湖南大学学报（自然科学版）
Journal of Hunan University (Natural Sciences)

第 50 卷 第 2 期
2023 年 2 月

Available online at http://jonuns.com/index.php/journal/index

Vol. 50 No. 2
February 2023

Open Access Article

https://doi.org/10.55463/issn.1674-2974.50.2.7

A Hybrid GWO-MPO-Based Maximum Power Point Tracking for Photovoltaic System for a New MLI with Minimum Number of Switches

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Received: December 18, 2022 ▪ Review: January 4, 2023 ▪ Accepted: February 10, 2023 ▪ Published: February 27, 2023

Abstract: Photovoltaic (PV) systems provide a number of challenges, one of the most critical of which is determining how to extract the maximum amount of usable power from the PV system even when the system is running in conditions of fast change in irradiance. This study aims to demonstrate a novel hybrid approach to maximum power point tracking (MPPT), which is built on the grey wolf optimization algorithm (GWO) and modified perturb and observe (MP&O) techniques. The second goal of this method is to provide a robust MPPT method with minimum losses in the MPP point of the PV module. This technique is based on the connection of a single KC200GT PV module. The KC200GT PV module is connected to the DC bus via DC/DC boost converter to raise the voltage and implement the MPPT algorithm. After that, the PV system was integrated to supply a new multilevel inverter (MLI) with a reduced number of switches. Additionally, the MATLAB/Simulink environment was used to demonstrate and evaluate the efficacy of the proposed MPPT approach. Complex fast changes in solar irradiation are applied to the module to verify the feasibility and efficacy of the hybrid method by comparing its performance to that of the P&O, and MP&O algorithms. The obtained results demonstrated that the hybrid GWO-MP&O MPPT method achieved an excellent level of efficacy in terms of MPP accuracy, convergence speed (0.05 sec), and overall tracking efficiency (99.7%) compared to other approaches.

Keywords: Grey Wolf Optimizer, maximum power point, boost converter, photovoltaic system, multilevel inverter, perturb and observe.

基于混合GWO-MPO的光伏系统最大功率点跟踪，适用于具有最少开关数量的新型多边语言

摘要：光伏系统面临许多挑战，其中最关键的挑战之一是确定如何从光伏系统中提取最大量的可用功率，即使系统在辐照度快速变化的条件下运行也是如此。本研究旨在展示一种新的最大功率点跟踪混合方法，该方法建立在灰狼优化算法和改进的扰动观察技术之上。该方法的第二个目标是提供一种稳健的最大功率点跟踪方法，使光伏模块的最大功率点损失最小。该技术基于单个KC200GT光伏模块的连接。KC200GT光伏模块通过直流/直流升压变换器连接到直流母线，提升电压，实现最大功率点跟踪算法。之后，集成了光伏系统以提供开关数量减少的新型多级逆变器。此外，还使用软件/仿真链接环境来演示和评估所提出的最大

功率点跟踪方法的功效。将太阳辐射的复杂快速变化应用于模块，通过将其性能与常规扰动观察和改进的扰动观察算法进行比较，验证混合方法的可行性和有效性。获得的结果表明，混合灰狼优化-
修正扰动和观察最大功率点跟踪方法在最大功率点精度、收敛速度（0.05秒）和整体跟踪效率（99.7%）方面取得了优异的效果。其他方法.

关键词：灰狼优化器、最大功率点、升压转换器、光伏系统、多电平逆变器、扰动观察.

1. Introduction

In recent few years, renewable energy, and solar energy in particular, is a significant and potential alternative power source for electric power production. Solar power is a great option since it may provide unlimited, clean energy with no environmental impact. Compared to other types of energy, it is the most readily available [1, 2]. Solar-to-electricity conversion has various potential uses, including transportation, marine, residential, aviation, and spacecraft [3]. This is why many people believe that solar energy will play a significant role in the global electricity production in the next decades. The usage of a photovoltaic (PV) system is one way to collect this energy [4, 5]. PV systems may be used independently or tied into the main power supply. It is certain that the penetration of PV systems on the utility grid or standalone operation will expand further, particularly on low and medium-voltage grids [6].

Moreover, the rapidly decreasing cost of PV modules, improvements in power electronics, and government incentives toward PV systems. Researchers are looking into more advanced PV systems to find ways to make and use PV systems that work better [7, 8]. Maximum power point tracking (MPPT) control is one of the developed methods for increasing the efficiency of PV systems. The MPPT is a device consisting of DC/DC converter and a suitable MPPT algorithm embedded in a microcontroller. Many factors, including cost, reaction time, complexity, oscillation around the MPP, and sensors, must be considered when deciding on an MPPT method. Such methods include perturb and observe (P&O) [9, 10], Incremental Conductance (INC) [11, 12], and Hill Climbing (HC) [13].Unfortunately, these methods fell short when trying to precisely monitor the global maximum power point (GMPP) under varying levels of irradiance. Additionally, these methods, do not discriminate between the GMPP) and a local MPP (LMPP) when the partial shading conditions (PSCs) occur. As a result, various MPPT-based optimization techniques have recently been published to predict the GMPP and improve the PV array's efficiency under PSCs. Such algorithms include: Genetic Algorithm (GA) [14], Cuckoo Search (CS) [15, 16], Particle Swarm Optimization (PSO) [17, 18], Ant Colony Optimization (ACO) [19], and Mine Blast Optimization (MBO) [20]. Besides, it has been observed from previous studies that most researchers have considered just a single optimization algorithm to detect the GMPP under PSCs. Nonetheless, optimization strategies grounded on swarm intelligence (SI) such ant bee colony (ABC) [21], ACO, and PSO have been used in the creation of MPPT controllers as well. They have substantial advantages, such as less computational effort and independence from intrinsic system factors, but they lack flexibility due to this necessity. However, earlier studies propose hybrid methods that boost the efficiency of the PSO-based MPPT algorithm when dealing with PSCs in PV plants, such as the ABC with PO (ABC-PO) [22] and the PSO with P&O (PSO-PO) [23].

Grey wolf optimization algorithm (GWO) is one of the SI family that emulates the hierarchy leadership and hunting technicality of grey wolves as proposed by Mirjalili et al [24]. The GWO-based MPPT is used in different studies to track the MPP and then increase the performance of the solar systems under uniform and non-uniform irradiation conditions. The authors in [25] proposed a hybrid GWO-PO-based MPP to enhance the performance of the PV modules under PSCs. This hybridization-based P&O algorithm, which has several issues such as low response, and failure under a fast change in irradiation. For this reason, the GWO algorithm is integrated with a modified PO (MPO) method to increase the PV system's efficiency under normal and PSC conditions. Moreover, to the author's knowledge, there is no previous work in the literature that deals with the hybrid GWO-MPO for MPPT in PV systems. In addition, the proposed technique directly modifies the duty cycle without the need to use a linear compensator in this work's MPPT controller, which simplifies the process and removes any computing overhead with adjusting the compensator gains. With these advantages, the suggested GWO-MPO-based MPPT technique can be seen as a promising prospect for PV systems working in both uniform and non-uniform irradiance circumstances.

The novelty of this paper is seeking to contribute to the new hybrid MPPT method and the following finding clearly this novelty:

1. Propose a new MPPT-based GWO and MP&O methods.
2. Increase the efficiency of the PV module under different weather conditions.
3. Minimize the power fluctuation under fast changes in irradiance.
4. Present a new MLI with a minimum number of switches.

2. Proposed System Description

2.1. System Structure

Fig. 1 displays the proposed PV system structure along with DC/DC power converter (boost converter), the PV panel type KC200GT (200 W), the proposed hybrid GWO-MP&O based MPPT, MLI with a minimum number of switches, the inverter's control scheme, and output load. The PV module is managed and interfaced with the boost converter circuit to apply the MPPT algorithm that is based on the suggested GWO-MP&O MPPT controller.

By using the DC/DC boost converter in this situation, the aim is to enhance and increase the output voltage of the PV system from 26.3 V to 100 V on the DC bus side. In addition, the goal of the PWM control is to provide a suitable sinusoidal PWM pulse for the proposed MLI inverter. The resistive load is connected with the inverter using seven levels of the output voltage.

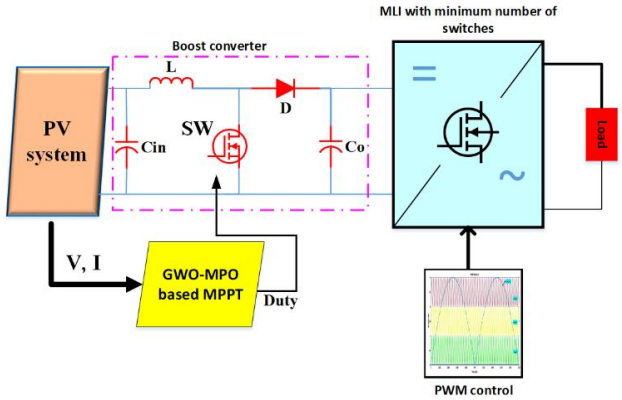


Fig. 1 The proposed system structure

2.2. Photovoltaic Module Model

By virtue of the photovoltaic effect, the PV cell accomplishes the direct transformation of solar energy into electrical energy. Since a typical PV cell generates between 1 and 2 watts of electricity [26], the output power of PV cells may be increased by configuring the cells into modules. As a result, the model of a single diode, which can be shown in Fig. 2, is used in this study, which considers the most equivalent circuit for the PV cell or module [27]. This model represented by the photocurrent, diode, parallel resistor, and series resistor. The output current of the module can be given as in Equation 1.

$$I_{PV} = N_P I_{Ph} - N_P I_0 \left[\exp\left[\frac{q}{V\,KT}\left(\frac{V_{PV}}{N_S} + \frac{I_{PV} R_{sm}}{N_P}\right)\right] - 1\right] - \frac{N_P}{R_{pm}}\left(\frac{V_{PV}}{N_S} + \frac{I_{PV} R_{sm}}{N_P}\right) \quad (1)$$

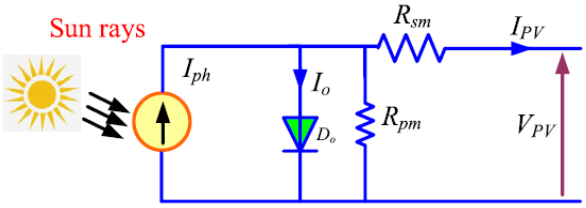


Fig. 2 Single-diode model of the PV module [27]

The above items can be represented by the following description:

- I_{PV} - the array's current.
- V_{PV} - the array's voltage.
- I_{Ph} - the photo current of the array.
- I_o - the diode current in the case of saturation.
- R_{sm} - the series resistor.
- R_{pm} - the parallel-resistor
- T - the ambient temperature.
- N_P - the number of parallel strings.
- N_S - the number of module strings.
- V - the thermal voltage.
- K - the Boltzmann constant $(1.380653 \times 10^{-23} J/K)$.
- q - the electron's charge $(1.60217646 \times 10^{-19} C)$

As discussed before, in this work, one PV module of KC200GT with 200 W was used to test and verify the proposed hybrid MPPT. The specification of this module under standard test conditions (STC) can be seen in Table 1.

Table 1 Technical electrical datasheet specification of the KC200GT Panel

Parameter	Description
P_{max}	$200\ W$
V_{max}	26.3
I_{max}	$7.6\ A$
V_{oc}	$32.9\ V$
I_{sc}	$8.21\ A$
k_v	$-80\ mA/C$
k_i	$2\ mV/C$
N_{ser}	54

Fig. 3 shows the I-V and P-V characteristics of the KC200GT under different values of irradiance. Also, the I-V and P-V curves of this module under different temperatures can be shown in Fig. 4. As seen in these figures, the solar current is very sensitive to solar

irradiation and this current is decreased by a reduction in the irradiance. The maximum power of 200 W is achieved under G = 1 kW/m², and T = 25 C°, where T is the temperature and G is the solar irradiance.

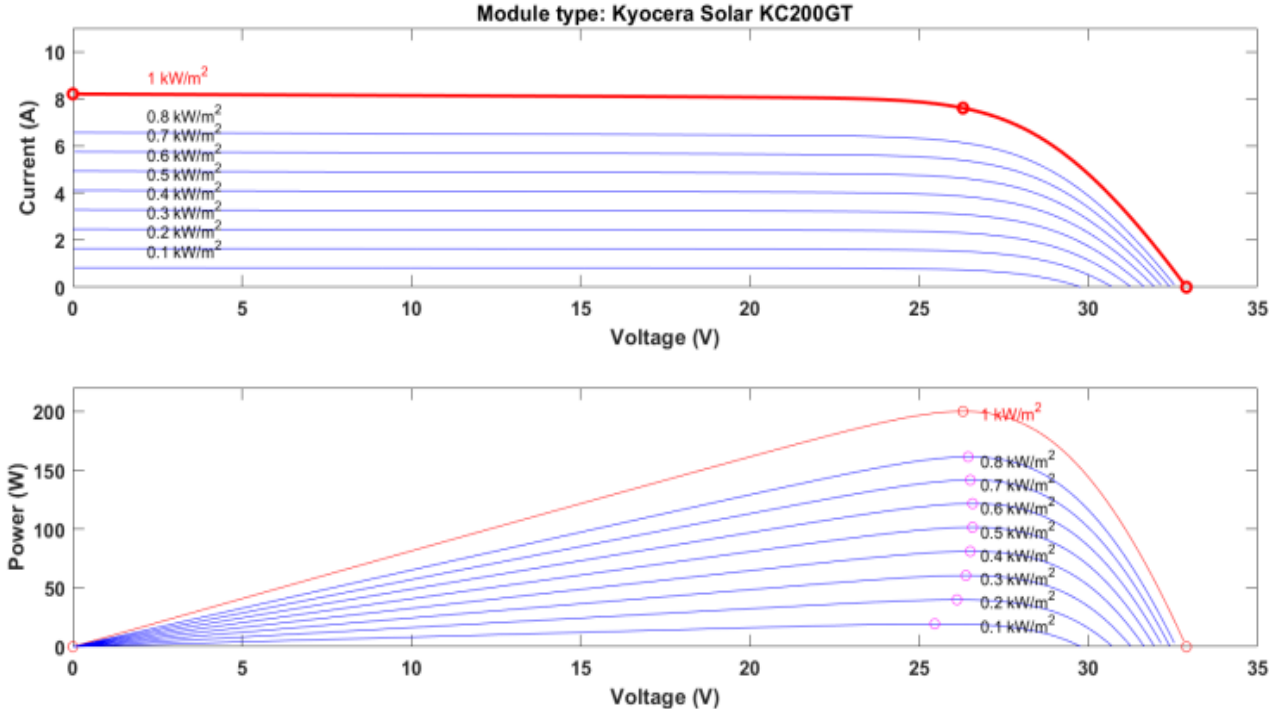


Fig. 3 The I-V and P-V characteristics of the KC200GT under different values of irradiance

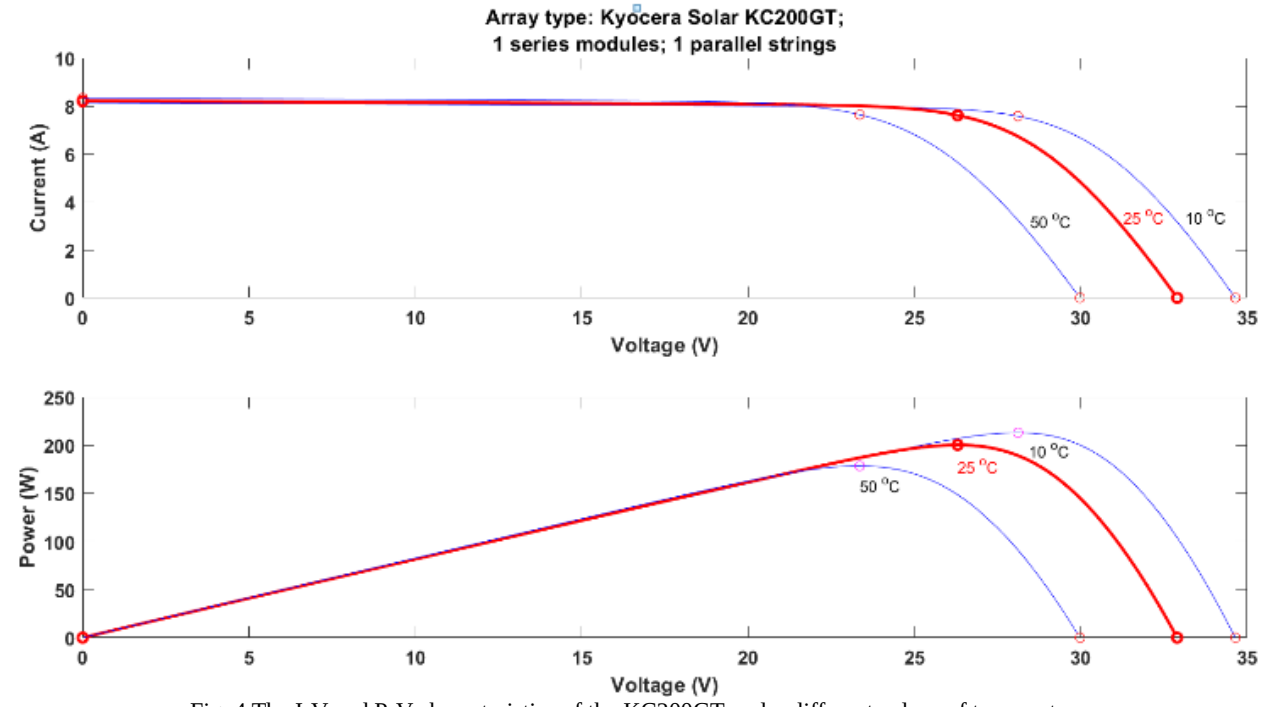


Fig. 4 The I-V and P-V characteristics of the KC200GT under different values of temperature

2.3. DC/DC Boost Converter Design

The DC/DC boost converter is installed in the space between the panel and the multilevel inverter to the load, and it is controlled by the MPPT controller with the use of a duty cycle [28, 29]. This invention intends to rectify the imbalance that currently exists between the PV panel and the load so that the PV panel may perform at its maximum possible efficiency. The electrical circuit of the boost converter is simple and easy to modeling. The simplicity and the low cost may be established are perhaps the most significant benefit of using a boost converter. As seen in Fig. 1, the boost converter circuit consists of a switch such as MOSFET or IGBT, diode, inductor, input capacitor, and output capacitor. The modeling of this converter is performed based on the following equations [29]:

$$L_b = \frac{V_{PV}\ D}{f_s\ \Delta I_{PV}} \tag{2}$$

$$C_{in} \geq \frac{D}{8 \times f_s^{\,2} \times L_b \times 0.01} \quad (3)$$

$$C_{out} = \frac{I_o \; D}{f_s \; \Delta V_o} \quad (4)$$

where L_b is the inductance, C_{in} is the input capacitor which is used to filter the voltage of the PV voltage, C_{out} is the output capacitor, D is the duty ratio, I_o is the output current of the boost converter, ΔV_o is the ripple in the output voltage, f_s is the switching frequency, which is 5000Hz. The parameters of this design are:

$L_b = 0.1\,mH, C_{in} = 1000\,uF,$ and $C_o = 1000\,uF.$

2.4. Design of the Modified P&O Method

In the research done, many MPPT algorithms have been used to extract the greatest amount of power that can be obtained from the PV panel in response to varying amounts of solar irradiation. The P&O algorithm is the ones that are used the most often. This algorithm is designed to change the duty cycle of a boost converter in such a manner that boosted DC voltage may be achieved [30]. This is accomplished by maximizing the efficiency of the boost converter. The perturbation (ΔD) that is introduced by P&O must either have variable step sizes or fixed step sizes to attain the maximum power point. Alterations in the intensity of the radiation might cause problems. The oscillation gives the impression of being in a stable state when the step size (ΔD) is kept constant as seen in the conventional flowchart of Fig. 5.On the other hand, a variable step size will determine the step sizes for automatically, which will lead to less oscillations and faster tracking [30]. In this particular piece of research, made the advantage of a variable step size while working with P&O.

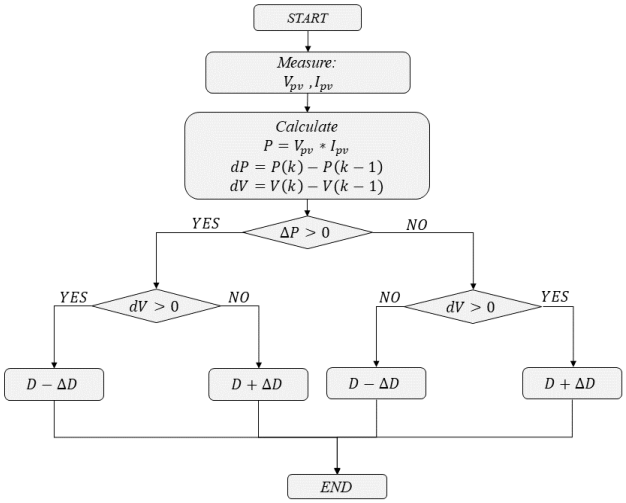


Fig. 5 Flowchart of the conventional P&O MPPT [30]

The MP&O is modified by sensing the change in the output power of the PV module and updating the perturbation based on the following equation:

$$AD = \Delta D(0).|dp| \quad (5)$$

where $\Delta D(0)$ is the initial perturbation of the duty cycle, and dP is the change in the PV power at any irradiance.

To design the MP&O method, the current and voltage of the PV must first be measured. Next, the power is computed and compared to the power that is previously measured. The algorithm produces a perturbation (ΔD) in the duty cycle in response to a change in the PV power. Also, another modification is done in this work, which is modified-loop to avoid the fast ripple in the power due to the quick varying in the irradiance. This can be seen in the flowchart below. As shown, the left side of the MP&O flowchart is added here to make the technique faster than the conventional P&O. The MP&O algorithm's flowchart is shown in Fig. 6.

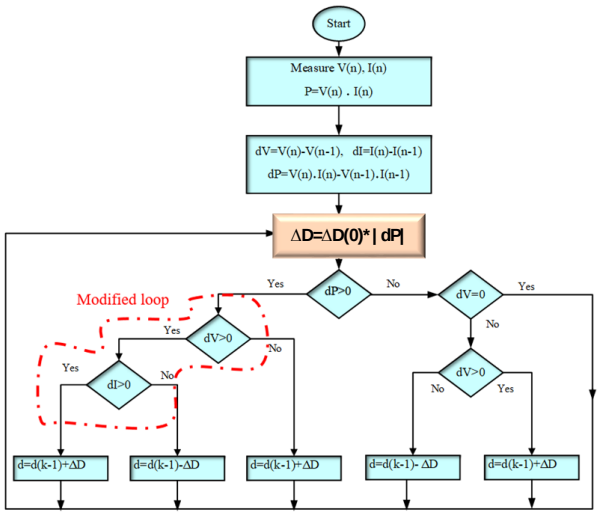


Fig. 6 Flowchart of the MP&O MPPT

2.5. Proposed Hybrid MPPT Method

As described by Mirjalili et al. [24], GWO is a metaheuristic algorithm that simulates the hierarchy, leadership, and hunting technique of gray wolves. The proposed MPPT is designed, as seen in Fig. 7. This work aims to integrate both GWO optimization with modified P&O-based MPPT techniques. The advantage of the GWO is to detect. The global MPPT during the partial shading conditions (PSCs), while the MP&O is used to detect the MPP of the module under uniform conditions. The MP&O MPPT approach, however, does not discriminate between a global MPP (GMPP) and a local MPP (LMPP) when applied to the PSCs. This occurs because it concentrates on the MPP, which is almost always a local MPP. Because of this, there is a significant loss of energy, which may reach up to 70%, which is a significant departure from the targeted ideal energy harvesting. As a result, this combination results in a good response with smooth power oscillation. The duty cycle of the proposed hybrid MPPT is achieved by taking the average duty ratio of these techniques after that detecting the output power of the PV module. Accordingly, the change in the power with a threshold value $P_{(thr)}$ is used to control the duty ratio and minimize the fast change in the duty

cycle that causes more oscillation and slow response. The duty of the hybrid MPPT, $D_{(H)}$ is written as follows:

$$D_{(H)} = \frac{\left(D_{(GWO)} + D_{(MP\&O)}\right)}{2} * P_{(thr)} \quad (6)$$

where $D_{(GWO)}$, $D_{(MP\&O)}$ are the duty cycles of the GWO and MP&O methods, respectively. The $P_{(thr)}$ is taken in this work less than $4\,W$. As a result, this condition makes the proposed MPPT more accurate and robust than the conventional techniques.

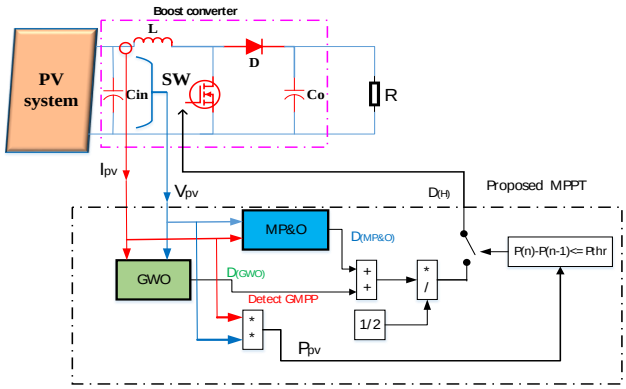


Fig. 7 Hybrid GWO-MP&O-based MPPT method

Furthermore, the design of the proposed MPPT, first the algorithm of the GWO method is analyzed based on the following equations (7-13) [24]. To establish the hierarchy leadership of the grey wolves, this algorithm uses all four levels of leadership available to them. These levels are denoted by their corresponding symbols: omega (ω), beta (β), delta (δ), and alphas (α) [24].

$$\overrightarrow{D_\alpha} = \left|\overrightarrow{C_1}.\ \overrightarrow{X_\alpha} - \vec{X}\right| \quad (7)$$

$$\overrightarrow{D_\beta} = \left|\overrightarrow{C_2}.\ \overrightarrow{X_\beta} - \vec{X}\right| \quad (8)$$

$$\overrightarrow{D_\delta} = \left|\overrightarrow{C_3}.\ \overrightarrow{X_\delta} - \vec{X}\right| \quad (9)$$

$$\overrightarrow{X_1} = \overrightarrow{X_\alpha} - \overrightarrow{A_1}.(\overrightarrow{D_\alpha}) \quad (10)$$

$$\overrightarrow{X_2} = \overrightarrow{X_\beta} - \overrightarrow{A_2}.(\overrightarrow{D_\beta}) \quad (11)$$

$$\overrightarrow{X_3} = \overrightarrow{X_\delta} - \overrightarrow{A_3}.(\overrightarrow{D_\delta}) \quad (12)$$

$$\vec{X}(t+1) = \frac{\overrightarrow{X_1} + \overrightarrow{X_2} + \overrightarrow{X_3}}{3} \quad (13)$$

where $\vec{D}$, $\vec{C}$, and $\vec{A}$ represent the vectors of coefficients, $\vec{X}$ represents the position vector of the grey wolf, $\overrightarrow{X_\alpha}$, $\overrightarrow{X_\beta}$, and $\overrightarrow{X_\delta}$ are the positions of α, β, *and* δ, respectively, t is the current iteration, $\overrightarrow{A_1}$, $\overrightarrow{A_2}$, $\overrightarrow{A_3}$, $\overrightarrow{C_1}$, $\overrightarrow{C_2}$ and $\overrightarrow{C_3}$ are random vectors. The general equations for $\vec{A}$ and $\vec{C}$ are given in Equations 14 and 15.

$$\vec{A} = 2\,\vec{a}.\overrightarrow{r_1} - \vec{a} \quad (14)$$

$$\vec{C} = 2\ \overrightarrow{r_2} \quad (15)$$

where $\vec{a}$ is the ingredient vector that reduces linearly during the iteration process from 2 to 0, $\overrightarrow{r_1}$ and $\overrightarrow{r_2}$ represented by random vectors [0,1]. The update process for the GWO optimizer of search positions in the search space can be seen in Fig. 8. Furthermore, the latest locations are in an arbitrary place in the search space internal a circle, which is performed by the locations of α, β, and δ. As a result, these factors assess prey positions, while other wolves modernize their locations randomly adjacent to the prey.

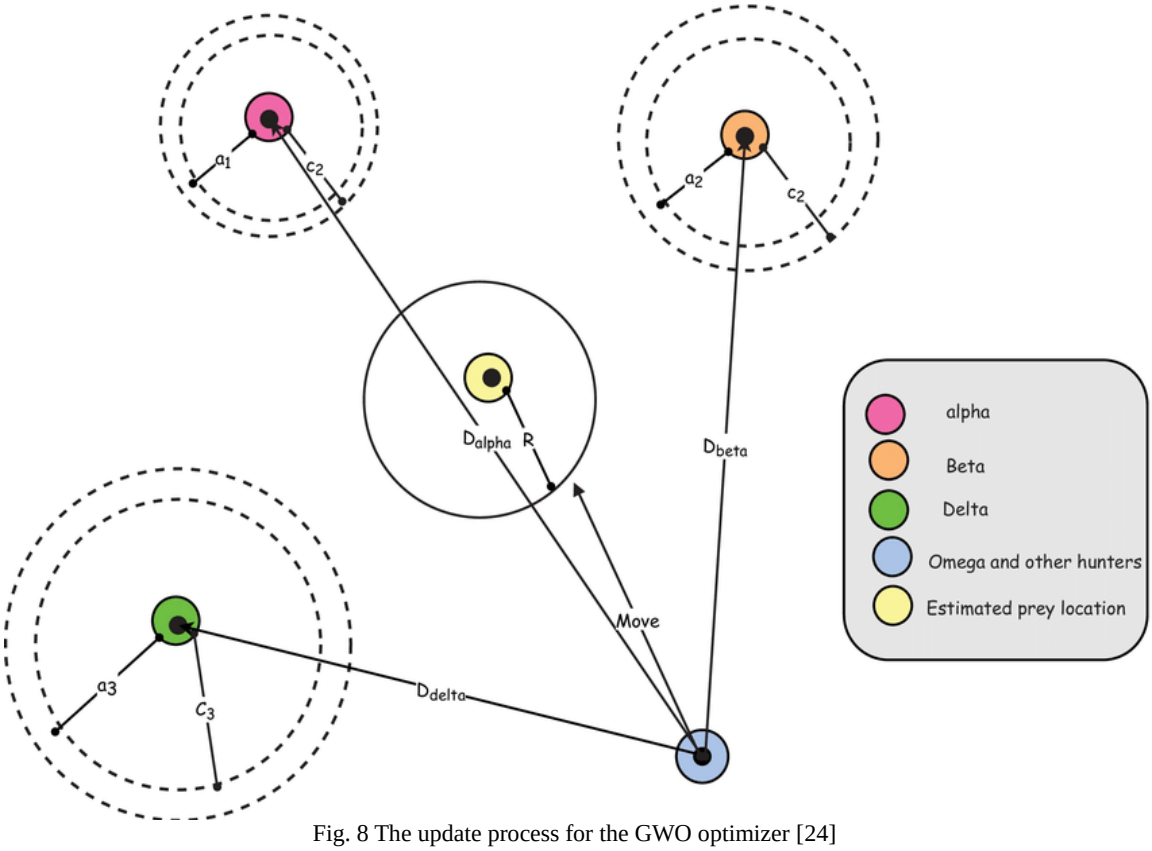


Fig. 8 The update process for the GWO optimizer [24]

The algorithm procedure for the GWO optimization with MP&O can be defined as follows:

1) Initial populations in the search space randomly.

2) α, β, and δ wolves appraise the plausible position of the prey via iterations.

3) $\overrightarrow{"a"}$ is reduced linearly from 2 to 0 to search forprey and abuse prey, individually.

4) Applicant positions tend to move far from the prey while $|\vec{A}| > 1$ and join to the prey while $|\vec{A}| < 1$, as a result, this keeps away from stagnation in the local solutions.

5) The GWO algorithm stops the searching process and sends the best solution to the MPO algorithm when the end paradigm is met.

Fig. 9 displays the flowchart of the proposed GWO-MPO method.

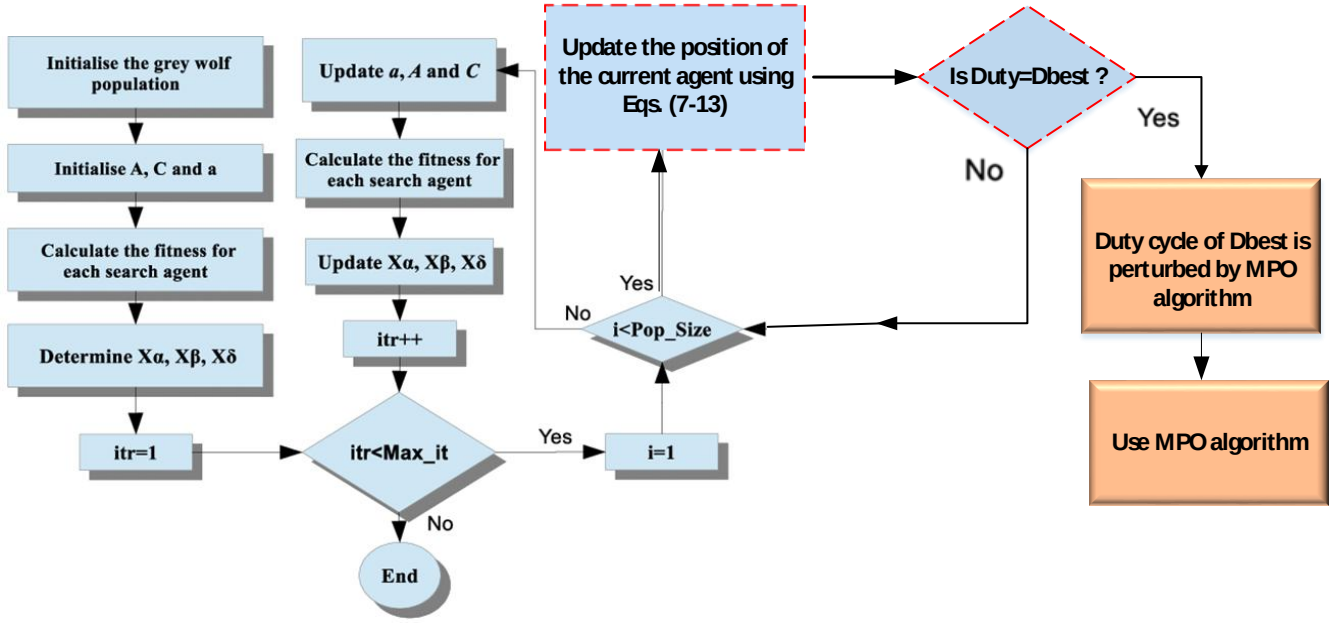


Fig. 9 The hybrid GWO-MP&O MPPT technique

3. Proposed MLI with Reduce Number of Switches

Fig. 10 depicts the multilevel construction with a reduced number of switches that has 7 levels and includes a switched capacitor. A single DC supply, eight switches, two diodes, and two capacitors are parts of the suggested inverter. There are four switches complimentary to one another (S1, S2, S3, and S4). The output of the inverter, denoted by the symbol Van, is proportional to the source voltage (Vd. C). The input voltage (DC voltage) is generated from a PV system of three panels in series to study the PSCs and it is the effect on the performance of the proposed MLI.

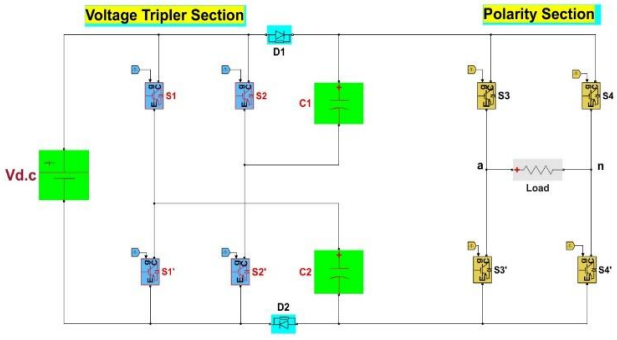


Fig. 10 Proposed 7-level MLI circuit

The proposed MLI is divided into two sections, as shown on the left side of Fig.10; the first component consists of (S1, S2, S1', S2', C1, C2, D1, D2, and source voltage (VD. C). This section is responsible for generating the required levels of the output voltage. The second part of the suggested circuit is a polarity part and is used to generate the required single-phase voltage based on the four switches (S3, S3', S4, and S'4) that are used to invert the polarity of the component (H-bridge). The modes of operation of switches can be summarized in Table 2.

Table 2 Switching states of a proposed 7-level inverter

States	Tripler circuit		Polarity circuit		Capacitors		Van
1	1	0	1	0	Charge	Charge	$+V_{dc}$
2	1	1	1	0	Discharge	Charge	$+2V_{dc}$
3	0	0	1	0	Charge	Discharge	$+2V_{dc}$
4	0	1	1	0	Discharge	Discharge	$+3V_{dc}$
5	0	1	0	0	Idle	Idle	$0\ V$
6	1	0	0	1	Charge	Charge	$-V_{dc}$
7	0	0	0	1	Discharge	Charge	$-2V_{dc}$
8	1	1	0	1	Charge	Discharge	$-2V_{dc}$
9	0	1	0	1	Discharge	Discharge	$-3V_{dc}$

The circuit control method based on the PWM-type phase dispositions technique is used in this paper, as seen in Fig. 11. The proposed control method is based on some logic gates and comparators. The sinusoidal waveform is used to extract the rectified wave, and then this signal is compared with the waveforms based on triangles with the same frequency and phase as seen

in Fig. 12.

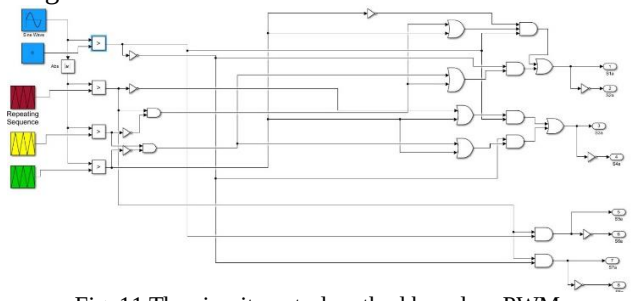


Fig. 11 The circuit control method based on PWM

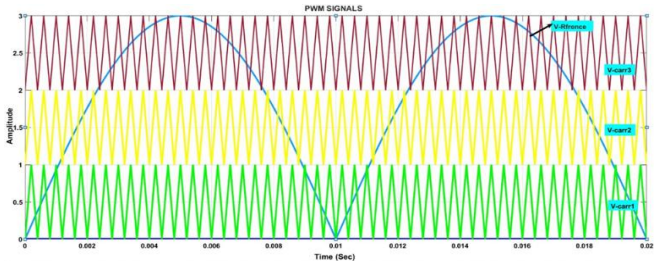


Fig. 12 The rectified wave with the waveforms based on triangle waveforms

4. Results and Discussion

This section describes themodeling and verification of the suggested MPPT method. MATLAB/Simulink is used to test the performance of the KC200GT in simulation under various values of irradiance and constant temperature (T=25 C°). The proposed MPPT is compared with conventional P&O, and MP&O methods in terms of oscillation, and tracking speed. The irradiance and temperature profiles used in this simulation are illustrated in Fig. 13. As seen, in this figure, the solar irradiation is varied from low to high levels for a total simulation time of 3 seconds. An irradiance level with a value of 500 W/m^2 is applied during the time interval (0 - 1sec), and this value is increased from 500 to 1000 W/ m^2 from 1 to 2 sec. Finally, this level is decreased again from high to low level to show the response of the MPPTs.

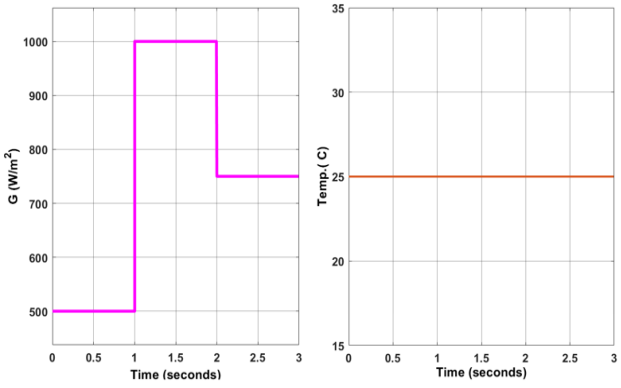


Fig. 13 Irradiance and temperature profiles

Fig. 14 shows the extracted power from the PV module for the proposed GWO-MP&O, MP&O, and P&O MPPT techniques. As seen in this figure, the proposed MPPT offers an excellent response, low oscillation in the output power, and stable dynamic speed. The MP&O is more efficient than the conventional P&O, but it still has issues when the solar irradiance changes quickly. As a result, the tracking efficiency is less than that of the hybrid MPPT, which provides fast speed and a stable power curve at a step change in irradiance.

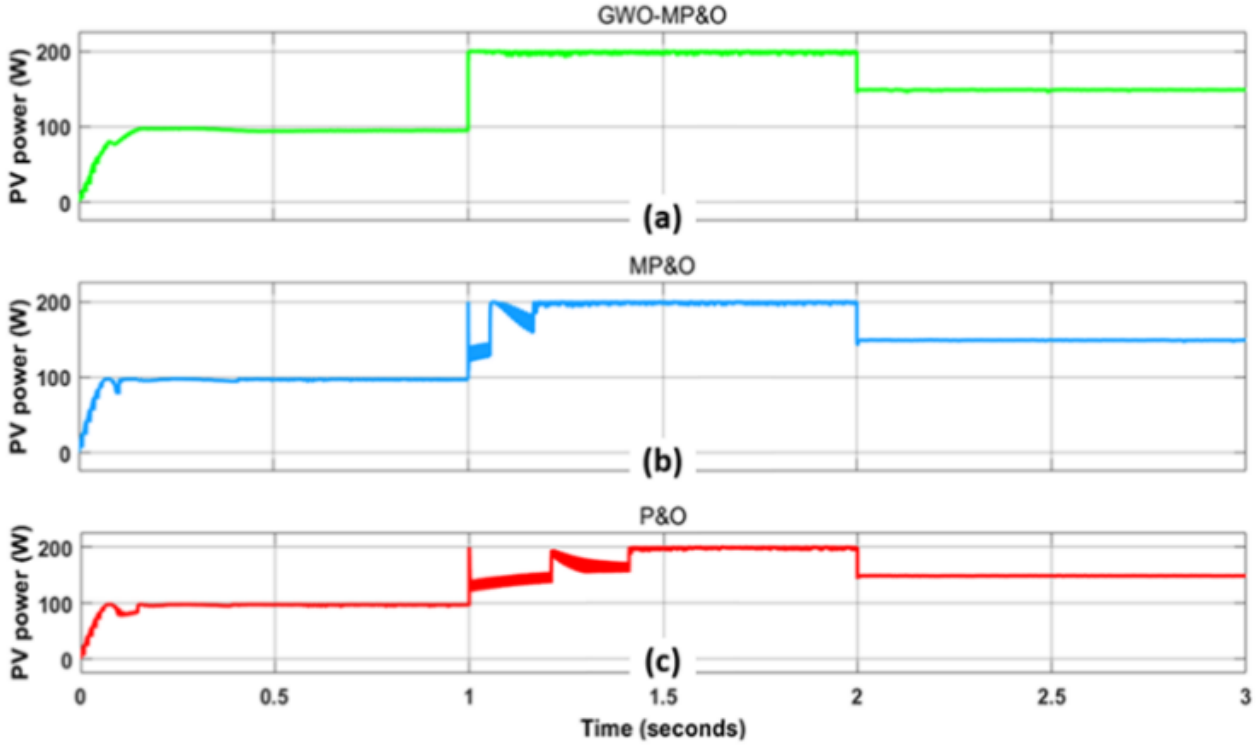


Fig. 14 Power curves of: (a) the proposed GWO-MP&O, (b) MP&O, (c) P&O MPPT methods

The output voltage of the PV module at different weather conditions is seen in Fig. 15. These results were obtained in the three MPPT methods used in this work. As seen, the suggested MPPT methods provide high voltage values and the steady state of this voltage is smooth and it does not influence by changing the solar irradiation against the other MPPT methods.

The conventional P&O has a slow response compared with other methods. Moreover, the output current of the PV module under hybrid MPPT and other methods is displayed in Fig. 16. The suggested MPPT provides a good response, especially at a time interval (1 sec to 2 sec). This variation in the current is small and a high a speed response.

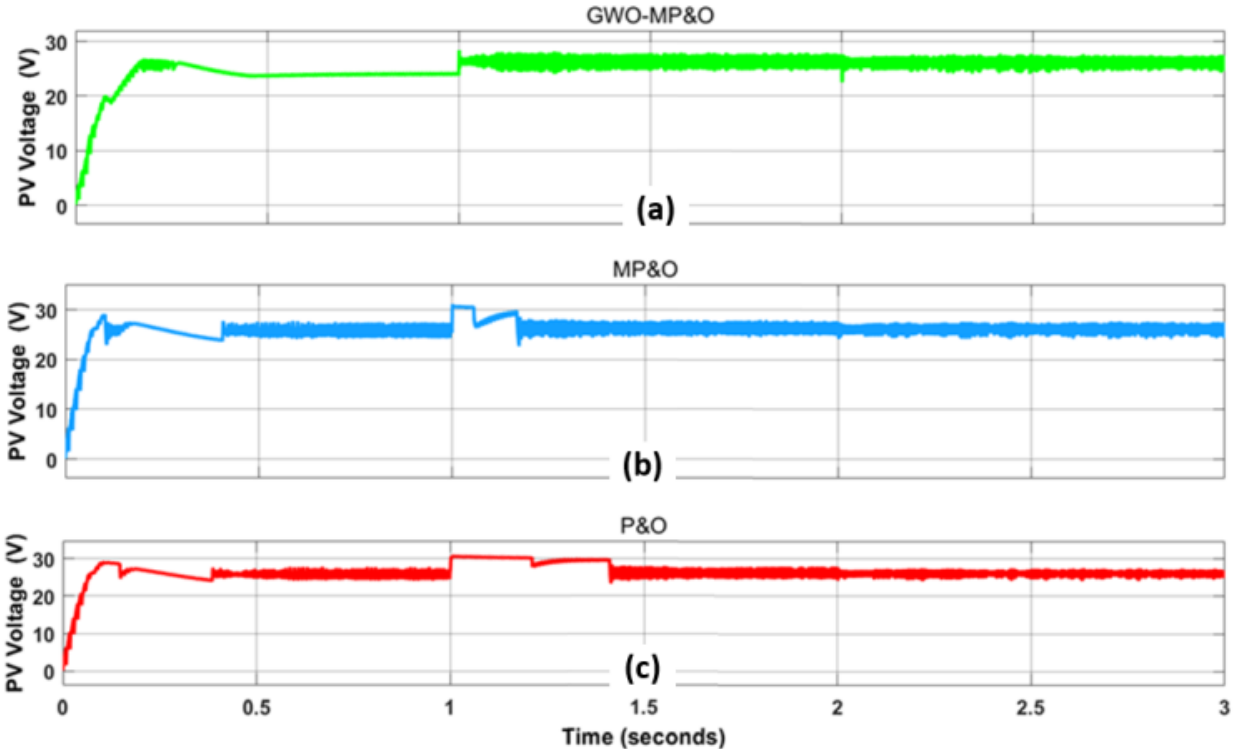


Fig. 15 Output voltage of the PV module from top to bottom: (a) GWO-MP&O, (b) MP&O, (c) P&O methods

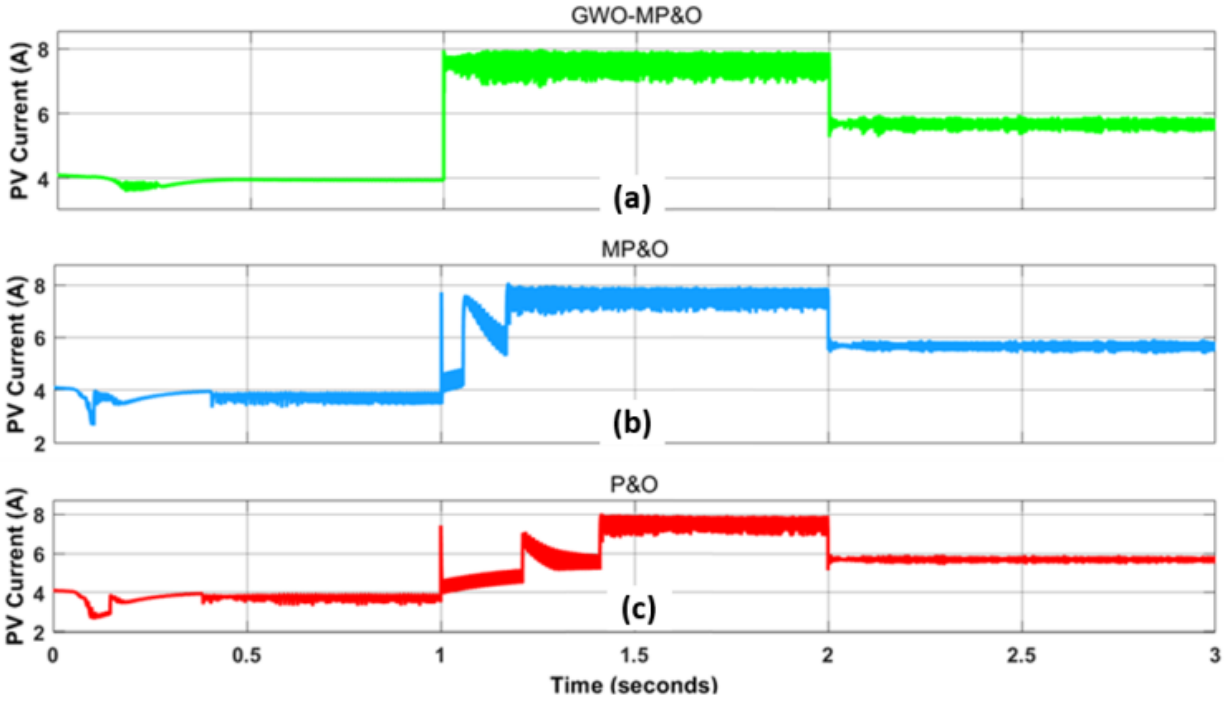


Fig. 16 Output current of the PV module from top to bottom: (a) GWO-MP&O; (b) MP&O; (c) P&O methods

To show the dynamic response of the proposed MPPT, Fig. 17 is used. As seen, the output power from the PV module using the hybrid method is more smooth and faster than the conventional techniques. This is explains the novelty of this work, where the exerted power at different irradiance values is more

stable and has low oscillation around the MPPT. Fig. 17 depicts the panel's power under various irradiance circumstances. As can be seen in the illustration, the extracted power is controlled in accordance with its maximum power at theoretical conditions (P_{max} = 200 W), with a low overshoot and minimum oscillation. On the basis on these findings, it is evident that the suggested MPPT that is presented has superior high smooth power quality, improved stability, and good tracking efficiency.

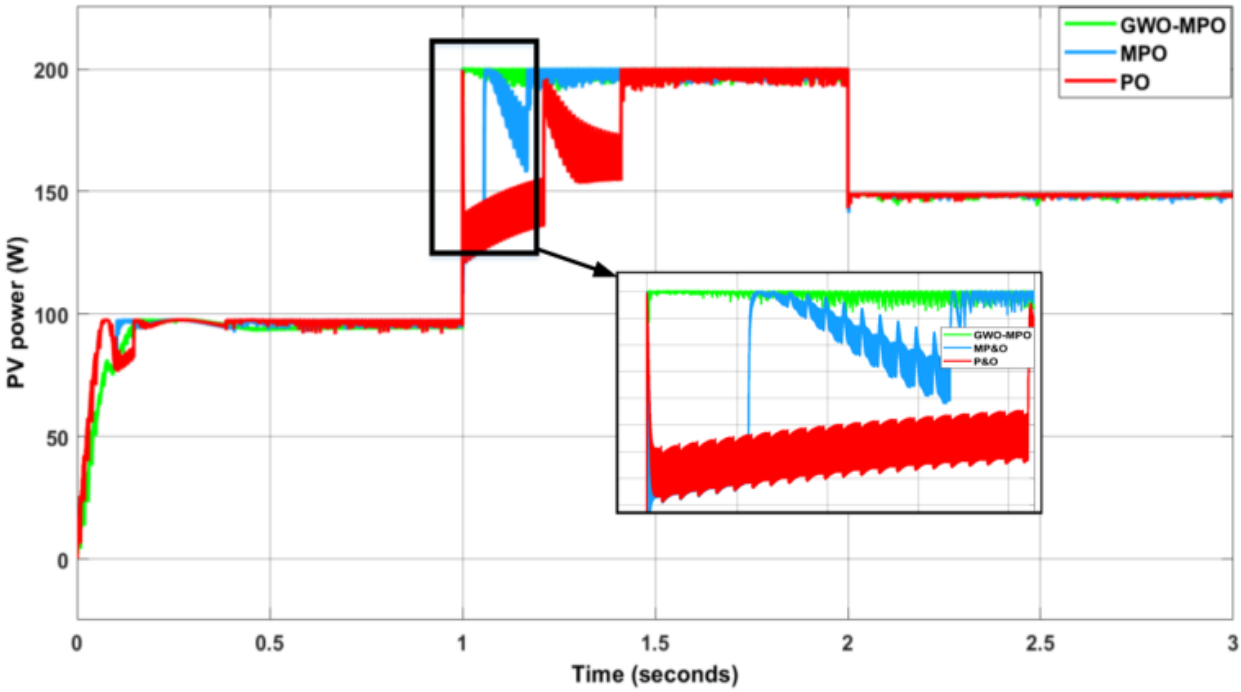


Fig. 17 Comparison between the hybrid MPPT and the other techniques as the same irradiance level

Fig. 18 shows the DC link voltage and the PV voltage at different values, the maximum voltage of the DC bus is obtained under 1000 W/m2 (100 V). Also, the value of the DC voltage that is used as the input voltage for the proposed MLI is varied according to the solar irradiance or temperature.

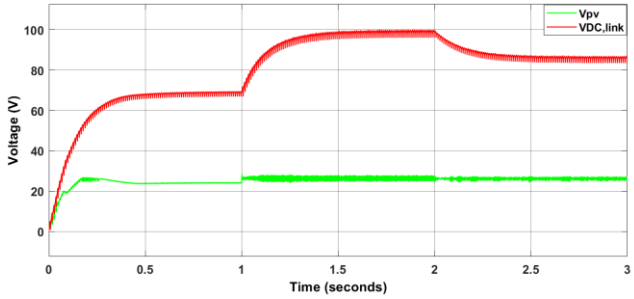


Fig. 18 DC link voltage with PV voltage according to the irradiance profile

The output voltage and current of the proposed MLI used in this work are seen in Fig. 19. As seen, the proposed MLI is tested under a purely resistive load. The seven-level output is achieved according to the value of solar irradiation. The output voltage and current are in the same phase due to the resistive load. The total harmonic distortion (THD) in the output current is obtained based on the Fast Fourier Analysis (FFT) using the MATLAB toolbox. The value of the THD at 1000 W/m2 is 18.16%, for the RMS current $i_o = 1.173\ A$. The value of the THD at 750 W/m2 is 18.17%, for the RMS current $i_o = 1.022\ A$. The value of the THD at 500 W/m2 is 18.19%, for the RMS current $i_o = 0.8\ A$. To demonstrate the originality of this work, a comparison is made in Table 3 between the performance of the suggested hybrid MPPT and the traditional techniques. The efficiency (η) is calculated based on the extracted power at each technique according to the maximum power of the datasheet. Additionally, The time response in seconds (T_R), average extracted power P_{avg}, and fluctuation in the power are used to make the comparison. The proposed GWO-MP&O presents excellent efficiency, especially at high irradiances, where an efficiency of 99.7 % is obtained. Although the MP&O presents good efficiency in the higher irradiance it is severe from the high power fluctuation. The time response of the proposed MPPT is very low, and this technique considers faster that both MP&O and P&O at 750 W/m2 and 1000 W/m2.

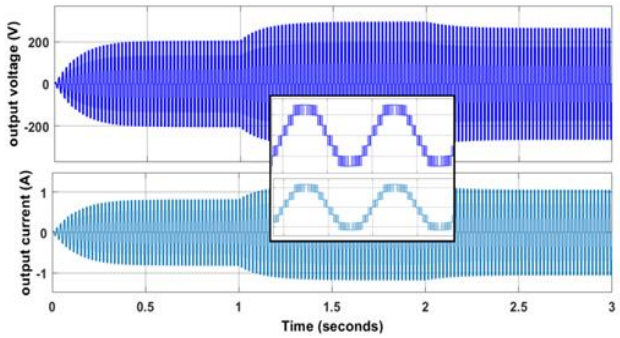
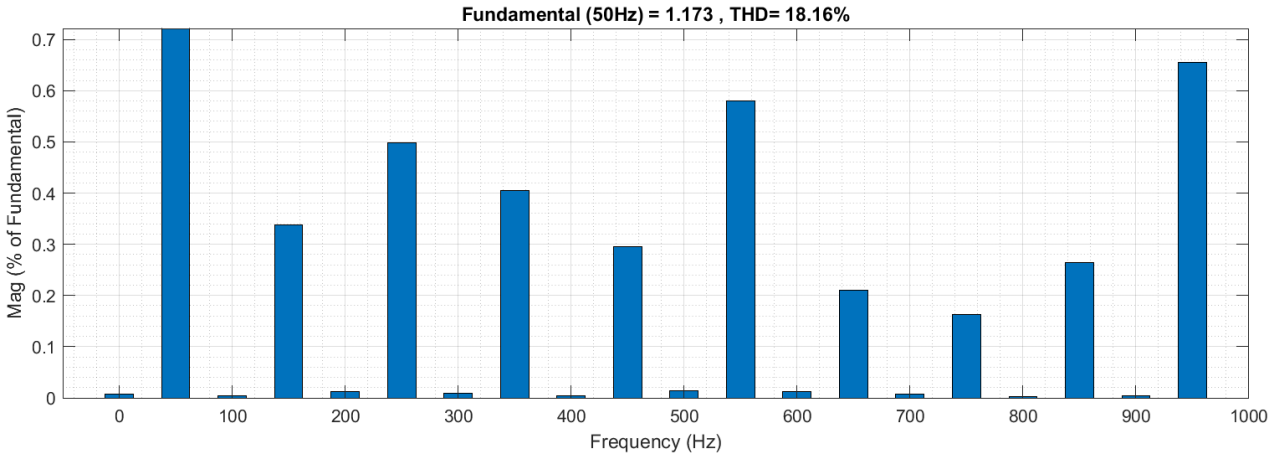
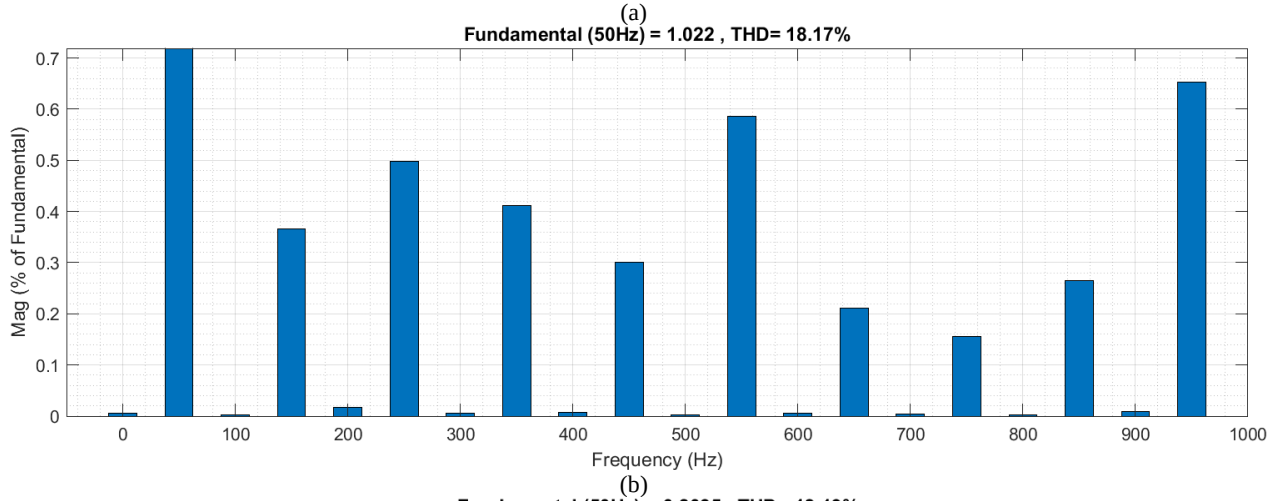


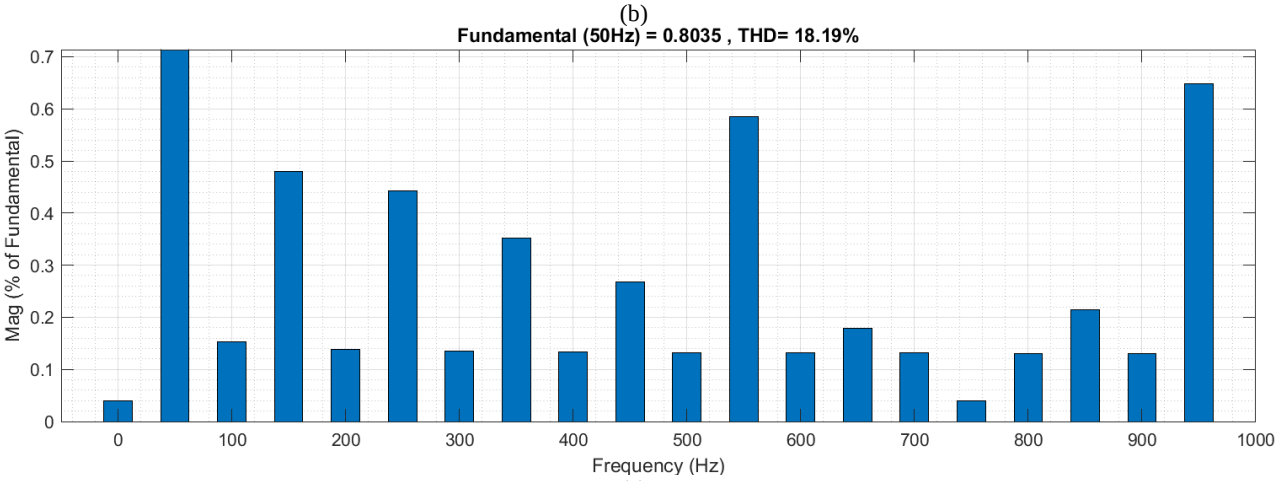
Fig. 19 The output voltage and current of the proposed MLI



(a)



(b)



(c)

Fig. 20 THD values in the output current at different irradiance (a) THD at 1000 W/m2 (b) THD at 750 W/m2 (c) THD at 500 W/m2

Table 3 Comparison between the hybrid MPPT and the conventional techniques

G (W/m^2)	P_{max} of panel (W)	MPPT Methods	T_R (S)	P_{avg} (W)	Fluctuation (W)	η(%)
1000	200	P&O	0.45	162.8	6	81.4
		MP&O	0.25	199	4.3	99.5
		Proposed MPPT	0.05	199.7	0.8	99.7
750	150	P&O	0.3	142	5	94.6
		MP&O	0.18	143.2	4	95.4
		Proposed MPPT	0.06	148	1.5	98.6
500	100	P&O	0.17	90.75	6.3	90.7
		MP&O	0.11	96.25	5.34	96.25
		Proposed MPPT	0.13	97.5	2.2	97.5

5. Conclusion

This paper aims to propose a new hybrid MPPT method for a PV system to supply a new MLI with a minimum number of switches. The proposed MPPT method is combined from the grey wolf optimizer and the modified P&O MPPT method. The KC200GT PV panel with a rated power of 200 W has been used to show the effectiveness of the suggested method. The MATLAB simulation used to test the performance of the PV system under fast changes in irradiance. The circuit of the MLI is connected to the DC bus via a boost converter. The output power of the PV module is shown using the proposed MPPT, MP&O, and

conventional P&O methods. The obtained results show that the proposed hybrid GWO-MO&O is more efficient and has excellent efficiency of (99.7%) at high irradiance. Compared to the other techniques, the suggested MPPT provides less power oscillation, high speed response, and low power fluctuation. The seven-level output voltage from the proposed MLI with lower THD values in the output current are obtained using this method.

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