Artificial Neural Network and Space Vector Pulse Width Modulation Control Technique for a Photovoltaic System with a Power Grid Connection and Lead Acid Battery Storage

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Abstract – *In order to reduce the pollution generated by fossil fuels, the integration of the photovoltaic (PV) system into an electricity grid became a challenge and a solution to overcome this problem. However, to avoid the uncertain presence of solar power output as well as the increase of load demands during the cloudy day or at night, a storage element which is the battery is needed. This paper presents the design and simulation of a grid-connected PV system using MATLAB Simulink. Then, it focuses on the Artificial Neural Network (ANN) technique and the Space Vector Pulse Width Modulation (SVPWM) method to respectively control the DC/DC Boost converter and the main element of all the system which is "the inverter". Moreover, it gives the design and the simulation of a Lead Acid (LA) battery storage connected through a bi-directional (Buck-Boost) converter to control its charge and discharging behavior. In fact, simulation results show that PV module has successfully integrated into the grid thanks to the efficiency of the ANN and SVPWM methods. Then prove that the storage element is able to store energy and provide it when the PV power is insufficient based on the charging and discharging process results of the storage battery.*

Keywords: *Grid-connected PV system, Artificial Neural Network, MPPT, Space Vector PWM, Lead Acid Storage Battery, Bi-directional (Buck-Boost) converter.*

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Nomenclature

RE	Renewable Energy
STC	Standard Test Condition
TSP	Tunisian Solar Plan
ANME	National Agency for the control of energy
T	Temperature
G	Irradiation
D	Duty cycle
P_{mpp}	Maximum Power
I_{mpp}	Current at MPP
V_{mpp}	Voltage at MPP
I_{sc}	Short-circuit current
I_{scr}	Short-circuit current at STC
V_{oc}	Open circuit voltage
Ns	Series-connected cells number
k_i	Short-circuit temperature coefficient
n	ideal factor
R_d	Internal Diode resistance
R_{on}	FET resistance
L_{on}	Internal diode Inductance
f	Frequency
L_F	Filter inductance
R_F	Filter Resistance
dc_{ref}	DC-Bus voltage desired (reference)value
$grid_{ph-ph}$	Phase to Phase grid voltage
$grid_{ph-N}$	Simple grid voltage
F_{grid}	Grid frequency

I. Introduction

Due to the increase of energy demand and the finite reserves of fossil fuels, the use of renewable energy is quickly becoming a necessity and an important part of energy balance in the world, thanks to its free availability and its cleanliness.

In fact, the use of energy does not stop increasing and according to the Renewable 2018 which is an International Energy Agency (IEA) market analysis and forecast from

2018 to 2023 on renewable energy, global energy consumption in 2018 increased by nearly twice the average rate of growth since 2010 by 2.3% and it is expected to grow by one-fifth in the next five years to reach 12.4% in 2023. That is why it is a necessity to use renewable energy to overcome this problem.

Added to that, every year, several renewable energy production statistics are done and prove that the demand for this energy does not stop increasing, and in 2018, renewable energy around the world added about 181 GW[1] as net capacity.

Taking the case of Tunisia, around 97% of Tunisia's electricity is generated from fossils fuels, mainly natural gas while renewables constitute only 3% of the energy mix including hydroelectric, solar and wind energy [2]. Besides, at the end of 2018, Tunisia had an installed capacity of 240 MW of wind power, 10 MW of solar and 62 MW of hydroelectric [2]. However, The Tunisian Solar Plan (TSP) has an official target for total RE share of 30% of the power mix by 2030 (ANME, 2012) [3].

The modeling in this study uses 2030 TSP targets for private sector, utility-scale investment of 940 MW for wind, and 835 MW for solar PV [3].

In fact, the main focus of this paper is on solar energy, especially, photovoltaic (PV) energy which is becoming an important form of renewable energy and the power generated by it in the world increased by more than 30% in 2018 to over 570 TWh and is estimated to reach 3300 TWh in 2030 [3].

Generally, PV array can be categorized into two main groups which are standalone (off-grid) and grid-connected (on-grid). However, the second type accounts in the world for about 99% of the installed capacity compared to the isolated type [4].

Actually, the main devices used to integrate PV system into the electricity grid are the "inverter" and the storage system. An inverter is considered as the most important component for the integration because it consists in converting direct current to alternative and making the grid more stable [5].

Added to that, many strategies and techniques in literature have been used to control these devices such as Pulse-width Modulation (PWM), Sinusoidal Pulse-width Modulation (SPWM), Space Vector Pulse-width Modulation (SVPWM) and etc. In fact, the SVPWM technique is widely used in literature because it is considered as a better technique of PWM implementation as it has advantages over SPWM in terms of good utilization of dc bus voltage, reduces switching frequency and produces more efficient output voltage with less total harmonic distortion [6].

Then storage system is an essential part because it plays an important role on the relation between production and consumption. Moreover, it is needed to store energy when the power produced by the PV system is higher than the load demand and provides energy when the production is less than the consumption.

In reality, batteries are widely used because of its mature technology, high efficiency and quick response [7]. As a definition, a battery is a cell or a group of cells which convert chemical energy into electrical energy using a reversible chemical reaction and may be recharged by passing a current through it.

Two major types of battery technology are used in power applications which are lead-acid and lithium ion (Li-ion). However, lead acid (LA) batteries have been the mainstream residential energy storage solutions because it is a mature and well understood energy storage technology which is robust and low cost. But, the short cycle life especially when it is operated in cycling applications represents the main drawbacks of LA batteries [8].

As a result, the integration of PV system will be successfully done only through the two electric components which are the Boost converter and the Inverter. The main role of the first one is to control the PV system and make it always generate its maximum of power under any weather conditions. And this is by using the Maximum Power Point Tracking (MPPT) techniques such as the Perturb and Observe (P&O) method, Fuzzy Logic Controller (FLC) technique, ANN algorithm and etc. These methods are used to control the duty cycle of the DC/DC converter.

Besides, the SVPWM is needed in this study to control the inverter and integrate the PV system to the grid with frequency and voltage synchronization, thanks to its advantages which are mentioned above.

This paper is organized in the following ways: section II presents the design of grid connected PV system using Matlab Simulink and focusses on the ANN MPPT technique and the SVPWM method used to control respectively the DC/DC and the DC/AC converters. Section III establishes and studies the lead acid battery storage principle, simulation results are presented and discussed in section IV. Finally, the conclusion and some perspectives are given in section V and final section of this paper.

II. Grid-connected PV System Using Matlab Simulink

A. The main circuit of PV System Using Matlab Simulink

The whole system used in this paper consists of PV panel, DC/DC boost converter to increase the PV module output voltage, DC-Bus or DC link capacitor to minimize the ripple content from the PV source and to improve power balancing [9]. Apart from that, the DC/AC converter for connecting PV panel to the grid, a filter for reducing harmonics, three-phase load and finally the grid are also included. The main circuit is shown in the following Fig. 1.

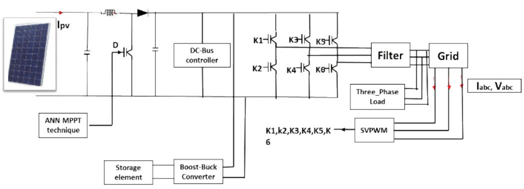


Fig.1. The main circuit

For the simulation and the experimental setup *a* Conergy PowerPlus module type is used and its parameters are given in the following Table I, using the STC, when T=25°C and G=1000W/m² [10].

TABLE I
PV MODULE PARAMETERS

Parameter	Value
P_{mpp}	244
V_{mpp}	30
I_{mpp}	8.13
V_{oc}	37.5
I_{sc}	8.63
N_s	90
N_p	125
Cells number	125
Cells Type	265
n	1.3
k_i	1.33e-3 (A/K)

The main parts of PV generators are cells which collect the sun lights and convert it into electricity. However, these modules have non-linear (Voltage-Power) characteristics, so it is necessary to improve its efficiency by operating it with MPPT which is a technique to maximize power contraction at any time and any weather conditions. Several MPPT methods are used such as P&O, FLC and ANN.

The P&O algorithm works by calculating the power P based on the measured current I and voltage V generated by the PV system. The value of current P, $P(k)$ is then compared with the previous value of P, $P(k-1)$ to obtain the change in power dP, defined as $dP=P(k)- P(k-1)$. If dP > 0, the duty cycle D is increased and decreased if dP < 0. [2] has proved that classical MPPT techniques offer simplified structure and implementation, but their performance is degraded because it has slow tracking and low utilization efficiency.

In addition, the Fuzzy logic is a robust technique especially for the non-linear problems. According to [2], this method has better performance than the P&O algorithm. However, it presents a few oscillations around the MPP, in other words, its output does not converge directly to the P_{mpp}, but it still oscillates around its value of power.

To overcome these problems, neural network techniques are proposed in the present days by which the efficiency is increased [11] due to its high-speed response and convergence, maximum power tracking performance converter. Therefore, it will be used in our current study.

The algorithm used for training of the neural network is back propagation. It only needs inputs and the desired output to adapt the weight. In other words, a feedforward Artificial Neural Network is added which takes V_{oc} and I_{sc} as two inputs and the V_{mpp} as the desired output target for different value of temperature T and irradiance G. Then, it gives the V_{mpp} as output which will be compared to the PV voltage and finally duty cycle D will be calculated and sent to the boost converter. The simulink model as well as the PID controller used in this article to calculate the duty cycle are given in the following Fig. 2 and Fig. 3.

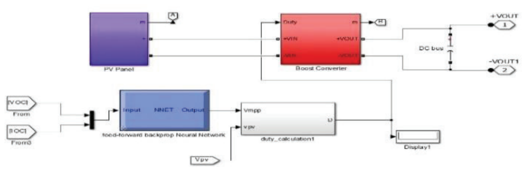


Fig. 2. ANN Simulink model

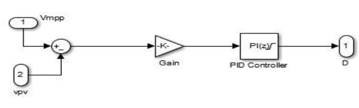


Fig. 3. Duty cycle calculation

As has been mentioned before, the essential element of the grid connected PV system is inverter which operates as an important interface between energy generation and consumption points or a grid in order to meet power requirement. The next sub-section discusses the importance of these components and presents one of the most important techniques used to control it.

B. The main circuit of PV System Using Matlab Simulink

One of the most important considerations in micro grid is the control of power converters [12] to correctly integrate the PV system into power grid and to meet the power requirement.

In fact, the role of DC/AC converter or inverter as shown in Fig. 4 is not limited to DC/AC conversion but also to control power flow and disconnect when it is necessary. Inverter is considered as the main factor that concern with the micro grid control and the thinking and processing component of it. Added to that, in order to be operated in a safe, controlled and effective environment, it is beneficial to equip it with optimal features which will be discussed later.

There are two categories of inverter in literature which are voltage source inverters (VSI) and current source inverter (CSI). The first type has been widely used in grid-connected applications for wind and photovoltaic energy conversion system [13], instead of CSI topology because the inductor used in CSI as storage element has a higher conduction losses, in other words, lower energy storage efficiency compared to DC-link capacitors of VSI [14]. For that in this article, the VSI topology will be used and designed.

Actually, the aim of using DC/AC inverter is to transmit the energy generated from the PV module to the grid in the most efficient way, in other words, inverter current has to be controlled in a way that ensures sinusoidal current injection to the grid to meet all standard regarding grid-tied system [15].

That is why, it is essential to choose the appropriate switching technique to minimize the harmonic rates as low as possible. Since the presence of several techniques such as Pulse Width Modulation (PWM), sinusoidal pulse modulation (SPWM) and space vector pulse width (SVPWM), researchers have been trying to find the optimal way to control the inverter.

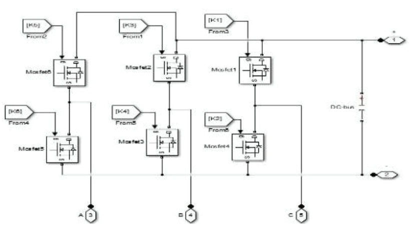


Fig.4. DC/AC converter structure

To integrate the DC/AC correctly, it is necessary to maintain the DC-bus voltage at the desired value. As a result, a PI controller is used to reach this desired value [13]. The Simulink block of the DC link voltage control is given in the following Fig. 5.

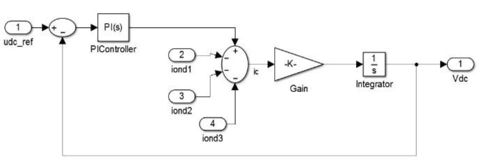


Fig. 5. DC-bus voltage controller

The SVPWM method used in this article is presented in the following basic steps. Firstly, the reference voltage V_a, V_b and V_c are converted to V_α and V_β using the transformation matrix presented in equation (1) [6], then, the rotating θ angle and reference voltage magnitude V_{ref} are determined as shown in the equations below.

$$\begin{bmatrix} V_\alpha \\ V_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \times \begin{bmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & \frac{\sqrt{3}}{2} & -\frac{\sqrt{3}}{2} \end{bmatrix} \times \begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} \quad (1)$$

Where V_a, V_b and V_c in the simulation setup are the grid low voltage and are written in the following way.

$$\begin{bmatrix} V_a \\ V_b \\ V_c \end{bmatrix} = \begin{bmatrix} 220\sin(wt) \\ 220\sin\left(wt - \frac{2\pi}{3}\right) \\ 220\sin\left(wt + \frac{2\pi}{3}\right) \end{bmatrix} \quad (2)$$

$$\theta = tang^{-1}\left(\frac{V_\alpha}{V_\beta}\right) = wt = 2\pi f t, \ \ f = 50Hz \quad (3)$$

After that, the sector S in which the reference vector is located as well as the switch time (T_1, T_2, and T_0) should be determined to calculate (K1, K2, K3, K4, K5 and K6) as shown in the equations (5),(6) and (7) and in Fig. 6.

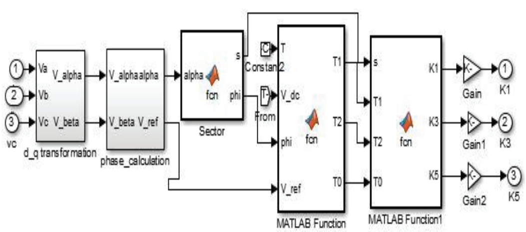


Fig.6. SVPWM architecture

$$T_1 = 2 \times T \times \frac{V_{ref}}{V_{dc}} \times \sin\left(\frac{\left(\frac{\pi}{3} - \varphi\right)}{\sqrt{3}}\right) \quad (4)$$

$$T_2 = 2 \times T \times \frac{V_{ref}}{V_{dc}} \times \sin\left(\frac{(\varphi)}{\sqrt{3}}\right) \quad (5)$$

$$T_0 = T - T_1 - T_2 \quad (6)$$

Where T is the period of the generated signal and φ is the position of the applied voltage vector and it is adjusted by the control frequency in each sampling period.

As it is known, PV modules provide power during the day and especially during the sunny day and many applications require energy when the sun is set. Hence, a battery is needed to store energy and provide it when it is necessary. The next session discusses the importance of a battery storage and gives its design using Matlab Simulink.

III. Lead Acid Battery Storage

Lead acid battery is still the most common option worldwide for stationary energy storage, and it is designed to perform a deep discharge when required.

Moreover, this type of battery is easy to install and has low maintenance cost compared to Li-ion. Added to that, the first model used for the simulation was developed by CIEMAT in Spain (Centro de Investigaciones Energéticas, Mediombientalesy Technologicas) and its equivalent circuit is given below Fig. 7 [16].

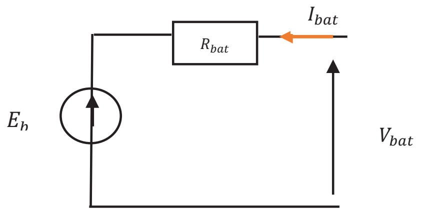


Fig. 7. Equivalent circuit of CIEMAT battery

According to some parameters such as the imposed current and the state of charge, this equivalent circuit defines the voltage across the battery which is given by the following equation (7) [16].

$$V_{bat} = n_b E_b + n_b (R_{bat} \times I_{bat}) \qquad (7)$$

Where V_{bat} and I_{bat} are the voltage and current of the battery respectively, E_b is the electromotive force of n_b battery cell and finally R_{bat} is the battery resistance.

The Simulink model of this type of storage element used in this paper is shown below Fig. 8.

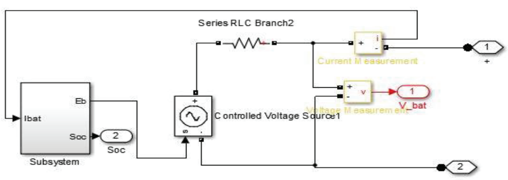


Fig. 8. Simulink block of Acid Battery

The State of Charge (SOC) represents the level of charge of a battery and its unit is the percentage. It can be calculated by using the equation below [16].

$$SOC = SOC_0 - \int \frac{I_{bat}(t)dt}{C_{bat}} \qquad (8)$$

Where SOC_0 is the initial state of charge and C_{bat} is the battery capacity.

In fact, when the SOC is equal to 0% that means the battery is empty, however when it is equal to 100% it is full. Nevertheless, to protect the battery lifetime, in other words, its cycle life, it is recommended not to charge it to 100% and discharge it to 0%. Hence, its SOC should be higher than 90% and less than 10% [17] to prevent premature battery degradation.

In order to integrate the storage element to the grid, a bi-directional DC/DC (Buck-Boost) converter is required to control their charging and discharging as shown in the following Fig. 9.

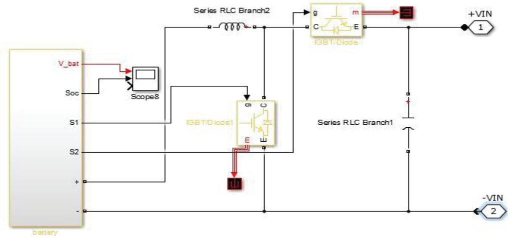


Fig. 9. Simulink model of Bi-directional Buck-boost converter

IV. Simulation Results

The simulation results of the grid-connected PV system are reported in this section using Matlab Simulink as a simulation tool, present the behaviour of the DC/AC converter after using the SVPWM technique to control it and discuss the performance of the storage element.

The Matlab Simulink block of the main system is given in below Fig. 10.

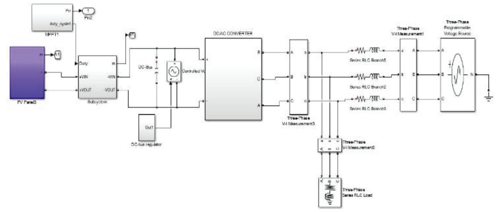


Fig. 10. Matlab Simulink block of the system

First of all, the PV system is operated at full irradiance *G* i.e. 1000W/m² and the temperature *T* is equal to 25°C. The aim of this part of simulation is to control the inverter using SVPWM technique and to see the robustness and efficiency of this method. The value of certain variables are taken according to Table II.

TABLE II
GRID AND FILTER CHARACTERISTICS

Parameter	Value
L_F	25 mH
R_F	0.5 Ω
Vdc_{ref}	380 V
$Vgrid_{ph\text{-}ph}$	270 V
$Vgrid_{ph\text{-}N}$	220 V
F_{grid}	50 Hz

As it has been mentioned before, PV system has non-linear (voltage-power) characteristics as it is shown in below Fig. 11 [2], so it does not always generate its maximum of power. That is why it is essential to use the MPPT technique to make the PV generator to always produce its P_{mpp}.

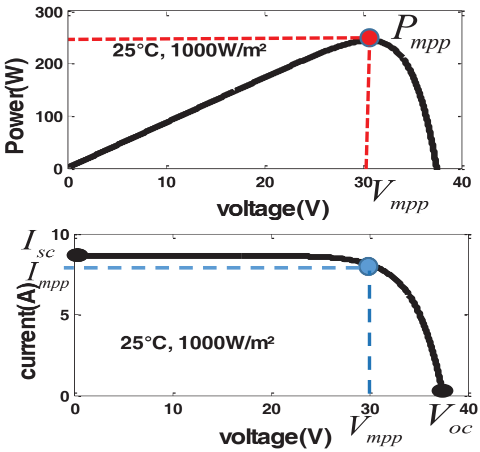
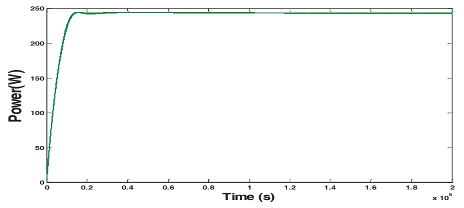


Fig. 11. The output power and current of PV source

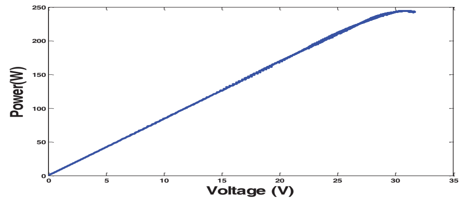
As result, after using the ANN method, the simulation results are given in the following curves in Fig, 12.

The ANN algorithm is used so that the PV panel generation is always at its maximum of power, according to Table I. The maximum power that this module can generate is equal to 244W.

So, from Fig.12 it can be seen that the maximum power given by the PV panel oscillates around 243 W which is near the desired value and fast converges to it with few oscillation around it. That proves the efficiency of ANN algorithm cited in section III in terms of speed convergence and maximum power tracking performance.



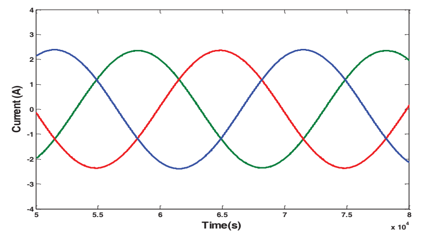
(a)



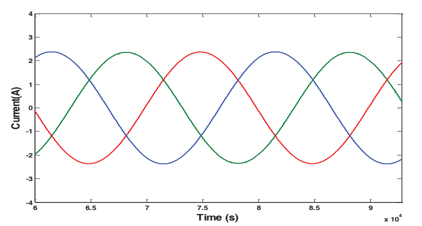
(b)

Fig. 12. PV output (a) power and (b) voltage using ANN algorithm

Figure.13 presents two curves which are respectively the inverter output current (a) using the SVPWM method and the grid current (b) and comparison is made between them. It is shown that the inverter output current is purely sinusoidal and is synchronized with the grid current. That proves that the converter has been successfully integrated to the power grid without presence of perturbation thanks to the efficiency and robustness of the technique used to control it and a the performance of the PI controller.



(a)



(b)

Fig. 13. Output current of (a) inverter and (b) grid

In fact, this controller is used to maintain the DC-Bus voltage at the desired value which is 380 V as shown in Fig. 14 which proves very well the efficiency of PI controller in terms of speed convergence and performance of tracking the reference value.

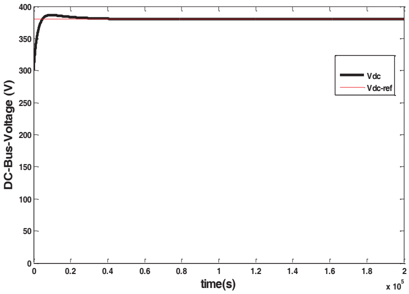
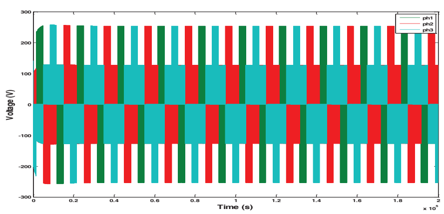


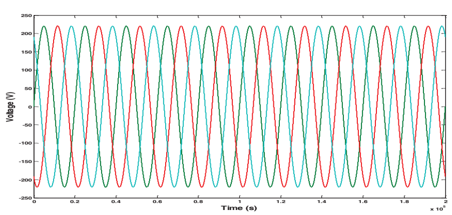
Fig. 14. Comparison between V_{dc} and V_{dc_ref}

Fig.15 presents the inverter output voltage before and after using the RL filter. According to (a), it is clear that the inverter output voltage is modulated due to the use of SVPWM but it should be synchronized with the grid voltage, that is why it is necessary to use a filter.

In fact, figure (b) shows filter output voltage which is purely sinusoidal and could be injected to the grid. That proves very well the importance of the RL filter used before the integration of PV system to the grid.



(a)



(b)

Fig. 15. Voltage of (a) inverter output and (b) grid

This part of simulation focus on the behavior of the storage element when it is connected to the whole system. In fact, power is generated from the PV and is used to supply the loads demand. Excess power generated from the PV can be stored in a battery to be used later on with the following explanation.

- Scenario1: if $P_{pv} > P_{load}$ the battery will store energy and the SOC will increase.
- Scenario 2: if $P_{pv} < P_{load}$ the battery will generate energy and the SOC will decrease.

In order to evaluate this behavior of the storage element and to discuss its performance using Matlab Simulink, its parameters are given in the following Table III.

TABLE III
BATTERY CHARACTERISTICS

Parameter	Value
E_0	12V
R_{bat}	0.0012 Ω
C_{bat}	100 Ah
SOC_0	50%
Maximum capacity	104 Ah

Fig. 16 presents the state of charge SOC, the current and finally the voltage of the battery respectively when it charges, in other words when the production of PV system is higher than the load demand so the battery will store this amount of energy.

Based on the figure, it is clearly shown that when the voltage increases, the SOC increases as well, but the current is negative since the battery depends on its state of charge and it is considered as a receiver.

However when the SOC reaches 90% as a higher limit, the battery stop charging and the current across it is null in order to avoid the overcharge which causes the life cycle of the battery to decrease. That proves that the storage system is successfully integrated to the grid according to scenario 1 which has been explained previously.

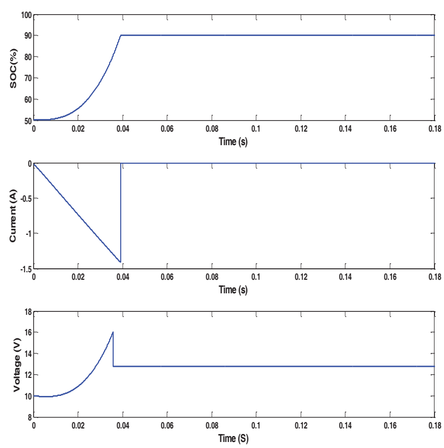


Fig. 16 SOC (%), current and voltage behaviour of the battery during charging process

Fig. 17 presents the state of charge SOC, the current and the voltage of the battery respectively in the discharge process, in other words when the power generated by the PV system is lower than the load consumption power. In this case, the battery will feed the load. According to this figure, when the voltage decreases, the SOC decreases too, however the current is positive because the battery is considered as a generator.

It is clear shown that when the SOC reaches its minimum value which is 10%, the battery stops and the current is equal to zero to avoid the undercharging problems. Hence, it can be seen according to this figure that scenario 2 is successfully proved.

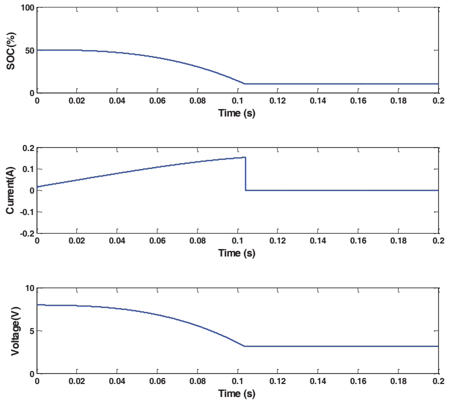


Fig. 17. SOC(%), current and voltage behavior of the battery during discharging process

Based on the simulation results given by the battery, it is clear shown that it strongly depends on its state of charge and plays an important role in the power production and demand.

V. Conclusion and Perspective

In this research work, PV system connected to the grid has been discussed and designed using Matlab Simulink, and two main components of this system have been successfully investigated which are the inverter and the storage element and a satisfactory simulation results have also been obtained. An SVPWM technique has been discussed and studied and simulation results have proved its efficiency. Moreover PI controller used to control the DC-bus voltage has been presented and simulated and two behavioural modes of a battery were presented which are the charge and the discharge. In fact, the storage element is presented to supplement the electrical power injected to the grid when PV power is not sufficient, where as a result the service is always ensured.

As a conclusion, this paper proved the efficiency of the ANN MPPT technique in term of speed convergence and its maximum power tracking, since it quickly reached the P_{mpp} of the PV system. Besides, when the SVPWM is used, the PV panel has successfully integrated to the grid without synchronization problems.

Several researchers have discussed PV grid integration and proved that despite its various advantages such as reducing pollution, free availability and etc., uncontrollable high PV penetration levels on the electric grid could be considered as a problem and could affect the grid power quality that is why it is necessary to study the effect of this integration on the grid. Hence, as a perspective to our current work, we will focus on the impact of PV arrays penetration on the electricity grid.

References

[1] IEA homepage, available:https://www.iea.org, accessed in 16/10/2019.

[2] Khenissi, I. Fakhfakh, M. A., Neji. R. (2018). Comparative Study of three MPPT Techniques of PV system, 3rd International Conference of Recent Advances Electrical Systems (ICRAES 18).

[3] Luetkehermoeller, K. Riechers, K., Roeser, F., Mossaoui, H. Belhaoune, M. R, (2018). "Tunisia:Derisking Renewable Energy Investement 2018" United Nations Development Programme (UNDP), New York, NY (United States).

[4] Sreedevi, J., Ashwin, N. and Raju, M.N., (2016), December. A study on grid connected PV system. In 2016 National Power Systems Conference (NPSC) (pp. 1-6). IEEE.

[5] Nwaigwe, K.N., Mutabilwa, P. and Dintwa, E., (2019). An overview of solar power (PV systems) integration into electricity grids. Materials Science for Energy Technologies.

[6] Abderrahim, T. and Said, B., (2017), May. Control and management of grid connected PV-Battery hybrid system based on three-level DCI. In 2017 6th International Conference on Systems and Control (ICSC) (pp. 439-444). IEEE.

[7] Samrat, N.H., Ahmad, N.B., Choudhury, I.A. and Taha, Z.B., (2014). Modeling, control, and simulation of battery storage photovoltaic-wave energy hybrid renewable power generation systems for island electrification in Malaysia. The Scientific World Journal, 2014.

[8] Jing, W., Lai, C.H., Wong, W.S. and Wong, M.D., (2017). Dynamic power allocation of battery-supercapacitor hybrid energy storage for standalone PV microgrid applications. Sustainable Energy Technologies and Assessments, 22, pp.55-64.

[9] Mihet-Popa, L., Koch-Ciobotaru, C., Isleifsson, F. and Bindner, H., (2012), May. Development of tools for simulation systems in a distribution network and validated by measurements. In 2012 13th International Conference on Optimization of Electrical and Electronic Equipment (OPTIM) (pp. 1022-1031). IEEE.

[10] Pattanaik, P.A., Pilli, N.K. and Singh, S.K., (2015), October. Design, Simulation & Performance Evaluation of three phase grid connected PV panel. In 2015 IEEE Power, Communication and Information Technology Conference (PCITC) (pp. 195-200). IEEE.

[11] Kumar, M., Kapoor, S.R., Nagar, R. and Verma, A., (2015). Comparison between IC and fuzzy logic MPPT algorithm based solar PV system using boost converter. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, 4(6), pp.4927-4939.

[12] Arbab-Zavar, B., Palacios-Garcia, E.J., Vasquez, J.C. and Guerrero, J.M., (2019). Smart Inverters for Microgrid Applications: A Review. Energies, 12(5), p.840.

[13] Bao, J., Bao, W. and Gong, J., (2012). A PWM multilevel current-source inverter used for grid-connected wind energy conversion system. Energy Procedia, 16, pp.461-466.

[14] Dardouri, M., el Khil, S.K. and Jelassi, K. (2018), Control and Filter Design of Single Phase Grid-Connected Inverter for PV applications. In International Conference on Green Energy & Environmental Engineering (GEEE-2018) Proceedings of Engineering and Technology–PET (Vol. 37, pp. 50-57).

[15] Türksoy, Ö., Yılmaz, Ü., Tan, A. and Teke, A., (2017). A Comparison Study of Sinusoidal PWM and Space Vector PWM Techniques for Voltage Source Inverter. Natural and Engineering Sciences, 2(2), pp.73-84.

[16] El Mehdi Laadissi, A.E.F., Zazi, M. and El Ballouti, A.2018, Comparative study of Lead Acid battery modelling. ARPN Journal of Engineering and Applied Sciences, Vol. 13, No. 15 (pp. 4448-4452).

[17] Muenzel, V., de Hoog, J., Brazil, M., Vishwanath, A. and Kalyanaraman, S., 2015, July. A multi-factor battery cycle life prediction methodology for optimal battery management. In Proceedings of the 2015 ACM Sixth International Conference on Future Energy Systems (pp. 57-66).