Smart power management using fuzzy controller of a hybrid photovoltaic/wind stand-alone system: A case study

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Abstract*— An off-grid energy system based on renewable photovoltaic (PV) and wind turbines (WT) generators are coupled via converters to electric and hydraulic networks. The electric network is composed of consumers and of a battery bank for electrical storage, while the hydraulic part is made of 5HP motor-pumps expected to meet the freshwater demand of a small isolated community. This study puts forward the prime importance of Water/Power flows management optimization. For this purpose, a Fuzzy Logic-based Energy Management Strategy (FLEMS) is proposed. Thus, both electric and hydraulic subsystems are strongly coupled in terms of energy making necessary to manage the power flows provided by renewable sources to optimize the overall system performance. In this paper, a kind of management strategies based on artificial intelligence control with the fuzzy logic controller consists of a "smart" power-sharing between the electrical and hydraulic networks with regard to the battery SOC and compared in the way they share the hybrid power sources between the storage devices and the electrical/hydraulic loads. A dynamic simulator of the hybrid energy system has been developed and tested using a MATLAB environment. Several tests are carried out using real meteorological data of the Adrar region and a practical load demand profile. The simulation results show that the "coupled strategy" clearly outperforms the classical management strategies.

Keywords—PV, Wind, Batterie, Power management, fuzzy logic,motor-pumps.

I. INTRODUCTION

Energy consumption has risen for all fuels except nuclear power; energy production has also increased for all fuels except coal. For oil and gas, global consumption development is more pathetic than energy production. Fig. 1 depicts world energy consumption in the year 2013, and According to the report of the International Energy Agency (IEA), the energy consumption of Algeria will double by 2040. Meanwhile, global energy utilization has been predicted to grow by 25% by 2040 concerning oil and coal consumption in absolute growth rate[1].

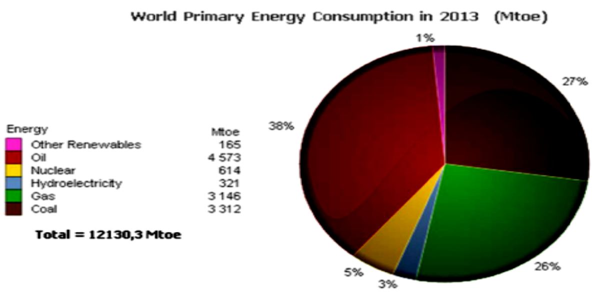


Fig. 1. World Energy Consumption

Fig. 2 demonstrates the PV installed capacity and the top main 10 nations in the year 2013. It plainly portrays that China, Japan, and the USA turned into the leading three PV installers. Nine countries have included more than 1 GW of sunlight-based energy to their matrices, and the circulation of new establishments keeps on broadening. By the year's completion, five nations consumed no less than 10 GW of aggregate limit, from top 2 countries in 2012. Asia introduced additional 22.7 GW to the end of 2013 with just about 42 GW of sunlight based power in operation. Capacity has been included so rapidly that grid integration and diminishment has resulted in difficulties. There is expanding enthusiasm for small-scale PV in distributed generation, and the government objective is to put more concentration towards the roof market. [2], [3]

Fig. 3 demonstrates the PV capacity and increments of the top 10 nations in the year 2013. China drove the market, followed by Germany, UK, India, and Canada. The principal countries for wind volume per occupant were Denmark (863W for every individual), Sweden, Spain, Portugal, and Ireland. China included an expected 16.1 GW of new limit in 2013, expanding aggregate introduced limit by 21% to 91.4 GW.

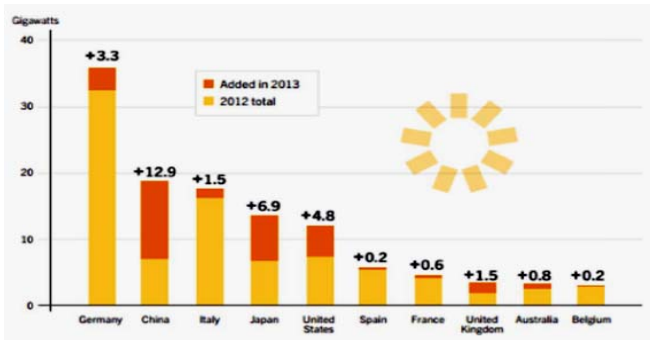


Fig. 2. PV Capacity and additions, Top 10 countries, 2013[4]

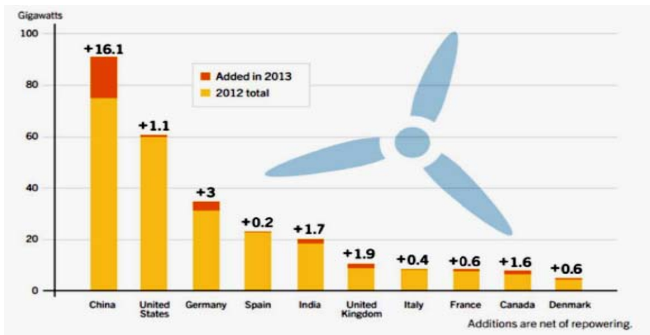


Fig. 3. Wind capacity and additions, Top 10 countries, 2013[5]

Around 14.1 GW is coordinated into the utility, with roughly 75.5 GW in commercial operation by year's completion. The rate of drop was from 17% in 2012 is decreased in 2013. Wind energy created 140.1 billion kWh by Chinese amid 2013; it is 40% more than 2012.[6]–[8]

II. LITERATURE REVIEWS: POWER MANAGEMENT AND CONTROL

In control systems based on microprocessors, Fuzzy Logic Control (FLC) technique is commonly used as it is non-sensitive to operation point variations and parameter changes and, doesn't require the precise model of the system. FLC is based on membership functions and rule basis, which is generally obtained by a trial and error approach. Hence FLC technique is an error-prone and extended process. Artificial neural networks (ANNs) are generally defined as a mathematical model with combinational abilities of learning and parallel data processing. ANNs use organized computational neurons in layers, which is interconnected to each node based on weight factors. ANNs with their advanced capabilities of adaptive and nonlinear structure, design independence from system parameters, and general skills are used in the microprocessor control systems. Due to their "black box" nature, ANNs face disadvantages without rules for defining the structure and network instruction problem [9][10]. Based on the design structure in intelligent control systems, ANNs

follow the complete opposite scheme to FLC [9], [10]. Neuro-Fuzzy Models (NFM) combines the parallel data processing capabilities of ANNs with inference ability of the fuzzy logic model. With the NFM, the time consumed for the development process is reduced with improved accuracy. In 1993, Jang developed an NFM called ANFIS by applying neural learning regulations to categorize and alter para- meters to develop a fuzzy inference system based on existing data [11]. The major features of ANFIS models are [9]–[12]: a) ease of imple- mentation; b) accurate and fast learning; c) strong generalization skills; d) easier understanding with fuzzy rules; e) easier inclusion of numerical and linguistic information for problem-solving.

In this technique, in every period the weights are updated through adaptive error back-propagation method. During inference, to avoid over-fitting problems the data set is divided into training dataset (70%) and validation dataset (30%)[13]. The validation dataset is further classified into, testing dataset (15%) and checking dataset (15%). Testing dataset is used to ensure the generalization capability of ANFIS and checking dataset manages the potential for the model that overfits the data. The validation dataset is entirely different from the training dataset. Root mean square difference is adapted to estimate final error, which is the difference between the current and desired outputs.

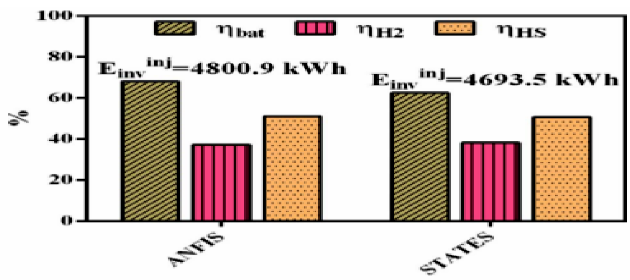


Fig. 4. ANFIS Vs STATES.

Fig.4 depicts the results of battery, hydrogen and hybrid system efficiency with two different energy injected grids using both ANFIS and STATES. Investigating the outcomes, it came to be under- stood that the ANFIS control attains superior battery and hybrid system efficiency and it is able of injecting additional energy into the grid than the traditional STATE control.

A. Energy management algorithm for stand–alone system

In case with system composed of wind and PV as the main resources, and a diesel generator is utilized as a hold-up power resource. To guarantee continuous power delivery, storage batteries are used to stock the excess energy. It is also premeditated for the dissipative load to be utilized in the occasion of over production and the storage batteries are completely filled. Entire precedent essentials tangled in the global structure are associated to stay DC bus sprightly through power converters. The principal aim of this entire scheme is to provide a remote

Family and confirm energy creation without disruption employing renewable sources and hence diminish the interference of the traditional source. Further to providing power without a break, the scheme must yield into the working of each component, mainly loading batteries, and must enforce an optimum behavior to raise its life span[14]. The power management procedure is intended for our scheme to

Fulfill the demand irrespective of the variations in the generation of power from renewable. Surely, the hybrid structure is naturally dynamic, and meanwhile, climate situations fluctuate extraordinarily during the daytime. Besides, the demand is extremely inconsistent, which creates the procedure exceptionally fragile[15], [16]. To upturn the lifespan, the power supervision algorithm should ideally utilize the renewable resources and the storage batteries. The diesel generator, which must be requested as small as, could be allowed which adds up to exhaust the most extreme in renewable based generators to fulfill the load side demand.

III. SYSTEM DÉSCRIPTION

The microgrid considered in this paper is a medium voltage isolated microgrid located in a remote area. Energy demand of microgrid consumers is supplied from non-dispatchable wind and PV power plants. In order to keep balance between generation and demand, maximizing renewable energy utilization and reducing energy loss through dump load (water-pomp), an energy storage system is applied. The microgrid is equipped with smart grid technology and has required infrastructures to implement demand response programs for energy management purposes.[17], [18]

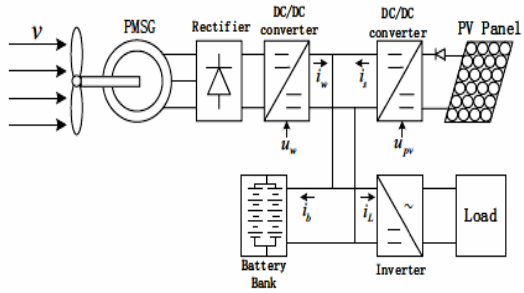


Fig 5. Block diagram of PV-Wind hybrid system proposed

Fig. 5 shows the components and their connections of the isolated microgrid considered in this paper.

The growing rise of renewable technologies, especially those with uncertain power generation like wind and PV, leads to need for a diversity of storage solutions to smooth intermittency and ensure secure supply. The type of these solutions directly depends on the resources and terrain of particular regions and locations. Among different electricity storage technologies, battery energy storage and pumped-storage system are more common and practical in the real world. Therefore, these technologies have been analyzed and compared here from different points of view in order to justify the choice of pumped-storage system in this work[8], [15].

From environmental point of view impacts of batteries are more related to their disposal at the end of their life, and to the extraction of the resources to produce new batteries. Pumped-storage system may cause more environmental impact. However, in most construction of new pumped-storage, sites are selected where impacts can be mitigated to acceptable levels.[19]–[21]

From technical point of view batteries have shorter installation time, can provide fast response times and usually are located close to generation or load centers [19]. However, they have not demonstrated the ability to provide a full range of ancillary services needed to support the grid yet. A particular consideration for batteries is degradation. Batteries degrade as they age, which decreases the amount of energy they can store. To maintain a steady capacity for storage as batteries degrade, battery plants will require ongoing staged installation and replacement of batteries. In comparison, pumped-storage system is a reliable technology and is able to meet the needs of the grid and provide sustained output for up to a century without degradation.[1], [22]–[25]

IV. PV SYSTEM MODELLING

Fig. 6 shows a simplified scheme of a standalone PV system with DC–DC buck converter.

This section is devoted to PV module modelling which is a matrix of elementary cells that are the heart of PV systems. The modelling of PV systems starts from the model of the elementary PV cell that is derived from that of the P–N junction .[26]

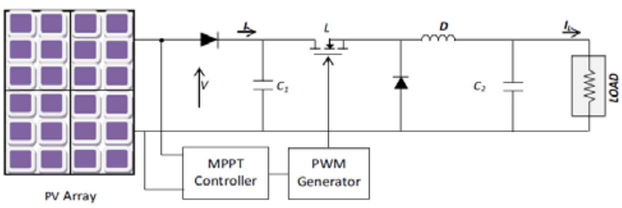


Fig.6. A PV system with a DC–DC buck converter

A. Ideal photovoltaic cell

The PV cell combines the behavior of either voltage or current sources according to the operating point. This behavior can be obtained by connecting a sunlight-sensitive current source with a P–N junction of a semiconductor material being sensitive to sunlight and temperature. The dot-line square in Fig. 7 shows the model of the ideal PV cell. The DC current generated by the PV cell is expressed as follows

$$I = I_{PV,Cell} - I_{s,Cell}\left(e^{\frac{V}{aVt}} - 1\right) \tag{1}$$

The first term in Eq. (1), that is Ipv,cell, is proportional to the irradiance intensity whereas the second term, the diode current, expresses the non-linear relationship between the PV cell current and voltage. A practical PV cell, shown in Fig. 1, includes series and parallel resistances [10]. The series resistance represents the contact resistance of the elements constituting the PV cell while the parallel resistance models the leakage current of the P–N junction.

This model is known as the single diode equivalent circuit of the PV cell. The larger number of diodes the equivalent circuit contains, the more accurate is the modelling of the PV cell behavior, however, at the expense of more computation complexity. The single diode model is shown in Fig. 7 is adopted for this study, due to its simplicity.

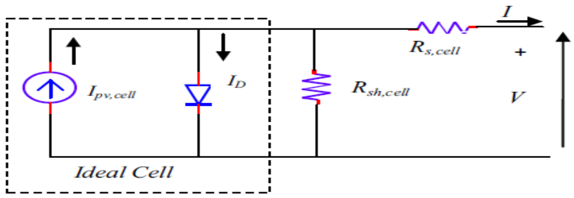


Fig. 7. The Equivalent circuit of an ideal and practical PV cell.

B. PV module modelling

Commercially photovoltaic devices are available as sets of series and/or parallel-connected PV cells combined into one item, the PV module, to produce a higher voltage, current and power, as shown in Fig. 8.

The equation of the I–V characteristic of the PV module is obtained from Eq. (1) by including the equivalent module series resistance, shunt resistance and the number of cells connected in series and in parallel.

$$I = N_p\left(I_{PV} - I_s\left(e^{\frac{q(V+I.R_s)}{aN_sKT}} - 1\right)\right) - \frac{(V+I.R_s)}{R_{sh}} \tag{2}$$

Where Vt the PV cell thermal voltage in Eq. (1) is substituted by that of the module thermal voltage given by $V_t = \frac{N_sKT}{q}$and Ns and Np are respectively the number of cells connected in series and in parallel forming the PV module.

The constant an expressing the degree of ideality of the diode may be arbitrary chosen from the interval (1, 1.5) .[27] The light generated current of PV cell depends linearly on the irradiance and is also influenced by the temperature:

$$I_{PV} = \left(\frac{G}{G_{STC}}\right)\left(I_{PVn} + K_i(T - T_{STC})\right) \tag{3}$$

Ipvn is the nominal light-generated current provided at GSTC, TSTC which refers to the values at nominal or Standard Test Conditions (1 kW/m2, 25°C). The nominal light-generated current is not available in the datasheet of the PV panel but estimated as [28]:

$$I_{PVn} = \left(\frac{R_s + R_{sh}}{R_s}\right) I_{scn} \tag{4}$$

-The second term in Eq. (2) is the diode current that is function of the voltage and current coefficients given by the equation below:

$$I_s = \frac{I_{scn} + K_I\Delta T}{e^{\frac{V_{ocn}+K_V\Delta T}{aV_t}} - 1} \tag{5}$$

Where Iscn is the nominal short-circuit current or the maximum current available at the terminals of the practical device at nominal conditions.[29]

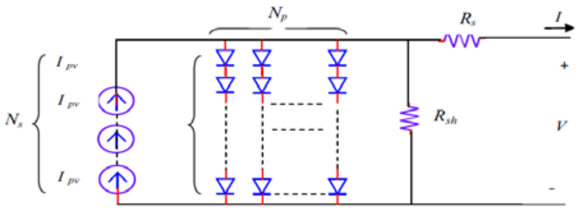


Fig. 8. Equivalent circuit of PV module.

V. WIND TURBINE

The Simulink model of WTG developed with asynchronous generator and is shown in Fig. 10. The simulated wind turbine block uses a 2-D lookup table to compute the turbine torque out- put (Tm) as a function of wind speed (w_Wind) and turbine speed (w_Turb), shown in Fig. 11. At the wind speed more than 2 m/s, the WTG produces enough power to supply the load. As the asyn- chronous machine operates in generator mode, its speed is slightly above the synchronous speed (1.011 pu). According to characteris- tics of turbine, for a 2 m/s wind speed, the turbine output torque is adjusted to deliver 0.5 pu of power which is 3 kW. Practically, the systems with cut-in speed as low as 2.8 m/s are commercially available in markets which are very much viable for low power stand-alone operation. [30].

VI. MODEL OF THE MOTOR-PUMP

The proposed models are quasi-static models which performances have been previously compared and validated with reference to dynamic models using Bond-Graph formalisms [32].

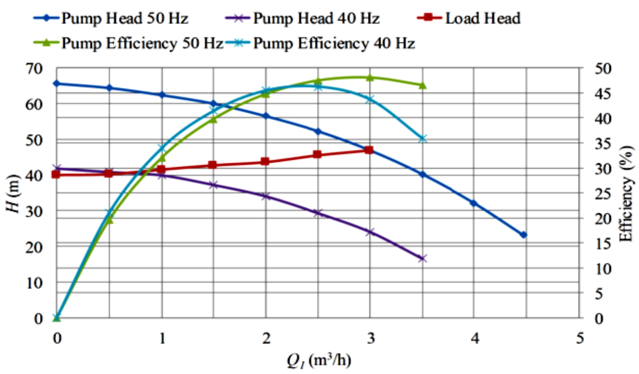


Fig. 9. Hydraulic Characteristics of Motor-pump

The motor-pump model nominal power was selected for pumping water from well to the tank water storage 1. The rated motor-pump power is 2 kW. The characteristics H(Q1) and the efficiency curve of the motor-pump for two frequencies 50 Hz and 40 Hz and the load characteristic H_{load}(Q1) are shown in Fig.9. The operating point of pumping is the crossing point between H(Q1) and Hload(Q1). A weak variation of the motor-pump frequency (i.e. 40 Hz) decreases the pump efficiency. For this reason, we use the optimal operation of the pump with a fixed frequency (i.e. 50 Hz).[17]

VII. FUZZY LOGIC ENERGY MANAGEMENT STRATEGY (FLEMS)

In this study, we have designed a single input–single output FIS where the given DC power and the FS of the tank are defined as the FIS inputs and the power-sharing factor (α) as the output. The designed FIS based on "Mamdani" architecture and uses the "Centroid" method for Defuzzification giving a crisp output value. This method is considered as the most popular Defuzzification method which returns the centroid of the area under the curve. The chosen Membership Functions (MFs) of inputs and output are illustrated in Fig.6. Triangle MFs are chosen to represent the FIS output and most of the two inputs. Nevertheless, we have chosen trapezoid.[20], [23], [31]

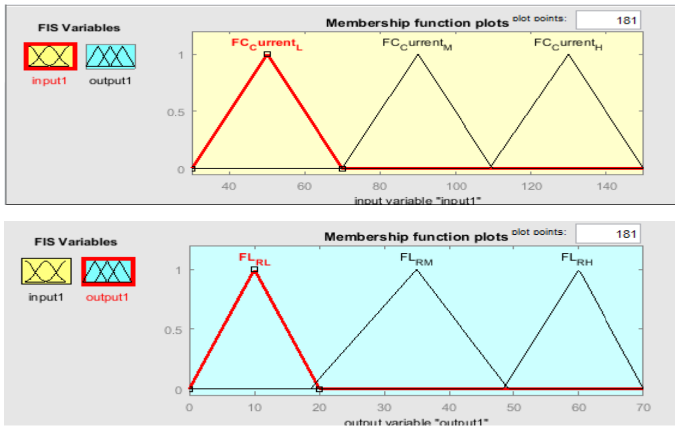


Fig.10. Input and output membership functions

VIII. SIMULATION AND RESULTS

The simulation of the proposed hybrid Renewable sources has been accomplished using the real data of Atmospherics conditions (irradiance and wind speed) and PV-Wind power generation recorded every hour for one day the 30th July 2018 of Adrar region in Southwest Algeria.

In this paper, we have used 96 PV Array Sunpower SPR-305-WHT models to produce power from sun eliminate the temperature. Fig11show the IV and PV panel characteristic.

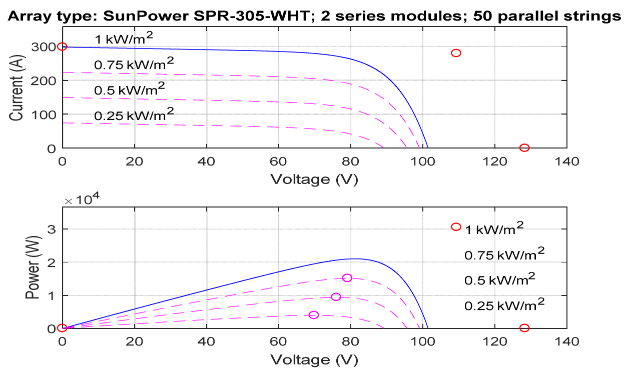


Fig 11. I-V and P-V characteristics of PV Array.

Fig 12 and Fig13 shows the atmospheric conditions (irradiance and wind speed) schemes of 30th July 2018 using in the simulation of this paper.

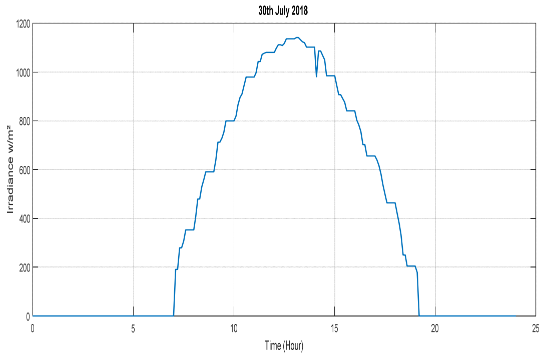


Fig 12. The irradiance of 1 day 30th July 2018.

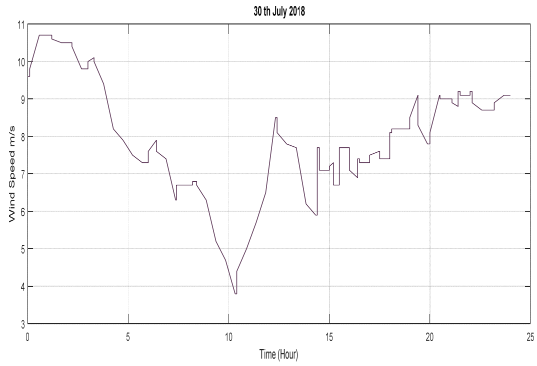


Fig 13. Wind speed of 1 day 30th July 2018.

Fig 14, Fig 15, Fig 16 shows the wind generator current, wind generator voltage, and wind power generator respectively.

Fig 17 presents the power generated by PMSG wind turbine for 1 day of wind speed data. The variation in the speed wind under time caused unstable phenomena of the wind system influence on the realiabilité and robustness of wind generator at all.

For this and author reasons, it should add a speed regulator to control and stabilized the rotor speed under this wind speed variation.

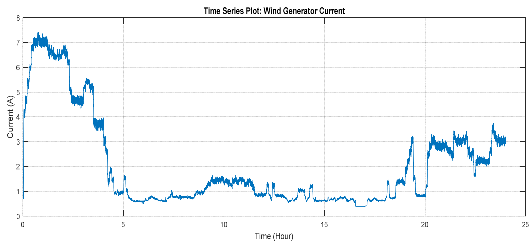


Fig 14. Wind generator current.

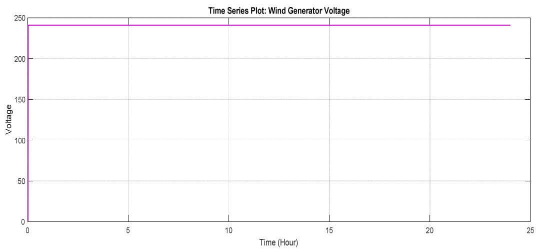


Fig 15. Wind generator voltage.

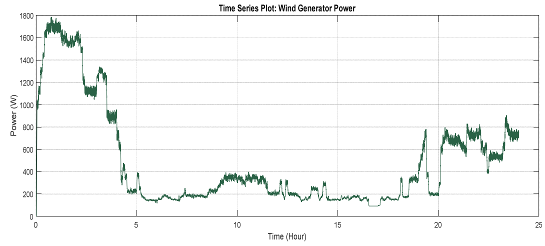


Fig 16. Wind generator power

Fig 17, Fig 18, Fig 19 Presents electromagnetic torque, rotor speed and stator current of wind generator presented in PMSG machine.

These schemes show clearly the impact of the wind variation speed in electromagnetic torque and stator current, this variation caused many effects with the time and damaged the machine.

To conserve the wind system, many propositions in the literature are proposed to stabilize wind generation with new techniques of intelligence control.

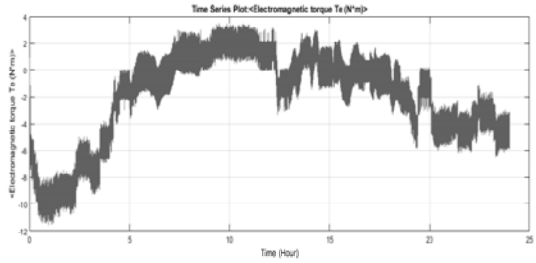


Fig 17. Electromagnetic Torque of PMSG machine.

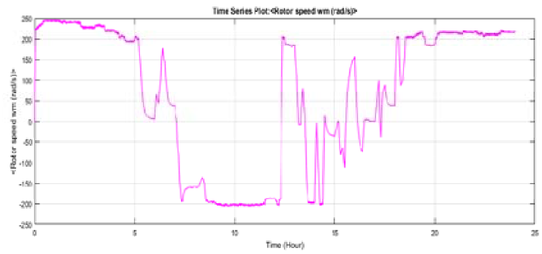


Fig 18. Rotor speed of PMSG machine.

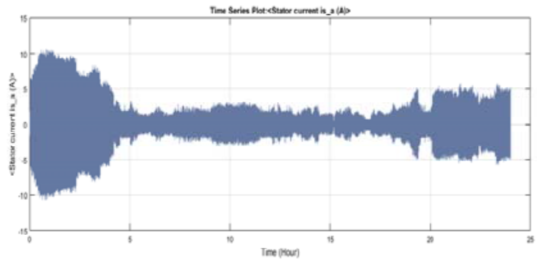


Fig 19. Stator current of PMSG machine.

Fig 20 show PV results such as PV voltage, PV current and PV power for 1 day of irradiance (30th July 2018) in ADRAR region.

This result shows the performance of the PV panels (Sunpower SPR-305-WHT) used in this paper without consideration of temperature.

This results will be deferent if take consideration all atmospherics condition including Temperature because of its negative effects.

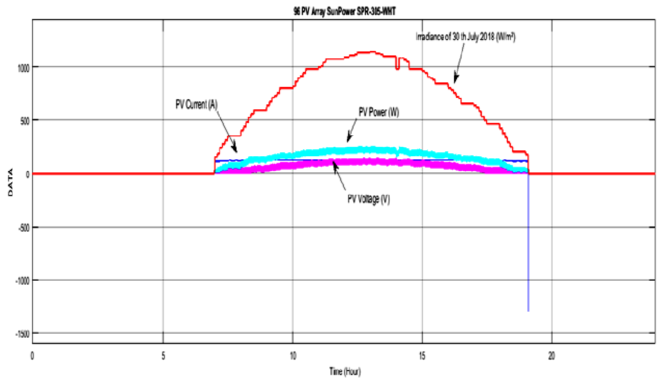


Fig 20. PV results, Current, voltage, and power

The 5 HP Water-pump plays a very important role in our system. To manage the power to pump the water for the remote area, it is necessary to produce a solution to this issue.

Fig 21, Fig 22, Fig 23 Present the water-pump speed, Armature current, and electromagnetic torque, From the mourning 00.00 AM to 5.00 AM the power production is lower than the power consumed, and in this time we need to compensate with the batteries power.

The power generated by the hybrid renewable power system (PV-wind system) and batteries is hight 200% of the power load demand preparing to the critical situation when the atmospheric condition unwell (shading days and no wind speed).

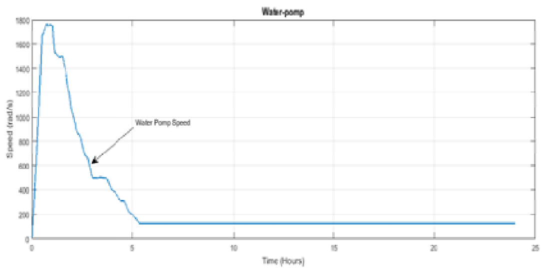


Fig 21. Water-pump speed.

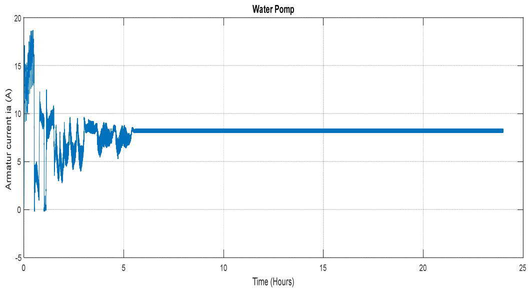


Fig 17. Armature current of water-pump.

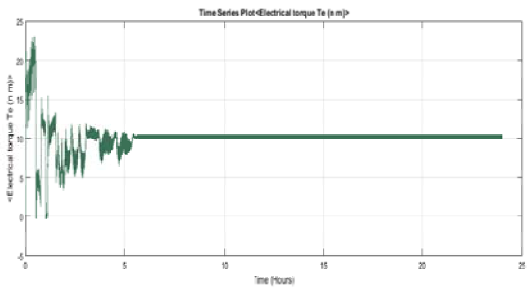


Fig 23. The electromagnetic torque of water-pump.

Fig 24 presents the power generated by the both photovoltaic and wind systems at the run of 1 day.

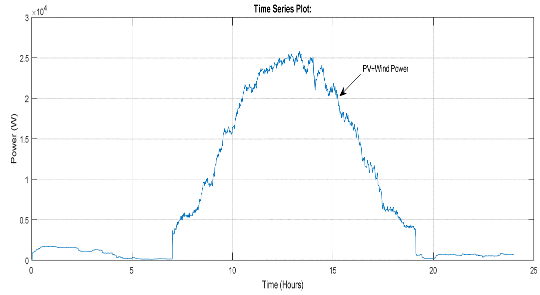


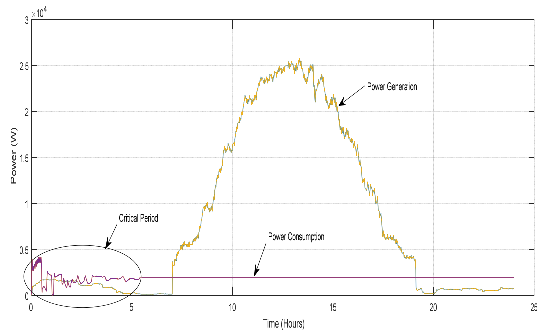
Fig 24. Power generated by hybrid PV-wind system

Fig 25 presents the power generated vs power consumed by the pump.

From 00.00 AM to 05.00 AM the system is in a critical period caused by the battery discharge, in this time the wind system is incapable to satisfy the power demand, the water-pump work in a fault condition and rescued for damage.

To solve this problem, we should keep the batteries instantly charged by the time.

The PV system work 12 hours in the day, the rest hours the wind system support the load alone, the batteries bank charged in the peak when the PV and Wind systems with a maximum in the day.



IX. Conclusion

In this paper, a specific class of standalone battery-less PV/Wind desalination system has been presented. This issue has been addressed through a specific and optimized water and power flows management strategy based on the fuzzy logic theory.

The major scientific challenge that this work contributes to rising is the development of an optimized power management system, which could work in real-time for such an autonomous system especially dedicated to remote communities. The sought objective through the developed this system is to produce fresh water as much as possible while taking advantage of the available electric power offered along wind speed and sun irradiation conditions. So, according to the input electric power, fuzzy rules have been used to identify the instantaneous power sharing between the two motor-pumps so that to maximize freshwater production according to the available generated power.

The power management system by fuzzy logic play important role in management of power generated by RES and the load presented in water-pump.

Implementing an autonomous water desalination system powered by RESs in remote areas is still being a problematic issue that needs to be carefully addressed to guarantee freshwater supply. Energy management represents the major problem of such a system and the proposed approach in this paper could be used to solve the problem in real-time, but an experimental validation needs to be carried out on the experimental test bench to confirm the simulation results and the feasibility of the proposed FLEMS.

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REFERENCES

[1] V. Indragandhi, V. Subramaniyaswamy, and R. Logesh, “Resources, configurations, and soft computing techniques for power management and control of PV/wind hybrid system,” *Renew. Sustain. Energy Rev.*, vol. 69, no. May 2015, pp. 129–143, 2017.

[2] S. E. Reviews, “Renewable and Sustainable Energy Reviews,” vol. 68, no. July 2016, pp. 1–18, 2017.

[3] A. Chauhan and R. P. Saini, “A review on Integrated Renewable Energy System based power generation for stand-alone applications : Con fi gurations , storage options , sizing methodologies and control,” *Renew. Sustain. Energy Rev.*, vol. 38, pp. 99–120, 2014.

[4] “National Power Sector Report, viewed 2 March 2014, and provided by Frank Haugwitz, Asia Europe Clean Energy (Solar) Advisory Co. Ltd. (AECEA), and personal communication with REN21, March 2014.”

[5] “Chinese Wind Energy Association (CWEA), provided by Shi Pengfei, CWEA, personal communication with ren21, 14 March 2014.”

[6] Y. Himri, A. S. Malik, A. B. Stambouli, S. Himri, and B. Draoui, “Review and use of the Algerian renewable energy for sustainable development,” vol. 13, pp. 1584–1591, 2009.

[7] K. S. Krishna and K. S. Kumar, “A review on hybrid renewable energy systems,” *Renew. Sustain. Energy Rev.*, vol. 52, pp. 907–916, 2015.

[8] A. Saidi, “Solar-Wind Hybrid Renewable Energy Systems: Evolutionary Technique,” vol. 64, no. 4, pp. 24–27, 2016.

[9] N. Altin, “dSPACE based adaptive neuro-fuzzy controller of grid interactive inverter,” vol. 56, pp. 130–139, 2012.

[10] “Azar AT. Fuzzy Systems. Vienna, Austria: In Tech; 2010.”

[11] J. R. Jang, “ANFIS : Adap tive-Ne twork-Based Fuzzy Inference System,” vol. 23, no. 3, 1993.

[12] J. R. Jang, “Neuro-Fuzzy Modeling,” vol. 83, no. 3, 1995.

[13] J. R. Jang, “Neuro Fuzzy and soft computing.” 1997.

[14] M. Dahmane, M. Ieee, J. Bosche, and M. Dafarivar, “Renewable Energy Management Algorithm for Stand – alone System,” no. October, pp. 20–23, 2013.

[15] A. Saidi, B. Cherif, and B. Chellali, “Fuzzy intelligent control for solar/wind hybrid renewable power system,” *EEA - Electroteh. Electron. Autom.*, vol. 65, no. 4, 2017.

[16] M. Dhimish, V. Holmes, B. Mehrdadi, M. Dales, and P. Mather, “Photovoltaic fault detection algorithm based on theoretical curves modelling and fuzzy classification system,” *Energy*, 2017.

[17] S. Ahmed, C. Benoudjafer, and C. Benachaiba, “MPPT Technique for Standalone Hybrid PV-Wind Using Fuzzy Controller,” in *Artificial Intelligence in Renewable Energetic Systems*, 2018, pp. 185–196.

[18] F. Harrou, Y. Sun, B. Taghezouit, A. Saidi, and M.-E. Hamlati, “Reliable fault detection and diagnosis of photovoltaic systems based on statistical monitoring approaches,” *Renew. Energy*, vol. 116, 2018.

[19] H. Li, Q. An, B. Yu, J. Zhao, L. Cheng, and Y. Wang, “Strategy Analysis of Demand Side Management on Distributed Heating Driven by Wind Power,” *Energy Procedia*, vol. 105, pp. 2207–2213, 2017.

[20] I. Ben Ali, M. Turki, J. Belhadj, and X. Roboam, “Optimized fuzzy rule-based energy management for a battery-less PV/wind-BWRO desalination system,” *Energy*, vol. 159, pp. 216–228, 2018.

[21] W. El-Baz, P. Tzscheutschler, and U. Wagner, “Day-ahead probabilistic PV generation forecast for buildings energy management systems,” *Sol. Energy*, vol. 171, no. June, pp. 478–490, 2018.

[22] M. Zaibi, G. Champenois, X. Roboam, J. Belhadj, and B. Sareni, “Smart power management of a hybrid photovoltaic/wind stand-alone system coupling battery storage and hydraulic network,” *Math. Comput. Simul.*, vol. 146, pp. 210–228, 2018.

[23] A. Tabanjat, M. Becherif, D. Hissel, and H. S. Ramadan, “Energy management hypothesis for hybrid power system of H2/WT/PV/GMT via AI techniques,” *Int. J. Hydrogen Energy*, vol. 43, no. 6, pp. 3527–3541, 2018.

[24] S. Saravanan and S. Thangavel, “Instantaneous reference current scheme based power management system for a solar/wind/fuel cell fed hybrid power supply,” *Int. J. Electr. Power Energy Syst.*, vol. 55, pp. 155–170, 2014.

[25] B. Sivaneasan, N. K. Kandasamy, M. L. Lim, and K. P. Goh, “A new demand response algorithm for solar PV intermittency management,” *Appl. Energy*, vol. 218, no. October 2017, pp. 36–45, 2018.

[26] A. Saidi, “Comparative study of different load under P&O MPPT algorithm for PV systems,” *EEA - Electroteh. Electron. Autom.*, vol. 64, no. 4, 2016.

[27] G. Wu, K. Y. Lee, L. Sun, and Y. Xue, “Coordinated Fuzzy Logic Control Strategy for Hybrid PV Array with Fuel-Cell and Ultra-Capacitor in a Microgrid,” *IFAC-PapersOnLine*, vol. 50, no. 1, pp. 5554–5559, 2017.

[28] Z. Cheng, H. Yang, and Y. Liu, “Self-adjusting fuzzy MPPT PV system control by FPGA design,” *Asia-Pacific Power Energy Eng. Conf. APPEEC*, pp. 1–4, 2011.

[29] S. Ahmed, C. Benoudjafer, and C. Benachaiba, “Modeling and Operation of PV/Fuel Cell Standalone Hybrid System with Battery Resource,” in *Artificial Intelligence in Renewable Energetic Systems*, 2018, pp. 299–307.

[30] F. Keyrouz, M. Hamad, and S. Georges, “A novel unified maximum power point tracker for controlling a hybrid wind-solar and fuel-cell system,” 2013.

[31] A. Khiareddine, C. Ben Salah, D. Rekioua, and M. F. Mimouni, “Sizing methodology for hybrid photovoltaic /wind/ hydrogen/battery integrated to energy management strategy for pumping system,” *Energy*, vol. 153, pp. 743–762, 2018.