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Research Paper

Investigation of the major internal and external factors that affect photovoltaic modules energy production and systems performance

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A B S T R A C T

Photovoltaic conversion is an optimal solution for the electrification of rural areas, especially deserts for the abundance of solar energy in these regions. In recent years, many studies have been carried out to maximize the energy productivity of a PV array system and increase its efficiency. However, the arid and semi-arid region is characterized by a climate whose parameters significantly influence the operation of PV installations. This paper presents an overview investigation of the major internal and external factors significantly affecting both the efficiency and the performance of solar cells and the power of PV systems. These factors include the type of PV material, solar radiation intensity received, cell temperature, parasitic resistances, cloud, and other shading effects, inverter efficiency, dust, module orientation, weather conditions, geographical location, and cable thickness. Simulation of a PV system has been carried out in MATLAB-SIMULINK to prove the effectiveness of the proposed modeling method. These simulation results are useful to predict the production of the PV module under real operating conditions.

1. Introduction

The production of energy is a challenge of great importance for the years to come. Indeed, the energy needs of industrialized societies are constantly increasing. On the other hand, developing countries will need more and more energy to carry out their development. Today, much of the

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world's energy production comes from fossil sources. The consumption of these sources gives rise to greenhouse gas emissions and therefore an increase in pollution. The additional danger is that excessive consumption of the natural resource stock reduces the reserves of this type of energy in a way dangerous for future generations. The production of electricity by clean means (non-polluting) has become a primary necessity to satisfy the power supply of future generations. Then the new clean, renewable, sustainable, and inexhaustible sources will have to be used which makes it possible to guarantee the satisfaction of the demand for electrical energy. Renewable energies can be classified into two main families, solar energy (via photovoltaic panels), or energy in the form of heat (geothermal, solar thermal, etc.).

Improving the conversion efficiency of solar panels has become a challenging area of study for researchers. These researchers have shown that the performance of different PV technologies depends on the specific climatic conditions of the location. In general, many random physical and meteorological factors can have a huge impact on the PV output power including solar radiation, latitude, partial shading, ambient temperature, accumulation of sand dust, and wind speed [8]; [13]; [26]; [39]. Thus, knowledge of the performance of PV systems under real operating conditions is essential for choosing the right product and accurately forecasting power generation.

In recent years, many studies have been carried out on the degradation of photovoltaic modules and operational lifetime of different types of PV modules from various manufacturers when exposed to natural environments to observe degradation in reality [9]; [21]; [30]. Azizi et al found that a photovoltaic module suffers from degradation over time which reduces its performance [4]; [23]. The maximum power point is indeed dipped through time with a degradation rate that varies in an, unlike manner according to the location and the technology of the photovoltaic installation [40]. In the Algeria desert, Bandou et al found that, 30.24 kWp installations after 28 years degradation rates about 1.22%/yr [5]. In Ghana, David A. et al found that degradation rates of mc-Si PV modules after 16 years about 1.54%/year [11].

This work examines the important factors affecting the solar panel efficiency and output of a PV system. The various factors contributing to the performance of solar power plants. Some of these factors include the type of PV material, internal PV cell, solar radiation intensity received, cell temperature, parasitic resistances, degradation cloud, and other shading effects.

The paper is divided into seven sections. The second section describes the faults occurring in a PV system. The third section is dedicated to methods for detecting defects related to photovoltaic systems. The fourth section describes the grid connected Photovoltaic PV system.

The fifth and sixth sections section studies the internal and external parameters that affecting the PV cell. The seventh section and last section conclude the paper.

2. Factors affect the efficiency and performance of Photovoltaic array

The faults occurring in a PV system are mainly related to the PV array, the inverter, the storage system, and the electrical grid. Fig 1 shows the factors that affect the efficiency and performance of the PV array.

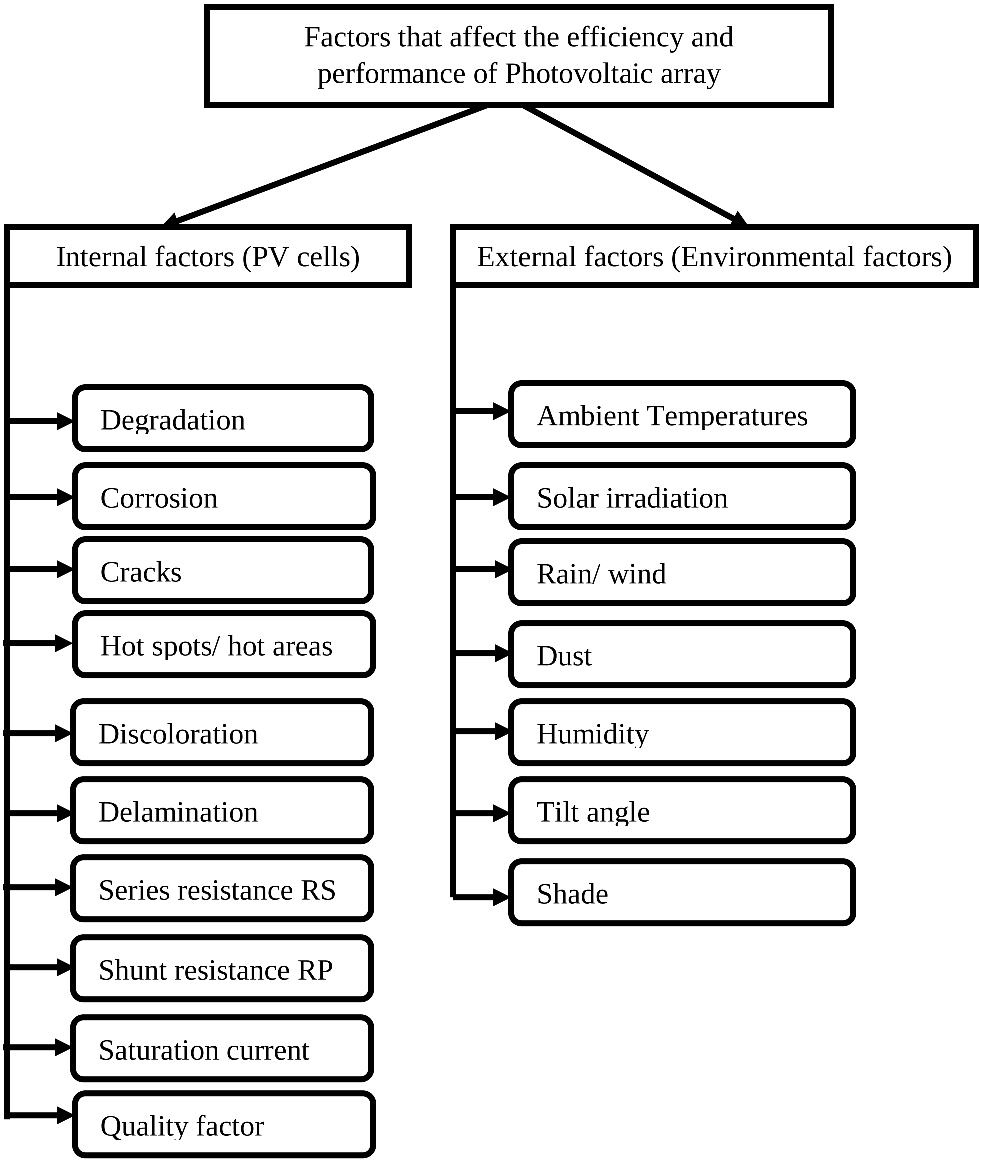

Fig. 1. Factors that affecting both the efficiency and the performance of solar PV module [16]

3. Methods for detecting defects related to photovoltaic systems

To evaluate the operational and quality of photovoltaic modules, there are several detection methods, which can depict an objective view of the technical condition of photovoltaic modules. Among the most used fault detection methods occurring in the PV array cited in the literature summarized in Fig 2:

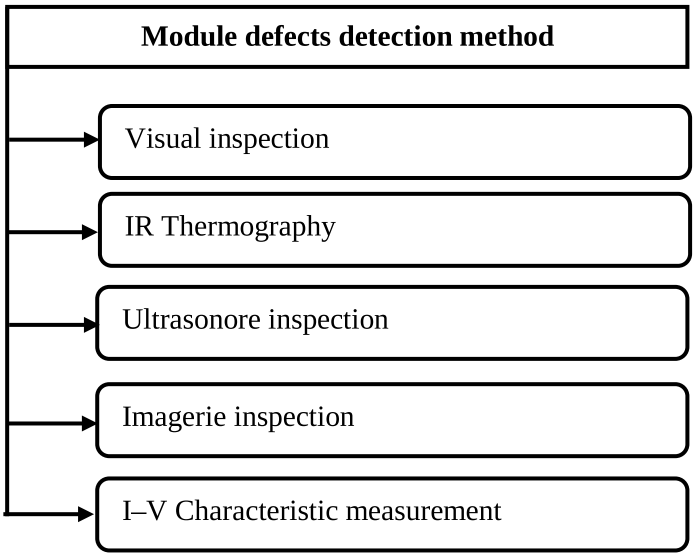

Fig. 2. PV module defects detection method [3]; [10]

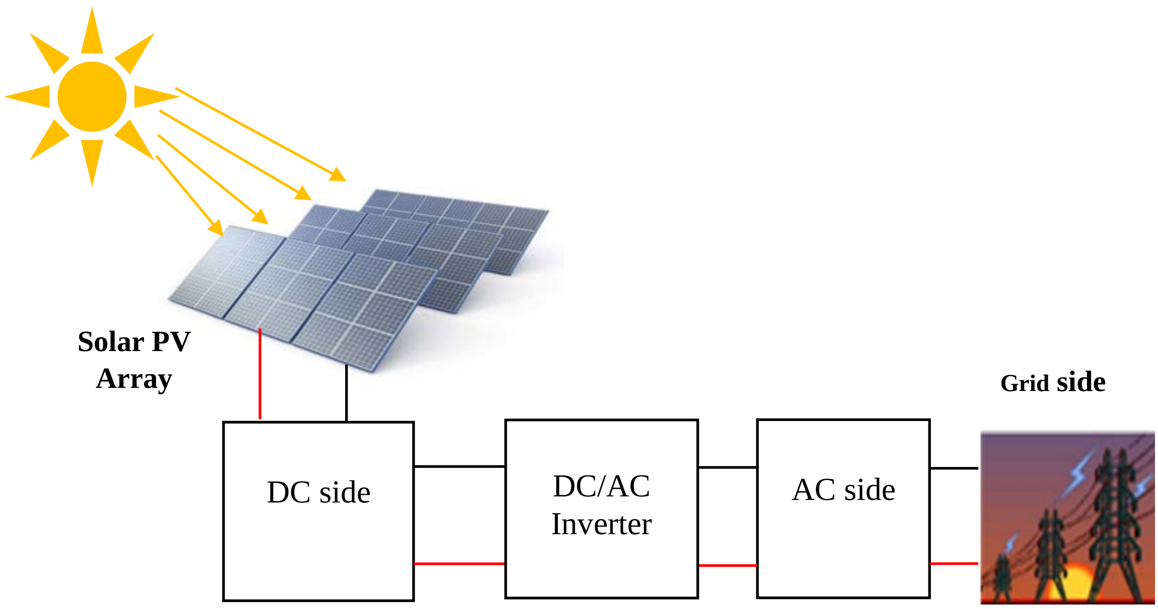

Fig. 3. General block diagram of single-stage grid connected PV system

4. Grid connected Photovoltaic PV system

As shown in Fig 3, the single-stage photovoltaic PV system chain includes a solar PV array source and a PWM inverter connected to load.

4.1 Modelling of PV array

As shown in Fig. 4, the equivalent circuit of the PV cell (Single diode model) is composed of photocurrent source, diode, parallel resistor, series, and shunt resistor describing the internal resistance to the current flow. The basic equation that describes the I-V characteristic of a single diode model of PV cell is given as [8]; [38]:

$$\begin{cases} I = Iph - Is\left(exp\left(\frac{V+RsI}{aV_T}\right)-1\right)-\frac{V+RsI}{Rsh} \\ V_T = \frac{N_s kT}{q} \\ I_{ph} = \frac{G}{G_r}\left[I_{pvn}+K_1(T-T_r)\right) \\ I_0 = I_{on}\left(\frac{T_r}{T}\right)^3 \exp\left[\frac{qE_g}{ak}\left(\frac{1}{T_r}-\frac{1}{T}\right)\right] \\ I_{on} = \frac{I_{scn}}{\exp(\frac{V_{ocr}}{aV_{Tr}}-1)} \end{cases} \tag{1}$$

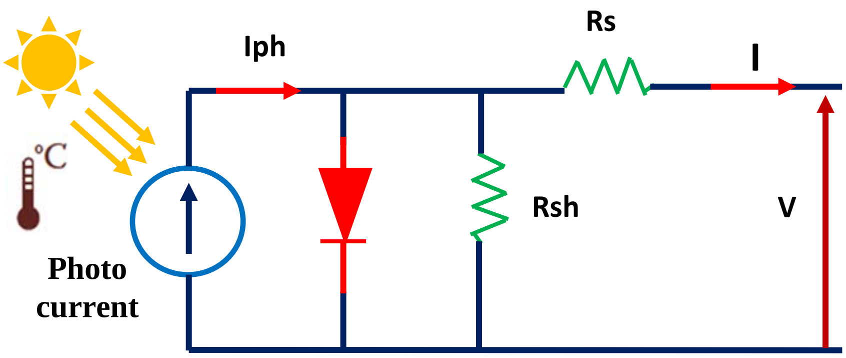

Fig. 4. Equivalents circuits of photovoltaic cell (Single diode model)

The output current of the PV array is given by the following expression [32], [33].

$$I = I_{ph} - I_0 N_{pp}\left[exp\left(\frac{V+R_s\left(\frac{N_{ss}}{N_{pp}}\right)I}{V_T a N_{ss}}-1\right)\right]-\frac{V+R_s\left(\frac{N_{ss}}{N_{pp}}\right)I}{R_{sh}\left(\frac{N_{ss}}{N_{pp}}\right)} \tag{2}$$

Where:

- I, I_{ph} and I_0 are the current array, the photo generated, and the reverse saturation current respectively.
- V , V_T are the array voltage and the thermal respectively.
- a is the diode ideality factor for the single diode model.
- R_s , R_{sh} are cell series and shunt resistance
- N_{ss} , N_{pp} are the number of modules in series and parallel.
- q is the electron charge [$1.60217646*10^{-19}$C].
- k is the Boltzmann constant [$1.3806503*10^{-23}$J/K].
- T is the temperature of the cell, Tr is the reference temperature of the cell, Eg is the width of the band-gap, G is the irradiance in W/m^2, Gr is the reference irradiance (1000 W/m^2).

The single-diode model is easy to set up, simplest approach, less number of unknown parameters, plus the shorter computation time, under STC, compared to the two-diode model, sufficient to describe the behavior and the characteristics of most photovoltaic cells. It can therefore be applied in the majority of models, particularly in the case of rapid variations in climatic conditions. In addition, the most widely used model in PV system simulation. However, for applications in real weather conditions, the two-diode model is preferable because it takes into account losses and all physical phenomena at the level of the photovoltaic cell and is, therefore, more precise compared to the one-diode model. The single diode model does not adequately represent the behavior of the cell when subjected to environmental variation, especially at low irradiation. The two-diode model is not mentioned in this study due to the length of this work.

According to IEC standard 61724, the performance ratio is the ratio between the actual energy and the expected energy yield of a site under environmental conditions [17]. International Standard IEC 61724 has been prepared by The IEC (International Electrotechnical Commission) technical committee in the first1 April 1998. This International Standard recommends methods and terminology for performance monitoring and analysis of photovoltaic (PV) systems.

$$PR = \frac{G_T * E_{out}}{G_{stc} * P_{max}} \tag{3}$$

Where:

E_{out} : [kWh] Energy output from PV system (AC), so after the inverter.

P_{max} : [kW] array power rating (DC) the total DC power output of all installed PV modules at the power rating reference condition, (STC reference values irradiance 1 000 W/m^2, at normal incidence, PV cell temperature 25 °C).

G_T : [kWh/m^2] in-plane irradiation.

G_{stc} : [kWh/m^2] irradiance at reference condition, (STC reference values irradiance 1 000 W/m^2, at normal incidence, PV cell temperature 25 °C).

The fill factor (FF) is defined as the ratio of the maximum power output from the solar cell to the product of open-circuit voltage (Voc) and short circuit current (Isc).

$$FF = \frac{I_m V_m}{I_{sc} V_{oc}} \tag{4}$$

The efficiency is the ratio of the total energy produced by the PV module to the total solar energy incident on the PV module [8]; [26]:

$$\eta = \frac{P_{out}}{P_{in}} = \frac{FF I_{sc} V_{oc}}{P_{in}} = \frac{FF I_{sc} V_{oc}}{GA} \tag{5}$$

Where

A: module surface (m²), I_{sc} : Short circuit current,V_{oc} : Open circuit voltage.

Table 1. Solarex MSX-60 PV module and PV array electrical specifications

Parameters	Solarex MSX-60 PV module PV module	PV array
Type of the PV cells	Polycrystalline silicon	polycrystall ine
Typical peak power (P_{MPP})	60W	6000W
Voltage at peak power (V_{MPP})	17.1V	342 V
Current at peak power (I_{MPP})	3.5A	17.5A
Open-circuit voltage (Voc)	21.1V	422V
Short-circuit current (Isc)	3.8A	19 A
Temperature coefficient of open-circuit voltage Voc	-(80±10)mV/°C	/
Temperature coefficient of short-circuit current(µsc)	(0.065±0.015)%/°C	/
Temperature coefficient of power	-(0.5±0.05)%/°C	/
Number of PV cells connected in series (Ns)	36	/

We consider for this study the Solarex MSX-60 PV module as an example for simulation and details of the sheet technique are shown in table 1. This PV module consists of 36 solar cells constructed from polycrystalline silicon and configured as two 18-cell series strings. The MSX 60 provides 60 watts of nominal maximum power. The PV array characteristics chosen are summarized in table 1. It consists of 20 modules in series and 5 modules in parallels.

Simulink model of MSX-60 PV module PV directly connected to a variable resistive load is shown in Figure 5. The main factors affecting internal and external PV performance that cause a decrease in the PV panel's power can be divided into two categories.

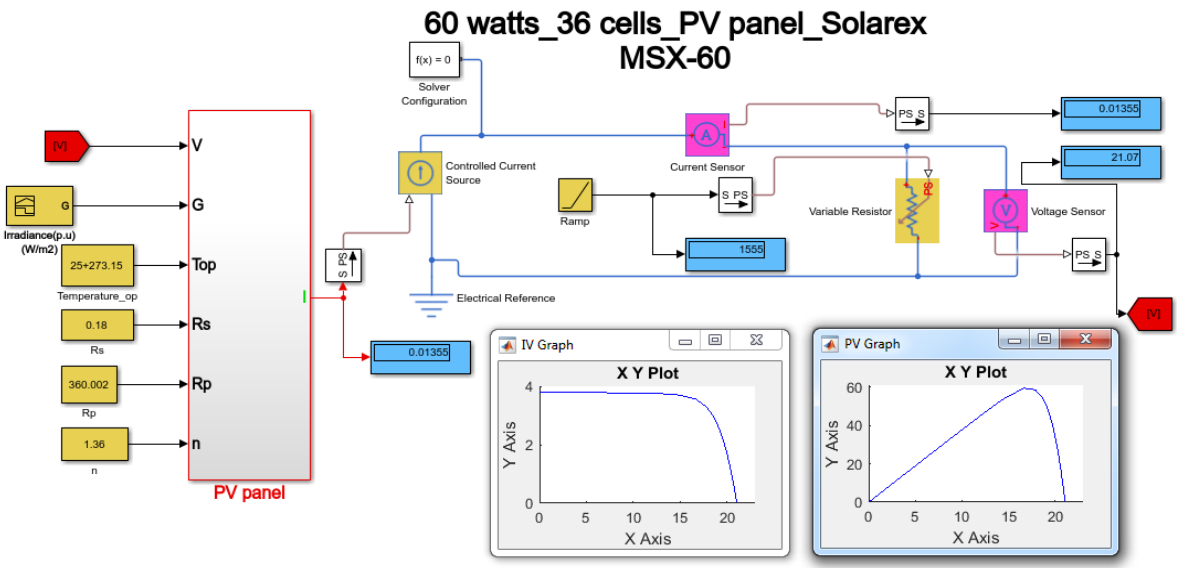

Fig. 5. Simulink model of MSX-60 PV module PV directly connected to a variable resistive load.

5. Internal parameters

Knowing the influence of these parameters on the characteristic of the model is very important to then be able to classify the type of fault responsible for the variation of these parameters. The studies of the influence of the model parameters on the characteristic of the PV cell will be examined in this part. In order to analyze the behavior of the PV model, simulation is carried out in MATLAB/Simulink environment.

5.1. Influence of series resistance

Fig 6 show current-voltage curve for various series resistance (R_s(mΩ) = 10, 20, 30,40 and 50). It can be seen that the series resistance of the module R_S influences significantly the photovoltaic output power. When it is high, it decreases the short circuit current value (Isc). It has a large impact on the slope of the curves I= *f (V)*.

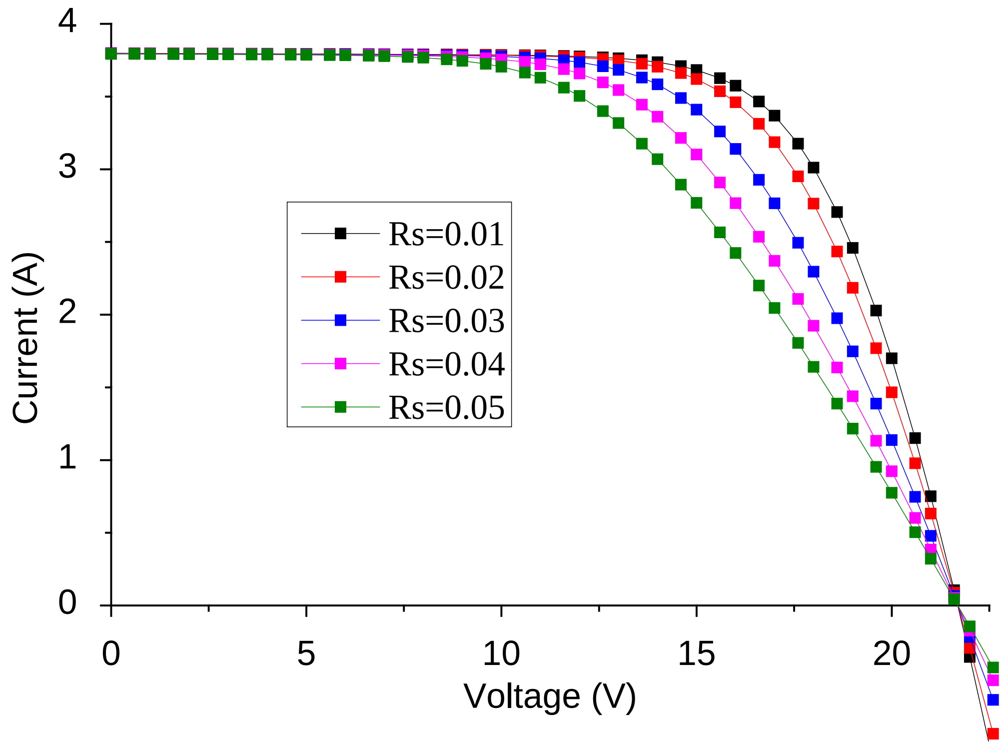

Fig. 6. Series resistance influence on I(V).

5.2. Influence of the diode ideality factor

Fig. 7 show the *I-V* curve for several diode factor ideality (n = 1, 1.2, 1.4, 1.6). The ideality factor is one of the diode I-V characteristics parameters. It depends on the voltage across the cell. The effect of their variations on the I-V curve resembles the effect of temperature. From these results, it can be seen that this factor does not influence the short-circuit current. On the other hand, the open-circuit voltage varies proportionally as a function of this factor. The increase of the diode ideality factor inversely affects the area or point of maximum power and this is reflected by a decrease power level of the area of operation.

5.3. Influence of saturation current Is

Fig 8 below illustrates the effect of saturation current Is on the characteristic I(V) of the solar cell under illumination; It is found that increasing the saturation current (Is) for the diode causes a reduction of the open-circuit voltage (Vco) by against the short-circuit current (Isc) remains constant [37].

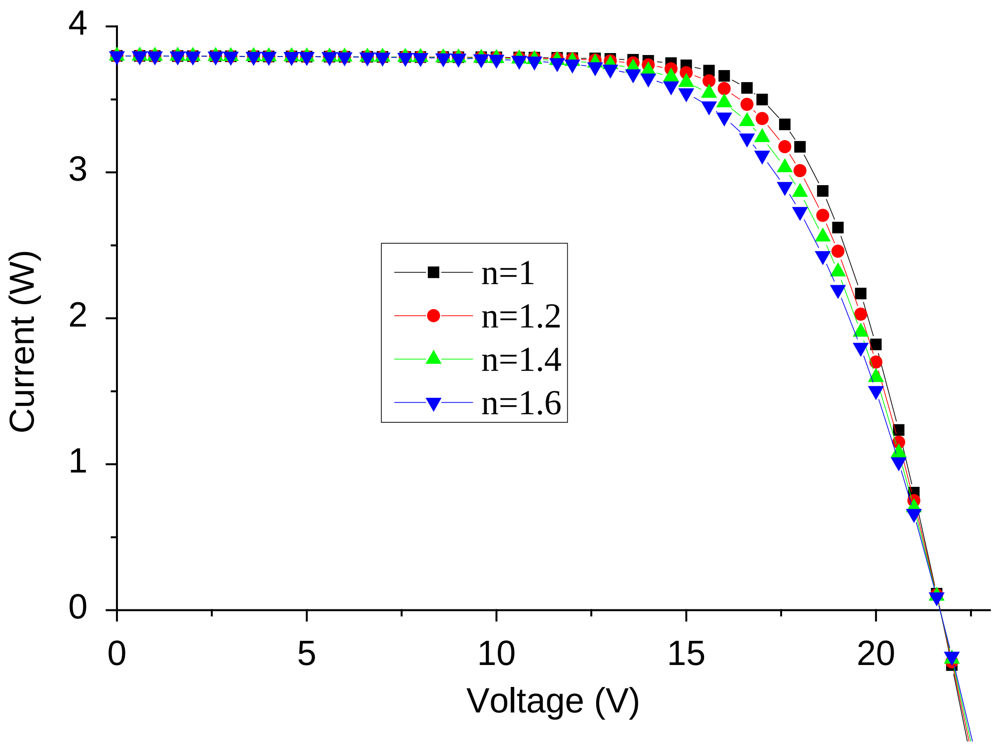

Fig. 7. Quality factor influence on I (V)

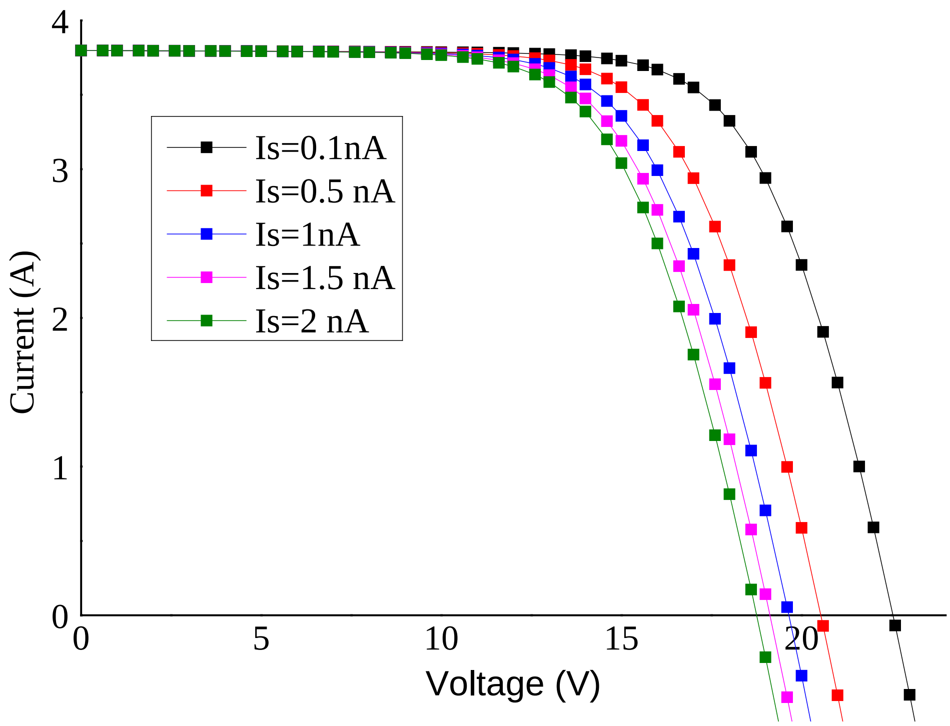

Fig. 8. Influence of saturation current on I (V)

5.4. Influence of the shunt conductance (parallel)

Fig 9 below illustrates the effect of the resistance parallel *Rsh* on the I(V) characteristic of the cell under solar irradiation. Note that the shunt resistor represents any path of the leakage current: leakage current between cells, leakage current between the cell and the edge of the module. Note that the open-circuit voltage (*Voc*) and the short-circuit current (*Isc*) are not changed; but the characteristic deforms very quickly, this influence has reflected in an increase in the slope of the I(V) characteristic of the cell in the area corresponding to an operation as a power source (low voltage). The shunt resistor should be highest enough for better power output.

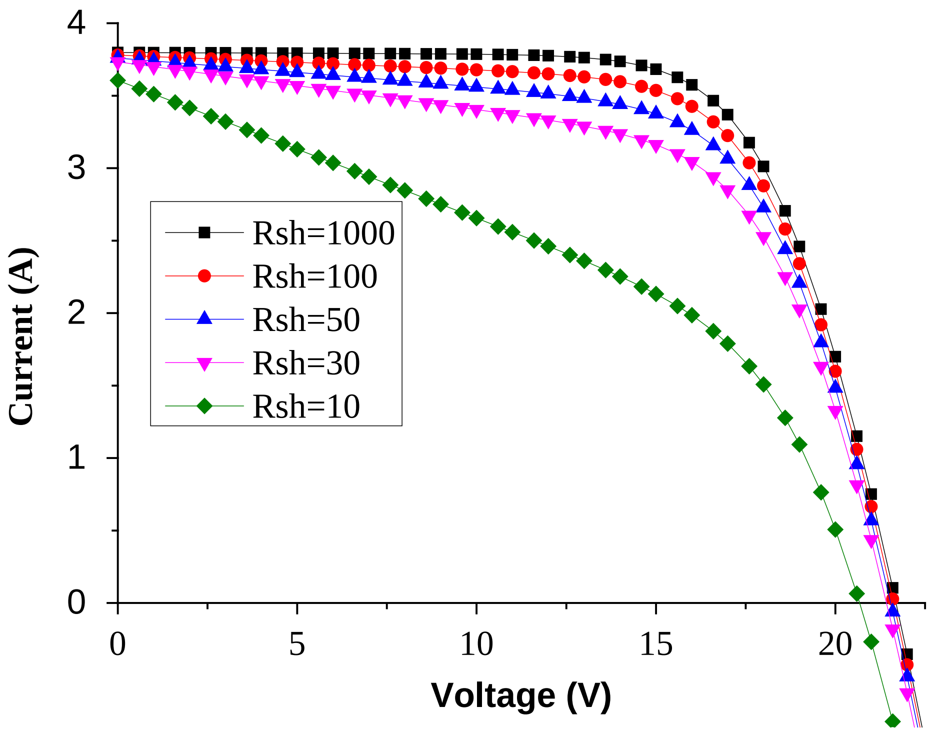

Fig. 9. Influence of quality of the shunt resistance on I (V)

6. External parameters

6.1. Effect of radiation

Fig. 10 shows the *I-V* characteristics of PV modules at various solar irradiances from 200 W/m^2 to 1000 W/m^2 and a constant temperature of 25 C.

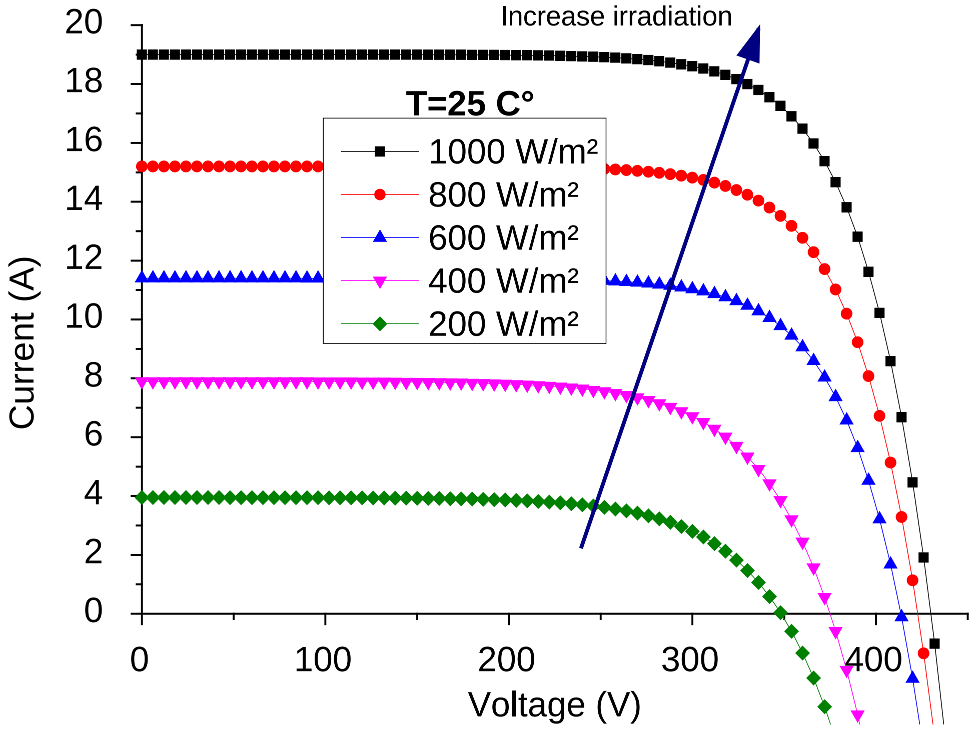

Fig. 10. Effect of irradiation on the I-V characteristic of PV Array (6 kWp)

Solar radiation is the most factor that impacts directly the current of the photovoltaic cell, module, or array because the current value is proportional to the sunlight. According to Figures 10, it is observed that the increase in irradiation causes an increase in PV power production. For a fixed temperature, when the irradiance decreases, the short-circuit current Isc and the output power decrease, which is the behavior expected from a solar-energy-converting system.

6.2. Influence of temperature

Figs 11 show the effect of ambient temperature on the I-V characteristic of the PV Array. The model was simulated for different temperatures from 0°C to 100°C and a constant irradiance of 1000 W/m^2. For a fixed irradiance, when the temperature decreases the open-circuit voltage Voc increases, and the output power increases. This increased power effect is not obvious but is concordant with temperature’s effect on Voc. It can be summarized that there is a relationship between temperature and PV power production. It is observed that the increase in temperature causes a decrease in PV power production. In general, about 0.5% loss of efficiency per degree celsius increase in temperature is typical in silicon cells [34]. To reduce the temperature-related issues on PV modules, a cooling system is proposed.

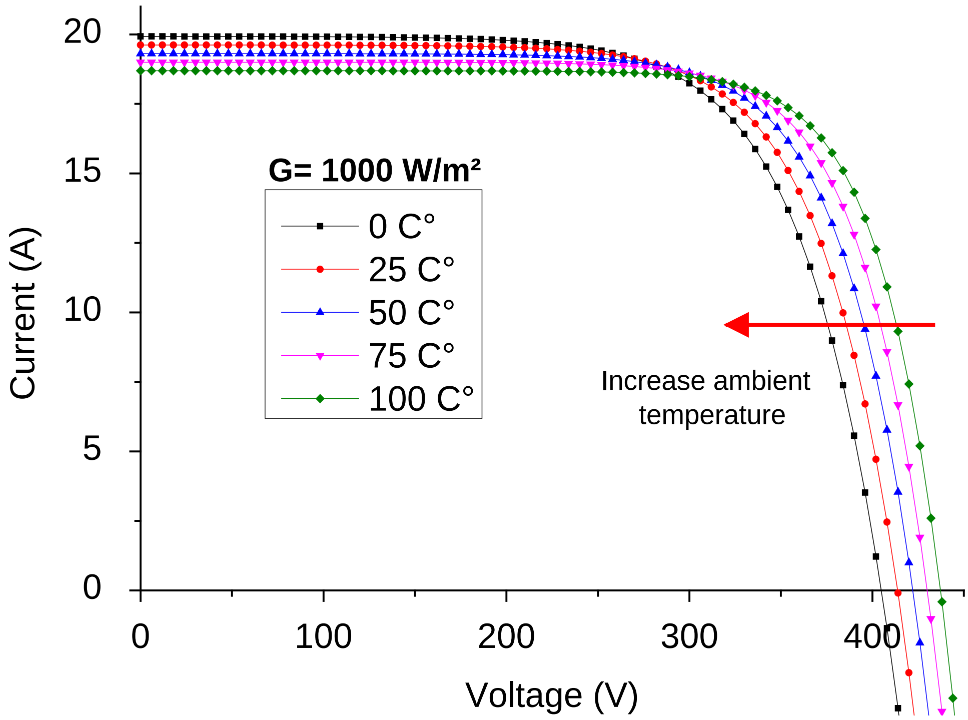

Fig. 11. Effect of ambient temperature on the I-V characteristic of PV Array (6 kWp)

6.3. Dust effect on PV array

Soiling is causing severe performance losses and poses a serious problem for PV power plants installed especially in dusty and sandy sites, such as in arid or semi-arid regions, where photovoltaic applications are more attractive [24]; [25]; [26] ;[29]. In literature, various types of dust are studied particularly in desert environments to show their effects [1], [2]. The dust is generated by many sources may be sand, limestone, salt; ashes, and soil (see Fig 12). The accumulation of dust on the PV module doesn't create shading but a hot spot [18]. The performance of a PV module decreases by surface soiling, and the PV power loss increases with an increase in the quantity of soil on the PV module. Bouraiou et al found that a decrease in dust PV module parameters compared to the identical clean PV module. The performance factors such as maximum output voltage (Vmax), maximum output current (Imax), maximum power output (Pmax), open-circuit voltage (Voc), short-circuit current (Isc) of PV modules are degraded after few years of exposition [8]. A percentage decrease in power found about 5% [8]. Fig. 18 shows the effect of the dust accumulation sandstorm on some PV modules and sensors.

Fig. 12. Dust accumulation effect (left) and sandstorm on the PV panels (right)

6.4. Effects of partial shading on PV

The term shading is used to describe the accumulation of snow, dirt, clouds, dust, leaves, trees, pollen, near buildings, and bird droppings on PV panels [14]. The I-V characteristic of the PV array becomes complex with multiple peaks. These different peaks are generated due to the non-uniform insolation levels that are received on a partially-shaded PV array surface. The PV array efficiency is decreased due to these non-uniform characteristics [15]. PV array exposed to different partial shading conditions is considered one of the main challenges that face MPPT techniques. A small configuration of a PV system with two PV modules under partially shaded conditions with a bypass diode caused by a passing cloud is shown in Fig.13.

Modeling and simulation of a PV system have been carried out in Matlab Simulink. In this case, the photovoltaic field consists of two identical PV arrays connected in series as in Fig.14. One array receives irradiation of (500W/m^2) and the other is exposed to full irradiance in the presence of bypass diodes (1000 W/m^2).

Fig.15 shows a comparison between unshaded and shaded PV array characteristics. It shows two peaks of current values far from each other under partial shading conditions. The maximum power of the PV system was reduced the corresponding power from P=1200 W to P=6000 W, due to uniform and non-uniform conditions. The current of the PV system also reduces from I=18 A to I= 9 A, due to uniform and non-uniform conditions. A two peaks power point (a non-uniform condition with bypass diode). In this case, the photovoltaic field consists of three identical PV arrays connected in series as in Fig 16. The first array receives irradiation of 1000W/m^2 while the second and third arrays respectively receive irradiation of 500 W / m^2 and 100W / m^2.

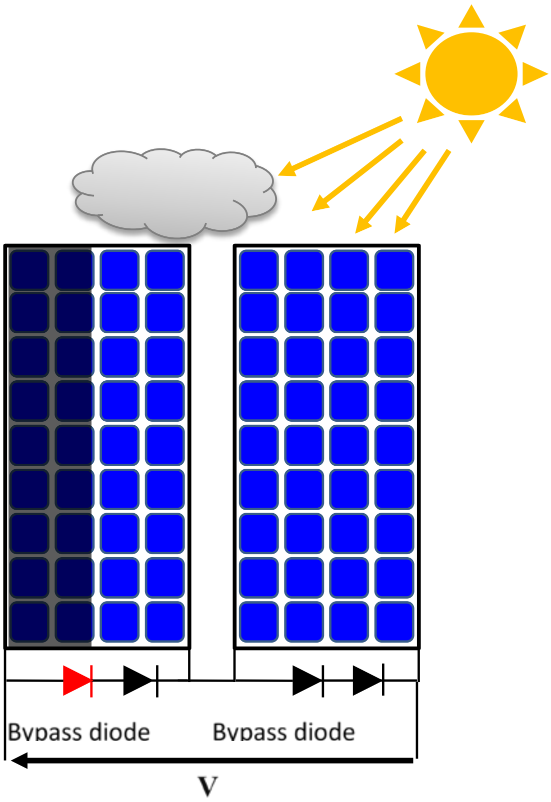

Fig. 13. Photovoltaic array under partial shading appearance

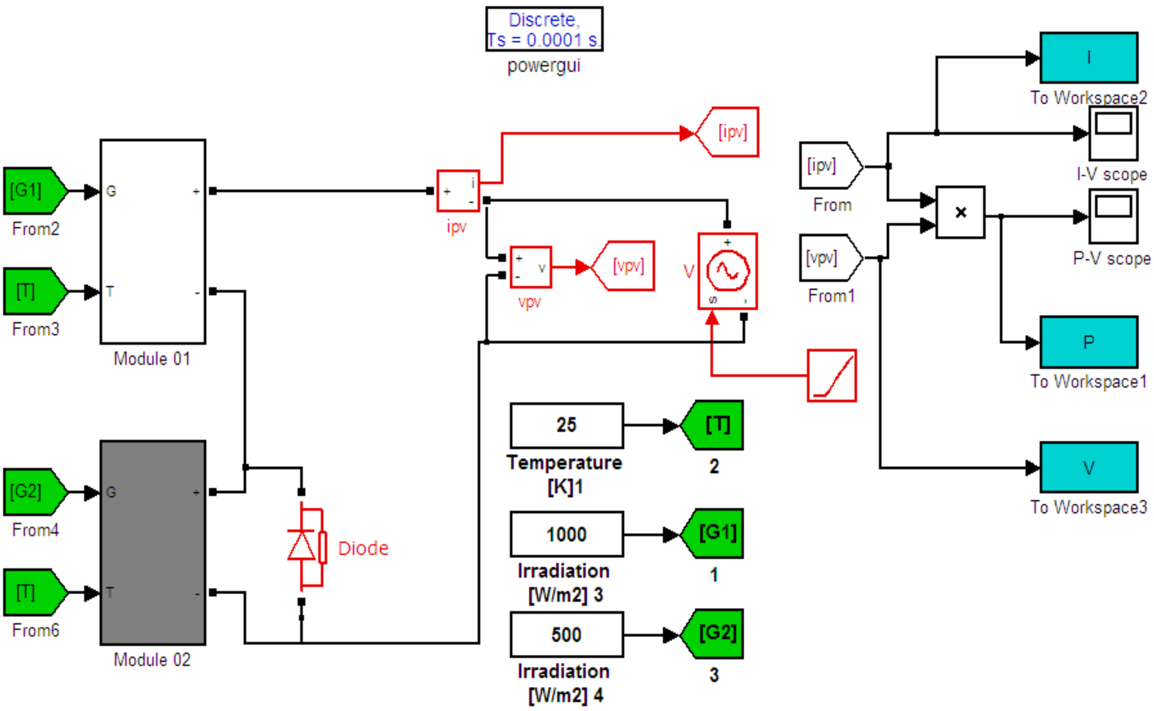

Fig. 14. Matlab/Simulink simulation of PV array under partial shading conditions (one module is under shading)

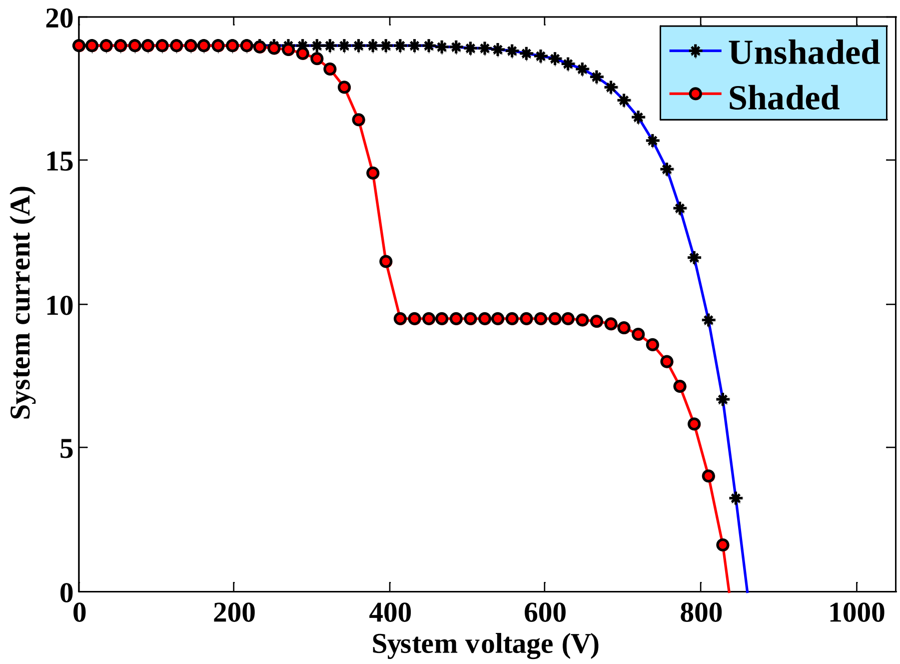

Fig. 15. I-V curves of two series connected modules on different irradiation levels (array 1 G=1000W/m² and array 2 G=500 W/m²).

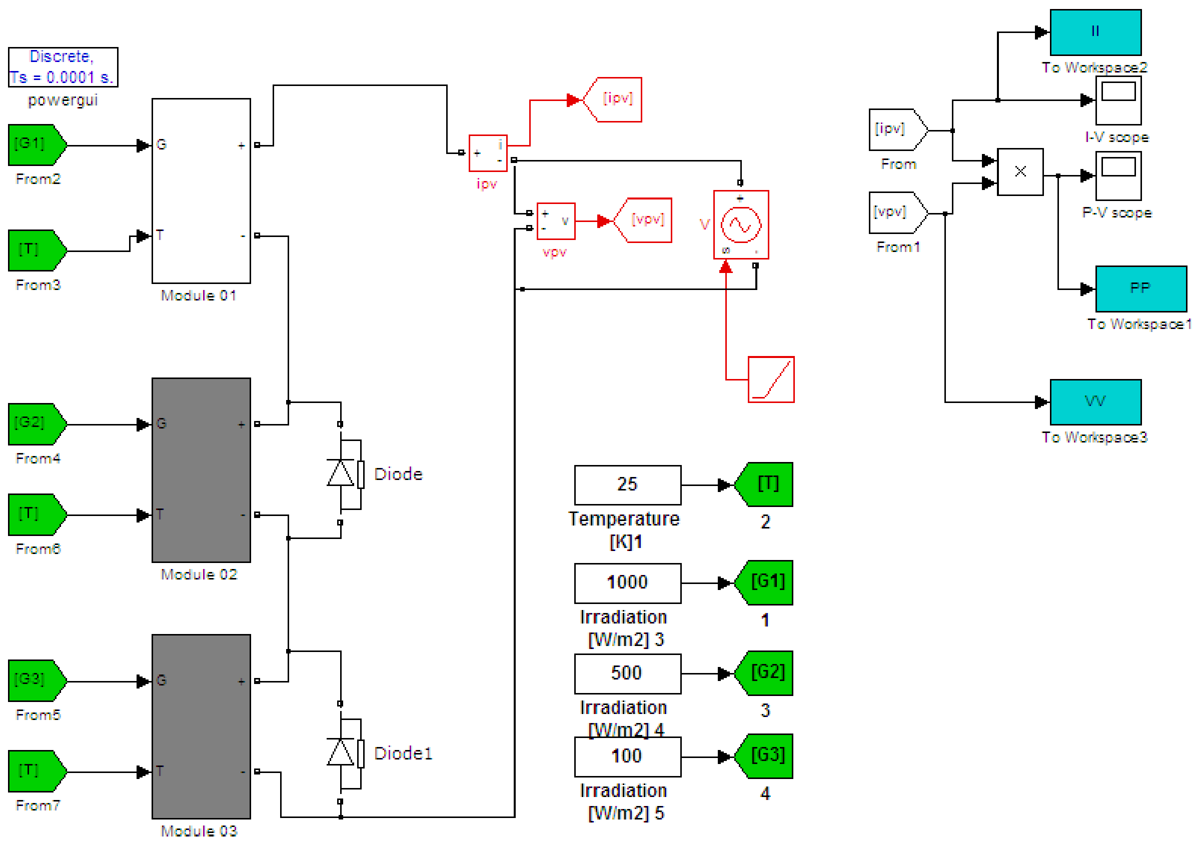

Fig. 16. Matlab/Simulink simulation of three series arrays.

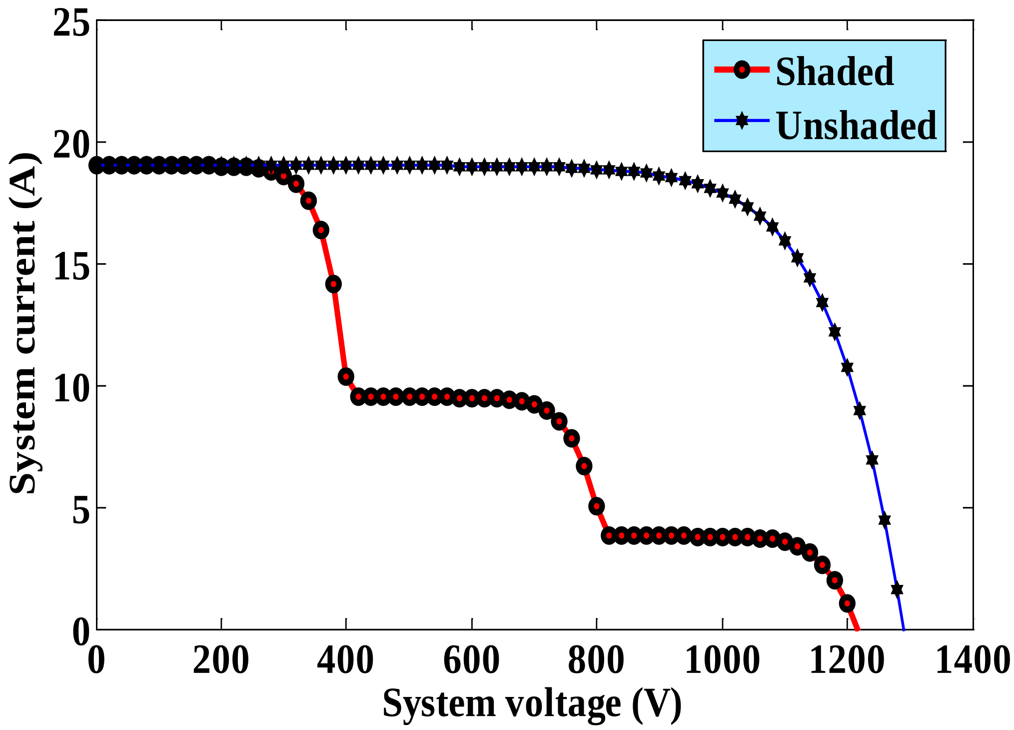

Fig. 17. I-V curves produced by three series-connected modules when two of them are shadowed (array 1 G=1000W/m², array 2 G=500 W/m², and array 2 G=200 W/m²)

Fig. 17 shows the corresponding characteristic of the current. It can be seen that there are three different MPP levels of power. One of which is global MPP and the other two are local MPP. The PV generator compound of three identical PV arrays connected in series. Therefore, the PV generator has three times wide operating voltage compared to the single PV array .the functional operating voltage range of the PV generator has three times the voltage magnitude of one PV array. However, the series-connected PV array will not amplify the current generation. The current generated by the PV array is the same as the PV module. Nevertheless, the generator power generation will be three times biggest than the output power produced by a single PV array. We conclude that the existence of the bypass diodes improves the output power value in particular in the cases where one of the modules is under full shading conditions.

6.5. Degradation (Aging)

To evaluate the photovoltaic performance modules after long term exposure, the degradation rate $R_d$and annual degradation rate R_{da}were calculated analytically by the following expressions [5]; [7]; [8]; [12] ;[20]; [27]; [28]:

$$\begin{cases} R_d(A)(\%) = \left(1 - \frac{A}{A_0}\right) * 100 \\ \mathrm{R_{dA}(A)(\%)} = \frac{\mathrm{R_D(A)}}{\Delta \mathrm{T}} \end{cases} \quad (6)$$

Where ΔT (years) is the duration of exposure under the real operating conditions. The degradation rate of the module's short-circuiting current (*Isc*), open-circuit voltage (*Voc*), maximum current (*Imax*), maximum voltage (*Vmax*), and maximum power (*Pmax*) is determined as per Eq. (6) [11]:

$$\begin{cases} \mathrm{R_D}(\mathrm{I}_{sc})(\%) = \left(1 - \frac{\mathrm{I}_{sc_{\mathrm{meas}}}}{\mathrm{I}_{sc_{\mathrm{stc}}}}\right) * 100 \\ \mathrm{R_D}(\mathrm{V}_{oc})(\%) = \left(1 - \frac{\mathrm{V}_{oc_{\mathrm{meas}}}}{\mathrm{V}_{oc_{\mathrm{stc}}}}\right) * 100 \\ \mathrm{R_D}(\mathrm{I}_{mp})(\%) = \left(1 - \frac{\mathrm{I}_{mp_{\mathrm{meas}}}}{\mathrm{I}_{mp_{\mathrm{stc}}}}\right) * 100 \\ \mathrm{R_D}(\mathrm{V}_{mp})(\%) = \left(1 - \frac{\mathrm{V}_{mp_{\mathrm{meas}}}}{\mathrm{V}_{mp_{\mathrm{stc}}}}\right) * 100 \\ \mathrm{R_D}(\mathrm{P}_{mp})(\%) = \left(1 - \frac{\mathrm{P}_{mp_{\mathrm{meas}}}}{\mathrm{P}_{mp_{\mathrm{stc}}}}\right) * 100 \end{cases} \quad (7)$$

Also, series resistance in the photovoltaic module is concerned. The aging influence increases the series resistance, which in turn limits the PV array current output. The series resistance R_s according to time (t) is given by expressions [4]:

$$R_s(t) = R_{s0}(\alpha R_s t + 100\%) \quad (8)$$

Where αR_s coefficient of degradation and R_{s0} is the series resistor (before degradation).

Fig 18 shows the impact of aging on the P-V characteristic of PV Array after 10 and 20 years for G=1000 W/m². The environmental conditions are the standard test ones: irradiance G=1000 W/m² and module temperature T=25 C° corresponds to a power value equal to 6000 W. After 10 years of use of the photovoltaic array, the effective irradiance is cut down by 6% in other words G (10 years) =940 W/m² ° corresponds to a power value equal to 5640 W. After 20 years of use of the photovoltaic array, the effective irradiance is cut down by 12%, in other words, G (20 years) =880 W/m² corresponds to a power value equal to 5280 W.

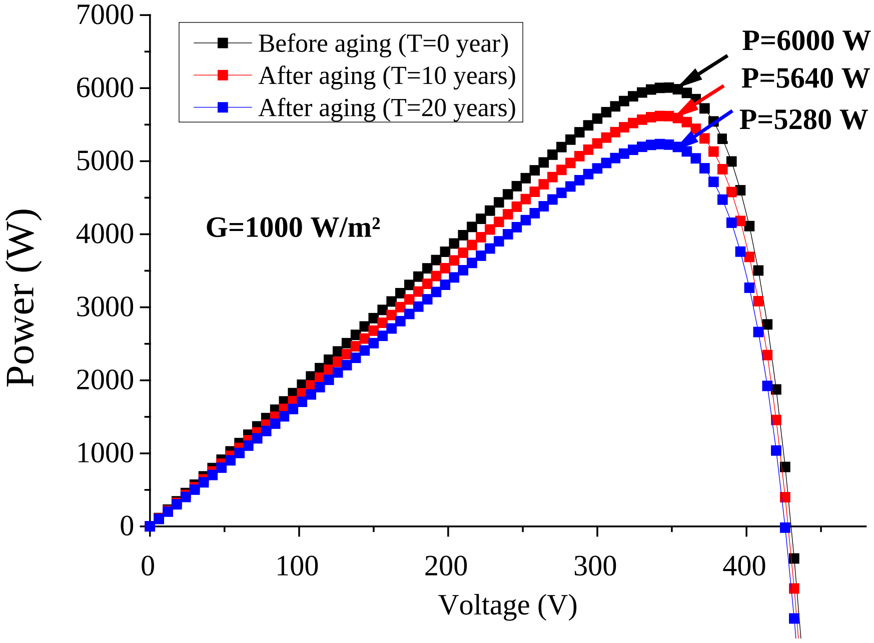

Fig. 18. Impact of aging on P-V characteristic of PV Array after 10 and 20 years for G=1000 W/m²

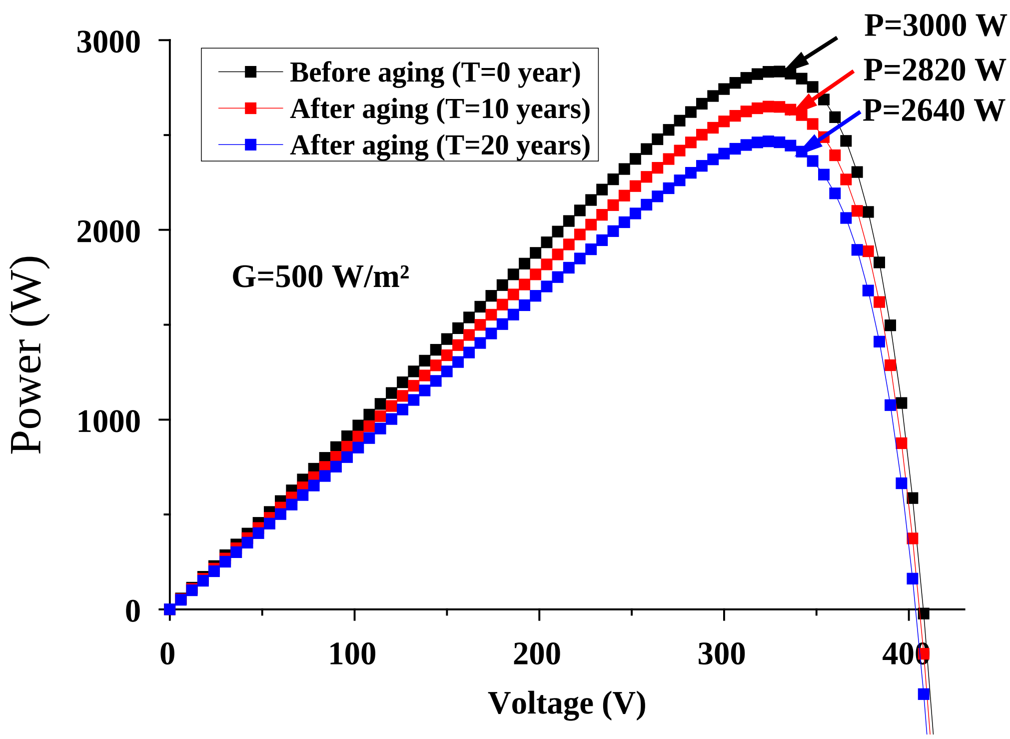

Fig. 19. Impact of aging on P-V characteristic of PV Array after 10 and 20 years for G=500 W/m²

Fig 19 shows the impact of aging on the P-V characteristic of PV Array after 10 and 20 years for G=500 W/m². Before Aging irradiance G=500 W/m² and module temperature T=25 C° corresponds to a power value equal to 3000 W. After 10 years (After Aging) of use of the photovoltaic array, the effective irradiance is cut down by 6% in other words, G (10 years) =470 W/m² ° corresponds to a power value equal to 2820 W. After 20 years (After Aging) of use of the photovoltaic array, the effective irradiance is cut down by 12%, in other words, G (20 years) = 440 W/m² corresponds to a power value equal to 2640 W.

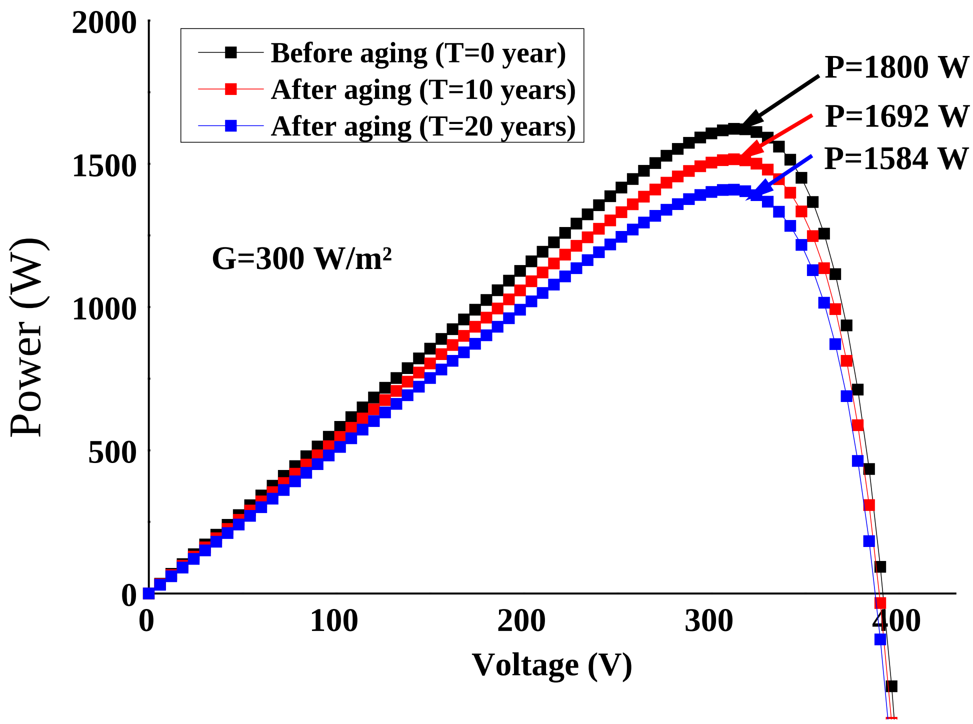

Fig. 20. Impact of aging on P-V characteristic of PV Array after 10 and 20 years for G=300 W/m²

Fig 20 shows the Impact of aging on the P-V characteristic of PV Array after 10 and 20 years for G=300 W/m². Before Aging irradiance G=300 W/m² and module temperature T=25 C° corresponds to a power value equal to 1600 W. After 10 years (After Aging) of use of the photovoltaic array, the effective irradiance is cut down by 6% in other words, G (10 years) =282 W/m² ° corresponds to a power value equal to 1504 W. After 20 years (After Aging) of use of the photovoltaic array, the effective irradiance is cut down by 12%, in other words, G, (20 years) =264 W/m² corresponds to a power value equal to 1408 W.

6.6. Degradation modes

Fig. 21 depicts a standalone PV system where the DC output of the PV array is directly connected to a resistive load through a DC-DC boost converter and MPPT controller unit. The

MSX60 PV modules are used in the simulation for a 20 X 5 array configuration. In this work, the MPP is tracked using the conventional Perturbation and Observe (P&O) algorithm.

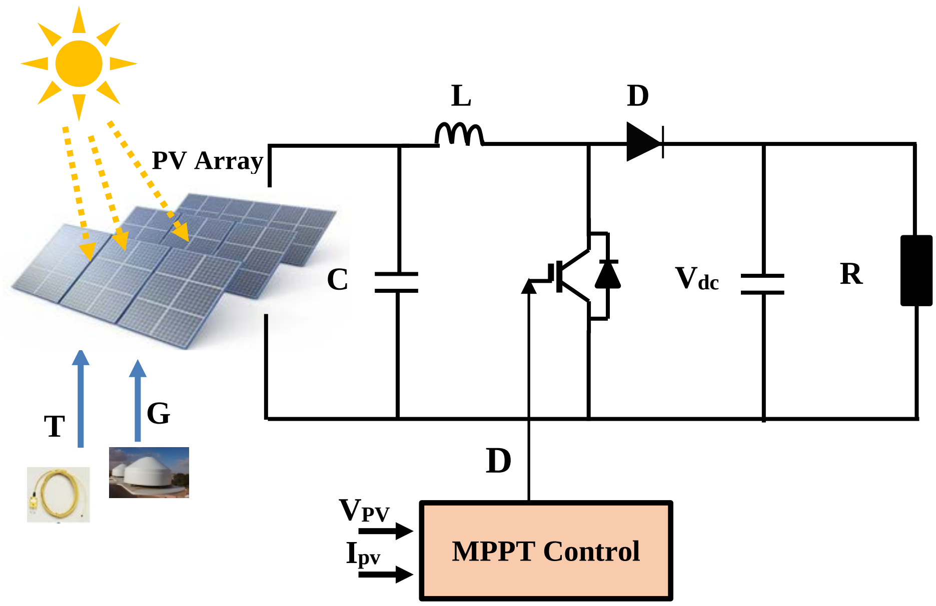

Fig. 21. Block diagram of PV Module with MPPT Controller connected to a load

6.6.1. Model of the boost DC-DC converter

The schematic diagram of the DC-DC boost converter connected to the photovoltaic generator to a resistive load is shown in Fig 21. The state-space averaged model of the boost converter can be written as [35], [36]:

$$\begin{bmatrix} \dot{\mathrm{I}}_{\mathrm{L}} \\ \dot{\mathrm{V}}_{\mathrm{dc}} \end{bmatrix} = \begin{bmatrix} 0 & -\frac{1}{L}(1-D) \\ \frac{1}{C}(1-D) & -\frac{1}{C.R_L} \end{bmatrix} \begin{bmatrix} I_L \\ V_{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L} \\ 0 \end{bmatrix} V_{pv} \tag{9}$$

Where D is the duty cycle, V_{pv} is the input voltage to the boost converter, I_L is the inductor current, C is the capacitance, R_L is the load resistance and V_{dc} is the DC link output. Equation (9) can be written as:

$$\begin{cases} \dot{x_1} = -\frac{1-u}{L}x_2 + \frac{1}{L}u \\ \dot{x_2} = \frac{1-u}{C}x_1 + \frac{1}{RC}x_2 \end{cases} \qquad \text{Where } \; x = [\dot{I_L}, V_c] \quad ; \quad u: V_e \tag{10}$$

6.6.2. Perturbation and Observe (P&O) algorithm

The P&O method is the widely popular MPPT algorithm due to its simplicity and its easy implementation. Fig 22 shows the flow chart of the conventional P&O method. After a disturbed operation, the power is calculated and compared to the previous value to find the power change. ΔP. If ΔP>0, then the operation continues in the same direction of perturbation (incremented voltage). In the reveres operation, the perturbation decremented the voltage to reach the maximum power point.

Fig. 23 shows the evolution of PV array degradation of the output voltage with time (before aging, after 10 and 20 years) under variable irradiation (300 w/m², 600 w/m², and 1000 w/m² for T=25°C). The result shows the relationship between the irradiation and the output voltage of the PV panel. After 10 years of use of the photovoltaic array, the effective irradiance and voltage evolution profile is cut down by 6%. After 20 years of use of the photovoltaic array, the effective irradiance and voltage profile are dropped by 12%.

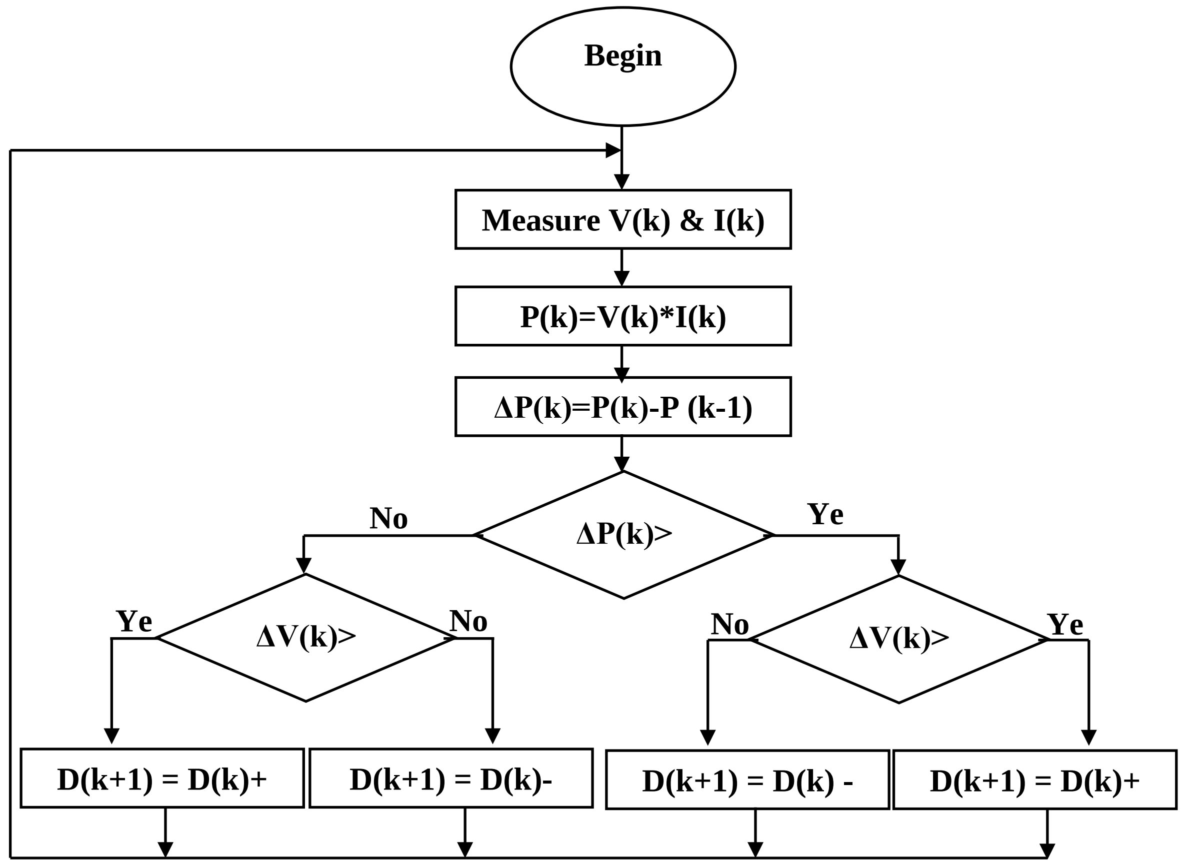

Fig.22. Flowchart of Perturb and observe algorithm [6];[22]

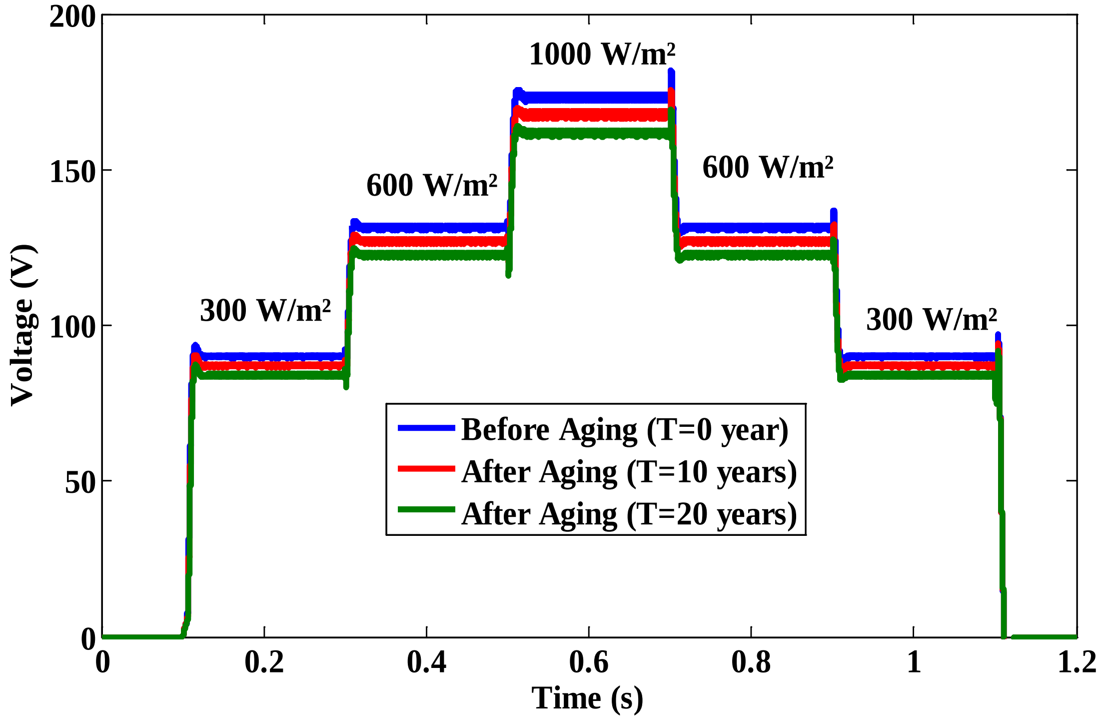

Fig. 23. PV Array voltage after 10 and 20 years

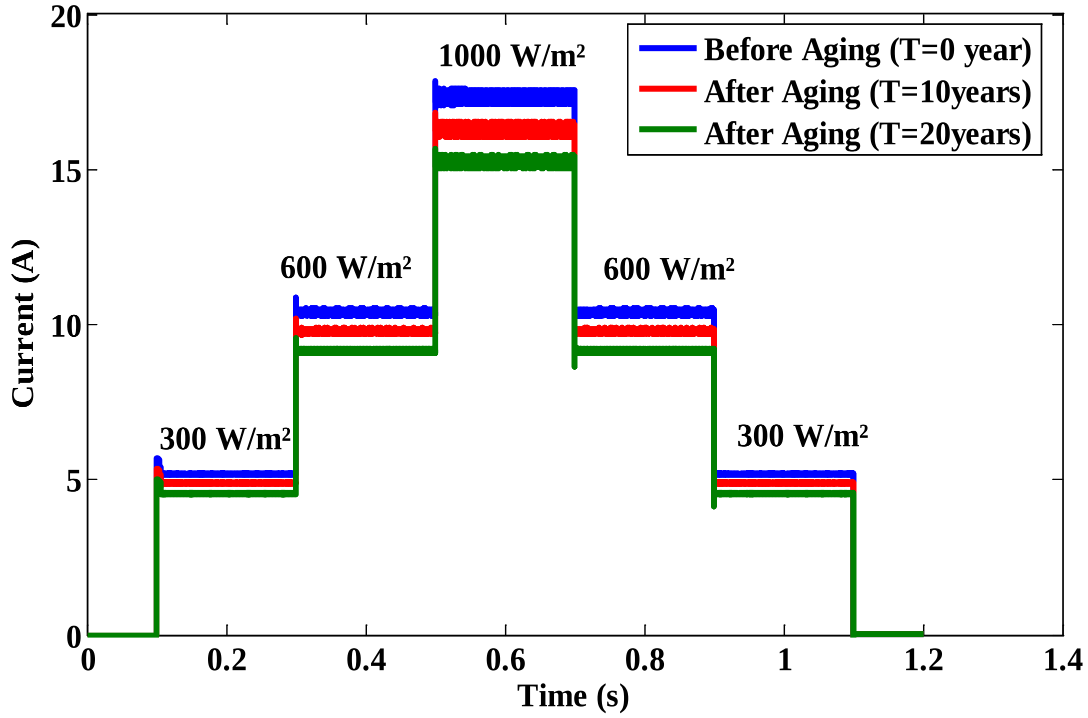

Fig. 24. PV Array current after 10 and 20 years

Fig. 24 shows the evolution of PV array degradation of the output current with time (before aging, after 10 and 20 years) under variable irradiation (300 w/m², 600 w/m², and 1000 w/m² for T=25°C). The result shows the relationship between the irradiation and the output voltage of the PV panel. After 10 years of use of the photovoltaic array, the effective irradiance and voltage evolution profile is cut down by 6%. After 20 years of use of the photovoltaic array, the effective irradiance and voltage profile are dropped by 12%.

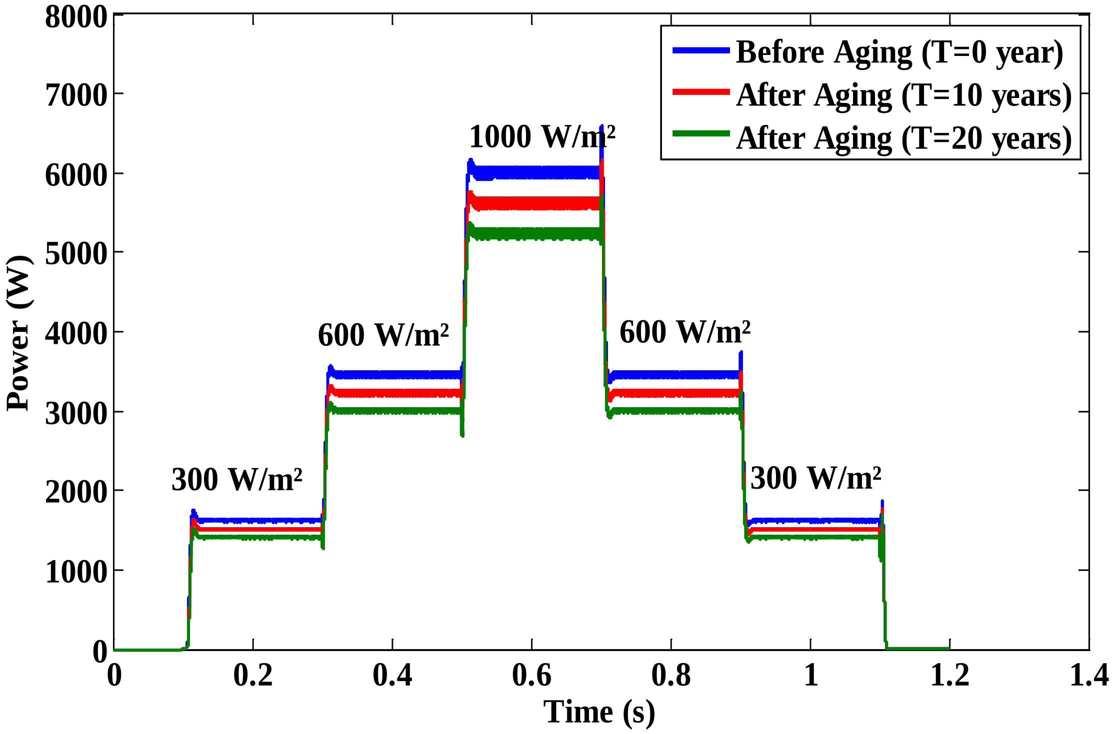

Fig. 25. DC-DC converter power after 10 and 20 years

Fig. 25 shows the evolution of PV array degradation of the output power with time (before aging, after 10 and 20 years) under variable irradiation (300 w/m², 600 w/m², and 1000 w/m² for T=25°C). The result shows the relationship between the irradiation and the output voltage of the PV panel. After 10 years of use of the photovoltaic array, the effective irradiance and voltage evolution profile is cut down by 6%. After 20 years of use of the photovoltaic array, the effective irradiance and voltage profile are dropped by 12%. The influence of aging on the electrical production of a photovoltaic array is summarized in table 2-6

Table 2. Influence of aging on the electrical production of a photovoltaic module at 25°C and (G=300w/m², G=282W/m² and G=264 W/m²)

Years	0	10	15
G (W/m²)	300	282	264
Vpv (V)	96,44	90,65	84,87
Ipv (A)	4,93	4,63	4,34
Ppv (W)	1800	1692	1584

Table 3. Influence of aging on the electrical production of a photovoltaic module at 25°C and (G=5300w/m², G=470 W/m² and G=440 W/m²)

Years	0	10	15
G (W/m²)	500	470	440
Vpv (V)	160,74	151,09	141,45
Ipv (A)	8,22	7,73	7,23
Ppv (W)	3000	2820	2640

Table 4. Influence of aging on the electrical production of a photovoltaic module at 25°C and (G=600W/m², G=564W/m² and G=528 W/m²)

Years	0	10	15
G (W/m²)	600	564	528
Vpv (V)	192,88	181,31	169,74
Ipv (A)	9,87	9,27	8,68
Ppv (W)	3600	3384	3168

Table 5. Influence of aging on the electrical production of a photovoltaic module at 25°C and (G=1000W/m², G=940W/m² and G=880 W/m²)

Years	0	10	15
G (W/m²)	1000	940	880
Vpv (V)	342	321,48	282,90
Ipv (A)	17,5	16,45	14,47
Ppv (W)	6000	5640	5280
Rs (Ω)	0	0,409	0,418
Rd (%)	0	6	12
RdA (%)(after 10 years)	0	0,6	1,2

The results are comparable and in agreement with those that have appeared in the literature [5]; [19]; [31]. Annual degradation rates of the PV modules are calculated to be about 1%/year.

7. Conclusions

The performance of solar PV systems is influenced by many factors. Some of these issues are related to the module itself (internal factors) and others are related to the location and environment (external factors). Thus, knowledge of the performance of PV systems under real outdoor operating conditions is an essential element for improving the safety and productivity of PV systems. In the first part, we presented various defects that can occur in different stages of photovoltaic installation and the various simulations of the electrical characteristics of the model electrical equivalent of the photovoltaic cell. In the second part, we investigated a few of the major internal and external factors that significantly affect photovoltaic array energy production. The following conclusions are drawn:

- We can note that the power output of a solar panel does not depend only on the radiation and temperature of the exposure, but also on internal parameters (series resistance, shunt resistance, ideality factor, and saturation current).
- The output of the photovoltaic power system increases linearly with increasing solar irradiation.
- The performance of a PV module decreases by surface soiling, and the PV power loss increases with an increase in the quantity of soil on the PV module.
- Environmental parameters such as partially shaded conditions, high temperatures, high irradiation, and dust, common in arid areas, can drastically affect the performance of solar modules.
- The dirt and birds drop make a hot spot in the panel, and it can make temporary fail in the panel.
- Finally, degradation is an important problem: the accumulation of aggressive environmental parameters makes arid climates one of the most difficult conditions for photovoltaic panels.
- An intelligent cleaning solar panel system is proposed to increase efficiency by removing most of the dirt.

These results are found to be in close agreement with the experiment results of the manufacturer datasheet that proves the effectiveness of the proposed modeling method and the possibility of using it for all types of photovoltaic. Consequently, these models can be used to study all types of PV modules available in markets, for different temperatures and different irradiances.

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Nomenclatures:

- a : is the diode ideality factor for the single diode model.
- C : is the capacitance,
- D : is the duty cycle,
- Eg : is the width of the bandgap,
- G : is the irradiance in W/m^2,
- Gr: is the reference irradiance (1000 W/m^2).
- I, I_{ph} and I_0 are the current array, the photogenerated, and the reverse saturation current respectively.
- I_L : is the inductor current,
- k : is the Boltzmann constant [$1.3806503*10^{-23}$J/K].
- Ns : is the number of cells connected in series
- N_{ss} , N_{pp} : are the number of modules in series and parallel.
- q :is the electron charge [$1.60217646*10^{-19}$C].
- R_L : is the load resistance
- R_s , R_{sh} : are cell series and shunt resistance
- T : is the temperature of the cell,
- Tr : is the reference temperature of the cell,
- V , V_T: are the array voltage and the thermal respectively.
- V_{dc} : is the DC link voltage
- V_{pv} : is the input voltage to the boost converter,

Abbreviations:

- IEC standard 61724: International Electrotechnical Commission standard 61724
- MPP: maximum power point

- MPPT: maximum power point tracking
- P & O: Perturb and observe
- PV: photovoltaic module
- PWM: Pulse Width Modulation
- STC: The standard test conditions (G =1000. W/m^2 and T= 25 °C).

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