PV System with Battery Storage Using Bidirectional DC-DC Converter

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Abstract: — With the increase in demand for generating power using renewable energy sources, energy storage and interfacing the energy storage device with the load has become a major challenge. Energy storage using batteries is most suitable for renewable energy sources such as solar, wind etc. A bi-directional DC-DC converter provides the required bidirectional power flow for battery charging and discharging mode. The duty cycle of the converter controls charging and discharging based on the state of charge of the battery and direction of the current. In this paper, a nonisolated bi-directional DC-DC converter is designed and simulated for energy storage in the battery and interfacing it with the DC grid. The power extracted from the solar panel during the daytime is used to charge the batteries through the DC-DC converter operating in buck mode and when solar power is unavailable, the battery discharges to supply power to DC load through the converter operating in boost mode. Solar arrays connected through a DC bus to a load. Due to the instantaneous changes of solar irradiance and temperature, maximum power point tracking (MPPT) is integrated in the inverter control. The technique of maximum power point tracking (MPPT) is used in photovoltaic systems to extract the maximum power. The most popular MPPT techniques are reviewed and studied, such as: Perturb and Observe, Increment of Conductance and control based on fuzzy logic (LF). The simulation is done in matlab/simulink and results are presented.

Keywords: — photovoltaic system, Boost converter, bidirectional DC-DC converters, MPPT.

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1. Introduction

Renewable energy sources offer a clean production of electrical power from sunlight, wind, biomass, tidal waves etc.

Renewable energy generation has grown greatly due to the concerns of climate change and the increase in oil prices. The growth in renewable energy has been very consistent in the last two decades. Not only the increasing concerns regarding climate change and the increase of oil prices but also the great support by renewable energy legislation and incentives with a close to 150 billion US Dollars in 2007 have brought this alternative source of electrical power generation [15]. Photovoltaic (PV) systems are one of the most popular renewable energy sources. It is an interesting energy source as it is not only renewable but also inexhaustible and non polluting unlike the conventional fossil fuels such as coal, oil and gas. These unique features have made power generation through Photovoltaic sources one of the most popular renewable energy sources in the last decade [3]. Photovoltaic convert sunlight into electrical energy using photoelectric effect. Sun's radiation is converted directly into usable electricity by photovoltaic systems. Photovoltaic (PV) systems are made of photovoltaic modules which are semiconductor devices that convert the solar radiation directly into electrical energy [3]. The power generated using solar energy is stored in batteries during the sunshine hours and is consumed during night. A lot of research has been done to improve the efficiency of the PV modules. A number of methods to track the maximum power point of a PV module have been proposed to overcome the efficiency limitation [10][17]. The use of the newest power control mechanisms called the Maximum Power Point Tracking (MPPT) algorithms leads to increase the efficiency of solar module operation and is effective in the field of utilization of renewable sources of energy. MPPT algorithm controls the power converters to continuously detect the instantaneous maximum power working point of the PV array [2][4][8]. Perturb and observe (P&O) methods are widely applied as an MPPT controller due to their simplicity and easy implementation.

The P&O methods involves a perturbation in the operating voltage of the PV array, Incremental conductance (IC) method, which is based on the fact that the slope of the PV array power versus voltage curve is zero at the MPP has been proposed to improve the tracking accuracy and dynamic performance under rapidly varying conditions [6][7], and Fuzzy logic MPPT method which doesn't need the knowledge about model of the system, Inputs of the fuzzy logic controller are the error of the system and the change of error[5][9][13] .This control is better suited for non-linear systems. An improved MPPT algorithm for PV sources was proposed to reduce the involved tracking time where a dc-dc boost converter was used to track the MPP and was brought out that tracking performance depends upon the tracking algorithm. The overall performances of the PV system depends on the type of the DC-DC converter used and the algorithm used for tracking the MPPT both of this parameter plays an important role in increasing the performance of the PV array [1][11].The main objective of this work is to model and analyze a photovoltaic system incorporating battery energy storage systems based on bidirectional DC-DC converters comparative study between the three performed algorithms which is incremental conductance algorithm , perturbs and observe algorithm and fuzzy logic. The boost converter used to compare in this study.

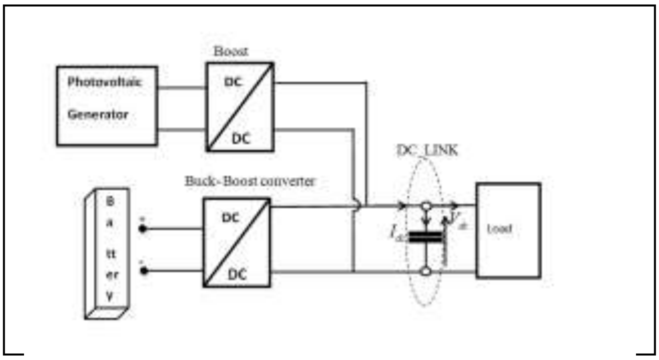

Figure 1 : Integration of battery energie storage system to solar PV panel

2. PV array

Photovoltaic devices are nonlinear devices. Their parameters are sunlight and temperature dependent. Sunlight is converted into electricity by photovoltaic cells. Photovoltaic arrays consist of parallel and series of PV modules. In order to form the panels or modules cells are grouped together. Not only a DC load can be fed by the voltage and current produced at the terminals of a PV but they can also be connected to an inverter to produce alternating current. Photovoltaic cell models have been used for the description of photovoltaic cell behaviors for researchers and professionals for a long time. The Single diode circuit model is among the most common models which are used to predict energy production in PV cells [3].

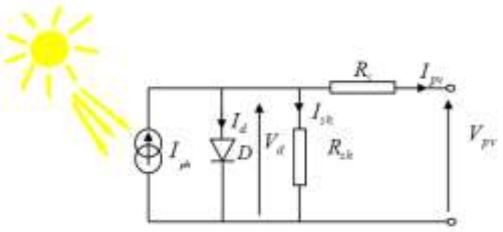

Figure 2 : Equivalent model of real cell

The equation relation of the output current and PV module

$$I_p = I_{ph} - I_d - I_{sh} \quad (1)$$

And :

$$V_d = V_p + R_s I_p \quad (2)$$

Photo-current of the module :

$$I_p = I_{ph} - I_s.[\exp(\frac{V_p + R_s I_p}{V_T}) - 1] - \frac{V_p + R_s I_p}{R_{sh}} \quad (3)$$

I_{ph} :photo-current,

I_{cc} **:** Short circuit current of the cell under the standard conditions reference (E_{ref} and T_{ref}),

E : Sunshine received by the cell (W/m^2),

E_{ref} : Reference sunshine,

K_{icc} : Current short-circuit-temperature coefficient (A/°C),

$V_T = \frac{n.K_B.T_j}{q}$: Thermodynamic potential

I_s : Inverse current saturation of the diode,

q : Charge of an electronn,

K_B : Constant of Boltezmann,

T_j : temperature of the junction(°C),

n: Ideal factor of the solar cell.

I_{pv} : Output current of the photovoltaic cell,

V_{pv} : Output voltage of the photovoltaic cell.

Incorporation of series resistance and shunt resistances provide accurate modeling opportunity of the PV cell as R_s corresponds to the internal losses due to current flow and R_p corresponds to the leakage current to the ground. Incorporation of series module (cells) n_s increases the output voltage of photovoltaic array and incorporation of the parallel module n_p increases the output current of the photovoltaic array. Manufacturers of PV modules provide reference values for specified operating condition such as STC (Standard Test Conditions) for which the irradiance is 1000 W/m^2 and the cell temperature is $25^{\circ}C$. Practical operating conditions are mostly different from the desired standard conditions, mismatch effects can also affect the real values of these mean parameters. The Simulink implementation of this photovoltaic model is shown in figure2. The Simulation was carried out for different levels of irradiances and also for different temperature levels. Irradiation level was varied from 0 W/m^2 to 1000 W/m^2 and the resultant P-V and I-V curves can be seen in Figure 3 and 4 .

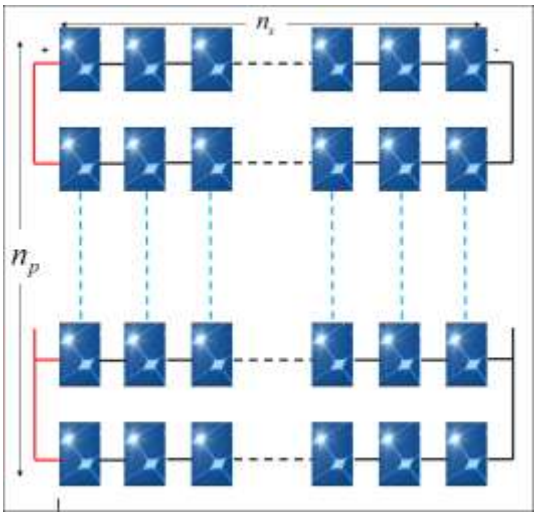

Figure 3 : PV generator

Ns	-Voltage are added -Current remains constant
Np	-Current are added -Voltageremains constant

The PV generator can be characterized by current / voltage curve, often called "characteristic I = f (V) and P = (V)". The following figure ensures the extraction of the optimum power from the photovoltaic generator.

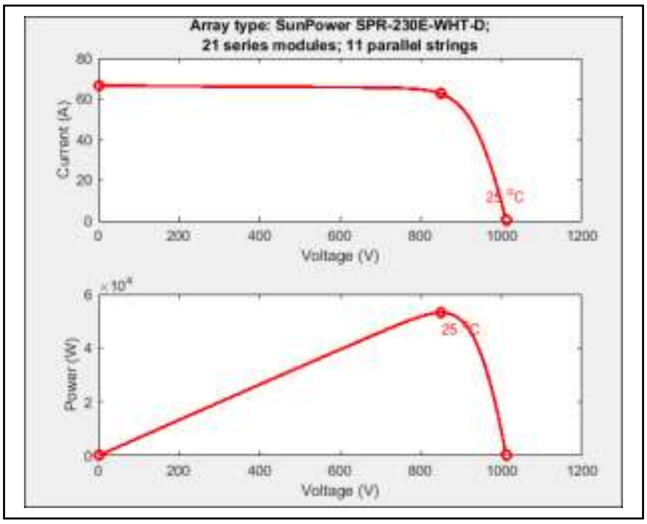

Figure 4 : Characteristic I = f (V) and P = (V).

Or the equations relation of the PV generator;

$$I_{pvg} = I_{phg} - I_{dg} - I_{shg} \quad (7)$$

$$I_{dg} = I_{sg}.[\exp(\frac{V_{dg}}{V_{Tg}}) - 1] \quad (8)$$

With the diode generator voltage is :

$$V_{dg} = V_{pvg} + R_{sg} I_{pvg} \quad (9)$$

$$V_{Tg} = n_s.V_T \quad (10)$$

Or

$$V_{phg} = n_p.V_{ph} \quad (11)$$

The overall current delivered by the PV generator is :

$$I_{pvg} = n_p I_{ph} - I_s.[\exp(\frac{V_d}{V_T}) - 1] - .\frac{V_p + R_s.I_p}{R_{sh}} \quad (12)$$

It is clear that the relationship between the output current and the voltage of the generator nonlinear because of the exponential. the result of simulating the generator current as a function of its voltage is a single representation where the output current is a constant during a well defined interval of the generator until it reaches a point where it begins to decrease. The figure shows Variation of the current and the power of the generator according to the voltage under different irradiations and at temperature equal to 25 ° C.

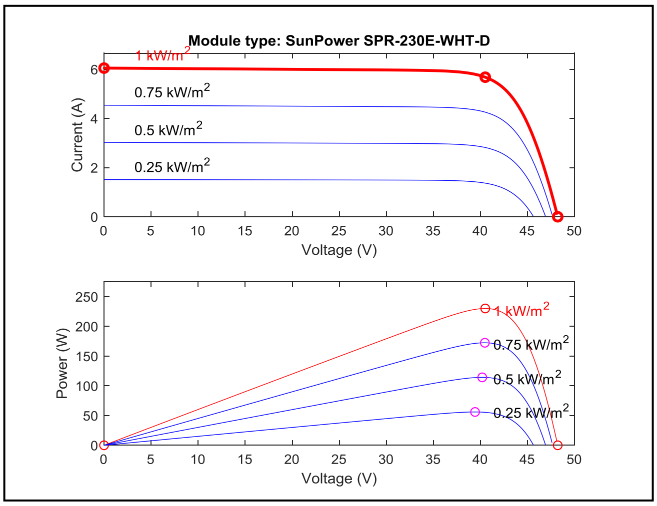

Figure 5 : Variation of the current and the power of the generator according to the voltage under different irradiations and at temperature equal to 25 ° C

The Simulation results obtained from the Figures 3 and 4 exhibit that the voltage variation with the change of irradiation is very little whereas with the increase in temperature the voltage decreases .Typically the voltage will decrease .It can also be seen that each curve has an operating point for a certain operating voltage at which the module produces the maximum power. This point is known as the Maximum Power Point(MPP). The aim is to operate the photovoltaic system at this maximum point to extract maximum power from the module. It can also be observed that at different levels of solar irradiation the open circuit voltages are almost the same and at different levels of temperatures the short circuit currents are almost the same. This in turn illustrates that at different levels of solar irradiation, the voltage at which maximum power point is located is almost the same. But at different levels of temperatures, the maximum power point is located at various operating voltages which are far from each other. This maximum power point varies at every instance and to have an efficient system it is necessary to track this maximum point at every instance of operation.

3. Maximum Power Point Tracking

The maximum power (MP) is obtained when the solar panel is being operated at the voltage where the global maximum of the P-V characteristic lies. It shows that for one specific operating point, the maximum power output can be obtained from the solar panel. This point in the P-V characteristic curve is called the Maximum Power Point (MPP). This point lies always on the knee of the I-V curve of the solar panel. In summary it can be concluded that on the I-V curve of the solar panel there is a point called MPP(Maximum power point) which always occurs on the knee of the curve where the generated PV power is maximized. This MPP changes with the change of the irradiation and temperature [4]. The irradiation and temperature are dynamic in nature, therefore the MPP tracking algorithm has to be working practically in real time by updating the duty cycle constantly and thereby keeping the speed and accuracy of tracking [8].

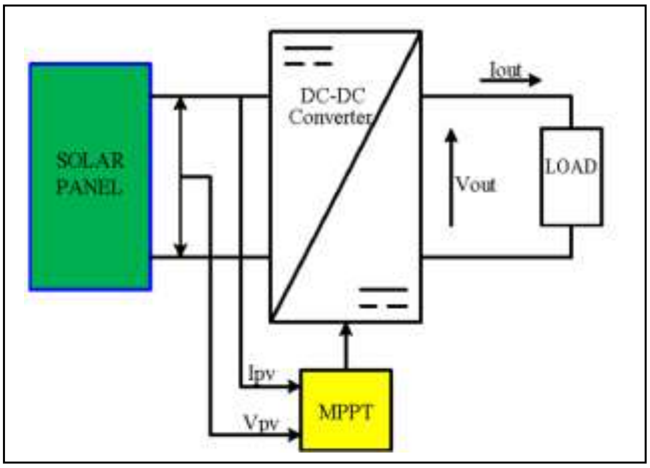

Figure 6 : MPPT schematic block diagram

The algorithm is executed by the MPPT controller to find the MPP. The measured output voltage and current of the solar panel are inputs of the controller. The algorithm performs its calculations depending on these inputs. The controller produces an output which is the adjusted duty cycle of the PWM. It drives the DC-DC converter‘s switching device. For every different operating point the controller produces a different duty cycle.

To obtain the maximum power from the solar panels, an efficient tracker algorithm is required for the MPPT. The tracker algorithm‘s task is to track the maximum power point of the solar panel as accurately as possible. The algorithm also has to be fast and reliable as well.There are several principles of operation of MPPT algorithms more or less successful based on the properties of the PV array.

And Table 1 summarizes the main specifications of the various and famous MPPT algorithms previously presented. Was evaluated and compared these algorithms in terms of complexity, precision, speed and technical knowledge of PV panel settings.

TABLE1 : Technical compare of MPPT

MPPT	P&O	InC	LF
Sensors use	1voltage 1current	1voltage 1current	1current
Identification pv panel parameters	Not necessary	Not necessary	Yes necessary
Complexity	low	medium	high
Number of iterations	45	48	27
Speed of convergence	medium	medium	very fast
Precision	95%	98%	99%

In this work, we interested t study the three famous algorithm :

3.1 Perturb and Observe (P&O) Algorithm

The principle of this control algorithm is to generate disturbances by reducing or increasing the duty cycle and observe the effect on the power output of the PV generator [6][7].

The P&O method operates periodically incrementing or decrementing the output terminal voltage of the PV and comparing the power obtained in the current cycle with the power of the previous cycle. If the voltage varies and the power increases, the control system changes the operating point in that direction, otherwise change the operating point in the opposite direction. Once the direction for the change of current is known, the current is varied at a constant rate. This rate is a parameter that should be adjusted to allow the balance between faster response with less fluctuation in steady state. The flowchart of this algorithm is presented in Figure 7.

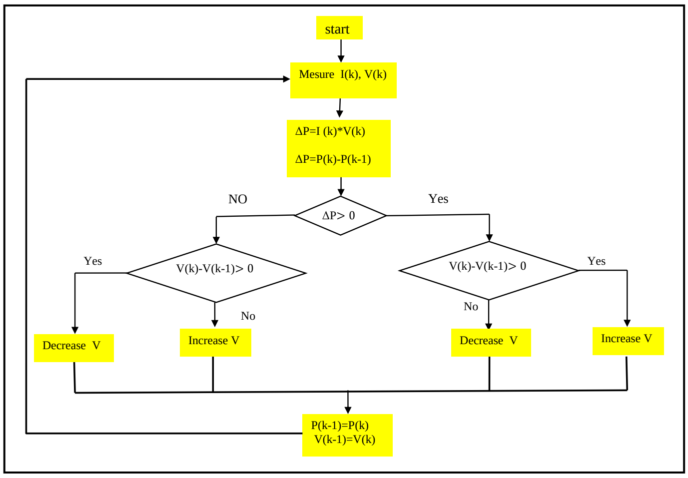

Figure 7 : P&O Algorithm

A modified version is obtained when the steps are changed according to the distance of the MPP, resulting in higher efficiency. A frequent trouble in P&O methods is that the output terminal voltage of the PV is perturbed every MPPT cycle even when the MPP is reached, resulting in loss of power.

3.2 Incremental Conductance (IC)Algorithm

The Incremental Conductance algorithm is an improvement to the Perturb & Observe Algorithm. This algorithm ensures higher accuracy and efficiency specially under varying atmospheric conditions. In spite of these advantages there are few drawbacks of this algorithm such as higher response time and it is also not economical for small scale PV plants [6]. The maximum power point is being tracked by the Incremental Conductance algorithm by means of comparing the module‘s instantaneous I-V characteristics and its incremental conductances (dI/dV). This algorithm can determine the distance to the MPP and thereby stop the perturbation and tracking procedure after it has reached the MPP [14]. The flowchart of the Incremental Conductance algorithm can be found in Figure 8. At maximum power point the slope of the P-V curve is equal to zero[7]. The following equations show these characteristics:

$$\frac{dP}{dV}=0 \quad (12)$$

$$\frac{dP}{dV}=\frac{d(V.I)}{dV}=V\frac{dI}{dV}+I\frac{dV}{dV}=V\frac{dI}{dV}=0 \quad (13)$$

Furthermore :

$$\frac{dI}{dV}=-\frac{I}{V} \quad (14)$$

In conclusion for Incremental Conductance algorithm,

$$\frac{dI}{dV} = -\frac{I}{V}, \text{ at MPP}$$

$$\frac{dI}{dV} \succ -\frac{I}{V}, \text{ left of MPP}$$

$$\frac{dI}{dV} \prec -\frac{I}{V}, \text{ right of MPP}$$

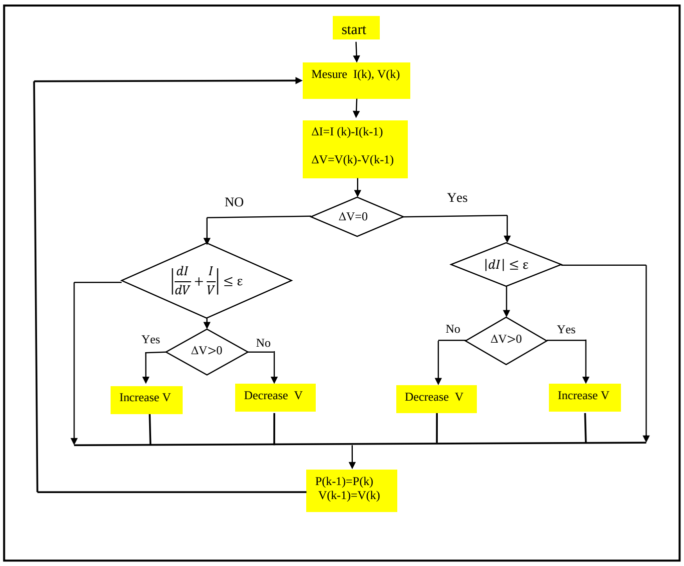

Figure 8 : Incremental Conductance Algorithm

3.3 Fuzzy logic

Conventional methods of tracking the optimal point of operation have shown their limits to sudden changes of weather and the load connected to the panel, several methods have emerged to try to alleviate these shortcomings and improve the operation of these generators. The approach of Artificial Intelligence in the case of fuzzy logic is implemented to improve control performance and the pursuit of maximum power point by simulation and modeling of a controller based on fuzzy logic [5][13]. The advent of microcontrollers has enabled the spread of fuzzy control in the pursuit of optimal points during the last decade[9].

The fuzzy controller has the following three blocks: Fuzzification of input variables by using the trapezoidal and triangular functions, then these variables fuzzification inference or are compared with predefined packages to determine the appropriate response. And finally the defuzzification to convert the subset fuzzification into values using the centric defuzzification. The five linguistic variables used are: NB (Negative Big), NS (Negative Small), ZE (Zero Approximately), PS (Positive Small), PB (Positive Big) [14][15]. The two FLC input variables are the error E and change of error CE at sampled times k defined by [13]: The operation of this algorithm is done in three blocks:

fuzzification, inference and defuzzification (figure 9).

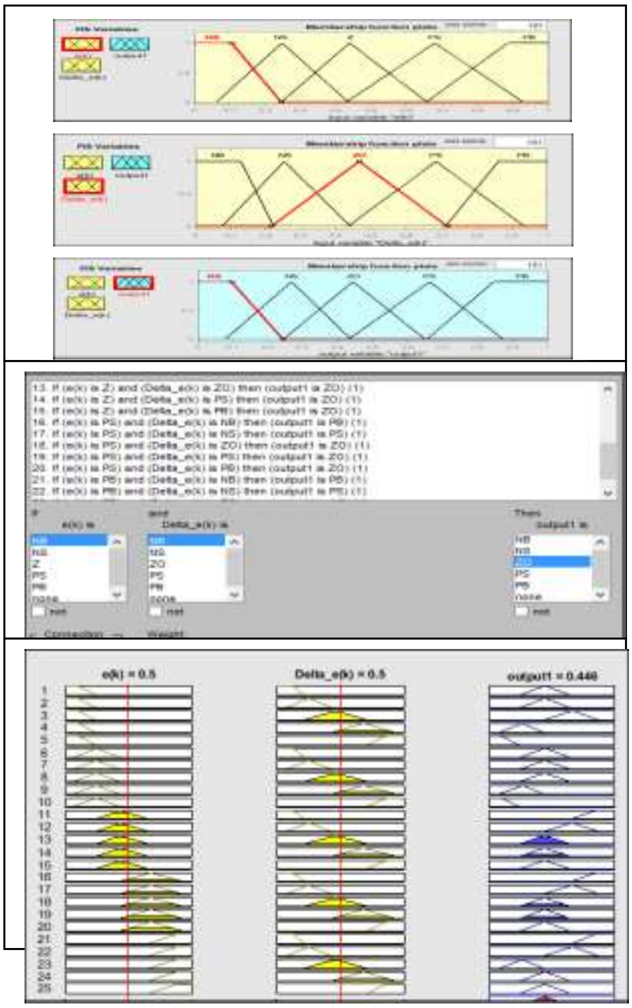

Figure 9 : Step of Fuzzy logic

Where P(k) is the instantaneous power of the photovoltaic generator. The input $\varepsilon(k)$ shows if the load operation point at the instant k is located on the left or on the right of the maximum power point on the PV characteristic, while the input $\frac{\partial\varepsilon(k)}{\partial t}$ expresses the moving direction of this point.

Table 2 : Fuzzy logic rules

ε / $\frac{\partial\varepsilon}{\partial t}$	PB	PS	ZE	NS	NB
PB	ZE	ZE	NB	NB	NB
PS	ZE	ZE	NS	NS	NS
ZE	NS	ZE	ZE	ZE	PS
NS	PS	PS	NS	ZE	ZE
NB	PB	PS	PB	ZE	ZE

4. Battery Storage

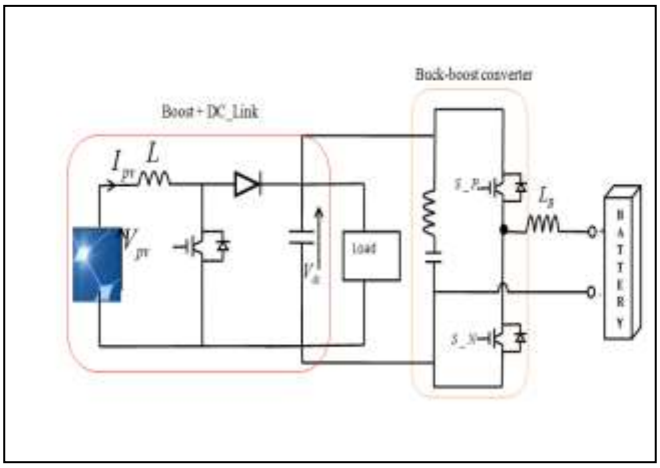

Figure 10 : Diagram of Photovoltaic system with Battery storage using bidirectional DC-DC converter

Bidirectional DC–DC converters are used to perform the process of power transfer between two dc sources in either direction. They are widely used in various applications. A bidirectional DC-DC converter is an important part of standalone solar Photovoltaic systems for interfacing the battery storage system. The circuit is operated in such a way that one switch, one coupled inductor and three diodes are used for step-up operation to boost the voltage of the battery to match the high voltage dc bus. The other switch, remaining diode and simple inductor are used for step down operation to charge the battery from the surplus PV energy. The high efficiency of the converter is achieved by optimizing components used for each step. The bidirectional DC-DC converter with high power rate plays a key role in the power storage system, while it converts DC voltage or DC current for the power storage battery. The Bidirectional DC-DC converter operates either as a buck or as boost converter at any instance. It works as a buck converter for charging the battery whereas it operates as a boost converter [12] while the battery discharges power to the load. From figure 14 it can be seen that the PV voltage source has immediately next to it a boost converter stage powered by MPPT controller which will step up the PV voltage to the desired DC bus voltage extracting maximum power from the PV system at every instance of operation. It is then followed by a couple of IGBTs and a battery acting as a secondary source. The Bidirectional DC-DC converter operation is carried out through these two IGBTs which are controlled by two different controllers. One controller provides the control signal for Boost operation and the other provides the control signal for Buck operation. It operates as a buck converter for charging the battery through the switching actions performed by the switch S3. On the other hand its operation as a boost converter is dictated by the switching actions of the switch S2 .

For the proper functioning of the hybrid energy system, the storage system plays a crucial role, it allows for continuity of service and better quality of energy supplied. We recall some electrical parameters used to characterize a battery, these are:

• Nominal capacitor (Qn): This is the maximum number of ampere-hours (Ah) that can be extracted from the battery, for given discharge conditions.

• The state of charge “SOC” (State Of Charge): This is the ratio between the capacity at time q(t) and the nominal capacity Qn, is :

$$SOC(t) = \frac{q(t)}{Qn}, \text{ with } (0 \le SOC \le 1) \quad (15)$$

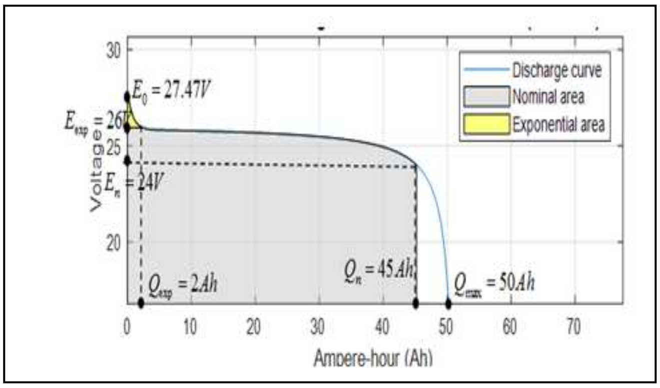

figure 11 : Battery discharge curve

If SOC=1 the battery is totally charged and if SOC=0 the battery is totally discharged.

• The charging cycle (or discharging): This is the parameter which reflects the relationship between the nominal capacity of a battery and the current at which it is charged (or discharged). It is expressed in hours.

•Cycle life : This is the number of charge/discharge cycles that the battery can sustain before losing 20% of its nominal capacity.

By analyzing the figure above, we can see the presence of three specific points on the characteristic (Q-V): these three points are: the full load voltage (E0), the voltage corresponding to the end of the exponential zone (Eexp) and the corresponding voltage at the end of the nominal zone (En).

The charge and discharge equations are given as follows :

*Discharge :

$$E_B = E_0 - Ri - K\frac{Q}{Q-i_t}(i_t + i^*) + E_{exp(t)} \quad (15)$$

*Charge :

$$E_B = E_0 - Ri - K\frac{Q}{Q-i_t}i^* - K\frac{Q}{Q-i_t}i_t + E_{exp(t)} \quad (15)$$

With :

$$E_{exp(t)} = B|i(t)|.(-E_{exp(t)} + Asel(t))$$

Figure 12 shows the discharge characteristic of the storage system used and the evolution of its voltage for different discharge currents.

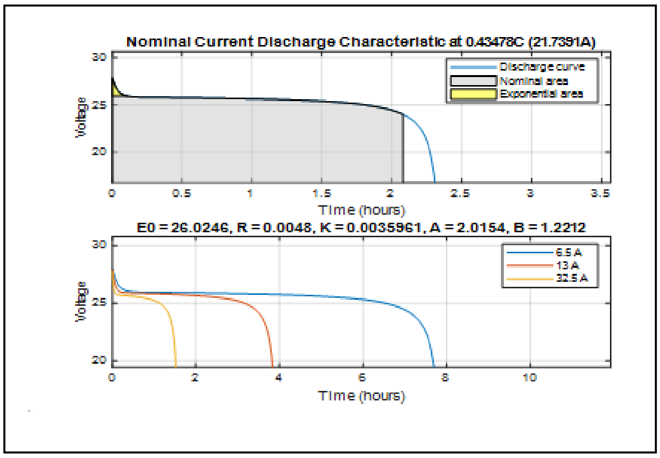

Figure 12 : Battery voltage characteristic for different discharge currents.

The bidirectional DC DC converter is a combination of boost and buck converters. Such a converter is used to charge and discharge the battery.

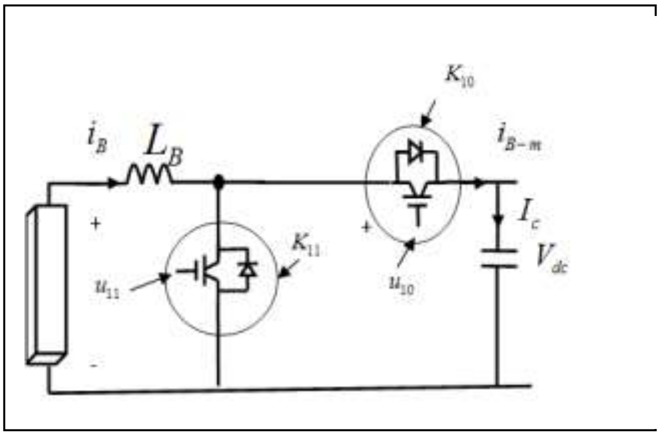

Figure 13 : Circuit of the DC–DC bidirectional converter

4.1 Boost Mode

The boost mode is applied for the discharging procedure of the battery storage. Figure shows the circuit of the boost mode operation of the converter, where the direction of the inductor current is from the lower voltage side to the higherK1 voltage side . The averaged large signal inductor current, i_L , and the DC-bus output voltage, V_{dc} , in a continuous conduction mode (CCM) of operation can be found using the equations below.
is closed $K_{10}=0$ and is open $K_{11}=1$.

$$L\frac{di_B}{dt}=V_B-V_{dc} \tag{14}$$

4.2 Buck mode operation

The buck mode is applied for the charging process of the battery storage. Figure presents the circuit of the buck mode operation converter. In contrast to the buck mode operation, the inductor current flows from the higher voltage side to the lower voltage side . The averaged large signal inductor current, i_L , and the output battery voltage, V_B, are calculated by the equations below, and describe the buck-mode operation in a CCM of the converter.
is open $K_{10}=1$ and is closed $K_{11}=0$

$$L\frac{di_B}{dt}=V_B \tag{15}$$

By analyzing these two configurations, we can conclude that the relationships between the input quantities (V_B, i_B) and the output quantities (V_{dc}, i_{B-m}) of the converter are given by the system of equations below

$$\begin{cases} L\dfrac{di_B}{dt}=V_B-V_{dc}(1-u_{11}) \\ i_{B-m}=I_B(1-u_{11}) \end{cases} \tag{16}$$

4.3 Quadratic DC bus control

Due to the intermittent and fluctuating character of hybrid systems (pv and wind), the voltage at the DC bus will be disturbed and fluctuating. This is why the DC bus voltage must be kept constant at its reference. In this case, the value of this voltage V_{dc} must be well chosen for proper operation of the PV system connected to the grid.

The capacitor at the input of the inverter has two essential tasks:

a) In steady state, it keeps the DC bus voltage constant with low oscillations.

b) it serves as an energy storage element to compensate for the difference in actual power between the load and the source during transient periods.
Figure 13 shows the DC bus voltage regulation loop to generate the reference power. The DC bus control generates the fluctuating power in the DC bus capacitor, subtracted from the power at the output of the inverter, giving us the reference active power that must be fed into the grid. A dynamic reference of reactive power, allows us for small powers to impose a zero reactive power.

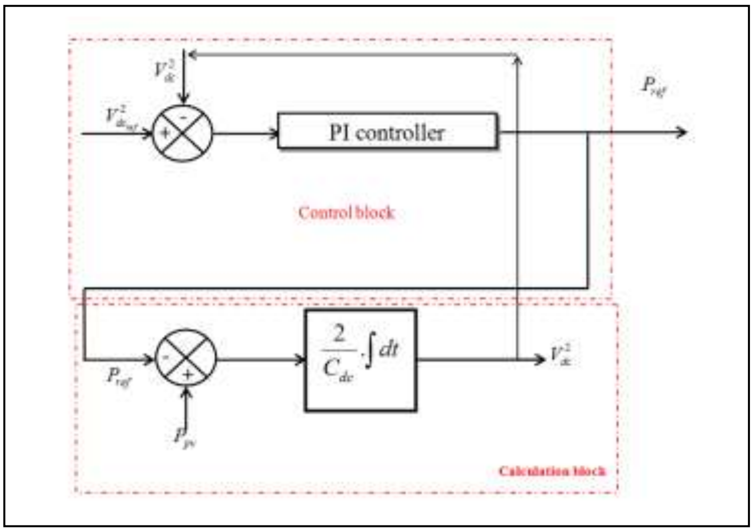

figure 14 : Quadratique control of DC bus

The DC power is :

$$P_{dc}=I_{dc}.V_{dc} \tag{17}$$

Then :

$$P_{dc}=\frac{1}{2}C_{dc}.\frac{dV_{dc}^2}{dt} \tag{17}$$

C_{dc} : the DC bus capacitor.
So :

$$V_{dc}(n)=\left[V_{dc}^{2}(n-1)+\frac{2Te}{C_{dc}}(P_{pv}(n)-P(n)\right] \quad (17)$$

Te : Sampling period

The control strategy is divided into two blocks the first is for the calculation and the second is reserved for the control.

5. Simulation and result

All simulations and results, of the previous algorithms studied, were performed under the same condition to ensure that the circuit comparison can be determined accurately. Input, output, voltage, current, and power are the primary comparison to consider. The complexity and simplicity of the circuit was determined on the basis of the literature. Convergence speed, required hardware and efficiency range. Table 3 takes an illumination of 1000 and a temperature of 25 as the initial value.

Table 3: Electrical characteristic of PV panel

Size	Value
Open circuit voltage Voc (V)	36.3
Voltage at maximum power point Vmp(V)	29
Short-circuit current Isc (A)	7.84
Current at maximum power point Imp (A)	7.35
Diode saturation current Is (A)	2.9259 e-10
Shunt resistance Rp (ohms)	313.3991
Series resistance Rs (ohms)	0.39383
Maximum power point tracking	213.15
Series-connected modules per string Ns	1
Parallel strings Np	5

The irradiation equals $1000W/m^2$ and the battery current is around -20 A. The state of charge (SOC) is increasing so it means the battery is charging and PV side power is 1000W. The Bus voltage is around 48 V. When the irradiation is decreased $700W/m^2$ the battery current is decreased around -10A. The moment of the changing irradiation the system is unstable and then a few seconds later the system returns stable. Decreasing the irradiation of $400W/m^2$ the battery current is zero.

We can say the battery is disable.

I want to decrease irradiation to $0W/m^2$ and the battery current is around 15 A. The state of charge (SOC) is decreasing so it means the battery is discharging and PV side power is $0W/m^2$. Then the PV power is disabled. When the irradiation is equal $400W/m^2$ the SOC is stable and the current battery is zero. So the battery is disable. When we increase the irradiation to $600W/m^2$ the battery is charging because the SOC is increasing and the battery current is negative. PV power is increasing. Then the bus voltage is constant.

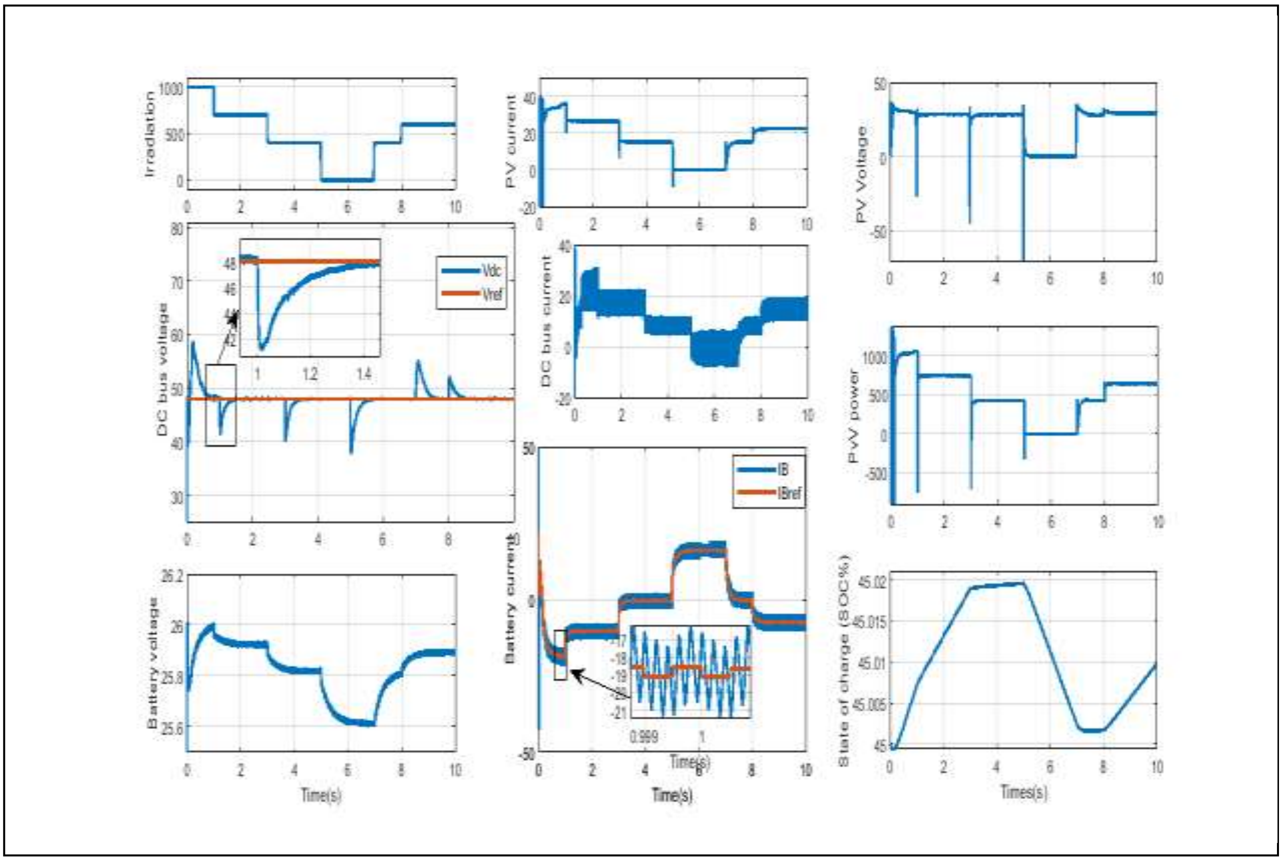

Figure 15 : Characteristic of pv with battery based on Perturb & Observe algorithm

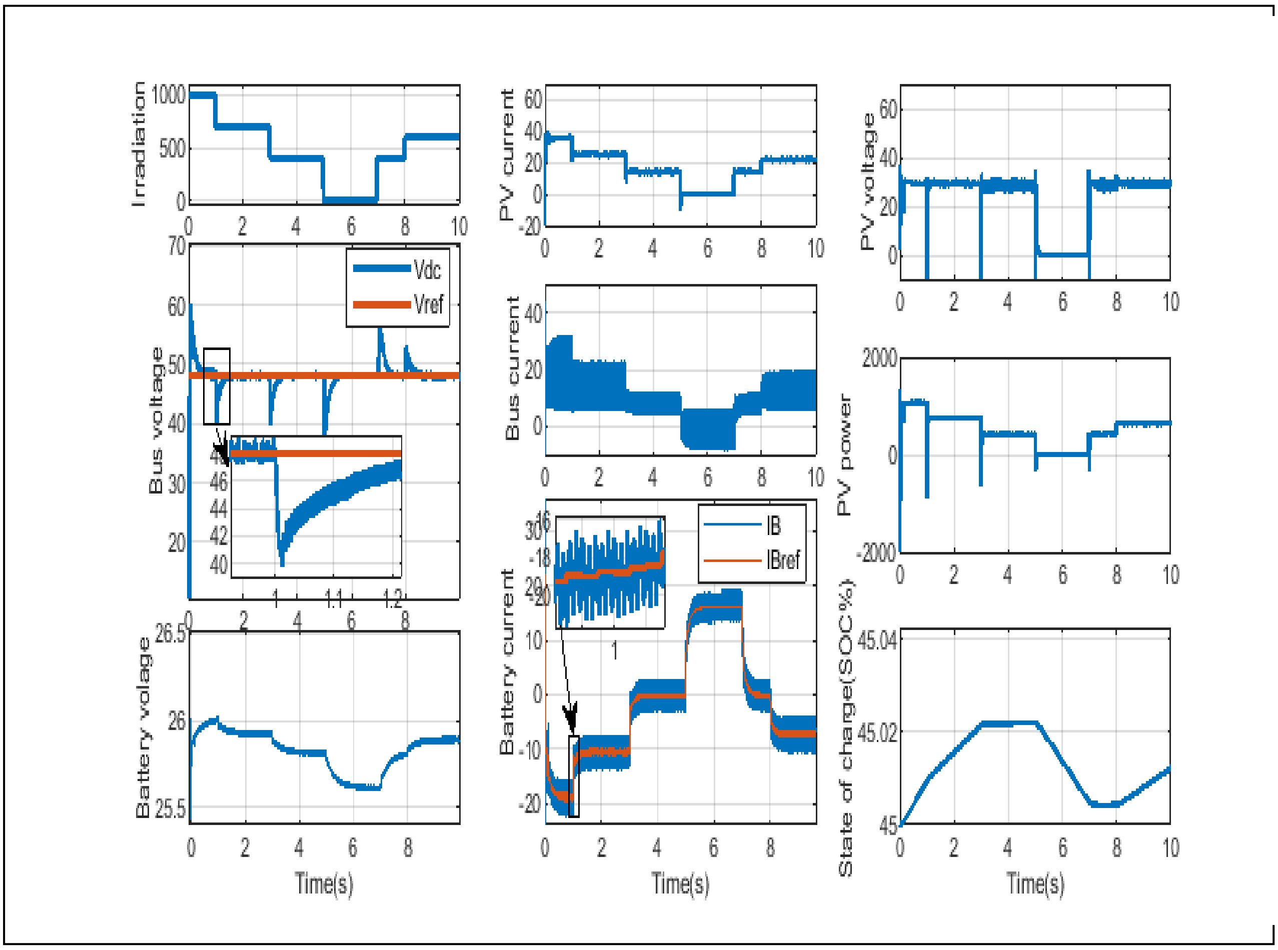

Figure 16: Characteristic of pv with battery based on incremental Conductance algorithm

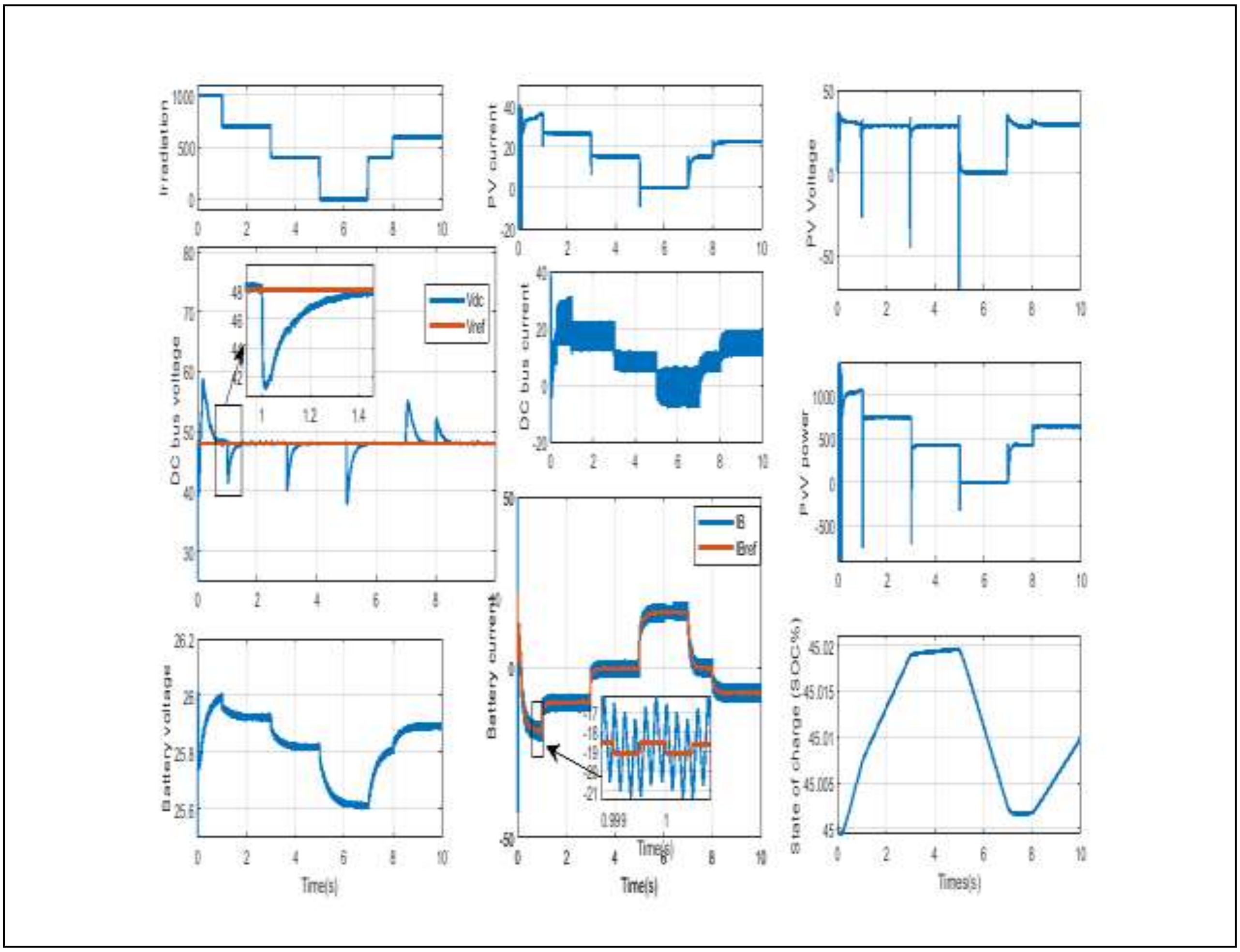

Figure 15 : Characteristic of pv with battery based on Fuzzy logic algorithm

Moreover, to evaluate the performance the proposed MPPT, the PV is exposed to different levels of irradiance that is changed randomly and rapidly (although normal solar irradiance does not abruptly, but this would happen in partially shaded PV systems. According to the obtained results presented in Figures 15,16 and 17 the MPPT algorithm tracks the values of maximum power. In each case, the power extracted from the PV is well controlled. The results prove that the convergence speed is relatively high.
To evaluate the performance of the PV with load, a comparison between the three methods of MPPT with battery storage. PV maximum power and that computed from the algorithm is carried out for different values of solar irradiance and the results are plotted . Moreover, the corresponding tracking efficiencies of the proposed MPPT under different irradiance levels are computed and presented in the figures of the simulation part..
According to the obtained results, the tracking efficiency is not less than 95 %.

Therefore, the proposed method guarantees good tracking efficiency under different operating conditions.

Discussion:

* The P&O algorithm is a classic and simple algorithm. In general, this algorithm depends strongly on the initial conditions and it oscillates around the optimal value. The major drawback of this algorithm is its poor behavior following a sudden change in illumination (clouds).

* The INC algorithm appears to be an improvement of the P&O algorithm. Indeed, it behaves better during a rapid change of meteorological conditions. However, this is a more complex algorithm than the previous one. Algorithms based on measuring a fraction of open circuit voltage or a fraction of short circuit current are very simple and easy to implement. The major drawback is the loss of energy and the stopping of power transfer when measuring the quantities Voc and Isc. To overcome this problem, a pilot cell of the same type as the panel cells is used. In addition, determining the optimum value of the parameter k is very difficult. Therefore, these methods seem just an approximation and they do not have enough precision and as a result the system does not always perform at the optimum point.
* The fuzzy logic algorithm is a robust and efficient algorithm. Indeed, this algorithm works at the optimal point without oscillations. In addition, it is characterized by good behavior in transient state. However, the implementation of this type of algorithm is more complex than traditional algorithms. In addition, the efficiency of this algorithm depends heavily on the inference table. The following table summarizes the main specifications of the various MPPT algorithms previously studied. We evaluated and compared these algorithms in terms of technical knowledge of PV panel parameters, complexity, speed and precision.

T=4s	P&O	INC	Fuzzy
Vpv (V)	28.4	28.6	28.71
Ipv (A)	20	20.01	20.14
Ppv (W)	425	425.01	426.02
VB (V)	25.83	25.9	26.1
SOC(%)	45.018	45.022	45.019

Also the battery characterized is changed with the variation of irradiation and the change of three MPPT algorithms . We can conclude that both the boost converter and the battery are affected by the mppt algorithm.

6. Conclusion

This work describes the main elements of the PV system. Then, we recalled the principle of three most popular MPPT algorithms. Finally, we ended with a simulation of the different algorithms. The simulation results show that the INC algorithm performs better than the P&O and the fuzzy logic based control shows good behavior and better performance compared to the P&O, INC. These algorithms improve the dynamics and steady state performance of the photovoltaic system as well as it improves the efficiency of the dc-dc converter system.

At the end of this work, several direct perspectives are announced and the following points are quoted by way of illustration :
 Experimental realization with a load also with the network.
 New strategies for the MPPT command.
 Study of diagnostic algorithms and fault isolation of the PV system.
 Study of fault-tolerant control algorithms.

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Conflict of Interest

The authors have no conflicts of interest to declare that are relevant to the content of this article.