AIP Conference Proceedings

A comparative study between the soft computing MPPT techniques and traditional incremental conductance under arbitrary environmental conditions

Cite as: AIP Conference Proceedings **2776**, 060007 (2023); https://doi.org/10.1063/5.0137308
Published Online: 12 April 2023

Ali Akbar Khaleel Mhmood and Fadhel A. Jumaa

AIP Publishing

A Comparative Study Between the Soft Computing MPPT Techniques and Traditional Incremental Conductance Under Arbitrary Environmental Conditions

Ali Akbar Khaleel Mhmood [a)] and Fadhel A. Jumaa [b)]

Al-Furat Al-Awsat Technical University, Technical College-AL Mussaib, Babil, Iraq.

[a)] Corresponding author: ali.akbar.tcm.23@student.atu.edu.iq
[b)] dr-fadhela.jumaa@atu.edu.iq

Abstract. The outcome of this research is to study and validate a photovoltaic (PV) module connected to the resistive load using soft computing Maximum Power Point Tracking(MPPT). The MPPTs used in this study are the Artificial Neural Network (ANN) and Fuzzy Logic (FL)which are used to track the maximum power of a 200W PV module. First, the mathematical analysis for the PV module, ANN technique, and FL technique is done. The MATLAB Simulink was investigated to model, verify, and simulate the MPPTs. Second, the studied PV system was tested under step change in load and irradiance conditions to obtain the difference in the performance between the soft computing techniques and conventional Incremental Conductance (IC) techniques in terms of oscillation value, dynamic speed, and method's efficiency. The obtained results from the simulation presents that both ANN and FL techniques have less steady state power oscillation, and they faster than the IC technique in terms of tracking the MPP. Therefore, the performance and efficiency of the studied PV module was improved and then the life time of the system is extended.

Keywords. Soft computing maximum power point tracking, the artificial neural network and fuzzy logic, maximum power point tracking, incremental conductance.

INTRODUCTION

Today, Renewable Energy Sources (RES) are the best most energy used for electricity in the world because it is clean, free, and friendly for the environment. Renewable sources types of wind, photovoltaic (PV), and fuel cells are widely supply the electrical power system because they available along the days [1]. RES gained by the solar PV arrays are the most economic common generator in terms of cost of mechanical installation [2,3]. A PV array is similar to a semiconductor that converts the sunlight energy to electricity which has physical work such a p-n junction semiconductor device like diode. A PV array consists of many panels or modules that formed from connect several small cells. A PV cell is small quit and therefore it can generate small DC power, and therefore these cells are formed in series configuration in order to produce high output power of the PV cell and utilize a PV panel or module [4,5].

A PV panel has non-linear characteristics based environmental conditions in terms of power generation. Therefore, a Maximum Power Point Tracking (MPPT) controller was produced and implemented to enhance the PV power for the various different irradiation and ambient temperature [5,6]. Several types of MPPT techniques are implemented and developed in recent years. moreover, these techniques can be summarized on the basis of different features such as convergence speed, dynamic response, complexity of implementation, number of sensors, and cost [6,7]. Also, several of MPPT techniques are proposed and reviewed in the literatures [7-10] which are considered

1st International Conference on Achieving the Sustainable Development Goals
AIP Conf. Proc. 2776, 060007-1–060007-21; https://doi.org/10.1063/5.0137308
Published by AIP Publishing. 978-0-7354-4441-6/$30.00

the most used MPPT techniques in the PV applications. The MPPT techniques are summarized into three main types conventional techniques, artificial intelligent based techniques, and hybrid techniques.

Baimel D. et al. [8] were proposed a Constant Voltage Controller (CVC) technique to track and get high power form the PV panel. This method was low cost and simple in terms of experimental implementation but it produced a lower efficiency and inaccuracy. However, several researchers are proposed and reviewed the simple and low cost such as incremental conductance (IC) technique [5,7,9] and Perturb and Observe (P&O) [10,11]. Although these techniques were provided small size components, less computations, and easy to implement but they have a lot of disadvantages. Accordingly, a P&O technique has more oscillate around the MPP which increase the power loss and decreased the control efficiency. Also, the IC method has many drawbacks in terms of the oscillation and transient response under fast change in the solar irradiance [9]. For this reason, the variable size incremental conductance technique is presented in [6] to solve the present issues in the CVC, P&O and IC techniques.

Nowadays, the MPPT based soft computing is widely used due to have more efficiency with higher accuracy in terms of the tracking the MPP during the varying in environmental conditions.

Kermadi M. and Berkouk EM. [12] were presented the AI techniques based MPPT are presented to avoid the main problems in the conventional methods such as fuzzy logic (FL), ANFIS, neural network (ANN) methods. Moreover, these techniques have more advantages as compared with the conventional techniques due to they work with nonlinear theory. As a result, they considered an efficient MPPT and have higher accuracy to track the operating point of the P-V curve for different atmosphere conditions such irradiance and temperature [13-15]. Also, a hybrid MPPT techniques were used to find the optimal MPP where the AI techniques such as proportional-integral (PI) with fuzzy and neural networks [14].

Robles A. et al [16] conducted design a fuzzy logic MPPT to increase the PV system efficiency for a 65 W under Matlab software. The proposed technique is investigated to solve the oscillation issues that happen in the traditional P&O technique under step varying of irradiance. As a result, the simulation results indicated that the fuzzy MPPT is more efficient than the P&O in terms of power loss, speed of the dynamic speed response and power oscillation.

Rezk H. et al. [17] presented a novel MPPT controller based adaptive FL to raise the system efficiency and refinement the PV system performance in wide range of the weather conditions. As implemented there, the performance of the present technique was tested and implemented practically in hardware design using a floating-point Digital Signal Processing (DSP) microcontroller TMS320F28335. The obtained results indicate that the proposed controller was more robust that the conventional fuzzy controller in terms of ripple oscillation, harmonic content, and accuracy.

Jyothy L.P et al. [18] conducted a comparative study for a neural network MPPT with conventional IC, P&O, and HC techniques which are used to increase output power of a stand-alone PV system. The simulation results are achieved using Simulink package, and then the performance of these techniques was study under different irradiance and temperature are discussed. As a result, high efficiency, small settling time, and high accuracy are obtained in neural network MPPT compared to other techniques.

In this paper, soft computing based an artificial neural network (ANN) and a fuzzy logic (FL) based MPPT are study and used in simulation to maximize the output PV panel KC200GT 200W PV panel under different load and weather conditions. In addition, the Matlab toolbox software was used to model and verify the these MPPTs and then compare the obtained results with that achieved in traditional IC technique in terms of power oscillation, steady state speed response, and the output efficiency. The main contribution of this paper is improving the dynamic response and reduced the power losses around the MPP by decreasing the oscillation using FL and ANN methods.

PHOTOVLATIC CELL MODEL

Figure 1 shows an electrical circuit of a PV cell model used in this study. As seen, the circuit used consists of single diode, series resistor, shunt resistor, and light- generated current [1, 19-21]. Besides, this circuit is the most used in several studies due to it has more advantages which is considered simple, and sufficient to model the behavior of the PV panel [22]. However, the current of the PV cell or module can expressed as in Eq(1) based the theory of semiconductors [19,20].

$$I = I_{ph} - I_s \left[exp\left(\frac{q\,V}{\alpha\,V_{th}} \right) - 1 \right] - \frac{V + R_s\,I}{R_{sh}} \tag{1}$$

Where the equation terms can be defined as:

- ✓ V is the output terminal voltage.
- ✓ $V_{th}(= N_s K\, T/q)$ is the thermal voltage while N_s is the cells that connected in series.
- ✓ T is the temperature in °C
- ✓ K is constant of Boltzmann ($1.3806503 \times 10^{-23}$ J/°K)
- ✓ R_{sh} and R_s are the shunt and series resistances
- ✓ I_{ph} is the source of photo-current,
- ✓ I_s is saturation current of diode
- ✓ α is the diode's constant
- ✓ q is the charge value of electron ($1.60217646 \times 10^{-19}$C).

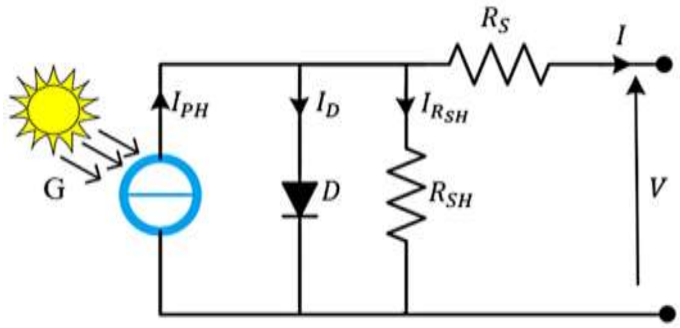


FiGURE 1. Electrical single–diode PV cell or module.

Moreover, the source of photo–current of PV module (I_{ph}) depends on amount of the solar irradiance during the day and it also influences by the change in the atmosphere temperature as seen in following equation [20,21].

$$I_{ph} = \left(I_{phn} + K_i \Delta T\right) \frac{G}{G_n} \quad (2)$$

Where $\Delta T = T - T_n$ ($T_n = 25°C$), G is the solar irradiance in W/m² while G_n is the reference value of irradiance which equals (1000W/m²) at STC.

The saturation current can be computed as follows [21]

$$I_s = I_{sn} \left(\frac{T_n}{T}\right)^3 exp\left[\frac{qE_g}{\alpha K}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (3)$$

Where I_{sn} is the revers saturation current of diode at constant temperature ($T = 25°C$), and E_g is the energy of the band-gap ($E_g = 1.12$). Moreover, the revers saturation current can be expressed as follows [21],

$$I_{sn} = \frac{I_{scn}}{exp\left[\frac{V_{ocn}}{\alpha\, V_{th}}\right] - 1} \quad (4)$$

Where I_{socn} is the reference value of the short-circuit current at STC conditions.Also, the open circuit voltage can be expressed as in Eq(5). the open-circuit voltage is strong effected by the change in the temperature due to it has a negative sign for the coefficient factor (K_v) [22].

$$V_{oc} = V_{ocn} + K_v\, \Delta T \quad (5)$$

Where V_{ocn} is the reference value of the open-circuit terminal voltage at STC conditions. Table 1 shows the electrical parameters of the used PV module under STC conditions.

TABLE 1. Parameters KC200GT solar PV panel at STC conditions

Parameter	Value
Maximum power, P_{mpp}	$200W$
Open-circuit voltage, V_{oc}	$32.9\ V$
Maximum voltage, V_{mpp}	$26.3\ V$
Short-circuit current, I_{sc}	$8.21\ A$
Maximum current, I_{mpp}	$7.61\ A$
Current coefficient, K_i	$0.0032\ A/K$
Voltage coefficient, K_v	$-0.123V/K$
Number of cells, N_s	54
Shunt resistance, R_{sh}	$415.405\ \Omega$
Series resistance, R_s	$0.221\ \Omega$
Ideality factor, α	1.3

PROPOSED PV SYSTEM DESIGN

Boost Converter Modeling

The target from the MPPT controller is to interconnecting the PV array or module through a DC/DC converter and the output load [23-25]. In order to find the MPP, the matching between the PV module and the load depends on the load impedance must be satisfied as below [23],

$$Z_{Load} = \frac{V_o}{I_o} \tag{6}$$

Were Vo, Io are the output voltage and current, respectively. Based on this mechanism the MPP point is achieved when the input impedance equal to the output impedance. As a result, the optimal impedance for the PV operationon the I-V characteristics curve can be defined as follows [23]:

$$Z_{opt} = \frac{V_{mpp}}{I_{mpp}} \tag{7}$$

Where V_mppand I_mpp are the maximum values of the PV voltage and current, respectively. Hence, the optimal value is considered when the load line is passed through the MPP point as shown in Fig.2.

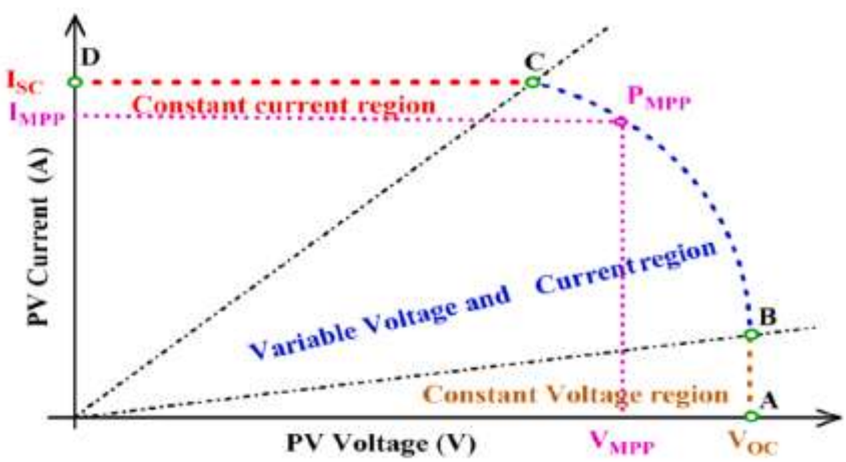
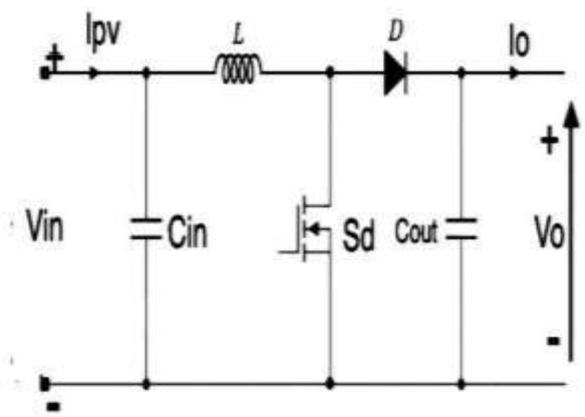
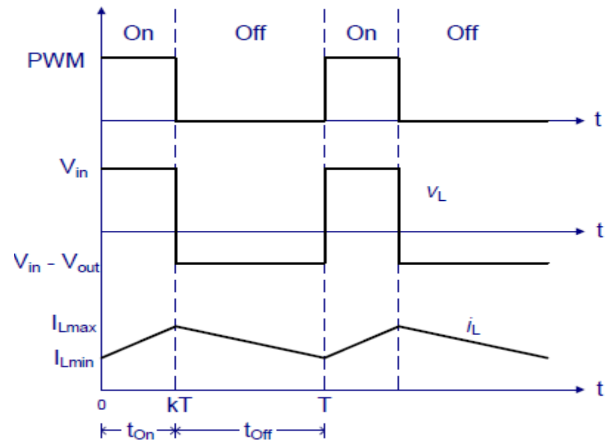


FIGURE 2. Load lines for PV operation

However, the step-up boost converter is most DC/DC converter used to implemt the MPPT controller due to it has more advanteges comparwd with other technologes. Besides, the boost converter can provide a higher output voltage at the load side, simple electrical structure, easy to implementation as seen in Fig.3.



(a) circuit wiring



(b) key waveforms.

FIGURE 3. Boost converter used in MPPT controller (a) circuit wiring (b) key waveforms.

The output voltage of boost converter can be calculated from the following equation [23,24],

$$V_O = \frac{1}{1-d} V_{in} \tag{8}$$

Also, the output current of boost converter can be expressed as [24]

$$I_O = I_L \ (1-d\ ) \tag{9}$$

The input inductor can be determined from Eq.(10) [24],

$$L = \frac{V_{in}\, d}{f_s\ \Delta I_L} \tag{10}$$

where f_s is the switching frequency, and $\Delta I_L = 0.3 I_L$.

also, the value of the output capacitor can be calculated as in equation below :

$$C_O = \frac{I_O\, d}{f_s\ \Delta V_O} \tag{11}$$

where $\Delta V_O = 0.02 V_O$. the input capacitor can be computed from [24] as below

$$C_{in} \geq \frac{d}{8\ \times f_s{}^2\ \times\ L \times 0.01} \tag{12}$$

Table 2 shows the design parameters of the boost converter under continuous conduction mode operation conditions.

TABLE 2. Electrical parameters of boost circuit

Item	Value
L	1.8 mH
C_{out}	100 μF
f_s	5000 Hz
C_{in}	220 μF
d_{max}	0.8

Conventional MPPT Techniques

Several types of MPPT techniques were implemented based on the simple algorithm and low-cost implementation such as IC and P&O techniques [26]. As presented in Fig. 4, the main mechanism of the IC technique based on the derivative of the power with respect to the voltage. As observed, the operating point of the PV module along the P-V curve is moved to achieve the optimal operating point (MPP) [26]. First, when the ratio of the change in power into the change in voltage is in the left MPP, the module operated with positive sign. Second, when the voltage is increased by increase the duty cycle and observe the power, the MPP is achieved at $\frac{dI_{pv}}{dV_{pv}} = 0$.

Unlike, when the $\frac{dI_{pv}}{dV_{pv}} < 0$, the operating point in the right of the MPP. Therefore, the PV voltage will decrease by decrease the duty cycle to a specific value to return the MPP again. To clear the principle action of the IC technique, the flowchart of the IC as in Fig.5, is presented where, the PV panel voltage can be adjust to the MPP by calculating the ratio of $\frac{dI_{pv}}{dV_{pv}}$ and instantaneous value of $\frac{I_{pv}}{V_{pv}}$ and making use of above equations [27,28].

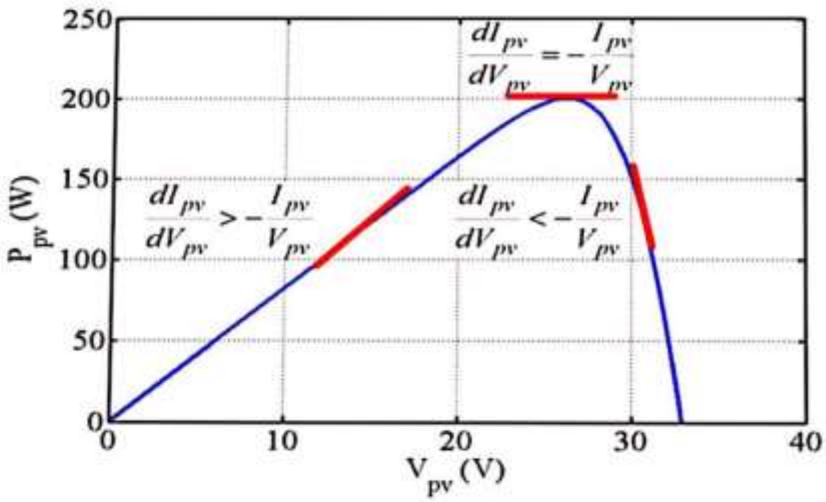


FIGURE 4. IC MPPT technique mechanism.

The main disadvantages of the IC technique, it fails to make a well decision when irradiance is changed faster. For this reason, this paper considered the soft computing based fuzzy logic and neural network are used in simulation to improve the dynamic performance and increase the system efficiency of the PV module instead of conventional IC method.

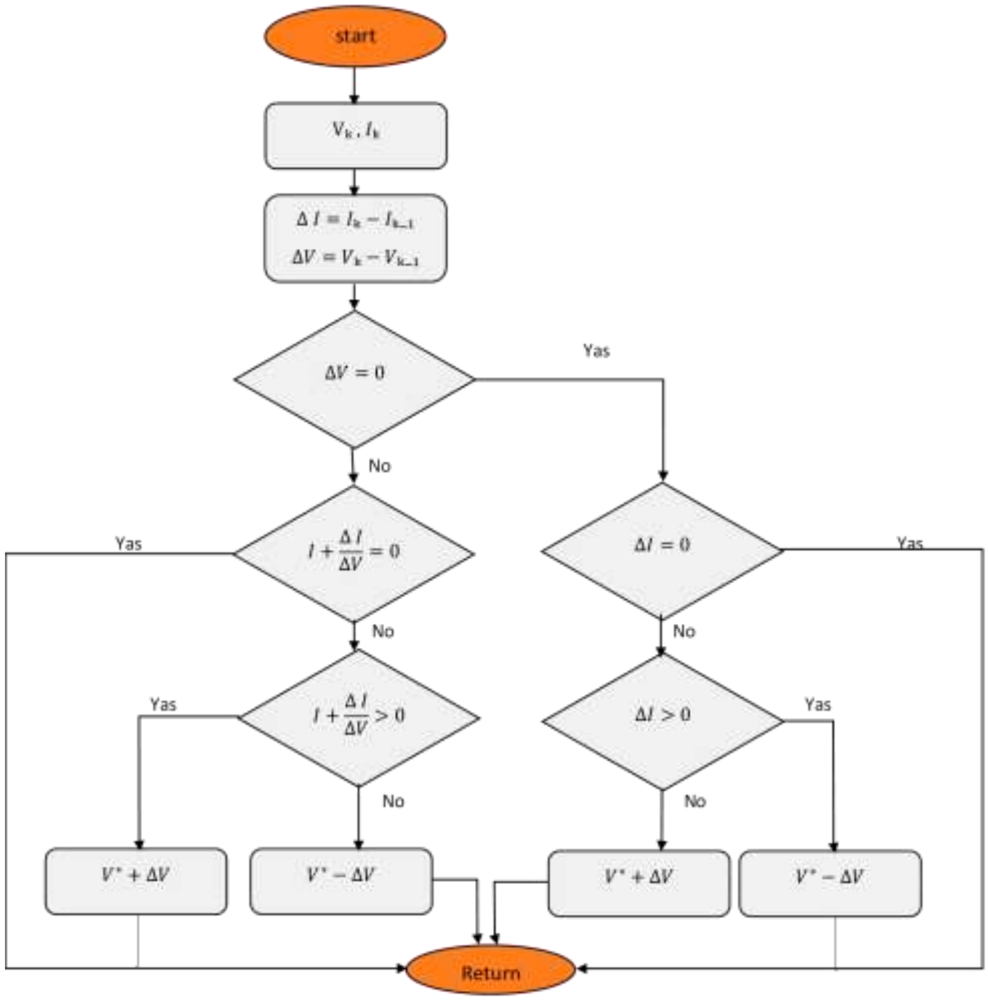


FIGURE 5. IC-MPPT flowchart.

Soft Computing MPPT Techniques

Artificial intelligence techniques, characterized by many characteristics, including the ability to analyze and engineer the manufacture of smart machines, and the ability of this system to analyze data correctly, directly and logically, and work to achieve certain goals. These characteristics can be employed by working in data analysis, working in areas of machine learning, working in advanced science and research centers, and supervising computer and robotics work.In this paper, soft computing based fuzzy logic and neural network MPPT are used to enhance and improve the performance of the PV module and then increase the system efficiency by reduce the power oscillation in steady state conditions.

However, a FL-MPPT is considered one of the most widely MPPT technique used to extract the peak power from the solar systems since it has several advantages such as no need of exact theoretical model of the system, it can work with indefinite inputs, and nonlinearity [29-31]. Unlike, there are some disadvantages in this technique which is formulation of the input and output membership functions is depended on the user experience. Today, an adaptive FL Controller is investigated to tune the memberships (MFs) and the table of the rule-base to obtain the optimum performance. The block diagram of the proposed FL used in this study is presented in Fig.6.

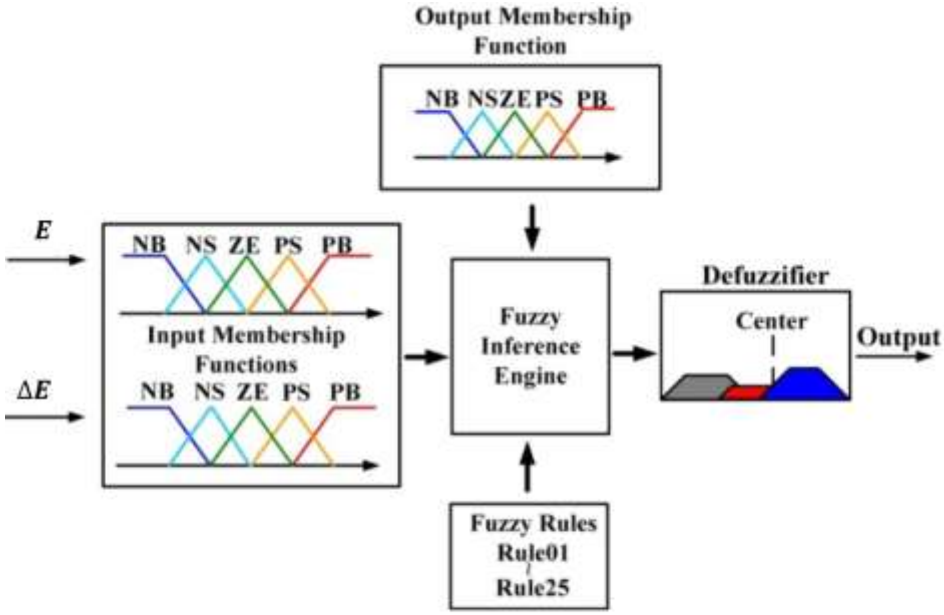


FIGURE 6. proposed FL-MPPT diagram.

In this study, the two inputs of the error E and the change in the error ΔE were used to implement the proposed FL algorithm. While the change in the duty cycle ΔD was used as output of the FL algorithm. So, the error can be expressed as,

$$E = \frac{P(k) - P(k-1)}{V(k) - V(k-1)} \tag{13}$$

$$\Delta E = E(k) - E(k-1) \tag{14}$$

Where P(k) and V(k) are the input power and input voltage, respectively and ΔE is the change in error.Furthermore, based on the rules of the FL algorithm decides the next operating point at every change in the voltage and power. In this algorithm, the five different fuzzy levels are used for inputs and output variables which are include negative big NB, negative small NS, zero ZE, positive small PS, and positive big PB). Furthermore, the proposed FL algorithm can be shown in Fig.7 which clear the flowchart and framework of the FL algorithm based MPPT used in this research.

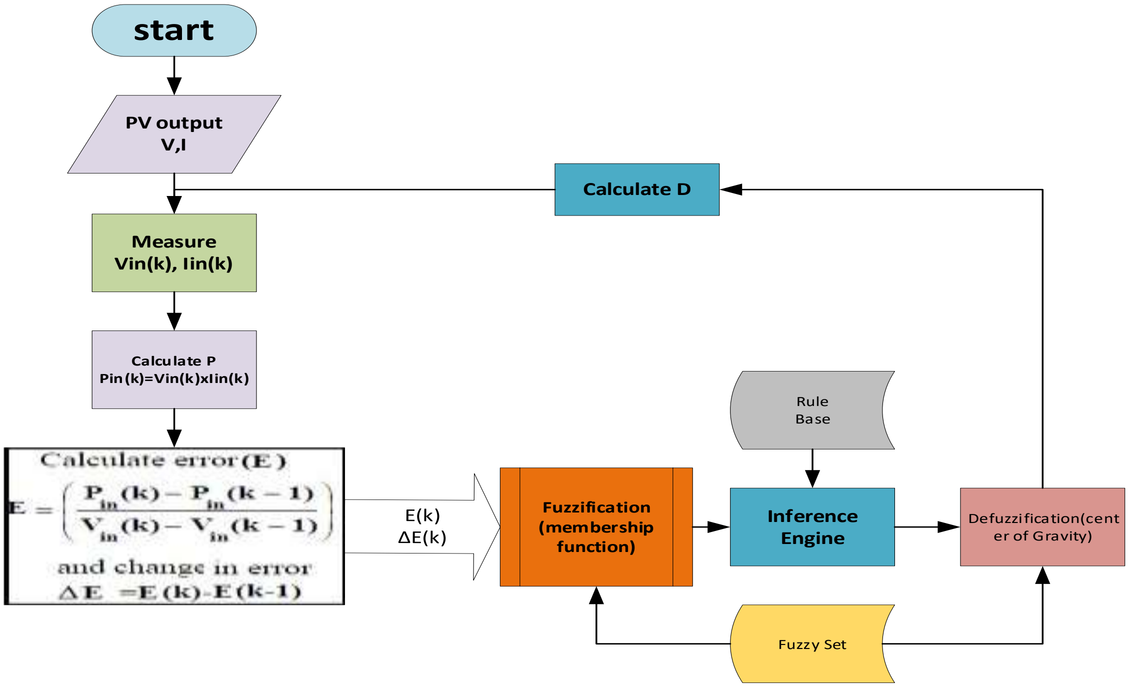


FIGURE 7. Flowchart of the FL based MPPT.

At same time, the Artificial Neural Network (ANN) based MPPT is considered an efficient technique and provide satisfactory accuracy in trucking the maximum power without need of the exact information of the system parameters. The main issue of this technique it is required a specific training in the implementation process to obtain the optimum value for the solar PV system [32-34]. Also, ANN has to be trained in specific time intervals to obtain an efficient and robust tracking for the MPP due to the nonlinear characteristics for the PV system [32]. In this method, the inputs of ANN are the PV voltage and PV current while the output is the duty ratio. Fig.8 illustrated the ANN based MPPT which implemented to generate the optimum duty cycle for the dc/dc boost converter that is connected to the resistive load and then obtaining the maximum power from the PV module. The online training method based backpropagation algorithm was used in this paper to training the ANN method.

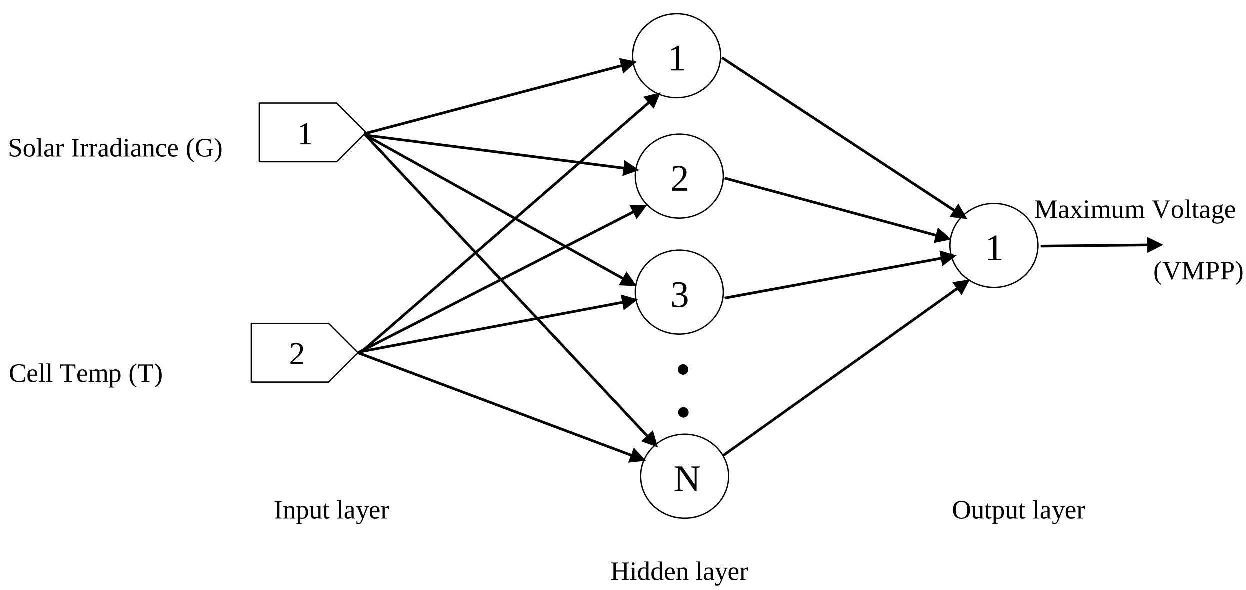


FIGURE 8. The developed ANN configuration used to determine reference voltage at MPP.

In this technique, the input voltage and current are sensed and entered as inputs for the ANN network at different weather conditions. Unlike some of ANN techniques that used in the inputs of irradiance and temperature. Moreover, the main idea of the ANN-MPPT is the input data receives the inputs while the second layer and hidden layer contain many hidden neurons which send the input data to the third layer. In addition, the third layer generates the optimum output to the system which is the duty cycle. Also, Eqs. (15 and 16) reports the input and output layers as follows [32]:

$$y_i^h = f\left(\sum_{i=1}^{N} W_{ij}\, X_i + \theta_j^h\right) \tag{15}$$

$$y_k^o = f\left(\sum_{j=1}^{N} W_{kj}\, Y_i^h + \theta_k^o\right) \tag{16}$$

The parameters of the of the above equations can be summarized below ,

- y_i^h is the output signal values
- X_i is the input signal values
- W_{kj} and $W_{ij}$are the weights's values between the three layers
- θ_k^o and $\theta_j^h$are the values of the bias for the output layer and hidden layer, respectifly.

RESULTS AND DISCUSSION

To prove the comparative study in this research, the performance of the used MPPT techniques is tested with Matlab/Simulink program. The proposed Simulink diagram is indicated as seen in Fig.9 which represent the model circuit of the PV panel, MPPT algorithm and boost converter circuit. Moreover, all MPPTs are tested with same conditions to obtain the MPP from the PV module under fast step change in irradiance and step change in load conditions. Furthermore, the IC-MPPT algorithm was conducted using the m-file function in Matlab package. Besides, the FL-MPPT algorithm was modeled using Matlab/ Simulink by sensing the voltage and current of the PV panel and then compute the PV power which is used to estimate the error value and the change in this error as seen in Fig.10. In the same study, the proposed ANN method is modeled using Simulink as seen in Fig.11. as illustrated in Fig.12, the change in the PV power is estimated and then this change is feed to find the optimum MPP. When the MPP is obtained the present voltage and global maximum power is used to find the optimum duty ratio.

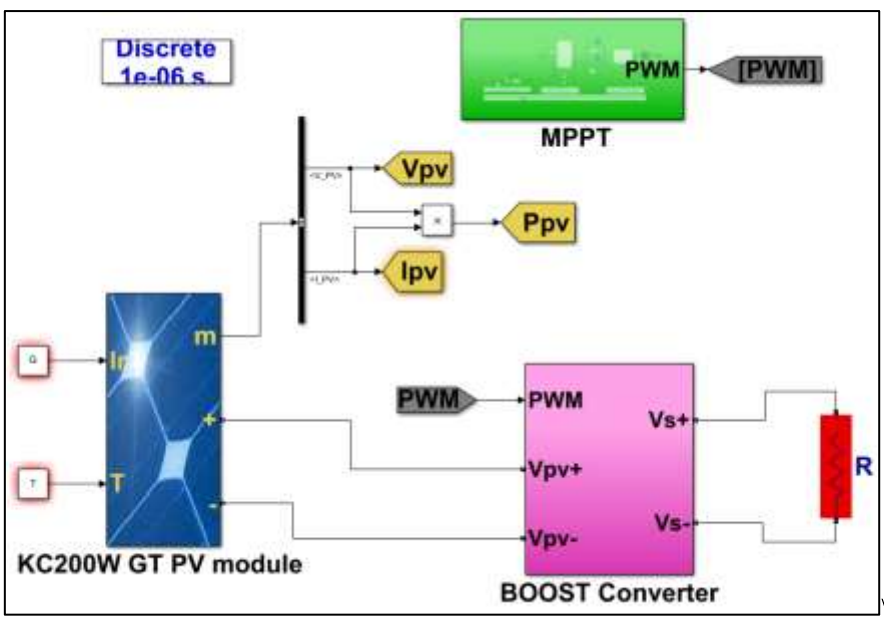


FIGURE 9. Matlab diagram of the proposed system.

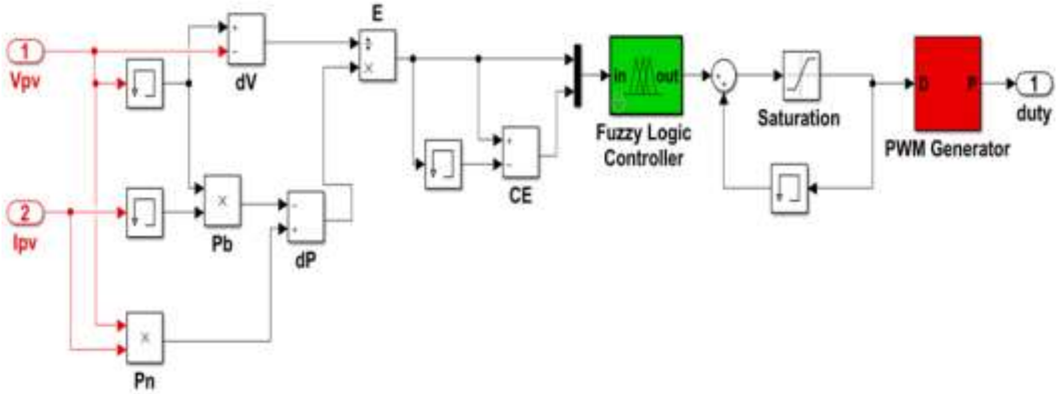


FIGURE 10. Fuzzy logic MPPT technique model under Matlab/Simulink.

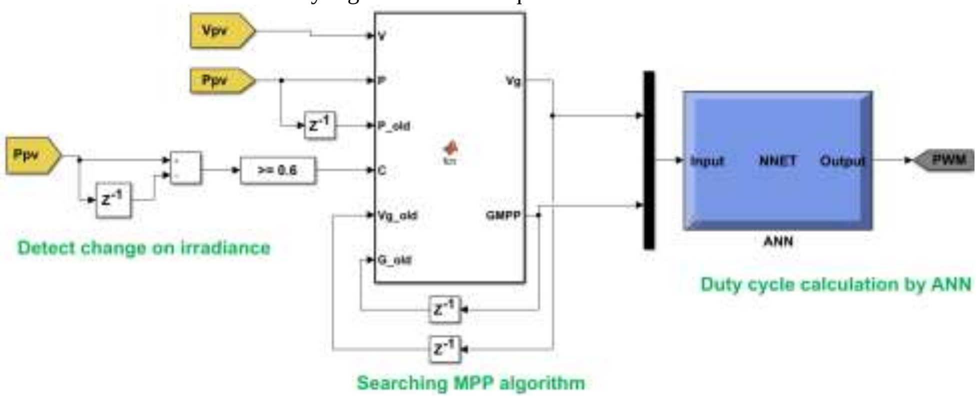


FIGURE 11. Proposed ANN method based MPPT.

In order to verify the used MPPTs, two scenarios are studied in this paper as follows:

Performance under Different Values of Irradiance

In order to find the difference between the most used MPPT and the soft computing methods, their performance is tested under the fast varying values of irradiance G with keeps the system works with fixed temperature value T=25°C. As indicated in Fig.12, irradiation value was varied from lower level of G=250W/m² at time t=0sec to t=0.06sec and it is increased from G=250W/m² to G=500W/m² at t=0.06sec, and then, the irradiance is increased to the STC value of G=1000W/m² for period t=0.12sec.

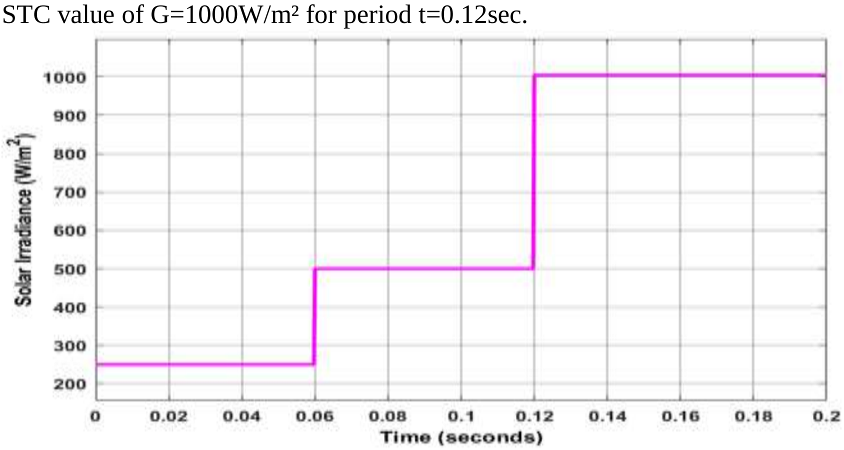


FIGURE 12. Proposed solar irradiance profile.

First, the conventional IC technique is simulated where the PV power is tracked according to its theoretical maximum value as seen in Fig.13. As conducted in this figure, the PV power is less than the maximum value and it has more oscillation around the MPP point which decreased the system efficiency. Also, in IC technique the tracking power is reached to its maximum after t=0.02sec. accordantly, the IC method results large oscillation in steady state power values and also it produces low the speed for the response.

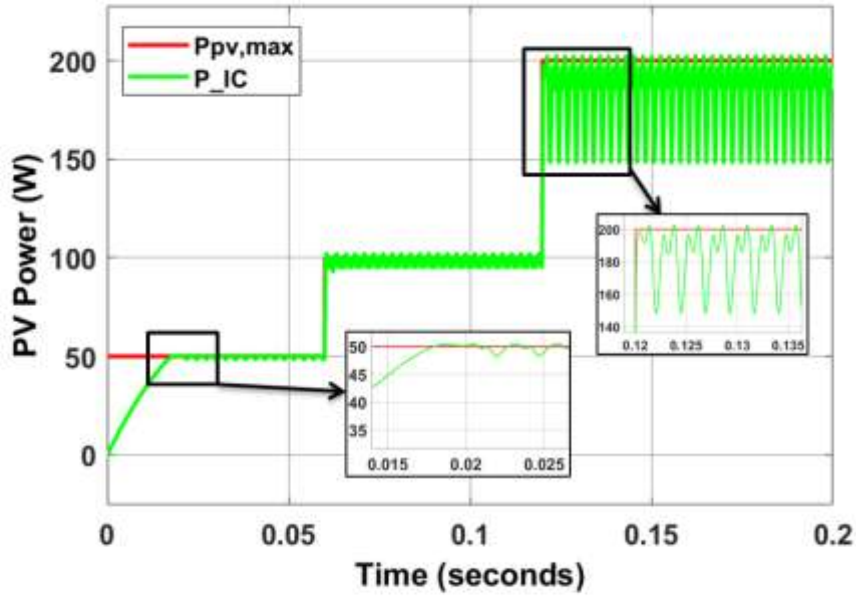


FIGURE 13. PV power with its theorical maximum value using IC MPPT technique.

Fig.14 presents the obtained results of the PV panel and output boost converter voltages under IC MPPT technique. As seen, the large ripple content in PV and boost voltages is occurred due to the oscillation of the MPPT algorithm which produce more loss in power and effect on the output load conditions. The average output voltage of the boost converter is about 80V at irradiation value of 1000W/m2. Also, Fig. 15 presents the output and input (PV current) currents for the boost converter at different solar irradiance. Some ripple is presents in the output current of the boost which is stepdown the PV current to 2.4A at 1000W/m2.

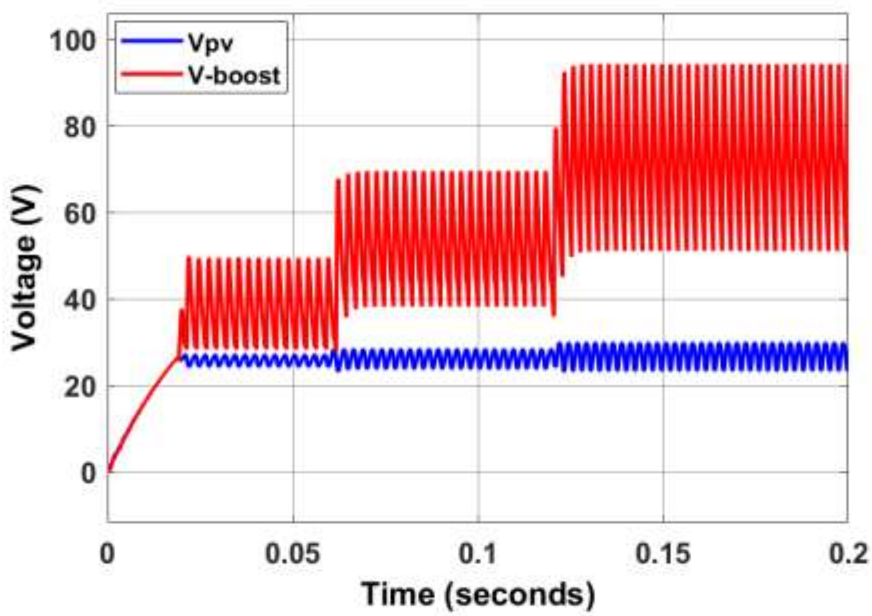


FIGURE 14. The obtained voltages using IC method.

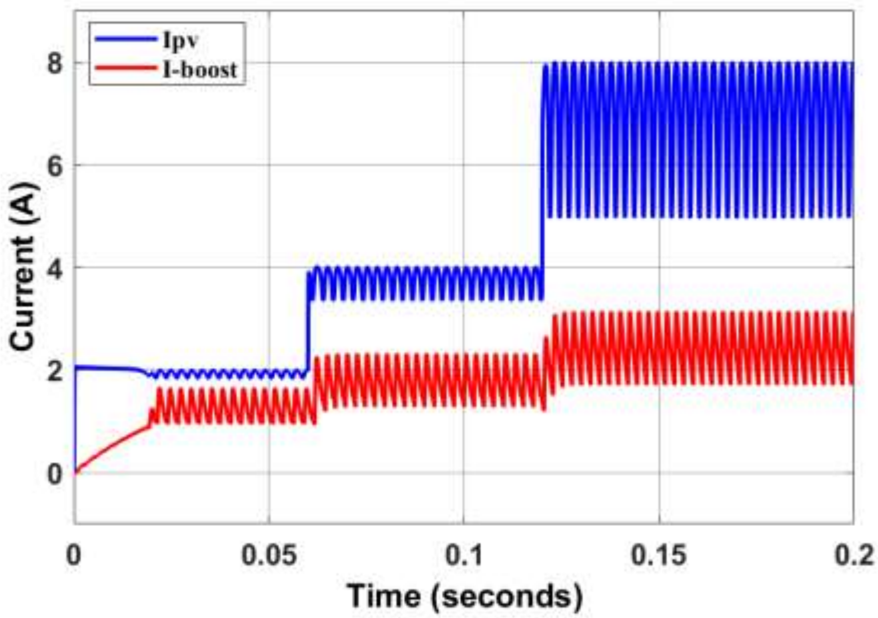


FIGURE 15. Results of the currents using IC method.

Fig. 16 shows the simulation results of the PV power using FL-MPPT technique . as observed, good performance is achieved using FL-MPPT technique according to the theoretical power of the PV module. Moreover, the FL has been shown good results compared to the conventional IC method in terms of oscillation, power loss, and response speed. Figs. (17 and 18) show the simulation results of the voltage and current for the input PV module and output boost converter. As seen in these figures, the ripple content in output side is improved by FL technique which lead to enhance the efficiency and produce a smooth waveforms for the load.

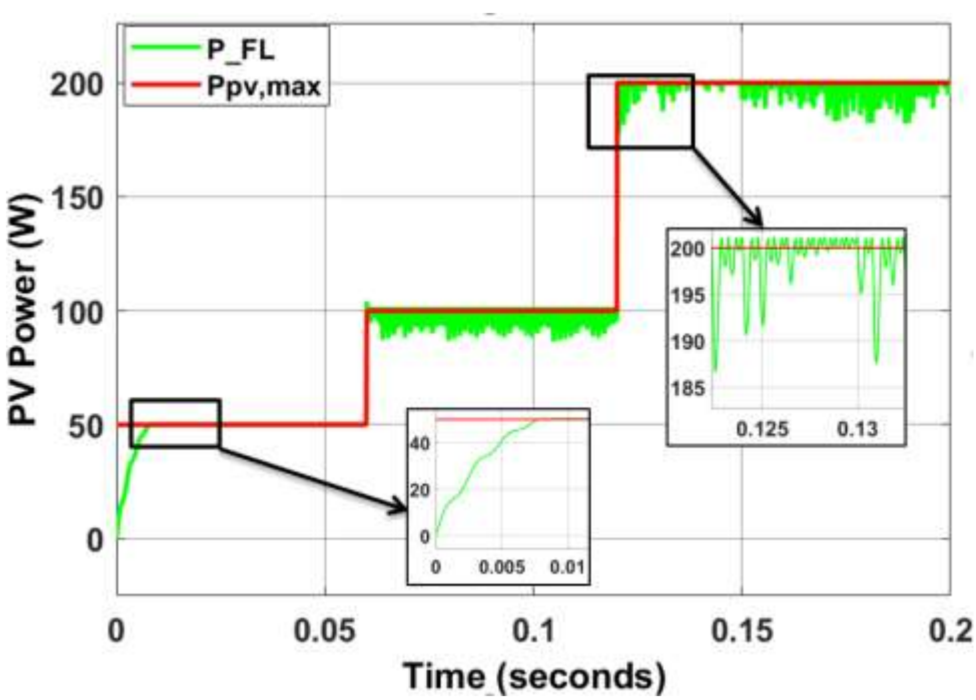


FIGURE 16. PV power with its theorical maximum value using FL-MPPT technique.

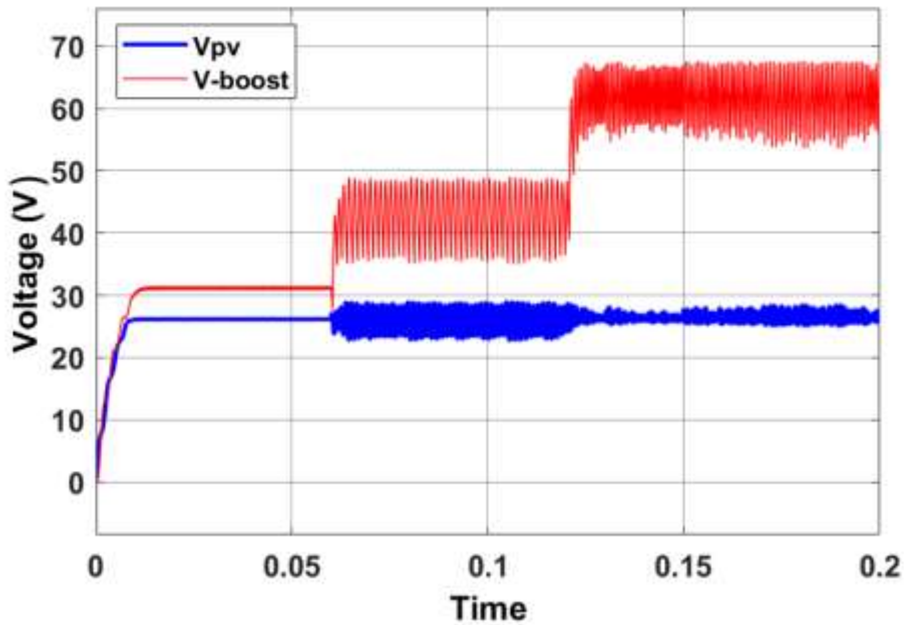


FIGURE 17. The obtained results of the voltages using FL method.

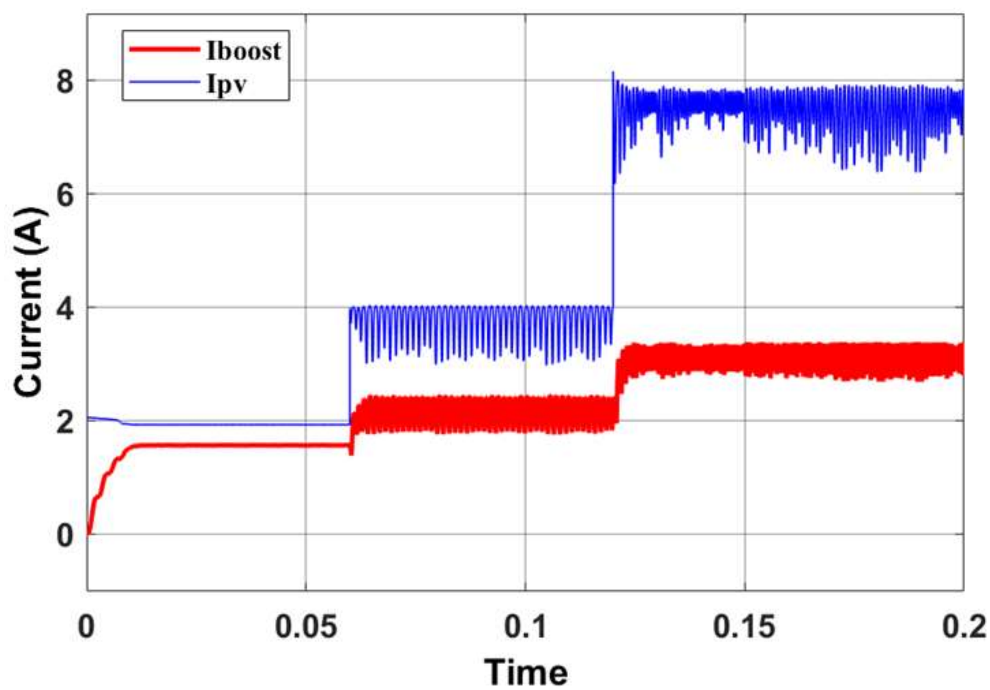


FIGURE 18. The results of the currents using FL method.

Fig. 19 shows the result PV power using the ANN method. As seen, the ANN-MPPT technique was represented the best choice for the PV module that used in PV system when it operation with high irradiance levels which is has low oscillation, high speed response compared to IC and FL techniques. But this method is generated a low dynamic response in case of low irradiance level which is produce low output power in PV module and then decrease the efficiency. unlike, more smooth results in voltage and current of output boost converter are obtained in case of ANN as compared to other used methods as seen in Figs.(20 and 21).

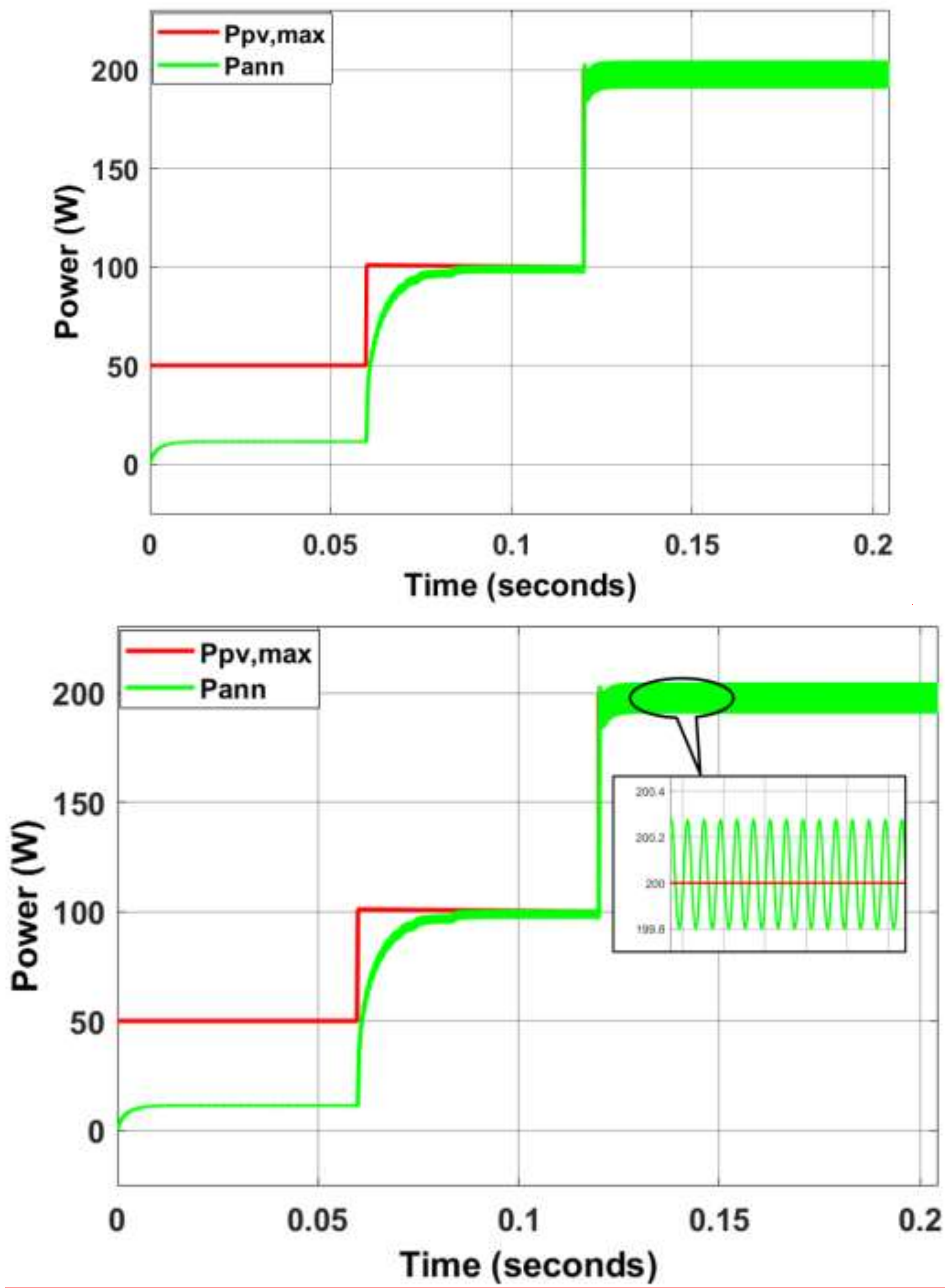


FIGURE 19. PV power with its theorical maximum value using ANN- MPPT technique.

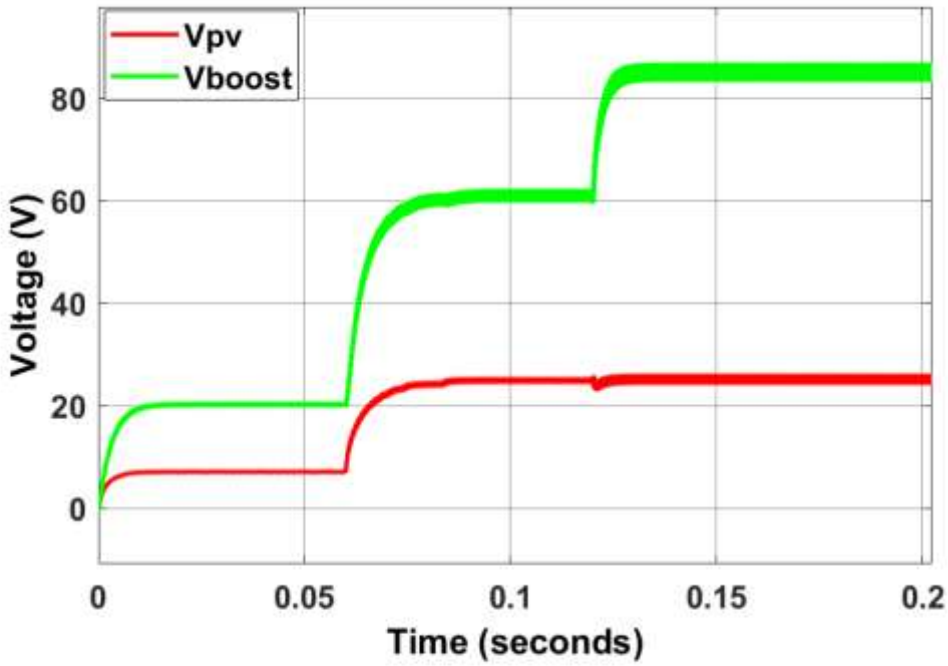


FIGURE 20. MATLAB results of the voltages using ANN technique.

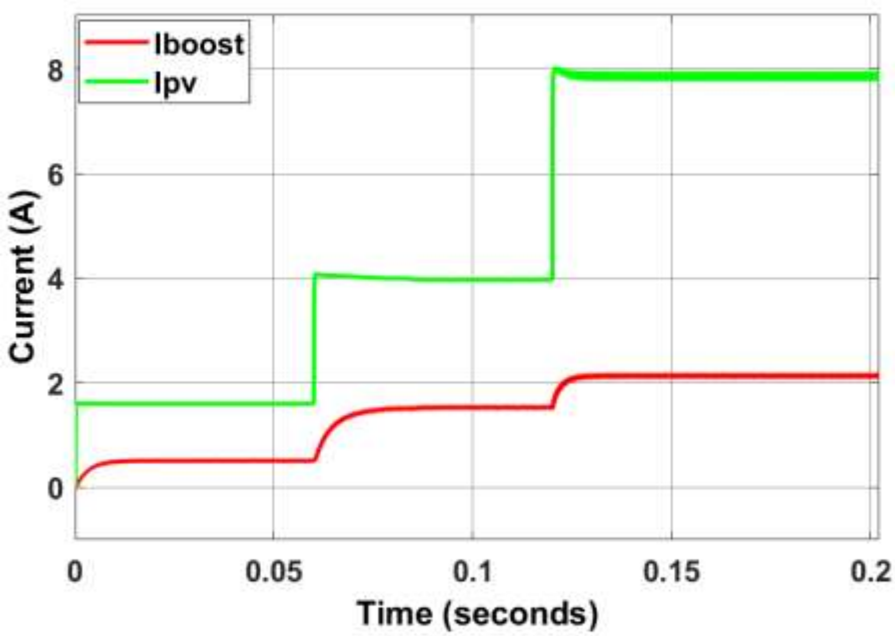


FIGURE 21. The simulation results of the currents using ANN technique.

Performance under Different Load Conditions

As discussed before, the used MPPTs are validated under different load conditions to see the difference between them in terms of efficiency, and response's speed. Therefore, the pure resistive DC load is connected across the boost converter. This load is changed by changing the resistance value during the simulation as presented in Fig.22. Therefore, Fig. 23 shows the simulation results of the PV module using conventional IC method. As seen, the IC method presents high ripple oscillation the voltage, current and power which reduced the overall system efficiency. Also, when the load resistance is varied from 40Ω to 20Ω, the steady state PV power is decreased from 200W to 100 W at end of the interval, and this due to the reduction in the PV current.

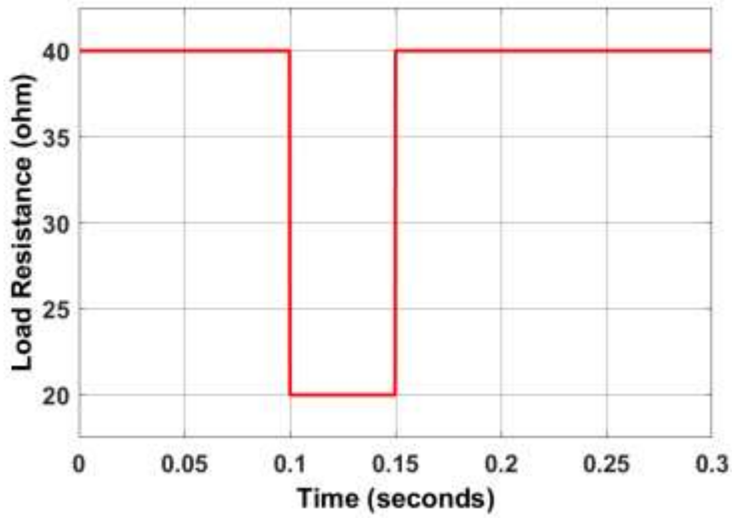


FIGURE 22. Fast change in load resistance value under simulation.

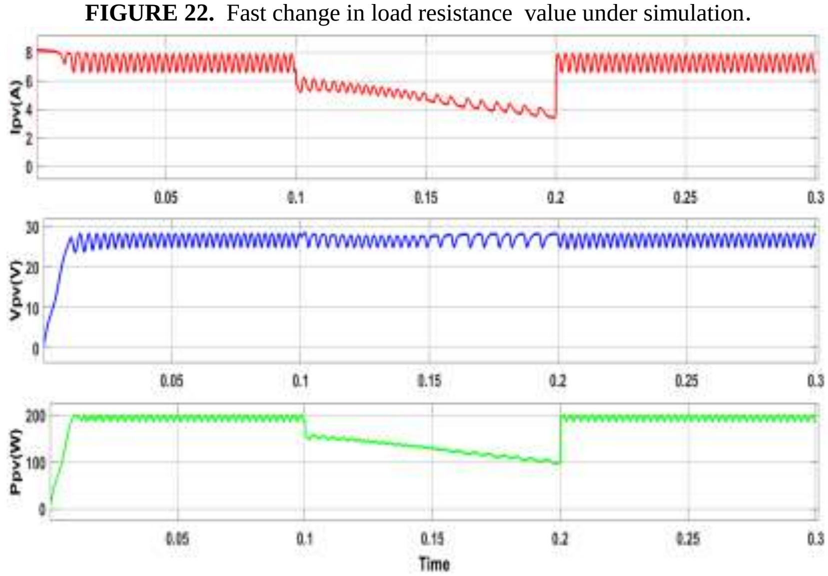


FIGURE 23. Simulation results of the PV module under conventional IC method.

Furthermore, the FL-MPPT has been tested under the same load profile and it is producing a well results when the resistance is decreased to lower value as seen in Fig.24. As seen, there are some ripples in the PV current but this doesn't affect on the output power which is maximized into 200W under this load conditions. As a result, more efficient and accurate method using FL is presented and it suitable for the PV module under different load conditions. While the proposed ANN method has been shown acceptable results in terms of different load condions. It results good results in terms of oscillation in steady state operation compared than the conventional IC method but it considered less efficient in terms of response to the changing in the load as presented in Fig.25. Finally, the PV module can be improved by using FL-MMPT which is considered the best choice for the MPPT under different load conditions and low irradiance levels.

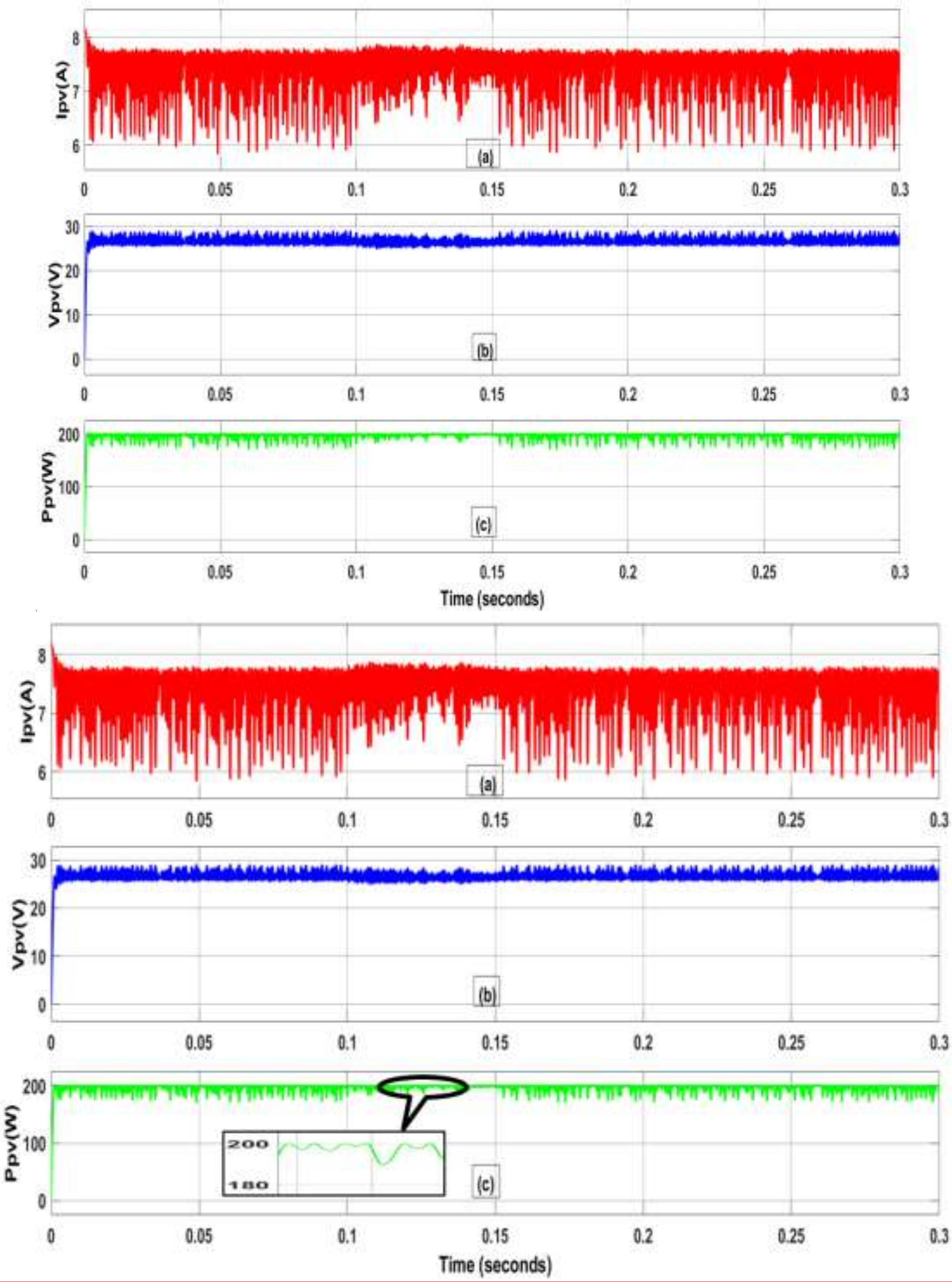


FIGURE 24. The obtained results of the PV module under proposed FL-MPPT method.

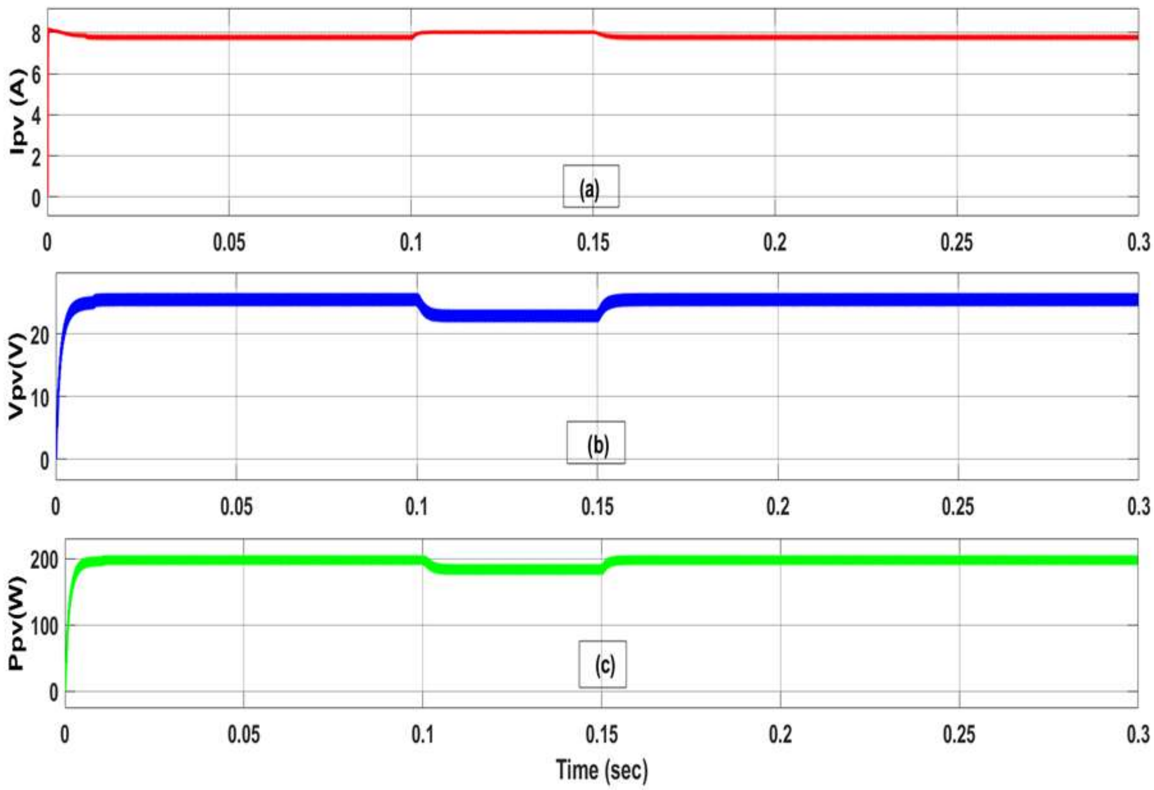


FIGURE 25. The obtained results of the PV module under conventional ANN method.

CONCLUSION

In this research, a comparative study between the soft computing MPPT techniques types an artificial neural network (ANN), and fuzzy logic (FL) and conventional incremental conductance (IC) technique for a 200W PV module is presented. The studied PV module type KC200GT is modeled in MATLAB software and it was simulated under different load and irradiance conditions to seen the performance of these methods. First, the used MPPTs are validated for fast change in solar irradiance for simulation time 0.2 seconds, where irradiance has been varied from 250W/m² to 500W/m² and then increased to 1000W/m² value at constant temperature C=25℃. The simulation results shown that the soft computing techniques have low oscillation in steady state power, fast speed and higher efficiency compared to the results of the IC technique. Second, the studied MPPTs are tested under fast change in the load resistance value which is varied from 40Ω to 20Ω during the simulation. From the obtained results, the proposed ANN technique was shown acceptable results in terms the oscillation in steady state operation compared than the conventional IC method but it considered less efficient in terms of response to the changing in the load. Unlike, the FL-MPPT presents good results in terms of power loss, oscillation, and speed of trucking which is considered the best choice for the MPPT under different load conditions.

REFERENCES

1. Qazi, A., Hussain, F., Rahim, N. A., Hardaker, G., Alghazzawi, D., Shaban, K., & Haruna, K. (2019). Towards sustainable energy: a systematic review of renewable energy sources, technologies, and public opinions. IEEE Access, 7, 63837-63851.
2. Sinsel, S. R., Riemke, R. L., & Hoffmann, V. H. (2020). Challenges and solution technologies for the integration of variable renewable energy sources—a review. renewable energy, 145, 2271-2285.
3. Sinsel, S. R., Riemke, R. L., & Hoffmann, V. H. (2020). Challenges and solution technologies for the integration of variable renewable energy sources—a review. renewable energy, 145, 2271-2285.

4. Nwambaekwe, K. C., John-Denk, V., Douman, S. F., Mathumba, P., Yussuf, S. T., Uhuo, O. V., & Iwuoha, E. I. (2021). Crystal engineering and thin-film deposition strategies towards improving the performance of kesterite photovoltaic cell. Journal of Materials Research and Technology.
5. Chalh A, El Hammoumi A, Motahhir S, El Ghzizal A, Subramaniam U, Derouich A. "Trusted Simulation Using Proteus Model for a PV System: Test Case of an Improved HC MPPT Algorithm" Energies, vol.13, no.8, Jan. 2020.
6. Motahhir, S., El Hammoumi, A., & El Ghzizal, A. (2020). The most used MPPT algorithms: Review and the suitable low-cost embedded board for each algorithm. Journal of cleaner production, 246, 118983.
7. Saleh, A. L., Obed, A. A., Hassoun, Z. A., & Yaqoob, S. J. "Modeling and Simulation of A Low Cost Perturb& Observe and Incremental Conductance MPPT Techniques In Proteus Software Based on Flyback Converter" In IOP Conference Series: Materials Science and Engineering ,vol. 881, no. 1, p. 012152). IOP Publishing, Jul. 2020.
8. Baimel, D., Tapuchi, S., Levron, Y., & Belikov, J. "Improved fractional open circuit voltage MPPT methods for PV systems" Electronics, vol.8, no.3. 2019.
9. Shang, L., Guo, H., & Zhu, W. "An improved MPPT control strategy based on incremental conductance algorithm". Protection and Control of Modern Power Systems, vol. 5, no. 1, 1-8. 2020.
10. Yaqoob, S. J., Hussein, A. R., & Saleh, A. L. "Low Cost and Simple P&O-MPP Tracker Using Flyback Converter" Solid State Technology, vol.63, no. 6, 9676-9689. 2020.
11. Sher, H. A., Murtaza, A. F., Noman, A., Addoweesh, K. E., Al-Haddad, K., & Chiaberge, M "A new sensorless hybrid MPPT algorithm based on fractional short-circuit current measurement and P&O MPPT" IEEE Transactions on sustainable energy, vol.6, no.4, 1426-1434. 2015.
12. Kermadi M, Berkouk EM. "Artificial intelligence-based maximum power point tracking controllers for Photovoltaic systems: Comparative study" Renewable and Sustainable Energy Reviews. Vol.69:pp.369-86. Mar. 2017
13. Nasser, K. W., Yaqoob, S. J., & Hassoun, Z. A. "Improved dynamic performance of photovoltaic panel using fuzzy logic-MPPT algorithm" Indonesian Journal of Electrical Engineering and Computer Science, vol.21, no.2, pp.617-624. 2021.
14. Liu, C.L., Chen, J.H., Liu, Y.H. and Yang, Z.Z., "An asymmetrical fuzzy-logic-control-based MPPT algorithm for photovoltaic systems" Energies, vol.7, no.4, pp.2177-2193. 2014.
15. Jiang, M., Ghahremani, M., Dadfar, S., Chi, H., Abdallah, Y. N., & Furukawa, N. "A novel combinatorial hybrid SFL–PS algorithm based neural network with perturb and observe for the MPPT controller of a hybrid PV-storage system" Control Engineering Practice, No.114, pp.104880. 2021.
16. Robles Algarín, C., Taborda Giraldo, J., & Rodriguez Alvarez, O. (2017). Fuzzy logic based MPPT controller for a PV system. Energies, 10(12), 2036.
17. Rezk, H., Aly, M., Al-Dhaifallah, M., & Shoyama, M. (2019). Design and hardware implementation of new adaptive fuzzy logic-based MPPT control method for photovoltaic applications. Ieee Access, 7, 106427-106438.
18. Jyothy, L. P., & Sindhu, M. R. (2018, February). An artificial neural network based MPPT algorithm for solar PV system. In 2018 4th International Conference on Electrical Energy Systems (ICEES) (pp. 375-380). IEEE.
19. Yaqoob, S. J., Motahhir, S., & Agyekum, E. B. (2021). A new model for a photovoltaic panel using Proteus software tool under arbitrary environmental conditions. Journal of Cleaner Production, 130074.
20. Rasheed, M., Al-Darraji, M. N., Shihab, S., Rashid, A., & Rashid, T. (2021, July). The numerical Calculations of Single-Diode Solar Cell Modeling Parameters. In Journal of Physics: Conference Series (Vol. 1963, No. 1, p. 012058). IOP Publishing.
21. Rasheed, M. S., & Shihab, S. (2020). Analysis of Mathematical Modeling of PV Cell with Numerical Algorithm. Advanced Energy Conversion Materials, 70-79.
22. Yaqoob, S. J., Saleh, A. L., Motahhir, S., Agyekum, E. B., Nayyar, A., & Qureshi, B. (2021). Comparative study with practical validation of photovoltaic monocrystalline module for single and double diode models. Scientific reports, 11(1), 1-14.
23. Jyothy, L. P., & Sindhu, M. R. (2018, February). An artificial neural network based MPPT algorithm for solar PV system. In 2018 4th International Conference on Electrical Energy Systems (ICEES) (pp. 375-380). IEEE.
24. Motahhir, S., El Ghzizal, A., Sebti, S., & Derouich, A. (2018). Modeling of photovoltaic system with modified incremental conductance algorithm for fast changes of irradiance. International Journal of Photoenergy, 2018.
25. Shaw, P. (2019). Modelling and analysis of an analogue MPPT-based PV battery charging system utilising dc–dc boost converter. IET Renewable Power Generation, 13(11), 1958-1967.

26. Xuesong, Z., Daichun, S., Youjie, M., & Deshu, C. (2010, August). The simulation and design for MPPT of PV system based on incremental conductance method. In 2010 WASE international conference on information engineering (Vol. 2, pp. 314-317). IEEE.
27. Putri, R. I., Wibowo, S., & Rifa'i, M. (2015). Maximum power point tracking for photovoltaic using incremental conductance method. Energy Procedia, 68, 22-30.
28. Safari, A., & Mekhilef, S. (2010). Simulation and hardware implementation of incremental conductance MPPT with direct control method using cuk converter. IEEE transactions on industrial electronics, 58(4), 1154-1161.
29. Rezk, H., Aly, M., Al-Dhaifallah, M., & Shoyama, M. (2019). Design and hardware implementation of new adaptive fuzzy logic-based MPPT control method for photovoltaic applications. Ieee Access, 7, 106427-106438.
30. Robles Algarín, C., Taborda Giraldo, J., & Rodriguez Alvarez, O. (2017). Fuzzy logic based MPPT controller for a PV system. Energies, 10(12), 2036.
31. Prasad, C. B., Sonam, S. K., Reddy, B. R. G., & Harika, P. (2017, June). A fuzzy logic based MPPT method for solar power generation. In 2017 International Conference on Intelligent Computing and Control Systems (ICICCS) (pp. 1182-1186). IEEE.
32. Rizzo, S. A., & Scelba, G. (2015). ANN based MPPT method for rapidly variable shading conditions. Applied Energy, 145, 124-132.
33. Ali, M. N., Mahmoud, K., Lehtonen, M., & Darwish, M. M. (2021). Promising MPPT Methods Combining Metaheuristic, Fuzzy-Logic and ANN Techniques for Grid-Connected Photovoltaic. Sensors, 21(4), 1244.
34. Kulaksız, A. A., & Akkaya, R. (2012). A genetic algorithm optimized ANN-based MPPT algorithm for a stand-alone PV system with induction motor drive. Solar Energy, 86(9), 2366-2375.