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A Fast Converging MPPT Control Technique (GWO) for PV Systems Adaptive to Fast Changing Irradiation and Partial Shading Conditions

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Abstract*: This document presents an implementation of the Dc-Dc converter with an MPPT design (Power Point Tracking) for a photovoltaic (PV) system with a new optimization technique. The new optimization method that overcomes the limitations, such as the lower tracking efficiency, the steady-state oscillations and the transients found in the perturbation and observation (P&O) and PSO techniques. The problem of tracking the global peak (GP) of a photovoltaic array in partial shadowing conditions is intended to be used to improve the MPPT technique. The proposed scheme is called gray wolf optimization, which has used the study studied for a multi-peak PSC array and the tracking performance is compared to that of two MPPT algorithms, P&O-MPPT and PSO MPPT. The GWO MPPT algorithm implemented in a photovoltaic system using MATLAB. In addition, an experimental configuration has been developed to verify the efficiency of the proposed system. The simulation obtained and the experimental results show that the proposed converter with the MPPT algorithm exceeds the MPPT of P&O and PSO.*

Keywords

Grey wolf optimization (GWO), maximum power point tracking (MPPT), partial shading conditions (PSCs), photovoltaic (PV).

1. INTRODUCTION

Different tracking algorithms of the maximum power point (MPPT) in the literature [1-3] were discussed about the occurrence of non-uniform non-coincident isolation resulting in a decrease in photovoltaic (PV) output power, the hot spot generated damage to the photovoltaic cells. Since the dynamics of the photovoltaic system with partial shading varies with time, the MPPT design for the photovoltaic energy system must be equipped with functions such as tracking the global maximum energy point (GMPP) in different circumstances, for example shadow, degradation of the photovoltaic cell and adaptability to the photovoltaic properties change in the photovoltaic matrix, smooth and constant tracking behavior. Various MPPT techniques have been proposed such as slope climbing (HC) [2], disturbance and observation (P & O) [4] [5] and incremental conductivity (IC) [5] to improve the efficiency of the photovoltaic system. . The HC method uses a disturbance in the operation of the current converter and the P&O method uses a disturbance in the operating voltage of the photovoltaic system [6] - [9]. Both methods produce oscillations at the maximum power point (MPP) due to the fact that the interference constantly changes in both directions to maintain the MPP and cause a loss of power.

The two parameters that influence the P&O algorithm, namely the disturbance frequency and the magnitude of the disturbance, are analyzed in [10]. To reduce these oscillations and improve the efficiency of the module, the IC method [11] was proposed, which reduced the oscillations, but not completely. The P&O and IC methods fail during these time intervals that are characterized by changing atmospheric conditions [12], [13]. Some improved IC algorithms were also proposed to improve the MPP tracking capacity during the irradiation level and the fast alternating charge [14], [9]. To achieve a fast follow-up response of MPP, a simple trigonometric rule is presented in [10] to determine the relationship between the load line and the I - V curve. In [15] a dynamic MPPT controller for photovoltaic systems is proposed low variable solar and PSC, which uses a scanning technique to determine the maximum power supply capacity of the panel under certain operating conditions.

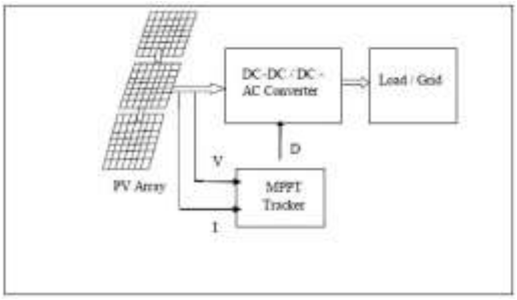

Fig. 1 Solar PV system with MPPT

We recently developed a metaheuristic algorithm known as Gray Wolf Optimization (GWO). This algorithm was inspired by gray wolves to praise the hunt. Robust and shows faster convergence. In addition, it requires fewer adjustment parameters and fewer operators compared to other evolutionary approaches, which is an advantage when considering the fast design process. After a thorough study of the literature, it is noted that GWO has not been exploited to design an MPPT. Therefore, this work attempts to exploit the GWO to design an MPPT for efficient tracking performance in the PSC

2. PARTIAL SHADING CONDITION (PSC)

The properties of the photovoltaic matrix are not linear with regard to irradiation and temperature. Figure 2 shows the voltage curve of the current rules for constant temperature and variable irradiation. Figure 3 shows the voltage curve of the current verses for the constant irradiation and the variable temperature. The maximum power using the maximum power tracking algorithms (MPPT) has a primary function to determine the maximum power dynamics (MPP) with regard to irregular irradiation and temperature. Without awning in the photovoltaic array, the power before the curve has only one peak in a curve.

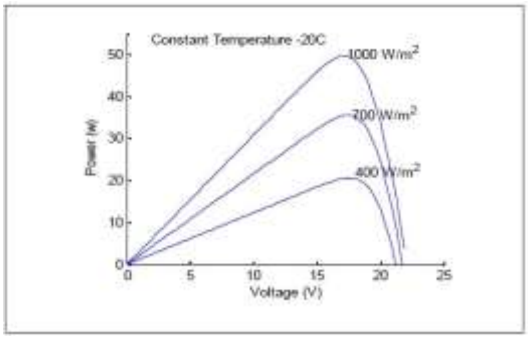

Fig.2 Power vs. Voltage Curve of PV panel for Variable Irradiances

The disturbance and sensing algorithms (P&O), incremental conductance, ripple correlation control (RCC) are the excellent conventional MPPT algorithm [3-4]. According to the strategies used in these algorithms, they are likely to find the first peak in the curve. Under partial shading conditions, there is a difference in the irradiance that falls on the photovoltaic panels, resulting in an uneven output power of the photovoltaic panels. The photovoltaic matrix consists of many photovoltaic panels and therefore the power for the curve of the photovoltaic matrix with partial shading has different peaks.

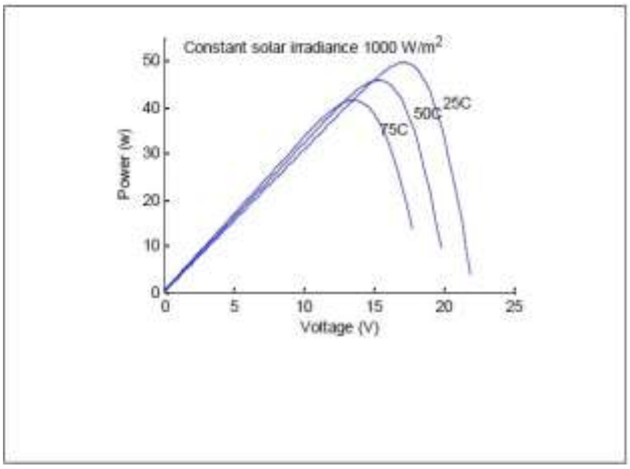

Fig 3: Power Vs. Voltage Curve of PV panel for Variable Temperatures

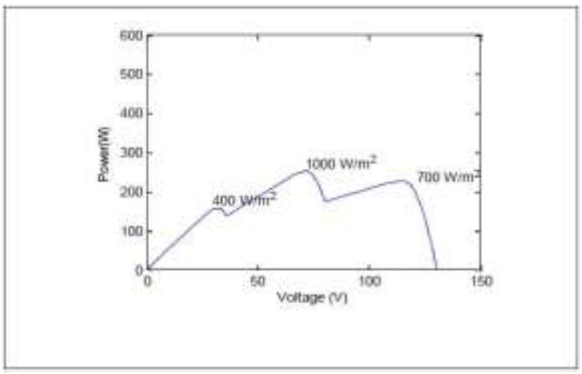

Fig 4: Power Vs. Voltage Curve of PV Array under partial shading condition

Figure 4 shows the multiple peaks in the power-to-voltage curve of the PV array under partial shadow conditions. The highest peak is called global peak or global maximum and other small peaks are called local peaks or local peaks. Following a global peak is a difficult job. If the MPPT algorithm crashes on one of the local peaks, a significant power loss occurs.

3. MPPT METHODS UNDER PARTIAL SHADINGCONDITION

To search for the MPP in the P-V curve under partial sun protection conditions, a rigorous and indirect investigation of the P-V curve is required. The MPP detection method under partial shadow conditions can be broadly classified based on the search techniques. Here, the MPPT methods are classified under partial shadow conditions into the following categories.

- Method based on the segmental search of the P-V curve.
- Methods based on the detection of hotspots
- Methods based on optimization.
- Methods based on hybrid approaches.

3.1 Method Based on Segmental Search of P-V Curve

The PV curve has multiple peaks under partial shade conditions. In the segmental search methods, a segment of the PV curve is scanned and local maxima for that curve are found. The local maxima of the next segment and the previous segment are compared and a decision is made depending on this global maximum.

- Global MPPT tracking method based on the extreme search control (esc)
- Three scanning and storage techniques.

3.2 Hot Spot Detection Based Methods

PV array consists of PV panels. With partial shading, some PV panels come under the shade and these shaded panels are called hot spots. Hotspot detection is useful for estimating the shadow pattern, for following the global

MPP. Consistent shadow on certain PV panels can physically damage the PV panel. Spot detection can help to perform the recovery action to prevent physical damage caused by shading.

- New two-step MPPT method
- Hot spot detection with AC parameter
- Virtual MPPT control based on thermography
- Power-Peaks estimation method

3.3 Optimization Based Methods

The optimization methods are applied to find the best optimal solution with regard to some condition or set of alternatives. There are various search methods for optimization that are inspired by natural phenomena. These methods are adaptable and can find an optimal solution for irregular data. Here, various optimization methods are discussed that are used to trace the MPP under partial shadow conditions.

- Particle Swarm Optimization Method (PSO)
- Artificial bee colony method (ABC)
- Gray Wolf Optimization (GWO)
- Genetic algorithm
- Simulated annealing method
- Firefly algorithm

3.4 Methods Based on Hybrid Approaches

Hybrid approaches are basically based on the combination of two or many approaches. With the hybrid approach, the disadvantage of one strategy is ignored by another. These approaches are applied to achieve one or more goals in an algorithm.

- A hybrid focus MPPT algorithm
- A hybrid algorithm based on P&O and PSO.
- DEPSO hybrid method

4. EXPLORATION OF MAXIMUM POWER POINT TRACKING APPROACHES UNDER PARTIAL SHADING CONDITION

In partial shading conditions, the location of the global MPP between the local MPP of the PV curve is a primary task of the MPPT algorithms. The full exploration of the PV curve, the partial exploration of the PV curve and the random exploration of the PV curve are the three ways to scan the PV curve. The tracking speed depends on the scan form of the PV curve. The detection of hotspots is one of the most important aspects to take into account in the case of partial shading. Hotspots can physically damage the photovoltaic panel. The entry of the access point detection helps to locate the approximate PV curve to be scanned to track the point with the maximum overall power. Partial exploration of the PV curve can be possible with the detection of hotspots and will therefore shorten the calculation time. The atmospheric conditions are very erratic and influence the characteristics of the PV panel. The adaptability of the tracking helps locate the point of the maximum global power that is inconsistent in erratic atmospheric conditions. This increases the adhesion efficiency. The relationship between the average output power obtained in the stable state and the maximum available power of the photovoltaic assembly under certain sun protection conditions is called tracking efficiency. Different MPPT algorithms are analyzed according to the shape of the PV curve: scanning method, detection of hot spots and adaptability.

Sr.	Methods Used to Mitigate Partial Shading Effect	PV curve scanning	Hot-spot detection	Adaptability
1	Extremism seeking control (ESC) method [5]	Full PV curve	Not done	No
2	Three scanning and storing Method [6]	Full PV curve	Not done	Yes
3	Novel Two stage [7]	Not done	Yes	No
4	Hot spot detection based on AC parameter[8]	Not done	Yes	No
5	Thermograph Based [9]	Not done	Yes	No
6	Power-Peaks Estimator [10]	Partial PV curve	Yes	No
7	Improved particle swarm optimization [11]	Full PV curve	Not done	Yes
8	Artificial Bee Colony [14]	Full PV curve	Not done	Yes
9	Grey Wolf Optimization [15]	Full PV curve	Not done	Yes
10	Simulated Annealing [16]	Full PV curve	Not done	Yes
11	Genetic algorithms [17]	Not done	Not done	Yes
12	Fireflies Algorithm [18]	Full PV curve	Not done	Yes
13	A Hybrid Approach [19]	Full PV curve	Not done	Yes
14	Hybrid Algorithm Based on P & O and PSO [20]	Partial PV curve	Not done	Yes
15	Hybrid Algorithm based on DE and PSO [21]	Full PV curve	Not done	Yes

A. Frequency control

Several grid codes require the participation of wind farms in primary and secondary frequency control, including frequency response capability and limitation of both ramp rates and active power output. The requirements are expected to become stricter at higher wind power integration levels in order to avoid exceed power gradients of conventional power plants responsible for primary and secondary frequency control. Some operators also require that WTGS should stay connected and in operation at a wider frequency band in order to contribute to frequency restoration and stable power systems operation.

B. Voltage control

The individual WTGS have to control their own terminal voltage to a constant value by means of an automatic voltage regulator, allowing that modern wind farms have capability to control the voltage at the Point of Common Coupling (PCC) to a pre-defined set-point of grid voltage. Expanded reactive power capabilities can bring advantages for system operators because it offers the possibility of better balancing the reactive power demand.

5. CHARACTERISTICS OF A PV SYSTEM UNDER PSCS

5.1 Basic Characteristics of a PV Cell\

A PV cell can be represented by an equivalent single diode model [2]. D a diode connected in parallel to the current source;

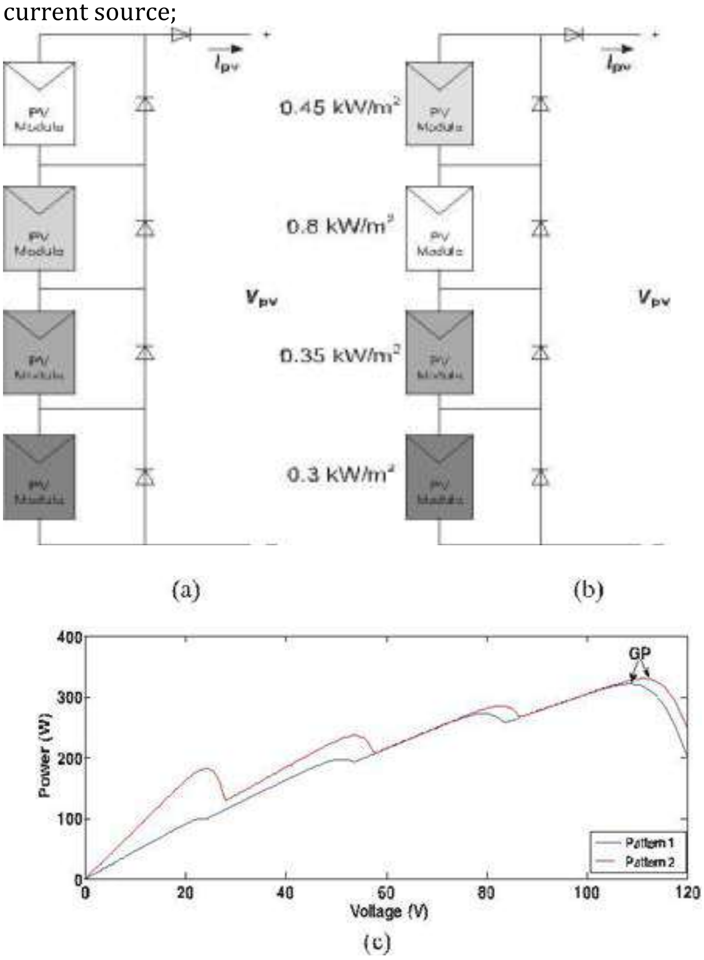

Fig. 5. 4S Configuration under different shading patterns. (a)Pattern 1. (b) Pattern 2. (c) P–V curves under PSCs.

R is the sum of the resistances due to all components entering the path of the current, which is useful to be as low as possible; Rp to represent the leak through the P-N junction that is desirable to be as high as possible; Difference between the photo current Ipv and the diode current ID, which is given by

I=Ipv-I0[exp(qV+qRsI/NsKsTa-1)]-V+RsI/Rp (1)

where I0 is the sauration current, a is the ideality factor of the diode, ks is the Boltz ann constant, q is the charge of an electron, T is the temperature in Kelvin and Ns is the number of cells in series.

5.2 System Description

A photovoltaic assembly consists of several photovoltaic modules that are connected in series to produce a higher voltage and in parallel to increase the current. Multiple peaks are observed during the PSC, i.e. local and global maximum points in the characteristic curve P - V due to the presence of bypass diodes. The two different PV arrays are considered in this work and are shown in FIG. The configuration 5 and 2A, which consists of four modules in series (configuration 4) with two different shadow patterns with their PV curves, is shown in figure 5. The second photovoltaic configuration that has two modules connected in series in parallel with two other modules in series (2S2P configuration) that have two different shadow patterns with their respective PV curves are shown in FIG. 6.

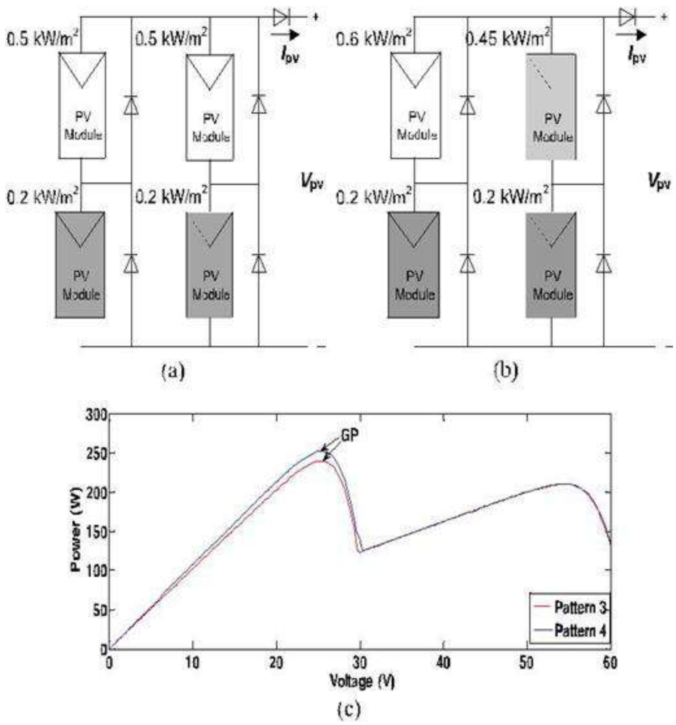

Fig.6. 2S2P configuration under different shading patterns. (a) Pattern 3.(b) Pattern 4. (c) P –V curves under PSCs.

6. GWO AND ITS APPLICATION IN MPPT DESIGN

The GWO algorithm mimics the leadership hierarchy and hunting mechanism of gray wolves in the wild, proposed by Mirjalili et al. [14]. Gray wolves are considered the top of the food chain and prefer to live in a herd. Four types of gray wolves, such as alpha (α), beta (β), delta (δ) and omega (om) are used to simulate the leadership hierarchy.

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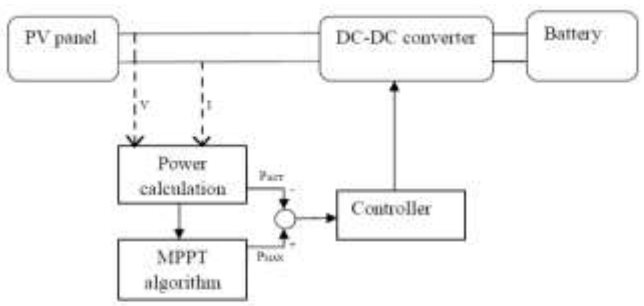

Fig.7.Block diagram

To mathematically model the social hierarchy of wolves during design, GWO considers the most suitable solutions as the alpha. Consequently, the second and third best solutions are called beta and delta, respectively. The rest of the candidate solutions is supposed to be omega. FIG. 3 shows three main steps of the GWO algorithm: hunting, hunting and prey tracking and prey attack implemented to design GWO optimization. The gray wolves that surround the behavior can be modeled by the following equations

D=|C. Xp (t)-Xp (T) (2)
X(t+1)=Xp(t)-A.D (3)

t-current iteration,
D, A and C- coefficient vectors,
Xp-position vector of prey,
X-position vector of grey wolf.

A=2a.r1-a (4)
C=2.r2 (5)

a-linearly decreases from 2 to 0, r1, r2-random vectors

6.1 Application of GWO for MPPT Tracking

FIG. 4 shows the block diagram of the MPPT scheme that has been proposed for the photovoltaic system. For the number of gray wolves, ie the working relationships, the controller measures Vpv and Ipv via sensors and calculates the output power. The flow chart of the MPPT algorithm based on the proposed GWO is shown in Figure 5. During partial shading, the PV curve is classified by multiple peaks with different local peaks (LP) and a GP. It is remarkable that when the wolves find the MPP, their correlated coefficient vectors become almost zero. In the proposed method, an attempt has been made to combine GWO with direct control of the duty cycle, that is, when the duty cycle of the MPP is held at a constant value which in turn is the steady state oscillations existing in the techniques reduces conventional MPPT and, finally, the power loss due to oscillations is reduced, resulting in greater system efficiency. Therefore (3) can be changed as follows

Di(k+1)=Di(k)-A.D. (6)

Thus the fitness function of the GWO algorithm is formulated as

$P(di^k)>P(di^k\text{-}1)$ (7)

Where p represents power, d is duty cycle, I is the number current grey wolves, and k is the number of iterations.

7. RESULTS AND DISCUSSION

Evaluate the performance of metaheuristic based on the proposed GWO. MPPT algorithm, its performance was compared with the P&O and PSO MPPT algorithms. The three previous algorithms were implemented under PSC and a rapidly changing level of isolation for the 4S and 2S2P configurations.

Current, voltage and current for configurations with PSC using GWO, PSO and the second pattern appear for the next 0.1. In pattern 1, it is assumed to exist for the first 0.1 s and the second pattern appears for the next 0.1 s. that is, the operating point that oscillates around the MPP results in a loss of power and also reduces the reaction speed of the algorithm and reduces the efficiency of the photovoltaic system. The simulation is now repeated so that the 2S2P configuration has two different main patterns, namely patterns 3 and 4.

MPPT GP based on GWO reaches 239.1 W, PSO follows GP mainly when it follows the peak that comes into contact first, that is, it can be a GP or LP that causes oscillations around the MPP. All of the above findings have been implemented for the existence of pattern 3 that appears for 0.1 s. for pattern 4, the GWO locates the 251.6W GP based on the MPPT, the PSO places the GP at 251.5w and the P&O is set to the 247W GP as before on the 3-pattern resulting in oscillations around the MPP. The tracking curves are shown in FIG. 7

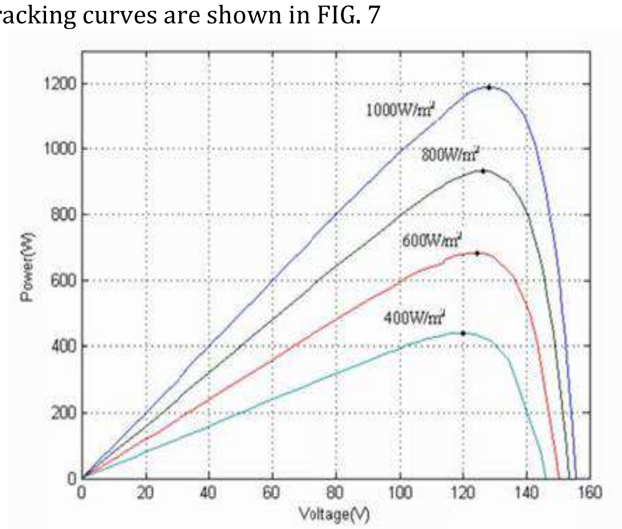

Fig.7.Pv curve of solar array for different irradiation and constant temperature of 25`C

7.1 Result

To validate the effectiveness of the MPPT based on the proposed GWO, experiments were carried out on a real photovoltaic matrix for the 4S and 2S2P configurations. The processor with a frequency of 250 MHz and a subsystem DSP slave based on TMS32oF240 DSP and Hall effect sensor are used to detect the voltage and current of the PV array before it is sent to the controller. Figure 9 shows the experimental arrangement of the system. New MP of the new PV curve. The following GWO and MPPT curves based on PSO reach a GP of 143.5 W, while P & O gets stuck on an LP of 65.32 W.

To validate the effectiveness of the proposed MPPT for another random pattern, experiments were performed for 2S2P configurations with two types of shading and pattern 7 with GP of 77.98 W and LP of 47 W and pattern 8 with GP of 58.25 W, respectively. The experimentally determined MPPT curves use the proposed and existing methods. The tracking curves of the GWO and PSO MPPT proposals can converge to GP of 77.98W and P & O by chance nested to the GP, resulting in oscillations. Then, sometimes, when the shadow pattern changes to a new P-V curve that is marked as pattern 8, the three algorithms look again at the PV curve for a new MPP. The curves of the proposed MPPT and the MPO based on PSO converge from the GP of 58.25W and P & O is set at a local optimum value of 46.64W.

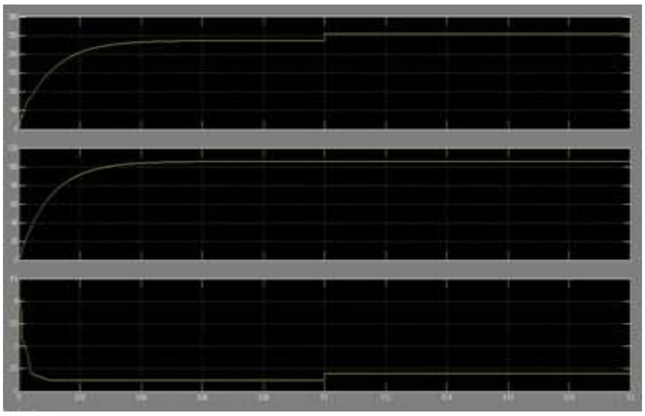

Fig.9. GWO-based MPPT.

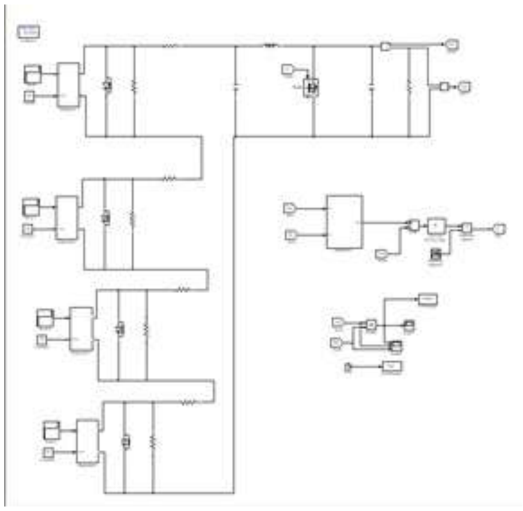

Fig 8: Schematic Model of GWO

To verify that the effectiveness of the proposed MPPT algorithm works accurately under the load of RL, experiments were performed for pattern 5. FIG. 6 shows that the establishment time increases, but that the MPPT performance proposed remains the same for the convergence with the GP.

The proposed method can successfully detect the shadow pattern in the variations and reinitialize the MPPT process with superior performance in terms of faster convergence than the GP, reduction of steady-state oscillations and faster tracking in the low-voltage photovoltaic system PSC.

TABLE II: PERFORMANCE COMPARISON OF THE PROPOSED MPPT METHOD FOR 2S2P CONFIGURATION

Shading Pattern	Maximum Power Curve from P-V Curve (W)	Tracking Techniques	Maximum Power (W)	Maximum Voltage (I)	Maximum Current (I)	% Tracking Efficiency
3	239.3	P&O	234	24	9.75	97.78
		IPSO	239.05	25	9.562	99.89
		GWO	**239.1**	**25.01**	**9.56**	**99.91**
4	251.8	P&O	247	23.9	10.3	98.09
		IPSO	251.5	25.64	9.808	99.88
		GWO	**251.6**	**25.64**	**9.812**	**99.92**

TABLE III: QUALITATIVE COMPARISON OF THE PROPOSED WITH OTHER FAST-CONVERGING MPPT TECHNIQUES

Type	P&O	IPSO	[9]	[13]	Proposed
Tracking speed	Slow	Medium	Fast	Fast	Very fast
Transient power fluctuation	Low	High	Moderate	Moderate	Low
Tracking accuracy	Low	Accurate	Highly accurate	Highly accurate	Highly accurate
Convergence to GP	Tracks which comes in contact first (LP or GP)	Yes	Yes	Yes	Yes
No. of tuning parameters	1	6	1	2	1
Steady state oscillations	Large	Zero	Zero	Zero	Zero
Power efficiency	High (uniform insolation) low (PSCs)	High	High	High	High
Implementation complexity	Low	Medium	Medium	Medium	Medium
Dynamic response	Poor	Good	Good	Good	Good

8. CONCLUSION

This article proposed a new approach, called gray wolf optimization, to design a maximum power extraction algorithm for photovoltaic systems to operate under PSC conditions. In this presentation of the evaluation of the effectiveness of this new MPPT (MPPT based on gray wolves), the performance was compared with two existing MPPT, namely the MPP methods based on P & O and PSO and the results obtained showed the MPPT based on GWO is a superior performance compared to two other MPPT.

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