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Optimization of Energy Transfer by Neuro-Fuzzy Control for the Management of a Multi-Source PV-Wind-Diesel System

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***Abstract*–** *This work aims to contribute to the understanding and control of hybrid systems maximizing the use of renewable energy while reducing the fuel consumption of the diesel engine. Knowing that the production of electricity from renewable energy depends heavily on climatic conditions, it is therefore necessary for us to develop a so-called intelligent control based on human reasoning and neural structure to ensure the management and optimization of energy transfer through the multi-source system; this control resulting from the association of fuzzy logic and neural control is called neuro-fuzzy control. To show the relevance of this control, we limited ourselves to the use of two renewable energy sources and a diesel engine to ensure continuity of service. The simulation of the project, which was done in the IDE of the Matlab/Simulink software, allowed us to model the hybrid sources (photovoltaic, wind turbine and diesel engine) and the neuro-fuzzy control initially; and secondly, a global modeling of the system to show the effectiveness of this control for two different load profiles.*

***Keywords*—** *Neural networks, fuzzy logic, PV, wind turbines.*

I. INTRODUCTION

Electrical energy can be produced either by non-renewable energies (oil, gas, coal, nuclear) or by renewable energies (sun, wind, water, biomass). Nowadays, 80% of this energy is produced from fossil or fissile fuels [10], however these are exhaustible resources and represent 40% of global CO2 emissions [1]. For sustainable development, renewable energy resources are "clean" and inexhaustible, therefore capable in the long term of satisfying most of our needs [2][3].

The use of renewable energies for energy production is a promising energy option that meets the growing demand for energy in the world, with advantages such as abundance, the absence of any pollution and availability in several points of the Earth. It is possible to predict that any sustainable energy system in the near future will be based on the use of these sources [1][4].

However, the energy efficiency of the conversion chain for these energies is relatively low. This poses a challenge for designers who are faced with developing robust and reliable MPPT (maximum power point cracking) devices to achieve maximum energy efficiency, useful for our applications.

The objective of this article is to make a scientific contribution to the field of renewable energies. This contribution focuses on two areas:

- The development of an MPPT method for the optimal transfer energy management in photovoltaic and wind turbine systems (integration of neural networks).
- The proposal of a new approach based on artificial intelligence for managing energy transfer in a multi-source system (integrating fuzzy logic).

After modeling all the system elements and conducting a study for two load profiles, we will use an intelligent control system combining both neural networks and logic to optimize the system to ensure continuity of service in the load.

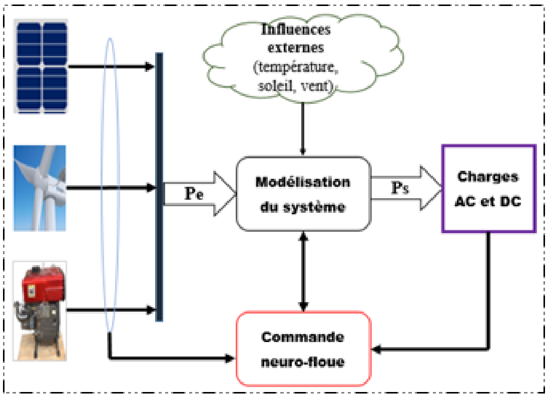

Fig. 1. Block diagram of the control system

II. LITERATURE REVIEW

There are many studies being carried out daily in the field of renewable energies in general and in particular in photovoltaic-wind-diesel hybrid systems; in this perspective, we can mention some scientific contributions:

- Tahar Tafticht who in his thesis << analysis and control of a hybrid photovoltaic wind system >> presented for the award of the doctorate at the University of Quebec in Trois Rivières in December 2006, states that the use of renewable energies for the production of energy is a promising energy option that would meet the growing demand for energy in the world, with advantages such as abundance, the absence of any pollution and availability in several points of the terrestrial globe; the objective of his thesis is to develop an MPPT method for the optimal transfer of energy in photovoltaic systems and the application of the MPPT principle to the wind generator. He develops among other things a new MPPT method based on a non-linear approach for the estimation of the reference of the optimal operating point of photovoltaic modules, the development of new MPPT algorithms for the optimization of energy transfer in photovoltaic systems and the design of MPPT converters for photovoltaic and wind sources [5].

International Journal of Scientific Engineering and Science
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• Ibrahim Yassine in his thesis entitled << Photovoltaic – Wind – Diesel Hybrid System without Storage>> presents renewable energy sources as the main means of producing electricity while minimizing air pollution; in parallel with his predecessor, this one connects the photovoltaic-wind hybrid system to a diesel generator in order to increase production and ensure continuity of service. He does the global modeling of the photovoltaic, wind, diesel generator and develops an MPPT control algorithm for the search for the maximum power point under the malta/Simulink platform.

• Adnane, Mr Zaimi, Dr Madjid Si Brahim, Mr Bencherif Bihel, Mr Kelkoul Bahia present renewable energies as the main sources that will fill the energy deficit, particularly wind energy; in order to extract the maximum power from the latter, a maximum power point search method has been developed to optimize the system through MPPT algorithms on the conversion of wind energy based on synchronous or asynchronous machines [6] [7] [8].

• Amara Karine, Mr Abbassen Lyes make a generalized and conventional study on solar energy; in fact, they develop an MPPT algorithm based on the search for the maximum power point in order to extract the maximum power from photovoltaic panels [9].

• Minh Huynh Quang, in his thesis "Optimization of renewable electricity production for isolated sites" stipulates the idea that renewable energy is the most suitable means of electricity production for isolated sites. In this thesis, he develops a technique for optimizing the production of renewable electricity for isolated low-power sites. A system using two renewable sources: photovoltaic and wind, is studied in order to improve the energy efficiency of the extracted energy. For the photovoltaic and wind conversion chain, he sets up a controller to track the maximum power point designed using the direct search approach (Perturbe & Observe method) combined with fuzzy logic, while taking into account the direction of variation of the disturbances [10].

III. Design Methods

The objective of this article is to design an artificial intelligence-based control system whose role is to ensure service continuity. The control system used here is a blend of neural networks and logic. To carry out our work, we will model all the elements of our system in Matlab/Simulink software and then apply neurofuzzy control to drive our system. To test the effectiveness of our control system, our specifications will be limited to two renewable sources: solar and wind power, and a backup source consisting of a diesel engine.

A. Modeling of a photovoltaic cell

To model a photovoltaic cell, it will be necessary to take into account resistive effects and imperfections due to manufacturing. consider the series resistance Rs (representing the losses by joule effect), the parallel resistance Rp (characterizing a leakage current) generally much higher than rs and a current source in parallel with an ideal diode [11] [12]

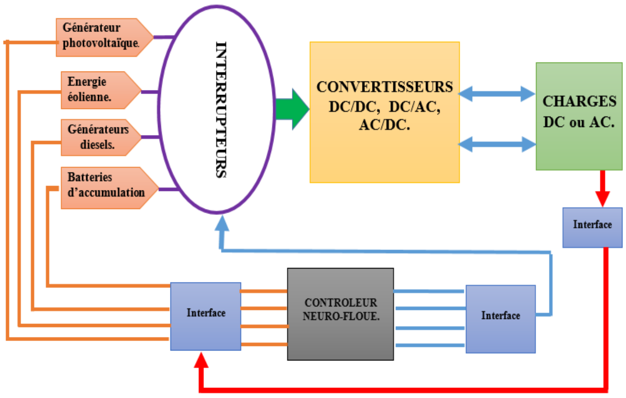

Fig. 2. Block diagram of the control system

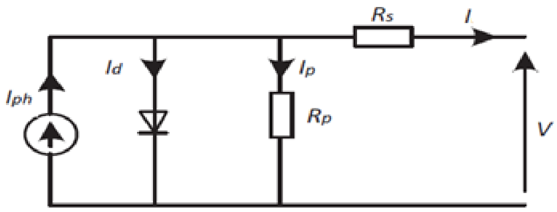

Fig. 3. Equivalent diagram of a photovoltaic cell [15]

From this diagram, we deduce the following equation: $I = I_{ph} - I_s\left(e^{\frac{q(V+Rs.I)}{nkT}} - 1\right) - \frac{V+Rs.I}{Rp}$

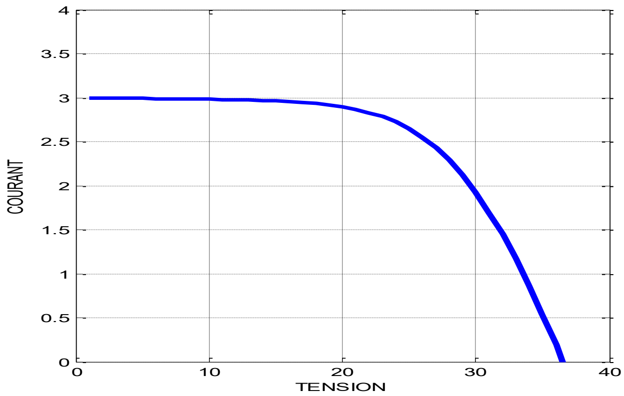

Fig. 4. Current-voltage characteristic of a photovoltaic plate

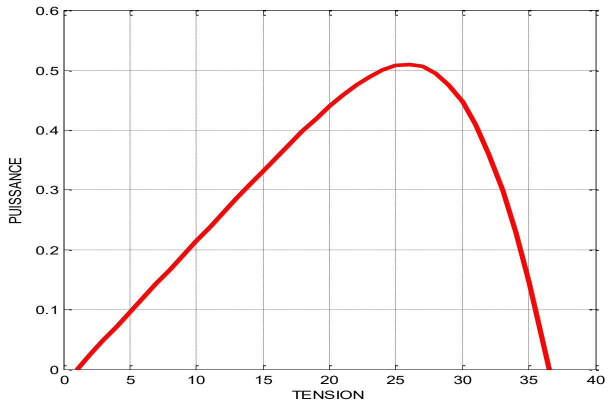

Fig.5. Power-voltage characteristic of a photovoltaic plate

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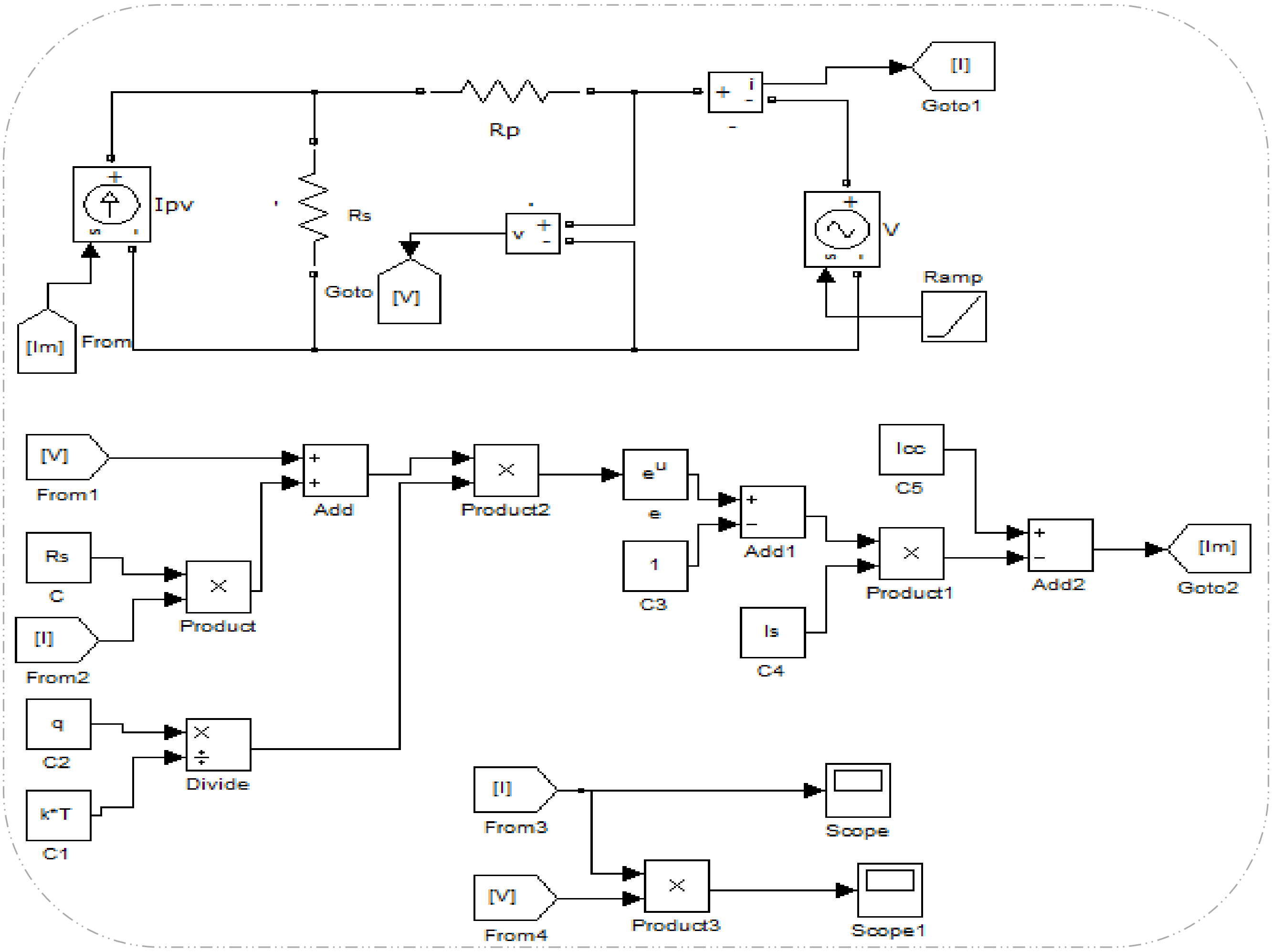

Fig. 6. Simulation d'une cellule photovoltaïque dans Simulink

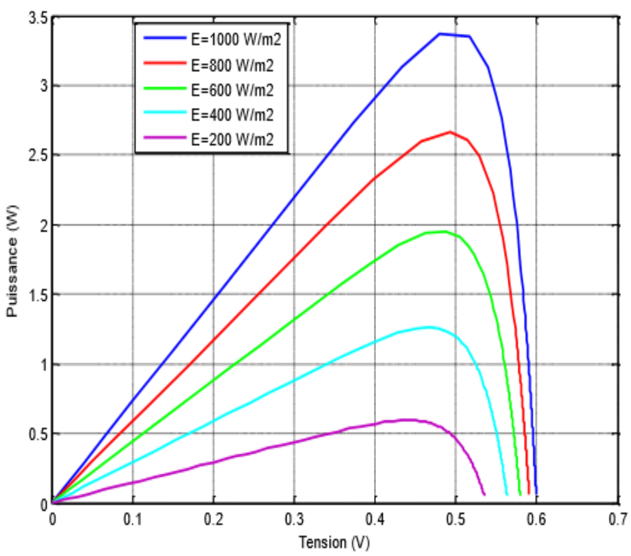

Fig. 7. Influence of illumination on the photovoltaic plate

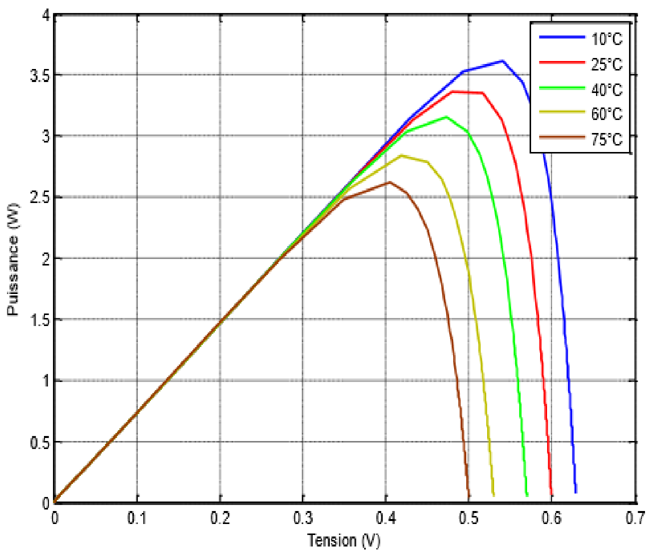

Fig. 8. Influence of temperature on the photovoltaic plate

B. Modeling and simulation of a wind generator

The study and modeling of a wind turbine can be divided into three stages; the turbine part (which converts the kinetic energy of the wind into mechanical energy), the multiplier part (which serves as a connection between the turbine and the generator, it increases the rotation speed of the shaft), and finally the shaft part of the generator. It all starts with the movement of air masses possessing kinetic energy [13] [14]. Kinetic energy is of the form $E_c = 1/2mv^2$ where m is the reduced mass of the air and v its speed. The power is therefore $P_v = \frac{(dE_c)}{dt}$ $et\ m = \rho\ .Volume\ =\ \rho.S.v.dt$,
S being the section. We then deduce the power of the air mass $P_v = \frac{1}{2}\ \rho.S.v^3$.

Considering that the power of the wind turbine (P_{aer}) could never be equal to the power of the air mass (presence of friction), we therefore introduce the power friction coefficient C_p such that $P_{aer} = C_p.P_v$ [13]; However, according to Betz's law, the power can never be extracted in its entirety; the maximum to be collected through a wind turbine is 59%,
$P_{aer_{max}} = \frac{16}{27}P_v = P\_aer\ = \frac{1}{2}\ \rho.S.v^3.C_p\ ,C_p < 0.59.$
In the literature, we find various expressions of the power coefficient C_p ; but in this work we will use only one expression ;
$C_p = \frac{1}{2}\left(\frac{98}{\lambda_i} - 0.4 - 5\right) e^{\frac{16,8}{\lambda_i}}$, où $\lambda_i = \frac{1}{\frac{1}{\lambda+0.089} - \frac{0,035}{\beta^3+1}}$
λ_i : Reduced speed (or speed ratio) and
β The curve below represents the curve of $C_p = f(\lambda)$

Taking into account the inertia of the wing and the friction of the bearings, the mechanical torque is different from the torque delivered by the turbine, and the aerodynamic power can be written: $P_{aer} = \frac{1}{2}\ \rho.S.v^3.C_p\ = C_{tur}.\Omega = C_{eol}.\Omega$,, where R is the radius described by the blades; substituting the expression for this reduced speed, we obtain:

$$C_{tur} = C_{eol} = \frac{P_{aer}}{\Omega} = \frac{1}{2\lambda}\ \rho S.v^2.C_p R$$

The gearbox provides the connection between the turbine and the generator; its role is to adapt the turbine speed to that of the generator: We therefore have: $\Omega_{mec} = G.\Omega_{tur}$, where G= is the speed multiplier gain Friction, elasticity, and energy losses in the gearbox are neglected, so the power is the same on the secondary and primary shafts: $C_g = \frac{1}{G}.C_{turbine}$

The fundamental equation of dynamics allows us to determine the rotational speed from the total mechanical torque applied to the rotor: :
$J\frac{d\Omega_{mec}}{dt} = C_{total} = C_g - C_{em} - C_{vis} = C_g - C_{em} -$ f. Ω_{mec} ;Where J is the total inertia that appears on the generator rotor; and the total mechanical torque takes into account the electromagnetic torque (C_{em}) produced by the generator, the viscous friction torque (C_{vis}) and the torque (C_g)

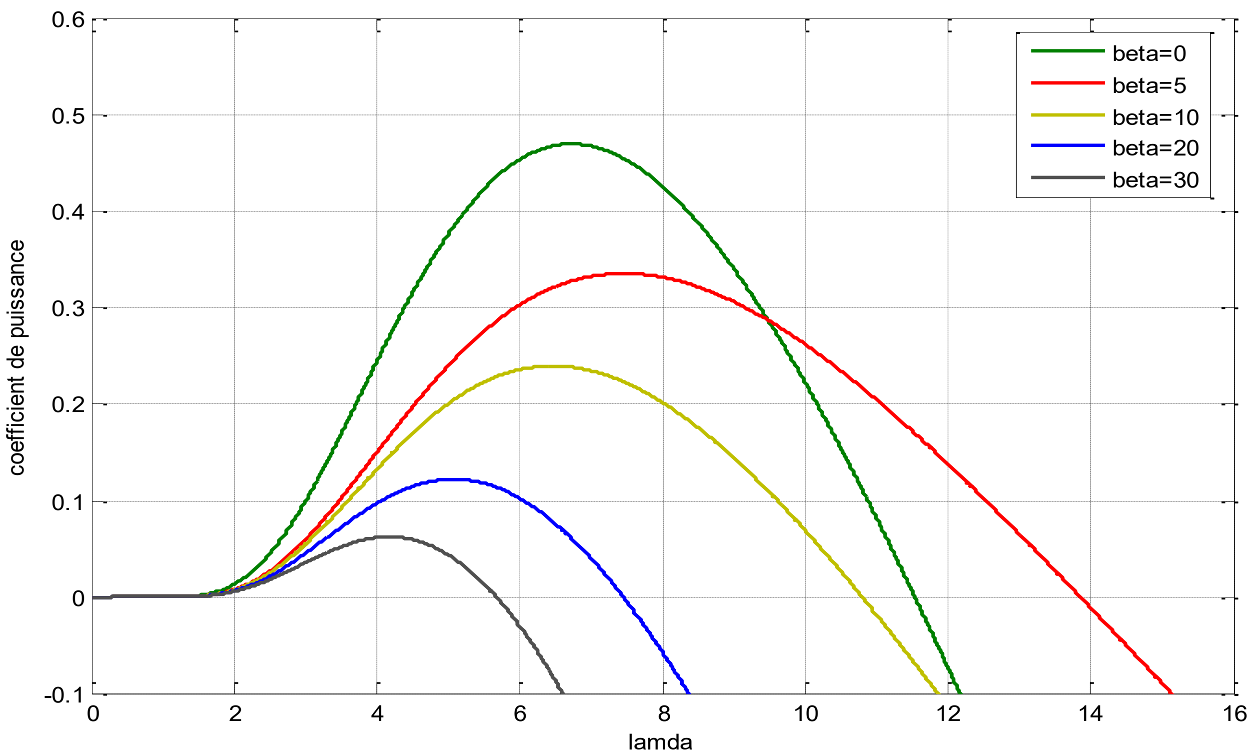

Fig. 9. Influence de l'angle de calage β sur Cp= f(λ)

International Journal of Scientific Engineering and Science
Volume 9, Issue 7, pp. 61-72, 2025. ISSN (Online): 2456-7361

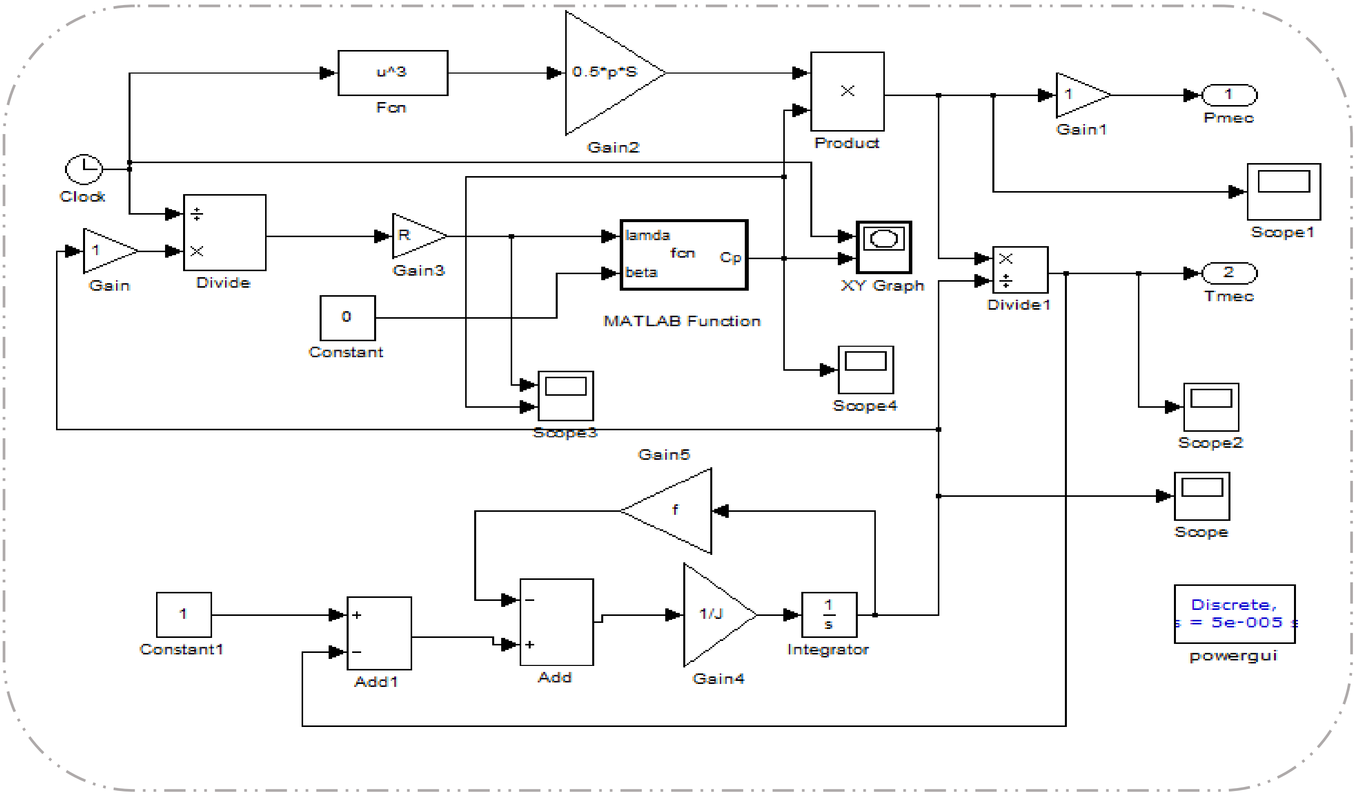

Fig. 10. Modeling of the turbine and rotor shaft

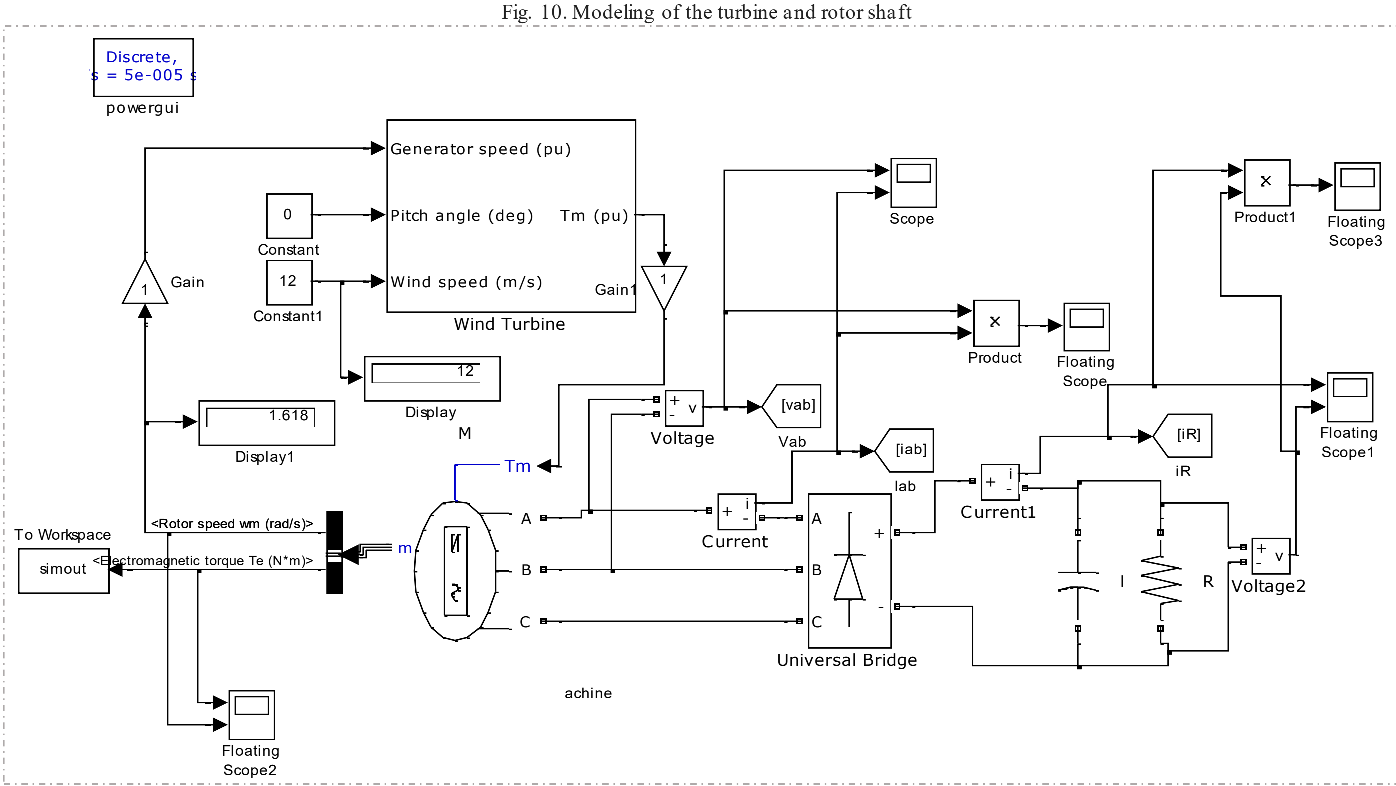

Fig. 11. Complete modeling of the wind turbine supplying a load

International Journal of Scientific Engineering and Science
Volume 9, Issue 7, pp. 61-72, 2025.
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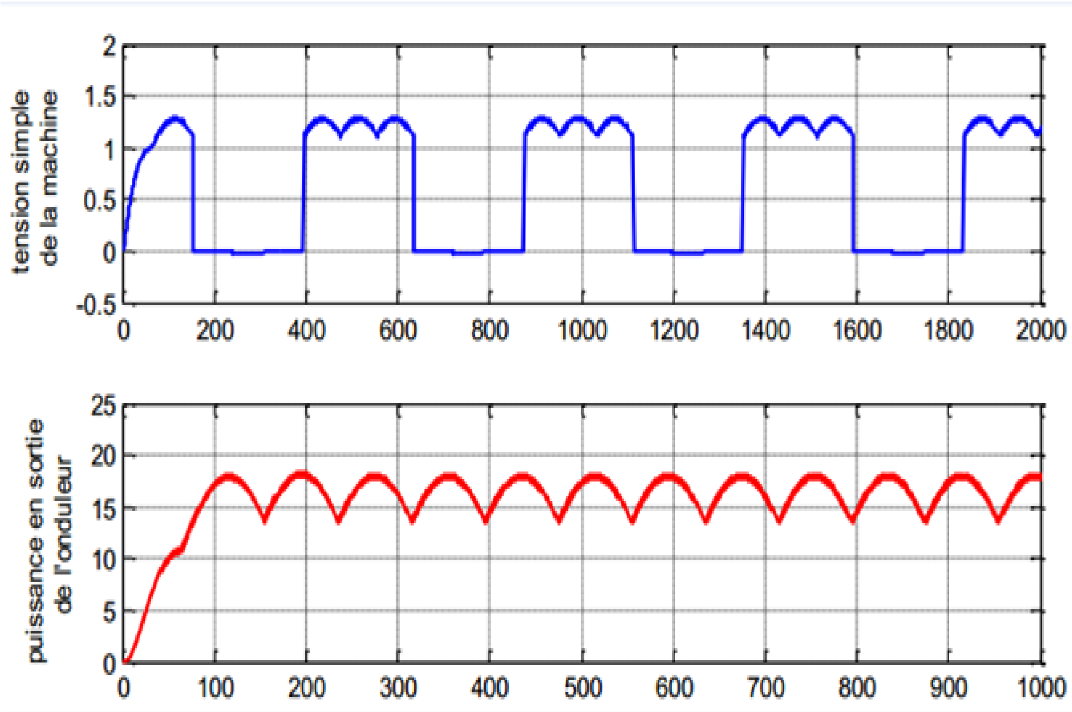

Fig. 12. Wind turbine load characteristics (output power and voltage)

C. Modeling of Neural Networks to the System.

The objective is to operate the renewable energy generators at their maximum energy. To do this, it will be necessary to identify and record the differences in the values of the maximum power point for different variations in temperature or illumination for the photovoltaic system and for different wind speeds for the wind turbine. These values, thus acquired, will constitute the learning base for the neural control. The perceptron network, which will have three layers—an input layer, an output layer, and a hidden layer of twenty neurons—will be used. It is therefore this neural control that is used to model the photovoltaic panel and the wind turbine. The procedure for creating a neural network in Matlab is as follows:

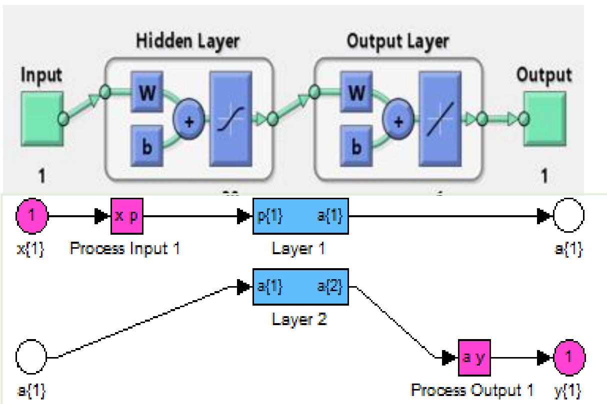

Fig.13. Creation of a neural network in nntool/Matlab

D. Modeling of fuzzy logic to the system.

Fuzzy logic calculations require, in addition to the basic MATLAB license, the purchase and installation of the Fuzzy Control Toolbox. This tool provides the user with two fundamental tools: a guide to building a fuzzy logic controller and a functional block to integrate into a Simulink control scheme. We have three important parts for designing our fuzzy logic-based control system.

- Fuzzy input variables: These represent the different power levels available at our energy sources and the power drawn by the load.
- Fuzzy output variables: These represent the different control signals for the switches that will turn our energy sources on or off.
- Inference rules: These are the set of different rules that allow us to predict a system's outputs based on different input combinations [5] [13].

The input variables Pch, Pv, Pe, Pdel, Pdiel represent respectively the power called by the load, the power delivered by the photovoltaic generator, the power delivered by the wind generator, the power supplied by the battery, the power delivered by the diesel generator while the output variables Cv, Ce, Cdel, Cdiel represent respectively the control of the photovoltaic generator, the control of the wind generator, that of the batteries and that of the diesel generator.

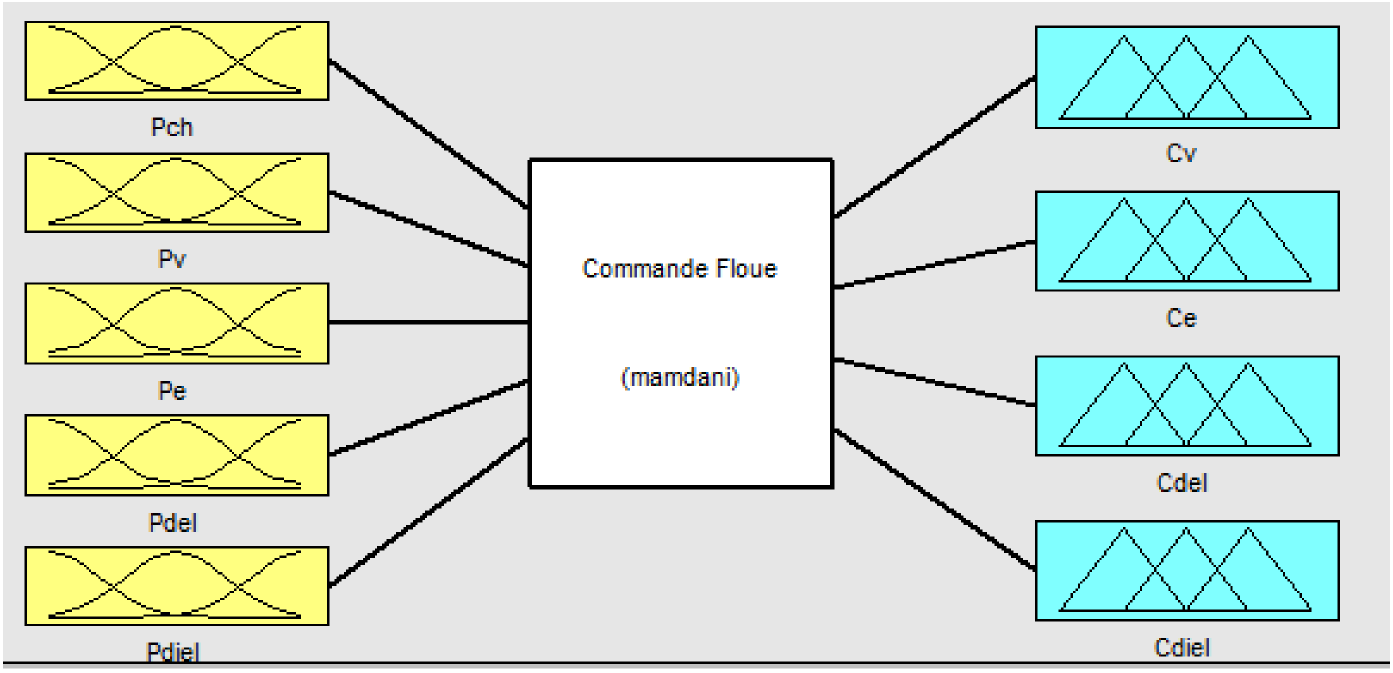

Fig. 14. Setting up the Fuzzy command of our system

E. Proposed model for multi-source system management

In this section, we propose a block diagram for optimal management of hybrid sources; we therefore combine fuzzy logic-based control and neural control to create our neuro-fuzzy control.

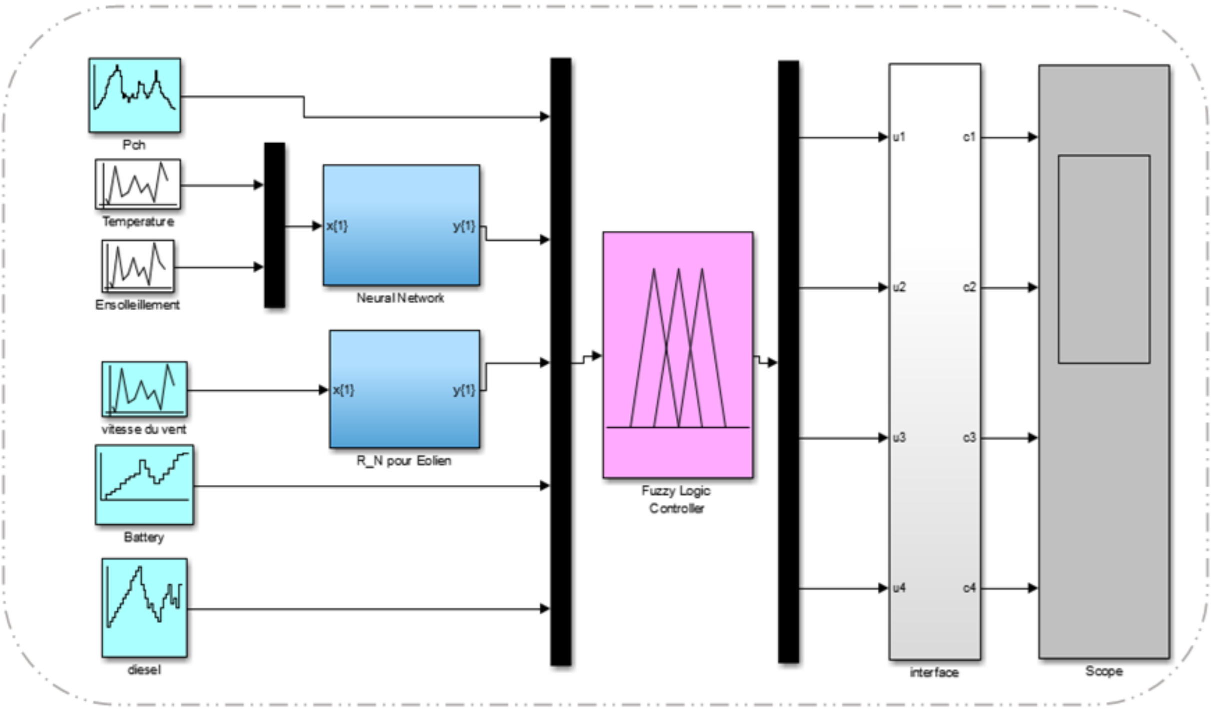

Fig 15: Complete block diagram of neuro-fuzzy control

International Journal of Scientific Engineering and Science
Volume 9, Issue 7, pp. 61-72, 2025.
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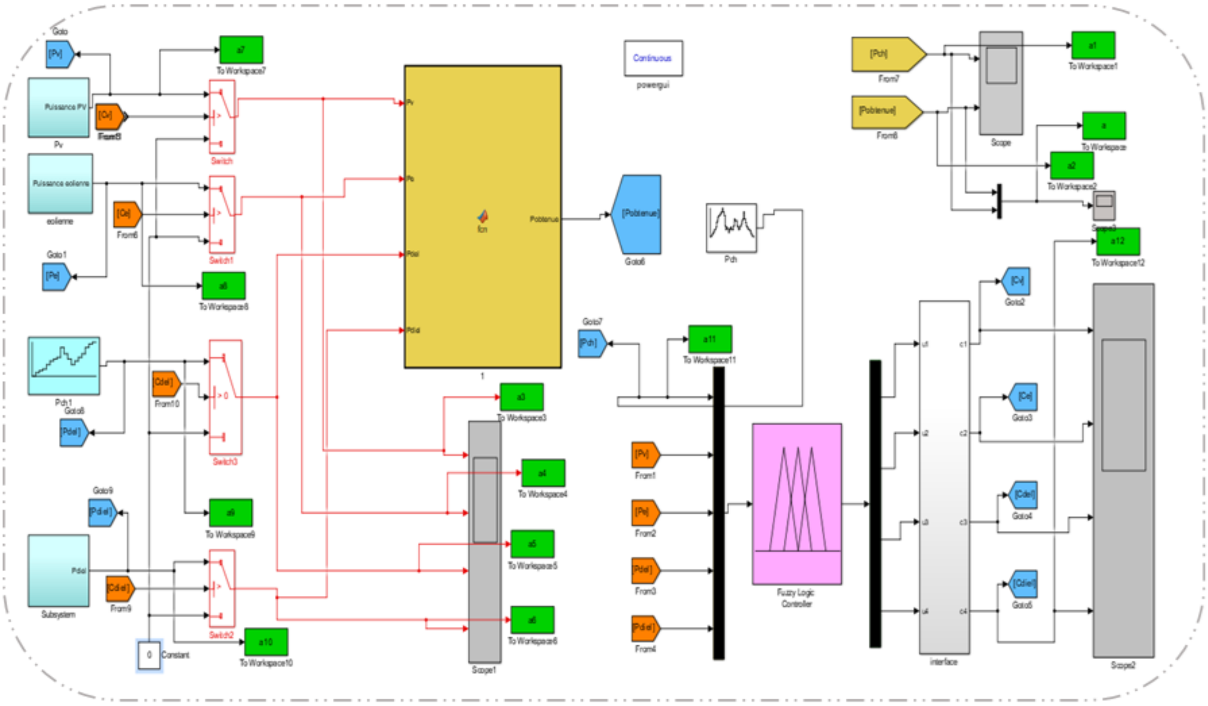

Fig. 16. Complete modeling of the system

IV. RESULTS

Simulation results were obtained for different levels of sunlight and wind speeds: these results reflect the overall performance of the neurofuzzy control applied to our hybrid system in the context of optimal energy transfer management.

A. *Results of non-optimized output power from non-renewable sources.*

A random temperature, sunlight, and wind speed are applied to the input of these renewable energy sources, respectively, for the PV and the wind turbine generator, in order to analyze the various output power of the sources. It is noted that in the absence of neural control, the power obtained is low and has a negative average value.

This is due to the fact that the output current of the PV and the wind turbine becomes negative for certain input values. To avoid this, anti-return diodes are often placed at the input of the sources for their protection and to prevent the return of the current; this procedure is necessary but not sufficient, because by doing so the load will be disconnected from the power supply which is far from the intended objective which is to ensure continuity of service. The use of neural control therefore increases the speed and robustness of the multi-source system. Furthermore, it also allows the sources to operate at their maximum power point, which eliminates the negative part of the power. The results below were obtained at the output of renewable energy sources under the random effect of wind, temperature and sunshine.

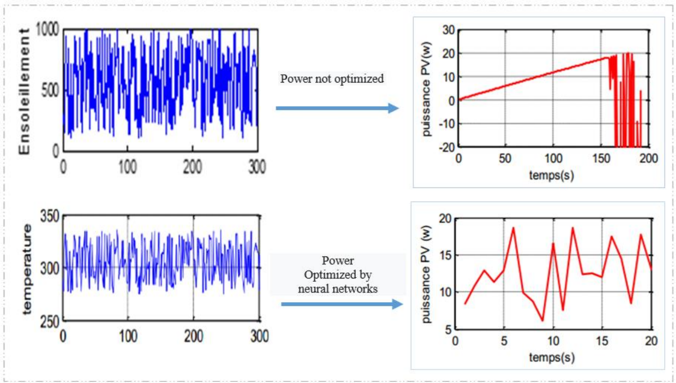

Fig. 17. Power optimized by neural network at the output of photovoltaic panels

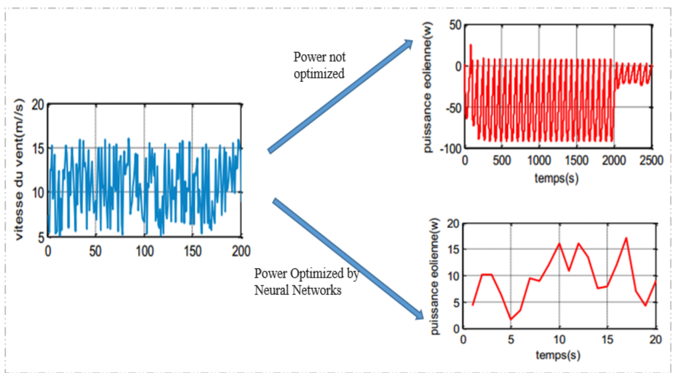

Fig. 18. Power optimized by neural network at the wind turbine output

B. *Final results generated by the Neuro-fuzzy command*

The graph below shows the different commands applied to renewable energy sources such as PV control, wind turbine

Volume 9, Issue 7, pp. 61-72, 2025.
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control, battery and diesel. In all cases, when the command is at "0", the corresponding source is disconnected from the power transfer chain and switches to the battery to ensure the battery's charge. Photovoltaic energy and wind energy are the main power sources, which explains the plethora of "1" in the PV and wind turbine controls. The storage battery has a dual role, when its command is equal to "1", it adds to the renewable sources and supplies the load, it only goes into storage position in the event of excess energy produced by the photovoltaic source. Diesel, for its part, only intervenes in the event of very unfavorable conditions; it plays the role of a backup source, which justifies the diagram below (command = "0"); the objective of minimizing diesel consumption is quite satisfactory

The system's power management is carried out specifically within this fuzzy logic control. Fuzzy logic retrieves all the information at the power levels and combines it in such a way as to produce only the energy needed to power the load and send the excess energy to the loads in load shedding. We note that the switches corresponding to renewable energies are constantly at "1" while the diesel remains almost at "0." This is consistent with our objectives; as we are maximizing the use of renewable energies while reducing fuel consumption in the diesel.

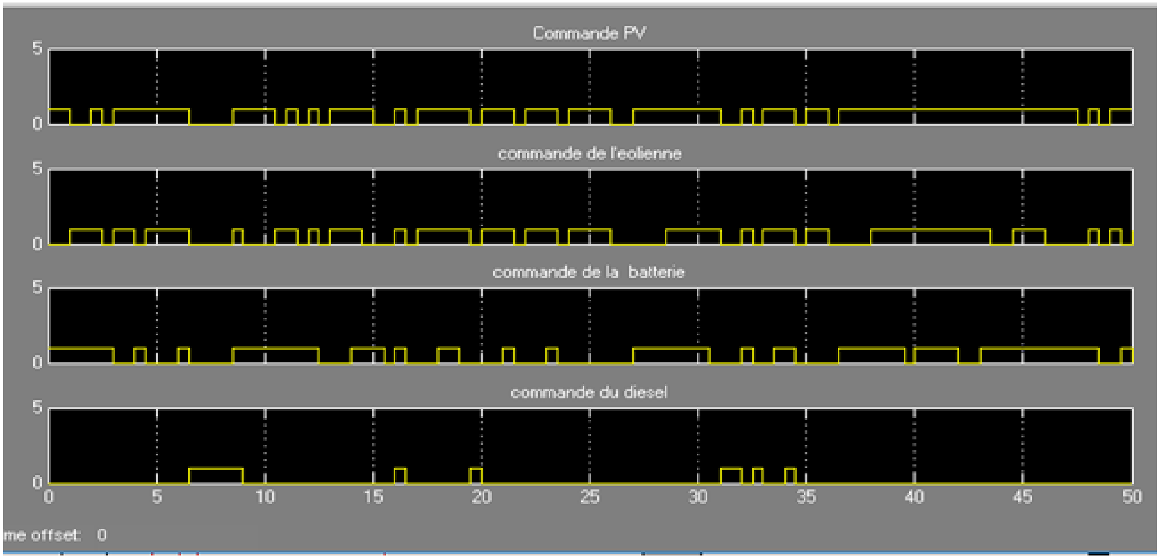

Fig.19. results of the switch commands at the output of the neuro-fuzzy block

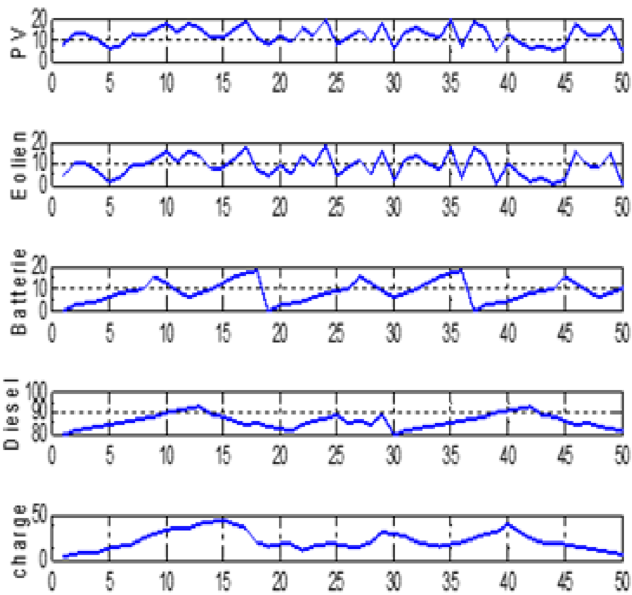

Fig.20. Curve of powers obtained after neural control

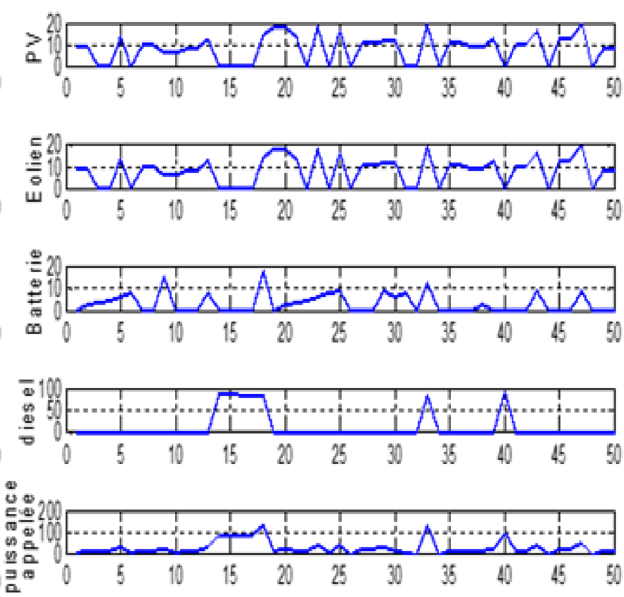

Fig.21. Curve of powers obtained after fuzzy control

International Journal of Scientific Engineering and Science
Volume 9, Issue 7, pp. 61-72, 2025. ISSN (Online): 2456-7361

C. Comparison between power demand and power released by the control

We used two load profiles to test the hybrid control. We note that in the second case, the system is controlled and is more precise because the power released by the control is practically equal to that demanded by the load. The observed power peaks represent the delay of the control with respect to its target. This is quite normal, because the neuro-fuzzy control performs a calculation at each level of power called in order to release only the energy necessary to power the load. Furthermore, we note that the precision increases with the number of linguistic variables as you can see in the diagram below. But the big problem is that by increasing the number of linguistic variables, the number of inference rules to drive the system also increases and becomes very complex.

1. First load profile

Fuzzy logic is used with a basic linguistic variable number, with three linguistic variables for each power at the input of the "fuzzy logic" block

2. Second load profile

We redo the same work with a second different load profile, and we increase the number of linguistic variables to five;

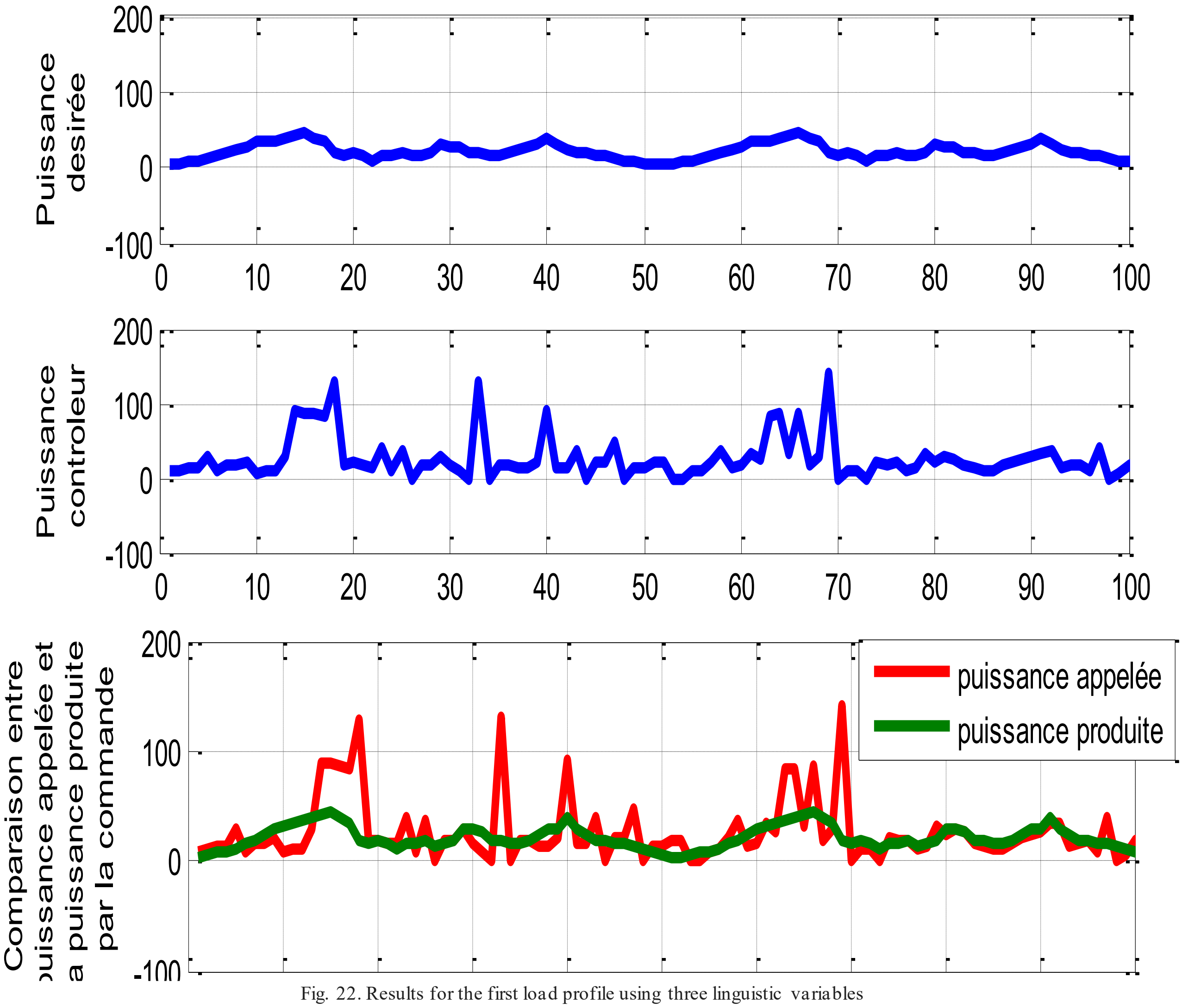

Fig. 22. Results for the first load profile using three linguistic variables

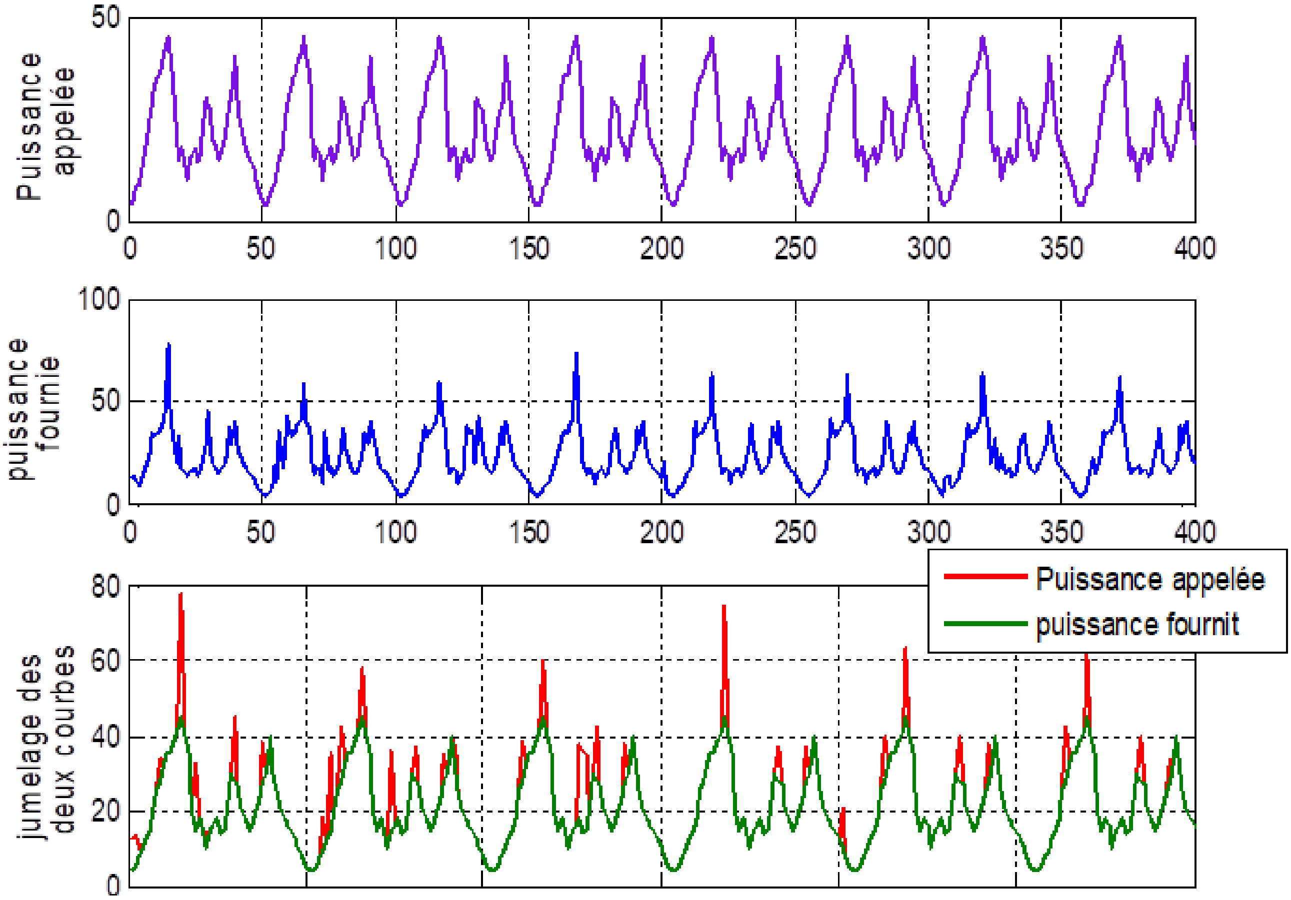

Fig.23. Results for the second load profile using five linguistic variables

V. CONCLUSION

The objective of this article was to optimize energy management from a hybrid system and reduce fuel consumption in diesel. Knowing that the renewable energies used (PV-Wind) are highly dependent on climatic and atmospheric conditions, a neural control system was implemented to operate them at their maximum power; fuzzy logic was used to control the system to meet the power required by the load, hence the name "Neuro-fuzzy control"; We used two load profiles to test the hybrid control system. We found that in the second case, the system is controlled and is more precise because the power released by the command is practically equal to that called by the load. The observed power peaks represent the delay of the command with respect to its target. This is quite normal, because the neuro-fuzzy control performs a calculation at each level of power called in order to release only the energy necessary to power the load. Moreover, we note that the precision increases with the number of linguistic variables as you can see in the diagram below. But the big problem is that by increasing the number of linguistic variables, the number of inference rules to control the system also increases and becomes very complex.

REFERENCE

[1] Boukhers Djamil “Optimization of a photovoltaic energy system applied to pumping”, Master’s degree in electrical engineering, November 28, 2007, Faculty of Engineering Sciences, Mentouri University of Constantine.

[2] Ramond Adrien “Design and implementation of a new multi-input multi-output architecture for micropower management in autonomous systems”, PhD thesis, National Institute of Applied Sciences, University of Toulouse, November 22, 2011. 1.1

[3] Ms. Hamecha Samira, Ep. Bourekache “Study and control of a wind turbine based on a permanent magnet synchronous machine” Master’s thesis, June 25, 2013, Faculty of Electrical Engineering and Computer Science, Mouloud Mammeri University of Tizi-Ouzou. 1.1,1.6.3

[4] Latreche Mohammed Tahar “Fuzzy control of the permanent magnet synchronous machine (PMSM) used in a wind system”, Master’s degree in electrical engineering, Algeria, June 24, 2012, Ferhat Abbas University of Setif. (document), 1.5.1, 1.6, 1.6.2, 1.6.3, 1.6.4

[5] Tahar Tafticht “Design and Control of a Hybrid Photovoltaic-Wind System” Doctoral Thesis, December 2006, University of Quebec in Trois-Rivières. 1.6.2, 1.6.3, 2.1.1

[6] Madjid Si Brahim "Study of a wind energy conversion system based on an asynchronous machine" Postgraduate thesis, Algeria, June 16, 2015, Mouloud Mammeri University of Tizi-Ouzou, Faculty of Electrical and Information Engineering. (document), 1.6.2, 1.6.2, 1.6.3

[7] Bencherif Bilel "Study and modeling of the different components of a wind turbine installation using a permanent magnet synchronous generator", Master's thesis, Faculty of Technology, Ferhat Abbas-Sétif University, Algeria, 2011.

[8] Kelkoul Bahia “Study and control of a wind turbine using a double-fed asynchronous machine” Faculty of Technology of the University of Tlemcen, Algeria June 29, 2011. 1.6.2, 1.6.3

[15] Brahmi Mahbouba et al “A novel MPPT Algorithm Based on MRAC-FUZZY Controller for Solar Photovoltaic Systems” article, University of Tunis, National Higher School of Engineers of Tunis (ENSIT), May 15, 2025

Volume 9, Issue 7, pp. 61-72, 2025. ISSN (Online): 2456-7361

[10] Minh Huynh Quang "Optimization of renewable electricity production for isolated sites", Doctoral Thesis, University of Reims Champagne-Ardenne, July 25, 2013. (document), 1.1, 1.1.5, 1.6.4
[11] Touil Nacer Eddine, Ghenbazi Slimane "Modeling and simulation of a photovoltaic system", Academic Master, September 2015, Faculty of Science and Technology of the Echahid Hama Lakhder University of El-oued. (document),1.5.4
[12] Souleymane Ndoye "Modeling and Simulation under Matlab/Simulink of the Power Supply Chain of a Telecommunications Relay Station in Photovoltaic Solar Energy in an Area Isolated from the Power Grid", Faculty of Science and Technology, Checkh Anta Diop University, Dakar, May 2010.
[13] Chibah Arezki "Design of a Power Stage Controller by FPGA" Master's Degree, Mouloud Mammeri University of Tizi-Ouzou, Algeria, June 2012. 1.1, 1.2, 2.1.1
[14] F. Kendouli, K. Nabti, K. Abed and H. Benalla "Modeling, Simulation and Control of a Variable Speed Wind Turbine Based on the Doubly Fed Asynchronous Generator", Faculty of Engineering, Mentouri University, Algeria 2011.