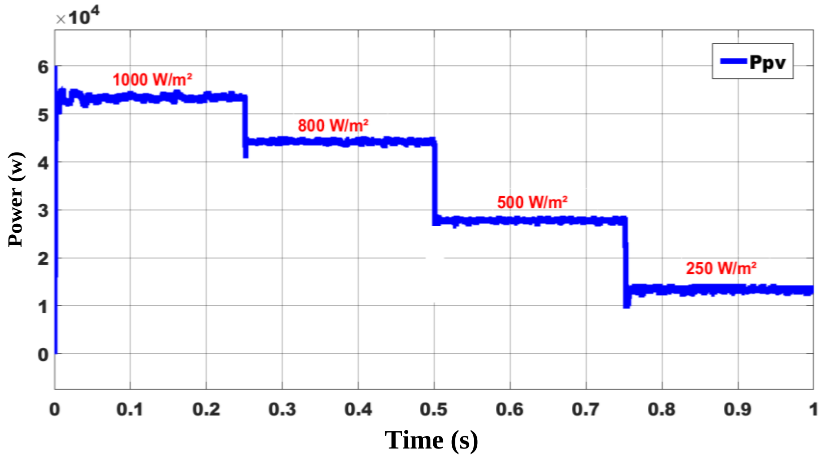

Figure 8. PV array system output power with MPPT P&O algorithm under variable irradiation conditions.

5.1. Response of the PV System Using the VC Strategy

The state of charge of the battery is fixed at 50%, the current of the batteries I_B is given by Figure 9. It is clear that the current of the batteries varies according to the variation of solar irradiation, to compensate the decrease of the power and ensure the continuity of the operation of the three-phase load. The load power is given by Figure 10.

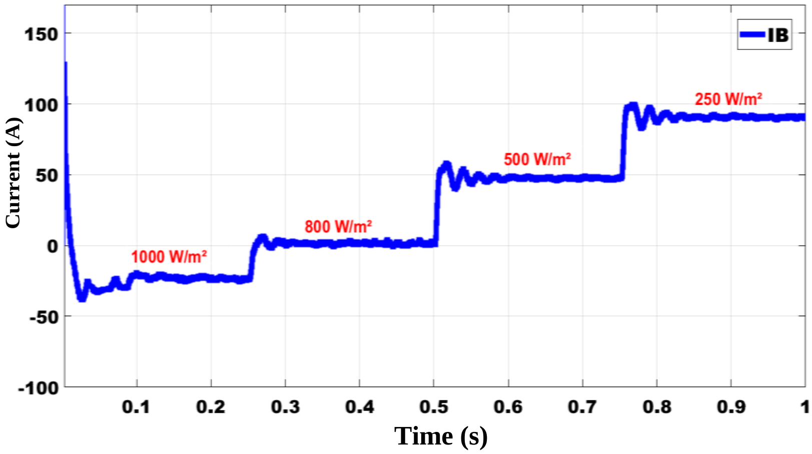

Figure 9. Current of the batteries under variable irradiation conditions using the VC strategy.

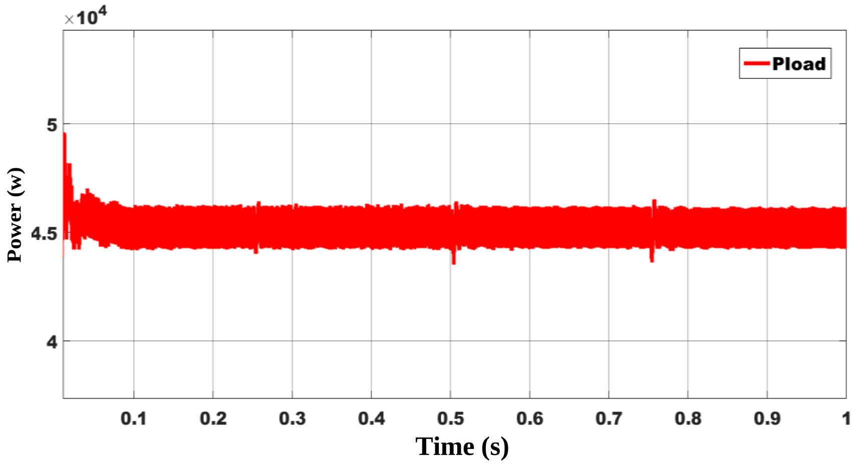

Figure 10. Load power under variable irradiation conditions using the VC strategy.

Based on the simulation results obtained above, it can be seen that the load power is constant whatever the variations of the irradiation. The voltage of the DC bus (V_{DC}) is given by the Figure 11. Using the VC strategy, we can see that the voltage of the DC (V_{DC}) bus is always constant even under low irradiation conditions. The power of the grid is given in Figure 12 below.

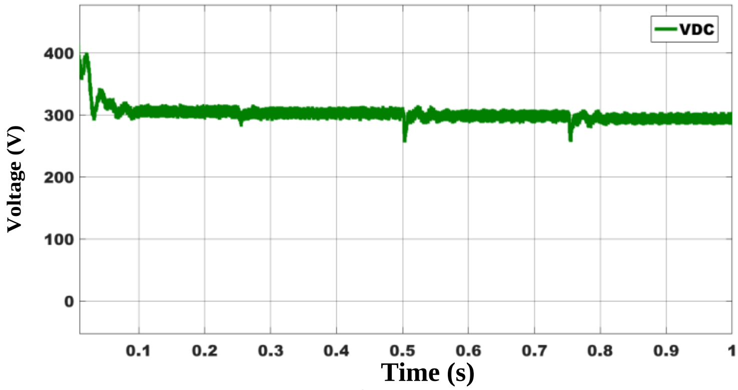

Figure 11. The voltage of the DC bus using the VC strategy.

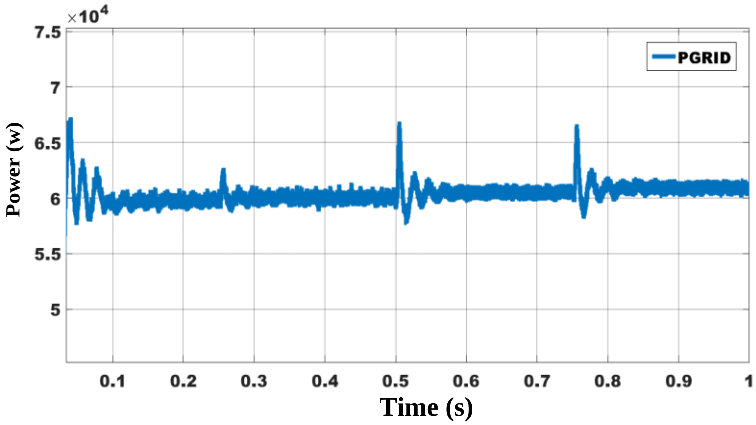

Figure 12. Power of the grid under variable irradiation conditions using the VC strategy.

It can be seen in Figure 12 that the power of the grid remains constant regardless of the vatation of the energy produced by the PV system. In fact, all the excess power is stored in the batteries system, and in case of a decrease of the produced power, the storage system compensates the missing power in order to supply the three-phase load.

5.2. Response of the PV System Using the CC-CV Strategy

The state of charge of the battery is fixed at 50%, the current of the batteries I_B is given by Figure 13.

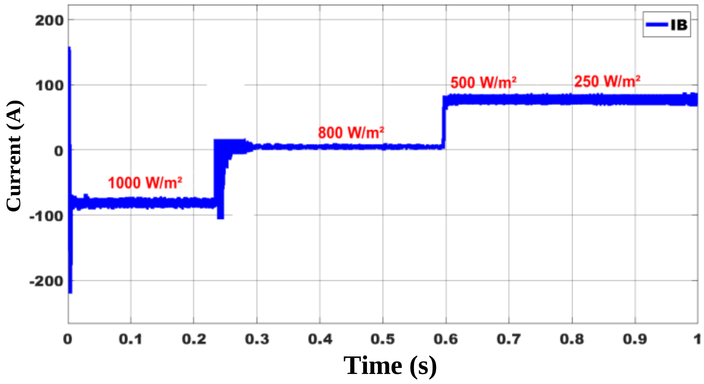

Figure 13. Current of the batteries under variable irradiation conditions using the CC-CV method.

Figure 13 shows that the battery current varies between two constant values 87 A and -87 A depending on the irradiation variation and takes the value 0 A when the irradiation is equal to 800 W/m².

Regardless of the power variations of the PV system generated at load, the CC-CV strategy provides constant power, both at charge and at discharge. In fact, when using the CC-CV strategy, a problem arises when the power generated is slightly higher or lower than the power consumed by the load this has a negative impact on the DC bus and the grid power. The power of the load is constant even when the power of the batteries becomes insufficient in this case, the grid generates the missing power.

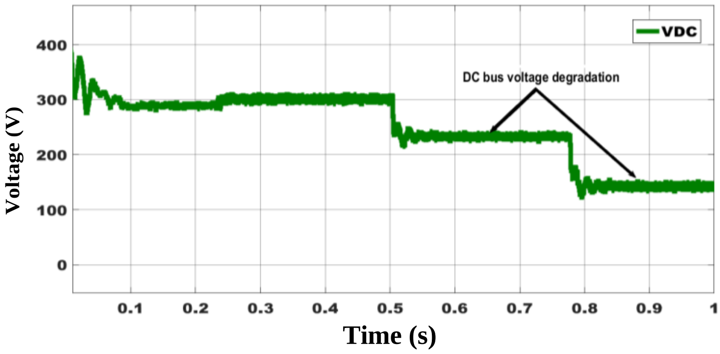

Figure 14. The voltage of the DC bus using the CC-CV method.

The voltage of the DC bus gradually decreases when the irradiation degrades, and this is due to the intervention of the grid to feed the load as shown in the Figure 14. The power of the grid under variable irradiation conditions is given in Figure 15 below.

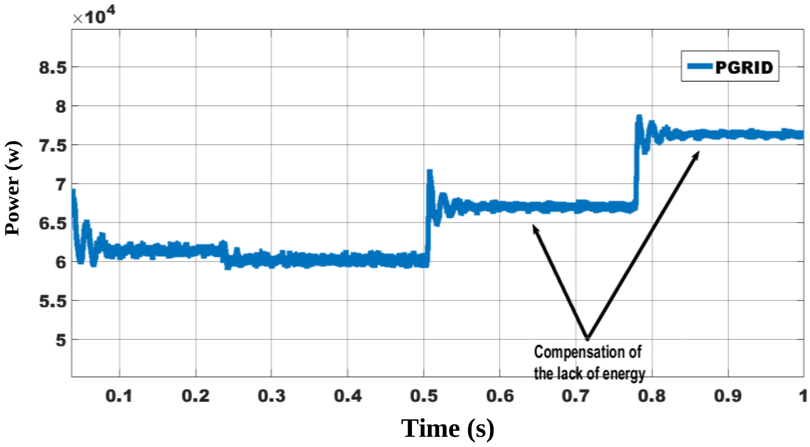

Figure 15. Power of the grid under variable irradiation conditions using the CC-CV method.

6. RESULTS AND DISCUSSION

In order to study and compare the performances obtained by the two proposed control strategies, the energy efficiency must be determined. To determine the energy efficiency of each system, we eliminate the power of the grid P_{GRID}. If the power of the battery is negative, $P_{bat} < 0$, the energy efficiency E is given by the following equation:

$$E = \frac{P_{pv}}{P_{load} + P_{bat}} * 100 \tag{1}$$

Otherwise, if $P_{bat} > 0$, then energy efficiency E is equal to:

$$E = \frac{P_{pv} + P_{bat}}{P_{load}} * 100 \tag{2}$$

Figure 16 show the evolution of energy efficiency. It is clear, that the energy efficiency of the installation, which uses VC technology is constant regardless of the change in solar irradiation, contrary to the CC-CV strategy a decrease in efficiency is noted when the irradiation deteriorates.

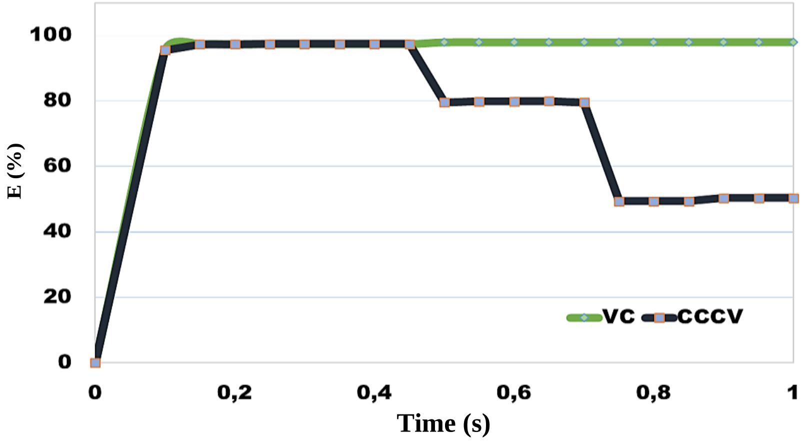

Figure 16. Energy efficiency of the VC and CC-CV strategy without P_{GRID}.

The VC control strategy requires a good sizing of the batteries, in order not to exceed the nominal current in case of a full charge or discharge, and also a management and protection system is required to protect the batteries and increase their lifetime. Therefore, the CC-CV technology offers natural protection without the intervention of a management system, this is due to a constant charge and discharge current, the batteries reach the full charge 100% and 0% in a safe way while maintaining a maximum life of lithium-ion batteries.

Simulation results show a high performance and stability obtained by the VC strategy. In fact, the voltage of the DC bus is always constant regardless of the variations of the power supplied by the PV system, and even when the solar irradiation is null, all the missing or excess power is absorbed/generated by the batteries storage system, which has a positive impact on the grid power since it is always constant, which implies that there is no energy exchange with the grid. Contrary to the CC-CV strategy, we notice that the DC bus voltage is variable, which implies an energy exchange with the grid due to energy excess or lack since the power absorbed/generated by the storage system is always constant.

7. CONCLUSION

In this study, two techniques VC and CC-CV are developed and compared for the control of the storage system based on li thiom batteries combined with a solar installation. The P&O algorithm is used to maximize the power generated by the photovoltaic system. In addition, a battery management and protection system is combined in the VC strategy. On the other hands, an ANN algorithm is used with the CC-CV technology. The simulation results show that an optimal energy efficiency is obtained without the intervention of the grid with the VC strategy, contrary to a constant current charge/discharge. Indeed, the CC-CV strategy offers natural protection of the lithium-ion batteries, and a maximum state of charge at 100% is obtained without using a protection algorithm. Finally, in future work, it will be interesting to investigate the response of the electrical system using the VC and CC-CV strategy in the case of a dynamic load.

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