Nanotechnology Perceptions
ISSN 1660-6795
www.nano-ntp.com

Analyzing PV power systems using MPPT based on Artificial Neural Networks

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By burning fossil fuel for electricity and transportation, we are contributing to change of climate and global warming, which are uncontrollable global challenges today. As a global society, most wealthy countries focus on the generation of new resources and on investing heavily in research and development. Wind, solar, and hydropower are all alternatives to traditional energy sources. The abundance of solar power in nature has made it one of the most popular alternative energy sources today. In this article, we examine how different weather conditions affect photovoltaic cells as a source of energy. Our research led to the development of an intelligent controller system for tracking the peak power point of a system. Renewable energy sources require a MPPT controller during certain seasons due to the variability of weather conditions. As the theme of this paper is to provide a model for the efficient integration of solar systems into existing power grids. In order to fulfill that intention, the formulation of the model is based Artificial Neural Networks (ANNs) with maximum power point tracking (MPPT) and has been simulated with the help of MATLAB. As part of the integration of photovoltaic energy into micro grids, a control system using an artificial neural network is developed that improves power quality and reduces THD.

Keywords: Artificial Neural Network, Microgrid integration , Maximum power point tracking, PV energy system.

1. Introduction

Climate change has become an increasingly significant issue in the last decade, and its consequences pose a serious threat to life on Earth. As a result of unpredictable gasoline prices, as well as the effects on the environment of widespread fuel consumption, experts are beginning to focus their attention on alternative energy and renewable energy (RE). Despite its low price and easy availability, a very significant contribution to the Energy development based on renewable resources been a part of development of photovoltaics(PV). Electricity grids in most of the countries have been integrated with renewable energy sources, leading to the development of microgrids (MGs) and smart grids. It is important to note that MGs encompass a wide range of concepts, this includes active power transmission and distribution networks as well as flexible loads, improved controllers, and self-repairing technologies. WT and PV reproductive technologies are being used to extend development of renewable energy sources, in order to reduce the cost of program. In addition, solar photovoltaic technology may be considered to be one of the most widely adopted and integrated technologies. The electrical energy from renewable sources such as wind energy and solar energy will be reduced rapidly at a lower cost than electricity(Alahmadi et al., 2021). In terms of financial symptoms, several factors can affect the strength effectively, Producers of WT and PV technologies, including their size, properties, and characteristics. For example, the cost of electric power in thermal power plants, the indicator of electricity, and the loss of energy depend on the size, properties, and characteristics of the producers of WT and Photovoltaic technologies(Christy, Mukundan, et al., 2018). In conjunction with the design of a model predictive control, a major research challenge is addressing how to optimize hybrid power systems in the context of the smart power grid framework. To reduce the industrial electricity consumption, strategy focusing to maximize the utilization of renewable energy, such as PV systems with battery storage(Ab-Belkhair et al., 2020). Solar energy storage for commercial buildings is specifically explored. Together with their technologies into microgrid energy coordination applications, the microgrid grid environment is meant to provide energy stability between generator and transmitter by collaborating with their technologies into microgrid energy coordination applications.

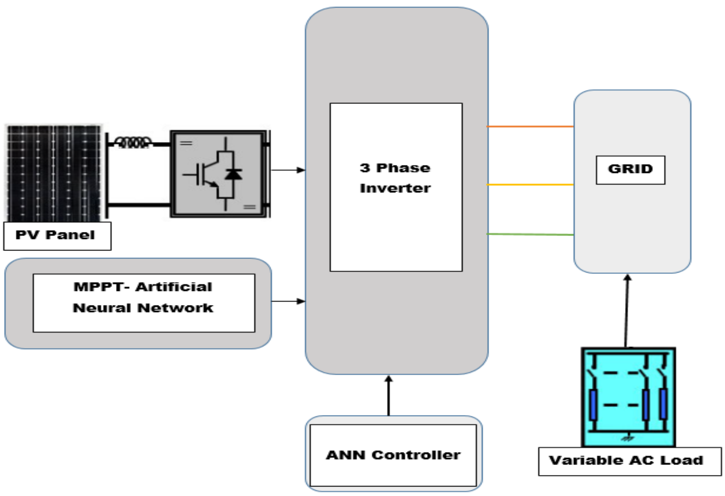

Figure 1. Artificial Neural Network based control of solar PV system based on a block diagram

Literature discusses the worldwide energy demand scenario and the integration of renewable energy resources, with solar photovoltaic and storage capacity of batteries being a most prevalent technologies. In the microgrid, the model predictive regulator controls power flow in tie lines and frequency fluctuations, achieving a power balance between demand of active power demand and generation of active power. A novel artificial neural network approach is presented in this paper for overcoming such problems in photovoltaic power generation systems, as shown in Figure 1. A major strength of this article is its use of Artificial Neural Networks in order to develop and model an algorithm for calculating a maximum power of a solar PV energy system, as well as analyzing its performance under different weather conditions. The design of an Artificial Neural Network-based voltage source controller for synchronization of microgrids and photovoltaic systems.

2. PV MODULE MODELLING

Solar cell is a semiconductor device that absorbs solar energy and converts that energy into electricity via a P-N junction. Photovoltaic cells produce a modest amount of power(Sedaghati et al., 2012). To create and market PV modules, series and parallel connections are used. Simulating a PV module with MATLAB-Simulink can be done through a mathematical model(Bouzidi et al., 2022). Figure 2 illustrates how KCL is used to calculate the PV cell's output current using equation (1).

$$\mathrm{Ipv} = \mathrm{Iph} - \mathrm{ID} - \mathrm{Ish} \tag{1}$$

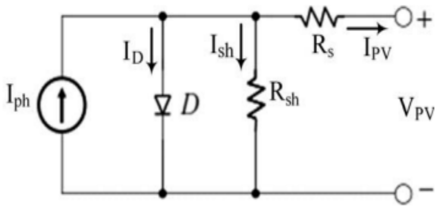

Figure 2. Mathematical model of Photovoltaic system

Photovoltaic cells produce an output current known as I_{PV}(J & SY, 2018). The current through a photovoltaic cell is Iph. In an electrical circuit, the current going through a diode is ID, and the current going through a shunt resistor is Ish. The equation can then be expressed as follows for a Photovoltaic module made up of parallel and series cells(Khan et al., 2021).

$$\begin{aligned} I_{pv} &= N_p I_{ph} - I_D - I_{sh} \\ &= N_p I_{ph} - N_p I_0 \left[\exp\left(\frac{q(V_{pv} + R_s I_{pv})}{N_s A K T} \right) - 1 \right] \\ &\quad - \frac{V_{pv} + R_s I_{pv}}{R_{sh}} \end{aligned} \tag{2}$$

where Io refers to reverse saturation current, Vpv is output voltage of the PV module(Christy, Manikandan, et al., 2018), Ns and Np are number of cells in series and parallel respectively, Rs and Rsh are series and parallel resistances respectively, q is electron charge ($1.602 \times 10{-}19$ C), A is diode ideality factor ($1 < A < 2$), K is Boltzm Artificial Neural Network constant ($1.38 \times 10{-}23$ J/K) and T is cell temperature.

2.1 Maximum Power Point Tracking System

In PV applications, MPPT algorithms are very crucial since MPP varies with temperature and irradiation of the sun(Ortiz et al., 2022). Maximizing the efficiency of a solar array, MPPT hill climbing algorithms should be used. MPPT controllers perturb current I(k) and voltage V(k) of the photovoltaic array and in order to acquire fresh power values. It is not necessary to make manual adjustments since the setup is automated. Therefore, P(k) will be compared to P(k-1) and dP/dV feedback will be provided to the controller. Increasing power increases operating voltage, and vice versa(Hossain et al., 2016). In the event that feedback results in a null value, the global MPP is reached(Guo et al., 2011). Flow chart for Perturb & Observe (P&O) (Sathish kumar.A et al., 2023) algorithm shown in Figure 3. DC-DC converters are switched by duty cycles generated by MPPT controllers. It is the gate of the MOSFET that receives the switching signal.

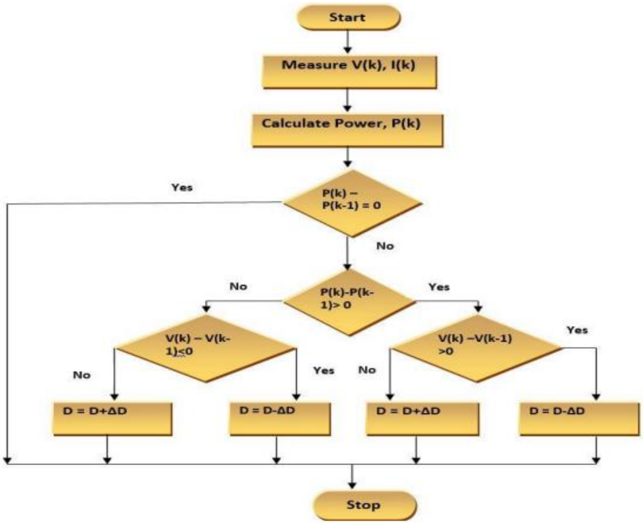

Figure.3 A flowchart of the Perturb & Observe (P&O) algorithm

3. ARTIFICIAL NEURAL NETWORKS SYSTEM

An effective way to map a nonlinear function between input and output is to use a neural network. It is necessary to train the neural network before it is used in to the PV system. Using a cascading neural network technique, we have proposed a design that incorporates a cascading neural network technique that will be able to predict the voltage at which the PV array will produce the maximum amount of power. A hidden layer of these devices works in a similar way to the neurons in our brain in that they have a nonlinear relationship between the inputs and outputs(Shanthi, 2018). As shown in Figure 4, power from the grid and boost converter error are input parameters to the hidden layer. After that, the signal will be sent to layer 1, where 10 neurons will be synthesized with weights, to produce a tangent sigmoid transfer function, which will be sent back to layer 2. By using the output of layer 1, layer 2 assigns weight to the values and uses another set of 10 neurons to generate a pure linear transfer function based on the weights assigned by layer 1. It is done by using a relational operator to add to the output signal the sine and cosine components contained in the array voltage(Haseeb et al., 2021). As a result of the relational operator, a binary output is generated, which is responsible for generating the duty cycle for switching inverters.

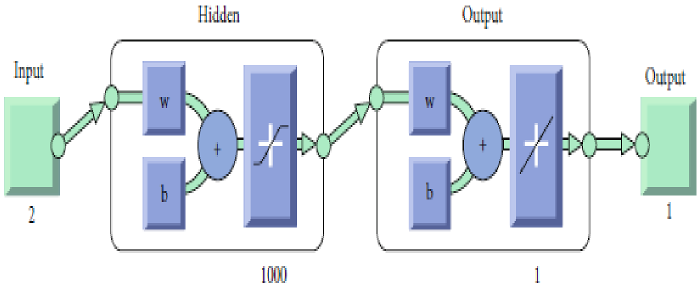

Figure 4. Artificial neural networks are used to model the PV-MPPT system

4. DEVELOPED A MODEL OF A BOOST CONVERTER BASED ON ANN

As illustrated in figure 5, a MPPT algorithm based on an ANN has been developed to reduce a precarious care of solar power systems and balance output power issues. PV systems are optimized by using an algorithm based on ANN for MPPT in order to improve their performance (Sabir Messalti et al., 2017). Neural network technique uses a more number of interconnected processors known as neurons(Villegas-Mier et al., 2021). Signals are transformed by neurons by a large number of weighted links. In this way, which is capable to managing a challenging task of processing and interpreting data. As hidden layers in this model, logging purelin and purelin activation functions are used with a feed forward back propagation ANN(Journal et al., 1998). During the offline step, Artificial Neural Networks are trained depending on the structure and algorithm of their activation functions. For the online step, the MPPT is tracked using the trained artificial neural network using MPPT. An artificial neural network is used for MPPT to adapt to solar radiation conditions and to derive power from PV array voltages and power derivations derived from the PV array voltages. In the table below, we summarize the basic principles of artificial neural networks based MPPTs, whose output reflects a normalized duty cycle (+1, 0, -1).

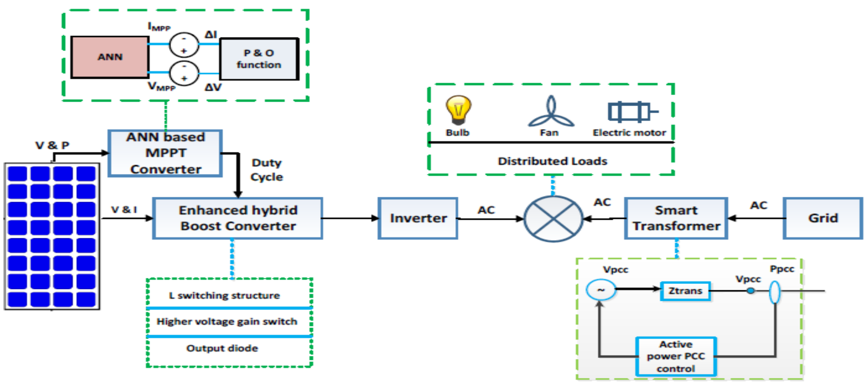

Figure 5. Development of a boost converter and MPPT model based on ANN

Table 1. MPPT controller based on Artificial Neural Networks.

vd	pd	pd/vd	Duty cycle
-1	-1	-1	D(n) = D(n - 1)
-1	+1	+1	
+1	+1	-1	
+1	-1	+1	

4.1 A Simulink model of MPPT based on Artificial Neural Networks

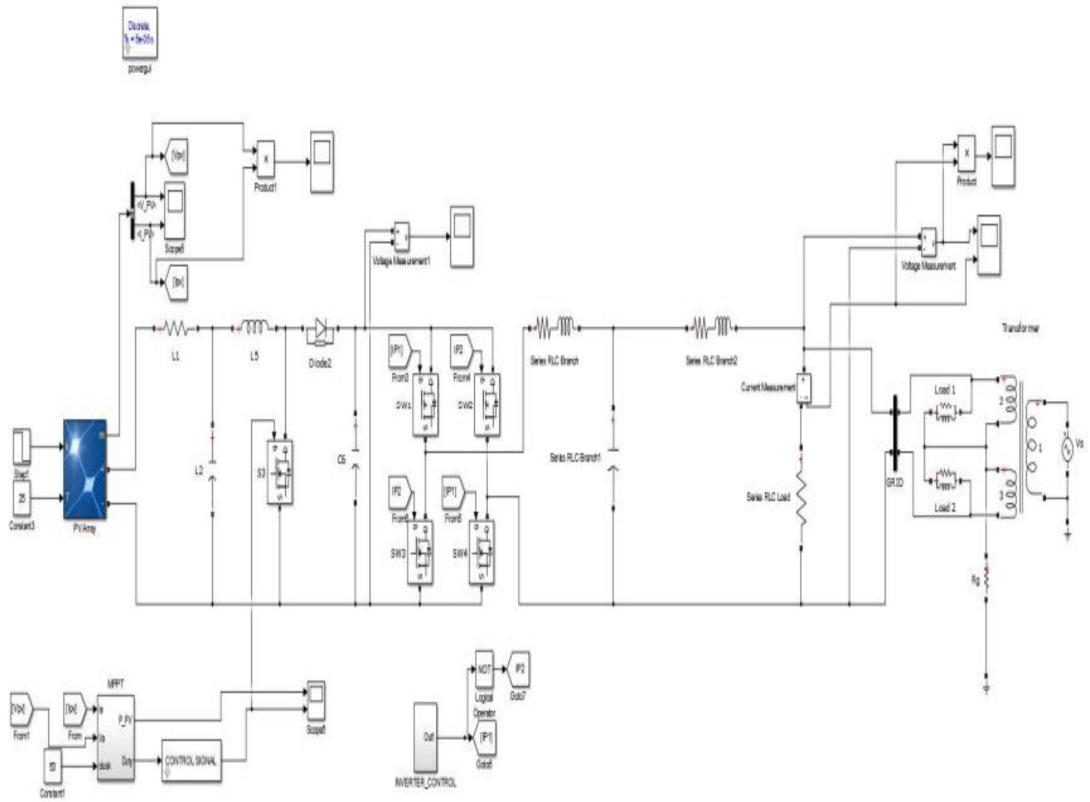

Figure 6. Artificial neural network based on MPPT circuit for solar photovoltaic cells

4.2 Enhanced Hybrid Single Phase Boost Converter Analytical Modelling

A new single phase boost converter is presented in this paper, which replaces the inductor with two inductors and three diodes, resulting in high gain and efficiency. A factor of (d + 1) is also added to the gain of the proposed converter in comparison to the traditional boost converter(Kumar et al., 2019). As shown in Figure 7, we assume that all components of the enhanced single phase DBC are lossless. In addition, all outputs and inputs are assumed to be pure Direct current signals for mathematical modeling. The voltage appropriate the inductor is determined by the voltage of input and Voltage of output when these conditions are met. It is estimated that the voltage across the inductor during ON and OFF times is as follows:

$$T_{ON} : V_L = V_{IN} \quad (3)$$

$$T_{OFF} : V_L = (-V_{0UT} - V_{IN})/2 \quad (4)$$

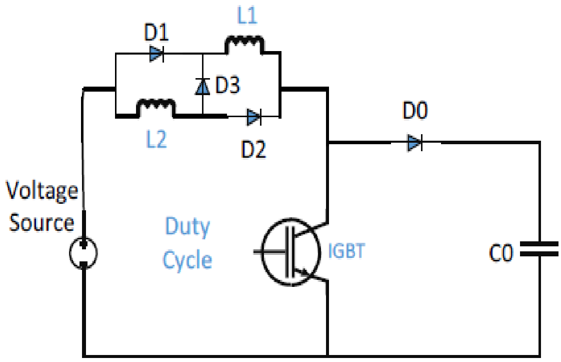

Figure 7. Enhanced Single Phase Developed boost converter

With the above formula, it can be seen that, positive voltage crosses the inductor when the switch is ON mode and it is in the OFF state, the voltage across inductor is a negative. The voltage of the inductor will have the same positive and negative areas. Calculating the output voltage from the above conditions is as follows:

$$V_{OUT} = \frac{1+d}{1-d}.V_{IN} \qquad d = \frac{T_{ON}}{T_P},\ 1-d = \frac{T_{OFF}}{T_P} \tag{5}$$

A solar module's input current and the switch's duty cycle determine the inductor's average current

$$\text{ILAV} = \frac{\text{IIN}}{1+\text{d}} \tag{6}$$

When determining the value of the inductor and capacitor in a circuit, a number of factors must be taken into account. A converter's output voltage and input voltage, as well as its maximum output power, should all be considered. Hence, from these parameters it is possible to calculate the input current and average inductor current based on the average inductor current. To determine an inductor's value, you can use the input and output voltages and duty cycle:

$$L_1 = L_2 = \frac{V_{IN} \cdot T_{ON}}{\Delta I_L} \tag{7}$$

$$L_1 = L_2 = \frac{V_{OUT} \cdot T_P}{\Delta I_L} \cdot \frac{d.(1-d)}{1+d} \tag{8}$$

Voltage variation is a very important factor in determining the capacitor capacity dimension because capacitors produce an AC voltage that overlaps with DC voltage.

$$C_{IN} = \frac{I_c \cdot T_{ON}}{\Delta \cdot V_c} \tag{9}$$

$$C_{IN} = \frac{I_{LAV} \cdot T_P}{\triangle \cdot V_{INmax}} \cdot d \cdot (1-d) \tag{10}$$

A capacitor's maximum voltage variation must be considered when selecting an output capacitor. This equation can be used to calculate the capacitor's current time area based on duty cycle and output current

$$C_{OUT} = \frac{I_{OUT} \cdot T_P \cdot d}{\triangle V_{OUTmax}} \tag{11}$$

$$C_{OUT} = \frac{I_{LAV} \cdot T_P}{\triangle V_{OUTmax}} \cdot d \cdot (1-d) \tag{12}$$

Depending on the percentage of the duty cycle at which an inductive current is averaged and the maximum variation in inductive current, a capacitor's output current will differ. So the output current will be

$$I_{INC} = I_{LAV}\sqrt{d \cdot (1-d) + \left(\frac{\triangle \cdot I_{Lmax}}{I_{LAV}}\right)^2 \cdot \frac{d^2 \cdot (1-d)^3}{12 \cdot (1+d)^2 (3 - 2 \cdot \sqrt{2})}} \tag{13}$$

5. SIMULATION RESULT AND DISCUSSION

A Matlab platform is used to simulate the PV system. Simulations are run under a variety of weather circumstances, including constant and uniform irradiance, quickly fluctuating irradiation, and partially shaded or non-uniform radiation. In the proposed model, an artificial neural network and a DBC-based MPPT are employed in order to improve productivity and performance. We are comparing the findings of the proposed model with those of a traditional boost converter that is driven by ANN and a proposed DBC that is driven by ANN. According to the results of the proposed model, in comparison to the output power produced by a typical boost converter based on AN N, the MPPT of a boost converter MPPT based on an ANN produces smooth output power. Matlab/Simulink software was used to analyze the proposed model. In order to gather the necessary information, a number of factors are taken into account, for example short circuit currents, current temperatures, maximum power levels, open circuit voltages, maximum voltages and voltage temperatures as well as standard irradiances, standard temperatures, maximum currents, maximum voltages, and maximum current, based on the given temperature and irradiance An artificial neural network uses input variables such as irradiance and temperature to generate a voltage output to determine the MPPT's current and power. This is accomplished by multiplying the input voltage and current by their corresponding V-I characteristics.

Artificial neural networks use a technique that is based on separating the data acquired from the training process into that of the testing process. Fig. 8 is a graph that displays the comparison between a MPPT controller based on an artificial neural network, and an advanced hybrid converter based on an advanced hybrid converter. The intensity of the irradiance changes instantly at 0 s, 0.04 s, 0.07 s, 0.11 s, and 0.15 s, while the temperature stays constant at 25 _C. There is a continuous power range between 0.04 and 0.5 seconds. During 0.5 seconds, there was a surge from 140 W to 220 W of power, causing the voltage to fluctuate. As a result of MPPT based on ANN, the uniformity of outcomes has been improved. According to Figure 9, the variation is increasing from 0.0 seconds to 0.2 seconds as a result of the documented instability in Figure 8. Constant outcomes are obtained at 0.04 s. In Figure 9, the variation in generated power is optimised due to the ANN and advanced hybrid converter. There is also another important term to pay attention to in the present model, which is the waves in output power at constant irradiance, which are 0.02Win in the model proposed, as shown in Figure 10. In Figure 11, we show how mean square error and epochs relate to the training, testing, validation, and benchmarking data for the artificial neural network approach. As shown in Figures 12 and 13, real and reactive power are used by the PV system, while Figures 13 and 14 show THD values. The output current waveform and microgrid voltage for the variable load response based on Artificial Neural Network and DBC with response to MPPT are shown in Figure 15 1st figure 16.

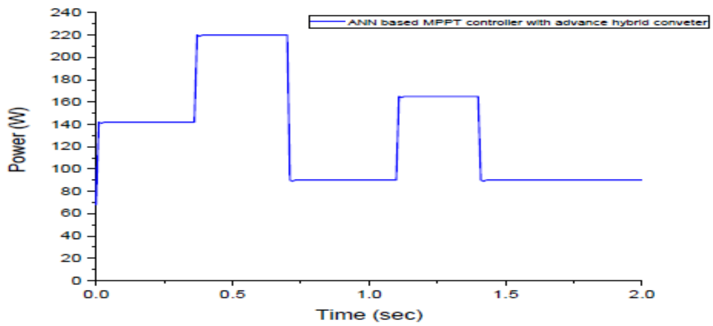

Figure 8. Hybrid MPPT controller based on artificial neural networks.

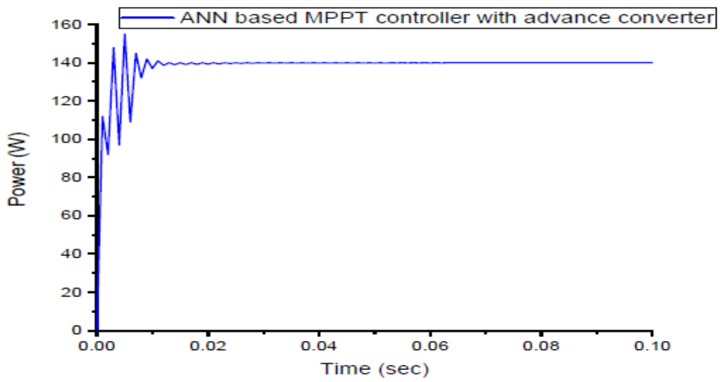

Figure 9. The MPPT controller with hybrid boost converter based on Artificial Neural Networks.

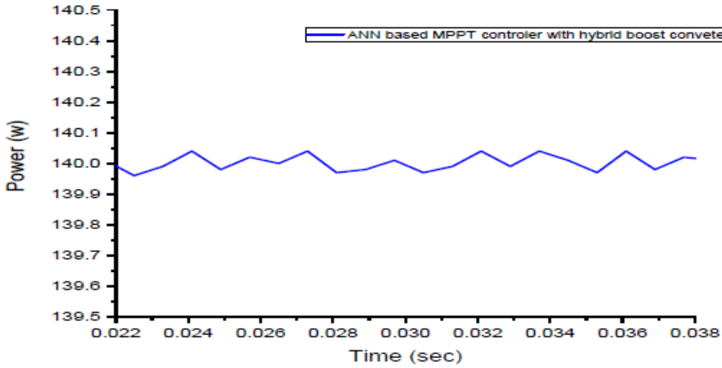

Figure 10. Boost converter-based MPPT converter was developed based on power ripples of an Artificial Neural Network.

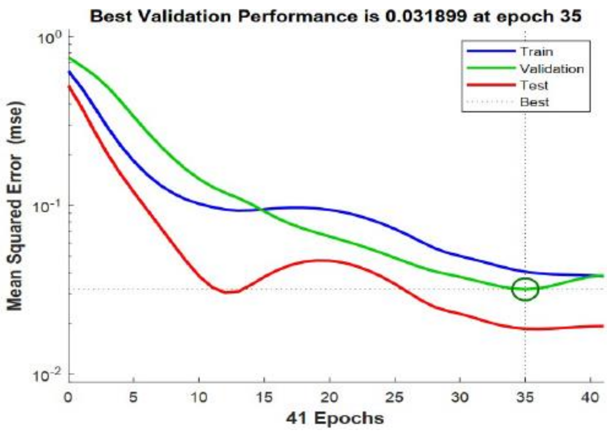

Figure 11. A performance evaluation using 41 epochs results in the maximum square error against epoch.

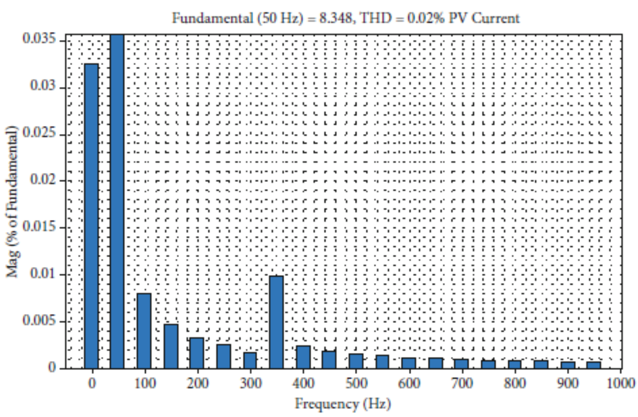

Figure 12. PV current THD values

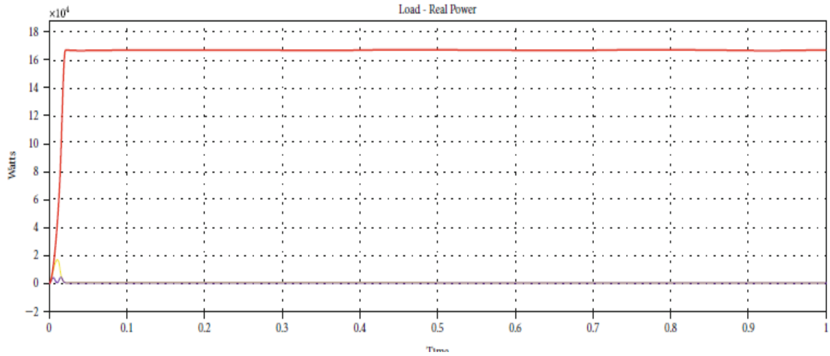

Figure 13. Load power consumption in real time.

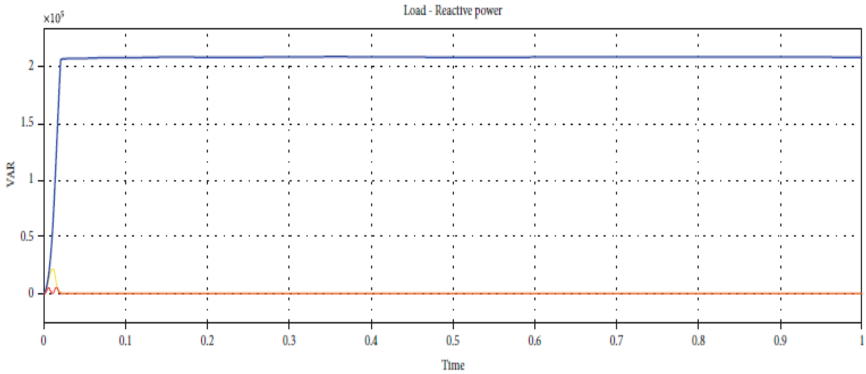

Figure 14. Loads consume reactive power.

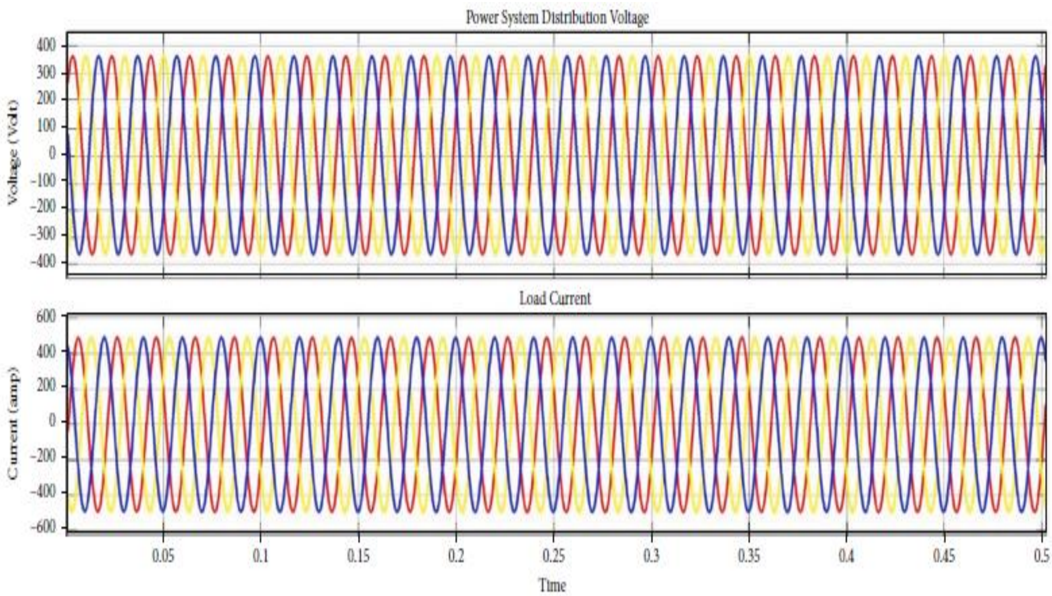

Figure 15. Voltage waveforms and current waveforms for microgrids.

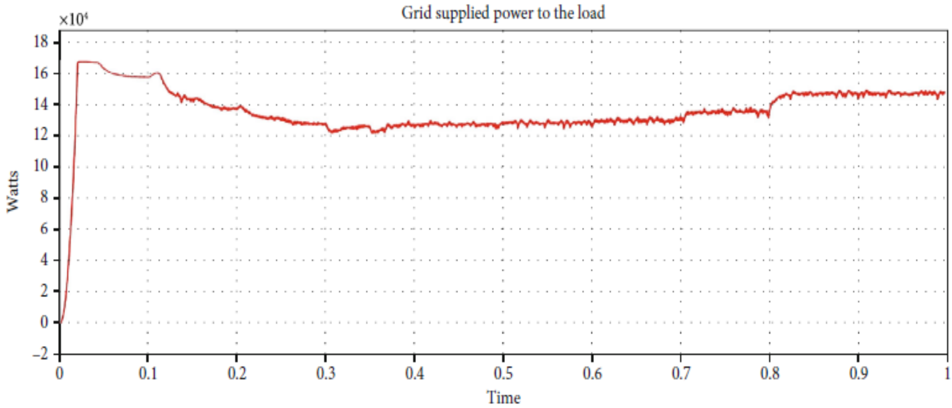

Figure 16. Loads were powered by the grid

6. CONCLUSION

A significant increase in the electric load has been recorded over the past decade. In order to reduce the pressure level on the main power grid, solar plants are a very effective solution. This paper, presents a load management technique based on a MPPT with an artificial neural network and a hybrid boost converter that can manage load. Additionally, as part of the load distribution system, a smart transformer is installed in order to ensure the output power is maintained. Artificial neural networks based controlled for MPPT with a hybrid converter has faster tracking and less fluctuations than the traditional MPPT controller. An explanation of the mechanism behind the Artificial Neural Network based on a mathematical background is provided. An attempt has been made in the present paper to simulate the proposed system under a variety of operating conditions and to present the results of the simulations, as well as the outcomes of the simulations. Among the objectives of this investigation is to demonstrate the THD values of the voltage and current profiles for solar, wind, and distributed grids in terms of their THD values. It is evident from these numbers that when solar and wind energy are integrated into the microgrid, the power quality is improved significantly. A standard value for THD is less than 5%, which has been observed for the proposed system. Power consumption and time consumption of a novel Artificial Neural Network and a boost converter based on MPPT are evaluated in this study. Consequently, we can conclude that solar power systems that are equipped with a hybrid converter are more efficient in terms of improving the efficiency of solar power systems than those that do not have one. In order to increase the productivity and performance of a solar power system, we have developed a method that uses an Artificial Neural Network (ANN) and a MPPT based on a boost converter.

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Acknowledgment: Nil

References

1. Ab-Belkhair, A., Rahebi, J., & Abdulhamed Mohamed Nureddin, A. (2020). A study of deep neural network controller-based power quality improvement of hybrid PV/Wind systems by using smart inverter. International Journal of Photoenergy, 2020. https://doi.org/10.1155/2020/8891469
2. Alahmadi, A. A. Al, Belkhier, Y., Ullah, N., Abeida, H., Soliman, M. S., Khraisat, Y. S. H., & Alharbi, Y. M. (2021). Hybrid wind/PV/battery energy management-based intelligent non-integer control for smart DC-microgrid of smart university. IEEE Access, 9(July), 98948–98961. https://doi.org/10.1109/ACCESS.2021.3095973
3. Bouzidi, M., Abdelkader, H., Mansouri, S., & Dumbrava, V. (2022). Modeling of a Photovoltaic Array with Maximum Power Point Tracking Using Neural Networks. Applied Mechanics and Materials, 905, 53–64. https://doi.org/10.4028/p-ndl3bi
4. Christy, A. A., Manikandan, R., Kumar, A. S., & Rajasomashekar, S. (2018). A novel optimization technique for optimal reactive power flow. Indian Journal of Public Health Research and Development, 9(10), 817–820. https://doi.org/10.5958/0976-5506.2018.01240.8
5. Christy, A. A., Mukundan, M. S., Kumar, A. S., & Rajasomashekar, S. (2018). A new optimization technique for minimization of power loss. Indian Journal of Public Health Research and Development, 9(10), 813–816. https://doi.org/10.5958/0976-5506.2018.01239.1
6. Guo, X. Q., Wu, W. Y., & Gu, H. R. (2011). Phase locked loop and synchronization methods for gridinterfaced converters: A review. Przeglad Elektrotechniczny, 87(4), 182–187.
7. Haseeb, I., Armghan, A., Khan, W., Alenezi, F., Alnaim, N., Ali, F., Muhammad, F., Albogamy, F. R., & Ullah, N. (2021). Solar power system assessments using ann and hybrid boost converter based mppt algorithm. Applied Sciences (Switzerland), 11(23). https://doi.org/10.3390/app112311332
8. Hossain, M. J., Tiwari, B., & Bhattacharya, I. (2016). An adaptive step size incremental conductance method for faster maximum power point tracking. Conference Record of the IEEE Photovoltaic Specialists Conference, 2016-Novem(February 2018), 3230–3233. https://doi.org/10.1109/PVSC.2016.7750262
9. J, K., & SY, F. (2018). Modeling of a Photovoltaic Array in MATLAB Simulink and Maximum Power Point Tracking Using Neural Network. Journal of Electrical & Electronic Systems, 07(03), 1–8. https://doi.org/10.4172/2332-0796.1000263
10. Journal, O. A., Kumar, S., & Alavandar, S. (1998). GRNN Based Inertia Parameters Identification of Robot Dynamics. 10(16), 115–119.
11. Khan, A. I., Khan, R. A., Farooqui, S. A., & Sarfraz, M. (2021). Artificial Neural Network-Based Maximum Power Point Tracking Method with the Improved Effectiveness of Standalone Photovoltaic System. In Studies in Big Data (Vol. 86, Issue February). Springer Singapore. https://doi.org/10.1007/978-981-33-4412-9_31
12. Kumar, A. S., Saravanan, M., Joshna, N., & Seshadri, G. (2019). Contingency analysis of fault and minimization of power system outage using fuzzy controller. International Journal of Innovative Technology and Exploring Engineering, 9(1), 4111–4115. https://doi.org/10.35940/ijitee.A4461.119119
13. Ortiz, A., Mendez, E., & Macias, I. (2022). Earthquake Algorithm-Based Voltage Referenced MPPT Implementation through a Standardized Validation Frame. 1–24.
14. Sabir Messalti., AbdelghaniHarrag., & AbdelhamidLoukriz. (2017). A new variable step size neural networks MPPT controller: Review, simulation and hardware implementation. Renewable and sustainable energy Review,68(1),221-233
15. Sathish Kumar.A, et al.(2023). An intelligent fuzzy-particle swarm optimization supervisory-based control of robot manipulator for industrial welding applications. Sci. Rep, 13 (1), 8253
16. Sedaghati, F., Nahavandi, A., Badamchizadeh, M. A., Ghaemi, S., & Abedinpour Fallah, M. (2012). PV maximum power-point tracking by using artificial neural network. Mathematical

Problems in Engineering, 2012. https://doi.org/10.1155/2012/506709
17. Shanthi, T. (2018). Neural Network Based MPPT Controller for Solar PV Connected Induction Motor. IAES International Journal of Robotics and Automation (IJRA), 7(2), 129. https://doi.org/10.11591/ijra.v7i2.pp129-139
18. Villegas-Mier, C. G., Rodriguez-Resendiz, J., Álvarez-Alvarado, J. M., Rodriguez-Resendiz, H., Herrera-Navarro, A. M., & Rodríguez-Abreo, O. (2021). Artificial neural networks in mppt algorithms for optimization of photovoltaic power systems: A review. Micromachines, 12(10), 1–19. https://doi.org/10.3390/mi12101260