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Conference paper

Comparative study of different types of DC/DC converters for PV systems using RBF neural network-based MPPT algorithm

Sarra Zaidi [a,*], **Bouziane Meliani** [a], **Riyadh Bouddou** [b], **Souheyb Mohammed Belhadj** [a], **Nasreddine Bouchikhi** [c]

[a] *Department of Electrical Engineering and Automation, Laboratory GIDD, Faculty of Science and Technology, University of Relizane, Algeria*

[b] *Department of Electrical Engineering, Institute of Technology, University Center of Naama, Algeria*

[c] *Department of Electrical Engineering, Laboratory Mechatronics (LMETR), Faculty of Technology, University of Setif 1, Algeria*

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ABSTRACT

In this article, a detailed comparison of various DC/DC converter topologies for photovoltaic (PV) systems is presented, focusing on conventional step-up converters and advanced quadratic step-up converters. The research is part of an enhanced maximum power point tracking (MPPT) strategy, using a radial basis function (RBF) neural network. The RBF-based MPPT algorithm efficiently tracks the optimal duty cycle by accurately identifying the maximum power point (MPP) of the PV system under various irradiance and thermal conditions, ensuring maximum energy extraction. The system is modeled using MATLAB/Simulink. The simulations include a complete PV configuration comprising solar panels, a resistive load, and an MPPT controller regulated by Pulse Width Modulation (PWM) signals. Performance indicators such as energy conversion efficiency, response time, and system stability are evaluated for both inverter topologies. The results show the superiority of the quadratic boost converter in terms of higher voltage gains and improved efficiency under certain operating conditions while exposing its limitations in terms of complexity and cost. This analysis offers valuable insights for optimizing the choice of converters.

1. INTRODUCTION

Finding alternative sources of energy is now the top priority for humanity, as fossil fuels are running out. Faced with the pressing global issues of a changing climate, degradation of the environment, and

* *Corresponding author, E-mail address: sarra.zaidi@univ-relizane.dz*

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the loss of natural reserves, it is becoming increasingly clear that reliance on fossil fuels is no longer viable. The need for clean, RE sources, including wind, PV, and hydropower, has never been greater. Investing in these alternatives not only reduces emissions of harmful gas but also promotes greater power security and economic stability. What's more, by making the transition to renewable energy, we have the opportunity to create new jobs and stimulate technological innovation, paving the way for a more sustainable and prosperous future for all. (A. Bouhouta, 2020). Wind and solar power are examples of the types of renewable energy (RE) that are increasingly being used as power generators to address the pressing issue of energy sustainability. The growing efficiency and falling costs of wind and solar technologies have made them increasingly accessible for large-scale energy production and individual households. Furthermore, by diversifying the energy sources available to the grid, incorporating these renewable sources not only improves energy security but also helps to reduce environmental effects.. The growing efficiency and falling costs of wind and solar technologies have made them increasingly accessible for both large-scale energy production and individual households. As countries around the world commit to ambitious climate targets, the transition to wind and solar power will play a key role in creating a sustainable energy future. (Lin et al., 2022), (Bouddou Riyadh, et al., 2020). While grid-connected solar systems remain expensive, stand-alone systems can serve as a crucial source of power for remote areas that are often not connected to the main electricity grid. As a result, photovoltaic systems have been widely deployed around the world, particularly in developing countries, enabling communities to achieve energy independence and improve their quality of life. The increased availability of affordable solar technologies has enabled many regions to harness solar energy, promoting sustainable development and improving access to energy for millions of people. (Anil Naik et al., 2022), (Yachir Amina, et al., 2024) and the demand for this form of power is increasing every year (Kermadi et al., 2017). The majority of researchers working today are focusing on energy distribution and generation systems linked to solar energy. This transformation is a result of the depletion of fossil resources and the pressing need for sustainable energy alternatives in response to climate change. Each photovoltaic cell produces a voltage of around 0.7 volts, which is relatively insignificant when considered individually. However, when several cells are connected in series or parallel to form a solar panel, the output voltage and current become sufficient to power a variety of applications, from small electronic devices to entire buildings. Researchers are continually exploring ways to improve the efficiency of these systems, including advances in cell materials, designs, and energy management strategies, to maximize the potential of solar power as a reliable energy source. (Kiran et al., 2022). As a result, many cells are connected to increase the supply voltage, creating a solar panel capable of generating a higher voltage output suitable for a variety of applications. This configuration allows individual cell voltages to be aggregated, enabling the system to meet the electrical needs of larger devices or systems. Additionally, connecting the cells in parallel results in an increase in load current capacity.l. By connecting several cells in parallel, the total current capacity of the solar panel is increased, enabling it to deliver more power to the load without overloading individual cells. This combination of series and parallel connections in photovoltaic systems maximizes both voltage and current output, improving overall energy efficiency and making solar energy a more viable option for a wide range of uses. (Ba et al., 2018). The two key variables influencing how much photovoltaic solar energy produces are temperature and irradiance(Oulad-Abbou et al., 2018). As these conditions fluctuate throughout the day, the performance of solar panels can vary considerably. The P-V and I-V curves, which indicate a particular operating point for maximum energy extraction, are used to illustrate the characteristics of photovoltaic systems. This is why it is essential to use MPPT in PV power system. An MPPT continuously monitors the P-V and I-V curves to determine the point of maximum power, adjusting for the modules' electrical working point to assure optimal power delivery under varying conditions. (Nemsi, Salima, et al., 2022) By employing an MPPT, the efficiency of solar energy systems can be significantly improved, ultimately leading to higher energy yields and better system performance.

(Kummara et al., 2020). Maximum voltage (V_MPP) and maximum current (I_MPP) reflect this operating point. The location of this MPP varies over time as a function of condition atmospheric(Mbarki et al., 2022). Photovoltaic panels generally have an output voltage level that is too low to be connected directly to the grid. However, photovoltaic panels can be connected in series to produce a higher voltage level, making them more suitable for grid integration. To effectively improve the DC voltage level of solar panels and achieve both high voltage and high gain, DC/DC converters play a crucial role in photovoltaic systems. These converters adjust the voltage level to meet the requirements of the grid or specific loads. (Belgacem Moussa, et al., 2021) By increasing the voltage, (DC/DC converters not only make it easier to connect solar energy systems to the grid, but also improve the overall efficiency of energy transfer. This ensures that the solar energy produced can be used efficiently, contributing to a more reliable and stable energy supply. (Azizkandi et al., 2019). Designed to make it easy to use and great efficiency, The boost converter is a widely used type of DC/DC converters (Yao et al., 2024). In general, there are two types of DC/DC converters: isolated and non-isolated categories (Liu et al., 2017). In comparison to non-isolated converters, isolated converter types are less efficient. Furthermore, Transformer rotation ratio adjustments can be used to increase the voltage gain in isolated converters (F. Abbasi, 2019). The conventional boost converter appears to be the preferred option among the several kinds of DC/DC converters when isolation is not needed (Meinagh et al., 2019). This is due to the need for components capable of withstanding higher voltages and the associated thermal management requirements. As a result, although the traditional boost converter is effective at increasing voltage levels, these limitations can impact the overall performance and profitability of photovoltaic systems using this topology. (Billy et al., 2023). An alternative boost converter topology could effectively meet the challenge of achieving a higher voltage rise ratio. Two promising options are switched-inductance and switched-capacitor converters. Both types of non-isolated DC/DC converters offer innovative methods of increasing voltage gain without the complexity and losses associated with traditional boost converters. Switched inductor converters use inductors that can be switched in and out of the circuit, allowing greater energy storage and more efficient energy transfer. (Achar Abdelkader, et al., 2023). This configuration can result in higher voltage gains while maintaining reasonable efficiency levels. On the other hand, switched capacitor converters exploit the principles of charge transfer through capacitors that are switched at appropriate intervals. This approach can also achieve significant voltage increases and is particularly useful in applications where size and weight are critical, as these converters generally require fewer passive components.

Switched inductor and switched capacitor converters therefore represent viable alternatives for applications requiring higher voltage outputs, widening the scope of possibilities for solar energy systems and other renewable energy technologies. (Chen et al., 2013). In(Y. Ajgaonkar, 2019), a lossless passive filter and a cascaded, high-step-up inductor-coupled DC/DC converters are suggested. The authors of reference (Pan et al., 2019) present a unique high-boost DC/DC converter with two voltage-multiplying cells and a connected inductance for high-boost voltage amplification. Two converter devices have been connected to enhance the total output voltage, according to a cascading structure in the topology given by the authors (Naresh et al., 2021). Structurally, the quadratic boost converter is similar to a dual cascade boost converter and has been designed to offer enhanced voltage conversion capabilities. This innovative topology combines the advantages of boost and quadratic conversion techniques, enabling a more significant increase in output voltage while maintaining efficiency. The quadratic boost converter works by using two energy storage stages, typically involving inductors and capacitors, which work together to achieve a higher voltage gain than traditional boost converters. This design allows it to effectively manage variable input conditions while minimizing the losses associated with energy conversion. By integrating multiple conversion stages, the quadratic boost converter can achieve higher output voltages without requiring excessively high duty cycles, which can lead to inefficiencies in standard boost converters. As a result, this topology is particularly well suited to applications in renewable energy systems, such as photovoltaics, where maximizing energy output is crucial. (Amiri et al., 2021). QBCs are commonly employed in various applications, including power factor correction and solar systems, that call for high voltage conversion ratios (Boujelben et al., 2017). There are numerous MPPT approaches available, both conventional and cutting-edge. MPPT based on artificial intelligence techniques (Bugshan et al., 2022), like fuzzy logic control and neural networks, track the maximum point more quickly and accurately. RBF is a neural network technique that has a straightforward network architecture and quick convergence. The RBFNN is capable of effectively controlling nonlinear and time-varying situations (Jenitha et al., 2023). This study aims to carry out a comparative analysis of conventional and quadratic boost converters integrated with an MPPT algorithm based on an RBF. By simulating the photovoltaic (PV) system using MATLAB, we evaluate the performance and efficiency of each topology under various environmental conditions, such as different levels of solar irradiance and temperature fluctuations. Through this comprehensive evaluation, we will analyze key performance indicators, including voltage gain, efficiency, response time, and the ability to efficiently track the point of maximum power. The information obtained from this research will assist to maximize PV system designs, improving their overall energy conversion efficiency and reliability. In addition, the results could provide valuable guidelines for the selection of appropriate converter topologies and control strategies, thereby supporting the advancement of solar energy technologies. The article is structured as detailed below: The second section focuses on modeling the solar system and presents various (DC-DC) converter topologies. Part III discusses the proposed RBF-based MPPT technique, while Part IV examines the performance of converters. The conclusion is provided in Part V.

2. SYSTEM CONFIGURATION AND MODELING

The analysis is performed on the complete system model shown in Fig. 1 below. This model comprises three essential elements: the PV panel, the DC/DC converter driven by the MPPT technique, and a constant load. The PV panel is responsible for converting solar energy into electrical energy, generating a variable output voltage and current depending on solar irradiance and temperature conditions. The DC/DC converter plays a crucial role in optimizing the output of the PV panel via modifying the current and voltage levels to match the load requirements while maximizing energy extraction using the MPPT technique. The constant load represents a typical application scenario, providing a stable energy demand, and allowing the performance and efficiency of the system to be assessed under realistic operational conditions. By simulating this complete system, we can assess the dynamic interactions between these components, analyze how variations in environmental conditions affect overall performance, and evaluate the effectiveness of the MPPT algorithm in improving energy conversion. This comprehensive approach will provide valuable information for optimizing photovoltaic systems to improve their performance in real applications.

2.1 PV modeling

The PV effect efficiently converts solar energy into electrical energy. This process occurs thanks to the photovoltaic effect, which involves the absorption of photons from sunlight. (Li et al., 2011). There are both linear and nonlinear components in the PV cell's diode equivalent circuit. The linear component is made up of a series resistor, which operates as a representation of the cell's internal resistance(Soliman et al., 2020). The shunt resistor shows losses caused by defective currents in the diode. The current source simulates the photocurrent, which is mostly dependent on the cell's temperature and irradiance. The nonlinear section is approximated using a perfect diode to describe cell polarization events(G. B.

A. Kumar et al., 2022). Ideally, the series resistance approaches zero while the shunt resistance has an infinite value and can be disregarded. (Bouchakour, S. et al., 2020)

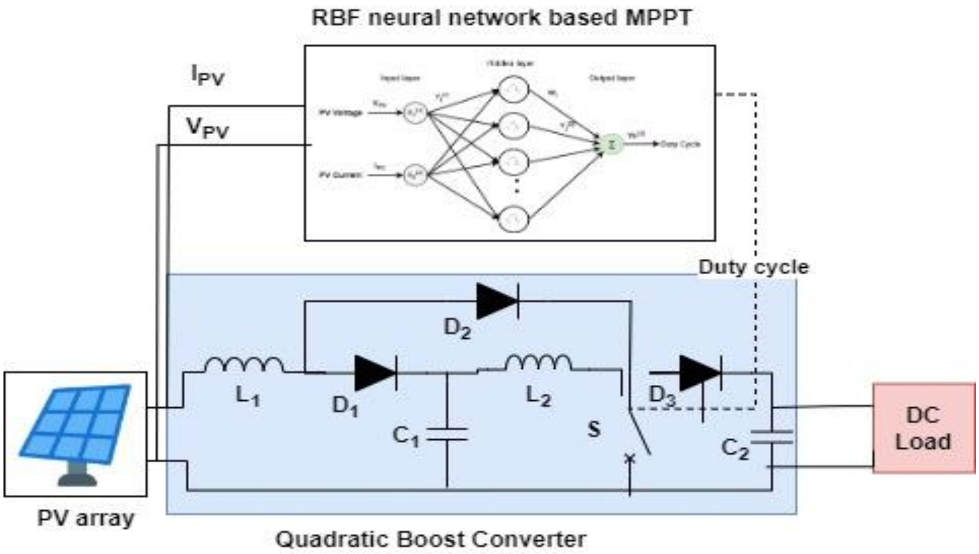


Fig 1. Proposed system structure

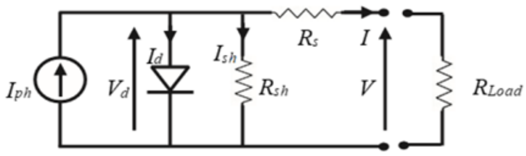


Fig 2. Photovoltaic modeling

The corresponding equation of the Photovoltaic system is as follows:

$$I = I_{ph} - I_d - I_{sh} \tag{1}$$

$$I_{ph} = [I_{ph\ STC} + I_{sat\ ref}(T - T_{STC})](\frac{E}{E_{STC}}) \tag{2}$$

$$I_d = I_{sat}(\exp\frac{q.(V + R_s I)}{N_s.K.T} - 1) \tag{3}$$

$$I_{rsh} = \frac{V + R_{sh} I}{N_s * R_{sh}} \tag{4}$$

$$I = I_{ph} - I_{sat} * \left[\exp\left(\frac{q(v + R_s I)}{nKT}\right) - 1\right] - \frac{V + RsI}{R_{sh}} \tag{5}$$

Where:

I, I_{ph}, and I_{sat} are solar cell current, photocurrent generated, and reverse saturation current.
q= 1.6 10^{-19}
C, k = 1.3 10^{23} J/k,
T is the temperature of cells,
R_s, R_{sh} = are series and shunt resistance respectively.

2.2 DC/DC converters

Power circuits are crucial to the utilization of sustainable energy sources, such wind power and PV systems. These circuits are designed to efficiently manage the generation, conversion, and distribution of electrical energy from renewable sources. In wind energy systems, power circuits facilitate the connection between the wind turbines and the electricity grid, ensuring that the energy generated can be transmitted efficiently. This involves the use of various components, such as inverters, converters, and transformers, which help to convert the variable output of wind turbines into a stable, usable form of electricity, Similarly, in photovoltaic systems, power circuits perform a crucial part in optimizing the energy harvested from solar panels. They include components such as MPPTs, which adjust the electrical load to maximize energy extraction, and (DC-DC) converters, which regulate voltage levels to ensure compatibility with the grid or energy storage systems. The design and efficiency of these power circuits directly influence the overall performance and reliability of renewable energy systems. By ensuring that energy is captured, converted, and distributed efficiently, power circuits help to improve the viability of renewable energy technologies, contributing to a more sustainable and resilient energy future. (Mohammed Belhadj et al., 2024), Belabbes, Abdallah, et al., 2024). The design of converters is a significant topic of research in power electronics. Photovoltaic solar energy harvesting needs (DC-DC) converters to transform currents and voltages from one DC level to another and run them properly (Zeb et al., 2018).

2.2.1 Conventional Boost Converter

As shown in Figure 3, The conventional boost converter (CBC) is one of the simplest and most commonly used topologies in switch-mode power systems. Its purpose is to increase the input voltage to a higher output voltage, rendering it suitable for applications such as photovoltaic systems. In these systems, the voltage generated by solar panels is frequently inadequate to directly power devices connected to the grid. The CBC operates in two modes, based on the conduction cycle of the transistor, and uses basic components such as an inductor, a switch (typically an IGBT or MOSFET), a capacitor, and a diode. But it has some restrictions, such as fluctuations near the MPP in photovoltaic applications, low efficiency for high voltage conversion ratios, and an increased need for more robust switches when the output voltage increases. (Punna et al., 2021).

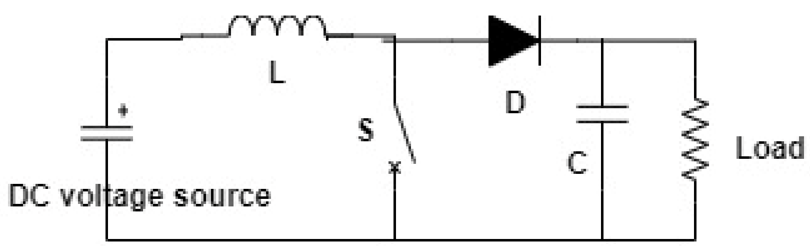


Fig 3. Conventional boost circuit model

The equations as follows represented a duty cycle and currents:

$$D = 1 - \frac{V_{in}}{V_{out}} \tag{6}$$

$$I_{out} = \frac{V_o}{R} \tag{7}$$

$$I_{in} = \frac{V_o}{(1 - D)} \tag{8}$$

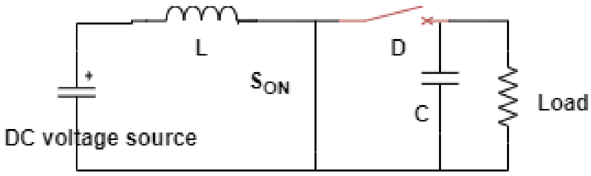


Fig 4. CBC Circuit on state

A traditional boost converter circuit is used in the first mode, as shown in Fig. 4. When in the ON position, the IGBT is activated while diode D is reverse-biased. When the supply voltage is delivered to the capacitor C, the inductor L gathers energy and turns active.

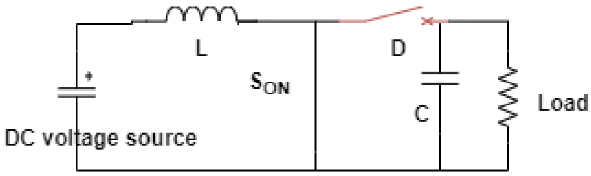


Fig 5. CBC circuit off-state

The second mode circuit of a conventional boost converter is shown in Fig. 5. In this state, the IGBT is blocked. To charge the capacitor C via the diode, the energy stored in the inductor L changes polarity.

2.2.2 Quadratic Boost Converter circuit

A quadratic boost converter (QBC) is constructed using a single switch and two traditional boost converters combined (Peddapati et al., 2022), as seen in Fig.6.

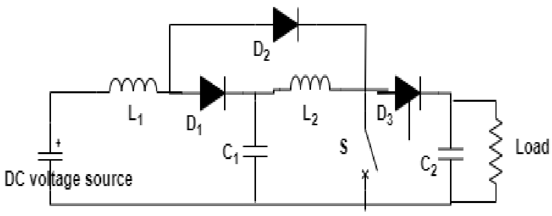


Fig 6. Quadratic Boost Converter circuit

The voltage and current of the input inductor are displayed in the following equations:

$$\frac{V_0}{V_{in}} = \frac{V_c}{V_{in}} = \frac{1}{(1-D)^2} \tag{9}$$

$$V_{in}\, I_L = V_0\, I_0 \tag{10}$$

$$I_L = \frac{V_{in}}{(1-D)^2 * R} \tag{11}$$

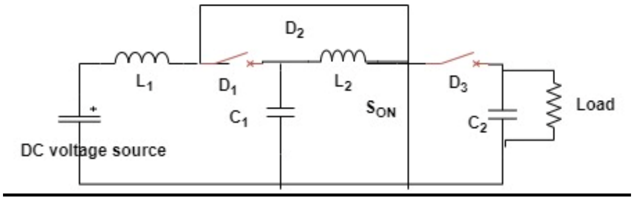


Fig 7. QBC circuit on state

The schematic diagram of a QBC is depicted in Fig. 7. In the on state, the IGBT is in the on state. D_1 and D_3 are blocked, while D_2 is conductive. V_{in} and C_1 supply inductors L_1, $and\ L_2$ respectively.

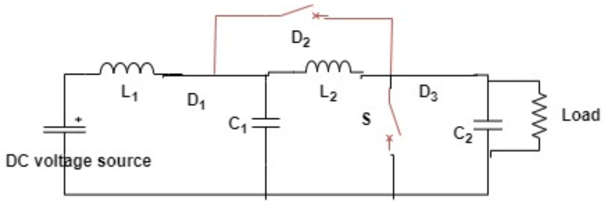


Fig 8. QBC circuit off-state

The QBC circuit is shown in Fig. 8. In the off state, the switch is blocked. D_1 and D_3 are conducting, while D_2 is blocked. From the energy stored in inductors L_1, L_2, respectively, diodes D_1, and D_2 charge capacitors C_1 and C_2. As a result, the inductor current reduces.

3. RBF NEURAL NETWORK

By continuously monitoring the MPP, the system dynamically adjusts the operating point to ensure that the PV array is operating at its optimum efficiency level. This process involves detecting changes in weather factors, including temperature and sun irradiation, which affect the voltage and current characteristics of the PV array. To maintain optimum performance, the system modifies the operating point and provides the necessary duty cycle to the inverter switch. This duty cycle governs the on and off cycles of the switch, directly influencing the energy exchange across the PV array and the load or grid. The duty cycle is essential for controlling the output voltage of the boost converter, as it determines the amount of energy stored in the inductor at each cycle and the amount of energy delivered to the load. By adjusting the duty cycle based on real-time measurements of the PV array, the system ensures that the inverter is operating at the point of maximum power, maximizing energy extraction from the solar panels. This technique is commonly known as MPPT. (Saravanan et al., 2016), MPPTs are used to optimize power extraction from PV systems (Chandra et al., 2020). A type of artificial neural network (NN) called RBFNN utilizes the RBF as the activation function for its hidden layer(Selvakumaran et al., 2024). RBFNN can transform vectors that are not linearly separable in low dimensions into a high-dimensional space, where they become linearly separable (Anand et al., 2016). RBF offers a wide range of practical uses. These include estimating nonlinear functions, predicting time series, classifying data, and controlling systems (S. Kumar et al., 2020)Artificial neural network (ANN) control, particularly with the RBF, offers a considerable advantage Regarding practicality of use and computational performance. Radial Basis Functions (RBFs) provide a more straightforward architecture and enhanced learning speed relative to other neural network variants, rendering them especially appropriate for real-time control applications. One of the main advantages of RBF control is its ability to approximate complex non-linear functions with a reduced number of hidden nodes and lower computational requirements. This makes it an ideal choice for systems requiring fast response times, such as MPPT in photovoltaic systems or dynamic voltage regulation in power converters. In addition, the RBF control algorithm can be implemented with less intensive hardware, making it more accessible for embedded systems or low-cost applications. Its adaptability to varying environmental conditions ensures that it can maintain optimum performance in a wide range of scenarios, contributing to the overall efficiency and reliability of the control system. Compared to other neural network types, RBFs have a simpler structure and train more quickly, which makes them especially useful for real-time control applications. Among the primary benefits of RBF control is capable to approximate complex non-linear functions with a reduced number of hidden nodes and lower computational requirements. As a result, it's the perfect option for systems requiring fast response times, such as MPPT in photovoltaic systems or dynamic voltage regulation in power converters. In addition, the RBF control algorithm can be implemented with less intensive hardware, making it more accessible for embedded systems or low-cost applications. (Rao et al., 2023), even for huge input variations. As seen in Fig.9, the RBF algorithm is composed of an input layer, a hidden layer, and an output layer. Every neuron in the following layer is connected to every other neuron, and these connections are not reversed (Zhao et al., 2023). RBF uses synaptic weights typically set to a unit value across the input and hidden layers, simplifying computation and making the learning process more efficient. The hidden layer neurons apply a radial basis function (such as a Gaussian function) to the input data, transforming the input space into a higher dimensional space where the problem can become more easily linearly separable. Each hidden layer neuron's output indicates the distance between the input data and the neuron's center. The radial basis function processes this distance to produce the activation output. These outputs are then combined linearly using the weights associated with the connections between the hidden layer and the output layer. The final output of the network is the result of this linear combination, which is adjusted during the training process to minimize the error between the predicted and actual outputs. This structure allows RBF to model complex non-linear relationships with a relatively simple and fast architecture, making them very effective for control tasks such as MPPT in photovoltaic systems or voltage regulation in power electronics systems. The hidden layer neurons apply a radial basis function (such as a Gaussian function) to the input data, transforming the input space into a higher dimensional space where the problem can become more easily linearly separable. These outputs are then combined linearly using the weights associated with the connections between the hidden layer and the output layer. The final output of the network is the result of this linear combination (Dhara et al., 2024). The multilayer perceptron is constructed using this approach, which is an example of supervised learning. Weights are optimized throughout training to provide the desired result for a given input (K. Kumar et al., 2017).

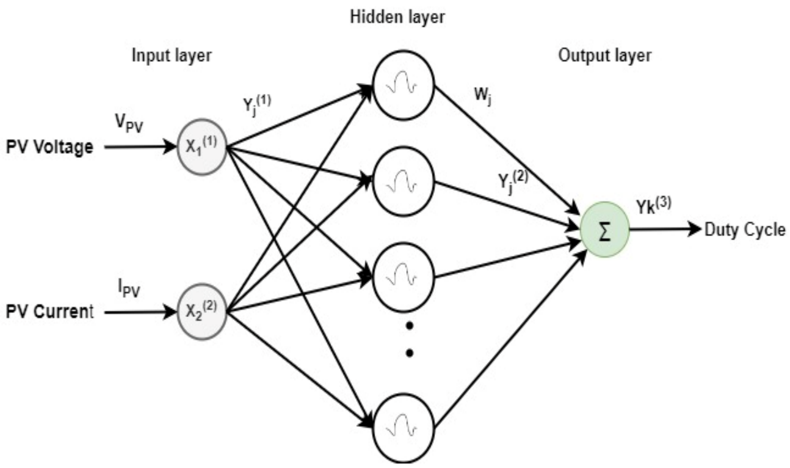


Fig 9. Suggested RBF Neural Network Structure

The recommended system achieves optimal power point tracking by learning the RBF algorithm using a PID controller and employing the output variables PV, voltage, and current as input parameters. The input data is structured so that the controller, which produces a duty cycle as its output, can be modified to provide the required output voltage. Fig.9. presents the stretched model.

The input of neural networks is presented,

$$X = [\, x_1 \; x_2 \; \ldots x_n \,]^T \tag{12}$$

The RBF vector is,

$$H = \; [\, h_1 \;\; h_2 \; \ldots \; h_j \;\; \ldots \; h_m \,]^T \tag{13}$$

The Gauss basis function expression is shown below,

$$h_j = exp\,(-\frac{\|X - c_j\|}{2b_j^2}) \tag{14}$$

The basis width vector is displayed as follows,

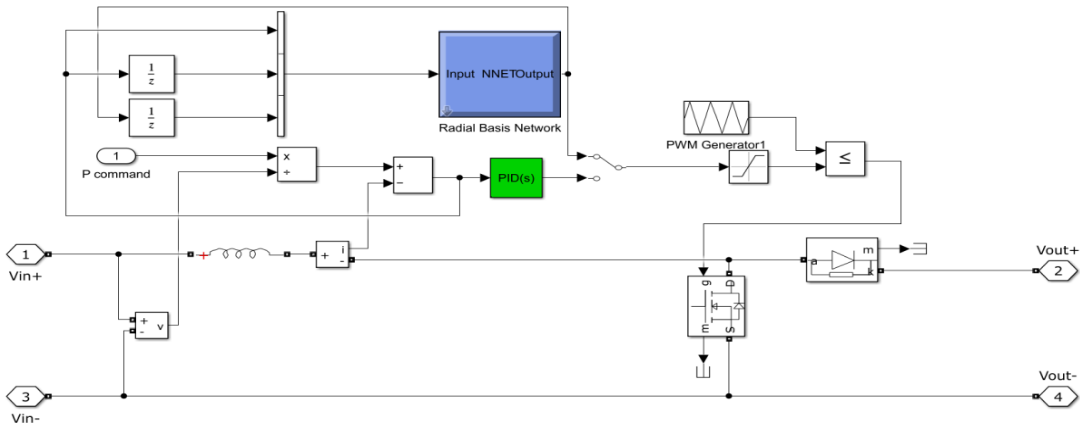
$$b = [\, b_1 \; b_2 \; \ldots b_m \,]^T \tag{15}$$

The RBF weight vector is shown below,

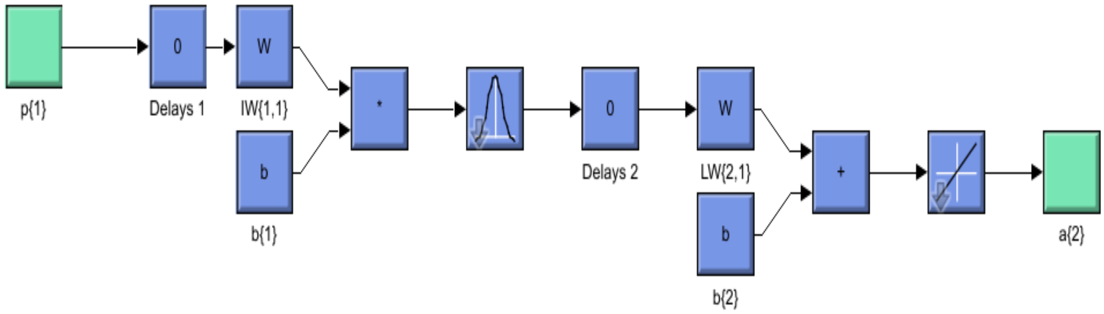
$$W = \; [\, w_1 \;\; w_2 \; \ldots \; w_j \;\; \ldots \; w_m \,]^T \tag{16}$$

The output of RBF is displayed as follows,

$$y_m(k) = w_1 h_1 + w_2 h_2 \ldots . + w_m h_m \tag{17}$$



(a)



(b)

Fig 10. (a) The simulation scheme is designed for the PV system operating with the CBC converter and RBF-MPPT algorithm (b) RBF internal structure.

3.1 RBF Prediction Model Training Effectiveness:

The performance index of the RBF prediction model is shown in Fig.11. Both the training set and the test set reached the expected error value of 100 during training. The error on the test set has reached the expected error value of $5.78411 * 10^{-14}$Notably, the validation error continued to increase until the network only needed 100 iterations to gradually achieve the best result by adjusting the learning rate during subsequent training sessions. The results indicate that the model's predictions exhibit high accuracy and rapid convergence.

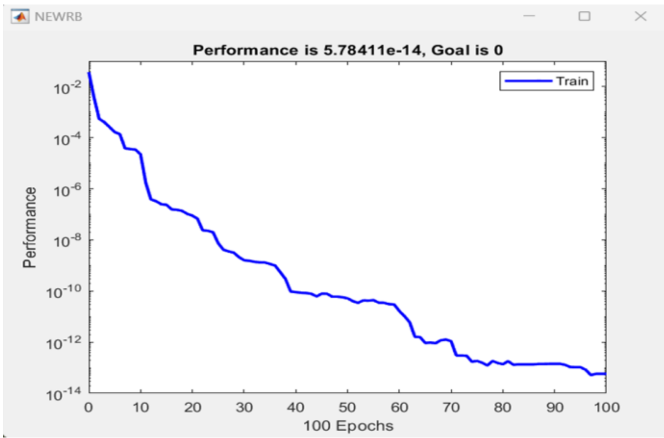


Fig 11. Performance plot of generated RBF.

The predicted result of the network is displayed in Fig. 12. Many dynamic processes that are within the further control of the system are present in the original data. There is a close alignment between the system's training aim and the neural network model's output. An excellent tracking effect is achieved even in the sole dynamic process. Dynamic behavior implies that the error is zero, which indicates that the model accurately captures the system.

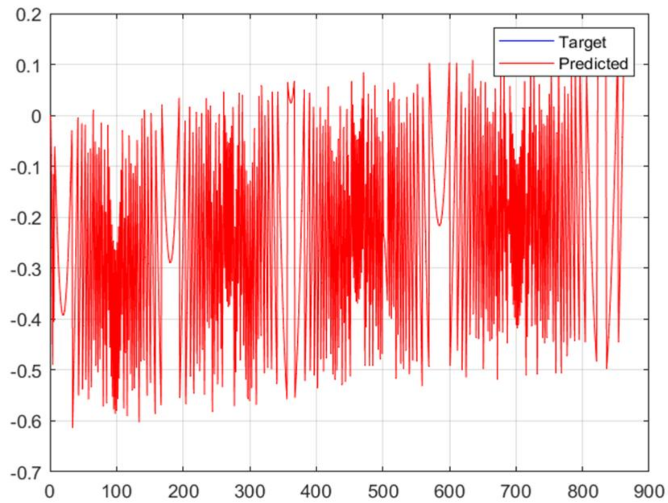


Fig 12. Predicted network output

4. RESULT AND DISCUSSION

Fig.13 below shows the full system's model, which is used to perform the evaluation. MPPT technology is used to maximize the output of the PV system.

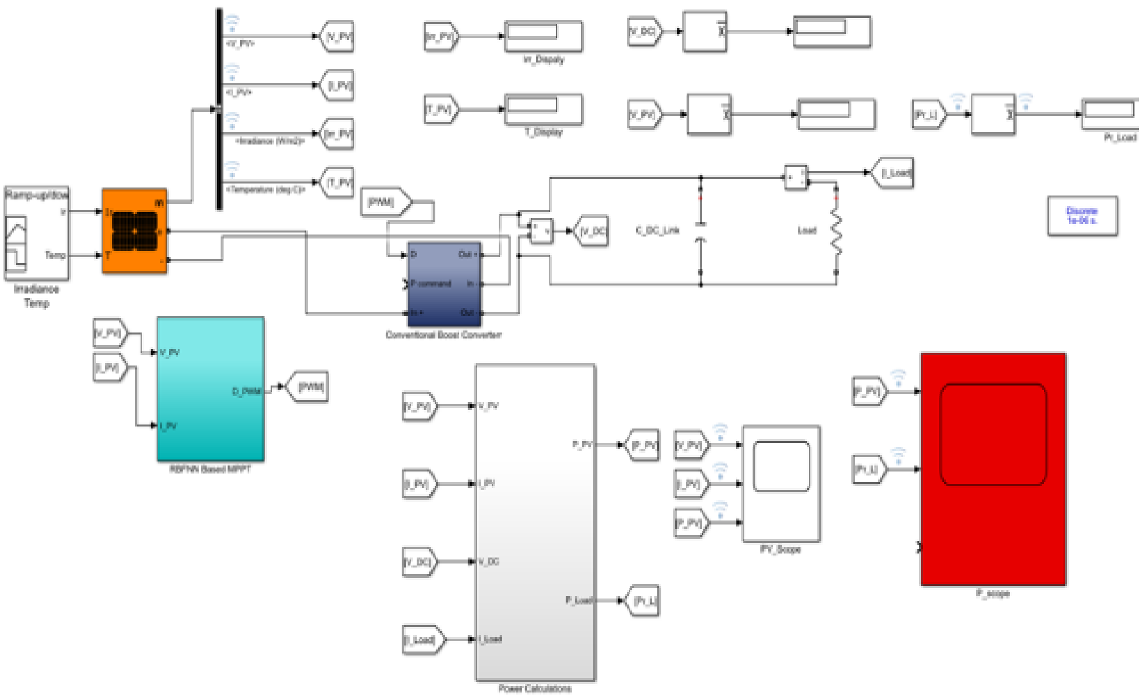


Fig 13. Simulink model of the system

This part gives the simulation results for the two types of converters and the MPPT technique mentioned in this article, with a comparative assessment of their performance.

MATLAB is used to implement the PV model to make an accurate comparison. The PV model has a maximum power of 120 watts. Temperature (°C) and irradiance (w/m^2) are the inputs for the PV array. (TABLE I) lists the main characteristics of the preset photovoltaic module (WU-120).

Table 1. PV panel WU-120(1000 $w/m^2; 25°C$

Pmpp	120.7
Cells per module	72
Vmpp	17
Impp	7.1
Voc	21
Isc	8

In the first scenario, we reduced the irradiance from 1000 to 400 W/m² while maintaining a constant temperature of 25°C to demonstrate the impact of sunlight on the PV system's efficiency. In the second scenario, we kept the irradiance at 1000 W/m² and increased the temperature from 25°C to 45°C to observe its effect on the system.

4.1 First test's simulation results

In this scenario, as illustrated in Fig. 14, the system under study is analyzed under varying irradiation conditions while maintaining a fixed temperature. To simulate the change in irradiance, a step function was used in the closed loop test (CTS) system, with the irradiance varying at t = 0.5 seconds, allowing rapid adjustment to changing environmental conditions. Figures 15(a)-(b)-(c) show the corresponding PV system outputs (voltage, current, and power) for the CBC and QBC integrated with an MPPT algorithm based on an RBF. The PV voltage oscillates between 16 and 18 V, while the PV current amplitude varies between 7.1 and 7.97 A, as shown in Fig. 14(a). In terms of the dynamic response of the system, the QBC reaches the MPP in 0.0302 seconds, while the CBC takes 0.0402 seconds to stabilize at its MPP value. This shows that the QBC has a faster stabilization time, validating its better dynamic performance compared with the CBC. The photovoltaic power curves indicate that the RBF-based controller successfully tracks the MPP, ensuring optimal performance under varying conditions. In addition, a comparative analysis of the different DC/DC converter topologies is presented in Table II, providing information on their efficiency, voltage gain, and dynamic response times.

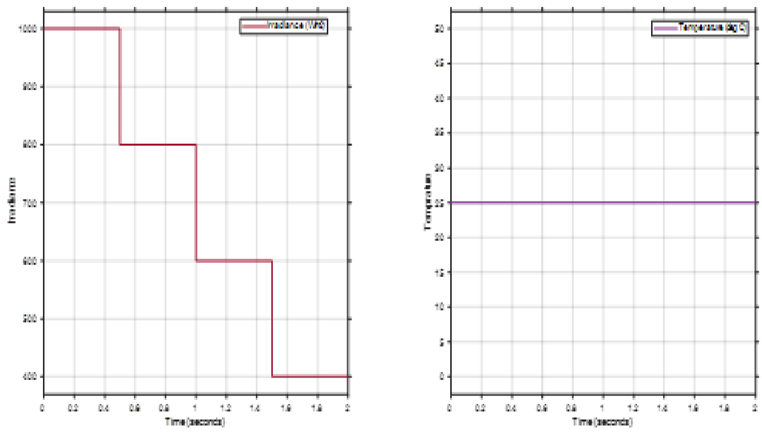


Fig 14. Irradiance profile 400, 600, 800, 1000 $\boldsymbol{W/m^2}$

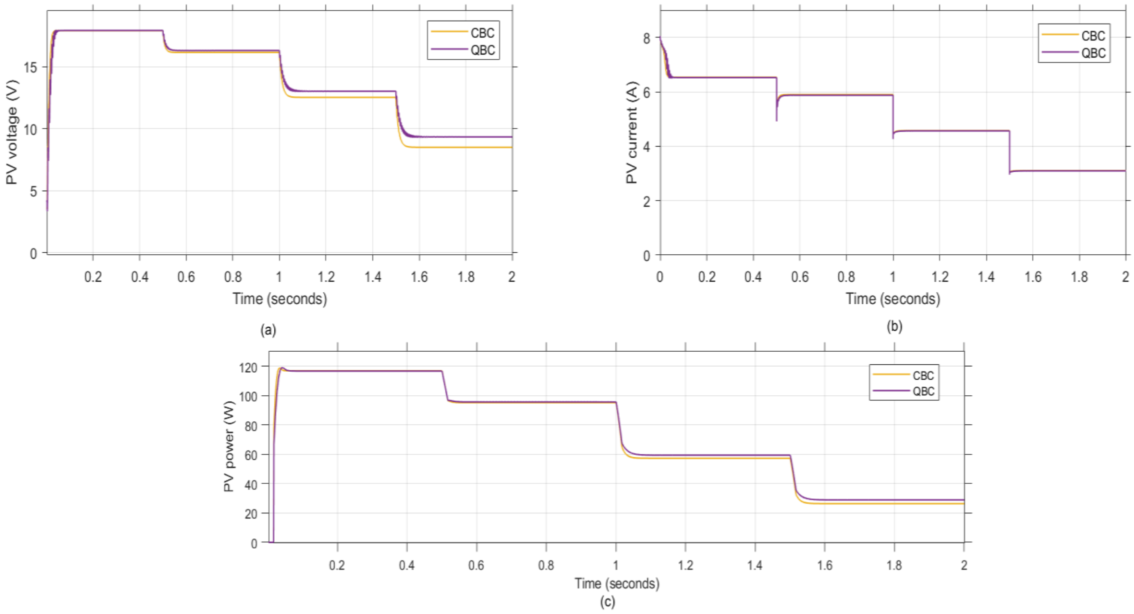


Fig 15. CBC, QBC Output waveforms with RBF-MPPT: (a) PV voltage, (b) PV current, (c) PV power.

Table 2. Performance of the solar PV system with connected CBC and QBC (First Test)

Irradiation/ temperature (W/M^2, °)	***Max power of Pv module*** P_{MPP}	***Output power with CBC***	***Output power with QBC***	***MPPT efficiency(%)***	
				CBC	***QBC***
1000, 25	120.7	117.2	118.83	97.1	98.45
800, 25	97.13	96.52	96.78	99.37	99.69
600, 25	73.06	64.82	67.44	88.72	92.3
400, 25	48.58	32.66	35.64	67.22	73.36

4.2 Second test's simulation results

In this case, with irradiation kept constant and a gradual increase in temperature as shown in Fig. 16, the response of the system to temperature variations is analyzed. At a temperature of 35°C, the RBF-based MPPT algorithm reaches the MPP at 1.012 seconds in the case of CBC. For the QBC, the MPPT algorithm reaches MPP slightly faster, at 1.009 seconds. This performance comparison shows that the QBC offers a slightly faster response time under increasing temperature conditions. Table III shows a detailed performance comparison of the MPPT algorithm for Case II, highlighting the improved efficiency and faster response of the QBC compared to the CBC. In Fig. 17, the power output of the PV system varies with temperature. At 45°C, the system generates a minimum power of 102 W, while at 25°C, the maximum power reaches 118 W. This variation highlights the significant impact of temperature on the overall energy conversion efficiency of the system. This performance comparison shows that the QBC offers a slightly faster response time under increasing temperature conditions. Table III shows a detailed performance comparison of the MPPT algorithm for Case II, highlighting the improved efficiency and faster response of the QBC compared to the CBC.

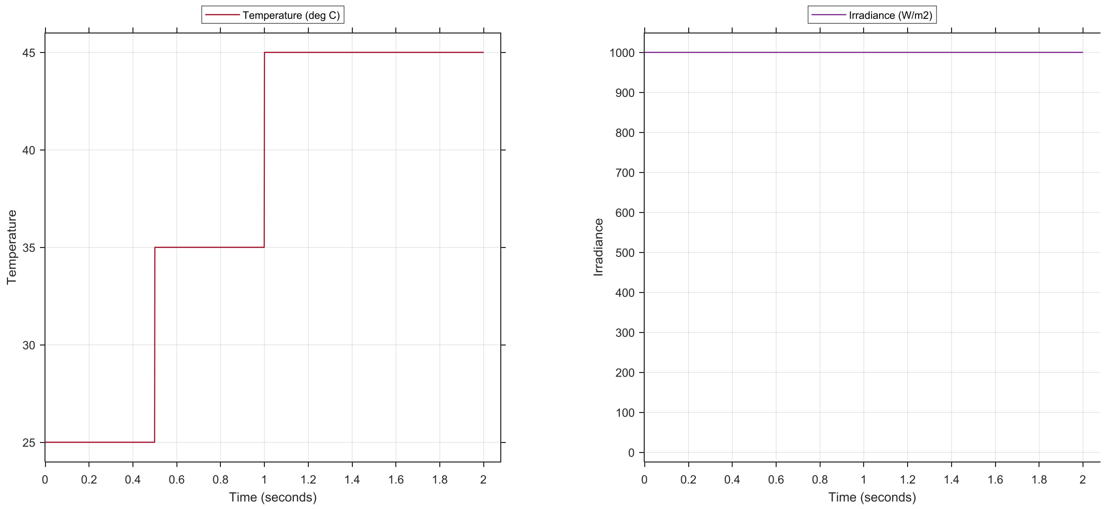


Fig 16. Temperature profile: 25°, 35°, 45°

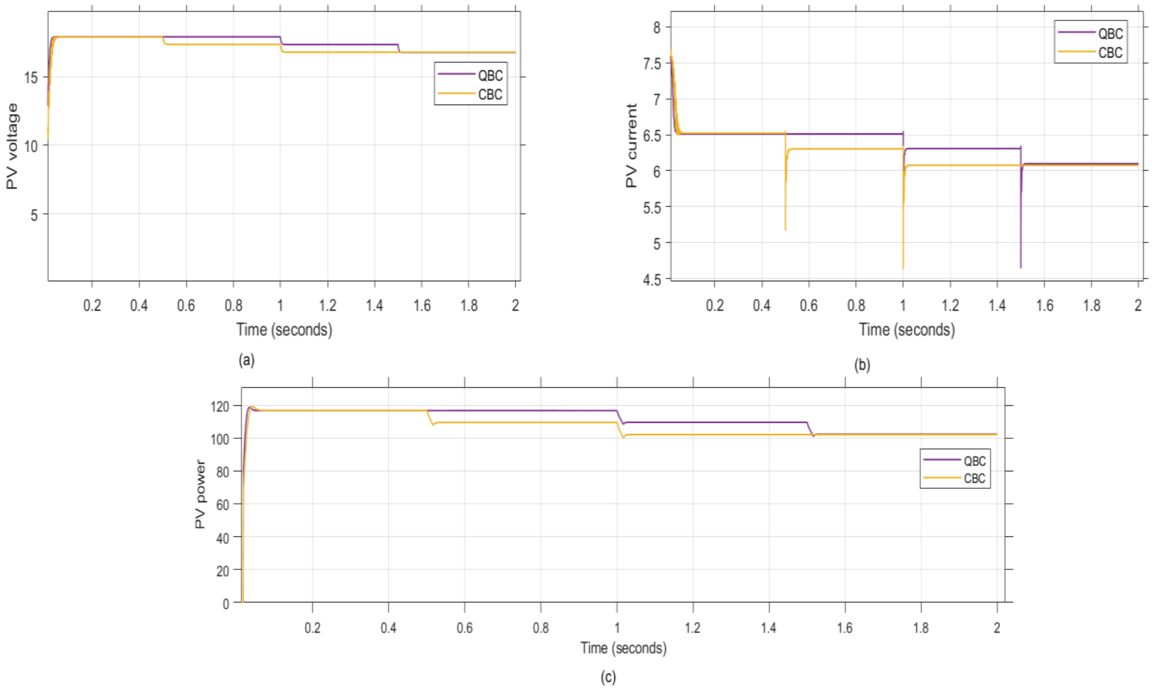


Fig 17. CBC, QBC Output waveforms with rbf MPPT: (a) PV Voltage, (b) PV Current, (c) PV Power.

Table 2. Performance of the Solar PV System with Connected CBC and QBC (second Test)

IRRADIATION/ TEMPERATURE (W/M^2, °)	*MAX POWER OF PV MODULE* P_{MPP}	*OUTPUT POWER WITH CBC*	*OUTPUT POWER WITH QBC*	*MPPT EFFICIENCY (%)*	
				CBC	*QBC*
1000, 25	120.7	117.2	118.83	97.1	98.45
1000, 35	115.71	102.09	109.56	88.22	94.68
1000, 45	110.65	102.09	102.09	92.26	92.26

5. CONCLUSION

This paper proposes an RBF-NN control algorithm applied to two types of (DC-DC) converters for PV systems. The proposed system operates under standard environmental conditions, with an irradiance of 1000 W/m² and a temperature of 25°C. According to the simulation results, the MPPT efficiency achieved by the CBC is 97.1%, while the QBC has a higher efficiency of 98.45%. This underlines the advantage of the quadratic topology over the conventional one, particularly when both converters have identical voltage conversion ratios. The efficiency analysis also reveals that the QBC maintains minimal efficiency loss, even under adverse weather conditions, unlike the CBC. In the case of CBC, oscillations around the MPP are observed in the MPPT algorithm as the system approaches the MPP, but these oscillations are considerably reduced in the QBC system. From a structural point of view, the QBC has the advantage of requiring only one switch to integrate the components of two boost converters, which simplifies its configuration and improves its overall performance. Of the topologies compared, the QBC stands out for its fastest tracking speed, making it the optimal choice for photovoltaic applications. As a result, the quadratic boost converter emerges as the most efficient and suitable topology for solar PV systems, offering improved tracking accuracy, increased efficiency, and simpler implementation compared with conventional solutions.

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