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Maximum Power Point Tracking using Grey Wolf Technique Under Fast-Changing Irradiance

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Abstract*: *In this paper, maximum power point tracking (MPPT) using Grey wolf optimization (GWO) algorithm is presented using MATLAB/Simulink. As we know that meta-heuristic or nature-inspired algorithm has proven to be superior in performance compared to the conventional MPPT methods. Grey Wolf optimization algorithm is a meta-heuristic algorithm based on the hunting behaviour of grey wolves. The proposed system includes modelling of PV system under changing irradiance and the MPPT control is driven by GWO algorithm. Most of the conventional MPPTs are unable to track multiple peaks and also shows oscillations on the output side, for this reason proposed MPPT algorithm is used in this paper. For eliminating oscillations, this algorithm has proven to be better compared to perturb and observe (P&O) and particle swarm optimization (PSO). The results are compared in terms of output power.

***Keywords*: Grey Wolf Optimization, Maximum Power Point Tracking, Particle Swarm Optimization, Perturb and Observe, Photovoltaic PV System.**

I. INTRODUCTION

As the global consumption of fossil fuel is increasing, the use of renewable sources for energy production has been consistently increasing. Energy generation using renewable sources has been an important task. Solar PV systems have been commonly used for energy production in tropical areas where the sun's irradiance is abundant in nature. Many solar farms have been set up to met the energy requirements for residential and commercial loads. As the initial set-up cost of solar PV farm is much high, a high investment is required. But as compared to other renewable resources, it does not require maintenance cost or any fuel cost. For real complex environment, bio-inspired algorithms are required for better computing and better result as compared to conventional MPPTs like Perturb and observe (P&O), Incremental Conductance (INC), etc.

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Partial shading condition where the solar PV panels are shaded and couldn't receive maximum irradiance due to shadow of trees, buildings, clouds and other objects that falls on PV array.
A non-uniform irradiance which falls on the panel could lead to decrease in power generated from the PV panel compared to the uniform one. This leads to numerous peaks and classical or conventional MPP algorithms cannot track these points.
Because of these drawbacks, the meta-heuristic or nature-inspired algorithms are used so that the global MPP can track down to give maximum possible output from the system. Meta-heuristic algorithms perform better than conventional ones.
Few bio-inspired algorithm are: Genetic Algorithm (GA), Differential Evolution (DE), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Artificial Bee Colony (ABC), Grey Wolf Optimization (GWO) and Cuckoo Search, etc. These algorithms take less computational time. This paper includes PV system modeling which is implemented in MATLAB/Simulink.
The MPPT control is used to drive the gate of the MOSFET used in the boost converter. The proposed system uses grey wolf optimization technique for maximum power point tracking under fast changing irradiance. Later, the output is compared with P&O and PSO.
The paper is organized as follows: section I presents introduction, section II gives modeling of solar PV system, section III gives Grey Wolf Optimization Techniques and its application in MPPT, section IV gives the software simulation, section V presents results and discussion and lastly section VI concludes the paper, followed by references.

II. MODELLING OF SOLAR PV SYSTEM

A solar PV system mainly consists of solar panel, DC-DC boost converter and Load. A solar panel is generally a series and parallel-connected solar modules. Modules consist of an array of solar cells. Solar cells are basically p-n junction fabricated in a layer of semiconductor. When solar irradiance falls on the surface of the semiconductor, energy greater than the band gap energy creates movements of electrons. These movements of electrons in turn creates current to flow which is proportional to the incident radiation.[3]
The equivalent circuit of the solar cell is shown below in figure 1.

It consists of a current source, diode, series and parallel resistance.

The theoretical current-voltage equation can be written as

Solar cell current (I) = $I_L - I_o[\exp(\frac{qV}{kT}) - 1]$ (1)

Output current of equivalent cell model (I) = $I_L - I_D - I_P$ (2)

Diode Current $I_D = I_o [\exp(\frac{V+IRs}{nVT}) - 1]$ (3)

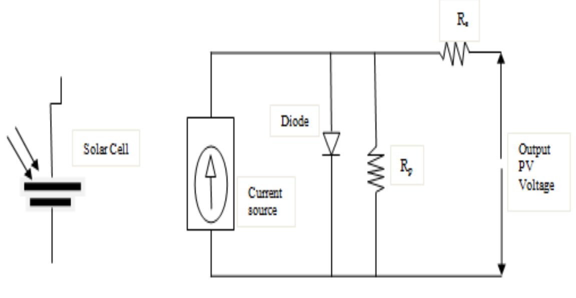
Current in parallel resistance (I_P) = $\frac{V+IRs}{Rp}$ (4)

Putting the values of I_D and I_P in equation 2, the equation can be modified as

Solar cell current (I) = $I_L - I_o [\exp(\frac{V+IRs}{nkT})] - (\frac{V+IRs}{Rp})$ (5)

Where,

K Boltzmann's constant (K=1.381*10^{-23} J/K)
q Charge of electron (q=1.602 *10^{-19} C)
n Diode ideality factor
T Actual Temperature
V_{oc} Open circuit voltage (V)
I_{sc} Short circuit current (A)
V_{mp} Maximum voltage (V)
I_{mp} Maximum current (A)
R_s Series resistance (Ω)
R_p Parallel resistance (Ω)
I_{sat} Saturation current (A)
I_p Current in parallel resistance (A)



(a) (b)

Figure 1: (a) Solar Cell (b) Equivalent circuit of solar cell

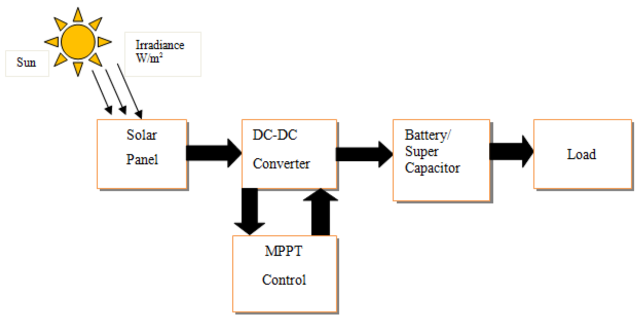


Figure 2: Block diagram of the proposed model.

The system model consists of solar panel, DC-DC converter, Battery or Super Capacitor, load and MPPT Control. Solar panel consists of PV array of series and parallel- connected PV modules. Maximum power point tracking (MPPT) helps to track maximum peak point of the P-V Characteristics of the solar panel. This peak point depends on the ambient temperature and irradiance. The gate of the MOSFET is triggered by the MPPT control unit. The MPPT control is driven by algorithm called grey wolf optimization algorithm. The DC-DC converter used in the proposed system is a boost converter. The boost converter basically consists of capacitor, inductor, diode, resistance and MOSFET.[5][3]

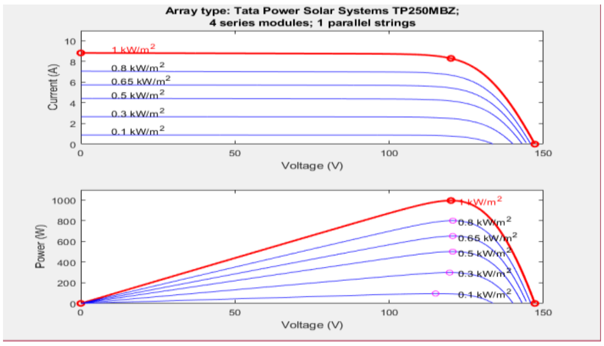


Figure 3: I-V & P-V Characteristics of the solar panel.

III. GWO ALGORITHM AND IT'S APPLICATION IN MPPT

A. Grey Wolf Optimization Algorithm

Grey wolf optimization algorithm is a meta-heuristic nature-based algorithm which is based on the hunting behavior of grey wolves. The main steps for hunting are searching, encircling and attacking the prey. They also have hierarchy among themselves-the leader, alphas makes decision about hunting process. The alphas are dominant and manage the pack. The betas are of second level and omegas are of lowest ranking. Deltas are subordinate but dominate the omegas [1]. The alpha chooses the strongest wolves among themselves and sends them for hunting purpose. The pack of selected wolves targets the prey and starts to encircle the prey within a certain boundary limit. The hunting is mainly done by alpha which also gives the best solution. The wolves finish the hunt by attacking when the prey stops moving.[4]

Encircling prey: mathematical model equations

$\vec{D} = |\vec{C} \cdot \vec{Xp}(t) - \vec{X}(t)|$ (1)

$\vec{X}(t+1) = \vec{Xp}(t) - \vec{A} \cdot \vec{D}$ (2)

Where t indicates current iteration, A and C are coefficient vectors, X_p is the position vector, X indicates the position of grey wolves. The vectors A and C are calculated below:

$\vec{A} = 2\vec{a} \cdot \vec{r_1} - \vec{a}$ (3)

$\vec{C} = 2 \cdot \vec{r_2}$ (4)

Where r1 and r2 are random numbers from 0 to 1 and 'a' is linearly decreasing from 2 to 0.[1]

B. Application of Grey Wolf Optimization Algorithm in MPPT

The flowchart of the proposed system is shown in fig.6. The number of grey wolves (the duty ratios), the system measures V_{PV} and I_{PV} and evaluates the output power.

A grey wolf based MPPT algorithm main objective is to obtain maximum output power from the PV array considering duty cycle as a control variable. We know that under fast changing irradiance, the P-V characteristics of the PV panel shows more than one maximum peak point (MPP). These MPPs cannot be tracked by conventional methods like hill climbing or P&O or INC. These methods shows steady state oscillation and overlapping of MPP occurs during tracking.

Considering all these drawbacks, GWO technique which controls the duty cycle of the MOSFET and also the power loss can be reduced which occurs due to oscillation. Here, the duty cycle is considered as grey wolf and a range of duty cycle is applied under certain boundary condition.[1][2] Therefore, duty cycle can be written as

$$D_i\ (k+1) = D_i\ (k) - A.D \qquad (6)$$

The power function can also be given as

$$P(d_i^k) > P(d_i^{(k-1)}) \qquad (7)$$

Where P represents power, d is duty cycle, i is the number of grey wolf and k is the iteration. []

A grey wolf based MPPT algorithm main objective is to obtain maximum output power from the PV array considering duty cycle as a control variable.

Now the objective function becomes:

Maximize-P(duty cycle)

Control variable- duty cycle, d, where dmin<d<dmax

- Initialization
- Initialize duty cycle population di between maximum and minimum limit. Also initialize the GWO parameters and number of iterations. Initialize (t-1) value for power, voltage and current.
- Evaluate duty cycle
- Sense voltage and current of the PV panel and calculate power.
- Check at which duty cycle, power is maximum (compare t and t-1value)
- Update all the parameters

After checking or comparing, update all the values for next iteration.

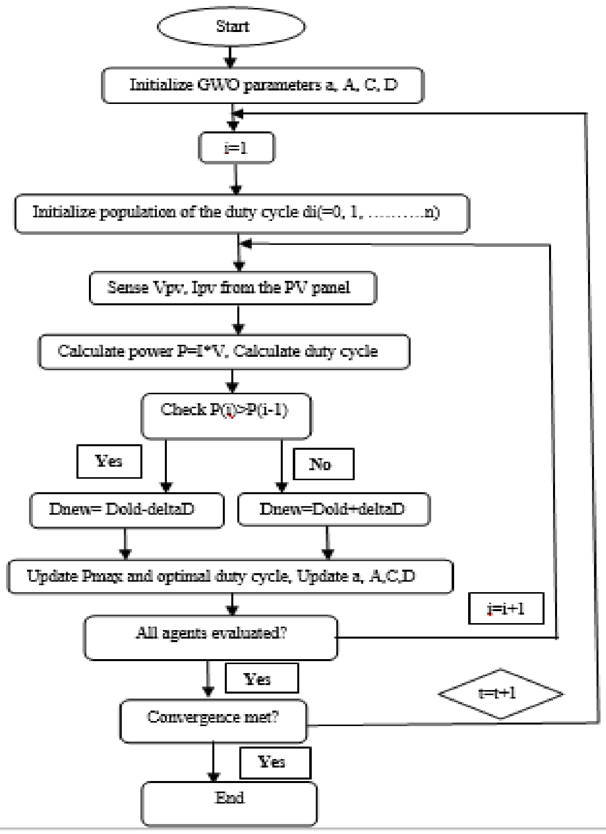


Figure 3: Flowchart of the proposed algorithm

IV. SOFTWARE SIMULATION

To validate the performance of the proposed GWO-based meta-heuristic MPPT algorithm, its performances were compared with P&O and PSO MPPT algorithms. These algorithms were all compared under partial shading condition or fast-changing irradiance. The Simulink diagram of the proposed system is shown in fig.4. For simulation the standard nominal values of the parameters for the PV module and the components of the system are tabulated below.

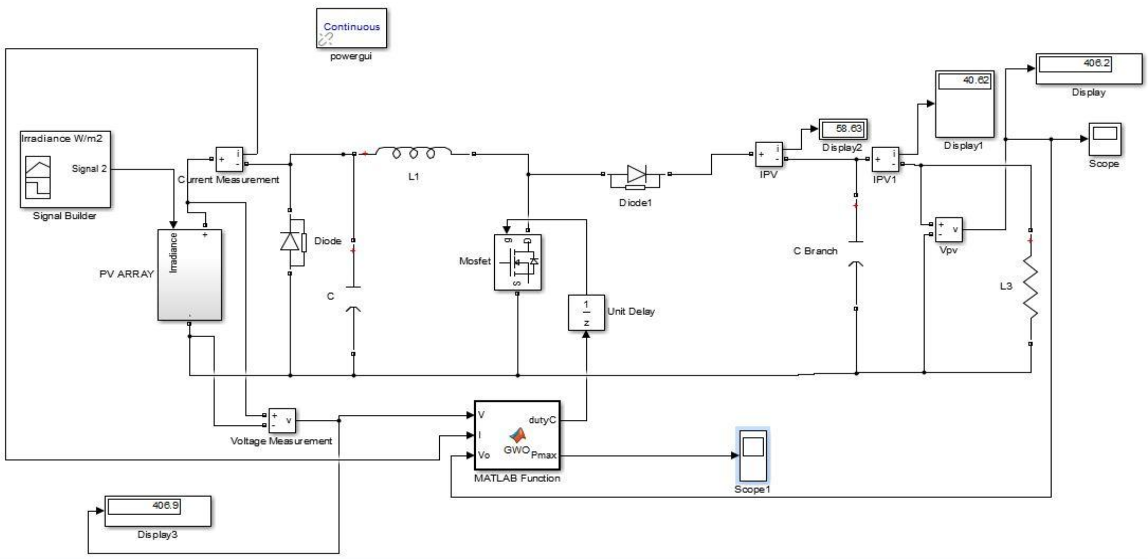


Figure 4: Simulink Diagram of the proposed system

Table-I: Circuit Parameters

	Parameters	Values
SOLAR PV PANEL	K (Boltzmann's Constant)	1.38×10^{-23} J/K
	T(Temperature)	300 K
	q(charge of electron)	1.6×10^{-19} C
	n(diode ideality factor)	1 to 2 (any random number) 1.3
	V_{oc} (open circuit voltage)	64.2 V
	I_{sc} (short circuit current)	5.96 A
	V_{mp} (maximum voltage)	54.7 V
	Imp(Maximum current)	5.98 A
	R_s(series resistance)	0.037998 Ω
	R_p(Parallel resistance)	993.51 Ω
	I_{sat} (saturation current)	1.1753×10^{-8} A
	I_{ph}(current in parallel resistance)	5.9602 A

Boost Converter	C_{in} (Input Capacitor)	100µF
	L(inductor)	5 mH
	C_{out} (Capacitor on the load side)	24 F
	Switching Device	MOSFET
LOAD	Resistance	10 Ω

V. RESULT AND DISCUSSION

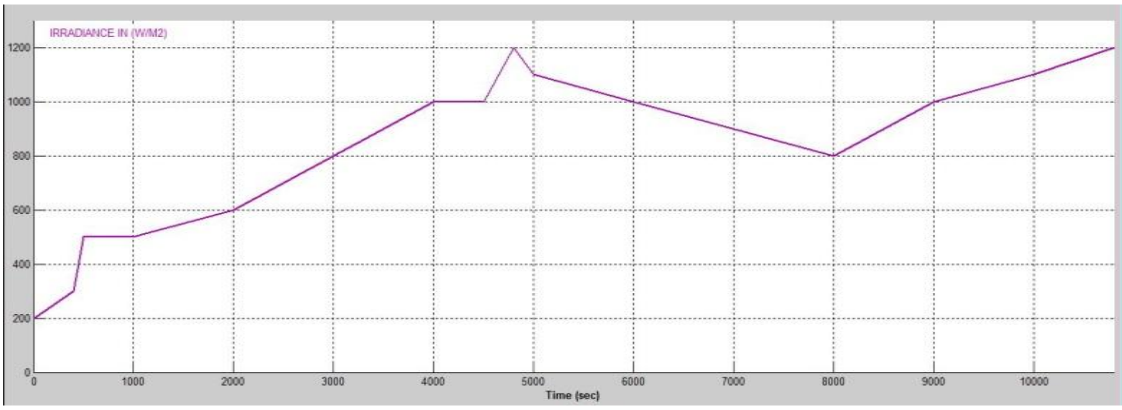
The input irradiance is a non-linear graph taken with a duration of 3 hours where the maximum irradiance is 1200 W/m2 and lowest of 200 W/m2. During this 3 hours' duration, partial shading occurs and the panel does not receive a steady irradiance. The system is then simulated in

MATLAB. The output voltage and power is also shown and is compared with P&O.

From the results, it is clearly seen that using grey wolf the system gives more accurate and steady output.

CASE-I

Irradiance in W/m^2

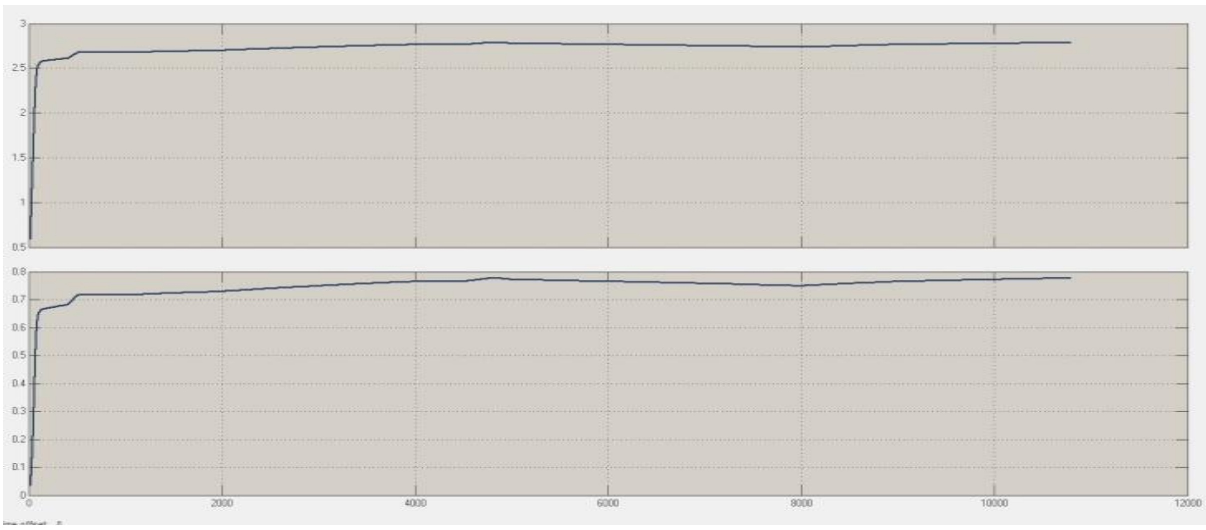


Time in seconds

Figure 5: Input as Irradiance in Watt/sq. meter for duration of 3 hours

Power in Watts

Voltage in Volts



Time in seconds

Figure 6: Output Voltage and Power by changing Irradiance for duration of 3 hours

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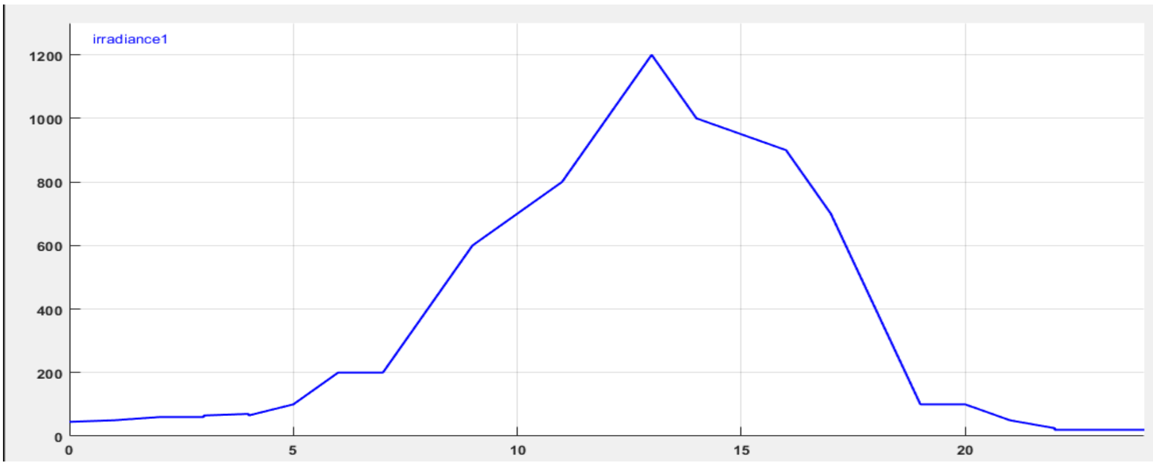
CASE-II

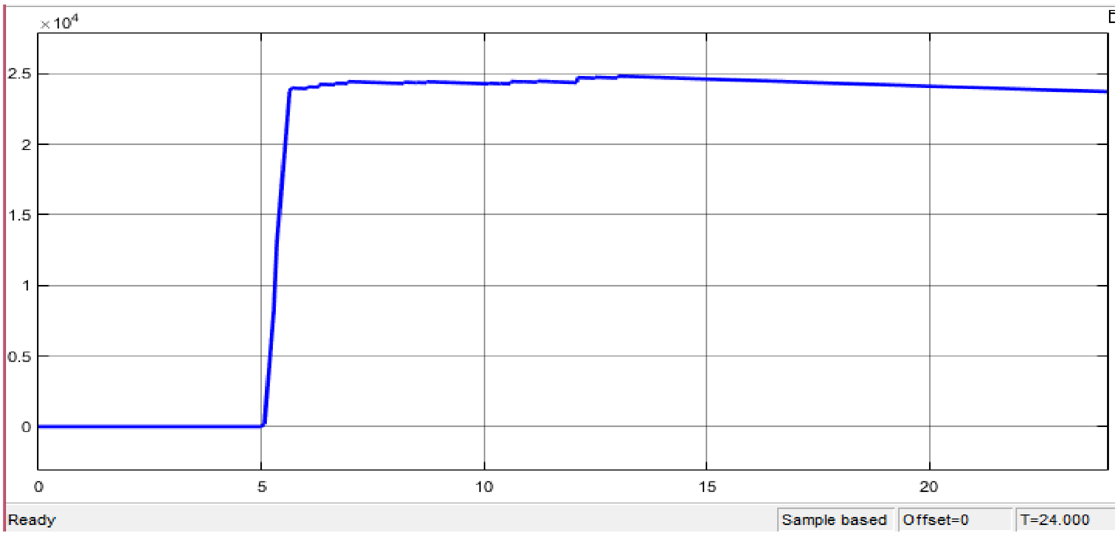
Irradiance in Watts/m^2



Time in seconds

Figure 7: Input Irradiance for 24 seconds

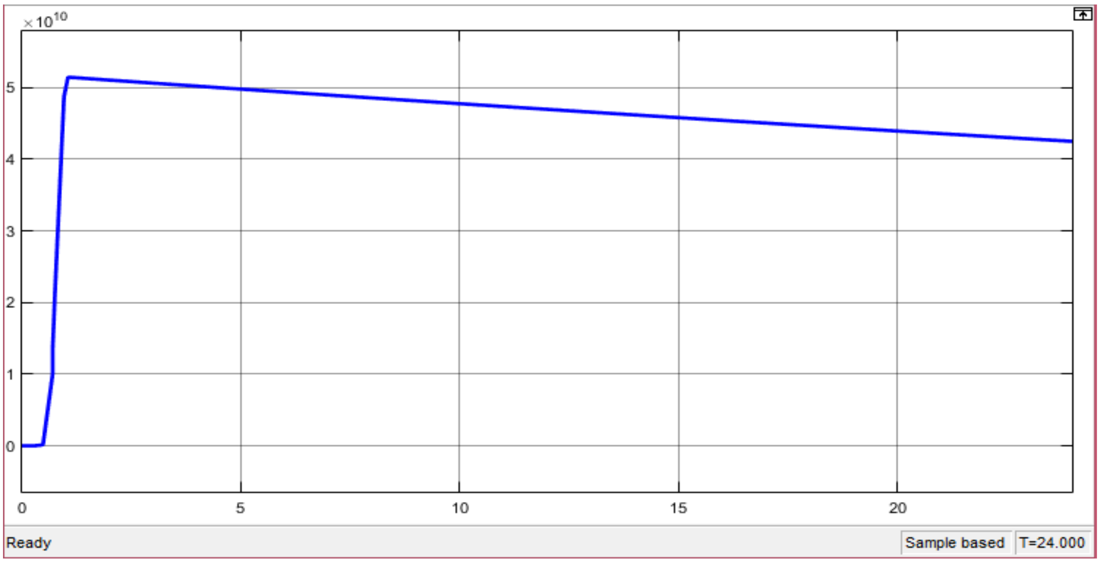
Power in Watts



Time in seconds

Figure 8: Output Power using Perturb & Observe method

Power in Watts



Time in seconds

Figure 9: Output Power using Particle Swarm Optimization Technique

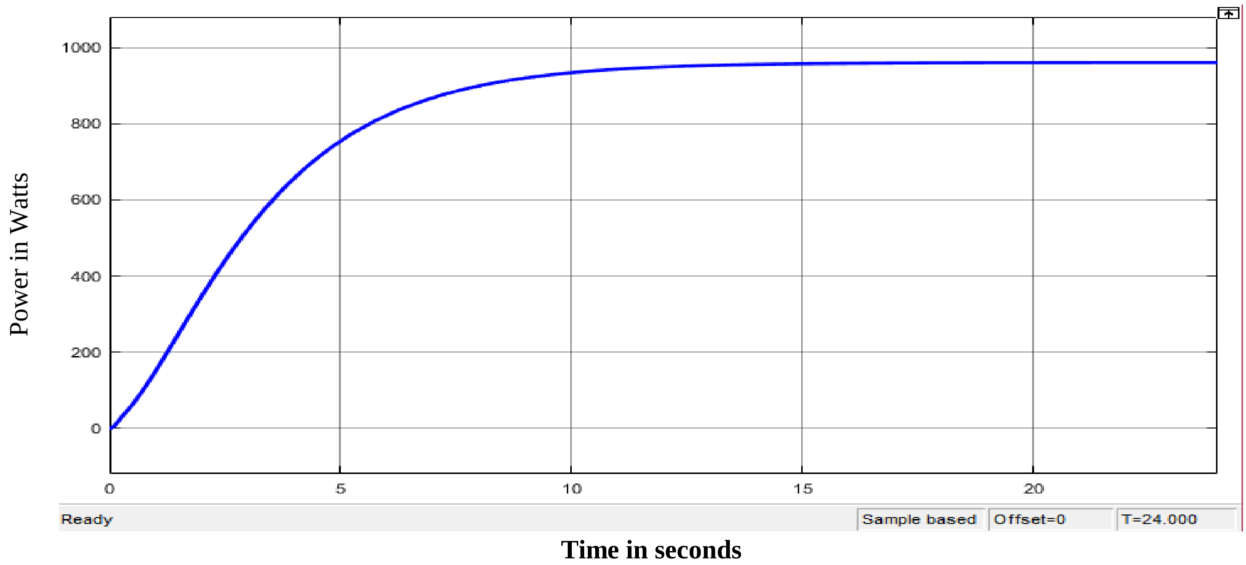


Figure 10: Output Power using Grey Wolf optimization Technique

Table-II: Experimental Results

	Algorithm used	Output Power
Case I (3 hours)	GWO	2.6×10^3
Case II (24 seconds)	P&O	2.47×10^4
	PSO	5×10^{10}
	GWO	9×10^2

From the above figure, in case-I the output voltage and power is shown when the input irradiance is supplied for 3 hours. In case-II, the output power of the proposed algorithm is compared with perturb & observe and PSO technique. The oscillation near the peak point as seen in P&O is removed in case of grey wolf optimization.

VI. CONCLUSION

A grey wolf technique is used in the proposed paper for PV system under fast-changing irradiance. The system shows a steady power output with zero oscillations. Both accuracy and efficiency is improved. As we know that conventional MPPT techniques cannot track global MPP, meta-heuristics or artificial intelligence based algorithms can track much accurately. Furthermore improvements can be done by using a hybrid algorithm considering the drawbacks and advantage of two algorithms and masking them, this can also be considered for future works.

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