Connection of a Passive Filter in Parallel for Harmonic Compensation in a Grid-Connected PV System

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Abstract: The quality of electrical energy concerns all the actors of the energy field and represents a subject of great interest since the electrical disturbances have a high cost for the industrialists because they generate a fall of the quality of the production, a premature ageing of the equipment, etc. In this research work, we are confronted with a major problem that affects the quality of electric power, namely the harmonic pollution within an electric network, which is due to the heavy use of power electronic devices. These devices exhibit non-linear behavior. At the same time, the distributed energy resource systems, can impose some harmonics in the network. With the presence of harmonic currents an increasing variation of the maximum current, so the value of the effective current and therefore an increase in the rate of harmonic distortion which led to the deformation of the sinusoid of the fundamental. For this, one of the solutions that we can propose to reduce this harmonic pollution is to mount a passive filtering in series the system. This filtering has a low cost and can be efficiently adapted to the connection to a high power electrical network. A simulation of a grid-connected PV system under Matlab/Simulink with and without filtering was performed to analyze the power quality related to PV systems and show the interest of adding passive series filtering. The simulation results performed under Matlab Simulink software showed the effectiveness of adding the passive series filtering system at the output of the inverter in order to attenuate the harmonics.

1 INTRODUCTION

In order to satisfy the high energy demand, DER systems appear as a favored means to cope with this situation. Due to the insertion of distributed generation, power flows and voltages are impacted not only by loads but also by sources. So, the connection of photovoltaic (PV) systems to the distribution network can have some impacts on the electrical networks; on the one hand, the impacts on the power flow, the voltage plan, the protection plan and the power quality (G. B. Alers, 2011)... and on the other hand, the characteristics, the operation and the disturbances on the distribution networks can influence the operation of PV systems. In order to avoid the malfunctioning or even the destruction of the electrical network components.... it is essential to understand the origin of the disturbances and to look for adequate solutions to eliminate them. Among the main types of disturbances that can degrade the quality of electrical energy: voltage dips and short interruptions, voltage unbalance, harmonic disturbances and overvoltages (Vanya Ignatova , 2009).

Several works available in the literature have presented various studies on the Impact of grid-connected PV system on the power quality of a distribution network. Although the active power generated is linearly proportional to solar irradiance, it may show an inverse trend at varying irradiance values. In addition, the use of a low switching frequency inverter with a PV system can produce high harmonic distortion. This then justifies that in connected PV systems, the THD level should be monitored throughout the day (ICEEE, 2014) . Two solutions to improve power quality are proposed (Walaa and walid, 2018). The first is based on switching at very low current flow conditions and the

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second is based on adding filters to the system. Both proposed approaches are implemented using MATLAB Simulink simulation and are compared for their effectiveness and applicability. The results are also demonstrated by determining the THD as a function of the photovoltaic load flow to the connected grid and applied on a case study tested during the spring and summer seasons. In (Masoud Farhoodnea & al, 2012 and Pedro González & al, 2011), a study on the impacts of grid-connected PV systems has been investigated. Simulation results using Matlab/Simulink software showed that the active power produced by the PV system causes an increase in voltage and a reduction in power factor, which can then create serious problems for the system components. For this, an internal control strategy is needed in the storage devices and the inverter to adjust the injected power according to the needs of the grid. In order to improve the stability of the system, reduce the voltage instability and improve the reliability of the whole power system, an L-S PV system is proposed and simulation results have shown their performance (Shady S.Refaat & al, 2018). In today's power electronics markets, there is a wide variety of inverter designs that can be attached to PV systems to meet the increasing demand for solar systems to be used in DG grids using modern control technologies. As a result, the harmonics delivered to the main power grid vary depending on the type of inverters used and their control strategy. Now, utility operators must address and remedy the impact of these components that accompany PV generation (Tiago E. C. de Oliveira & al, 2018). In this work, a study was carried out on grid-connected photovoltaic (PV) systems with the objective of studying the impact of grid injection, and then a simulation of a grid-connected PV system was performed in Matlab/Simulink to analyze the power quality related to the systems. The use of passive parallel filtering is proposed as a solution to reduce harmonic pollution due to its advantages in terms of cost, performance and efficient adaptation to the connection to a high power grid. Simulation results have been performed in Matlab/ Simulink software to show the interest of adding passive filter in parallel. The solar irradiation data are extracted from Benguerir site during the year 2017.

The rest of this paper is organized as follows. Section 2 presents a description of the overall system and the modeling of the subject of our study, namely the passive filter in parallel. The simulation results and their discussion are provided in Section 3. Finally, Section 4 ends this paper with conclusions.

2 SYSTEM DESCRIPTION AND MODELING

The studied system includes a photovoltaic generator which is connected to the common DC bus by a step-up converter, and connected to the grid via a DC/AC inverter. A passive filter at the output of the system whose role is to reduce the harmonic content as shown in the figure below.

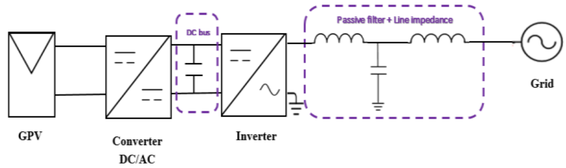


Figure 1: Synoptic of the studied system

2.1 Photovoltaic system:

In order to understand the electrical behavior of a conventional cell, the use of the equivalent electrical circuit is necessary. Under illumination the photovoltaic solar cell is represented by the equivalent electric circuit schematized in the following figure.

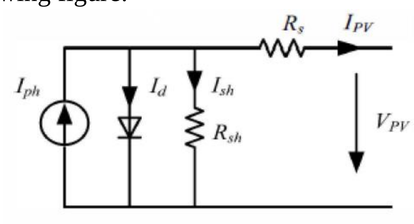


Figure 2: PV cell equivalent circuit

The output current can be expressed as follows:

$$I_{out} = I_{ph} - I_S\left(e^{\left(\frac{qV_j}{nKT}\right)} - 1\right) - \frac{V_j}{R_{sh}} \quad (1)$$

The voltage across the load resistor is:

$$V = V_j + R_s I_{out} \quad (2)$$

By deducing from the previous equation we finally find the following expression:

$$I_{out} = I_{ph} + \frac{R_S I_{out} - V}{R_{sh}} - I_S\left(e^{\left(\frac{q(V - R_S I_{out})}{nKT}\right)} - 1\right) \quad (3)$$

If we have Rs ≈ 0 and Rsh →∞ and, assuming Rs<<Rsh, our case becomes that of the equivalent circuit of an ideal lossless cell.

So the equation becomes:

$$I_{out} = I_{ph} - I_0\left(e^{\frac{V+I_{out}.R_S}{nV_T}} - 1\right), \text{ Or: } V_T = \frac{KT}{q} \quad (4)$$

Where:
q : Electron charge $1{,}602.10^{-19}\ C$, K : Boltzmann Constant $1{,}381.10^{-23}\ J/K$, n : Non-ideality factor of the junction between 1 and 5 in practice. T: The effective temperature of the cell in kelvin.
It can be seen from equations (2) and (4) that the voltage and current output of the photovoltaic cells are effectively influenced by the operating temperature of their environment which varies over time from hour to hour and from season to season. This will naturally have a direct effect on the photovoltaic generation model affecting the overall power quality that needs to be considered if these photovoltaic generation systems are connected to a common power grid, especially the THD% which can be calculated from equation (5) as follows (Si-Hun Jo & al, 2013):

$$THD_V = \sqrt{\frac{\sum_{k=2}^{N-1} V_k^2}{V_1}} \qquad THD_I = \sqrt{\frac{\sum_{k=2}^{N-1} I_k^2}{I_1}} \quad (5)$$

where:
N is the maximum number of harmonics from obtained samples during one period T, and the subscript k of voltage and current denotes the order of the harmonic.

2.2 Passive filter in parallel

As shown in the following figure, the parallel passive filter consists of an inductor in parallel with a capacitor. It has a low impedance for all harmonics and a sufficiently high impedance with respect to the fundamental, which prevents harmonic currents from propagating to the network. This filter has an inductive behavior for frequencies lower than the fundamental frequency and a capacitive behavior for frequencies higher than the fundamental frequency, which is a major advantage for the control of the current in the inductor.

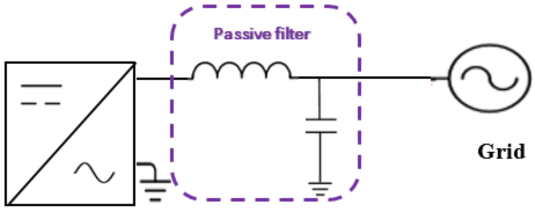


Figure 3: Diagram of a parallel passive filter

It is therefore necessary to adapt a design and specific values for the inductance L and the capacitor C (in (F)), the value of L (in (H)) being chosen so that the ripple content is 10% of the nominal current. The chosen capacitor depends on the reactive power it provides at 50 Hz. Therefore, for our application, we will work with a reactive power equal to 10% of the nominal power, and expressed as follows (NEKKAR Djamel, 2014):

$$C_{max} = \frac{10\% P_{nom}}{3 \times 2\pi \times f \times V_{nom}^2} \quad \text{And} \quad I_{min} = \frac{V_{DC}}{16 \times \Delta I_{L-max} \times f_{sw}} \quad (7)$$

Where f is grid frequency, P_{nom} is rated active power, f_{sw} is switching frequency, V_{DC} is DC bus voltage.

3 SIMULATION RESULTS AND DISCUSSION

Based on the above proposed model, the grid-connected PV system was implemented and simulated in Matlab/Simulink software. The proposed system consists of a GPV connected to a boost chopper which is controlled by the MPPT control of the "Conductance Increment" type given its advantage of tracking the maximum power during the rapid change of illumination, and the power produced by the PV array is 100 KW, all the parameters of the PV panel are shown in Table 1. The connection of these is done by a DC bus, then an inverter which is controlled by a regulation system in order to inject a balanced and sinusoidal current with the minimum harmonic distortions and the minimum power losses and finally connected to the electrical grid.
The global horizontal irradiation (GHI) and average ambient temperature (T amb) during the months of 2017 are given by Figure.4.

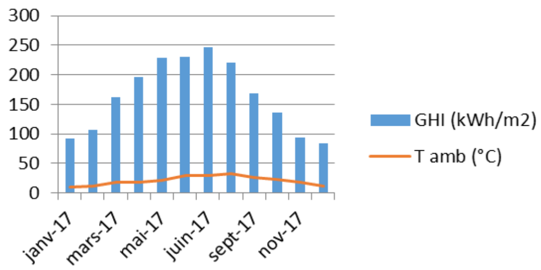
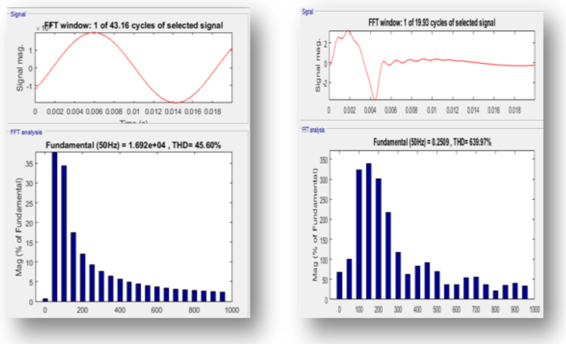


Figure 4: Global solar radiation in (KWh /m^2), at 31° angle and ambient temperature

Parameter	Value
Short circuit current (A)	5.96
Open circuit voltage (V)	64.2
Number of cells per module	96
Number of series connected modules per string	5
Number of parallel strings	66
Maximum current (A)	5.58
Maximum voltage (V)	54.7
Maximum power (W)	306
Parellel resistance (Ω)	993.51
Serie resistance(Ω)	0.037998
Diode saturation current (A)	$1.1753e^{-8}$
Light- generated photo current (A)	5.9602

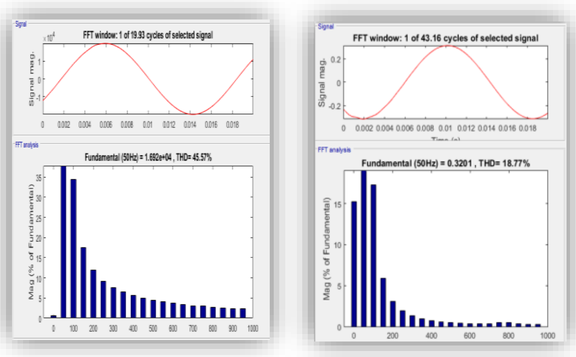
TABLE.1 : PV panel parameters

Our objective in this study is to provide a technical analysis of a grid-connected PV system in the power quality of the distribution network with emphasis on the total harmonic distortion. The study will also propose a solution to overcome the high THD during the operation of the solar system. The connection of inverters to the power grid leads to frequency fluctuations, harmonic distortion and power factor degradation.



(a) (b)

Figure 5: Spectral analysis of network voltage and current (without filter)



(a) (b)

Figure 6: Spectral analysis of network voltage and current (with filter)

3.1 Interpretation of simulation results:

- Without filter:

From figure (5b) we observe the distorted shape of the current injected to the network. The THD measurement of the two graders gives for the voltage 45.60% and for the current 639.97% (see fig.5).

- With filter :

From the figures (6) we can see that the addition of the filter improves the shape of the current and the voltage supplied to the network.
And we can see from the figures (6) the influence of the filter on the improvement of the voltage and the current injected to the network. The THD is well improved for the voltage 45.57% and for the current 18.77%.
As illustrated, a spectral analysis of power quality on a grid-connected PV system was simulated under

different solar irradiations using Matlab/Simulink software. The simulation results proved that the presence of high penetration grid-connected PV systems can cause power quality problems. As well as the efficiency of the passive filter connection in parallel.

4 CONCLUSIONS

This work presents a photovoltaic generator system connected to the electrical grid, and our objective is to study the impact of the injection to the grid. This system injects solar energy into the grid as active power through a two-stage conversion system, consisting of a DC/DC converter (Boost) controlled by a MPPT algorithm of the type "Conductance Increment" for tracking the maximum power point of the PV system under varying illumination conditions, and a DC/AC inverter. The harmonic problem was presented, the spectral analysis of the current and grid voltage showed the effect of harmonic disturbance on the power quality supplied by the GPV. Simulation results under SIMULINK showed the effectiveness of adding a passive filter in parallel to the output of the inverter to improve the quality of the current and voltage injected to the grid. The future work will be oriented towards the development of a control strategy for the DC/AC converter in order to reduce harmonics and ensure the stability of the system.

REFERENCES

Vanya Ignatova "Methods of analysis of electric power quality. Application to voltage dips and harmonic pollution "*page.18.27.28.30, 2009.*

G. B. Alers, "Photovoltaic Failure Analysis: Techniques for Microelectronics and Solar," in *PV Module Reliability Workshop, Colorado, USA, 2011*.

https://tel.archives-ouvertes.fr/tel-00592272/document.

Shady S.Refaat, Haitham Abu-Rub, Antonio P.Sanfilippo, and Amira Mohamed, 2018. “Impact of grid-tied large-scale photovoltaic system on dynamic voltage stability of electric power grids”. In *IET* 5^{th} *Renewable Power generation conf 2018, vol.12 ISS.2, pp.157-164.*

Masoud Farhoodnea, Azah Mohamed, Hussain Shareef, Hadi Zayandehroodi, 2012. “Power Quality Impact of Grid-Connected Photovoltaic Generation System in Distribution Networks”. In *IEEE Student Conference on Research and Development, Department of Electrical, Electronic and Systems Engineering Universiti Kebangsaan, Malaysia.*

Pedro González, Enrique Romero-Cadaval, Eva González, and Miguel A. Guerrero, 2011. “Impact of Grid Connected Photovoltaic System in the Power Quality of a Distribution Network”. In *IFIP International Federation for Information Processing, AICT 349, pp. 466–473, 2011*.

Tiago E. C. de Oliveira , PedroM. S. Carvalho, Paulo F. Ribeiro , and Benedito D. Bonatto , 2018. “PV Hosting Capacity Dependence on Harmonic Voltage Distortion in Low-Voltage Grids: Model Validation with Experimental Data”, *Energies 2018, 11, 465.*

Walaa Ibrahim Gabr and Walid Abdelaziz Salem, 2018. “Impact of Grid Connected Photovoltaic System on Total Harmonics Distortion (THD) of Low Voltage Distribution Network: A Case Study”. In *IEEE - Twentieth International Middle East Power Systems Conference (MEPCON), Cairo University, Egypt, 2018.*

International Conference on Environment and Electrical Engineering, Krakow, Poland, 10–12 May 2014; pp. 1–4.

Si-Hun Jo, SeoEun Son, and Jung Wook Park. On improving distortion power quality index in distributed power grid: *IEEE transaction on smart grid, vol 4, pp. 586-595, March 2013.*

NEKKAR Djamel “Contribution to the study of Control Strategies for Three-Phase Active Filters" *page.15.13.17.19.20 ,2014.*