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TECHNICO AND ECONOMIC OPTIMIZATION OF THE INJECTION OF A PHOTOVOLTAIC SYSTEM ON A LOW VOLTAGE NETWORK

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Abstract. ***This paper investigates an experimental study of photovoltaic PV modules behavior (SM110-24) connected to the low-voltage grid (230 V / 50 Hz) with a three-phase inverter. In order to ensure maximum power point tracking (MPPT), The input voltage is delivered via a DC/DC converter that is controlled by the Fuzzy Logic Technical FLC to ensure maximum power MPPT. The control system of the setup is designed for the extraction of maximum power. The primary aim of this investigation is to synchronize the two sources namely PV-grid, using the Phase Locked Loop PLL command with the injection of an alternating current into the network whose aim is stabilizing the system and minimizing the cost of the energy consumed by the load. In this study, the authors have taken into account the real kWh price of the Algerian society of distribution of electricity (Sonelgaz) as the basis for their research. The simulation results obtained by utilizing the MATLAB software show that the proposed system exhibits high performance and flexibility, indicating its potential usefulness for practical applications in the future.***

Keywords: PV module system (SM110-24), Modeling, Fuzzy Logic, Control, Technical and economic system

1. INTRODUCTION

The preoccupations related to the environment as well as the depletion of our reserves incites the use of an alternative energy that solar energy. Can provide in a country, such as Algeria, having a high solar potential with an average annual sunshine estimated to 2000 hours can create an irradiation of about 2651 kWh/m² / yearly in the south of the country and 1701 kWh/m² /yearly in the north, which corresponds to an electrical capacity 8 times higher than the country's natural gas reserves [1]. Algeria has one of the largest solar fields in the world, which encourages us to invest in the development of solar PV energy for example DESERTEC project between Algeria and German in 2021. PV systems are non-polluted systems and require little maintenance. Private investments are in favour of their use with different technologies as well. These two types: autonomous or connected to the grid [2], thanks to the low price of PV panels and government decisions that encourage the exploitation of renewable energies in the field of energy production. This project must compel a deep study of the design of PV stations, especially those connected to electric power transmission and distribution systems for use in different sites [3-4]. The efficiency of direct injection of PV solar energy into the distribution network is still a delicate task [5]. Therefore, from the interested studies related to the exploitation of the connection of the PV production line to an electric power distribution network, our work falls within this framework. In this context, it is interesting to collect solar energy, convert it into alternating current, inject it into the grid and make it available to consumers. This article is structured in a clear and concise manner, consisting of seven sections that cover various aspects of the research conducted. The second section provides a comprehensive overview of the site that was studied, including data on the monthly solar radiation of the area. This information is crucial for understanding the potential of the site for harnessing solar energy and forms the foundation for the subsequent sections of the article.

The third section delves into an overview of the system that was studied. This includes a detailed description of the various components that were used in the system, as well as their functions and interactions. The fourth section then provides an in-depth analysis of the electrical modeling of the main components of the system, highlighting the key parameters and assumptions that were used in the modeling process.

In the fifth section, the authors explain the electrical control techniques that were used in the system studied. This section provides valuable insights into the various strategies that can be employed to optimize the performance of the system and maximize its efficiency. The sixth section presents the findings of the research, with a focus on the electrical and economic results obtained. This section provides a detailed analysis of the data collected during the study and offers valuable insights into the practical implications of the research.

Finally, the article concludes with a comprehensive summary of the research findings and their implications for future research in this field. Overall, the clear and well-structured organization of this article makes it easy to navigate and understand, while the detailed analysis and insights provided offer valuable contributions to the field of renewable energy.

2. GEOGRAPHICAL SITUATION

Figure 1 represents the real values of the monthly solar radiation received by PV panels, for the city of Annaba, located northeast of ALGERIA, [6-7].

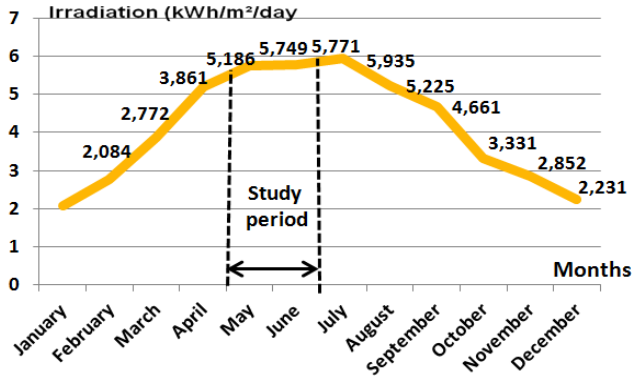


Figure 1. Monthly solar irradiation (Annaba).

According to Figure 1 we note that solar radiation in July is the greatest 5.771 kWh/ m^2 compared to that of January equal to 2.084 kWh/ m^2, which influences the decline in production of PVG panels [8]. For this we did a modeling and control to stabilize our system.

3. PRESENTATION OF THE STUDIED SYSTEM

This section establishes the steps followed for the injection of the power generated by the SIEMENS SM110-24 PV panels into the distribution network. The structure of the chain is in Figure 2. The first component presents the PV production system linked in series to a step-up chopper adapted by a fuzzy logic MPPT control in order to maximize the power extracted by the SM110-24 panels and in addition a capacitor which plays the role of a accumulator for stabilizing the voltage obtained. The second converter has a three-phase inverter supplied by a direct voltage. The control of power semiconductors is done by the Pulse Width Modulation PWM control strategy. In addition, the filter L is used to filter the three voltages of the inverter. Finally, the third component is the three-phase distribution network (voltage source).

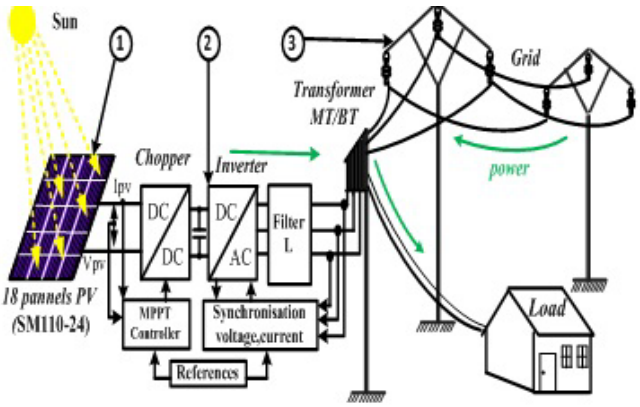


Figure 2. General Diagram of grid connected Panels (SM110-24) systems.

The following part represents the modeling and the electrical control technique of the system studied for each part of the system.

4. SYSTEM MODELING

4.1. Modeling of the PV production system

a) PV panel SM110-24. The solar panels installed with a power of 1.984kW consists of 18 monocrystalline silicon modules, (Model: SM110-24), [9]. The electrical characteristics of the used PV panel are duplicated in Table 1.

Table 1. Parameter of the PV panel SM 110-24

Power (P_{PV})	110W
Current (I_{mpp})	3.15A
Voltage (V_{mpp})	35V
Short circuit current (I_{sc})	3.45A
Open circuit voltage (V_{oc})	43.5V
α_{sc}	1.4mA/°C
β_{oc}	-152mV/°C
Module under solar irradiation	- 40 to +50 °C

The PV generator is organized into 6 panels connected in series and 3 panels in parallel as follows:

$$U_{PV} = N_{series} \times V_{mpp} = 6 \times 35 = 210[V] \quad (1)$$

$$I_{PV} = N_{braches} \times I_{mpp} = 3 \times 3.15 = 9.45[A] \quad (2)$$

$$\sum P_{PV} = I_{PV} \times U_{PV} = 9.45 \times 210 = 1984.5[W] \quad (3)$$

The Figure 3 represents the used PV panel, this panel protected by glass, a rainproof backplate, and an aluminum frame.



Figure 3. Picture of the experimental panel SM110-24

b) Equivalent circuit of the SM110-24. PV generators are constructed from a series and parallel combination of PV cells which are the basic structure in converting solar radiation into electricity [10]. The equivalent diagram of the PV cell that we have considered in this work is shown by Figure 4. The current I_{ph} is proportional to the incident illumination [11-12].

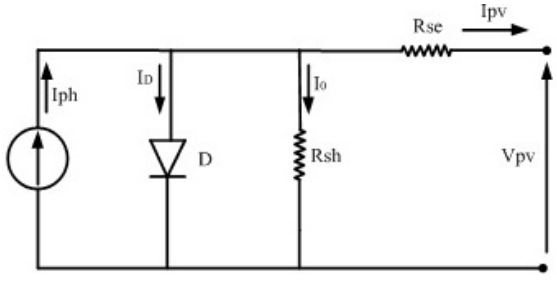


Figure 4. Standard equivalent model of PV cell.

The photovoltaic current of the solar module can be expressed by the attached equation (4), [13]:

$$I_{pv} = N_{sh} I_{ph} - N_{sh} I_0 \left[\exp\left(q \frac{(V_{pv} + \frac{N_s}{N_{sh}} I_{pv} R_{se})}{AkTn_s} \right) - 1 \right] - \frac{V_{pv} \frac{N_s}{N_{sh}} I_{pv} R_{se}}{R_{sh} \frac{N_s}{N_{sh}}} \quad (4)$$

Where:
I_{ph}: Generated photocurrent
I_o: saturating current.
q: Charge (1.602 .10^{-19} Coulomb).
K: Constant of Boltzmann
A: Ideality factor relative to the module.
T: Junction temperature
n_s: Number cell series
Where the saturation current (I_0) depends on the variation of the ambient temperature according to equation 5, [14]:

$$I_0 = I_{or} \left(\frac{T}{T_r} \right)^3 \exp\left\{ \frac{qE_G}{K_a} \left[\frac{1}{298} - \frac{1}{T} \right] \right\} \quad (5)$$

Where:
I_{0r}: Reverse saturation current.

Likewise, the photo-current (I_{ph}) links the temperature of the cell (T) and solar radiation (G), [15]:

$$I_{ph} = (I_{scr} + K_i (T - 298)) \frac{G}{G_r} \quad (6)$$

I_{scr} Reference short-circuit current.

The characteristics (current-voltage) of the PV module are defined as an energy conversion capacity under the effects of the two factors of solar irradiation and temperature [16-17]. Knowing that with the change of these factors, one can expect a change in the state of the PV [18].

Figure 5 presents the experimental and theoretical curve of PV module using the experimental data (G = 0.850 kW/m², T=38°C).

Note that the two curves are reasonably identical on the following three points: Isc(o), Pmax, Voc(o).

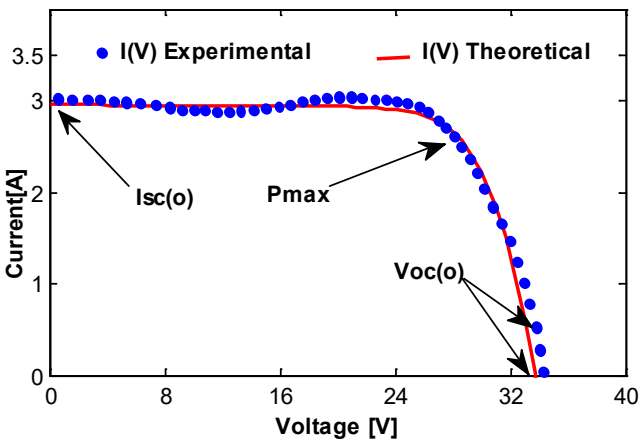


Figure 5. I–V theoretical and experimental characteristic of the SM110-24 module.

Figure 6 illustrates the experimental and theoretical power characteristic of the SM110-24 module under the conditions (EG = 850W/m², T=38°C).

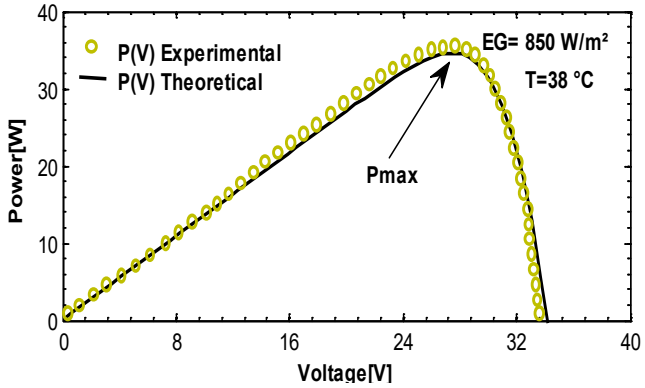


Figure 6. P–V theoretical and experimental characteristic of the SM110-24 module.

One notices in Figure 6 the convergence of the experimental and theoretical approaches, in particular at the point of the largest peak Pmax.

4.2. Chopper converter (DC/DC)

The DC/DC power inverter is considered as important converters in connecting PVG with the load to increase the efficiency of PV energy (Figure 7) [19]. This converter is controlled by MPPT approach [20]. The goal of this technique is to stabilize the PV array operation against the fluctuation of solar irradiation [21].

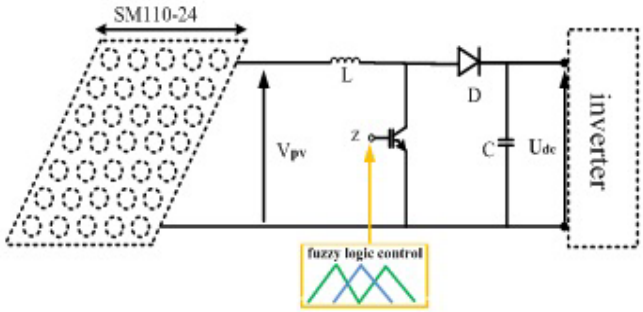


Figure 7. Chopper converter circuit

The following equation displays the output voltage of the converter [22]:

$$\frac{U_{DC}}{V_{PV}} = \frac{I_{PV}}{I_{DC}} = \frac{1}{(1-Z)} \quad (7)$$

Where: U_{dc} is the output voltage, V_{PV} is the input voltage and Z is the duty cycle which is the ratio between the time within which the MOSFET.

4.3. Model of inverter grid connected.

The actual three-phase inverter used for this study is powered by the voltage stored in a capacitor bank shown in Figure 8. This voltage is generated by the chopper connected to the PV generator.

For the modeling of the voltage inverter, we have opted for a variable typology modeling method. The following voltage equation embodies the experimental inverter applied in this research:

$$\begin{bmatrix} v_a \\ v_b \\ v_c \end{bmatrix} = \frac{V_{DC}}{3} \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ -1 & -1 & 2 \end{bmatrix} \begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix} \quad (8)$$

With S_i it is the state of the switch, such as $i^{ème}$ for the inverter arm (*a, b, c*).

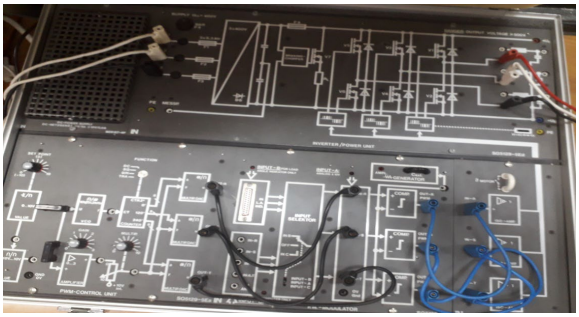


Figure 8. Experimental photo of a three-phase inverter

For this system to give the best performance, it must be studied with an appropriate command whose control is shown in the next section.

5. FUZZY LOGIC CONTROL FLC AND PLL COMMAND

To obtain the maximum power of the photovoltaic generator with different radiation data we used a technique FLC [23-24]. This technique consists of the following stages: fuzzification, inference method and defuzzification (Figure 9).

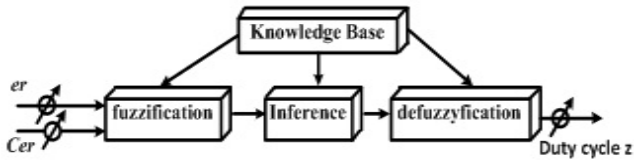


Figure 9. FLC structure.

Fuzzification transforms the physical variables entered into fuzzy sets. In this case, we can define the two input variables of FLC the error (er) and the variation of the error (Cer) by the following equation:

$$\begin{cases} er = \dfrac{p(k) - p(k-1)}{I(k) - I(k-1)} \\ Cer = er(k) - er(k-1) \end{cases} \quad (9)$$

Thus, the phase currents of the inverter are expressed by the system of equation:

$$\begin{cases} \dfrac{dI_1}{dt} = \dfrac{1}{L}(V_1 - V_{g1}) \\ \dfrac{dI_2}{dt} = \dfrac{1}{L}(V_2 - V_{g3}) \\ \dfrac{dI_3}{dt} = \dfrac{1}{L}(V_3 - V_{g3}) \end{cases} \quad (10)$$

Where, I_1, I_2, I_3 and V_1, V_2, V_3 denote the currents and the voltages of the inverter, V_{g1}, V_{g2} and V_{g3} are the three voltages of the distribution network.

By neglecting the resistances of the filter, the components of the currents at the output of the inverter are expressed by the following system of equation [25]:

$$\begin{cases} \dfrac{dI_d}{dt} = \omega . I_q + \dfrac{1}{L}.(V_d - V_{rd}) \\ \dfrac{dI_q}{dt} = -\omega . I_d + \dfrac{1}{L}.(V_q - V_{rq}) \end{cases} \quad (11)$$

Where, ω is the network pulse that is determined by the PLL. The role of PLL is to determine the angle and frequency at each instant that will be used in Park's direct and inverse transforms to compute direct quadrature components of currents and voltages for use in system control. The operational philosophy of PLL is illustrated in Figure 10, [26].

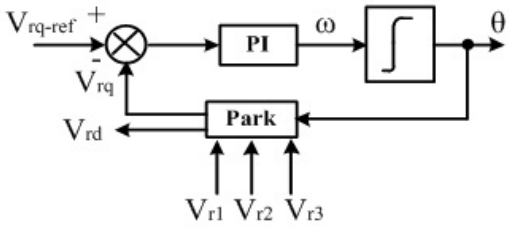


Figure 10. Principle of operation of the PLL.

Figure 11 illustrates the inverter current control technique. The $I_{d\text{-}ref}$ and $I_{q\text{-}ref}$ components are reference currents imposed by the booster chopper, so that the system operates interconnected close to a unit power factor (the quadrature component is forced to zero, $I_{q\text{-}ref}$ = 0) [27], where: **MLI:** Multi Level Inverter.

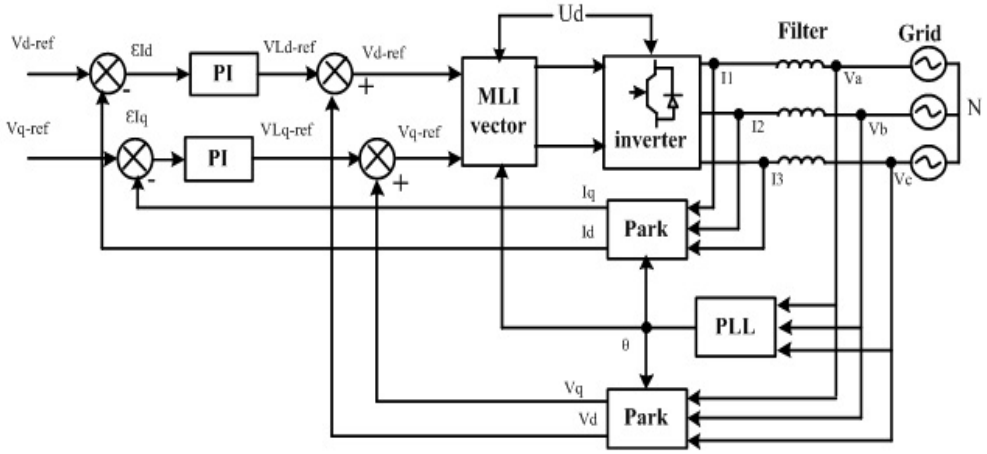


Figure 11. Block diagram of current control

6. RESULTS AND DISCUSSIONS

To simulate the system, we have realized the simulation scheme of Figure 2 under the software Matlab-*Simulink* (Figure 12).

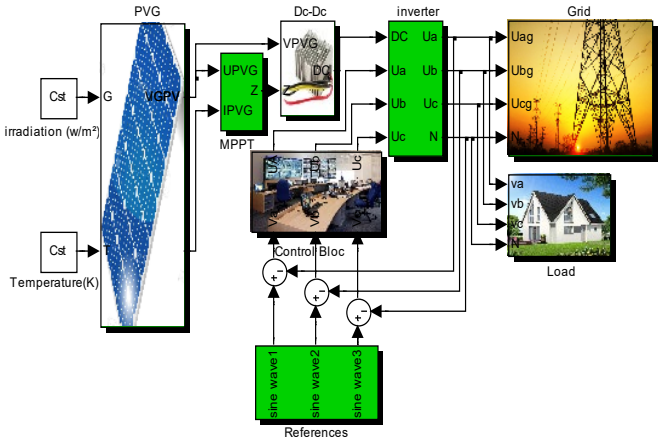


Figure 12. Structure of proposed system (PV-Grid).

We divide the results of the study obtained into two parts: energy and economic results.

6.1. Energy results

From Figure 13, note that the shape of the total output current of the 18 panels is continuously maintained constant I_{PV} = 9.2 A.

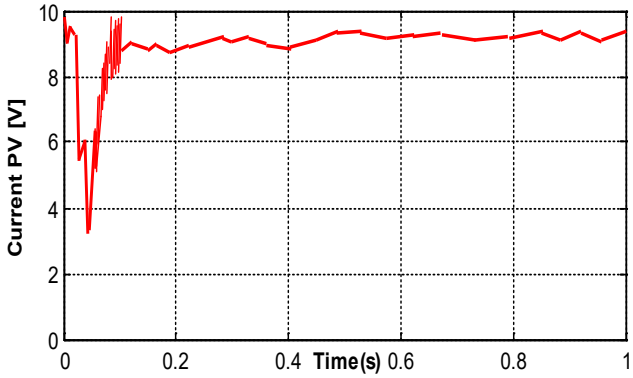


Figure 13. Evaluation of the direct current PV.

Figure 14 represents the total direct voltage produced by the PV group. The output voltage is amplified to a higher value by the converter (DC / DC) using the MPPT control.

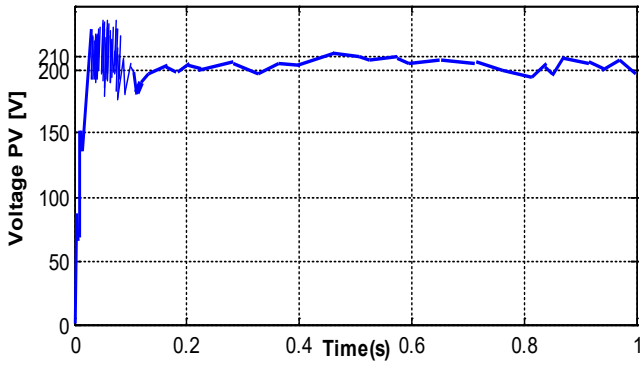


Figure 14. Variation of the PV output voltage

We notice in Figure 15, that the power generated by the SM110-24 panels is generally stable Ppv = 1.9kW.

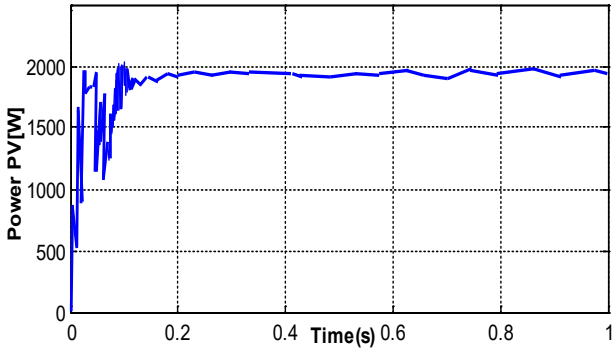


Figure 15. Variation of the active power PV.

Figure16, shows the voltages generated by the chopper (DC/DC). The blue and red curves respectively represent the DC voltage at the input and at the output of the chopper. It is also noted that the output voltage Udc = 465V is greater than the input voltage Vpv = 210V.

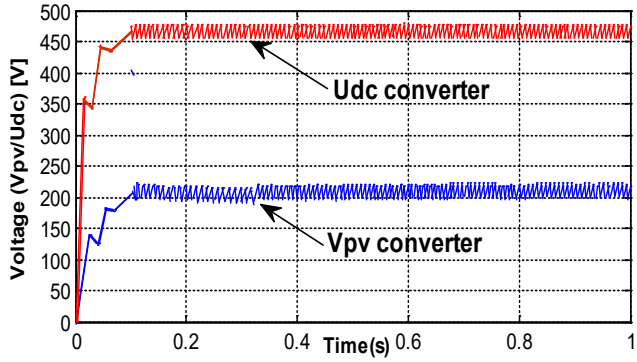


Figure 16. Continuous voltage of an elevator chopper

Figure 17 shows the voltage changes resulting from the inverter.

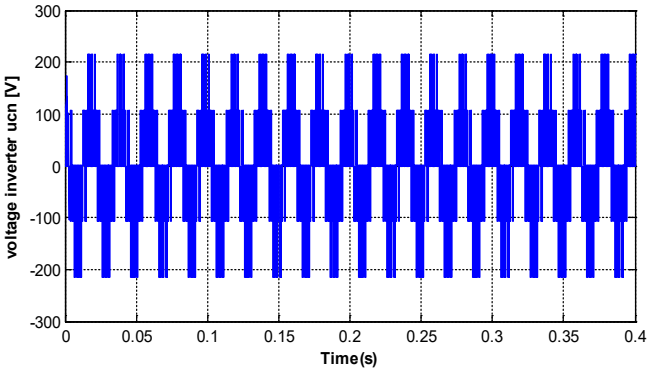


Figure 17. Voltage of one phase of the inverter

Figures 18 and 19, represent the voltages and the three-phase currents of the grid respectively during simulation time 0.1s, each voltage is equal to 220V and current is equal to 4.5 A.

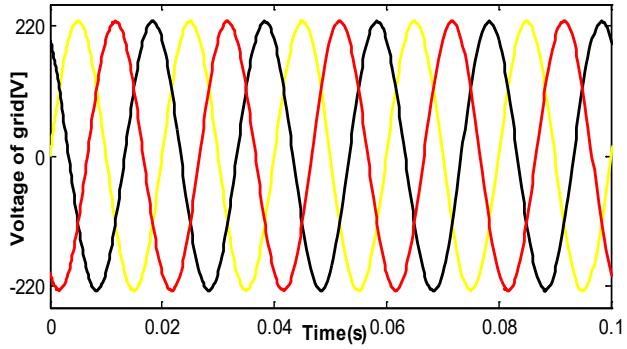


Figure 18. Evolution of the voltages generated by the grid.

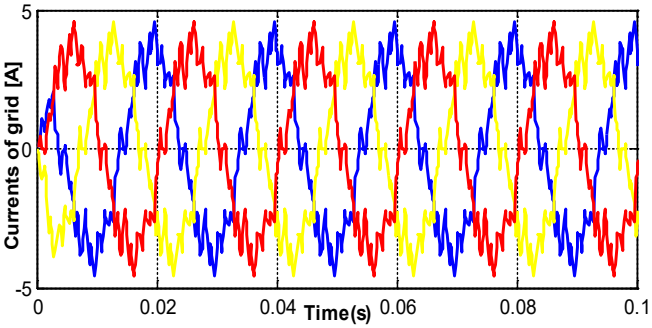


Figure 19. Evolution of currents generated by the grid.

Figure 20 represents the change in the shape of the frequency *f*.

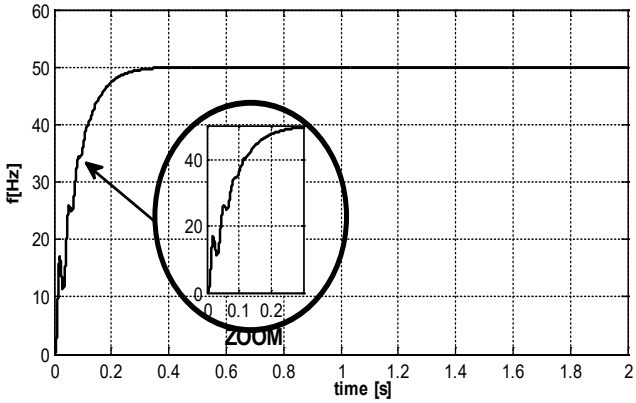


Figure 20. Frequency capture

We can see that this change is very negligible because the technique of the controller by fuzzy logic FLC is more precise and more stable and gives a faster response.

6.2. Experimental economic results

In order to justify our study, an economic analysis is required. In this context we really compare the two systems (grid only / grid + PV). This comparison consists in following the price of the consumption of the kilowatt hour of a single house through the energy produced by the two systems for three months (May, June and July).

These months are chosen when the solar radiation is at its maximum in that location. Knowing that the working hours are from 8:00 a.m. to 6:31 p.m., from sunrise to sunset.

Figure 21 shows the statistics of the monthly average energy consumption during the experimentation period where we made a comparison between the grid only system and (grid + PV).

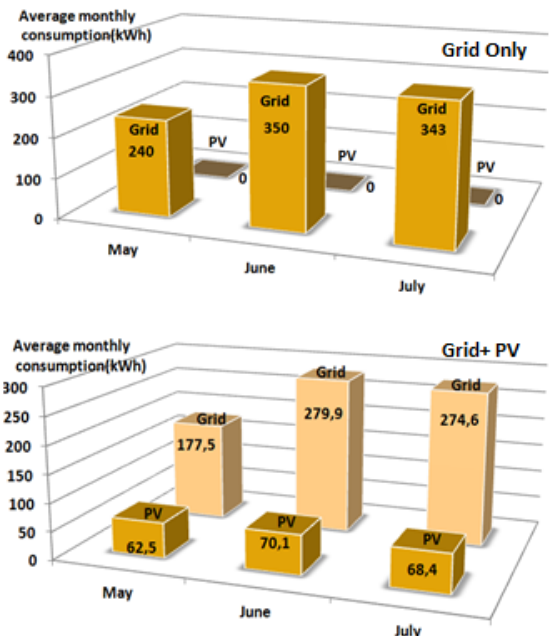


Figure 21. Average monthly energy consumption of the house in (Grid / Grid + PV)

The results in Figure 21 show a decrease in the amount of electricity consumed by the grid thanks to the help of solar panels.

Figure 22 represents the total price of the energy consumed and the economic gain during the period of experimentation of the system.

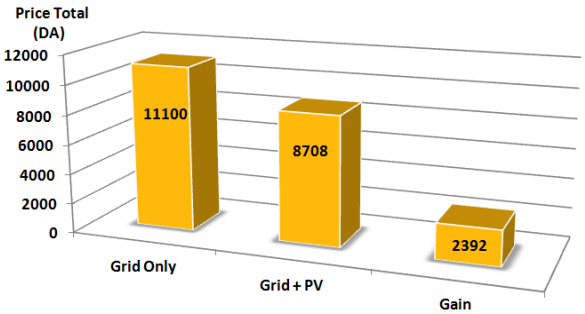


Figure 22. System cost comparison

According to the results of Figure 22, we note that the total cost of the kWh generated with system (Grid+PV) is lower than the total cost of the kWh generated with system grid only, which corresponds to the costs of 8708 DA and 11100 DA respectively because of the PVG integration to the network. Table 2 shows the statistics of a summary of the economic costs resulting from the system studied during the three months.

Table 2. Summary of economic costs generated by the studied system.

Month	Average monthly consumption of the house	Grid Only		Grid With PV	
		Average monthly consumption through the PV	Average monthly consumptio through the grid	Average monthly consumption through the PV	Average monthly consumption through the grid
May	240	00.00	240	62.5	177.5
June	350	00.00	350	70.1	279.9
July	343	00.00	343	68.4	274.6
Total consumption [kWh]	933	00.00	933	201	732
Total price [DA]	11100			8708	
Gain [DA]	11100 - 8708=2392				

These obtained results show the great environmental and economic advantages of the studied system, which has high solar irradiation and an average price of expensive electric energy consumption.

7. CONCLUSION

In this work the Experimental study of the integration of the PV system connected to the distribution network (230V/50Hz) of a house located in willaya ANNABA is interesting. This study analyzes the energy and economic side based on real data such as solar radiation values and the real price per *kWh*. The main objective of this studied system is to improve the energy performance and reduce the total annual cost of the system. Where, the study presented in this article has demonstrated the efficiency of renewable energy (solar energy), and its positive impact on the modern management of the electricity grid. We apply in this study the method of the intelligent optimization algorithm by FLC and the synchronization control PLL, to solve the problem of the economic distribution of a system (Grid + PV). The results showed that our method gives us a better performance with optimal results in all periods of work and respecting the imposed constraints. For this, we have just concluded that the integration of solar energy into the distribution network has a positive impact on the technical and economic distribution, where the individual can apply it for home use to reduce the monthly costs of paying the electricity bill. The simulation results and research statistics also show that this studied system considerably reduces the economic losses compared to the usual system. Moreover, the results obtained from the proposed system have enabled us to obtain a significant technical and economic gain in the cost of *kWh*. However, this technique is not considered an ideal and effective solution as it is not without some drawbacks. Rather, it is a study for new researchers to develop and improve its performance to reach more accurate and effective results in the future.

8. REFERENCES

[1] BARCELLONA, Simone, PIEGARI, Luigi, MUSOLINO, Vincenzo, *et al.* Economic viability for residential battery storage systems in grid-connected PV plants. *IET Renewable Power Generation*, 2017, vol. 12, no 2, p. 135-142.

[2] HASAN, Rasedul, MEKHILEF, Saad, SEYEDMAHMOUDIAN, Mehdi, *et al.* Grid-connected isolated PV microinverters: A review. *Renewable and Sustainable Energy Reviews*, 2017, vol. 67, p. 1065-1080.

[3] Abdulelah, Baraa Jalil, et al. "Modeling and analysis: power injection model approach for high performance of electrical distribution networks." *Bulletin of Electrical Engineering and Informatics* 10.6 (2021): 2943-2952.

[4] BENABDA, Amina, KELAIAIA, Mounia Samira, LABAR, Hocine,*et al.* Boost chopper MPP assessment based on solar irradiance and predictive duty cycle applied to a PV system. *International Journal of Hydrogen Energy*, 2017, vol. 42, no 30, p. 19403-19410.

[5] Zhang, Yong, and Wei Wei. "Model construction and energy management system of lithium battery, PV generator, hydrogen production unit and fuel cell in islanded AC microgrid." *International Journal of Hydrogen Energy* 45.33 (2020): 16381-16397.

[6] ALI, Adnan Hussein, HAMAD, Hassan Salman, et ABDULRAZZAQ, Ali Abdulwahhab. Performance Investigation of Grid Connected Photovoltaic System Modelling Based on MATLAB Simulation. *International Journal of Electrical and Computer Engineering*, 2018, vol. 8, no 6, p. 4847.

[7] SANGWONGWANICH, Ariya, YANG, Yongheng, SERA, Dezso,*et al.* Analysis and modeling of interharmonics from grid-connected photovoltaic systems. *IEEE Transactions on Power Electronics*, 2018, vol. 33, no 10, p. 8353-8364.

[8] AL-SHETWI, Ali Q. et SUJOD, Muhamad Zahim. Modeling and control of grid-connected photovoltaic power plant with fault ride-through capability. *Journal of Solar Energy Engineering*, 2018, vol. 140, no 2.

[9] Yaqoob, Salam J., Ahmed Raisan Hussein, and Ameer L. Saleh. "Low cost and simple P&O-MPP tracker using flyback converter." *Solid State Technology* 63.6 (2020): 9676-9689.

[10] Benahmida, Abdelaaziz, Noureddine Maouhoub, and Hassan Sahsah. "Numerical approach for extraction of photovoltaic generator single-diode model parameters." *Computer Science and Information Technologies* 2.2 (2021): 58-66.

[11] Ababacar Ndiaye et al, Degradation evaluation of crystalline-silicon photovoltaic modules after a few operation years in a tropical environment, 249 Solar Energy 103 (2014) 70-77. 250.

[12] Owais, Raja, and Sheikh Javed Iqbal. "Sensorless DC-link voltage regulation strategy for single-phase grid-connected solar photovoltaic systems." *International Journal of Modelling, Identification and Control* 41.1-2 (2022): 133-142.

[13] Dwivedi, Pushpendu, et al. "Advanced cooling techniques of PV modules: A state of art." *Case studies in thermal engineering* 21 (2020): 100674.

[14] HOSSAIN, M. Z., RAHIM, N. A., *et al.* Recent progress and development on power DC-DC converter topology, control, design and applications: A review. *Renewable and Sustainable Energy Reviews*, 2018, vol. 81, p. 205-230.

[15] KOM, Charles Hubert, and Bertrand MOFFO LONLA. "Duty Cycle Modulation and Fuzzy Controller of a Chopper Extracting the Maximum Power Point of a Solar Panel." *International Journal of Renewable Energy Research (IJRER)* 12.1 (2022): 70-80.

[16] Bouri, Sihem, Oussama-Abdelfettah Mekkaoui, and Anes Mohammed Mamem. "Comparative Study of Different MPPT Methods of a Boost Chopper of PV Generator." *Acta Electrotechnica et Informatica* 22.3 (2022): 24-31.

[17] AYUB, Munirah, GAN, Chin Kim, et KADIR, Aida Fazliana Abdul. The impact of grid-connected PV systems on Harmonic Distortion. In : *2014 IEEE Innovative Smart Grid Technologies-Asia (ISGT ASIA)*. IEEE, 2014. p. 669-674.

[18] LI, Xingshuo, WEN, Huiqing, HU, Yihua, *et al.* A novel beta parameter based fuzzy-logic controller for photovoltaic MPPT application. *Renewable energy*, 2019, vol. 130, p. 416-427.

[19] HAMROUNI, Nejib, JRAIDI, Moncef, DHOUIB, Ahmed, *et al.*Design of a command scheme for grid connected PV systems using classical controllers. *Electric Power Systems Research*, 2017, vol. 143, p. 503-512.

[20] Panigrahi, Ramanuja, et al. "Grid integration of small-scale photovoltaic systems in secondary distribution network—A review." *IEEE Transactions on Industry Applications* 56.3 (2020): 3178-3195.

[21] Derbeli, M., Napole, C., Barambones, O., Sanchez, J., Calvo, I., & Fernández-Bustamante, P. (2021). Maximum Power Point Tracking Techniques for Photovoltaic Panel: A Review and Experimental Applications. *Energies*, *14*(22), 7806.

[22] Zerglaine, Abdelaziz, et al. "Experimental investigation on photovoltaic source performances in case of degraded operating conditions for an integration feasibility in Algerian agricultural farms." *Sustainable Energy Technologies and Assessments* 48 (2021): 101659.

[23] Drir, Nadia, Fathia Chekired, and Djamila Rekioua. "An integrated neural network for the dynamic domestic energy management of a solar house." *International Transactions on Electrical Energy Systems* 31.12 (2021): e13227.

[24] Bennour, Fethi, and Hocine Mzad. "A numerical investigation of optimum angles for solar energy receivers in the eastern part of Algeria." *Energy Harvesting and Systems* (2022).

[25] Fadlallah, Sulaiman O., et al. "Steering North African countries towards REN21's path of sustainable solar energy development." *Sustainable Energy Technologies and Assessments* 53 (2022): 102735.

[26] Ksentini, Abdelhamid, and El Bahi Azzag. "Improvement and optimization of an autonomous photovoltaic pumping system." *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields* 32.3 (2019): e2547.

[27] Hassan, Tehzeeb-ul, et al. "A novel algorithm for MPPT of an isolated PV system using push pull converter with fuzzy logic controller." *Energies* 13.15 (2020): 4007.