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STUDY AND ANALYSIS OF THE PROPAGATION OF HARMONICS IN ELECTRICAL GRID CONNECTED PHOTOVOLTAIC SYSTEM

Yacine DJEGHADER *, **Samira BOUMOUS**, **Zouhir BOUMOUS**

University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria
LEER Laboratory Souk Ahras, Algeria
* Corresponding author, e-mail: yacine.djeghader@univ-soukahras.dz

Abstract

Renewable energy sources especially solar energy connected to an electrical grid system by using power electronic devices, known that devices degrade the power quality and especially generate harmonic currents. This article presents the study investigation and propagation of harmonics in the integration system of an electric grid connected to the photovoltaic system in the presence or not of a non-linear load (polluting load). In this study, the perturb and observe type MPPT controller for the boost converter and the PWM control for the three-phase inverter which provides the connection are used. We use a passive filtering technique (single and multiple filters) to mitigate the harmonic currents generated by the non-linear load. In the first case where the integration system is alone, the results obtained show that the values of the total harmonic distortion (THD) rates are within the standard used. But in the case of the presence of the non-linear load, the THD values are higher than the used norm. After using our proposed technique, the values of THD obtained are in the norm used for the application of a tuned filter at the fifth harmonic, and better results find with using of multiple filters (fifth and seventh).

Keywords: harmonic, power system, photovoltaic system power quality, passive filtering

1. INTRODUCTION

The demand for electric energy has increased in recent years, and the depletion of fossil fuel resources, makes the renewable energy source an important place for energy production. Renewable energy especially solar energy is very useful in our country because is clean energy and uses resources that are always available [1, 2]. To enhance the performance and efficiency of photovoltaic systems under varying weather and operating conditions should be using MPPT algorithms [2]. Actually, the integration of photovoltaic systems (PV) with electric grid network plays a predominant role and have become a strategic subject for a lot of researchers in the world [3,4]. Power electronic equipment has grown rapidly such as rectifiers, inverters...etc.; and their generalization in electric grids causes the problem the power quality (PQ) [4,5]. The field of power quality occupies great interest in the last years for producers and consumers of electric energy [6]. To achieve our goal of studying and analyzing the propagation of harmonics in our integration system studied (electrical grid-connected photovoltaic system), we have applied four simulations scenarios (for this reason we use MATLAB Simulink): the first case is to simulate the integration system without the non-linear load, and the second is simulated integration system with the non-linear load (polluting load); we choose a three-phase rectifier (PD3) as a non-linear load since it is the most used in the industry. The third is a simulation with the presence of a non-linear load and a passive filter (single-tuned at fifth, seventh, eleven, or thirteen). The last scenario is the simulation of all systems with multiple filtering (using two filters). The choice of passive filtering technique returns especially for its effectiveness and its cheap price. In each scenario, we focus on the harmonic spectrum of currents propagating into the PV system (PV current) and currents propagating into the electric grid (grid current). By also determining the values of the total harmonic distortion (THD) rates that exist in each scenario. Our goal is to know the best combination to give a minimum value of THD of current propagating into the PV system and currents propagating into the electric grid.

2. DESCRIPTION OF INTEGRATION SYSTEM STUDIED

The global structure of the studied system:" AC Grid-connected PV system" is presented in figure 1.

2.1. The Photovoltaic system

The photovoltaic system is modelled by using the model that contains a single diode [7, 8]. The model of a PV cell is composed of a shunt current source with a diode and a resistance, in addition, to another series resistance (see Figure 2). For the simulation application, we use MSX 60W PV panels.

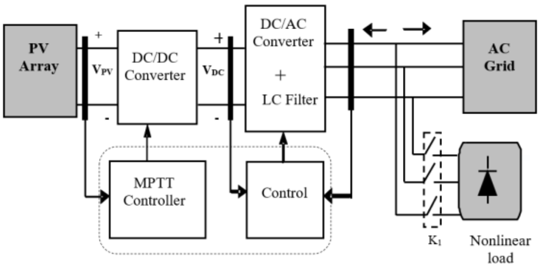

Fig. 1. Integration system studied

The following formula is used for the current calculation [9,10]:

$$I = I_{pv,cell} - I_{0,cell}\left[\exp\left(\frac{qv}{akT}\right) - 1\right] \quad (1)$$

$I_{pv,cell}$: The current generated by the incident light (directly proportional to sun irradiation),
$I_{0,cell}$: The leakage current of the diode,
q: is electron charge, 1.602×10^{-19} C
k: The constant of Boltzmann
T: The PN junction temperature
a: is the constant ideality of a diode

In practice, the photovoltaic generator (PVG) contains several photovoltaic cells connected in series and in parallel to increase the power [11,12]. For this reason, it is preferable to use another equation more generalized or the calculation of the current which contains other parameters not mentioned in equation (1):

$$I = I_{pv} - I_0\left[\exp\left(\frac{V + R_s I}{V_t a}\right) - 1\right] - \frac{V + R_s I}{R_p} \quad (2)$$

V: The voltage at cell output
R_p: Shunt resistance
R_s: Series resistance

In order to build a photovoltaic panel, the association of several cells in parallel and in series is a necessary step. So, we take into account all the losses presented by the shunt and series resistors (by contact and parasite respectively). We adapt equation (3) for the calculation of the current since it is more practical and takes into account all the losses caused by the association of the photovoltaic cells

$$I = N_{pp} I_{pv} - N_{pp} I_0\left[\exp\left(\frac{V + R_s I\left(N_{ss}/N_{pp}\right)}{V_t a N_{ss}}\right) - 1\right] - \frac{V + R_s I\left(N_{ss}/N_{pp}\right)}{R_p\left(N_{ss}/N_{pp}\right)} \quad (3)$$

N_{pp}: Parallel number of PV-connected modules.
N_{ss}: Series number of PV-connected modules.

Neglecting the voltage drops across the diode and the transistor:

$$V_0 = \frac{V_s}{1 - D} \quad (4)$$

Where
Vs is the input voltage, V_0 is the output voltage and D is the duty cycle of the switch.
The duty cycle is the ratio of time the switch is ON to the total switching period. The value of the duty cycle is less than one which makes the $V_o > V_s$. The boost converter is used to step up the voltage.

The main challenge when designing a converter is the type of inductor to be used. we know that the inductance is inversely proportional to the current. So, to reduce the current ripple it is recommended to use a larger inductor [14, 15].

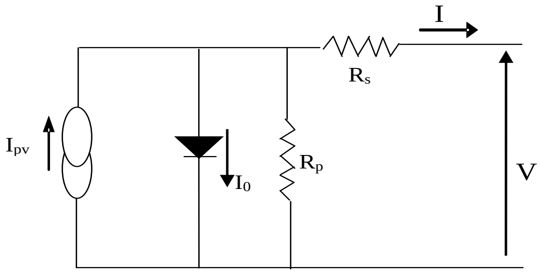

Fig. 2. Model of a photovoltaic solar panel

2.2. The Boost converter

The boost converter is a DC/DC converter, its role is to convert and control an input DC voltage into a higher output voltage. Figure 3 shows the diagram of the boost converter [12, 13].

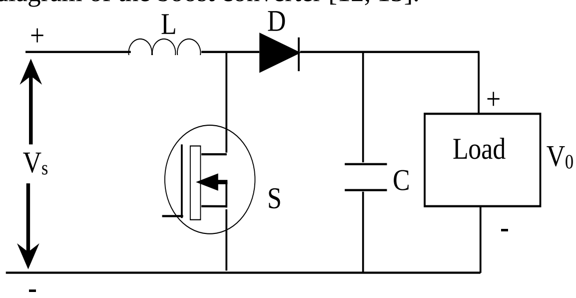

Fig. 3. The Boost Converter

2.3. MPPT Controller

The MPTT technique (maximum power point tracking) is a technique used at the level of the Boost converter (DC/DC) [16]. There are several types of this technique developed in the latest research; such as Perturb and observe (P&O) algorithm, Incremental conductance (IncCond) algorithm, Fractional open-circuit voltage (FOCV) algorithm,

Fractional short-circuit current (FSCC) algorithm. For our case, we used the technique P&O which is considered the most effective and easy for real-time implementation. [17, 18]. The algorithm used (P&O) is based on the principle of making a disturbance and then observing the voltage of the panel photovoltaic until the optimal power is reached with no disturbance. The overall goal of the MPPT technique is always the increase the efficiency and the energy yield of the photovoltaic panels, and that amounts to extracting maximum power. Figure 4. shows the flowchart of the P&O algorithm.

2.4. The DC/AC converter with filter

The DC/AC converter is one of the families of three-phase static converters, its role is the conversion from DC to AC. In this article, we used the PWM control especially the bipolar SPWM (sinusoidal pulse width modulation) technique whose goal was to achieve a voltage shape at the output of the inverter closer to a sinusoid, which meant a very low value of total harmonic distortion.

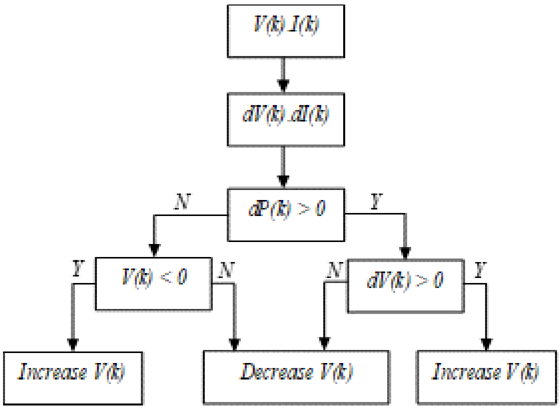

Fig. 5. Algorithm P&O

The passive filter which is between the inverter and the electrical network is generally of an inductive nature (L, LC, LCL), its role is to attenuate the switching harmonics generated during operation [17,18]. For a nonlinear load type, we choose a non-controlled three-phase rectifier (PD3) charging on an RL load that absorbs non-sinusoidal currents and degrades the quality of the energy. In our work, we use series and parallel associations of 11.8 kW connected to AC grid 220 / 380V.

3. SIMULATIONS RESULTS

3.1. Simulations Results: Without non-linear load

In the following figures, we present the harmonic spectrum of currents toward the PV system (PV current), and the other one which propagates towards the electrical grid (Grid current) as well as the value of the rates of total harmonic distortion obtained (THD) (table 1); in the case where the switch K_1 is open (in figure 1).

Fig. 6. Harmonic spectrum of PV current

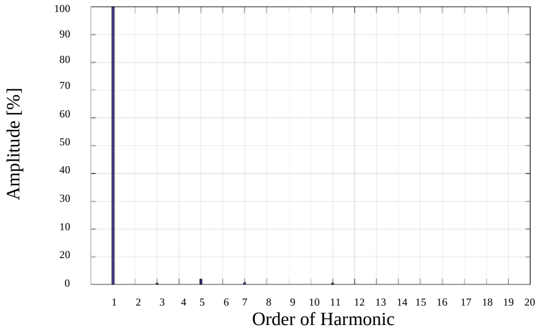

Fig. 7. Harmonic spectrum of Grid current

Table 1. THD and Characteristic harmonics values without non-linear load

	THDi [%]	Characteristic harmonics [%]			
		h_5	**h_7**	**h_{11}**	**h_{13}**
Grid current (i_G)	**2.99**	2.01	0.80	0.54	0.05
PV current (i_{PV})	**3.11**	2.43	0.99	0.68	0.08

Table 2. THD and Characteristic harmonics values case with non-linear load

	THDi [%]	Characteristic harmonics [%]			
		h_5	**h_7**	**h_{11}**	**h_{13}**
Grid current (i_G)	**12.95**	10.68	0.39	1.56	0.84
PV current (i_{PV})	**11.57**	5.19	2.41	1.03	0.57
Current Load (i_L)	**27.25**	20.01	14.04	9.01	7.53

3.2. Simulations results: With non-linear load

We present in the following figures the harmonic spectrums of currents (Grid current, PV current and load current) as well as t total harmonic distortion rates obtained in the presence of a non-linear load (three-phase rectifier PD3).
(Case: K_1 close in figure 1).

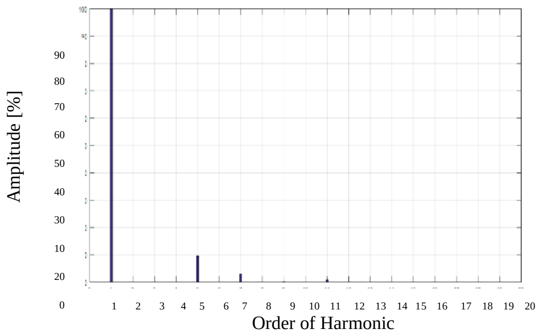

Fig. 8. Harmonic spectrum of PV current

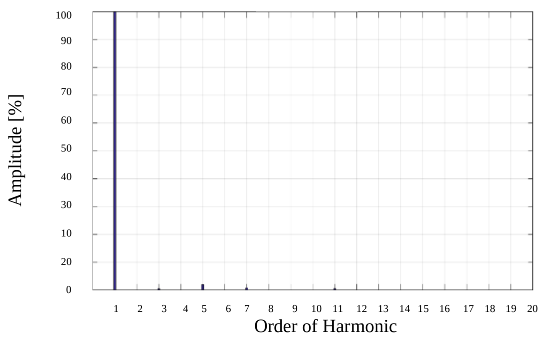

Fig. 9. Harmonic spectrum of Grid Current

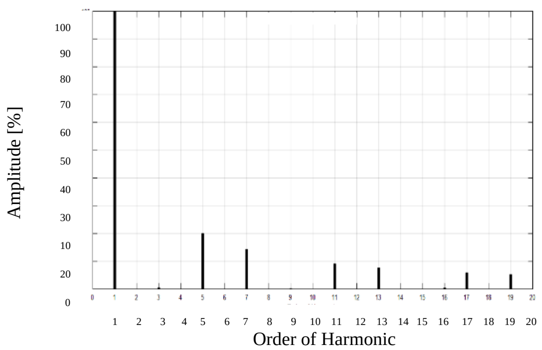

Fig. 10. Harmonic spectrum of load current

4. HARMONICS FILTERING

4.1. Using single branch filter

Passive filtering is used to eliminate a single harmonic rank only (e.g. 5th or 7th h ...). Its principle is based on the creation of resonance in the LC circuit tuned to the desired harmonic to eliminate [21, 22]. Equation (5) is designated to calculate the inductive reactance (X_{lf-h}) of the tuned passive filter; on the other hand, equation (6) makes it possible to calculate the capacitive reactance (X_{Cf-h}) of the tuned passive filter.

$$X_{Lf-h} = \frac{X_{L-h}}{\left(1-h^2\right)} \tag{5}$$

$$X_{Cf-h} = \frac{h^2.X_{L-h}}{\left(1-h^2\right)} \tag{6}$$

With:
- h: The harmonic order designated for the filtering.
- X_{Lf-h} and X_{Cf-h}: The inductive and capacitive reactance of the filter tuned to the harmonic (h)

Table 3. THD and Characteristic harmonics values case single filtering

	THDi [%]			
	With filter 5	With filter 7	With filter 11	With filter 13
Grid current (i_G)	**3.13**	9.64	10.06	10.1
PV current (i_{PV})	**1.85**	10.50	10.65	10.66

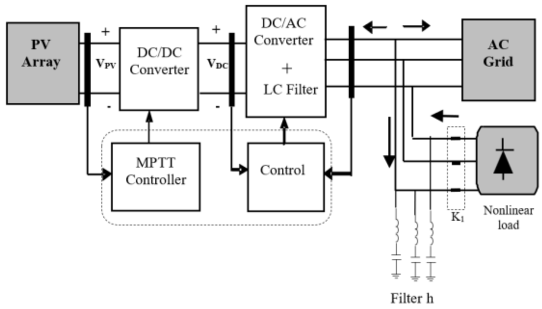

Fig. 11. System studied with single passive filter

4.2. Using multiple harmonic filtering

This method is based on the use of two tuned passive filters (of the order h and h') mounted in parallel with the load. In order to calculate the parameters of these four filters (X_{Lf-h}, X_{Cf-h}, $X_{Lf-h'}$ and $X_{Cf-h'}$); We will need to use four equations (7,8,9 and 10) [19,20].

$$X_{Lf-h} = \frac{(h+h').V^2}{(h^2-1).h'.Q} \tag{7}$$

$$X_{Cf-h} = \frac{h^2(h+h').V^2}{(h^2-1).h^2.Q} \tag{8}$$

$$X_{Lf-h'} = \frac{(h+h').V^2}{(h'^2-1).h.Q} \tag{9}$$

$$X_{Cf-h'} = \frac{h^2(h+h').V^2}{(h'^2-1).h.Q} \tag{10}$$

With:
- h and h': the harmonic orders designated for filtering.
- V and Q: The voltage and reactive power at the filter connection point.
- (X_{Lf-h} and X_{Cf-h}), and ($X_{Lf-h'}$ and $X_{Cf-h'}$): The inductive and capacitive reactance of the filter tuned to the harmonic (h) and (h') respectively.

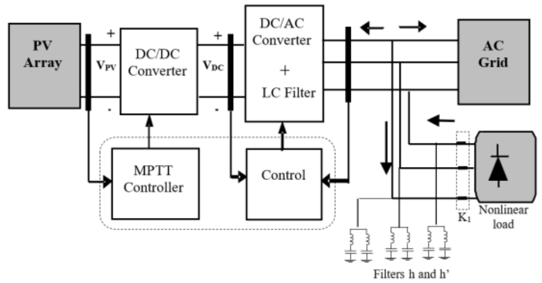

Fig. 12. System studied with multiple harmonic filtering passive filter

4. DISCUSSION

In the simulation results obtained in scenario N ° 01, we notice the calculated total harmonic distortion rates (THD) are under the used norm IEEE 512-1992 standard (5%), where we note 2.98% for grid current and 3.11% for PV current (see Table 1). We can generalize these results obtained by the non-existence of a non-linear load, as well as the LC filter which minimizes the important different switching, as well as the PWM control of the three-phase inverter which makes it possible to push back harmonics to higher frequencies.

Table 4. THD and Characteristic harmonics values case multiple filtering

THDi [%]	With filters 5 &7	With filters 5&11	With filters 5&13	With filters 7&11	With filters 7&13	With filters 11&13
Grid current (i_G)	**0.93**	**2.99**	**4.23**	9.61	10.06	10.06
PV current (i_{PV})	**0.42**	**1.81**	**2.55**	10.51	9.65	10.65

In the simulation results obtained in scenario N ° 02, we clearly show the degradation of the waveform of the current that propagates towards the photovoltaic system or towards the electrical grid, which essentially amounts to the existence of the non-linear load which injects disturbances. We also find that the total harmonic distortion rate of the currents (THD) has exceeded the standard used, 11.57% for the PV current and 12.95% for the grid current when the non-linear load injects at 27.25%; we know the photovoltaic system acts as a compensation of the harmonics with the control of the inverter (PWM) and the LC filter but remains insufficient (see table 2).

In the simulation results obtained in scenario N°.03, by using the single passive filter, we notice the best result was found with a tuned filter at the fifth harmonic (3.13% for grid current and 1.85% for PV current); but with orders filters (seven, eleven, thirteen) the THD values remain bigger than the used norm (see table 3).

In the simulation results obtained in scenario N ° 04, by using the multiple passive filters, we notice that the THD values are underused norm when we use a tuned filter at the fifth harmonic connected with others (seven, eleven, thirteen); and the best result use founded with a combination (fifth & seven) but with orders combination filters (7&11, 7&13 and 11&13) the THD values remain bigger than the used norm (see table 4).

5. CONCLUSION

In this paper, we presented the study and propagation of harmonics in electric grids integrated with renewable energies (solar energy). To archive this goal, we make four scenarios of simulation; the first is without nonlinear load; the second is with a nonlinear load, the third is by using single passive filtering, and the last is by using multiple passive filtering. The simulation results obtained show that our method used for harmonics mitigation is very effective and give minimum values of THD for the harmonics of the currents flow in different directions (into the grid and into the PV system).

Especially in scenario 3 the tuned filter at the fifth harmonic gives THD under the norm. For scenario 4 when we use multiple filters (two filters) the value of THD calculated is under the norm used for (filters 5&7, filters 5&11, and filters 5&13), and we note that the best value was found with (filters 5&7).

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Dr. Yacine DJEGHADER. Presently he is Associate Professor in Department of Electrical Engineering, University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria; Electrotechns and Renwable energy Laboratory (LEER). His fields of interest are Power Quality, Power System, FACTS, Power Electronic.
E-mail : yacine.djeghader@univ-soukahars.dz

Dr. Samira BOUMOUS. Presently she is Associate Professor in Department of Electrical Engineering, University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria Electrotechns and Renwable energy Laboratory (LEER). His fields of interest are Power system, heigh voltage, FACTS,
E-mail : samira.boumous@univ-soukahars.dz

Dr. Zouhir BOUMOUS. Presently he is Associate Professor in Department of Electrical Engineering, University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria; Electrotechns and Renwable energy Laboratory (LEER). His fields of interest are Electric Drive, control system, Power Electronic.
E-mail : zohir.boumous@univ-soukahars.dz