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Simulation of Photovoltaic generator Connected To a Grid

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Abstract

This paper presents the mathematical and the total Matlab-simulink model of the various components, of the photovoltaic power station connected to a network, (PSCN), namely the model of the photovoltaic generator. It is a comprehensive behavioural study which performed according to varying conditions of solar insulation and temperature. The photovoltaic generator and the inverter of single-phase current are modeled. The former by using a mathematical model that gives the values of maximum power according to the variation of the weather conditions, and the latter by a source of voltage controlled by voltage in order to inject a sinusoidal current and to estimate or predict the energy injected monthly or annually into the network.

Keywords: PV generator - Inverter - Control strategies-Photovoltaic injection of energy.

Nomenclature

A	diode quality factor
E or G	irradiation (w/m²)
I_0 or I_s	reverse saturation current of diode (A)
I_d	current shunted through the diode (A)
I_{mpp}	power point current (A)
I_{ph}	the generated photo-current (A)
I_{pv}	the PV array output current (A)
I_{sc}	cell short-circuit current at STC
K	boltzmann's constant (j/k)
K_t	current temperature coefficient
N_p	parallel cell number
N_s	series cell number
q	electron charge (C)
R_s	series resistance (Ω)
R_{sh}	shunt resistance (Ω)
T_a	ambient temperature (°C)
V_{mpp}	power point voltage (V)
V_{oc}	open-circuit voltage (V)
V_{pv}	the PV array output voltage (V)
V_t	thermal voltage (V)

Greek symbols	
η	efficiency
Φ	irradiation
Subscripts	
Ph	photons
pv	photovoltaic
ref	reference
s	series
sc	short-circuit
sh	shunt

1. Introduction

The development in photovoltaic solar technology has promoted the installation of photovoltaic (PV) solar panels (or arrays/cells) in public infrastructures, residential houses and PV solar power plants. As the PV solar energy penetration level continues to increase, solar power generated electricity is taking a higher portion in the total generated electric power [1]. Usually electric power generated from PV solar panels is more expensive than conventional fuel generated electricity due to the price of PV material and systems and the fact that the power generated by the PV solar panel is largely affected by local weather conditions. Utility grid is gaining more and more visibility due to many national incentives [2].

With a continuous reduction in system cost (PV modules, DC/AC inverters, and installation), the PV technology has the potential to become one of the main renewable energy sources for future electricity supply. The market for grid-connected PV power applications continues to develop at a high rate.

Feeding the photovoltaic energy to the AC grid is not evident. It poses some problems in controlling the energy transfer and connecting the two systems together by using static converters.

The classical connection between photovoltaic array and AC grid is shown in fig.1. The main objective, from this interfacing, is to feed all the collected energy at the PV plant to the commercial AC grid [3].

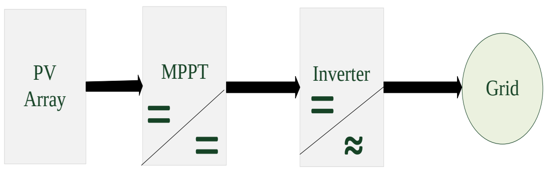


Figure 1. PV grid connected system.

This is achieved by the following

- The PV array responsible on transforming, the sun light into electricity.
- MPPT controller, this is used to maximize the power coming from the PV array at any atmospheric conditions.

Inverter, this is a device which transforms DC input into an AC output at the same waveforms as the grid line.

2. Modeling and Simulation of the PV Grid System

2.1. Characteristics of PV array

Basically, the PV cell is a P-N semiconductor junction that directly converts light energy into electricity. It has the equivalent circuit shown in fig. 2 [4-5].

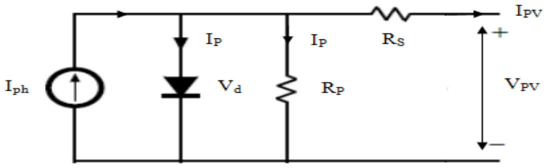


Figure 2. Equivalent PV cell circuit

The current source I_{ph} represents the cell photocurrent, R_s and R_p are the intrinsic series and shunt resistance of the cell respectively. The PV cell exhibits non-linear voltage-current characteristics.

The following are the simplified equations describing the behavior of the PV cell [6].

$$I_{pv} = I_{ph} - I_0\left(e\frac{V_{pv} + R_s I_{pv}}{V_t} - I\right) - \frac{V_{pv} + R_s I_{pv}}{R_p} \tag{1}$$

The photo current I_{ph} is proportional to the sun irradiance that a solar cell receives and to the cell temperature which can be described by [7-8]:

$$I_{pv} = \left[I_{sc}\Phi_N + I_t[T_c - T_r]\right]N_p \tag{2}$$

$$I_0 = I_{0r}\left(\frac{T_c}{T_r}\right)^3 \exp\left(\frac{qE_g}{AK}\left(\frac{1}{T_c} - \frac{1}{T_r}\right)\right) \tag{3}$$

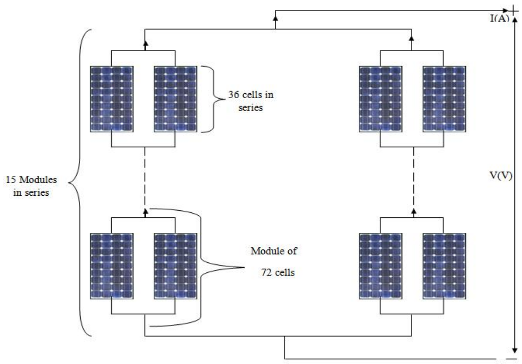
$$V_{0c} = \frac{KT_c}{q}\ln\left(\frac{I_{sc}}{I_0} + 1\right) \tag{4}$$

Now (5) can be solved using Newton's method, which can be described as:

$$x_{n+1} = x_n - \frac{f(x_n)}{f'(x_n)} \tag{5}$$

Where I_{ph} is the PV array output current, Vpv is the PV array output voltage; q is the charge of an electron, k is Boltzmann's constant, Eg is the band gap of the semi-conductor, I_{sat} is the diode reverse saturation current, T_c and T_r are the cell temperature and the reference temperature both in Kelvin, A and B are the diode ideality factors where their values varied between 1 and 2, ΦN is the normalized insolation, I_{sc} is a short circuit current given at standard condition, I_t and I_{or} are constants given at standard conditions; N_s and N_p are the series and the parallel cell number respectively.

Fig. 4 show the (P-V) characteristics at different insulations and temperatures levels (Module Isofoton 106 Wc, Ns = 510, Np = 4).



(a) (b)

Figure 3. (a) Installation of the photovoltaic generator on the roof of CDER, (b) diagram of each generator.

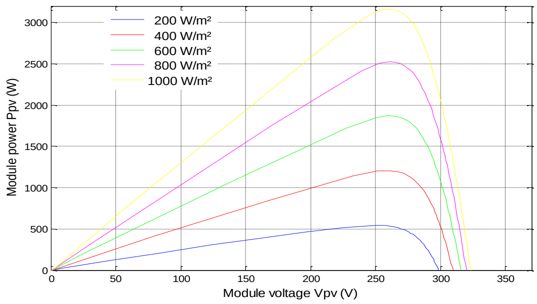


Figure 4. P-V characteristics of PV panel

It is shown, in fig. 4 that the maximum power that can be delivered by a PV panel depends greatly on the insulation level and the operating temperature. Therefore, it is necessary to track the maximum power point all the time. Many researchers have focused on various MPP control algorithms to lead the operating point of the PV panel to the optimum point. Some of these algorithms are the constant voltage method, the perturbation and observation (P&O) method, and the incremental conductance method (IncCond) [9].

2.2. Maximum power point Tracking (MPPT)

In order to get the shape of the injected current to the grid, it is necessary to calculate the coordinates of the maximal power point (Vmpp, Impp). For this, and to simplify the implementation model in Matlab, the coordinates of the maximum power point are given by the following equations [10-11].

$$I_m = I_{mr} \times \frac{G}{G_{ref}} + K_t\left(T_c - T_{ref}\right) \quad (6)$$

$$V_m = V_t \ln\left[I + \frac{I_{sc} - I_m}{I_{sc}}\left(e^{\frac{V_{0c}}{V_t}} - 1\right)\right] - R_s I_m \quad (7)$$

Where V_t is the thermal voltage given by:

$$V_t = \frac{kT_c}{q} \quad (8)$$

Acquisition system in the station of CDER

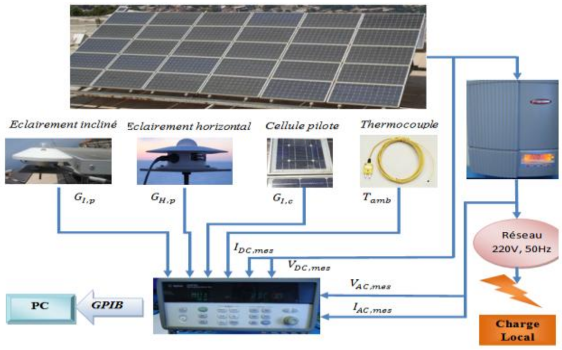
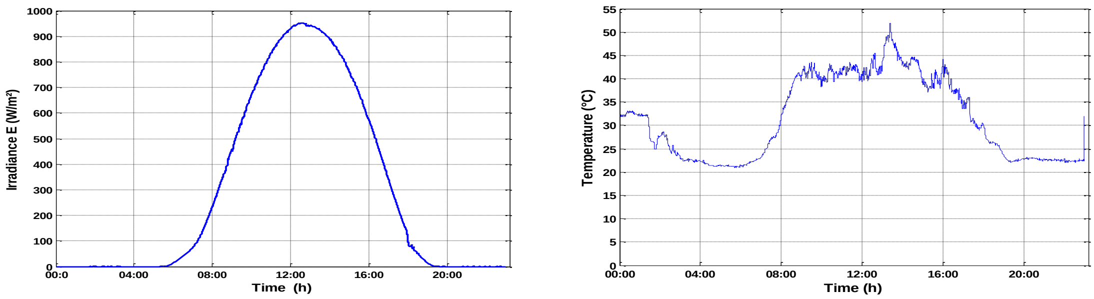


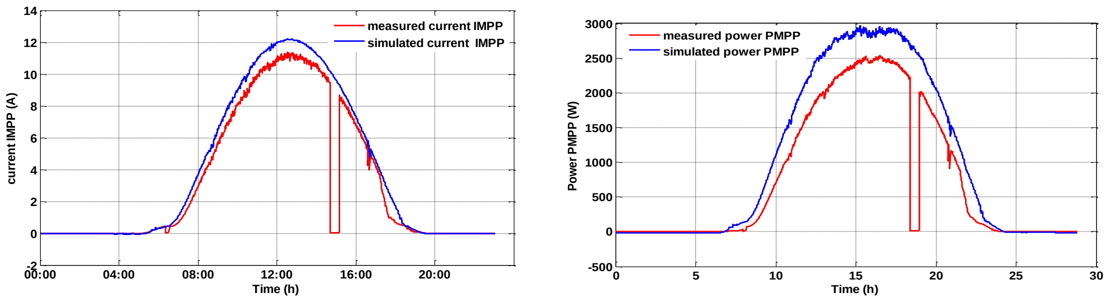
Figure 5. Synoptic total of the system acquisition.

The simulation result of 3 KWc photovoltaic grid connected system are shown in the figures below. The entry to the simulation file is a real data of solar insulation and temperature in one day.



(a) (b)

Figure 6. Illustration the variation of the weather conditions, (a) Profile of Irradiance E (W/m²) and (b) Profile of Temperature (°C).



(a) (b)

Figure 7. (a) Illustration the measured and simulated current, (b) Illustration the measured and simulated power.

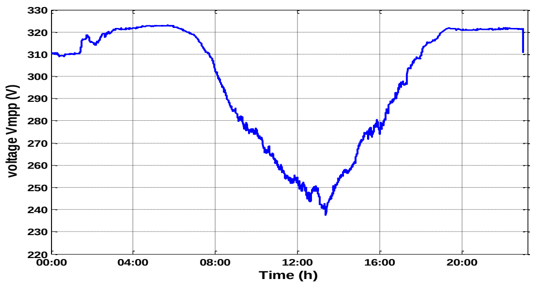


Figure 8. Simulated optimal voltage, Vmpp.

2.3. Inverter modeling

The main specification of the grid connected inverter is that current must be drawn from the PV plant and delivered to the utility grid at unity power factor [12].

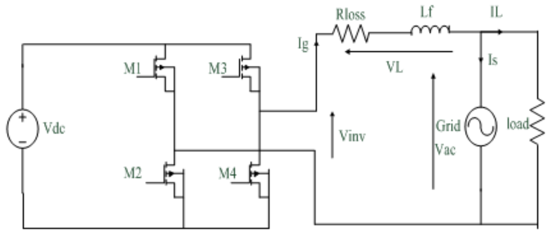


Figure 9. Full bridge grid connection.

Assuming that the losses are negligible, It is seen that

$$V_{in} = V_{ac} + V_L \tag{9}$$

Where all variables are vectors of the form: $v = Ve^{j\Phi}$
Then:

$$V_{inv} = V_{ac} + jL_f\omega I_g \tag{10}$$

To achieve the unity power factor condition, the current waveform must be in phase with the utility voltage waveform, in vector form. The key to controlling this operation is the inverter voltage variable, V_{inv} from (10), I_g can be written as:

$$I_g = \frac{V_{inv} - V_{ac}}{jL_f\omega} \tag{11}$$

2.4. Simulation of the PV grid inverter

Due to the high computational requirement of a full PWM implementation, a simplification has been made to the inverter model. The full bridge inverter is modeled as current controlled voltage source, where harmonic content is ignored. In this case an indirect current control is used to draw a reference current given by the calculated maximum power from the PV model.

The magnitude of the current that the inverter has to draw is given by the power balancing principles:

$$I_g = \frac{2 \times I_m \times V_m \times \eta}{V_{max}} \tag{12}$$

Where η is the inverter efficiency, assumed to be constant (η= 0.95). The implementation of this bloc diagram in MATLAB is shown in Fig.10. In this scheme, an Average Behavior Modeling (ABM) is used. The inverter output is modeled as a voltage controlled voltage source. The reference current of the grid is calculated from the PV model and is modeled as current source controlled by a current.

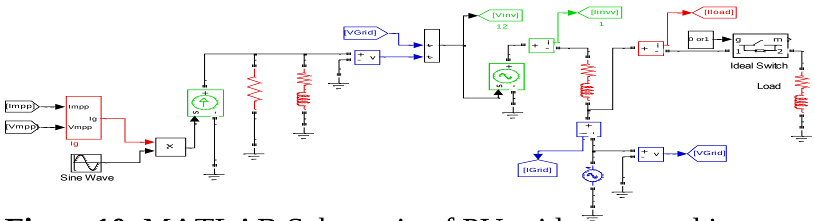
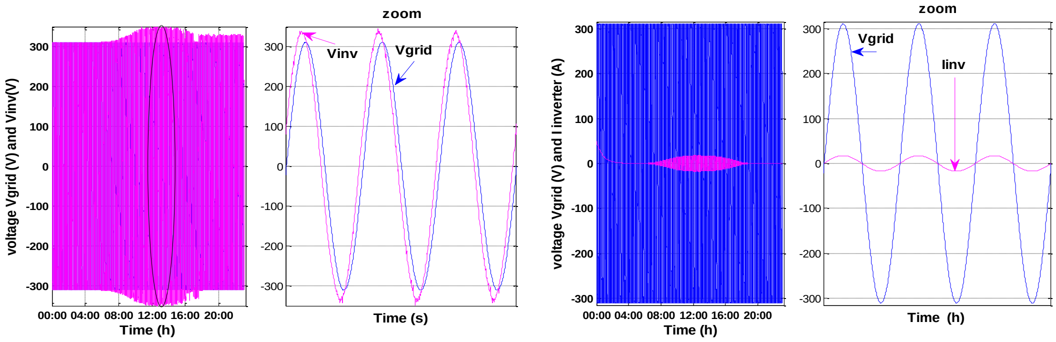


Figure10. MATLAB Schematic of PV grid connected inverter.

The values of the maximum AC power can be calculated from the amplitudes at the inverter output for the two considered irradiance levels:

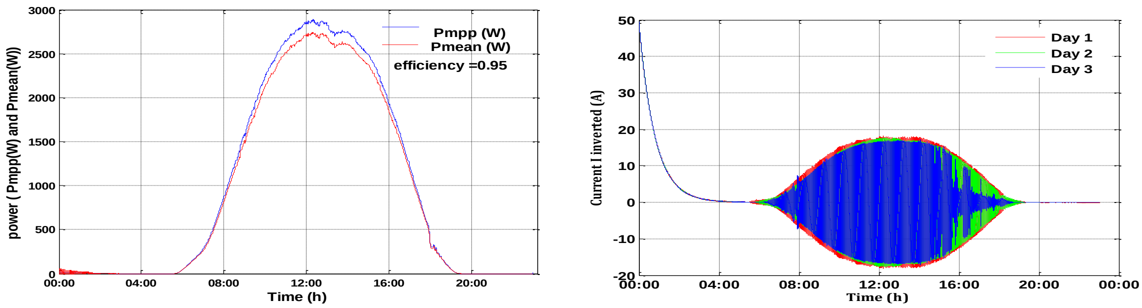
$$p_{ower} = V_{rms} I_{rms} = \frac{1}{2} V_{peak} I_{peak} \tag{13}$$

The simulation results are given in the Fig. 11, 12 and 13 showing the waveforms: current, voltage and power, (before and after passing the inverter).



(a) (b)

Figure 11. Simulated (a) inverter voltage ‘Vinv’, grid voltage ‘Vgrid’ and (b) inverter current ‘ Iinv’ Vgrid voltage’.



(a) (b)

Figure12. (a) Simulated power ‘Pmpp‘and power mean ‘Pmean‘. (b) Simulated shape of the Iinv injected current.

Simulation under MATLAB of the model of the energy injected into the network gives us values of energy of: 23.4 kWh, 22 kWh and 19 kWh.

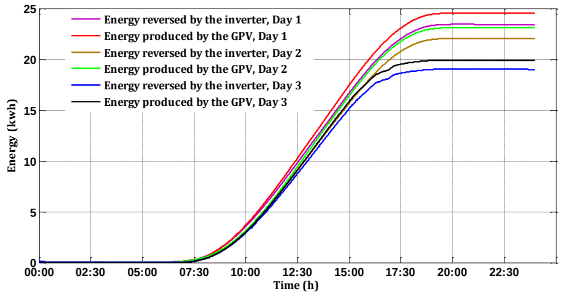
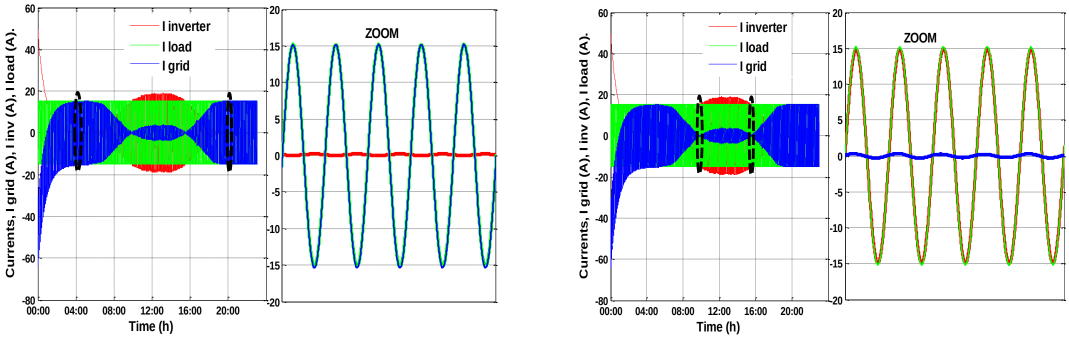


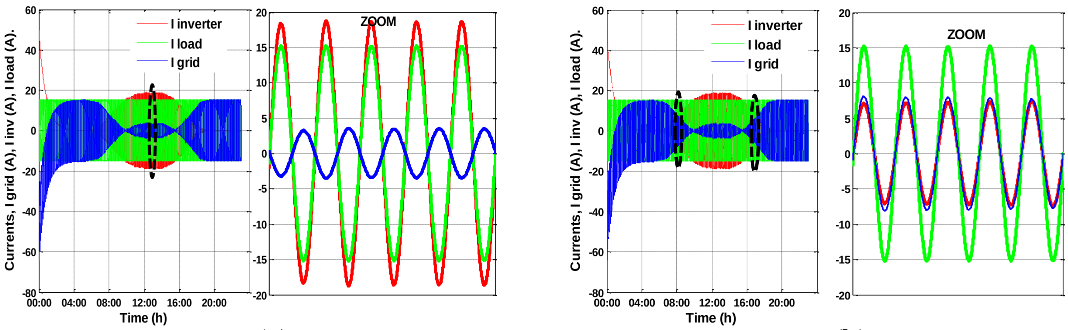
Figure 13. The Energy inverted and produced by the inverter and PV generator respectively.

Based on the consideration of the daily load demand and the weather conditions, this simulation is focused to assume some instants where as the system is predicted to respect the daily operation modes. For achieving that, the irradiation and temperature was increased gradually from zero until its maximum value then was decreased gradually to zero.



(a) (b)

Figure 14. (a,b) Simulation shape of currents Igrid, Iinv and Iload.



(a) (b)

Figure 15. (a,d) Simulation shape of currents Igrid, Iinv and Iload.

Fig. 14 (a) shows that, the PV energy is zero and the load is completely supplied by the utility. This condition usually happens at nighttimes or at short specific weather conditions where the PV array may be covered quietly by a cloud.

Fig. 14 (b): Shows an auto-sufficient period where the PV energy is just able to supply the load.

Fig.15 (a): Illustrates that the PV energy is larger than the load demands, the excess energy will be exported to the utility. The suitable times for that are usually from late morning to middle evening.

Fig. 15 (b): Indicates that there is insufficient PV energy whereby the utility is concerned to cover this shortcoming of energy. This condition usually occurs at low insolation periods, in early morning or late evening.

3. Conclusion

In addition to the dynamic behavior investigation, the simulation has shown the power flow exchange between different components of the system for different modes of operation. Thanks to this study, we can estimate or predict the energy injected monthly or annually into the network. This type of prediction is significant at the time of the feasibility study of a Photovoltaic Power station Connected to the Network.

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