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. It represents a subject of great interest since the electrical disturbances have a high cost for the industrialists because they generate a fall in the quality of the production, premature ageing of the equipment. In this research work, we are faced with a significant 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 behaviour. At the same time, distributed energy resource systems, can impose some harmonics in the network. With the presence of harmonic currents, an increasing variety of the maximum winds, so the value of the effective current and therefore an increase in the rate of harmonic distortion led to the deformation of the sinusoid of the fundamental. One of the solutions that we can propose to reduce this harmonic pollution is to mount passive filtering in parallel the systems. This filtering has a low cost and can be efficiently adapted to a high power electrical network connection. A simulation of a grid-connected PV system under Matlab/Simulink with and without filtering was realised to analyze the power quality related to the PV system and show the interest in adding passive parallel filtering. The Simulation results demonstrated the effectiveness of adding the passive filtering system in parallel to the output of the inverter to attenuate the harmonics.

1 INTRODUCTION

To satisfy the high energy demand, Distributed Energy Resources (DER) systems appear as a favoured means to cope with this situation. Owing to the insertion of DER, power flows and voltages are impacted not only by loads but also by sources. So, the connection of the photovoltaic (PV) system to the distribution grid can have some effect on the electrical network; on the one hand, the impact on the power flow, the voltage plan, the protection plan and the power quality (G. B. Alers, 2011). On the other hand, the characteristics, the process and the disturbances of the distribution network can influence the operation of a PV system. To avoid the malfunctioning or even the destruction of the electrical network components, it is crucial to find out the origin of the disturbances and look for adequate solutions. Among the main types of disruptions that can degrade the quality of electrical energy: voltage dips and short interruptions, voltage unbalance, harmonic disturbances and overvoltages (Vanya Ignatova, 2009).

Several literature studies have presented various studies concerning the impact of a grid-connected PV systems 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 generate high harmonic distortion. This can justify that in a connected PV system, the Total Harmonic Distortion (THD) level should be monitored throughout the day (ICEEE, 2014). Two solutions to improve power quality are proposed (Walaa and Walid, 2018). The first one relies on switching at shallow current flow conditions. However, the second one is based on adding filters. Both proposed approaches are implemented using MATLAB Simulink and compared in terms of effectiveness and applicability. Moreover, the results are also demonstrated by

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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 impact of a grid-connected PV system has been investigated. Simulation results using Matlab/Simulink software showed that the active power produced by the PV systems causes an increase in voltage and a reduction in power factor, which can then create severe problems for the system components. Thus, an internal control strategy is needed in storage devices and the inverter to adjust the injected power according to the grid's needs. To upgrade the stability of the system, limit voltage instability and improve the reliability of the whole power system, a Large-Scale photovoltaic (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 attached to PV systems to meet the increasing demand for solar systems in Distributed Generation (DG) using modern control technologies. As a result, the harmonics supplied to the electrical grid vary depending on the type of inverter and the control strategy used. Utility operators must address and fix the impact of these components that accompany PV generation (Tiago E. C. de Oliveira & al, 2018). In this work, research was carried out on grid-connected photovoltaic (PV) systems to study the impact of grid injection. Then a simulation of a grid-connected PV system was performed in Matlab/Simulink to analyze power quality related to the system. The use of passive parallel filtering is proposed to reduce harmonic pollution due to its advantages in terms of cost, performance and efficient adaptation to a high power grid connection. Simulation results have been performed in Matlab/ Simulink software to show the interest in adding a passive filter in parallel. The solar irradiation data are extracted from the Benguerir site during the year 2017.

The rest of this paper is organized as follows. Section 2 presents a description and modelling of the overall system. The simulation results and discussion are provided in Section 3. Finally, Section 4 ends this paper with a conclusion and perspectives.

2 SYSTEM DESCRIPTION AND MODELING

The studied system includes a photovoltaic generator connected to the common DC bus by a boost chopper, and connected to the grid via a DC/AC inverter. A passive filter is installed in the output of the system with an aim to reducing the harmonic content, as shown in the figure below.

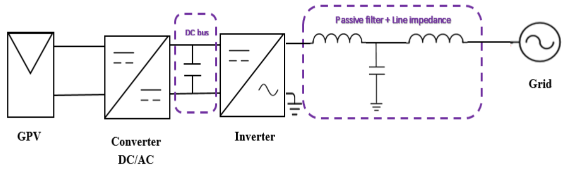


Figure 1: Synoptic of the studied system

2.1 Photovoltaic System

To understand the electrical behaviour of the conventional cells, the use of the equivalent electrical circuit is necessary. The equivalent electric circuit of the PV cell is depicted by the following.

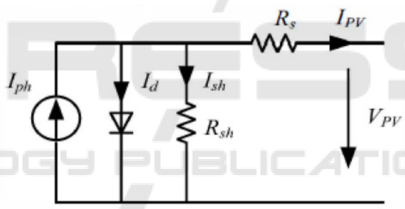


Figure 2: A PV cell equivalent circuit

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:

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

We were assuming that Rs<<Rsh, our case then becomes that of the equivalent circuit of an ideal cell without losses.
Then (1/ Rsh) →0, So the equation (3) 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 is the electron charge. It is equal to $1{,}602.\,10^{-19}\,C$. K is the Boltzmann Constant $1{,}381.10^{-23}\,J/K$. n is the Non-ideality factor of the junction between 1 and 5 in practice, and T is the effective temperature of the cell in kelvin.

From equations (2) and (4), we can see the influence of the temperature that varies overtime on the voltage and current output of photovoltaic cells. For this purpose, it must be taken into consideration, in particular the THD%, which can be calculated from equation (5) as follows (Si-Hun Jo & al, 2013):

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

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 figure 3, the parallel passive filter consists of an inductor parallel with a capacitor. It has a low impedance for all harmonics and a sufficiently high impedance for the fundamental, preventing harmonic currents from propagating to the network. This filter has an inductive behaviour for frequencies lower than the fundamental frequency and a capacitive behaviour for frequencies higher than the fundamental frequency, which is a significant advantage for controlling the current in the inductor.

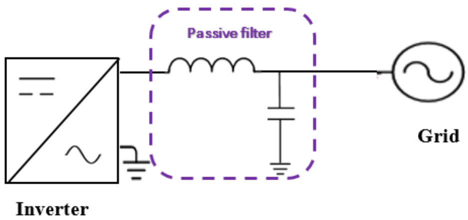


Figure 3: Diagram of a parallel passive filter

It is necessary to adopt 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):

$$C_{max} = \frac{10\%P_{nom}}{3 \times 2\pi \times f \times V_{nom}^2} \quad \text{And} \quad I_{min} = \frac{V_{DC}}{16 \times \Delta I_{L-max} \times f_{sw}} \quad (6)$$

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

3 SIMULATION RESULTS AND DISCUSSION

Based on the above-proposed grid-connected PV system model, the implementation and simulation were realized. The proposed system consists of a GPV connected to a boost chopper which controlled by the Maximum Power Point Tracking (MPPT) control of the "Conductance Increment" type. This type has the advantage of tracking the maximum power during the rapid change of illumination. The energy produced by the PV array is 100 KW, and all the parameters of the PV panel are shown in Table 1. Then, the connection of these is made by a DC bus with the inverter, which is controled by a regulation system to inject a balanced and sinusoidal current with the minimum of harmonic distortions and the minimum of power losses and finally connected to the electrical network. The global horizontal irradiation (GHI) and average ambient temperature (T amb) during 2017 are illustrated in Figure 4.

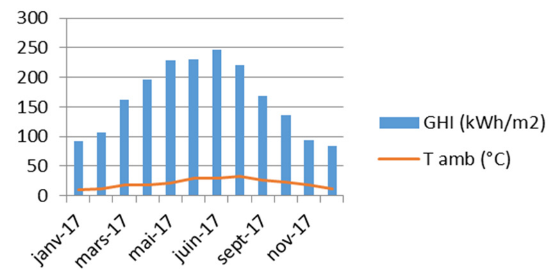
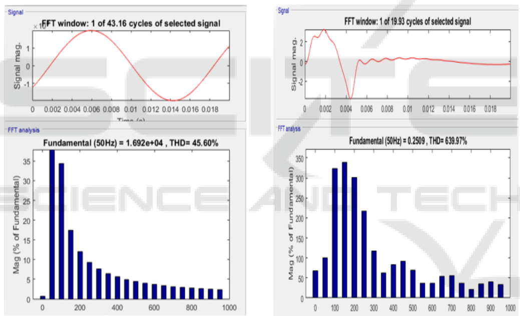


Figure 4: Global solar radiation in (KWh /m^2), at 31° angle and ambient temperature

Table 1: PV panel parameters

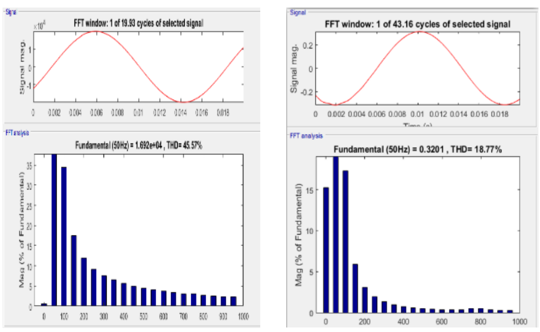
Parameter	Value
Short circuit current (A)	5.96
Open circuit voltage (V)	64.2
Number of cells per module	96
Number of series- connected modules per string	5
Number of parallel strings	66
Maximum current (A)	5.58
Maximum voltage (V)	54.7
Maximum power (W)	306
Parallel resistance (Ω)	993.51
Serie resistance(Ω)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

The connection of inverters to the electrical grid leads to fluctuations, harmonic distortion and power factor abasement. For this reason, our objective in this study is to supply an analysis of a grid-connected PV system with a focus on total harmonic distortion (THD). The study will suggest a solution to overcome the high THD during the operation of the solar system.



(a) (b)

Figure 5: The spectral distribution of the network voltage and current. (without filter)



(a) (b)

Figure 6: The spectral distribution of the network voltage and current. (with filter)

3.1 Interpretation of Simulation Results

The shapes of the network voltage and current are shown in Figures 5 and 6 without and with filter, respectively. Thus, they offer the spectral distribution of the network voltage and current.

From the figure (5b), we observe the distorted shape of the current injected into the network, which shows that these currents are rich in harmonics with a THD equal to 639.97% and the same for the voltage 45.60%.

We observe from the figure (6b) the improvement of the shape of the current injected into the network. Moreover, we can see from figures (6) the influence of the filter on improving the voltage and the current injected into the network. The THD is well improved for the voltage of 45.57% and the current 18.77%.

A grid-connected PV system was simulated under different solar irradiations using Matlab/Simulink software. The simulation results proved that the connecting a PV system to the grid could cause power quality problems namely harmonics. Thereby, the efficiency of coupling the passive filter in parallel to the output of the inverter showed to improve the quality of the voltage and current injected into the grid.

4 CONCLUSIONS

This work presents a photovoltaic generation system connected to the electrical grid. Our objective is to study the impact of the injection into the grid. This system injects energy as active power through a DC/DC converter (Boost) controlled by a Conductance Increment MPPT algorithm, and an inverter. The effect of the harmonic problem on the quality of the power supplied by the GPV was introduced. Simulation results under SIMULINK illustrated the effectiveness of adding a passive filter in parallel to the output of the inverter to enhance the quality of the current and voltage injected into the grid. Our future work will be directed around the development of a control strategy for the inverter 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 5th 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". *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". *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 the 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.*