IIETA International Information and Engineering Technology Association
Advancing the World of Information and Engineering

Journal Européen des Systèmes Automatisés
Vol. 57, No. 3, June, 2024, pp. 877-886
Journal homepage: http://iieta.org/journals/jesa

Enhancing Photovoltaic Panel Performance Through Artificial Neural Network and Maximum Power Point Tracking

Luma A. Almajeed*, Layth Fadhil, Aous Naji Rasheed, Khalaf S. Gaeid

Electrical Department, Engineering College, Tikrit University, Tikrit 34001, Iraq

Corresponding Author Email: lama.a.almajeed@tu.edu.iq

https://doi.org/10.18280/jesa.570327

Received: 9 March 2024
Revised: 30 May 2024
Accepted: 7 June 2024
Available online: 25 June 2024

Keywords:
solar radiation, photovoltaic panels, maximum power point tracking, MPPT, artificial neural networks, ANN

ABSTRACT

The fast expansion of renewable energy sources, particularly photovoltaic (PV) panels, has become critical in meeting the world's rising energy needs while also addressing environmental issues. An effective control technique is a factor worth consideration to achieve enough power from PV panels. This abstract summarizes in detail the use of maximum power point tracking (MPPT) and Artificial Intelligence-based technologies for achieving better performances of PV systems Firstly we will analyze the techniques of MPPT and artificial neural network (ANN) that are the best choices for high-quality power and considerations on the discussion will be put forward. The precision of determining the current, voltage, and power gradients has been accentuated by artificial intelligence to predict solar radiation within a close range of the true value. With the in-crease in the radiations, the corresponding current values go up too. In turn, voltage values increase as well as the power values. The AI system is the better watchdog as op-posed to traditional methods to temperature ambient. Now temperature change begins to adversely affect these factors. The given chart shows that current values start to decrease drastically from 25°C of temperature. Then at 65°C one of the power value drops to 175V and then to 16000W. The optimum power value is 16800W at 65°C. AI is also smart to determine the best possible current, voltage.

1. INTRODUCTION

The three main sources of renewable energy (wind, solar, and hydro) have become a particular focus across the planet where more eco-friendly and sustainable energy production is on the rise. PV (photo-voltaic) modules transform sunlight into energy with high levels of efficiency, but this efficiency greatly depends on environmental factors like the intensity, temperature of the sun, and the shading conditions. The output power of the PV changes according to the operating voltage at fixed values of environmental variables which are known as the Power-Voltage curve, maximum power point tracking MPPT algorithm is used to find the appropriate voltage which meets the maximum absorbed power from the PV, there are several algorithms and method for finding MPPT for PV systems such as perturb and observation (P&O), hill clamping (HC), incremental conductance (IC), open voltage method, short circuit current I_{sc}, etc.

Conventional methods and algorithms are usually based on changes and observing the results on the system performance, P&O algorithm is used with a boost converter [1] for MPPT under different values of solar irradiance and partial shade to improve overall performance for the PV system, then it uses P&O algorithm with Water Cycle Optimization to reduce output ripples in power and voltage. Incremental conductance IC algorithm with variable step size with boost converter was used for MPPT [2] to enhance 250W PV panel performance, the variable step was applied to reduce the settling time for the algorithm, by taking large voltage steps at the beginning then reduce it when the system reaches MPP. These methods have two drawbacks, first is power escalations around the MPP, and second is large time to reach the MPP, in recent years with the artificial intelligence revolution, much research has been introduced to apply AI algorithm to enhance renewable energy performance such as neural network, practice swarm, bee colonies, etc. to overcome the drawbacks of conventional methods.

The integral part of maximizing the PV panel performance is applying smart control devices, which reacts to the variable situations. The application of MPPT Algorithms together with ANN Systems is the example of such a technique that attracted great attention within the scientific community.

AI can be used in different ways to improve power system quality and enhance PV performance as finding optimal operating way [3]. A metaheuristically optimized multilayer feedforward ANN controller for a shunt active power filter (APF) PV system was proposed. In summary, it was a three-phase power structure linked to power an arc-welding machine. The controller ensures the highest power output of PV arrays and overcomes the shortcomings of conventional MPPT methods through MMP tracking. The controller ANN-ACO MPPT applies the ant colony optimization strategy to adjust the coating weights and thresholds Simulation experiments demonstrate higher MPP tracing and less steady-state oscillation variety, pointing out the power of power electronics. Also, both conventional and AI can be combined to improve renewable energy performance [4], two techniques for implementing the perturb and observe algorithm for maximum power point tracking were explored in a solar photovoltaic system. There are two major methods for the solution of the problem. The first is Matlab function block while the other is artificial neural network. The block is comprised of a PV panel, MPPT algorithm, and boost converter. Simulation modeling is conducted. Also, AI methods can be used for finding the optimal response for a system based on the operating conditions [5] offered a photovoltaic system controller design to effectively prevent overcharging and deep discharge, comparing classical and workable techniques. At the end of this course, you will learn the principals of MATLAB and SIMULINK to run simulations.

Most AI research focused on MPPT because it has significant effects on PV systems performance [6]. Emphasized the use of ANN to design a MPPT controller in the photovoltaic solar systems compares their execution with traditional methods like hill ascending, incremental conductance, and fractional open circuit voltage. Simulations are carried out with the aid of Matlab/Simulink. Also, MPPT of a PV solar module in the perturb and observe method was introduced in the study [7], the research papers consist of comparison results obtained from the genetic algorithm optimized ANN MPPT system with the current system. With temperature and irradiance as its basis, the Bayesian regulation-oriented ANN approach performs system power output prediction at maximum power points. The findings demonstrate the fact that the GA-optimized ANN approach yields a power supply with minimal oscillation and an acceptable power factor. Nevertheless, this approach is being proposed in the study [8] for tracking the global maximum power point in the PV systems with shading areas in solar photovoltaic systems using an artificial neural network controller as well as a scanning technique. MATLAB/Simulink was used to simulate the PV system, a case study using the particular method is trivial and lightning-fast under either uniform or non-uniform irradiation. Simulation study was performed to examine the optimal power point tracking (OPPT) for photovoltaic systems using an artificial neural network [9]. MPPT allows regulation of electrical power parameter under various conditions, thus raising power efficiency. The simulation employs MATLAB/Simulink that integrated multi-stage models of solar PV and DC/DC Boost converter. Results proved that when there are disturbances even at the extreme grades, optimal monitoring of MPPT is done.

Some researches that investigate the performance of different fields of AI for doing the controller purpose, Compared ANN and adaptive neuro-fuzzy inference system (ANFIS) AI-based maximum power point tracking approaches for monitoring PV arrays [10]. Traditional algorithms struggle with high oscillations, leading to poor efficiency. ANFIS outperforms ANN-based controllers in tracking MPP with shorter settling time, overshoot, and oscillations. Reviews recent developments in maximum power tracking control AI systems for photovoltaic systems were introduced in the study [11]. It compares algorithms used to maximize power, focusing on the most efficient ones. The paper also includes recent additions and serves as a reference for future work on maximum power tracking control in renewable energy sources. The electricity industry faces challenges in meeting rising power demand due to limited resources [12], leading to a rise in renewable energy sources like wind and solar. Maximum power point tracking techniques are used to maximize solar module efficiency. ANN has become popular due to their efficiency. This work uses a genetic algorithm and a PI controller to optimize data and compares it to incremental conductance. An improved MPPT controller for photovoltaic systems presented in the study [13], utilizing an artificial neural network and the traditional P&O method. The controller forecasts the optimal voltage of the PV system using feedback propagation and inputs solar radiation, ambient temperature, and module temperature coefficients. The new method outperforms the traditional algorithm, enhancing conversion efficiency and resulting in quicker response times.

Based on the literature review it is clear that there are many researchers concerned about renewable energy systems' performance and overcoming the conventional algorithms and methods' drawbacks, in this paper P&O algorithm and ANN performance will be investigated to enhance PV system performance under different operating conditions for environmental variables, the proposed methods will be applied on boost converter connected with resistive load. the performance comparison will focus on the output power, voltage ripple, power ripples, and settling time, and other points.

2. METHODOLOGY

The proposed structure for the system is shown in Figure 1. The system consists of 22kW PV panels connected with a load thought boost converter, the DC-DC converter is driven by MPPT algorithm, first P&O and then ANN, the simulation process of the control system for the solar panel to obtain the largest possible capacity of electrical energy requires precise configuration of the system's parts.

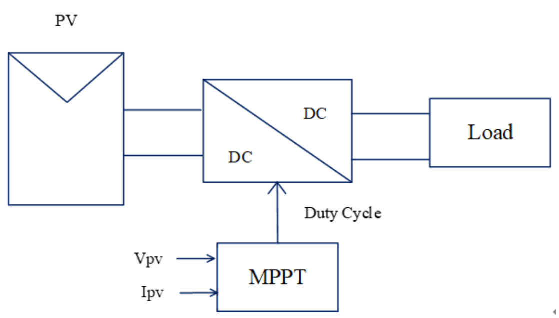

Figure 1. The proposed system structure

2.1 Photo voltage panels

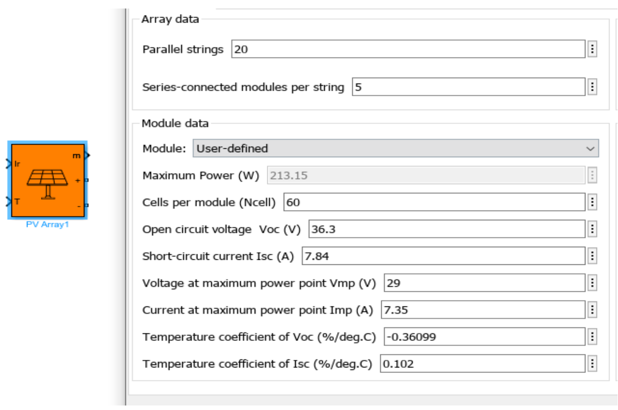

Figure 2. Performance of PV panels

The solar panel was selected from within the solar panel icon in the database of the Simulink program, where the properties and data of this panel were listed in Figure 2, the overall power for the PV panels also can be assigned by this block.

2.2 DC-DC boost converter

A DC-DC boost converter is a power electronic circuit that steps up a DC voltage to a higher level. It is widely used in various applications, including renewable energy systems, electric vehicles, and portable electronic devices. Simulink, a simulation and modeling environment that embedded in MATLAB software, delivers a sophisticated tool for designing and analyzing DC-DC boost converter systems.

The principle of a boost converter is the rhythmic switching of a transistor or MOSFET, which moderates the flow of energy. When this switch is closed, energy is stored in an inductance and, when it is open, that energy goes via a diode to the output. That is, by flying forward and backward, this process makes voltage amplification.

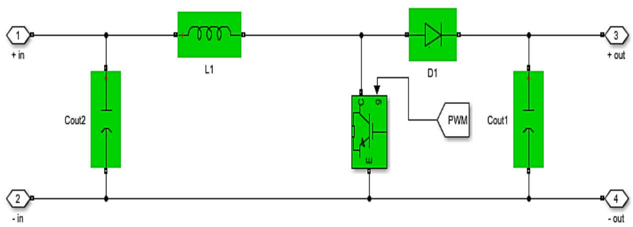

Figure 3. DC-DC boost converter in Simulink

$$V_{out} = \frac{D}{1-D} V_{in} \quad (1)$$

where, V_{out} stands for the output voltage, V_{in} represents the input voltage, D is the duty cycle, which is the fraction of on time to the overall cycle Inductor current equation:

$$(1 - D) * V_{in} = L\frac{di}{dt} \quad (2)$$

where, L stands for the boost converter inductance and di/dt is the rate of change of inductor current in this instance. Switching node equation:

$$V_{in} = V_L + V_{out} \quad (3)$$

where, V_L is the voltage across the inductor.

These equations are the ones that control and govern the circle of the operation and characteristics of the boost converter [14, 15], including the steady-state and transient circumstances in Figure 3.

2.3 MPPT algorithm

Perturb and obversion P&O MPPT algorithm was used to find MPP under different operating conditions by adjusting the output voltage for the PV panels, P&O makes changes in the duty cycle for the boost converter then it obverse the changes on the power, Figure 4. shows the flowchart for this algorithm.

The flowchart in the Figure 5 was coded in MATLAB/Simulink as user defined function, the inputs for the function are PV voltage and current, them it calculates the power and the changes of power to determine the change into operating voltage, which will be applied on the boost converter as the duty cycle.

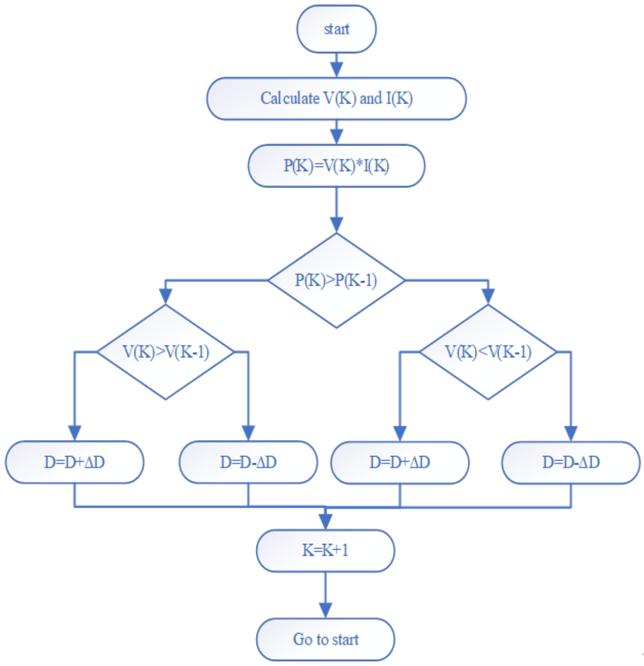

Figure 4. P&O algorithm flowchart

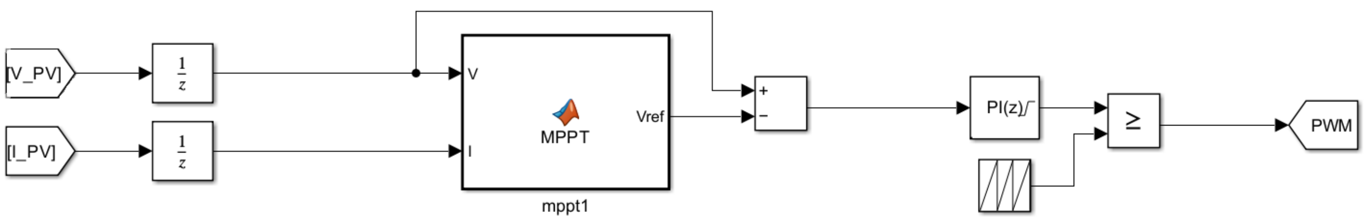

Figure 5. MPPT algorithm in Simulink

On the other hand, represents one of the approaches aimed to increase the output from solar panels by tracing the point (MPP) on the V-I characteristic curve where the maximum power is generated. Simulink, which can be used with MATLAB for simulation and modeling, serves as a very useful tool that allows for designing and simulating MPPT algorithms in PV systems. MPPT algorithms do the adjustment of the operating point of the PV system to have the maximum possible out-put. Along with that, environmental factors such as solar irradiance, temperature, and the features of the PV panel will be taken into consideration. Simulink creates an open and modifiable platform for comparing MPPT techniques and observing the variation in their response.

According to the MPPT algorithm is the most commonly implemented one is the P&O approach. Indeed, it controls the period of the duty cycle of a DC-DC converter as it tracks the maximum power point (MPP). The P&O regulation's components can be described as follows:

$$V_{ref} = \Delta V + V_{mpp} \tag{4}$$

where, V_{ref} is the reference voltage used; V_{MPP} is the PV module voltage at the maximum power point (MPP); ΔV is the small perturbation added. The P&O algorithm changes the reference voltage periodically and observes the variation in power output. If the disturbing force increases, then there will be no change in the direction of the effect. If the perturbation persists, the disturbance initiates the process of going back. The algorithm uses the approach of continually changing the reference value which leads to an MPPT optimal point [15-18].

2.4 Neural block

ANN stands for artificial neural network (ANN) and is one of the classes of regression and discriminating models. It facilitates learning, adapting, fault tolerance, and parallel computations while also possessing the ability to generalize. As a result of the intricacy of the excavator system, the output of the fuzzy controller is given as an input to the specimen neural network. With its ability to learn, this hybrid technique can be used to improve the performance of the control system. The proposed neural block is designed with a single-node neural structure and consists of one input layer and an output layer, where the input layer receives the signal output from the fuzzy block. The output layer contains a set of adjustable parameters, only one neural node with input function.

$$f = \sum_{i=1}^{m} w_i \times u_{F_i} \text{ with } m = 3 \tag{5}$$

where, u_{F_i} is the input signal of this node the activation function of the neural output is given by the equation [15]:

$$a = u_m \frac{f}{\sum_{i=1}^{m+1} u_{F_i}} \tag{6}$$

The learning algorithm of the neural block is based on the minimization of the cost function which is defined as:

$$E = \frac{\varepsilon^2}{2} \tag{7}$$

where ε is calculated as the following equation [16]:

$$\varepsilon = u_{\text{cantrol}} - u_{nn} = u_{PD} \tag{8}$$

Figure 6 shows the neurons structure.

The update process of the synaptic weights or adjustable parameters w_i is computed as follows:

$$w_i(t+1) = w_i(t) + \eta \times u_{PD} \times \frac{u_{F_i}}{\sum_{i=1}^{m} u_{F_i}} \tag{9}$$

In this paper multilayer neural network is proposed to find the MPP for the PV panel under different operation conditions, training DATA set is obtained by using the P&O algorithm with different solar irradiance and temperature to determine the reference voltage for the PV, then export the inputs and output to the workspace as illustrated in Figure 5, after that use the DATA to train the ANN, the training DATA was 10000 value for current and voltage under different values for solar irradiance and temperature, the output was the reference voltage for the boost converter. Figure 7 shows the proposed structure for ANN in this work, which has one hidden layer with ten neurons with tan-sigmoid activation function and one neuron in the output layer with linear activation function.

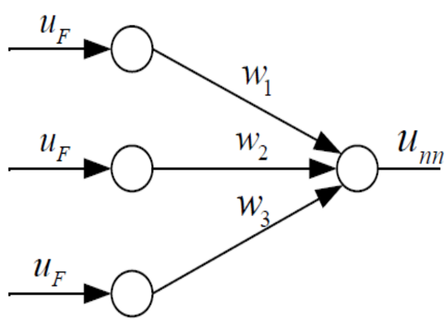

Figure 6. Neural output node

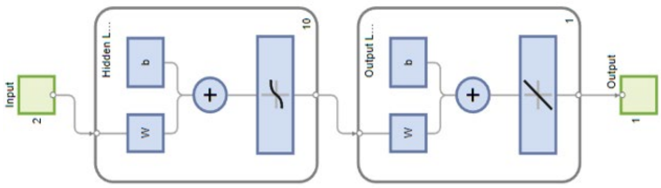

Figure7. The proposed ANN structure

Simulink is a graphical programming environment integrated with MATLAB that allows modeling, simulating, and analyzing dynamic systems, including neural networks. It provides a block diagramming interface for defining network architecture, specifying training algorithms, and providing training data. The neural network block is a convenient tool for such structures as neural network implementation. Simulink provides different import options, output metrics as illustrated in Figure 8, and visualization tools for investigating the success of training in the way we need. Once the network is trained, this can be exported to MATLAB for more in-depth investigations and deployment.

Training Progress

Unit	Initial Value	Stopped Value	Target Value
Epoch	0	1000	1000
Elapsed Time	-	00:00:07	-
Performance	4.26e+05	2.75e+04	0
Gradient	5.63e+05	0.301	1e-07
Mu	0.001	0.0001	1e+10
Validation Checks	0	390	1e+03

Figure 8. Neural network training

Neural network training ends with the training state in which the network is adjusting its parameters and performing on a training data set. It gets updated iteratively by the error difference between the predicted and the true output and the training is finished when each epoch is ended by some new parameter values and new accuracy. The saved training state is so that it retains the ability to start and pause and to check on new input and early stopping. A visualization, say, plots can be used to track down the training state and highlight any problems like over-learning. An error histogram is a tool used to show the distribution of errors between what a model predicts as output and what the true values should have been. It is about the performance of the model through the error frequency and the magnitude of the error. A histogram will help to find the model defects, for example, outperformance or underfitting. It can as well reveal various patterns or trends in errors, including an uptick of something at a specific error magnitude, which suggests an issue with that point of data or the model's architecture or training processes. A histogram of model errors is a handy tool for assessing the machine learning model's precision. Figure 9 shows the error gradient during ANN training epochs.

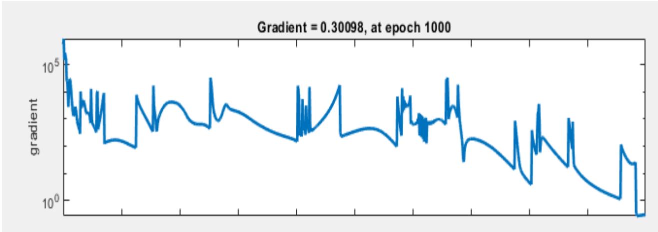

Figure 9. Error gradient during ANN training epochs

After the training ends the neural network will be exported to the Simulink as NNET block to investigate its performance for MPPT, Figure 10 shows the exported neural network in MATLAB/Simulink.

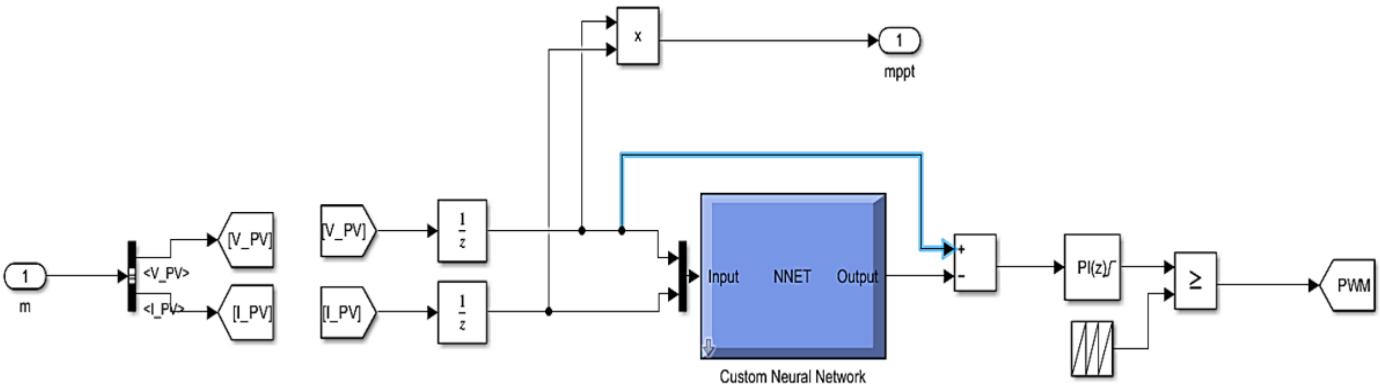

Figure 10. Exported neural network in MATLAB/Simulink

3. RESULTS AND DISCUSSION

After coding the P&O algorithm, training ANN, and export the network to Simulink, the results from each method will be compared under input and load variations, Figure 11 shows the system simulation in MATLAB/Simulink, first, power and voltage escalations during the changes of environmental variables will be compared between P&O and ANN, after that the solar, temperature, and load effects will be discussed separately.

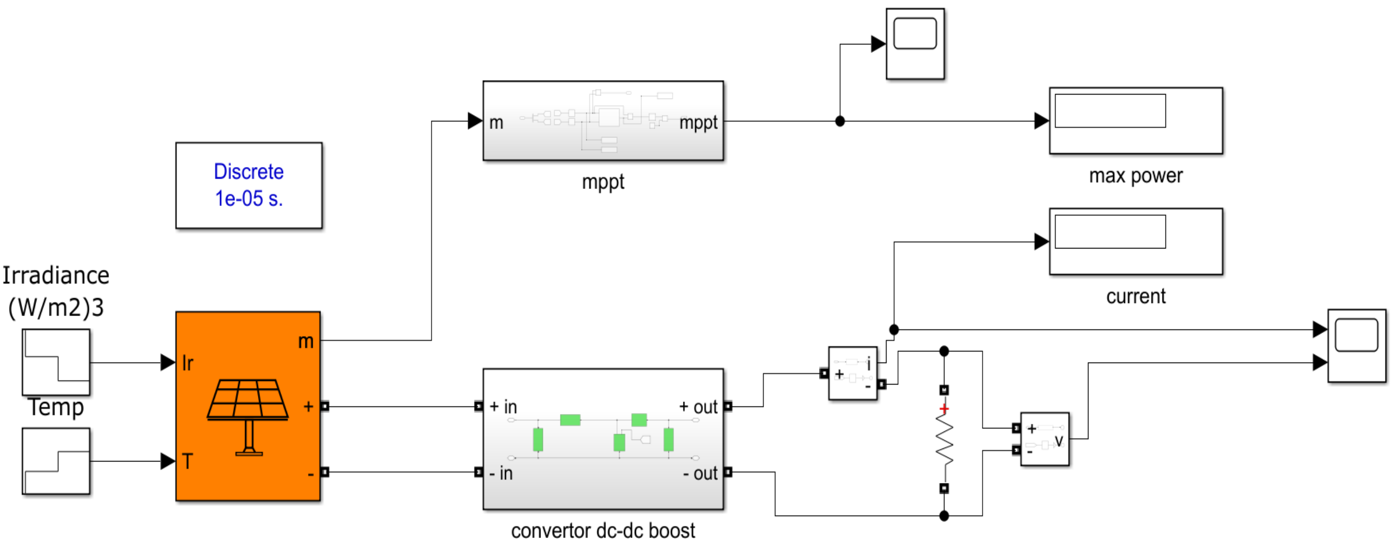

Figure 11. System simulation in MATLAB/Simulink

For solar irradiance and temperature, Figure 12 shows the changes during simulation in the first case.

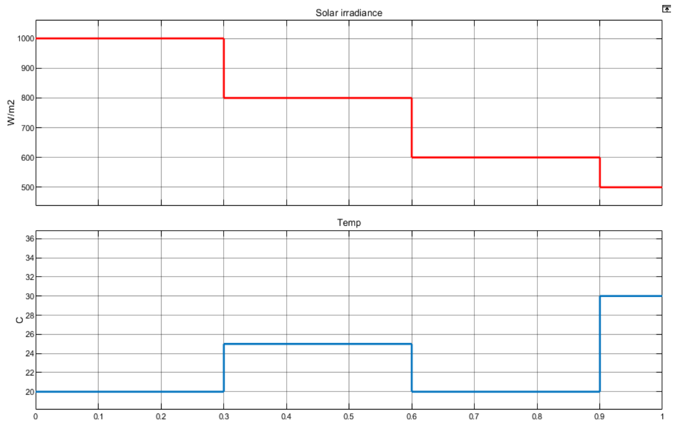

Figure 12. System simulation in MATLAB/Simulink

The results displayed by the Simulink simulation program will be studied through two cases of MPPT or ANN to get the highest amount of power and the most suitable one will be considered.

3.1 Changes in solar irradiance and temperature

P&O algorithm is considered one of the most famous MPPT algorithms because of its simplicity, but it with low irradiance, power oscillations are major drawback, Figure 13 shows the ripples in PV panel voltage according to the changes in Figure 12 with ANN and P&O.

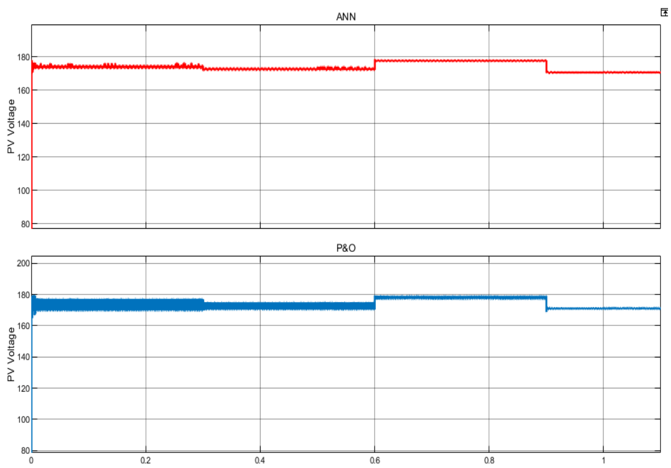

Figure 13. PV voltage with ANN and P&O

The trained ANN can regulate the output voltage of PV more smoothly than the P&O algorithm, also the output power for the PV panels has to be affected by the MPPT algorithm, Figure 14 shows ripples in the output power with ANN and with P&O.

From Figure 14 by using the same inputs and circuit components, it can be concluded that using ANN improves power quality by damping the oscillations in the power and voltage because it adjusts the duty cycle smoothly according to the inputs, also, the highest ripples in the power were [0-10w] with ANN, but with P&O in the range [0-170w], and voltage ripples with ANN were [0-2V] and with P&O was [0-7V].

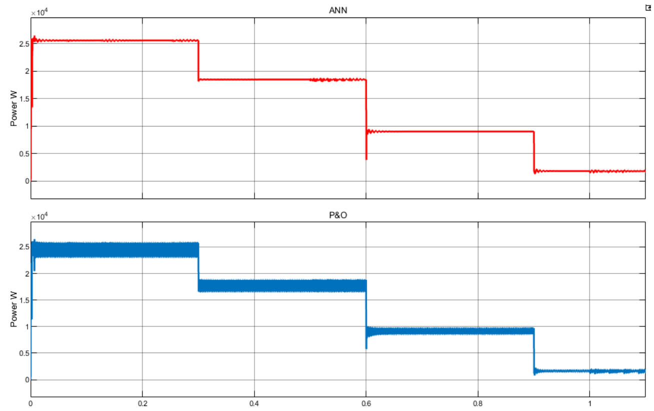

Figure 14. Output power with ANN and P&O

3.2 Effect of solar radiation

The combination of MPPT and ANN can be formed to increase the output of solar PV units and to improve efficiency. MPPT is a process that continuously studies the point where a solar panel works to generate the maximum electrical power at which their panels operate around their maximum power point. This magnifies output, maximizes energy capture, and decreases system price [17]. ANNs, which is a technique of machine learning, can provide the MPPT system accurate modeling of the link between the environmental factors and the PV panels output. ANNs can figure out better operating points for the MPPT which system takes into account different weather conditions making the system a better monitoring system rather than just an ideal MPPT. Not only they can alter their environment to adapt to various circumstances, but these devices can be adjusted at any time to optimize their power production in some situations where the intensity of sunlight and temperature change throughout the day. The energy losses in MPPT due to an inefficient control approach can be minimized by the ANN data updated ANN control method, which will in turn mean a greater energy efficiency rate.

ANNs can provide a robust solution for MPPT even when standard fixed-control algorithms do not perform well. Combining MPPT with ANN systems can result in a more intelligent and adaptive approach to maximizing solar PV panel performance, enabling greater total energy output and better reaction to changing environmental circumstances. However, outcomes may differ depending on the quality of the ANN model, the MPPT method used, and the system's complexity.

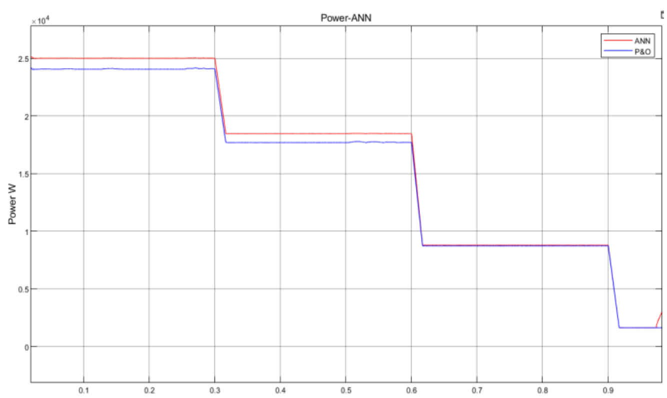

Figure 15. Power under different solar irradiance values

By adjusting the inputs in the simulation, the performance for both ANN and P&O algorithm can be investigated, in this case different values for solar irradiance will be used as (1000, 800, 600, 400, 200) W/m^2 and fixed temperature at 25℃ Figure 15 shows the power under different solar irradiance values.

From Figure 15, it's clear that the available power in the PV has been increased by using ANN, after that the increment in the current and voltage profile according to the solar irradiance curves can be plotted as Figure 16, which represents the gradient of current with solar radiation depending on the type of system. It is noted that the value of the current increases with the increase in incident solar radiation, reaching 52 amps when the incident solar radiation is 1000 W/m^2. The clear superiority of artificial intelligence is evident in obtaining the best value of the current and tracking it to reach 55 amps during the same incident solar radiation of 1000 W/m^2. Figure 17 represents the gradient of voltage with solar radiation depending on the type of system. It is noted that the value of the voltage increases with the increase in incident solar radiation, reaching 208 V when the incident solar radiation is 1000 W/m2. The clear superiority of artificial intelligence is evident in obtaining the best value of the voltage and tracking it to reach 210 V during the same incident solar radiation of 1000 W/m2. Figure 18 represents the gradient of power with solar radiation depending on the type of system. It is noted that the value of the power increases with the increase in incident solar radiation, reaching 21400 W when the incident solar radiation is 1000 W/m^2. The clear superiority of artificial intelligence is evident in obtaining the best value of the power and tracking it to reach 22000 W during the same incident solar radiation of 1000 W/m^2.

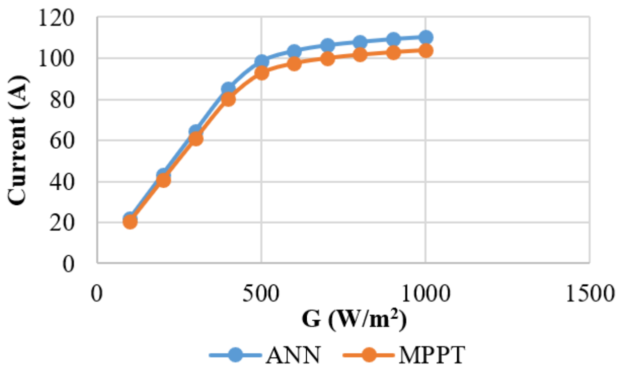

Figure 16. Current gradient with solar radiation

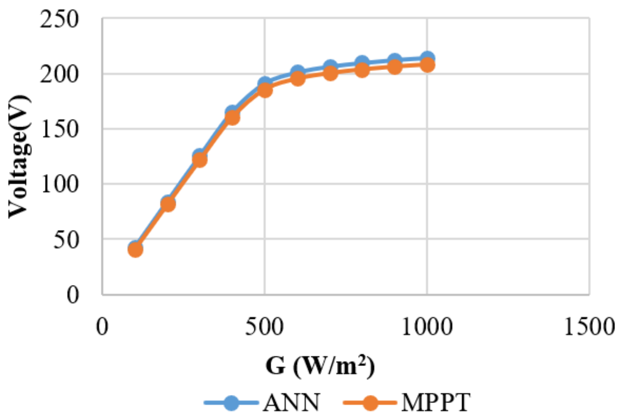

Figure 17. Voltage gradient with solar radiation

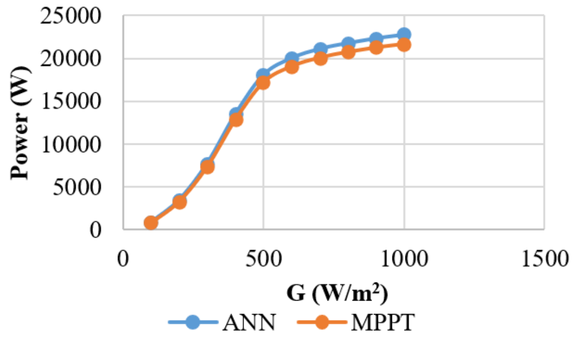

Figure 18. Power gradient with solar radiation

3.3 Effect of ambient temperature

Temperature changes can significantly impact the performance of photovoltaic (PV) panels. The negative temperature characteristics of solar panels lead to a decrease in their efficiency, primarily when it is very hot in the summer. In order to curb the effect, MPPT together with ANN can be used. MPPT controllers are able to vary the working voltage and current to realize maximum power output, supply a sufficiently low voltage when needed, and monitor temperature using thermocouples. The algorithm adaptation also represents a significant factor when it comes to MPPT systems. ANNs enable MPPT systems in their recognizing the linkage between temperature, panel efficiency, and power output. In addition, they are also able to predict temperature change in real time, and as a result, better and faster adjustment in response to such change can be achieved. Energy release happens even with the danger of fluctuations under the circumstances. ANNs have the capability to detect such issues as panel or system faults due to temperature changes and therefore, can aid in troubleshooting of the system. Furthermore, ANNs can optimize the entire system by considering not only temperature but also other environmental conditions like sunlight intensity and shade. By combining MPPT with ANNs, a more flexible and intelligent system can be constructed, leading to improved energy production and more efficient PV panel use. However, the effectiveness of such a system depends on the quality of the ANN model, the MPPT algorithm, and control techniques used, as well as the individual properties of the PV panels used.

By using different values for temperature (20, 25, 30, 35, 40, 45)℃ and constant solar irradiance 1000 W/m^2, Figure 19 shows the PV power by using ANN and P&O under different temperature values.

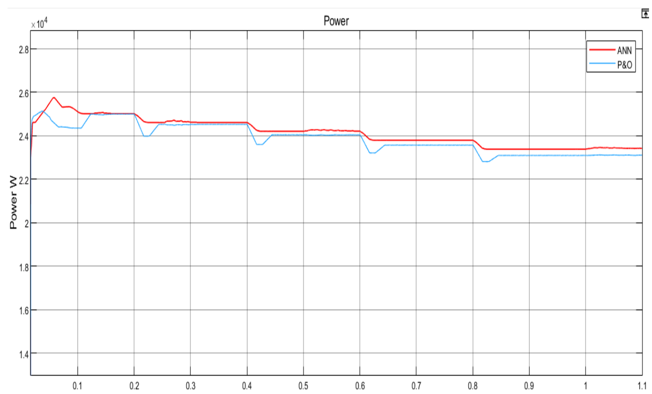

Figure 19. PV power by using ANN and P&O under different temperature values

ANN simply can assign the reference voltage according to the changes in the current and voltage which improve the system response for the sudden changes.

Using the same method, it's possible to draw the PV current and voltage curves under different operating conditions, depending on the kind of system, Figure 20 shows the gradient of current with ambient temperature. It should be observed that the value of the current falls as the ambient temperature rises, peaking at 104 amps at 25℃. The ability of artificial intelligence to monitor the current to 110 amps at the same ambient temperature of 25℃ clearly demonstrates its superiority.

Depending on the kind of system, Figure 21 shows the gradient of voltage with ambient temperature. It should be noticed that the voltage value drops as ambient temperature rises, peaking at 175 V at 65℃. When the voltage is tracked to reach 190 V at the same ambient temperature of 65℃, it is apparent that artificial intelligence is better.

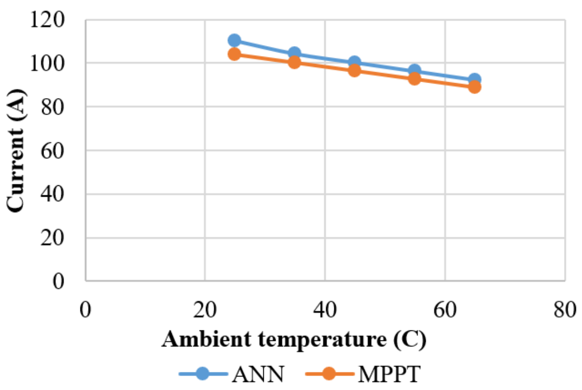

Figure 20. Current gradient with ambient temperature

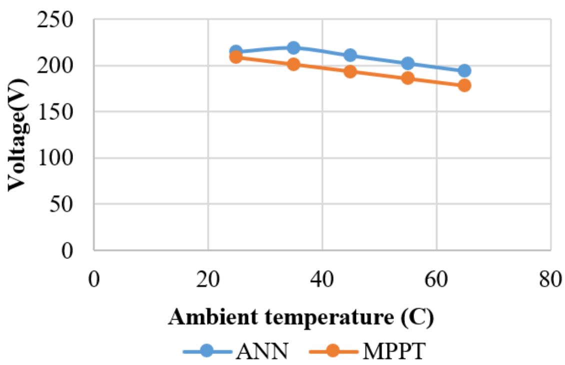

Figure 21. Voltage gradient ambient temperature

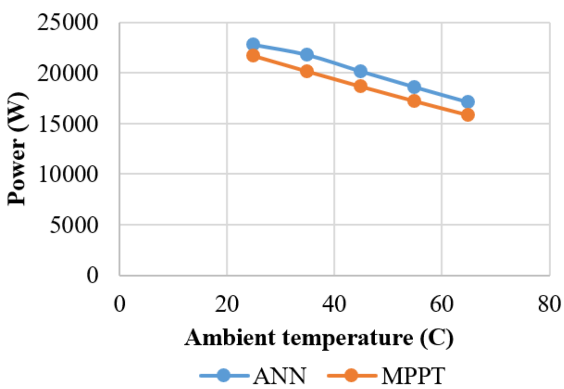

Figure 22. Power gradient with ambient temperature

Depending on the kind of system, Figure 22 shows the gradient of power with ambient temperature. It should be noted that when ambient temperature rises, the value of the power falls, peaking at 16000 W at 65℃. The optimum value of the power was obtained, and it was tracked until it reached 16800 W at the same incidence ambient temperature of 65℃, demonstrating the obvious superiority of artificial intelligence.

3.4 Effect of resistance load

Resistance load on photovoltaic (PV) panels significantly impacts power output and system performance, particularly in the context of MPPT and ANN systems. The I-V (current-voltage) curve explains this effect, with infinite load resistance causing zero voltage across the panel and zero current flowing through the load [19]. The maximum power point (MPP) is the load resistance at which the PV panel produces the most power, optimizing both voltage and current to provide maximum power. MPPT systems monitor the MPP of the PV panel, constantly changing the load resistance to maintain the operating point at the MPP, ensuring maximum power is taken from the panel. ANN integration can improve MPPT systems by delivering more intelligent control methods based on data modeling and real-time environmental conditions. ANNs can model the link between load resistance, environmental factors, and PV panel behavior, predict optimal load resistance settings based on real-time inputs, enable quicker and more accurate load adjustments, detect issues related to load resistance, and optimize the overall system by considering various parameters, including load resistance, to maximize energy production and minimize losses. Integrating MPPT with ANNs ensures real-time adjustment of load resistance to track the MPP, maximizing power output from the PV panel. This combination is especially useful in dynamic or partly shaded settings where the MPP varies often, enabling energy production to be more efficient by adjusting to changing load circumstances and environmental variables. However, the effectiveness of such a system depends on the quality of the ANN model, the MPPT algorithm, and the specific characteristics of the PV panels and load [20].

In this case, the load will be changed during simulation which will cause voltage drop and may cause misoperation in the MPPT algorithm, to study the load effects, constant solar irradiance and temperature will be applied with changing load. Figure 23 shows PV power with ANN and with P&O during different loading cases.

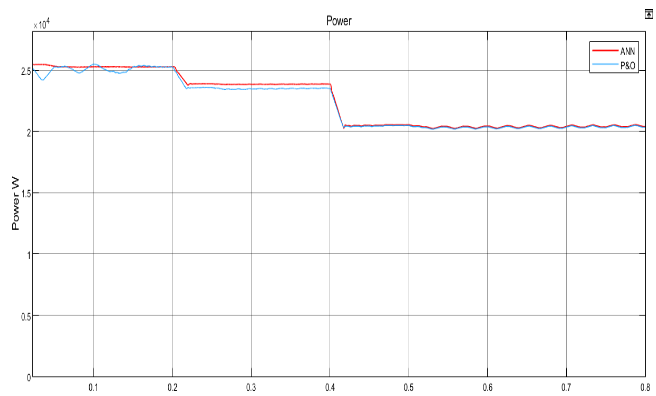

Figure 23. PV power with ANN and with P&O during different loading cases

Depending on the kind of system, Figure 24 depicts the gradient of current with resistance load. The current value drops as the resistance load increases, reaching 94 amps when the resistance load is 2 ohm. The obvious advantage of artificial intelligence is visible in determining the optimal current value and following it to attain 98 amps under the same resistance load of 2 ohm.

Figure 25 depicts the voltage gradient with resistance load based on the kind of system. It is noticed that the voltage value grows as the resistance load increases, reaching 213 V when the resistance load is 6 ohm. The apparent advantage of artificial intelligence is visible in determining the optimal voltage value and tracking it to achieve 224 V under the same resistance load of 6 ohm.

Figure 26 depicts the power gradient with resistance load based on the kind of system. The power value drops as the resistance load increases, reaching 7800 W when the resistance load is 6 ohm. The obvious advantage of artificial intelligence is visible in getting the optimal power value and monitoring it to achieve 8100 W under the same resistance load of 6 ohm.

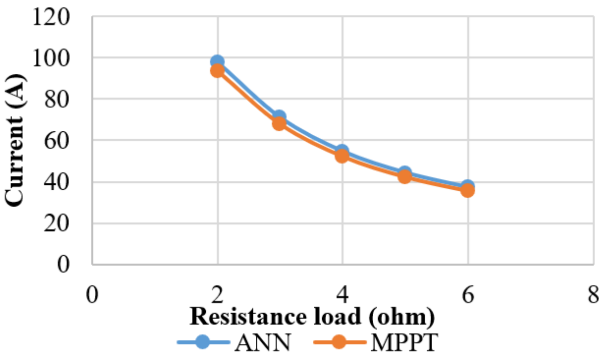

Figure 24. Current gradient with resistance load

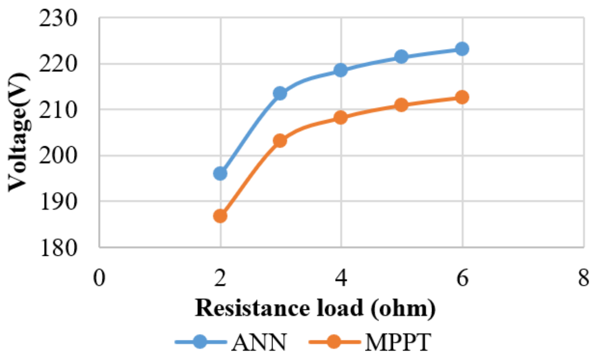

Figure 25. Voltage gradient resistance load

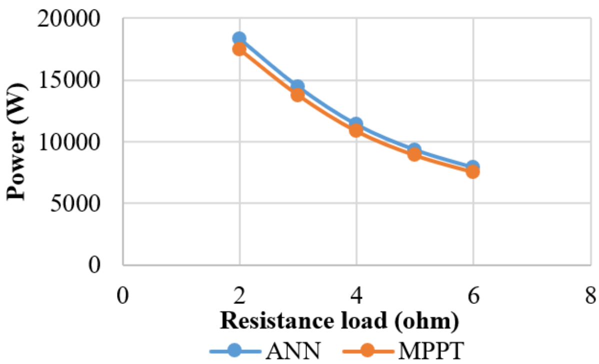

Figure 26. Power gradient with resistance load

4. CONCLUSION

Renewable energy sources like photovoltaic panels are crucial for eco-friendly energy generation. However, their efficiency is influenced by environmental factors like solar intensity and temperature. Innovative control systems, such as maximum power point tracking and artificial neural networks, are needed for optimal energy production, also this system can be applied on hardware by export the wights and activation function of the ANN in the microcontroller or DSP with the inverter voltage and current measurements.

1. Artificial intelligence significantly improves the accuracy of determining the gradient of current, voltage, and power with solar radiation. The current value increases with the increase in solar radiation, reaching 104 amps at 1000 W/m^2. The voltage value also increases with the increase in solar radiation, reaching 208 V at 1000 W/m2. The power value also increases with the increase in solar radiation, reaching 21400 W at 1000 W/m^2.

2. Artificial intelligence outperforms traditional methods in monitoring current, voltage, and power gradients with ambient temperature. Current values decrease as temperature rises, with the highest value at 25℃. Voltage drops to 175 V at 65℃, while power values fall to 16000 W at 65℃. The optimum power value is 16800 W at 65℃, demonstrating AI's superiority.

3. Artificial intelligence can determine the optimal current, voltage, and power values for various systems based on resistance load. It can determine the current value to reach 98 amps under a 2 ohm resistance load, the voltage value to reach 213 V under a 6 ohm load, and the power value to reach 16200 W under the same load.

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