Smart controller based on fuzzy logic of a hybrid renewable energy production system

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ABSTRACT

This work proposes to a novel economic smart strategy energy flow management system based on multiples inputs and outputs fuzzy logic technic applied for hybrid photovoltaic solar panels with wind turbine and storage system, assisted by the electric grid. A priority order is given to the renewable and storage energy sources allowing a non- interrupted energy supply for typical dwelling consuming up to 4,000 Wh per day. This system is governed by an Arduino 2560 mega microcontroller where has been implemented the core fuzzy logic program with event display. A sizing of the hybrid system and parametric study of the system and simulation are performed in order to highlight the proposed control strategy to finally guarantee a continuous home accommodation. The preliminary results concern the electronic switches output control signals, which convey the energy via single-phase DC/AC inverter to power the alternative current load for accommodation.

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1. INTRODUCTION

The conventional energy sources used for long time such as coal, natural gas, and crude oil causes increased generation costs in electrical energy because of increasing electricity demand besides their pollutant effects to environment [1]–[3]. After the oil crisis met in 1970s [2], [4] and the energy transition, the renewable energy sources are paid much attention and are began intensively to be studied. The solar is the most widely used renewable energy sources in electricity generation and then wind, hydraulic and then tidal sources [3]. Researches have studied distinctly these sources for a long time to increase energy alternatives and efficiency. However, it is possible to develop hybrid renewable energy conversion system owing to widely performed distributed generation studies [3].

Abdourraziq and Kabalci [5], [6] concentrate on optimum sizing and component selection of different hybrid renewable energy (HRE) systems (PV stand-alone, PV-wind, and PV-wind-diesel) with the main objective is to achieve the balance between the cost and the reliability of the systems. In [7]–[10] describes the distributed generation as ‘‘an electric power source connected directly to the distribution network or on the consumer side of the meter’’. The distributed power generation systems based on renewable energy sources such as photovoltaic (PV) cells, wind turbines, fuel cells, and micro-turbines is experiencing a rapid development to meet the energy demand all around the world [11], [12].

This paper is a continuity of previous work, where a complex hybrid energy system is studied, sized, optimized and a smart router system is achieved to manage electric energy flow based on fuzzy logic technics. The added value in this contribution is the implementation of artificial intelligence in hardware based on Arduino type microcontroller which built on multi analog/digital inputs/outputs and PWM, from where electronic switches command' signals are highlighted and discussed.

2. HYBRID ENERGY SYSTEM DESIGN

The proposed hybrid energy system (HES) is a combination of solar energy conversion system comprising solar panels with integrated maximum power point tracker (MPPT) converter, wind energy conversion system built on direct current outcome converter permanent magnet synchronous wind turbine and then a storage system with acid-plumb batteries. The equipment of the dwelling operates at 220 V–50 Hz with an optimal use of the energy thanks to economic LED lighting lamps and zenithal daylight. The standard equipment used in this house consume a total amountenergy about 4 kWh per day with a peak of 660 W when using all the electric component at the same time. The system energy flow is managed by a smart energy router system based on artificial intelligence using fuzzy logic algorithm [13]. Figure 1 shows the global hybrid system with the combination of solar PV, wind turbine andstorage within all the regulators.

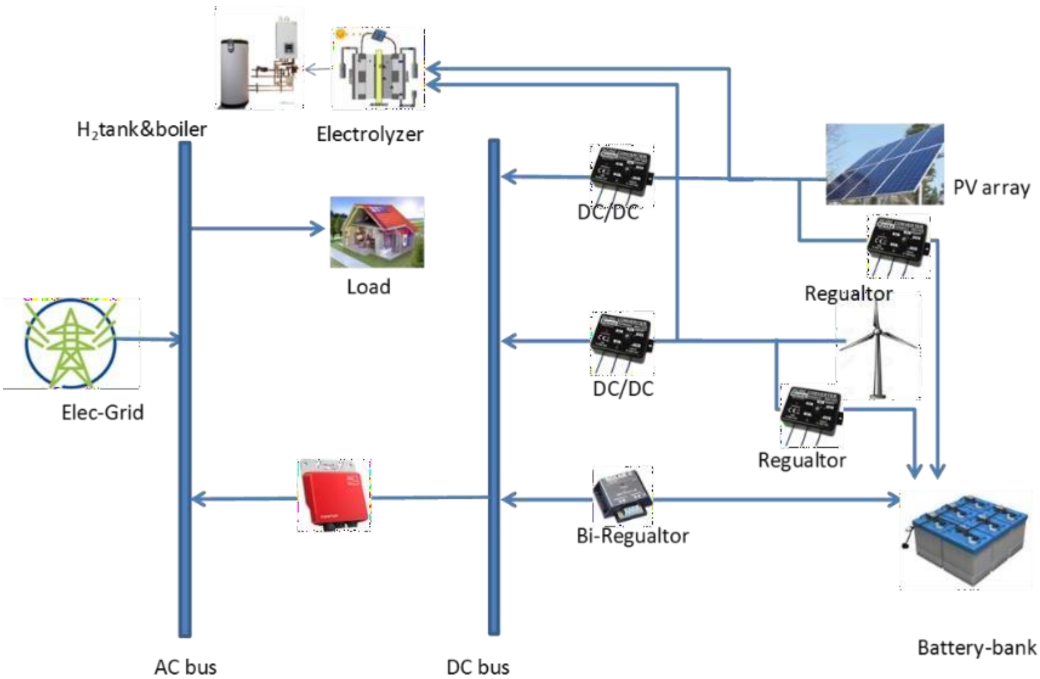


Figure 1. Synoptic of the proposed HPS

3. COMPONENTS OF THE YBRYD ENERGY SYSTEM

As part of our work, solar energy has been favored as a primary renewable energy source because of the chosen site at north of Algeria. The selected photovoltaic panels are polycrystalline type delivering, each of them, an output summer voltage amount of 30.7 V and developing 250 W nominal power. The panels are equipped with MPPT regulators [14] and connected in parallel to obtain an overall power of 2,000 W. This choice was pointed due to their quality/price [14] and [15]. The connection of the solar panels in parallel mode to multiply the output current and maintain a standardized output voltage at 24 VDC which is fed directly into the common DC bus of the system.

Considering the case study, the instantaneous power cannot exceed, according to the established dimensioning and for the case of maximum of energy demand, the value of 660 W. For this reason and taking into account the wind potential in the study area, our choice was oriented towards a small, inexpensive EO-24-1,000R-UGS-silent three-bladed wind turbine with 2.9 meters rotor diameter, developing nominal power up to 1,000 W. Because of their availability on the market in different capacities, as well as their proven Effectiveness, especially in the automotive field, our choice was pointed to an electrochemical lead-acid storage type, although the cycling behavior of the latter is not important compared to other technologies such as lithium. But they have the advantage of an affordable investment, much simpler maintenance and their resistance to high electrical capacity demands. What joins our goal to develop at low cost the use and generalization of the ENR in our country.

Given the uncertain nature of renewable resources, particularly solar and wind, deficits and excess energy production can be observed. For the second situation, the excess of energy is often harmful for the stability of the system. For that, several works proposed an evacuation of this surplus produced electric energy in a specific load which one calls dump load [16]. Previous work in reference [17], proposed to recover this surplus of energy production, from only renewable sources especially during favorable climatic conditions, and to exploit it to produce hydrogen with the help of an electrolyzer device in order to be useful for household heating and cooking.

4. FUUZY LOGIC CONTROLER

The intelligent controller, as shown in Figure 2, with its multiple image entries of the available power profiles as well as the outputs such as G2L, PV2L, W2L, BAT2L, PV2B, W2B, G2B, PV2E, and W2E, represents the routes pointed by the intelligent controller allowing renewable and conventional energies transfer to the load, to the electrolyzer and the storage.

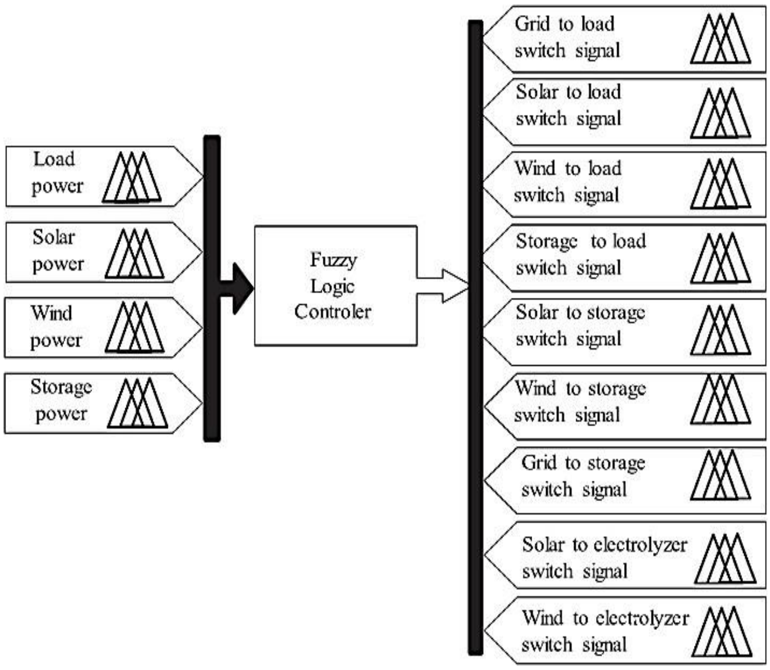


Figure 2. FLSC intelligent controller diagram (fuzzy logic smart controler)

The FLSC is designed according to well-defined basic conditions allowing the best functioning of the overall system for all its scenarios and possible operating points by considering the logical constraints initially fixed by an expert [18]-[25] as:

- The photovoltaic field and the wind energy are the primary sources to feed the load, and then come the storage ofthe batteries and finally the electrical grid,
- Only when photovoltaic and wind energy are low, batteries are recharged by the grid,
- The power grid only powers the load when the other sources are at zero,

the hydrogen production system is only powered by photovoltaic solar energy and the wind generator.

These instructions and recommendations initially dictated for suitable operation of the intelligent controller are shown in the simplified diagram in Figure 3, which generate a set of 81 rules. The formulation and implementation of these constraints are established using fuzzy logic tools and performing dozens of combinations with the three levels “H (high)→3: M (medium)→2: and L (low)→1”. On the other hand, the logical results of the FLSC are imposed for each combination at the entrance of the four energetic states (charge, solar, wind, storage).

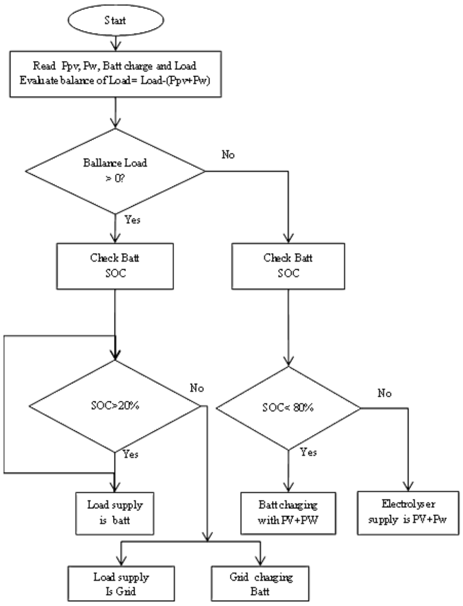


Figure 3. Operational flowchart of the HES-FLSC

5. FLSC HARDWARE IMPLEMENTATION

In the last section on a previous work [9], we presented a simulation work on MATLAB fuzzy logic, the results obtained are detailed, where the outputs of the FLSC manage the pulse width modulation (PWM) blocks in order to control the command signals duty cycle of electronic switches. In the goal to move from simulation to emulation, we successfully implemented the topology of smart controller under Arduino Mega 2560 microcontroller, which is built on more eeprom memory capacity, over than fifty analogic and digital I/O and thirteen ready pulse width modulation PWM outputs. That why we pointed this type of hardware. It corresponds wildly to the presented FLSC controller, which needs to control nine electronic switches. The work consists to convert the MATLAB fuzzy logic FLSC program to IDE Arduino sketch. The entries are images depicted of the input's energy profiles like the load demand, the GPV, the wind turbine and the capacity of the batteries.

Figure 4 presents the electrical scheme of the controller using proteus electronic software where all connections with the microcontroller are shown. The outgoings are connected to LEDs displaying the level of the output PWM signal depending on the four inputs power profiles' states exactly as illuminated in precedent section. To ensure the reliability of the designed FLSC controller, data power profiles so as solar and wind energies and battery storage were imposed to the system during a typical day on May, using MATLAB tools for simulation [19]. The load supplies change according to each month. In northern hemisphere, hottest months are related to summer. Therefore, the load demand for those months would be less and for the three other seasons, more cloudy days are expected with lower temperature. Thus, these months would require a higher electricity demand, due to eventual heating and additional lighting. Figure 5 presents the power profiles inputs which vary throughout the typical day.

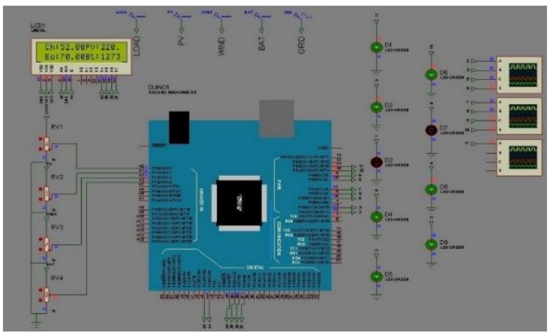


Figure 4. Electrical scheme of the Arduino-FLSC controller

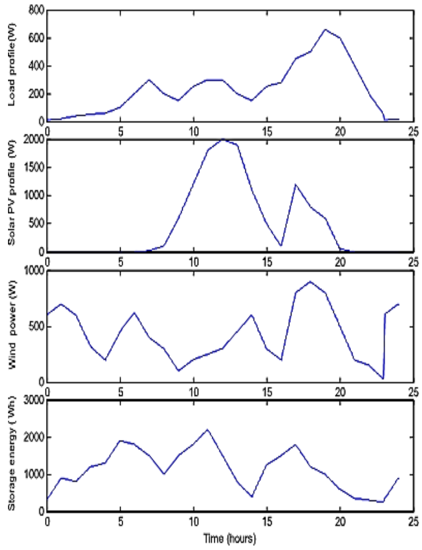


Figure 5. Power profiles versus time of the HPS during 24 hours

6. RESULTS AND DISCUSSION

The defuzzification results of the FLSC using the associated membership functions in MATLAB fuzzy tools are shown in Figure 6. The outcome analogic signals fluctuate between 0 and 1 and each FLSC output is converted to square signal with variable duty cycle at fixed frequency, using PWM technics. Each obtained command signal is injected into a respective electronic switch and all the selected quantities of available energy sources by all the switches are summed and converted to AC current through the DC/AC inverter, so that to satisfy appliances of the habitation. Excess DC produced renewable energy is directly used for hydrogen production. Based on these results [20]-[25], the implementation of the hardware consists to conversion and adaptation of the validated MATLAB program in the IDE platform where command lines are processed and compiled in IDE-Arduino microcontroller software.

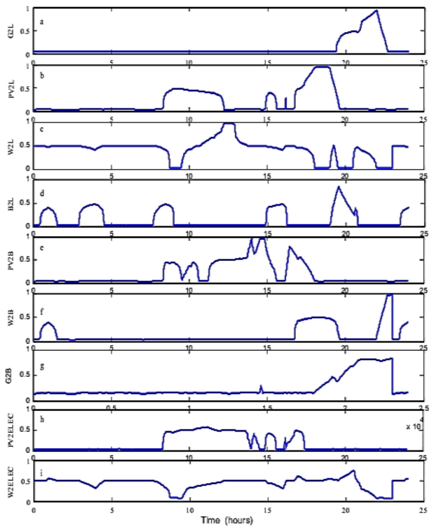


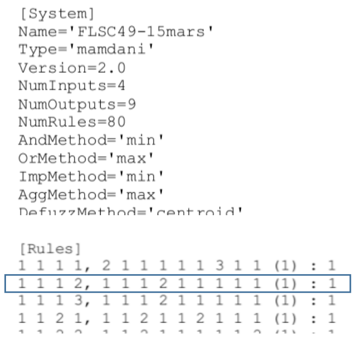
Figure 6. FLSC outcome switches command signals

In order to validate the operative FLSC program after many steps from MATLAB to IDE-Arduino, a simulation in Proteus software is scheduled and rule #2 is tested, where the inputs and the outputs of the FLSC-Arduino obey to a series of codes as mentioned in the framed line [1.1.1.2, 1.1.1.2.1.1.1.1.1] shown in the Figure 7. The settings of the input levels are assumed by potentiometers which are visualized on LCD display in Figure 4, as:

- Load (Ch): 52 W of 660 W → Low L → level 1,
- PV: 220 W of 2,000 W → Low L → level 1,
- Wind turb: 70 W of 1,000 W → Low L → level 1,
- Batt: 1,273 Wh of 2,400 Wh → Medium M → level 2.

Figure 8, presents a screenshot of the real cabling andrunning hardware.

With the same reasoning, the FLSC-Arduino outcomes are shown in the Figure 9 under PWM command signals, whichare ready to excite the electronics switches. The width (duty-cycle) of the 9 outputs from the top to the bottom correspond widely to the suite of the series line [1.1.1.2; 1.1.1.2.1.1.1.1.1]→[L.L.L.M ; L.L.L.M.L.L.L.L.L].



```
[System]
Name='FLSC49-15mars'
Type='mamdani'
Version=2.0
NumInputs=4
NumOutputs=9
NumRules=80
AndMethod='min'
OrMethod='max'
ImpMethod='min'
AggMethod='max'
DefuzzMethod='centroid'

[Rules]
1 1 1 1, 2 1 1 1 1 1 3 1 1 (1) : 1
1 1 1 2, 1 1 1 2 1 1 1 1 1 (1) : 1
1 1 1 3, 1 1 1 2 1 1 1 1 1 (1) : 1
1 1 2 1, 1 1 2 1 1 2 1 1 1 (1) : 1
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Figure 7. FLSC fuzzy inference system file screenshot (codification of rule#2

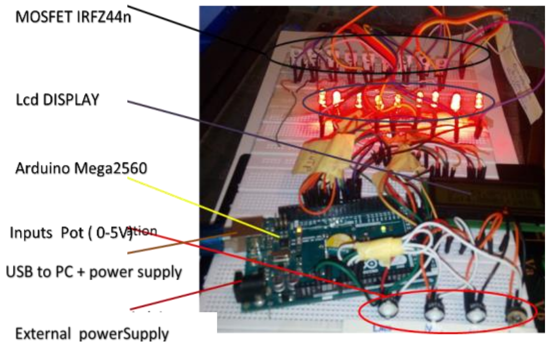

Figure 8. Image of the FLSC-Arduino on a test plate

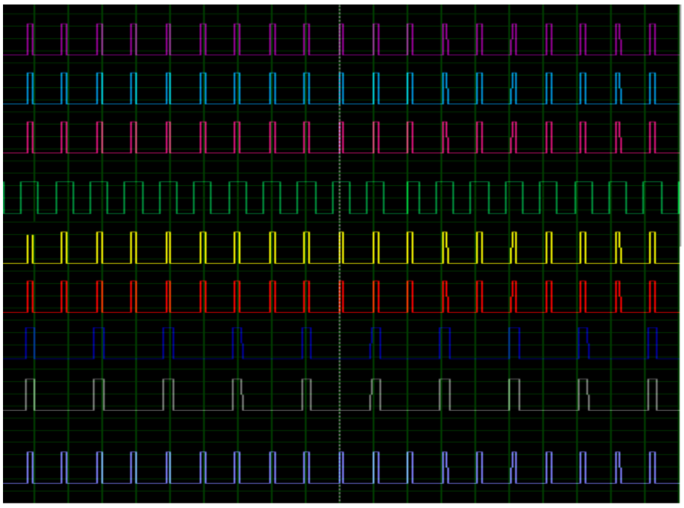

Figure 9. PWM signals from FLSC-Arduino. From top to bottom: the multiple outputs are G2L, PV2L, W2L, BAT2L, PV2B, W2B, G2B, and PV2E, W2E

7. CONCLUSION

A fuzzy logic smart controller for a residential hybrid energy system, integrating solar-wind sources and storage was designed and simulated. Backup, and energy request, associated to the management strategy, 81 operating rules were established and implemented in the system. The fuzzy logic program processed on MATLAB has been adapted and converted to IDE-Arduino program which is implemented in microcontroller type Arduino Mega 2560. The validation of the operating FLSC under the hardware was successful and outcomes correspond likely to the rules and constraints imposed by the expert. The FLSC-Arduino output PWM signals can excite directly the electronic switches in order to convey simultaneously the available energy from the sources to the user.

REFERENCES

[1] J. Figueiredo and J. Martins, “Energy production system management–renewable energy power supply integration with building automation system,” *Energy Conversion and Management*, vol. 51, no. 6, pp. 1120–1126, Jun. 2010, doi: 10.1016/j.enconman.2009.12.020.

[2] S. Assahout, H. Elaissaoui, A. El Ougli, B. Tidhaf, and H. Zrouri, “A neural network and fuzzy logic based MPPT algorithm for photovoltaic pumping system,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 9, no. 4, pp. 1823–1833, Dec. 2018, doi: 10.11591/ijpeds.v9.i4.pp1823-1833.

[3] O. Ozgener, “A small wind turbine system (SWTS) application and its performance analysis,” *Energy Conversion and Management*, vol. 47, no. 11–12, pp. 1326–1337, Jul. 2006, doi: 10.1016/j.enconman.2005.08.014.

[4] A. M. Baniyounes, Y. Y. Ghadi, M. M. A. Zahia, E. Adwan, and K. Oliemat, “Energy, economic and environmental analysis of fuzzy logic controllers used in smart buildings,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 2, p. 1283, Jun. 2021, doi: 10.11591/ijpeds.v12.i2.pp1283-1292.

[5] M. A. Abdourraziq and M. Maaroufi, “Experimental verification of the main MPPT techniques for photovoltaic system,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 8, no. 1, p. 384, Mar. 2017, doi: 10.11591/ijpeds.v8.i1.pp384-391.

[6] E. Kabalci, “Design and analysis of a hybrid renewable energy plant with solar and wind power,” *Energy Conversion and Management*, vol. 72, pp. 51–59, Aug. 2013, doi: 10.1016/j.enconman.2012.08.027.

[7] K. H. Chalok, M. F. N. Tajuddin, T. Sudhakar Babu, S. Md Ayob, and T. Sutikno, “Optimal extraction of photovoltaic energy using fuzzy logic control for maximum power point tracking technique,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 3, p. 1628, Sep. 2020, doi: 10.11591/ijpeds.v11.i3.pp1628-1639.

[8] A. Derrouazin, M. Aillerie, N. Mekkakia-Maaza, and J.-P. Charles, “Multi input-output fuzzy logic smart controller for a residential hybrid solar-wind-storage energy system,” *Energy Conversion and Management*, vol. 148, pp. 238–250, Sep. 2017, doi: 10.1016/j.enconman.2017.05.046.

[9] L. Farah, A. Haddouche, and A. Haddouche, “Comparison between proposed fuzzy logic and ANFIS for MPPT control for photovoltaic system,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 2, p. 1065, Jun. 2020, doi: 10.11591/ijpeds.v11.i2.pp1065-1073.

[10] M. Birane, C. Larbes, and A. Cheknane, “Comparative study and performance evaluation of central and distributed topologies of photovoltaic system,” *International Journal of Hydrogen Energy*, vol. 42, no. 13, pp. 8703–8711, Mar. 2017, doi: 10.1016/j.ijhydene.2016.09.192.

[11] S. D. Al-Majidi, M. F. Abbod, and H. S. Al-Raweshidy, “A novel maximum power point tracking technique based on fuzzy logic for photovoltaic systems,” *International Journal of Hydrogen Energy*, vol. 43, no. 31, pp. 14158–14171, Aug. 2018, doi: 10.1016/j.ijhydene.2018.06.002.

[12] A. Derrouazin, N. Mekkakia-Maaza, R. Taleb, M. Nacef, and M. Aillerie, “Low cost hybrid energiess smart management system applied for micro-grids,” *Energy Procedia*, vol. 50, pp. 729–737, 2014, doi: 10.1016/j.egypro.2014.06.090.

[13] S. Semaoui, A. H. Arab, S. Bacha, and B. Azoui, “Optimal sizing of a stand-alone photovoltaic system with energy management in isolated areas,” *Energy Procedia*, vol. 36, pp. 358–368, 2013, doi: 10.1016/j.egypro.2013.07.041.

[14] A. Chaithanakulwat, “Track the maximum power of a photovoltaic to control a cascade five-level inverter a single-phase grid-connected with a fuzzy logic control,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 10, no. 4, p. 1863, Dec. 2019, doi: 10.11591/ijpeds.v10.i4.pp1863-1874.

[15] D. Saheb-Koussa, M. Haddadi, and M. Belhamel, “Economic and technical study of a hybrid system (wind–photovoltaic–diesel) for rural electrification in Algeria,” *Applied Energy*, vol. 86, no. 7–8, pp. 1024–1030, Jul. 2009, doi: 10.1016/j.apenergy.2008.10.015.

[16] G. Tahri, Z. A. Foitih, and A. Tahri, “Fuzzy logic control of active and reactive power for a grid-connected photovoltaic system using a three-level neutral-point-clamped inverter,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 12, no. 1, p. 453, Mar. 2021, doi: 10.11591/ijpeds.v12.i1.pp453-462.

[17] S. S. 20 ANS, “Victron smart RS converter.” .

[18] J. F. Manwell, “Hybrid energy systems,” in *Encyclopedia of Energy*, Elsevier, 2004, pp. 215–229.

[19] L. A. Zadeh, “Fuzzy sets,” *Information and Control*, vol. 8, no. 3, pp. 338–353, Jun. 1965, doi: 10.1016/S0019-9958(65)90241-X.

[20] A. D. Ahmed, “Contribution à l’optimisation d’un système intelligent de routage des sources d’énergies hybrides pour l’application à l’habitat,” 2017.

[21] R. S. Ravi Sankar, S. V. J. Kumar, and G. M. Rao, “Adaptive fuzzy PI current Control of grid interact PV inverter,” *International Journal of Electrical and Computer Engineering (IJECE)*, vol. 8, no. 1, p. 472, Feb. 2018, doi: 10.11591/ijece.v8i1.pp472-482.

[22] K. A. Naik and C. P. Gupta, “Fuzzy logic-based pitch angle controller/or SCIG based wind energy system,” in *2017 Recent Developments in Control, Automation and Power Engineering (RDCAPE)*, IEEE, Oct. 2017, pp. 60–65, doi: 10.1109/RDCAPE.2017.8358240.

[23] T. Ackermann, G. Andersson, and L. Soder, “Electricity market regulations and their impact on distributed generation,” in *DRPT2000. International Conference on Electric Utility Deregulation and Restructuring and Power Technologies. Proceedings (Cat. No.00EX382)*, IEEE, 2000, pp. 608–613, doi: 10.1109/DRPT.2000.855735.

[24] Q.-V. Ngo, C. Yi, and T.-T. Nguyen, “The fuzzy-PID based-pitch angle controller for small-scale wind turbine,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 1, p. 135, Mar. 2020, doi: 10.11591/ijpeds.v11.i1.pp135-142.

[25] A. Yasmine, B. Rafik, B. Rachid, and M. Adel, “Grid connected photovoltaic system efficiency and quality improvement using fuzzy-incond MPPT,” *International Journal of Power Electronics and Drive Systems (IJPEDS)*, vol. 11, no. 3, p. 1536, Sep. 2020, doi: 10.11591/ijpeds.v11.i3.pp1536-1546.