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Investigation and Filtering of Harmonic Currents in Hybrids Renewable Energy System

Abstract. *This study investigates and filters harmonics currents generated by a hybrid system with a storage system (photovoltaic-wind-battery) for Household Applications. In this paper, we prefer to use passive filtering to mitigate the harmonic's currents especially the passive tuned filter (single and multiple). This method is the most used because it's cheap and effective. The hybrid system studied is used for power supply household applications. This modern system can improve efficiency, reliability, and security while reducing operating costs and offering flexibility. For better working for our system, we use two commands called maximum power point tracking command (MPPT); one for photovoltaic panels, and the second for the wind system, the pulse width modulation control (PWM) for the inverter, and for the control the battery we apply a DC/DC buck-boost. The simulation results obtained with filtering show the improvement of current waveforms and acceptable values of total harmonic distortion (THD).*

Streszczenie. *Niniejsze badanie koncentruje się na badaniu i filtrowaniu prądów harmonicznych generowanych przez system hybrydowy z systemem magazynowania (bateria fotowoltaiczna-wiatrowa) do zastosowań domowych. W tym artykule wolimy stosować filtrowanie pasywne do łagodzenia prądów harmonicznych, zwłaszcza pasywny filtr strojony (pojedynczy i wielokrotny). Ta metoda jest najczęściej używana, ponieważ jest tania i skuteczna. Badany system hybrydowy jest wykorzystywany do zasilania w gospodarstwach domowych. Ten nowoczesny system może poprawić wydajność, niezawodność i bezpieczeństwo przy jednoczesnym obniżeniu kosztów operacyjnych i zapewnieniu elastyczności. Aby lepiej pracować dla naszego systemu, używamy dwóch poleceń zwanych poleceniem śledzenia maksymalnego punktu mocy (MPPT); jeden do paneli fotowoltaicznych, a drugi do systemu wiatrowego, sterowanie modulacją szerokości impulsu (PWM) dla falownika, a do sterowania akumulatorem stosujemy buck-boost DC/DC. Wyniki symulacji uzyskane z filtrowaniem wskazują na poprawę przebiegów prądowych oraz akceptowalne wartości całkowitego zniekształcenia harmonicznego (THD). (**Badanie i filtrowanie prądów harmonicznych w hybrydowych systemach energii odnawialnej**)*

Keywords: Filtering, Harmonics, Hybrids systems, DC/DC converter
Słowa kluczowe: filtrowanie, układy Harmonics, Hybrids, przetwornik DC/DC

Introduction

Hybrids' renewable energy system utilizes two or more energy sources, usually solar along with wind sources because of their abundance in nature [1]. Hybrid renewable energy systems are an effective approach to reducing the consumption of fossil fuel energy resources [1, 2]. Photovoltaic panels (PV) transform light energy into direct electrical energy directly. A wind turbine (WT) transforms mechanical energy into alternative electrical energy which will then be transformed into continuous energy using a rectifier. However, adding battery banks is necessary to satisfy a peak or temporary period of load demand. For the energy storage system, we use in this article the batteries which are widely used in autonomous systems due to their high efficiency, quick response, easy technology, and especially low cost, as well as they, contribute to the improvement, stability, and reliability of the power supply [2, 3]. We use to charge a battery a bi-directional DC-to-DC converter. Our stand-alone hybrid system (PV-Wind-Battery) proposed and studied in this article has been modeled, designed, and simulated under the Simulink environment of MATLAB. The simulation results are presented to verify its performance under various weather circumstances. We concentrate on the alternative side which is power quality problems at the consumer level. We analyze the degradation of waveforms of currents and voltages, which essentially comes down to unstable climatic conditions (wind speed and variation in irradiance); and we note a high value of total harmonic distortion (THD) of the current above the standard norm (5%) [3]. For reducing this problem, we used a simple and effective method for filtering the harmonics distortion. Passive filtering and especially tuned filters are employed for filtering harmonics currents in this paper [4].

Hybrid System Studied

Our proposed hybrid system consisting of a photovoltaic (PV) system connected with a wind turbine (WT) system with the presence of a battery (stand-alone hybrid system) as shown in Figure 1. The studied system is applied to three-phase domestic applications; it has a simple and economical topology.

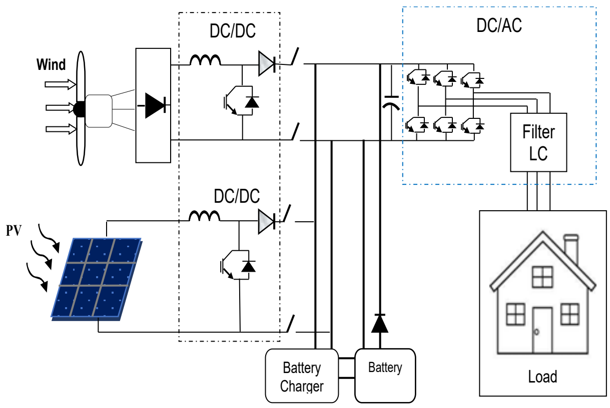


Fig.1. Hybrid System Studied

The Photovoltaic system

The studied photovoltaic system is based on MSX 60W PV panels and for the simulation we adapt the single diode cell model. The model of a PV cell is represented by a current source in parallel with a diode and a series resistance as shown in Figure. 2. The basic current equation is given in the following equation [5].

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

where: $I_{pv,cell}$ –the current generated by the incident light (directly proportional to sun irradiation), $I_{0,cell}$ – the leakage current of the diode, q – electron charge 1.60217646e10^{-19} C, k –the Boltzmann constant, T–the temperature of the PN junction, a– is the diode ideality constant.

But practically the PV array comprised with many PV cells connected in series and parallel connection. This makes some additional parameters to be added with the basic Eq. (1).
The modified equation is shown in the following equations:

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

A large number of cells connected in parallel and in series to build a photovoltaic panel. The two resistors, series and parallel, respectively represent the loss of contact and the parasite in the PV module [1,9]. In order to find a general model of a photovoltaic generator, which takes into account all the losses caused by the series and parallel association of the panels, we use the equation (3).

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

where: N_{pp}– is the number of parallel PV modules, N_{ss}– is the number of series PV modules.

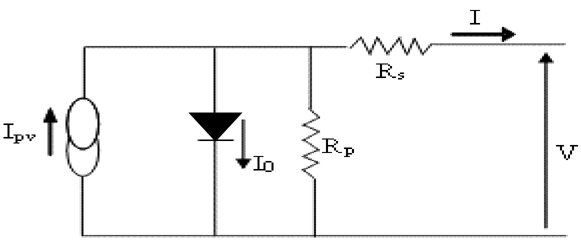


Fig 2. Model of a photovoltaic system (PV)

2.2. The DC/DC converter

The DC/DC converter is the boost converter used to convert and control an input voltage to a higher output voltage. the diagrams of this converter are shown in figure 3 [5,6].

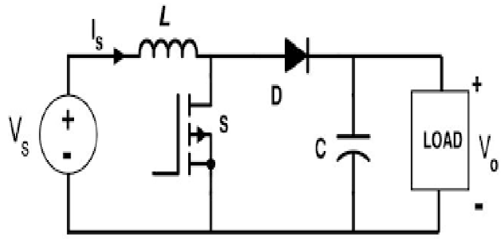


Fig.3. Boost Converter

With the aim of increasing the efficiency et yield of photovoltaic panels, and find to extract maximum power; a technique called MPTT is used, which designates a maximum power point tracking. This technique is applied to the level of the DC/DC converter. Several MPTT techniques have been proposed in recent years, among them the P&O technique used in our article because its simplicity and ease of real-time implementation [7,8]. This algorithm is based on the principle of disturbing and observing the voltage of the panel photovoltaic until the optimum power is reached with a disturbance step. the flowchart of the P&O algorithm is shown in Figure 4.

2.3. The Wind System

2.3.1. Wind Turbine Modeling

The wind turbine captures the kinetic energy in a rotor made up of two or more blades. These blades are mechanically coupled to an electric generator, whose aerodynamic power available in the wind can be calculated using this equation [7, 8].

$$P_w = C_p \frac{\rho A}{2} V_w^3 \quad (4)$$

Where: P_w–the output power of the wind turbine [W], ρ– the air density [kg / m^3], A– the area swept by the wind turbine [m^2],V_w–Wind speed [m / s], C_p– the performance coefficient (depends on the peak speed ratio (λ) and the blade tilt angle (β).

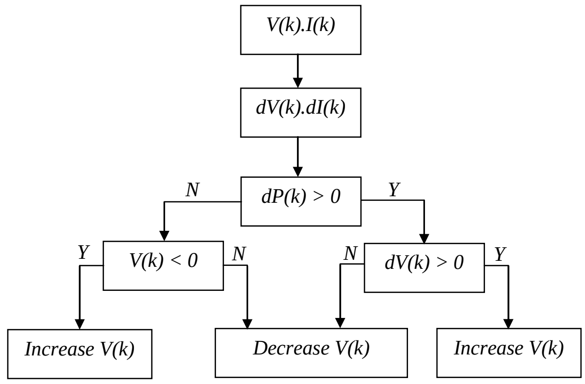


Fig 4. Algorithm P&O

We also defended the ratio (λ) as the ratio between the speed of rotation of a blade and the actual wind speed. We know that the angle of inclination of the blades (β = 0°) always remains zero since the WT generally gives a maximum torque. The maximum value of C_p is theoretically almost always equal to 0.59, this is why the remaining power is discharged or wasted in the downstream wind [8].

2.3.2. Modeling of PMSG

The permanent magnet synchronous generator (PMSG) is intended primarily for the production of electrical energy from mechanical power captured by the wind. We used the two-phase synchronous frame of reference to derive it from the dynamic model of the PMSG, (reference q-d) [7, 8]. To maintain the synchronization between the two-phase system (d-q) and the three-phase system (a-b-c) using a phase locked loop (PLL) [3,11]. We define the mathematical model of PMSG in the synchronous frame of reference (d-q) and expressed in the form of equations of state as follows [3,5].

$$\begin{aligned} \frac{di_d}{dt} &= \frac{1}{L_d}(-R_s I_d + L_q p\omega_r i_q + V_d) \\ \frac{di_q}{dt} &= \frac{1}{L_q}(-R_s I_q - L_q p\omega_r i_d - p\psi_f \omega_r + V_q) \\ T_{em} &= 1.5p(\psi_j i_q - (L_d - L_q) i_d i_q) \\ \omega_e &= p\omega_r \end{aligned} \quad (5)$$

where: V_d and V_q –are the voltages of the axis d and q is the voltage respectively and i_q –are the currents of the axis d and q is the voltage respectively, R_s, L_d and L_q –are the resistance and inductance of the stator (on the axis d) and the inductance (the axis d).

ω_r –is the angular speed. T_{em} is the electromagnetic couple, Ψ_f –is the magnetic flux,p– is the number of pairs of poles.

The mathematical equation of the group is given by the following equation:

(6) $$\frac{d\omega_r}{dt} = \frac{1}{J}(T_{em} - B\omega_r - T_m)$$

where: J– inertia of rotor, B: Friction of rotor, θ_r– rotor angle.

With the decrease in the wind speed the extract of the energy collected by the rotor theoretically can go up to 59% (Betz limit). But in the practical case the percentage of the rotor efficiency varied between 35% and 45%. More realistically, a complete wind system with all these accessories can provide between 10% and 30% of the energy captured by the wind [3].

The DC/AC converter with filter

The DC/ AC converter is a three-phase static converter that allows the transformation of the continuous type energy into an alternative energy. The form of the voltage of the output of the inverter must be closer to a sinusoid, is that the harmonic rate is very low, and it depends mainly on the control technique used. In this article we used the PWM command. The main role of the filter, generally of an inductive nature (L, LC or LCL), is to filter and attenuate the switching harmonics, and reduce the dynamics of the current [10].

The Battery

We use a lead-acid battery in this study. This type of battery is the most used, and the cheapest, it is for this reason it's used in many applications. In our work we model the battery by a resistor in series with a variable voltage source. The inputs of our model are the power measured at the ambient temperature, in addition with the average value of the discharge current [11].

Bidirectional DC-to-DC converter

The bidirectional converter (buck-boost) is mainly used to manage the storage of electrical energy between the autonomous hybrid system used (PV, Wind), and the battery [8]. Its role is to facilitate the storage of electrical energy generated by the autonomous hybrid system during overproduction; therefore, it provides the energy stored in the battery in the event of a shortage (lack) of electricity. Because of the structure of this bidirectional converter, it is possible to define two operating modes for this converter, depending on the direction of the power flow: the boost (increase) and buck (decrease) modes [9, 11].

Harmonics Filtering

Using single branch filter

This filter eliminates a specified harmonic rank (Example harmonic order 5 or 7 or 11 or 13…). The principle based on resonance of LC circuit on specified harmonic eliminated [12,13]. For this reason, we must have two equations to solve this system with tow unknown parameters (X_{Lf} and X_{Cf}).

(7) $$\omega h = \frac{1}{\sqrt{LC}} = \frac{1}{\sqrt{\frac{X_{Lf}}{X_{Cf}}}}$$

(8) $$X_{Lf} - X_{Cf} = X_L$$

with: L, C– filter inductance and capacitance– the harmonic rank, X_{Lf}– reactance of the tuned filter, X_{Cf}– reactance of the tuned filter,X_L– reactance of the load.

By using equations 7 and 8 we can deduce the formulas which allow us to calculate respectively the inductive and capacitive reactance for the tuned filter at the desired harmonic (h):

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

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

Multiple harmonic filtering

This method consists in using two passive filters tuned (to ranks h and h ') in parallel with the load. To calculate the parameters of these filters; we need four equations (7,8,9, and 10) to determine the four unknowns' parameters [12,14].

(11) $$h^2 = \frac{X_{Cf-h}}{X_{Lf-h}}$$

(12) $$h'^2 = \frac{X_{Cf-h'}}{X_{Lf-h'}}$$

(13) $$\frac{V^2}{X_{Cf-h} - X_{Lf-h}} + \frac{V^2}{X_{Cf-h'} - X_{Lf-h'}} = Q$$

(14) $$Z_{f-h'} = \frac{h'}{h}.Z_{f-h}$$

By using equations 11,12,13 and 14 we can deduce the formulas which allow us to calculate respectively the inductive and capacitive reactance for the tows tuned filters at the desired harmonics (h et h'):

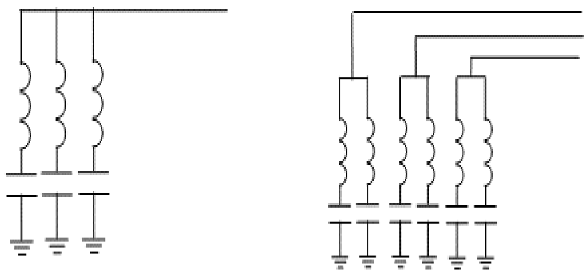
(15) $$X_{Lf-h} = \frac{(h+h')V^2}{(h^2-1).h'.Q}$$

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

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

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

where :h and h'– the harmonic ranks to be filtered,Q– Compensated reactive power,V –Voltage at the place of filtering,X_{Lf-h} and X_{Cf-h} – inductive and capacitive reactance of the tuned filter at harmonic (h), $X_{Lf-h'}$ and $X_{Cf-h'}$– inductive and capacitive reactance of tuned filter at the harmonic (h').



a. single filter   b. Multiple filter

Fig 5. Principle scheme of tuned filter (single and multiple)

Simulations Results

Simulation results without filtering

- According to the results of simulations obtained we notice that our hybrid system works in the correct way for a domestic three-phase load of maximum voltage equal to 325 V=230 *√2, of frequency 50 Hz, and absorbs a current of the order of I_{rms}=21 A.

- From figures 6 and 7 show that there is a degradation of the waveform of the current and the voltage at the load and it comes down to random variations in wind speed.
- From Figure 8 we see a phase shift between the voltage and the current, which means there are a reactive power and a low power factor.
- In Figure 9, we notice a high THD value of 12.62% for current; which exceeds the standard 5% (IEEE-512-2014), and large amplitudes for harmonics 3,5,7,13, and 15.

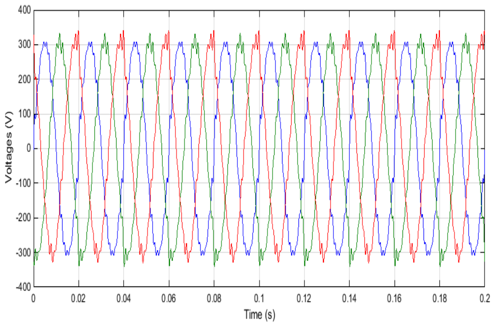


Fig 6. Three-phase voltages at load

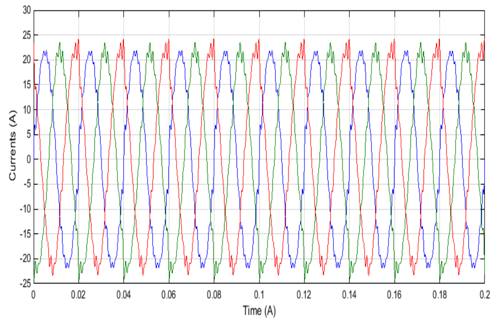


Fig 7. Three-phase currents at load

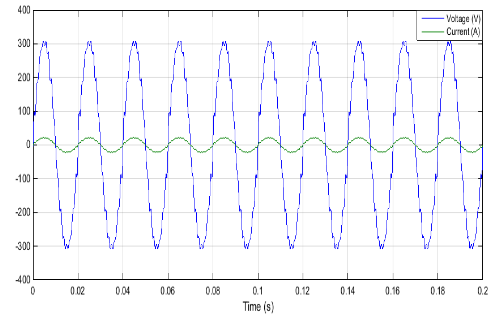


Fig 8. Phase shift between voltage and current

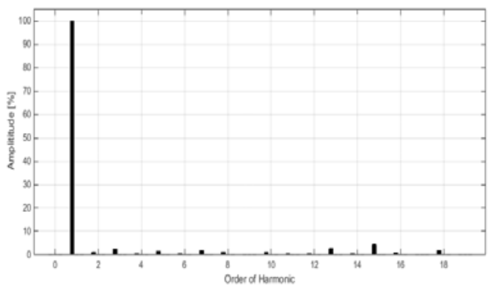


Figure 9. Spectrum harmonic of current

Table 1: Harmonics currents & THD_I

Harmonic Currents	Value [%]	Harmonic Currents	Value [%]
H_2	1.03	H_{11}	0.60
H_3	**2.57**	H_{12}	0.64
H_4	0.48	H_{13}	**2.68**
H_5	**1.45**	H_{14}	0.47
H_6	0.56	H_{15}	**4.35**
H_7	**1.94**	H_{16}	0.95
H_8	1.22	H_{17}	0.11
H_9	0.29	H_{18}	1.08
H_{10}	1.19	H_{19}	0.12
THD_I	**12.62%**		

Simulation results with filtering

Simulation results with single branch filter

In the following figure, we present the total harmonic distortion of current with using a tuned filter at harmonic (3,5,7,13, and 15).

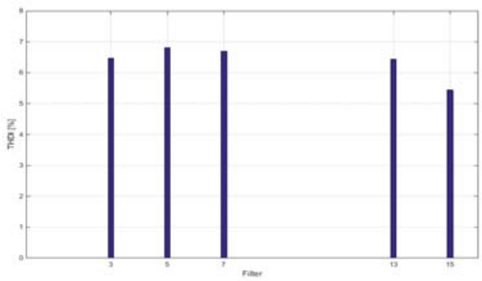


Fig10. Total harmonic distortion with single filtering

Simulation results with multiple filter

In the following figure, we present the total harmonic distortion of current with the use of two filters tuned to the harmonics selected.

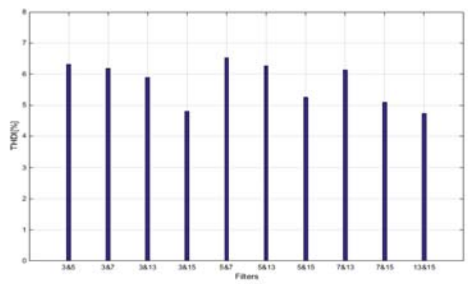


Fig11. Total harmonic distortion with multiple filtering

Table 2: THD values with passive filtering

Single filter	THD_I [%]	Multiple filter	THD_I [%]
Filter 3	6.47	Filters 3&5	6.31
Filter 5	6.81	Filters 3&7	6.18
Filter 7	6.69	Filters 3&13	5.89
Filter 13	6.43	Filters 3&15	**4.80**
Filter 15	5.44	Filters 5&7	6.53
		Filters 5&13	6.26
		Filters 5&15	5.25
		Filters 7&13	6.13
		Filters 7&15	5.09
		Filters 13&15	**4.74**

We notice from the results obtained with passive filtering that there are improvements in the current waveform where we note the best results with the combination of two filters 3 & 15 (4.80%), and with filters 13 & 15 (4.74%) which are below the standard norm (5%).

5. Conclusion

In this article, we study the harmonics (investigation and filtering) of the integration of two sources of renewable energy sources (solar and wind) with the battery, which is used to store excess energy from renewable resources in the case where this energy would be greater than the energy required by the load and otherwise discharged using a bidirectional converter.

The aim of this work will allow us to deduce the rate of disturbance caused by this integration which essentially comes down to unstable climatic conditions (wind speed, variation in irradiance).

In order to solve this problem, we have chosen passive filtering (a simple method; cheap and efficient). The simulations results obtained grant our choice efficiency.

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REFERENCES

[1] M. Azaroual, M. Ouassaid, and M. Maaroufi, "An optimal energy management of grid-connected residential photovoltaic-wind-battery system under step-rate and time-of-use tariffs"', Int. Journal of Renewable Energy Research, vol. 10, no 4, pp. 1829-1843, December 2020
[2] MEKKAOUI Ali , LAOUER Mohammed , YOUNES Mimoun ,"Power exchange in smart grids integrating renewable energy" Przeglad Elektrotechniczny, vol. 12, pp. 91-94, 2020.
[3] L. W. Chong, Y. W. Wong, R. K. Rajkumar, R. K. Rajkumar, D. Isa: Hybrid Energy Storage Systems and Control Strategies for Stand-Alone Renewable Energy Power Systems, Renewable and Sustainable Energy Reviews, Vol. 66, December 2016, pp. 174 - 189
[4] B. Belabbas, T. Allaoui, M. Tadjine, et M. Denai, « Power Quality Enhancement in Hybrid Photovoltaic-Battery System based on three–Level Inverter associated with DC bus Voltage Control », J. Power Technol., vol. 97, no 4, p. 272–282, 2017
[5] Hana' A. Rabab'ah, Yaser N. Anagreh," Stand-alone Hybrid System for Extracting Maximum Power and Constant Voltage under Load Variation", Przeglad Elektrotechniczny, vol. 7, pp. 76-80, 2022.
[6] Priya, Ramalingam Adikesavan, Devaraj Dhanasekaran, and Parasurama Chandrasekaran Kishoreraja. "Performance analysis of PMSG based wind energy conversion system using two stage matrix converter." Przeglad Elektrotechniczny 2 (2019).
[7] A. Aktas, K. Erhan, S. Ozdemir, E. Ozdemir: Experimental Investigation of a New Smart Energy Management Algorithm for a Hybrid Energy Storage System in Smart Grid Applications, Electric Power Systems Research, Vol. 144, March 2017, pp. 185 - 196.
[8] Y.Djeghader, Z.Chelli , M.Hachichi and S.Djellabi "Investigation of Harmonics Problems in Grid Connected PV-Wind-Battery for Household Applications ", IEEE 1st International Conference on Sustainable Renewable Energy Systems and Applications (ICSRESA), December 04-05, 2019, Tebessa, Algeria
[9] Y.Djeghader, L.Zellouma, A.Lakehal and Z.Chelli : Harmonic Mitigation in Electrical Radial Distribution System Using Photovoltaic Unified Power Quality Conditioner (PV-UPQC) , IEEE the 8th International Conference on Systems and Control, Marrakech, Morocco, October 23-25, 2019.
[10] Y.Djeghader ,Z.Chelli and S.Rehaimia,: Harmonic Mitigation in Electrical Grid Connected Photovoltaic System, 4th International Conferonce on Advanced Mechnical Engineering ; Istanbul Turkey December 19-21, 2018.
[11] A. Tani, M. B. Camara, B. Dakyo: Energy Management in the Decentralized Generation Systems Based on Renewable Energy - Ultracapacitors and Battery to Compensate the Wind/Load Power Fluctuations, IEEE Transactions on Industry Applications, Vol. 51, No.2, March 2015, pp. 1817 -1827.
[12]Y.Djeghader, L. Zellouma ; « Harmonics Mitigation in DC Electrified Railway System Using Hybrid Power Filter» ; The Mediterranean Journal of Measurement and Control Volume 13, N°. 1, January 2017 pp. 720-727.
[13] Y. Djeghader, L. Zellouma, and Z. Chelli: Filtering of Harmonics in DC Traction Substation System, Journal of Electrical Enginee Vol. 17, N°.2, 2017, pp29-35.
[14] Y. Djeghader, H. Labar, L.Zellouma, R.Labdani : Propagation and Filtering of Harmonics in Electrical Networks, The International Conference on Electrical Networks, ICEN'10 Sidi Bel Abbès , 28 & 29 Sep 2010.