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MPPT for PV systems based on Optimization Techniques

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Abstract—The output power of a photovoltaic (PV) array, which is highly dependent on both solar radiation and cell temperature, is continuously maximized using Maximum Power Point Tracking (MPPT) techniques. The complexity of non-traditional approaches and the PV power fluctuations around the maximum power point (MPP) caused by conventional methods are compelling arguments for the need for new MPPT techniques. In order to increase the convergence, speed, and accuracy of the PV system, this study discusses numerous MPPT algorithms, including hill climbing methods like the Perturbation and Observe method (P&O), Incremental Conductance (INC), Genetic Algorithm (GA), Evolutionary Algorithms like Cuckoo Search Algorithm (CSA) and Grey Wolf Algorithm (GWO). In the typical test conditions, the suggested technique may also effectively track the global MPP. The optimum performance of the PV panel during MPPT was achieved by employing GWO more frequently to get the quick reaction of the power transient's reduction. This was done to address the oscillations and spikes problem in the output power. To extract the most power possible from the PV resource, the suggested controllers used a DC/DC boost converter. The software MATLAB/SIMULINK is used for system programming and modeling. Comparisons are made between the acquired results and those from other MPPT algorithms. To identify the global maximum power point (MPP) for PV arrays, numerous evolutionary algorithms (EA) have also been taken into consideration. The following EA algorithms are used: grey wolf algorithm, teaching-learning-based technique, mine blast optimization, genetic algorithm, particle swarm optimization (PSO), ant colony, and PSO algorithm.Even though the aforementioned EAs in terms of MPPT function satisfactorily, there is still a need to advance contemporary EAs. The aforementioned GWO results are contrasted with current optimization methods like CSA, P&O, INC, and GA.

Keywords—Maximum Power Point Tracking; Grey Wolf Algorithm (GWO), Perturb &Observe(P&O), Boost Convertor,Genetic Algorithm (GA), Cuckoo Search Algorithm (CSA), Incremental Conductance (INC),MATLAB/Simulink.

1. INTRODUCTION

One of the most important sources of renewable energy, photovoltaic solar energy helps to reduce the quantity of electricity generated from fossil fuels. It is employed in residential applications, such as the production of power for off-grid and on-grid isolated locations, including buildings, residences, schools, and clinics. It is also used in industrial settings as a primary source of electricity for off-grid remote loads such as large-scale water pumping systems, desalination plants, radio and television stations, spacecraft, lighthouses, and aircraft warning lights as well as a standby supply of electricity for on-grid workloads.

Road illumination, reverse osmosis desalination plants, and electric vehicles are now just a handful of the widespread usage of photovoltaic systems (PVs) [1]. In order to improve PV performance in terms of high efficiency in small-scale water pumping systems, a significant amount of research was conducted in. Additionally, when connected to an electric network infrastructure, it reduces overall greenhouse gas emissions. For systems in remote, rural, and island areas, PVs rank among the top alternatives [2]. This is because it has so many benefits, like being totally free, endless, widespread, and environmentally beneficial [3].

An array of photovoltaic (PV) panels connected in series or parallel makes up a photovoltaic (PV) system. Variations in environmental conditions, such as temperature and sun irradiation, have an impact on the whole PV array's maximum power point (MPP). Here, all work is completed under the typical test conditions of 25°C temperature and 1000 Kw/m2 radiation. Due to the PV array's non-linear output power characteristics, the efficiency of the PV power generating system is improved by obtaining the maximum amount of power from the PV modules, typically utilizing the maximum power point tracking (MPPT) control method [4]. It is possible to produce many types of PV curves by using MPPT for the PV array module.

There is a certain point on the power-voltage characteristic where the photovoltaic power is maximum because the current-voltage characteristic of a PV cell is non-linear for a specific insulation and temperature. The Maximum Power Point (MPP) is what is referred to as this point [5].

The PV system should constantly run at MPP in order to be utilized as effectively as possible. This can be accomplished by connecting the PV system to the power electronic converter, which functions as a Maximum Power Point Tracker (MPPT) and incorporates one of the MPPT methods. There are various MPPT approaches, but in this comparison between them, Perturb and Observe (P&O) is used to suggest a Duty Cycle control strategy based on a variable duty cycle step [6]. Particle Swarm Optimization,[7]. (PSO), Genetic Algorithm (GA) and Cuckoo Search Algorithm (CSA) MPPT techniques [8].

Finally, the following is done to finish the contributions mentioned above: Section 2 provides the problem's mathematical formulation as well as the goal functions. The suggested MPPT approach is formulated in Section 3 along with an explanation of the fundamental reliability factors. The main conclusions, comments, and comparisons with other techniques are presented in section 4. Section 5 has the conclusion of this paper.

2. PV SOLAR SYSTEM DESCRIPTION AND MODELLING

This section deals with the PV System modelling for solar panel. Fig. 1 displays the schematic illustration of PV model. The PV module model was created in MATLAB/Simulink (2021a), and table 1 contains information about the PV panel specifications. The PV array should be selected based on the required maximum load. According to eq.(1), where Np and Ns are the parallel and series modules, respectively, Imp is the whole PV framework configuration current at the MPP, and V_{mp} is the whole PV framework configuration voltage, the maximum power (P_{mp}) of the array is determined.

$$P_{mp} = N_p * I_{mp} * N_s * V_{mp} \quad (1)$$

The cell model, shown by the circuit in Figure 1. is used to evaluate the power of each individual where R_p and R_s are the series and parallel resistances of the cell, respectively [9] [10].

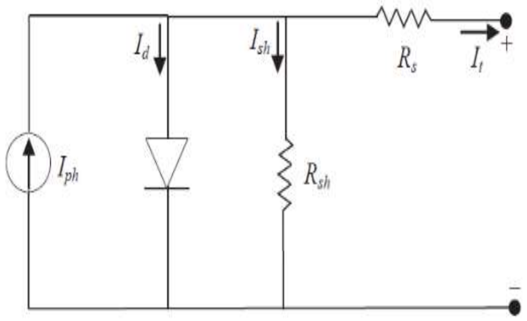

Figure 1Equivalent circuit of solar cell with single diode.

A variety of models have been used to describe the electrical properties of PV cells, with the Single Diode Model (SDM) and Double Diode Model (DDM) being the most popular, particularly for electrical engineering applications [11]. In comparison to DDM, SDM is less complex, making it the model that is most frequently used to describe a PV cell's static properties (I-V and P-V). Fig. 1 depicts the equivalent circuit of SDM. The components of this analogous model are a photogenerated current source connected in series with a diode, a series resistor to represent the Ohmic losses brought on by the load current, and a shunt resistor to represent the leakage current [12].

Thus, the PV cell terminal current It can be expressed byeq. (2)

$$I_t = I_{Ph} - I_d - I_{sh} \quad (2)$$

Where I_{ph} denotes the photo generated current, I_d symbolizes the diode current, and I_{sh} represents the shunt resistor current, respectively. Moreover, in term of Shockley equation, Id can be calculated by

$$I_d = I_{sd}[exp(q(V_t + I_t R_s) / aKT) - 1] \quad (3)$$

Where I_{sd} refers to the diode reverse saturation current, V_t represents the cell terminal voltage, R_s is the series resistance, a denotes the diode ideality factor, k is the Boltzmann constant ($1.380*10^{-23}$ J/K), q is the electronic charge ($1.602 * 10^{-19}$ C), and T is the PV cell absolute temperature in Kelvin, respectively. Moreover, via Kirchhoff's voltage law, I_{sh} can be obtained as

$$I_{sh} = (V_t + I_t R_s) = R_{sh} \quad (4)$$

Where R_{sh} is the shunt resistance. Consequently, by combining Eqs. (2), (3) and (4), the I-V relationship of the SDM can be written as follows [13].

$$\mathrm{I_t} = \mathrm{I}_{ph} - \mathrm{I_{sd}}[\exp(q\,{}^{(\mathrm{V_t} + \mathrm{i_t R_s})}/_{aKT}) - 1] - \mathrm{V_t} + \mathrm{i_t R_s}/\mathrm{R_{sh}} \quad (5)$$

As a consequence, SDM has five unknown parameters, namely, I_{ph}, I_{sd}, R_s and R_{sh} that can be identified based on experimental I–V data.

2.2. PV Panel and PV array model

The PV panel contains Ncellpar (parallel strings) of Ncellser (series strings) cells per string[14]. So,it comes that

$$I_{panel} = \sum_{i=1}^{\mathrm{Ncellpar}} \mathrm{I_{ti}}, \mathrm{Ncellpar\ I_t} = \mathrm{NcellparI_t} = \mathrm{Ncellpar\ I_t} \quad (6)$$

$$V_{panel} = \sum_{i=1}^{\mathrm{Ncellser}} \mathrm{V_{ti}}, \mathrm{Ncellser\ V_t} = \mathrm{Ncellpar\ V_t} = \mathrm{Ncellpar\ V_t} \quad (7)$$

The system considered in this paper is composed of PV array feeding a resistive load via MPPT-controlled boost converter shown in Fig. 2.

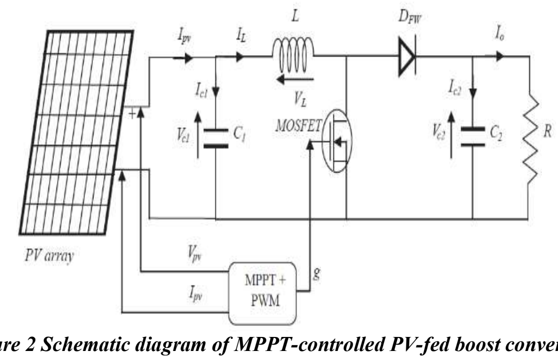

Figure 2 Schematic diagram of MPPT-controlled PV-fed boost converter.

2.3. Boost converter model

The boost converter is used to extract the maximum power from the PV array via duty ratio control [15]. The instantaneous values model of boost converter can be expressed by the following voltage and current equations

$$V_{c2} = (V_{c1} - V_L)g + V_{c2}(1-g) = (V_{pv} - V_L)g + V_{c2}\,(1-g) \quad (8)$$

$$V_L = (V_{c1})g + (V_{c1} - V_{c2})(1-g) = L\frac{\mathrm{dI_l}}{\mathrm{d_t}} \quad (9)$$

$$I_{c1} = C_1\frac{\mathrm{dI_{c1}}}{\mathrm{d_t}} = I_{PV} - I_L \quad (10)$$

$$I_{c2} = C_2\frac{\mathrm{dI_{c2}}}{\mathrm{d_t}} = I_L(1-g) - I_0 \quad (11)$$

The average values model of the boost converter can be presented by the two following equations:

$$V_{c2} = \frac{1}{(1-\mathrm{D})}\mathrm{V_{c1}} \quad (12)$$

$$I_0 = (1-D)I_L = (1-D)I_{PV} \quad (13)$$

3. PROPOSED METHOD

In this paper, GWO is a new novel inspired meta-heuristic algorithm based on the mimics' leadership hierarchy and hunting mechanism of grey wolves in nature developed Mirjalili[16]. Four types of grey wolves such as alpha (α), beta (β), delta (δ) and omega (ω) are employed for simulating the leadership hierarchy.

Further the three key steps of hunting pointed for prey encircling prey and attacking the prey are implemented.

3.1 Mathematical Modeling/formulation of GWO

The following are the major steps in mathematical formulation.

3.1.1 Social hierarchy of GWO

Considering the wolves α, β, δ in the algorithm α is considered to be the solution of best fit; followed by β and δ as the second and third best solutions fit respectively. The 'ω' wolves follow α, β, and δ and the hunting in GWO algorithm is guided by these three wolves.

3.1.2Grey wolves encircling prey

While hunting grey wolves' foremost encircling prey the encircling position is presented in ref [12] and represented as follows.

$$\vec{K} = \left|\vec{C}\cdot\vec{V_k}(it) - \vec{V}(it)\right| \quad (14)$$

$$\vec{V}(it+1) = \vec{V_k}(it) - \vec{D}\cdot\vec{H} \quad (15)$$

where it is current iteration, $\vec{V}$ and $\vec{V_k}$ denote the position vector of a grey wolf and the prey respectively. $\vec{C}$ and $\vec{D}$ be a sign of coefficient vectors and are intended by the following equations.

$$\vec{D} = 2\cdot\vec{a}r_1 - \vec{a} \quad (16)$$

$$\vec{C} = 2\cdot r_2 \quad (17)$$

$$\vec{a} = 2(1 - \frac{it}{max-w}) \quad (18)$$

Here r_1 and r_2 are random numbers between 0 and 1. $\vec{a}$ Component is decreased linearly from 2 to 0 over the course of the iterations.

3.1.3 Hunting Prey

Mathematically to simulate the hunting behavior of grey wolves, assume that α, β and δ have better information concerning about the potential position of the prey. So the first three best solutions set on so far are saved for compelled to update their positions according to their best positions. In the following formulas were developed in this view[17].

$$\vec{H_\alpha} = \left|\vec{C_1}\cdot\vec{V_\alpha} - \vec{V}\right| \quad (19)$$

$$\vec{H_\beta} = \left|\vec{C_2}\cdot\vec{V_\beta} - \vec{V}\right| \quad (20)$$

$$\vec{H_\delta} = \left|\vec{C_3}\cdot\vec{V_\delta} - \vec{V}\right| \quad (21)$$

$$\vec{V_1} = \vec{V_\alpha} - \vec{D_1}\cdot(\vec{H_\alpha}) \quad (22)$$

$$\vec{V_2} = \vec{V_\beta} - \vec{D_2}\cdot(\vec{H_\beta}) \quad (23)$$

$$\vec{V_3} = \vec{V_\delta} - \vec{D_3}\cdot(\vec{H_\delta}) \quad (24)$$

$$\vec{V}(it+1) = \frac{\vec{V_1}+\vec{V_2}+\vec{V_3}}{3} \quad (25)$$

The exploration and exploitation abilities of the GWO's are represented by searching and attacking of grey wolves for prey respectively [18]. The hierarchy of the GWO top to bottom α, β, δ,ω is shown in the fig 3 [19].

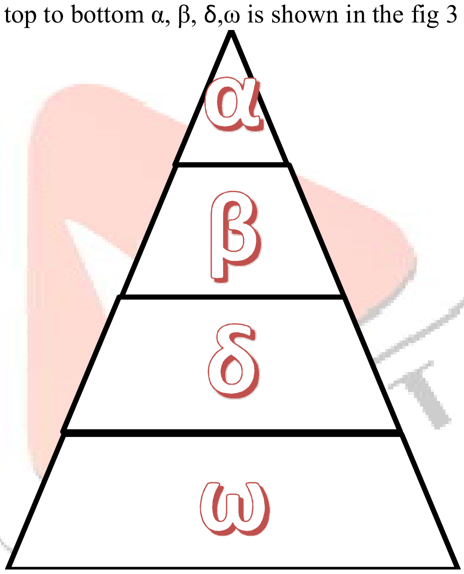

Figure 3 The hierarchy level from top to bottom

3.2 GWO applied to MPPT

I. Read peak voltage and peak current of the given system.
II. Initialize the parameters of number of wolfs size, max-iterations, rated parameters.
III. Generate wolf hierarchy according to the rating of panel.
IV. Simulate the objective functions of the optimization techniques (GWO) till the error will be minimal.
V. Check for minimal error of Gbest solution, if satisfied go for optimization technique result.
VI. Else initialize new random wolfs by using eq. (14) to (25), go to step 4.

Flowchart of GWO has shown in fig 4.

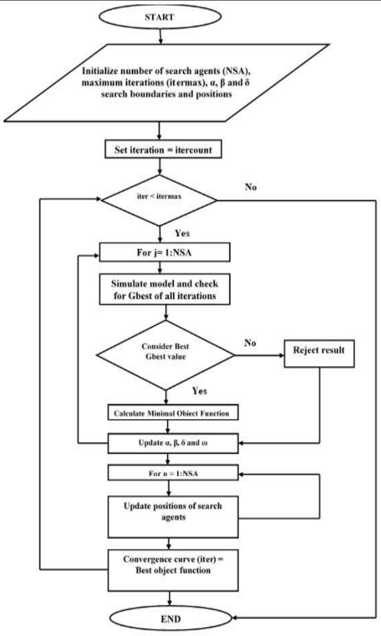

Figure 4Flow chart of GWO algorithm

4. SIMULATION MODEL

4.1 PV Panel

There are user-defined parameters for the Simulink model's PV panel. Modeling of the PV module is carried out in MATLAB/Simulink. By employing a boost converter, we may obtain the highest boosted DC voltage while taking the panel's temperature and irradiance into account. We can get the Gbest value by sending pulses to the boost converter's gate using the MPPT algorithm, which is built into a MATLAB function block. The solar panel will therefore run at its highest possible power level. MPPT based on GWO optimization technique is applied on the solar panel, ratings of the PV system are given in table I.

Table I Electrical Specifications of Simulated PV System

Parameter	Value
Maximum Power (Pmax)	100.167W
Voltage at Vmax (Vmax)	17.3V
Current at Imax (Imax)	5.79A
Open Circuit Voltage (Voc)	20.76V
Short Circuit Current (Isc)	6.87A

One can determine that the operating power is high and keep PV panels operating at or near their maximum power by using GA, INC, P&O, and CSA. As a result, efficiency rises. This study compares the P&O, GA, INC,CSA approaches for harvesting and tracking MPP from a solar array with online EAs optimizers (GWO). Through the use of the online-developed optimizers, the duty cycle of the DC/DC boost converter is updated.

Based on P&O, PSO, GA, CS, and GWO optimization functions using embedded user interface functionality in MATLAB programming, initialized in simulation system, and evaluated with the objective functions. Figure 5depicts the MATLAB/SIMULINK schematic diagram

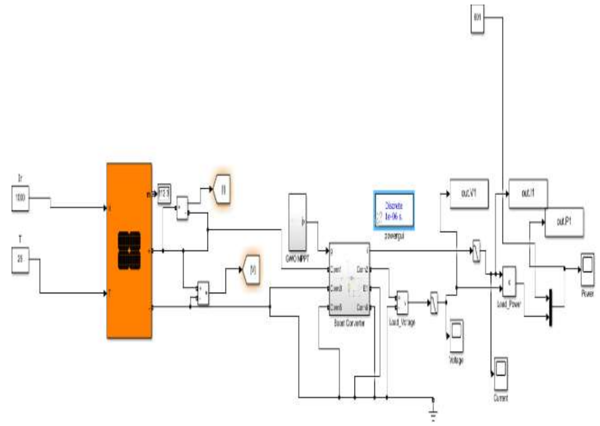

Figure 5 Simulink Model of MPPT

of the system under consideration, which links a PV array to a boost converter and a resistive load.

4.2 Results and Discussion

The performances of the proposed GWO algorithm over P&O, PSO, GA, CSA has been shown in below simulation results. All the algorithms are applied to control the boost converter as MPP techniques under the pattern of uniform irradiance and temperature for PV array.

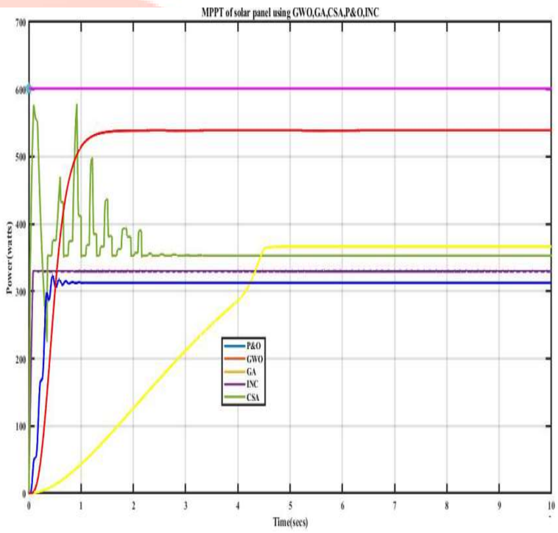

Figure 6 Power comparisons of MPPT

When it comes to operating a PV panel at its greatest capacity, the GWO algorithm has produced the best results as shown in figure6. It also produces less oscillations and distortion than other MPP techniques which was clearly visible in the graph of figure 6. The reference power (pink in color) or maximum of the output power waveform, is closer to the output power. The power graphs of the all MPP like GA, CSA, P&O, INC are having the less power extraction and also oscillations in the power waveform which enforces us to convert dc to ac and ac to dc to reduce oscillations. It will be more cost effective. If dc is at less distortion is easy to utilize like for storage purpose in battery. By this battery life is also be increased. The PV panel's efficiency will rise, and fewer PV panels will be needed to fulfill the load requirement.

Table II Comparative analysis of the MPPT Algorithms

Methods	P & O	INC	GA	CSA	GWO
P (W)	323.6	330.2	360.5	356.9	538.9

The power of the all MPPT's has been compared in the table II. All the comparison values are been shown in the mathematically way to see the difference. By the above tabulated values, the Grey Wolf algorithm based MPP was been observed as best MPP compared over other existing methods.

5. CONCLUSION

The main research axis of several research works has been the improvement of power efficiency of PV systems, which already have low power conversion ratios. Maximizing the output power of PV arrays was therefore a critical element in raising the effectiveness of PV systems. Due to the fact that the solar irradiance value under typical test settings has a significant impact on PV array output power. The aforesaid control strategies employed in this study will provide the optimum operational efficiency by eliminating oscillations at output power, outperforming other control techniques that have been established for maximum power point tracking of PV array output power.

The proposed GWO algorithm based MPP govern over other algorithms in the aspects of possessing less distortion in power output than the P&O, INC, GA, and CSA techniques. It has also been shown that the Grey Wolf based MPPT method for tracking MPP is very stable in output power. The outcomes are displayed in table II. With these results, it is possible to use the control strategy to obtain high-quality, stable functioning of the photovoltaic (PV) system output side.

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