



Energy Management and Control of a multi-sources PV System in Building in tropical area (Senegal)

Amadou BA^{1*}, Alphousseyni Ndiaye¹, Senghane Mbodji¹, Daouda Gueye¹, Mamadou Traore² and El Hadji Mbaye Ndiaye¹

¹ University Alioune Diop, Bambey, Senegal

² University of Kankan, Guinea.

*Corresponding Author

Amadou BA

Article History

Received: 15.01.2026

Accepted: 02.03.2026

Published: 22.03.2026

Abstract: In this study, the main objective is to develop an energy management system to satisfy power production of a photovoltaic system with storage in building in tropical area. These projects are now the main challenge to participate in energy transition in key sectors like building. Furthermore, they enhance the resilience of the multi sources systems through a modern management hard skill based on artificial intelligence applied to renewable energies. We begin by the optimization of the PV system to enhance the production and at the end, a control and management of energy of the whole system is done. Adaptative technics based on Artificial Neural Network are used for the optimization and system control due their good performances on non-linear applications. The energy management is an important task in hybrid system; it must have the ability to do the repartition of the energy in the different sources of the system. To meet demand, optimized energy must be distributed fairly in the whole system. The system is developed and simulated for a variation of the sunshine using MATLAB/Simulink. The simulation results indicate that the proposed controllers enhance the power of the system, a low harmonic distortion is noted and the management of the energy is assured in the whole system.

Keywords: ANN, DC low Voltage, PI, THD, RBFNN.

Cite this article:

Amadou BA., Ndiaye, A., Mbodji, S., Gueye, D., Traore, M., and El Hadji M. N., (2026). Energy Management and Control of a multi-sources PV System in Building in tropical area (Senegal). *ISAR Journal of Science and Technology*, 4(3), 59-68.

I. INTRODUCTION

Nowadays, in tropical area, various nonconventional energy sources such as solar energy, wind energy, hydro energy etc... are converted to electrical for energy needs. The use of renewable energy sources can reduce the environmental pollution by cleaner electrical energy production and contribute to our energy transition. Nowadays the use of energy in building increase and make the sector on the first place in energy consumption in Sénégal. Renewable energy in particular photovoltaic systems (PVS) seem to be the solution to this problem because it doesn't limit to standalone systems but also contribute reduce building energy depending on fossil oil [1]. Senegal government had participated in this mix energy challenge by its renewable's energies potentials [2], [3]. An electronic component such as a converter and/or an

inverter are used to transfer the energy produced by the PVS [4] to the grid and a control strategy of each component is necessary to avoid to disrupt the grid. There are several topologies of single-phase PV grid connected [5], [6] systems and two-stage configuration are mainly used because of its advantages of decoupled control since maximum power point tracking (MPPT) control and current injection control are decoupled at different stages. However, to enhance to production of these systems, the energy injected to the grid

[7] must be optimized. Even if everyone is involved in this area, the grid-connected PV system is accountable for meeting the requirements for integrating a PV system to the grid. As defined by the Institute of Electrical and Electronics Engineers (IEEE) standard like a total harmonic distortion (THD) of the injected current must be less than 5 % [8].



These reasons make that it is fundamental and necessary to design a controller in order to solve the problems raised of the multi-sources PV systems. These controllers can be split in three categories, the first is to optimize the energy, the second is to control and regulate of the DC voltage link, the three is the management of the energy between the sources and loads. In the literature, various control techniques commonly known as Maximum Power Point Tracking (MPPT) controls have been developed to optimize the efficiency of photovoltaic modules. Various controllers classical and intelligent are developed to optimize the conversion efficiency of PV systems [2]. These commands are fuzzy logic (FL), genetic algorithms, artificial neural networks (ANN), the Optimization swarms of particles (PSO) and the Adaptive Neuro Fuzzy Inference System (ANFIS) which the combination of artificial neural network and fuzzy logic. In [3], we note the good performance of ANFIS control compared to a heuristic INC command to optimize the conversion efficiency of a PV system. The results show that the intelligent control displays a response time an order of 2.4 s and leads to an efficiency of 99.94 % compared to 94.41 % obtained with InC control. In [9], a MPPT method based on Artificial Neural Network (ANN) was proposed for continuing the overall of the MPP in various weather conditions for a stand-alone PV system compared to an ANFIS MPPT. The proposed method includes the PV characteristics scanning procedure with the ANN and ANFIS controller in the shading effect. The simulation results show that the proposed method is able to find the MPP and ensures rapid convergence towards this point with good efficiency in non-uniform weather conditions. To ensure an optimal transfer of the energy to the grid, the input voltage of the inverter must be kept at a constant value and it is impacted by the weather conditions. The variation of the DC link voltage is disturbed by the current variations of the PVS and the load or grid current [10], [11] and many researchers have focused their study on regulation of DC link voltage. In [12] a proportional integral (PI) and Model Predictive Control (MPC) for maintaining a constant DC link voltage is proposed. The simulation results of this study found that the control strategy maintains the dc-link voltage and the (MPC) give the better performance with low overshoots. In order to enhance the performance of the conventional and the most useful controllers like (PI) and proportional integral derivative (PID) an intelligent controller based on fuzzy logic (FL) is used. The (FL) controller readjusts the (PID) gains in real-time to improve the process output response as adaptive PID during system operation under parameter uncertainty and disturbances and it has a robust behavior and good transient response [13]. A comparative study of a fuzzy logic and a PID controller is done in [14] to maintain the DC link constant of a stand-alone DC application. The FL reduce the peak overshoot of the DC link voltage by 16.23 % and 14.62

% respectively as compared to the system with PID controller. Another control techniques and strategies have been proposed such as conventional and intelligent control for the control of the inverter grid system. The conventional controllers like PI and PID are the most used in the industry because of their simple design procedure and are the basis of systems control. Because of the proportional, integral and or derivable action, they give good performance in systems control. These correctors are used in [15], [16] for grid connected PV applications. The resonant correctors are most used in photovoltaic systems because they give good performances. These are similar to PI correctors; the only difference is the way in which the integral action takes part and integrates only the frequencies near to the resonance frequencies [17]. In [18] a synthesis of the resonant corrector is made for to control of the output current of a single-phase inverter connected to the grid. A comparative study of a resonant corrector (RC) and PI is made in [19] for the control of the current of a three-phase inverter grid connected supplied by a photovoltaic source. The comparative study is focused on the Total Harmonic of Distortion which must be below 5 % [20] for the currents. The simulation results show the good performance of the resonant corrector and gives a current THD of 2.21 and 1.27 % respectively for the PI

[24] a fuzzy logic controller associated with a PID corrector has been studied. The FL controller changes automatically the PID parameters according to the load variations. This objective is achieved with a fuzzy logic controller combined with a PI corrector [25] in order to improve the performance of the conventional correctors. An implementation of a fuzzy logic PWM (Pulse Width Modulation) is done in [26], [27]. The main goal is to obtain good power quality with less distortion and quick response. Simulation results with fuzzy logic under Matlab give a low THD compared to a PI. A combination of two fuzzy regulators is made and the study has shown that the fuzzy-PID logic controller gives better precision and the advantage is a reduction of the PID parameters variation and the rules of the fuzzy controller. In [28], [29] a study of a neural controller to control an inverter is made. Then the vector control of these is done successively by MLI and hysteresis. The objective is to enhance the active and reactive power of the system. The simulation results show a good performance with the possibility of compensating for reactive power and a low THD. A study of an adaptive control of a single-phase inverter is made in [30] the objective is found the optimal parameters of the PI by an ANN to improve the energy quality. Simulation results showed that the proposed method is able to control the current under all weather conditions and an TDH is 0.41%. We also note the good performance of a response time and precision of a neural control compared to a classic PI in [31]. The two output components of the controller direct are

direct (V_d) and quadratic (V_q) voltage and the genetic algorithm is used for learning. To enhance a performance of a fuzzy logic, an artificial neural network is used to choose the membership function [32]. The objective is to reduce the ripples of active and reactive power and to generate a perfectly sinusoidal current waveform and a low THD. The simulation results confirm good performance and excellent robustness of these controls. To enhance power quality (PQ) of a grid connected Photovoltaic (PV) system in [33] a combined performance of both the Radial Basis Function Neural Network (RBFNN) and Proportional Integral (PI) controller is done. During the testing time, the RBFNN predicts the gain parameters of the PI controller as the grid side parameter variation and the PQ of the grid side has been enhanced and it is proficient over the other conventional technique. In [34] a closed loop control of nonlinear system connected inverter based on the hybrid technique is proposed. The proposed method rests on the hybrid technique which is the combined performance of both, particle swarm optimization (PSO) technique and Radial basis function neural network (RBFNN). The comparison results have proved that the proposed method is the most effective technique to reduce the THD, and to improve the efficiency and power factor compared to the others control and in [35] we show a good performance of a Radial Basis Function Neural Network (RBFNN).

Other researchers are interested to the synchronizing the grid photovoltaic systems in order to allow an adequate transfer of energy. A precise synchronization system is needed to estimate the grid voltage parameters that are voltage amplitude, frequency, and phase angle, as these values are needed for conducting an accurate control of the active and the reactive power delivered to the grid but synchronization system works as an oscillator at a fixed frequency. In order to inject the maximum power extracted to the photovoltaic system, while ensuring unit power factor operation, the angle of the network is estimated by a phase locked circuit (PLL) [36], [37] so that the network voltage must be on the quadrature axis.

Important research has done in literature to enhance the power quality of the grid connected PV system. There is lack of published to use an intelligent controller based on neuron network to control two-stage energy conversion system. The proposed intelligent control enhances the quality of the power injected to the grid and reduce the THD to a level low than the IEEE standard.

II. HYBRID PV-BATTERY SYSTEM CONNECTED TO THE GRID

Figure 1 shows the schematic diagram of a multi-sources PV system connected to the grid. Two-stage configuration is used and includes a boost converter, single phase inverter and the grid. The DC–DC converter along with an MPPT

controller are used to extract the maximum power from the PV module. Many MPPT methods have been proposed in literature to optimize the PVS power. In this paper an ANN (Artificial Neuron Network) already implemented has been used and the model of the PVS and the converter is done [38]. To control the injected current to in to the grid an intelligent controller is also used based on radial basis function neural network (RBFNN). And the energy management between the sources and the loads is done by an energy management system implanted to protect the batteries and also perform it lifetime. This system can be used in many applications and participate to enhance the energy mix in Senegal, where important policies have been developed to reduce the energy dependence by exploiting our renewable energy resources. the power of renewables energies (solar PV) in 2023 is 226 MWc in our electricity mix [39]. This an important step for Senegal for the energy transition and need to enhance this part in order to have a universal electricity until 2025 on of the government priority. In other hand, the management of energy helps building to optimize the consumption in line with energy management policies make place by Senegal. This study system is given below and has several applications and multiple sources, PVs, Storage, DC Loads, AC Load and Grid. The main objective of this work is to make place an energy management software to control the whole system.



Figure 1. Schematic diagram multi-sources connected photovoltaic system.

III. POWER OPTIMIZATION

A. MPPT based on ANN

Power optimization by Artificial Neural Network (ANN) Artificial intelligence is considered as the most appropriate control techniques through their coping capacities for nonlinear systems [40]. It is no longer limited to win championships ‘alpha GO’. There are many applications of artificial intelligence, which is used in the recognition systems, in the image processing, in the industries, etc.... In the present paper, we used ANN to control a converter to extract the maximum power of a photovoltaic panel. As in artificial intelligence technique, we used artificial neural

networks that are highly connected to networks of elementary processors operating in parallel. Each elementary processor calculates a single output based on the received information. Here, in our work we used multilayer perceptron (MLP) that better fit with the non-linear systems [41]. The neurons are connected in multiple layers and the signal goes from the input to the output layers

[42] and it has no interconnection between neurons of the same layer. We are going to go along with the following steps to design the network MLP artificial neurons. There are several steps to design the ANN in Matlab and all these steps are summarized in the Figure 2. The converter maintains continuously the PV panel operating at the MPP in order to extract the maximum power available for each variation of the environmental conditions.

B. RBFNN current controller for a single-phase inverter

An artificial neural network (ANN) is a massively parallel distributed processor inspired from biological neural networks, which can store experimental knowledge and make it available

basis functions and the output layer. The RBFNN output constituted k of is given by the

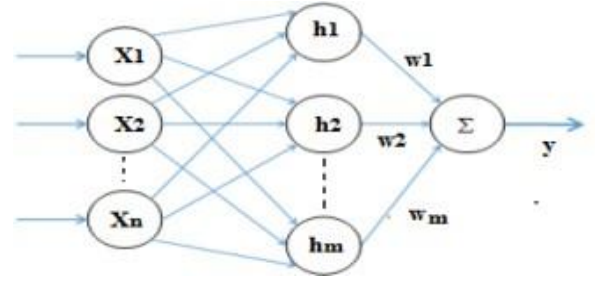


Figure 3. Radial Basis Function neural network architecture.

following equation [44]

$$Y = \sum_{i=1}^n \omega_i h_i - b \quad (1)$$

h_j is radial basis function is also taken to be Gaussian function [45], [46] and defined as follows:

$$h_m(x) = \exp\left(\frac{x - C_m}{1 - 2\beta_m^2}\right) \quad (2)$$

Where, k is number of neurons in the output layer m is number of neurons in the hidden layer

w is the weight of the network

x is the network input

c is the center vector of the m^{th} neuron

β_j is the spread parameter of the j^{th} neuron

The design procedure of the RBF neural network includes determining the number of neurons in the hidden layer. Then, in order to obtain the desired output of the RBF neural network β_j , C , m and ω parameters might be adjusted properly. This technic to adjust these parameters is called learning (or training) method. The Gradient Descent is commonly used [47][49] based optimization algorithm used for finding a local minimum of the function and minimize the error E.

$$E = \sum (t^k - s^k)^2 \quad (3)$$

Where y tilde is the desired output of the RNFNN and the updated equation of the weights can be expressed as following:

$$\Omega_{km} = \Omega_{km}(t+1) - \zeta \frac{dE}{d\Omega_{km}} \quad (4)$$

$$C_m = C_m(t+1) - \zeta \frac{dE}{dC_m} \quad (5)$$

Nowadays instead of conventional control and optimization methods, artificial intelligence techniques are rising for the

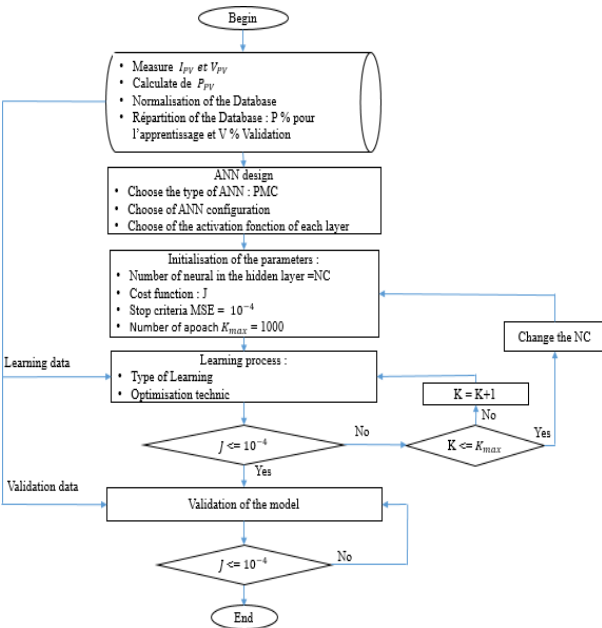


Figure 2. Algorithm of energy optimization.

for use. There are several different types of ANNs and multi-layer perceptron networks (MLPNN) and radial basis function neural network (RBFNN) is the most used. RBFNN network is a type of feed forward neural network composed of three layers, namely the input layer, the hidden layer and the output layer. Differing from MLPNN, Gaussian transfer function is employed in the neurons of hidden layer [43]. Figure 3 show the RBFNN architecture composed of the input layer, the hidden layer, with a high enough number of nodes (neurons) and each of these nodes performs a nonlinear transformation of the input, by means of radial

optimization and control of renewable power systems. They are improving efficiency of renewable power generation. To design an ANN, it is available to obtain a data base required for the training or learning task. Here, the RBFNN has been training by using the inputs and the outputs of a PI controller as show in figure 4.

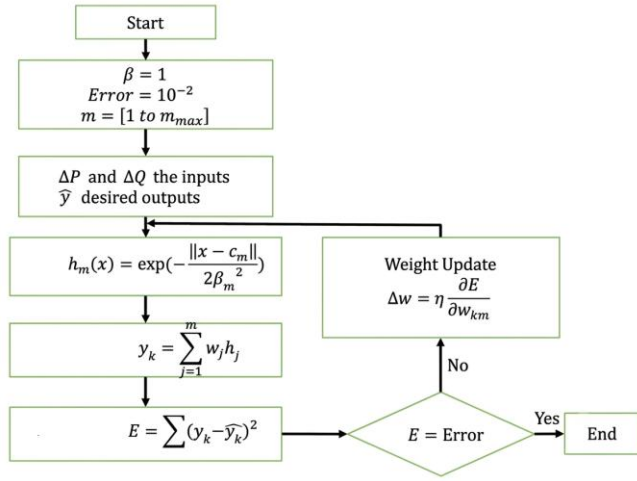


Figure 4. RBFNN flowchart.

The inputs are the errors of either active ΔP or reactive ΔQ current and during the learning step the RBFNN predicts the outputs of the PI controller.

To create the RBFNN the flowchart shown in figure 4 is implemented in matlab. The network is built up iteratively by adding a neuron at any time step, so on until the error falls into the expected limits. The parameters of artificial neuron are the spread β and the model performance is comparatively better with spread value of 1 [50]. The trained network was then tested for the prediction of the all data series providing a correct response with low error.

IV. ENERGY MANAGEMENT

The main objectif to develop an energy management is to ensure it repartition between the sources and the load. Depending on the different weather conditions, the system operates in one of the following modes Figure 5.

The structure of the energy management between the sources and the load is presented in figure 5. When the power available of the PV system is superior of the energy need by the load, the PV system feeds the load and charge the battery. In otherwise the battery is discharged and feeds the load.

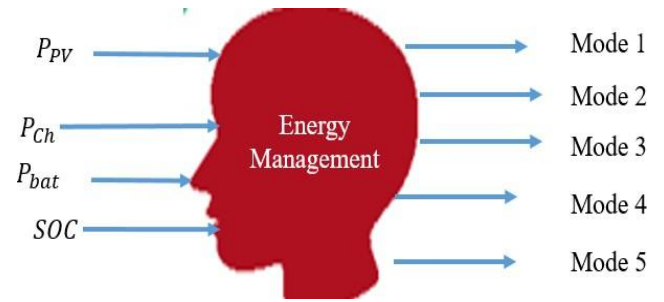


Figure 5. Energy management.

- Mode 1: If the power of the panels (P_{PV}) is equal to the load power (P_{Ch}) S1 is ON, S2 and S3 are off.
- Mode 2: If (P_{pv}) is higher than (P_{Ch}) and the Soc (State of charge) of the battery is between 20 % and 85% S1 is On, S2 is On and S3 is Off.
- Mode 3: If ($P_{PV} = 0$), there is no production from the PV panels and the Soc is between 20 % and 85 % le battery supplies the load S1, S2 are Off and S3 is On.
- Mode 4: If there is no production from the PV panel and the battery is discharged S1, S2, S3 are Off.
- Mode 5: If the PV system power is egal to zero (0), non-weather conditions, and the SOC of the battery is between 20 and 85 %, the batteries feed the loads S2 and S3 are connected.

The energy management method study with the whole multi sources system will be implemented in Matlab software. We present now the simulation results and evaluate the performance the controller and discuss the results.

V. SIMULATION RESULTS AND DISCUSSION

The system is described in figure 1 is implemented in Matlab/Simulink. The proposed technics of the whole system are analyzed by using the sunshine shown in figure 6 and 7 and they performances were analyzed. To evaluate the performance of the ANN MPPT in partial shading conditions and it is compared to a classical InC MPPT.

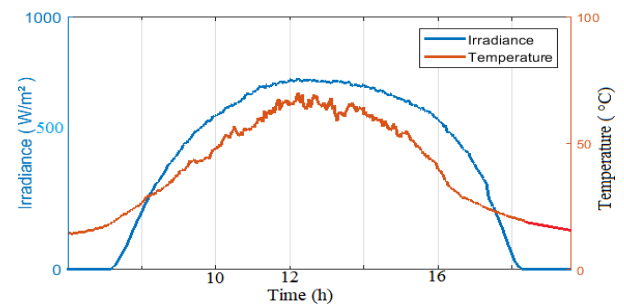


Figure 6. Mars Sunshine characteristics.

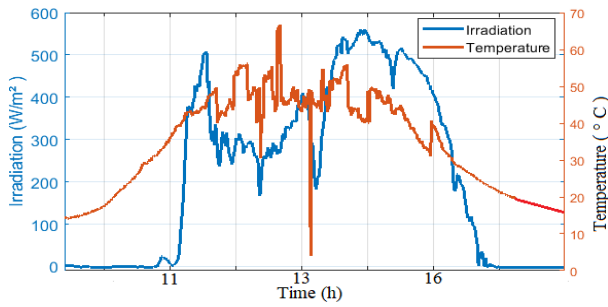


Figure 7. August Sunshine characteristics.

A. Power optimization

The simulations results are summarizing in two steps: optimization power and the repartition of the power between the different sources to the load.

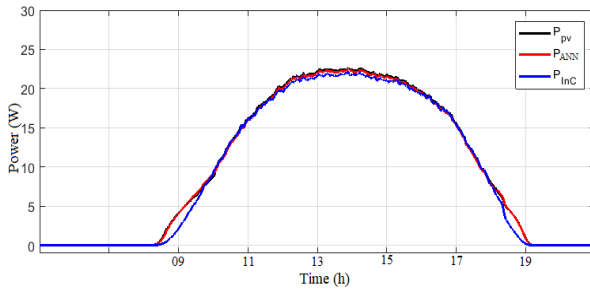


Figure 8. Power generated by PV in March.

As shown in Figure 8 and 9 we noted that the proposed methods show a good prediction of the power for different weather variations. For a variation of sunshine, as illustrated in Figure 8, the power of the ANN controller is about 34 W for solar panel. ANN and InC exhibit very good performance to track the MPP. ANN MPPT predicts the power of the panel with high rapidity; accuracy and few oscillations compared to the InC MPPT. The statistics analysis like the RMSE (Roots Mean Square Error), the MAE (Mean Absolute Error) and the MAPE (Mean Absolute Percent Error) [51] for each controller are plotted in Figures 10 and 11. These results show that the ANN control has a low RMSE and both the MAE and

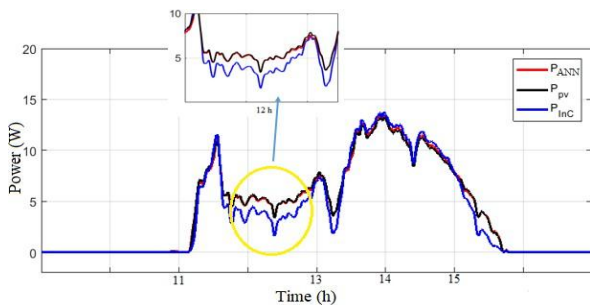


Figure 9. Power generated August.

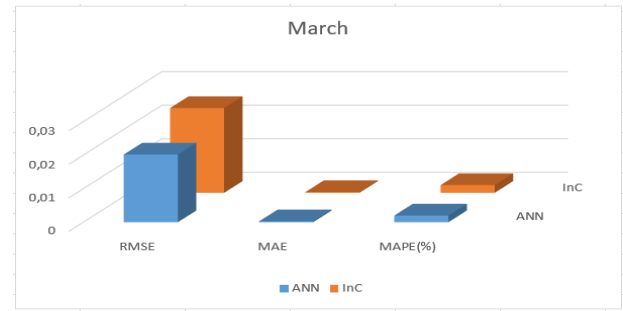


Figure 10. Statical tests.

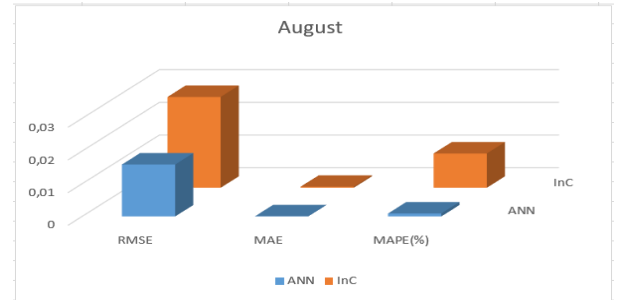


Figure 11. Statical tests.

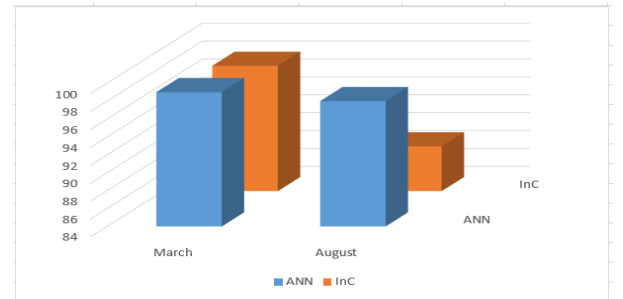


Figure 12. Yield (%).

MAPE give low values compared to the INC command. MAPE helps us to verify if the predicting model results fit the results of the practical design or not. Usually, smaller values for MAPE indicate a better fitting model. Therefore, the ANN achieves lower values compared to InC controllers as shown in Figures 10 and 11. Figures 12 evaluate the yields of the two MPPT controller in no-uniforme weathers conditions. For a sudden variation of the climatic conditions, the adaptive controller based on ANN give better performance and is most robuss than the InC MPPT controller.

B. Inverter control

The regulation of the DC link is made by using a classical PI controller in order it follow the reference voltage. Similarly for the current control two methods are used, a classic PI and an intelligent based on RBFNN controllers.

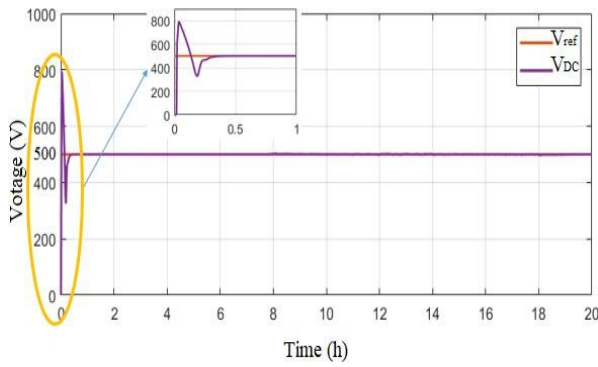


Figure 13. The output voltage tracking of the boost converter with PI.

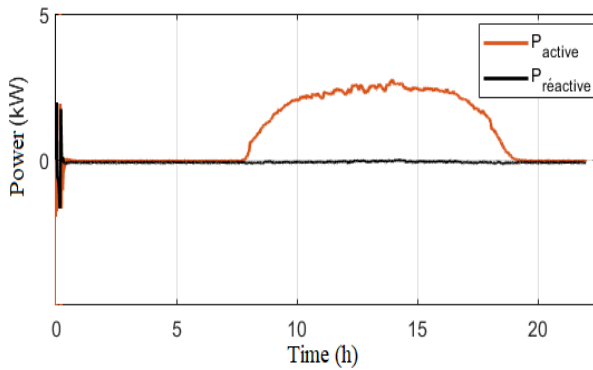


Figure 14. Active and reactive power with PI and RBFNN in partial shading condition.

TABLE 1: CURRENT QUALITY.

Corrector	THD
PI	2.04 %
RBFNN	1.84 %

We show in figure 13 that the regulated DC link voltage is done, it is maintained at the constant value $V_{ref} = 500V$ for each sunshine variation with the PI controller. According to

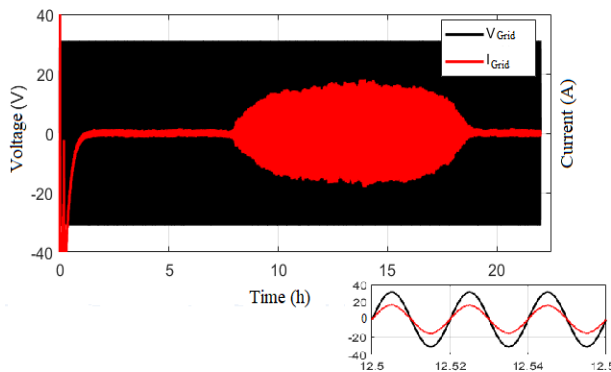


Figure 15. Injected current and grid voltage.

TABLE 2: PERFORMANCE STUDY

Corrector	Response time (ms)	Overshoots
PI	6	80
RBFNN	2	20

The statements listed above, the photovoltaic output waveform output track the reference.

Hence, Figure 14 show the active and reactive power exchange and the grid power factor is maintained unity by sustaining the reactive power is zero. This unity power factor is confirmed by as shown in figure 15 where the injected grid current is in phase with grid voltage. An analysis is done to evaluate the injected current quality of the proposed controllers. For variable irradiation, the current THD of the system is plotted while employing PI and RBFNN controller. The THD Table I of current using different controllers lie below 5 % of the IEEE standard and we found 1.84 and 2.04 % respectively for the PI and the RBFNN. The result shows that the proposed method gives a low THD unlike the RBFNN proposed in the reference

[52] where the author obtained a THD of 2.72 % larger than our result. Table II shown the robustness of the RBFNN in partial shading condition and it has a fast response time and low oscillations. Optimization of the energy produced by the sources will be followed by good communication between them to ensure control of energy needs. Next, we will set up a system for managing the energy produced by the sources.

C. Energy management

The figure 16 show the powers variations during the simulated day. The figure 17 and 18 indicate the state of charge of the battery and the switch mode of the converters (Boost and Buck-Boost) and the operate in complimentary mode. By comparing the switching times with the power variation curve, it is possible to evaluate the ability of the control algorithm to perform the energy management of the system according to the variations of the sources and of the demand

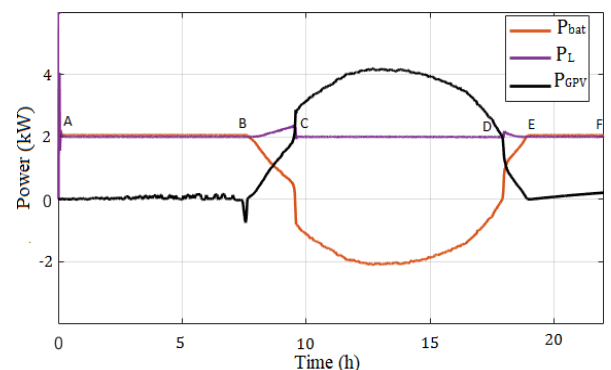


Figure 16. Power management between the sources.

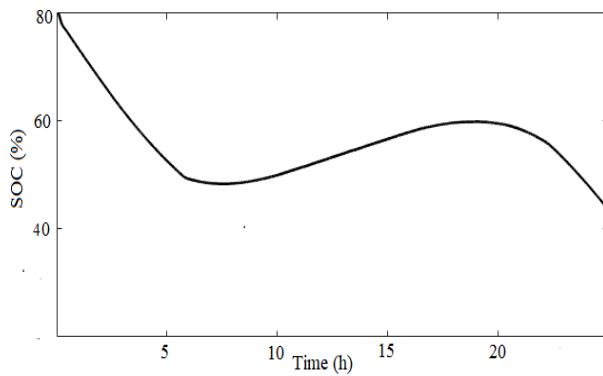


Figure 17. State of Charge.

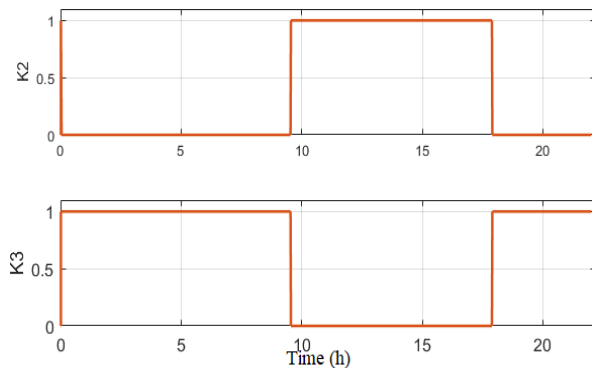


Figure 18. Operation switch of the buck-boost converter.

- From 0:00 to 8h, there is no sunlight yet, only the battery supplies the load: the buck-boost converter operates on mode boost S1 and S2 are OFF and S3 is ON;
- From 8h to 10h, the solar panels start to produce but the power delivered is still lower than that requested by the load and the battery discharge to complete the to the required power the buck-boost converter operate in mode boost S2, S2 and S3 are ON;
- From 10h to 17h, the solar panels produce more than they consume charge, the excess is used to charge the battery the buck-boost converter operate in mode buck S1, S2 is and S3 are OFF;
- From 17h to 18h, solar illumination decreases and photovoltaic power is found lower than that of the load, the battery discharge converter operates in mode boost S1 is Off and S2 and S3 are ON;
- From 17h to 23h, there is no more sunlight, only the battery supplies the load converter operate on mode boost S1 is off and S2 and S3 are ON.

One of the currents priorities is to make rational use of energy through optimal use. The developed energy management method shows a uniform distribution of energy between sources and also allows the protection of the storage system.

VI. CONCLUSION

The management of energy is now developed in many contries due it advantages to reduce the dire energy loss. In building, the use of renewable energy is a main key to satisfy the energy consumption in tropical area. The In this study, an energy management and control of a multi- sources PV system is designed and studded. To enhance energy production, adaptatives controllers are used to track the MPP in no uniform weathers conditions and compared to a classical method. The simulation results show the aptitude of the algorithm to follow the variations of the environment and ensure the energy management between the sources. In the future, we will test this energy management controller in the whole months of the year.

ACKNOWLEDGMENT

Many thank for the physic department of Alioune Diop University for the data.

REFERENCES

1. Bajpai, P., & Dash, V. (2012). Hybrid renewable energy systems for power generation in stand-alone applications: A review. *Renewable and Sustainable Energy Reviews*, 16, 2926–2939.
2. Ba, A., Ndiaye, A., Traore, M., & Mbodji, S. (2020). Energy situation of Senegal: Sub-sector of electricity. *SOAPHYS*, 2, 1–5.
3. Aidarai, M. C., Fam, A., et al. (2023). Contribution to the building of a weather information service for solar panel cleaning operations at Diass plant (Senegal, Western Sahel). *De Gruyter*, 15, 2–12.
4. Mahalakshmi, R., & Thampatty, K. (2015). Grid connected multilevel inverter for renewable energy applications. *Procedia Technology*, 21, 636–642.
5. Hasan, R., Mekhilef, S., Seyedmahmoudian, M., & Horan, B. (2017). Grid-connected isolated PV microinverters: A review. *Renewable and Sustainable Energy Reviews*, 67, 1065–1080.
6. Islam, M., Mekhilef, S., & Hasan, M. (2015). Single-phase transformerless inverter topologies for grid-tied photovoltaic systems: A review. *Renewable and Sustainable Energy Reviews*, 45, 69–86.
7. Mohamed, A. A., Metwally, H., El-Sayed, A., & Selem, S. (2019). Predictive neural network based adaptive controller for grid-connected PV systems supplying pulse-load. *Solar Energy*, 193, 139–147.
8. Lakshmi, M., & Hemamalini, S. (2016). Decoupled control of grid connected photovoltaic system using fractional order controller.
9. Ba, A., Ndiaye, A., Ndiaye, E. H. M., & Mbodji, S. (2023). Power optimization of a photovoltaic system with artificial intelligence algorithms over two seasons in tropical area. *MethodX*, 10.
10. Traore, M., Ndiaye, A., Ba, A., & Mbodji, S. (2020). Adaptive proportional integral controller based on ANN for DC link voltage control of a single-phase inverter connected to the grid. *Journal de Physique de la SOAPHYS*, 2, 1–6.

11. Ndiaye, E. H. M., Ndiaye, A., & Faye, M. (2019). Design and implementation of a hybrid neuro-fuzzy corrector for DC bus voltage regulation. *EAI Endorsed Transactions on Energy Web*, 1–9.
12. Jayachandran, M., & Ravi, G. (2020). Predictive power management strategy for PV/battery hybrid unit based islanded AC microgrid. *International Journal of Electrical Power & Energy Systems*, 110, 1–9.
13. Rakhtala, S., & Roudbari, E. S. (2016). Fuzzy PID control of a stand-alone system based on PEM fuel cell. *International Journal of Electrical Power & Energy Systems*, 576–590.
14. Rai, N., & Rai, B. (2018). Control of fuzzy logic-based PV-battery hybrid system for stand-alone DC applications. *Journal of Electrical Systems and Information Technology*, 5, 135–143.
15. Abo-Elyousr, F. K., & Abdelaziz, A. Y. (2018). Optimal PI microcontroller-based realization for technical trends of single-stage single-phase grid-tied PV. *Engineering Science and Technology, an International Journal*, 945–956.
16. Gueye, D., Ndiaye, A., Tankari, M. A., Faye, M., Thiam, L. T. A., & Lefebvre, G. (2018). Design methodology of novel PID for efficient integration of PV power to electrical distributed network. *International Journal of Smart Grid*.
17. Zeb, K., Uddin, W., Khan, M. A., Ali, Z., Ali, M. U., Christofides, N., & Kim, H. (2018). A comprehensive review on inverter topologies and control strategies for grid connected photovoltaic system. *Renewable and Sustainable Energy Reviews*, 1120–1141.
18. Mishra, S., & Achary, B. S. (2014). A novel controller for a grid connected single phase PV system and its real-time implementation. In *IEEE Conference Proceedings*.
19. Revana, G., & Kota, V. R. (2019). Simulation and implementation of resonant controller-based PV fed cascaded boost-converter three-phase five-level inverter system. *Journal of King Saud University – Engineering Sciences*.
20. Andishgar, M. H., Gholipour, E., & Hooshmand, R. (2017). An overview of control approaches of inverter-based microgrids in islanding mode of operation. *Renewable and Sustainable Energy Reviews*, 1043–1060.
21. Lakshmi, M., & Hemamalini, S. (2018). Decoupled control of grid connected photovoltaic system using fractional order controller. *Ain Shams Engineering Journal*, 9, 927–937.
22. Barra, K., & Rahem, D. (2014). Predictive direct power control for photovoltaic grid connected system: An approach based on multilevel converters. *Energy Conversion and Management*, 825–834.
23. Chatterjee, A., Mohanty, K., Kommukuri, V. S., & Thakre, K. (2017). Power quality enhancement of single-phase grid tied inverters with model predictive current controller. *Journal of Renewable and Sustainable Energy*.
24. Rakhtala, S., & Roudbari, E. S. (2016). Fuzzy PID control of a stand-alone system based on PEM fuel cell. *International Journal of Electrical Power & Energy Systems*, 576–590.
25. Sukumar, S., Marsadek, M., Ramasamy, A., Mokhlis, H., & Mekhilef, S. (2017). A fuzzy-based PI controller for power management of a grid-connected PV-SOFC hybrid system. *Energies*.
26. Rajeswari, R., Venkatesan, M., & Deverajan, N. (2015). A fuzzy logic-based three-phase inverter with single DC source grid-connected PV system employing three-phase transformer.
27. Shanathi, B., Natarajan, S., & Anbukodi, S. Fuzzy control for single-phase multilevel inverter.
28. Abadlia, I., Bahi, T., Lekhchine, S., & Bouzeria, H. (2016). Active and reactive power neurocontroller for grid-connected photovoltaic generation system. *Journal of Electrical Systems*, 146–157.
29. Singh, M., Ugender, M., & Bhavani, M. D. (2014). Performance of micro-grid connected hybrid photovoltaic/fuel cell with ANN control to improve the power quality. *Advanced Science and Technology Letters*, 75–82.
30. Traore, M., Ndiaye, A., Ba, A., Ngom, I., & Mbodji, S. (2021). Adaptive control of single-phase DC/AC converter for grid connected photovoltaic applications. In *IEEE Conference Proceedings* (pp. 2421–2425).
31. Sairam, P., & V., S. (2015). Implementation of artificial neural network-based closed loop control for a cascaded H-bridge multilevel inverter. *International Journal of Research in Engineering & Technology (IJRET)*, 3, 1–10.
32. Jamma, M., Bennassar, A., Barara, M., & Akherraz, M. (2017). Advanced direct power control for grid-connected distribution generation system based on fuzzy logic and artificial neural networks techniques. *International Journal of Power Electronics and Drive Systems (IJPEDS)*, 8, 979–989.
33. Sujatha, B., & Anitha, G. (2018). Enhancement of power quality in grid-connected PV system using hybrid technique. *Ain Shams Engineering Journal*, 9, 869–881.
34. Deshmukh, V., & Patil, A. (2015). Comparison and performance analysis of closed-loop controlled nonlinear system connected PWM inverter based on hybrid technique. *Journal of Electrical Systems and Information Technology*, 2, 86–98.
35. Kaushal, J., & Basak, P. (2020). Power quality control based on voltage sag/swell, unbalancing, frequency, THD and power factor using artificial neural network in PV integrated AC microgrid. *Sustainable Energy*.
36. Arulkumar, K., Palanisamy, K., & Vijayakumar, D. (2016). Recent advances and control techniques in grid-connected PV systems: A review. *International Journal of Renewable Energy Research*, 6, 1038–1049.
37. Ahmeda, T. S., Idir, H., Mohamed, E. G., & Scipioni, A. (2015). Direct components extraction of voltage in photovoltaic active filter connected in a perturbed electrical network (based on robust PLL algorithm). In *International Conference on Technologies and Materials for Renewable Energy* (pp. 966–972).
38. Ba, A., Ndiaye, A., & Mbodji, S. (2020). Supervision strategy of a hybrid system PV with storage for injection to the electrical network. *Springer Proceedings*, 321, 134–145.
39. Aidara, M. C., Fam, A. P. A., Danso, D. K., et al. (2023). Contribution to the building of a weather information service for solar panel cleaning operations at Diass plant (Senegal, Western Sahel). *De Gruyter*, 15, 1–12.
40. Ye, Z., Yang, J., Zhong, N., Tu, X., Jia, J., & Wang, J. (2019). Tackling environmental challenges in pollution control using artificial intelligence: A review. *Science of the Total Environment*, 1–78.
41. Bouarroudj, N., Boukhetala, D., Feliu-Batlle, V., Boudjema, F., Benlahbib, B., & Batoun, A. (2019). Maximum power

- point tracker based on fuzzy adaptive radial basis function neural network for PV systems. *Energies*, 12, 2–19.
42. Wang, R., Li, D., & Miao, K. (2020). Optimized radial basis function neural network-based intelligent control algorithm of unmanned surface vehicles. *Journal of Marine Science and Engineering*, 8, 2–13.
 43. Hamdi, H., Regaya, C. B., & Zaafour, A. (2019). Real-time study of a photovoltaic system with boost converter using the PSO-RBF neural network algorithms in a MyRio controller. *Solar Energy*, 183, 1–16.
 44. Kopal, I., Hláčková, M., Vojáček, J., Krmela, J., & Lukáč, O. (2019). Radial basis function neural network-based modeling of the dynamic thermo-mechanical response and damping behavior of thermoplastic elastomer systems. *Polymers*, 11, 2–20.
 45. Zhang, T., Lv, C., Ma, F., Zhao, K., & Wang, H. (2020). A photovoltaic power forecasting model based on dendritic neuron networks with the aid of wavelet transform. *Neurocomputing*, 397, 438–446.
 46. Chandra, S., & Gaur, P. (2020). Radial basis function neural network technique for efficient maximum power point tracking in solar photovoltaic systems. *Procedia Computer Science*, 167, 2354–2363.
 47. Kasiviswanathan, K., & Agarwal, A. (2012). Radial basis function artificial neural network: Spread selection. *International Journal of Advanced Computer Science*, 2, 394–398.
 48. Tahir, S., Wang, J., Baloch, M. H., & Kaloi, G. S. (2018). Digital control techniques based on voltage source inverters in renewable energy applications: A review. *Electronics*, 18, 2–37.
 49. Athari, H., Niroomand, M., & Ataei, M. (2017). Review and classification of control systems in grid-tied inverters. *Renewable and Sustainable Energy Reviews*, 72, 1167–1176.
 50. Xie, K., Hu, G., Yi, H., Lyu, Z., & Xiang, Y. (2017). A novel digital control method of a single-phase grid-connected inverter based on a virtual closed-loop circuit and complex vector representation. *Energies*, 10, 2–14.
 51. Yousif, J. H., Kazem, H. A., Alattar, N. N., & Elhassan, I. I. (2019). A comparison study based on artificial neural network for assessing PV/T solar energy production. *Case Studies in Thermal Engineering*, 13, 100407.
 52. Marmouh, S., Boutoubat, M., & Mokrani, L. (2018). Performance and power quality improvement based on DC-bus voltage regulation of a stand-alone hybrid energy system. *Electric Power Systems Research*, 163, 73–84.