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Solar photovoltaic power predictive optimization for maximum power point tracking system using AI

Srinivas S[1]
Shamala N[2]

(Corresponding Author)

[1]*Department of Electronics and Communication Engineering, VTUPG Centre, Mysuru, India.*
Email: srinivas.s043@gmail.com
[2]*Department of Electrical and Electronics, VVIET, Mysuru, India.*
Email: shamalanarayan1672@gmail.com

Abstract

Solar tracking systems are commonly used in large-scale solar power installations, where maximizing energy production is crucial. By utilizing solar trackers, these systems can increase their energy output by up to 30% compared to fixed-tilt solar installations. These systems are more complex and expensive than fixed-tilt systems but can provide higher energy yields in locations with high solar insolation. The objective of solar power tracking systems is to maximize the capture of solar radiation by continuously adjusting the orientation and tilt of the solar panels. these systems can ensure that the solar panels receive the highest possible level of sunlight throughout the day. This optimized alignment allows for increased energy production and improved overall system performance. Two different ML approaches, such as support vector machine (SVM) and Gaussian process regression (GPR), were considered and compared. The basic input parameters, including solar PV panel temperature, ambient temperature, solar flux, time of day, and relative humidity. In this paper to showcase the effectiveness and accuracy of SVM and GPR models in forecasting solar PV power, the results of these models are compared using root mean squared error (RMSE) and mean absolute error (MAE) criteria.

Keywords: Artifcial intelligence, DC-DC buck converter, Gaussian process regression, Global MPPT, Optimization, Parital shading, Solar energy, Support vector machine, Sustainability.

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Contents

Contribution of this paper to the literature

Many scholars are contributing to the scientific work on solar PV systems, which have progressively integrated AI to improve predictive optimization in MPPT. In this paper the proposed MPPT protocol that leverages artificial intelligence for predictive optimization of power point tracking in solar PV systems. The proposed prototype is meticulously framed out through MATLAB simulations.

1. Introduction

The photovoltaic maximum power point tracking (PV-MPPT) has been extensively used in practical application because of simple in idea and implementation. Development progress of a country depends on its energy production, usage and storage. The primary energy source for electricity generation is fossil fuels; which are harmful for the climate and air quality. The energy generated from the burning of fossil fuels is transferred into the atmosphere in the form of heat, which results in rising levels of global temperatures [1, 2]. To supplement these adverse effects, rising levels of global population are increasing energy demand and subsequently causing an acceleration in the rate of combustion of fossil fuels, thereby exponentially increasing global warming and climate change. This methodology for energy generation is not only eco-hazardous, it is also unsustainable in the long term as fossil fuels are a finite fuel source and their recovery rate is extremely slow as compare to their current burn rate. Solar energy has gained significant traction amongst alternative energy solutions due to its sustainability and economical benefits [3, 4]. Moreover, the amount of solar energy available on the planet has been found. Photovoltaic (PV) systems are able to convert this abundantly present solar energy into more usable electrical energy, which is why they have gained significant traction lately. Their advantages include the fact that they do not add to environmental pollution, can safely store energy in batteries, and are easy and simple to implement and install both commercially and residentially. It is well known that a photovoltaic (PV) array under uniform irradiance exhibits a power versus voltage (PeV) characteristic with a unique point, called the Maximum Power Point (MPP), where the array provides maximum output power. Because the PeV characteristic of a PV array and hence its MPP change as a consequence of the variation of the irradiance level and of the panels' temperature (which is in turn function of the irradiance level, of the ambient temperature, of the efficiency of the heat exchange mechanism and of the operating point of the panels), it is necessary to track continuously the MPP to maximize the power output from a PV system, for a given set of operating conditions [5]. Temperature of the panel is an important factor that impacts the power generation of PV panels. The panels are made of semi-conducting wafers. The current and voltage output of these semi-conductors is significantly governed by temperature. Temperature, therefore, plays a major role in terms of power generation for these systems. A temperature rise causes a minor increase in current when short-circuited and causes a major decline in potential difference across the panel. Moreover, the rise in temperature negatively affects PV performance. The significant reduction in output voltage is not sufficiently offset by the increase in short circuit current of the panel. Distributed MPPT (DMPPT) technique will be used with specific reference to an MPPT technique simultaneously acting on the output of each PV module representing the source of each micro-converter is shown in Figure 1.

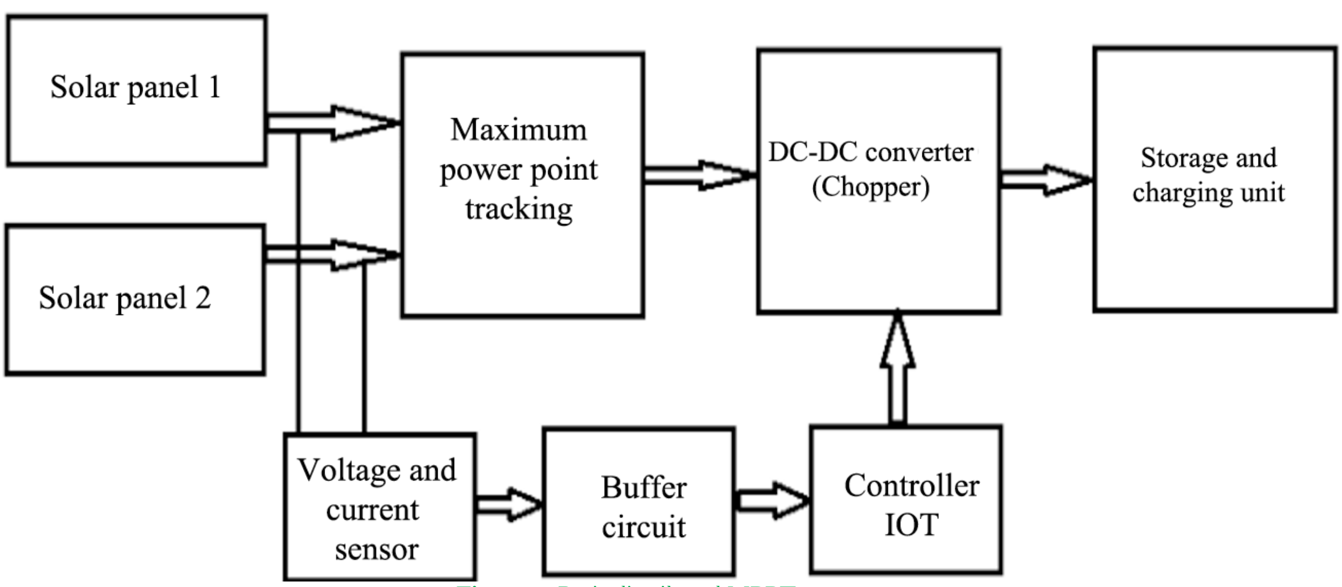

Figure 1. Basic distributed MPPT systems.

Hereafter, a system composed by a PV module equipped with micro controller IOT will be called self controlled PV unit [6, 7].

The circuit in Figure 2 shows the basic distributed MPPT model. The circuit has been simulated using Circuit maker 2000 pro.

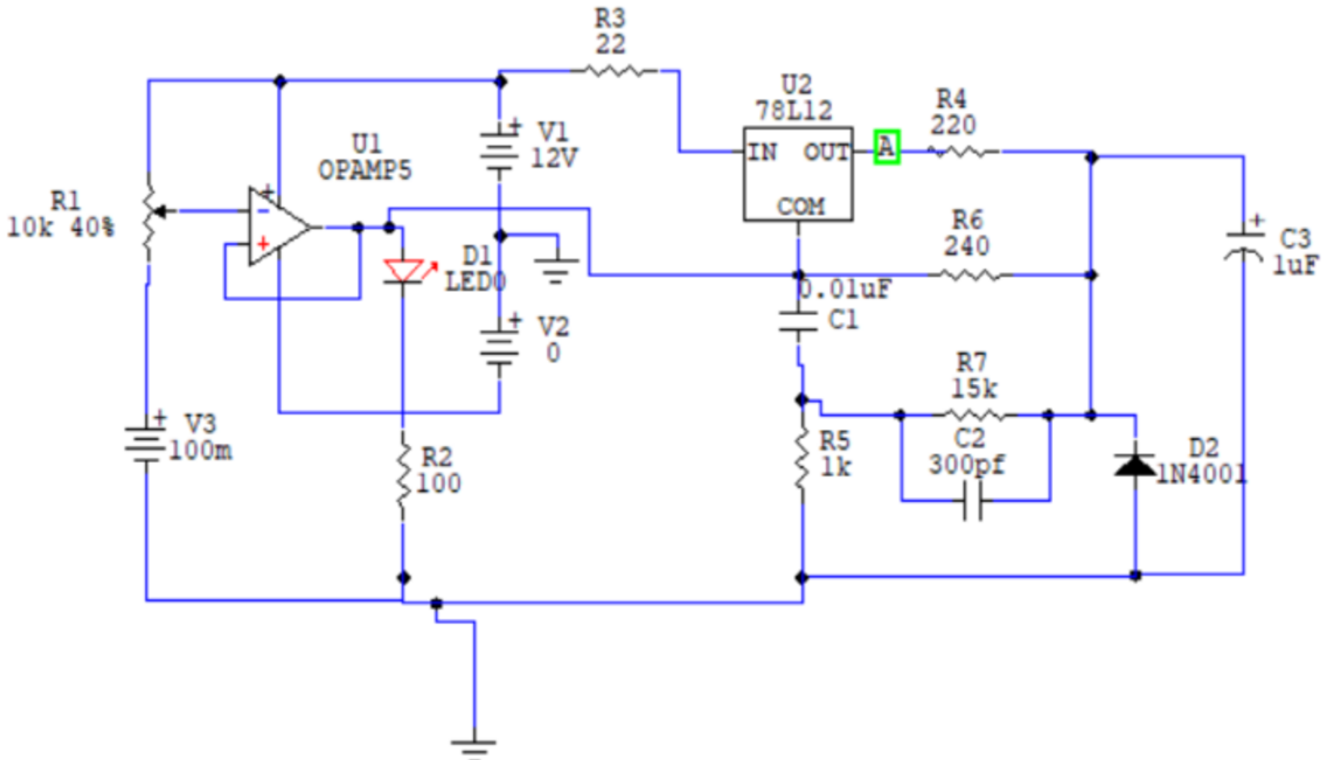

Figure 2. A basic circuit of distributed MPPT system.

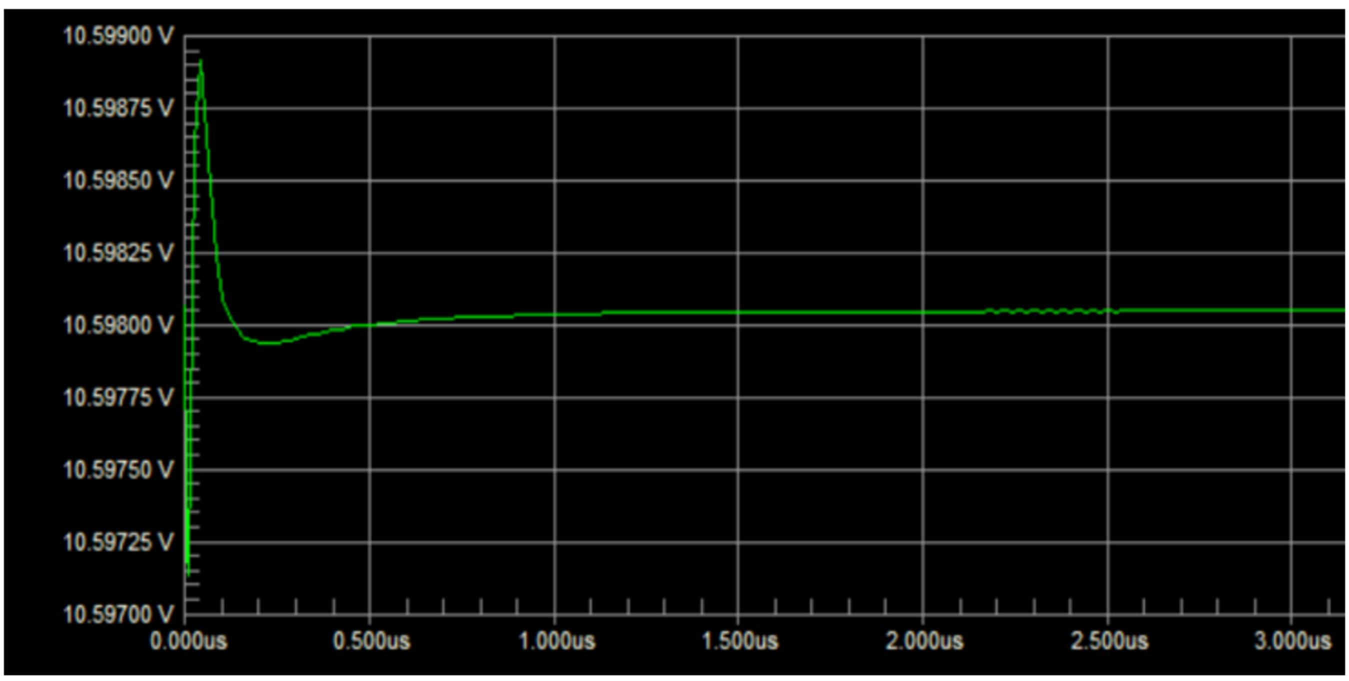

Figure 3. Simulation of an Basic MPPT system.

In this paper, a Distributed optimized predictive Maximum Power Point Tracking scheme is proposed in which each PV module is operated at its own Maximum Power Point. This scheme will tend to increase the output power of the different PV panels which is connected under partially shaded conditions.

The VI characteristics for the PV under partial shaded conditions is shown in Figure 3. This is due to non linear behaviour with the circuit The capacitor causes a lag on the inverting terminal as the supply voltage drops at the power supply turn off, causes positive difference between the input terminals. The generation of power through solar energy requires more than one photovoltaic panel connected in series and parallel to each other to make a solar system. The MPPT is used for the system to track the point at which the maximum power is obtained. In existing system the MPPT is used in common for all the PV panels that are connected in series as well as in parallel. If the irradiation from the sun is constant over all the panels it will provide an efficient output. But when the irradiation from the sun changes for different panels due to the passing clouds, shadow of buildings, crossing of birds, etc., will leads to variation of output from each panel. PV System with Optimization Algorithms [8-10]: This project involves designing a Simulink model based on a PV system, including components like a PV array, battery, converter, PI controller, inverter, and charge controller. It uses optimization algorithms such as Genetic Algorithm (GA), Particle Swarm Optimization (PSO), and Neural Network (NN) for Maximum Power Point Tracking (MPPT). Neural Network MPPT for PV. In applying a genetic algorithm (GA) to optimize a solar PV system involves several steps.

Create the Initial Population: Generate a set of potential solutions (individuals) randomly. Each individual represents a possible configuration of the solar PV system.

Evaluate Fitness: Assess each individual's performance using the objective function. This step determines how well each configuration meets the optimization goal.

Selection: Choose the best-performing individuals to be parents for the next generation. This can be done using methods like roulette wheel selection or tournament selection.

Crossover: Combine pairs of parent individuals to create offspring. This step involves exchanging parts of the configurations to create new potential solutions.

Mutation: Introduce small random changes to the offspring to maintain diversity in the population and avoid local optima.

Repeat: Evaluate the new generation, select the best individuals, and repeat the process until a satisfactory solution is found or a maximum number of generations is reached.

Output the Best Solution: The final best-performing individual represents the optimized configuration of the solar PV system.

This script enhances the MPPT process in Solar PV systems using a Neural Network trained with the PSO algorithm. This approach improves the efficiency of tracking the maximum power point.

Maximum Power Point Tracking (MPPT) using Particle Swarm Optimization (PSO) under partial shading is a fascinating topic. PSO is an optimization technique inspired by the social behavior of birds flocking or fish schooling, and it's used to find the maximum power point (MPP) of a photovoltaic (PV) system even under challenging conditions like partial shading [7, 11].

Partial shading can create multiple peaks on the power-voltage (P-V) curve of a PV array, making it difficult for traditional MPPT methods to find the global MPP. PSO, however, can effectively navigate these multiple peaks and track the global MPP by simulating a group of particles (potential solutions) that explore the search space and adjust their positions based on their own experience and the experience of neighboring particles.

2. Methodology and Implementation

In this study of approach including support vector machine (SVM) and Gaussian process regression (GPR) were used for predicting PV panel power and determining suitable algorithm as the predictive approaches.

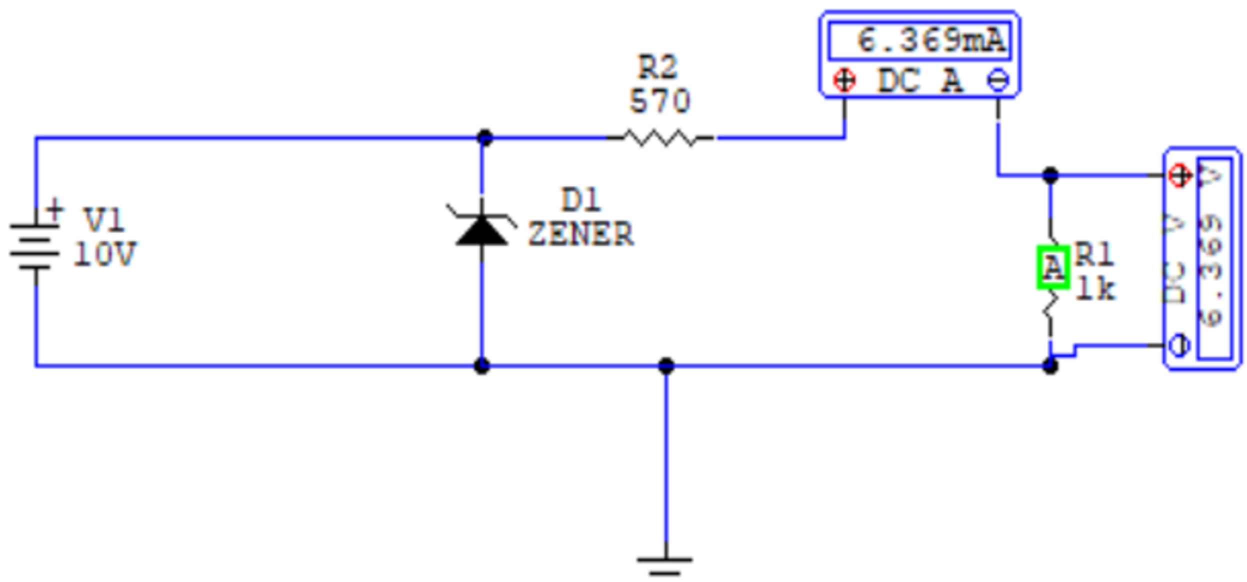

Figure 4. Equivalent circuit of a solar panel.

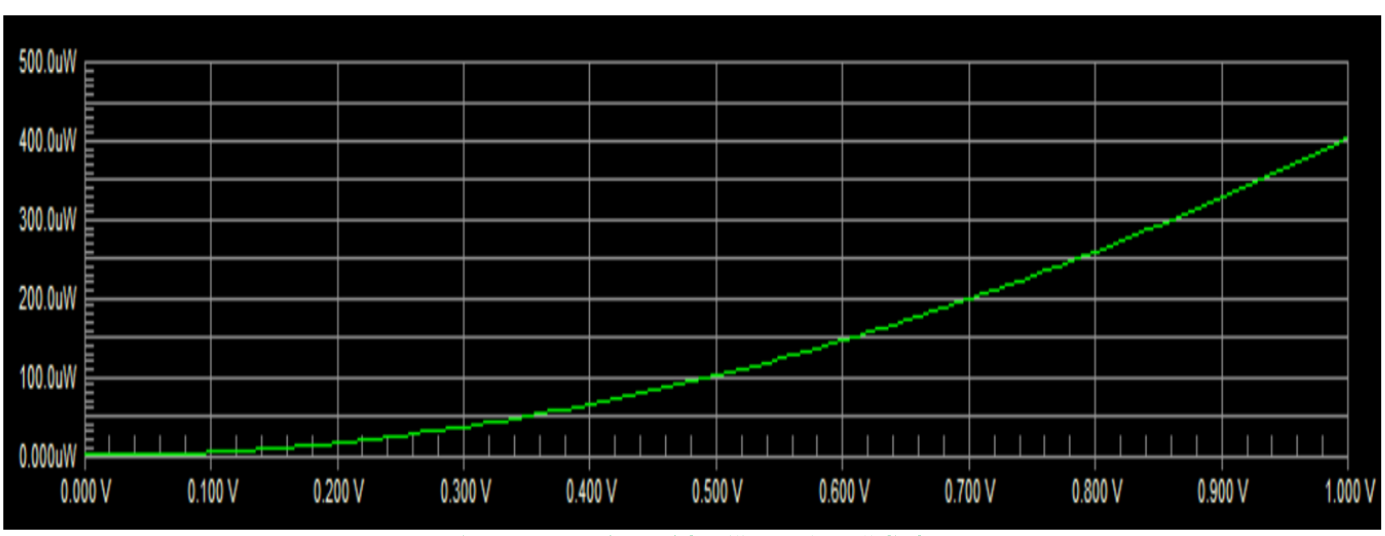

Figure 5. Waveform of the silicon solar cell diode.

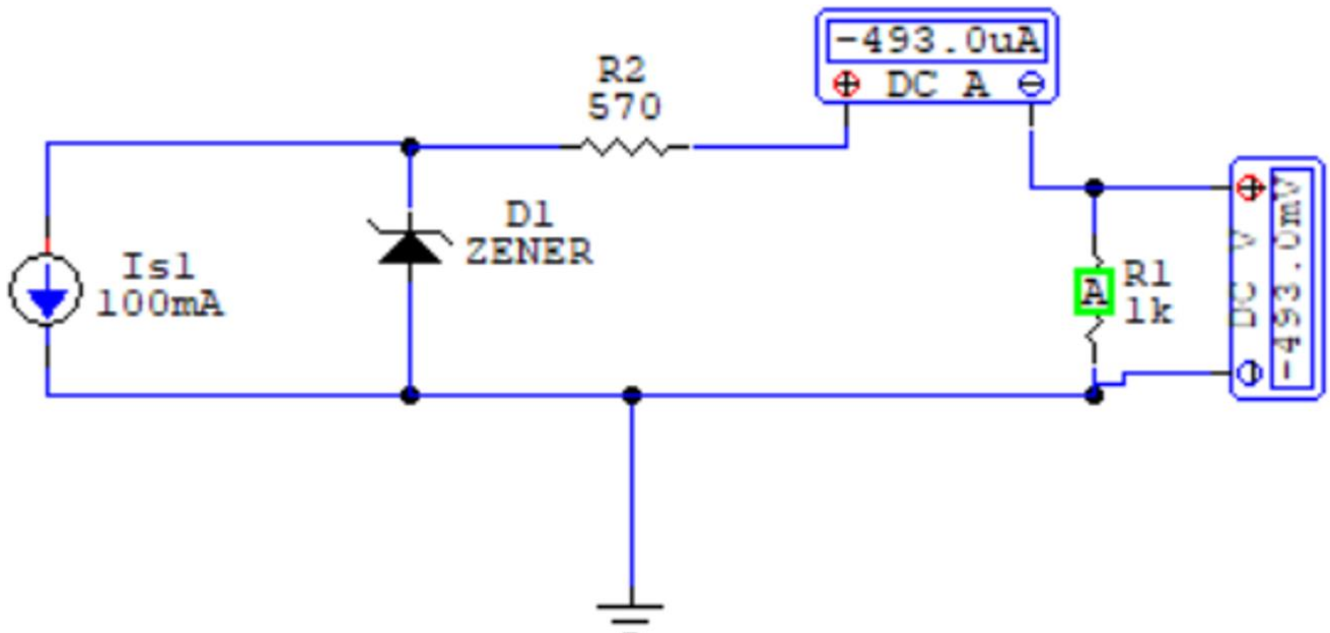

Figure 6. Equivalent circuit of a solar panel.

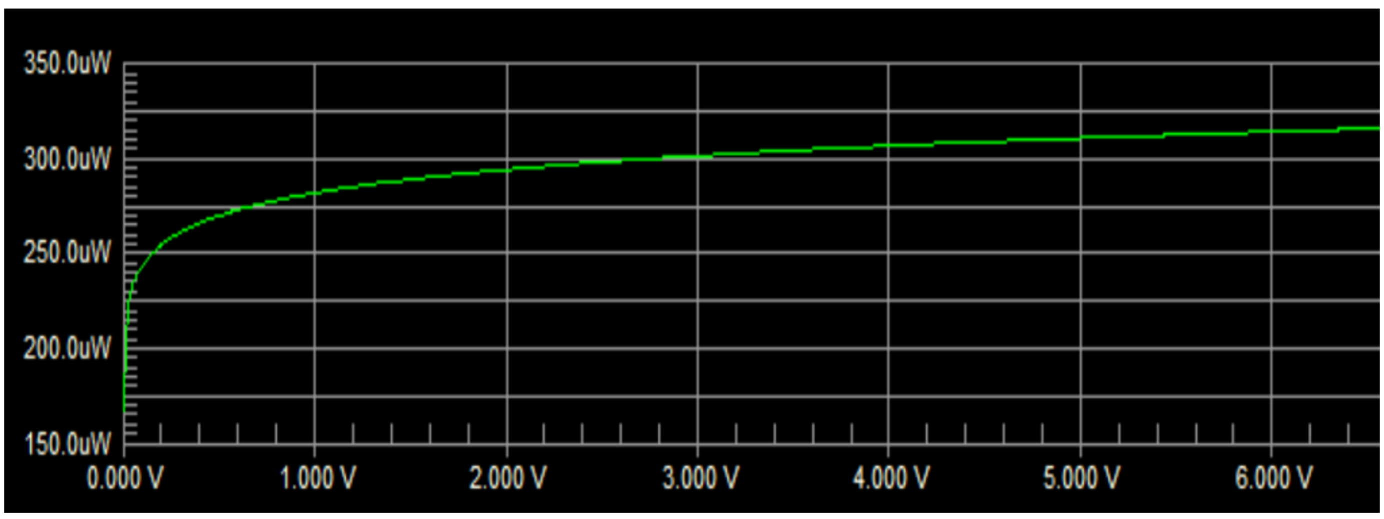

Figure 7. Equivalent circuit of a solar panel.

The electronic load was controlled and programmed by an IV plotter program created using circuit maker 2000 pro software. The solar cell single diode model as shown in Figure 4 and 6. The comparative waveform are shown in Figure 5 and Figure 7.

The solar cell single diode model is given by.

$$I_{SOLAR} = I_P - I_0\left[e^{\frac{1}{A_D}\left\{\frac{V}{V_T}-\frac{IR_S}{V_t}\right\}} - 1\right] - [V_{SH} + V_S] \quad (1)$$

Where,
I_{SOLAR} = Measured solar cell current (A).
V_{SH} = Measured solar cell voltage (V).
Ip = Photosynthesis generated current (A).
I0 = Reverse saturation current (A).
Rs = Series resistance (Ω).
Vsh = Shunt Voltage ($I_{sh}.R_{sh}$).
A_D = Diode ideality factor.
VT = Thermal voltage (V) = kT/q.
k = Boltzmann constant (eV/K).
T = Solar cell temperature (K).
q = Elementary charge constant ©.

The aggregate output current of the parallel and series connected PV modules is expressed in Equation 1 is modified for N solar panel cell is given by

$$I_{SOLAR} = N_p\left[I_P - I_0\left[e^{\frac{1}{A_D}\left\{\frac{V}{V_T}-\frac{IR_S}{V_t}\right\}} - 1\right]\right] - \frac{[V_{PV}+R_S I_{PV}]}{N_S R_P} \quad (2)$$

The PV array can be obtained by connecting the number of PV modules either in series or in parallel for required voltage and current.

The mathematical relationship between the current and voltage of the PV array is indicated by Equation 2.

$$I_{P,V} = I_P.N_P - I_R N_P\left[e^{\left(\frac{q\left(V_{p,v,a}+R_S\left(\frac{N_S}{N_P}\right)I_{P,a}\right)}{n_S kTa}\right)} - 1\right] - \frac{V_{P,va}+R_s\left(\frac{N_S}{N_P}\right)I_{P,a}}{R_{sh}\left(\frac{N_S}{N_P}\right)} \quad (3)$$

MPPT evolves into an algorithm based on evolutionary, heuristic and meta-heu-ristic techniques. It is designated to track global peak instead of local peaks since conventional HC MPPT techniques fail to track global peak under PSC and rapid changing of solar irradiance. Apart from electronically implemented MPPTs, there are other techniques to improve solar energy efficiency such as integrated soft-computing weather forecast and adjustment of the tilting angle of solar panel to track the sun direction.

We only focus on the artificial intelligence (AI)-based MPPT techniques for DC-DC converter in the solar power system.

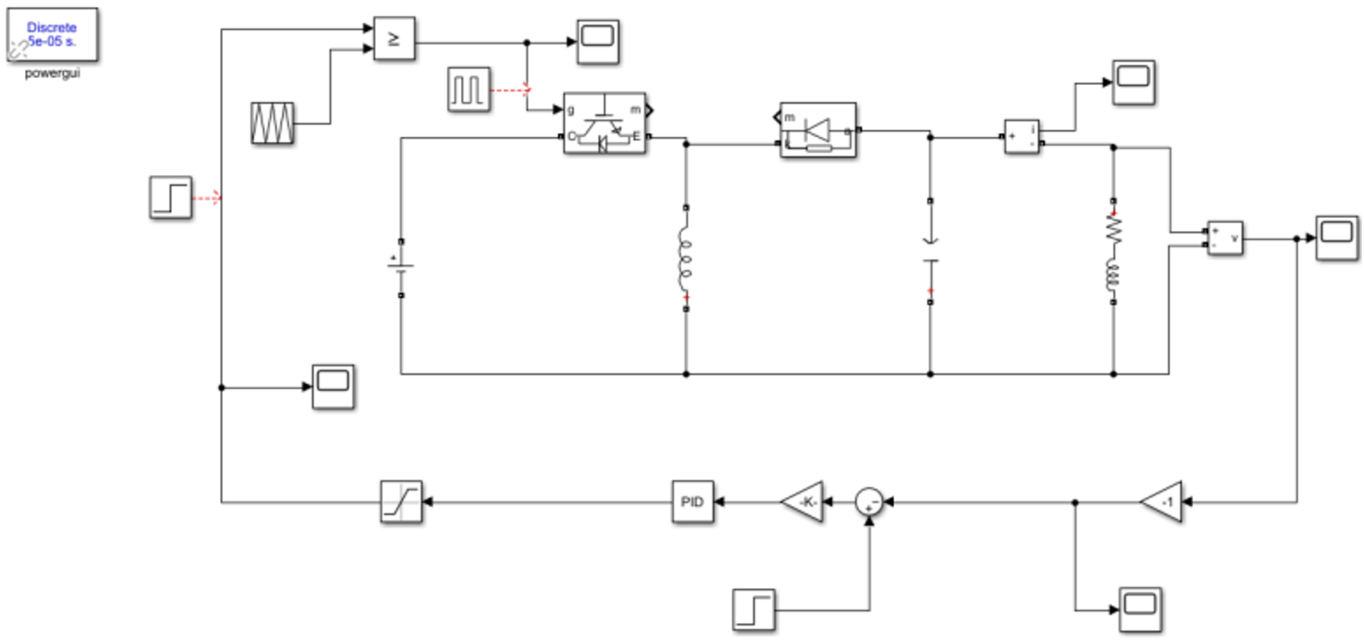

Figure 8. Buck-Boost Converter with PWM module.

A Buck-Boost Converter with a PWM module is a type of DC-DC converter that can step up or step down voltage levels while maintaining efficiency is as shown in Figure 8. It combines the functionality of both buck (step-down) and boost (step-up) converters, making it useful for applications where input voltage fluctuates but a stable output is required.

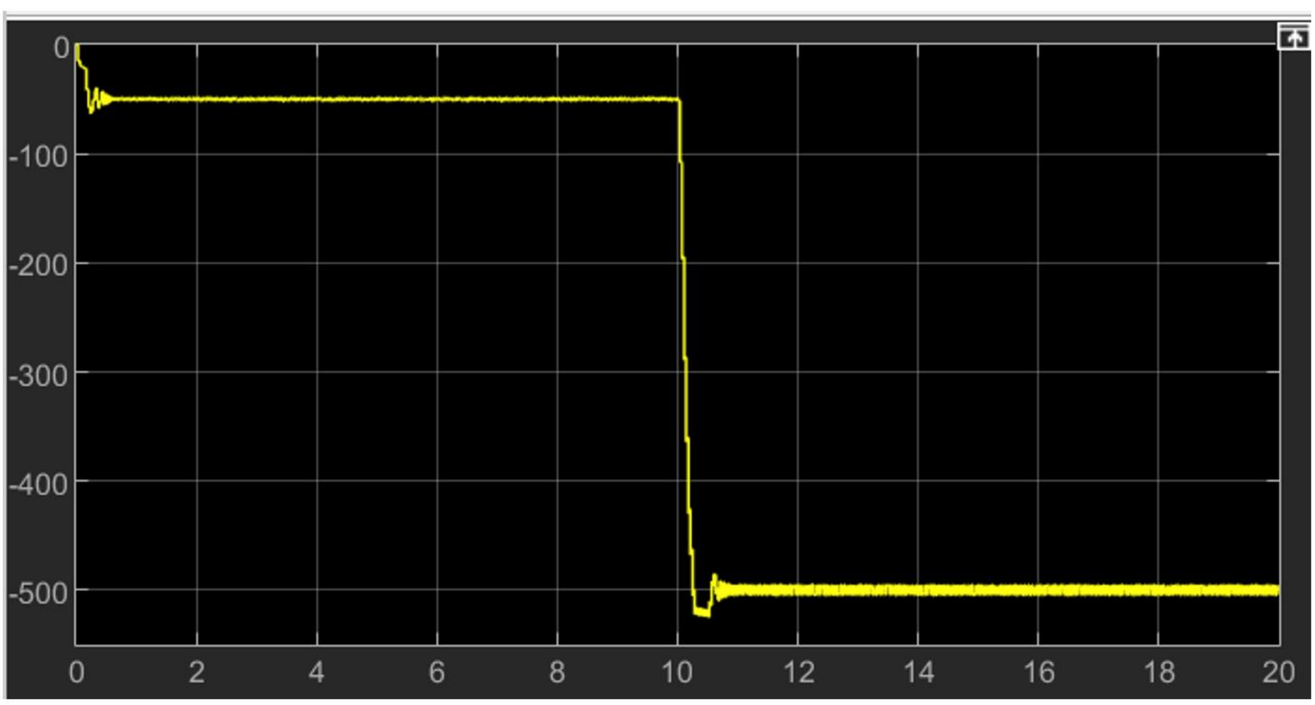

Figure 9. Waveform of an PWM DC-DC converter.

The Pulse Width Modulation (PWM) Controls the duty cycle to regulate output voltage efficiently. Voltage Regulation provide a stable voltage output despite variations in input voltage. A High Efficiency reduces power loss compared to linear regulators.Often used in battery-powered devices, renewable energy systems, and embedded electronics. A periodic square wave that alternates between high and low states, depending on the duty cycle is shown in Figure 9. A smoothed version of the switching waveform, regulated by the converter's control system.

3. Simulation Results

All research-oriented performance were implemented in MATLAB R2021b and run on Windows 11 pro version Dev with intel Core Intel (R) Core (TM) i5-3317U CPU @ 1.70GHz and 64-bit ,8.00 GB (7.88 GB usable) of RAM. Few parameterics are assumed based on the initialization of the particles are shown in Table 1.

Table 1. Parametric simulation for proposed traditional MPPT protocol.

Simulation parameters	Symbols	Values
Open-circuit voltage (V	V_{oc}	22
Short-circuit current (A)	I_{SC}	5
Minimum voltage and maximum (V)	Vmin and Vmax	Vmin = 0 Vmax = Voc
Load resistance	R_L	94.4 Ω
Number of particles	Num_particles	30
Maximum number of iterations	Max_iter	100
Irradiance	I_r	Steps of 200 W/m² on every 20 s
		400 W/m² to 1000 W/m
Temperature	T	47° C
Inertia weight	w	0.5
Cognitive parameter	c1	1.5
Social parameter	c2	2

The parameters of an AI-based MPPT controller are the design complexity, ability to track GMPP, cost-effectiveness, PV panel dependency, prior training requirement, dataset requirement, convergence speed, analogue or digital architecture, required sensory information, periodic tuning, stability, and efficiency [5, 6].

The objective function of Maximum Power Point Tracking (MPPT) in solar systems is to maximize the power output from the solar panels by continuously adjusting the operating points to ensure they operate at their maximum power output, even with changing environmental conditions like sunlight intensity and temperature.

In mathematical terms, the objective function can be expressed as.

$$Maximum\ P_{out} = V_{mppt} * I_{mppt} \qquad (4)$$

Where,

P_{out} = Power output

V_{mppt} = Voltage at maxmimum power point I_{mppt} = Current at the maximum power point

MPPT technology ensures that the solar panels are always operating at their optimal point on the power-voltage (P-V) curve, which varies with conditions such as shading, temperature, and the load's electrical characteristics.

There are several approaches to implementing Solar PV algorithms using MATLAB.

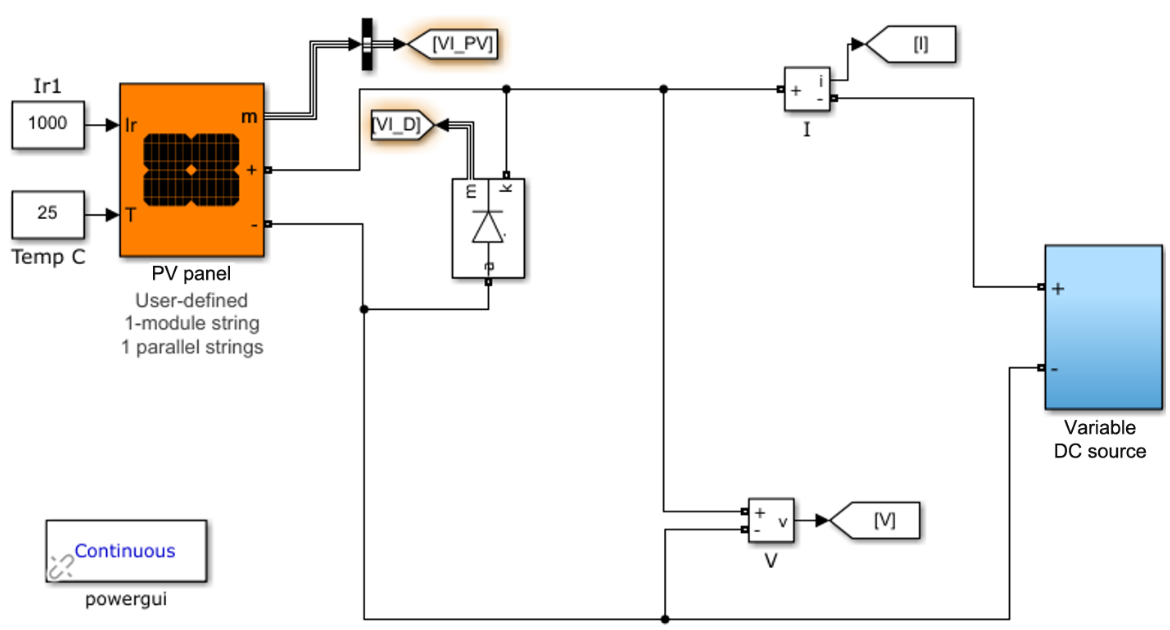

Figure 9. Solar PV MPPT protocol.

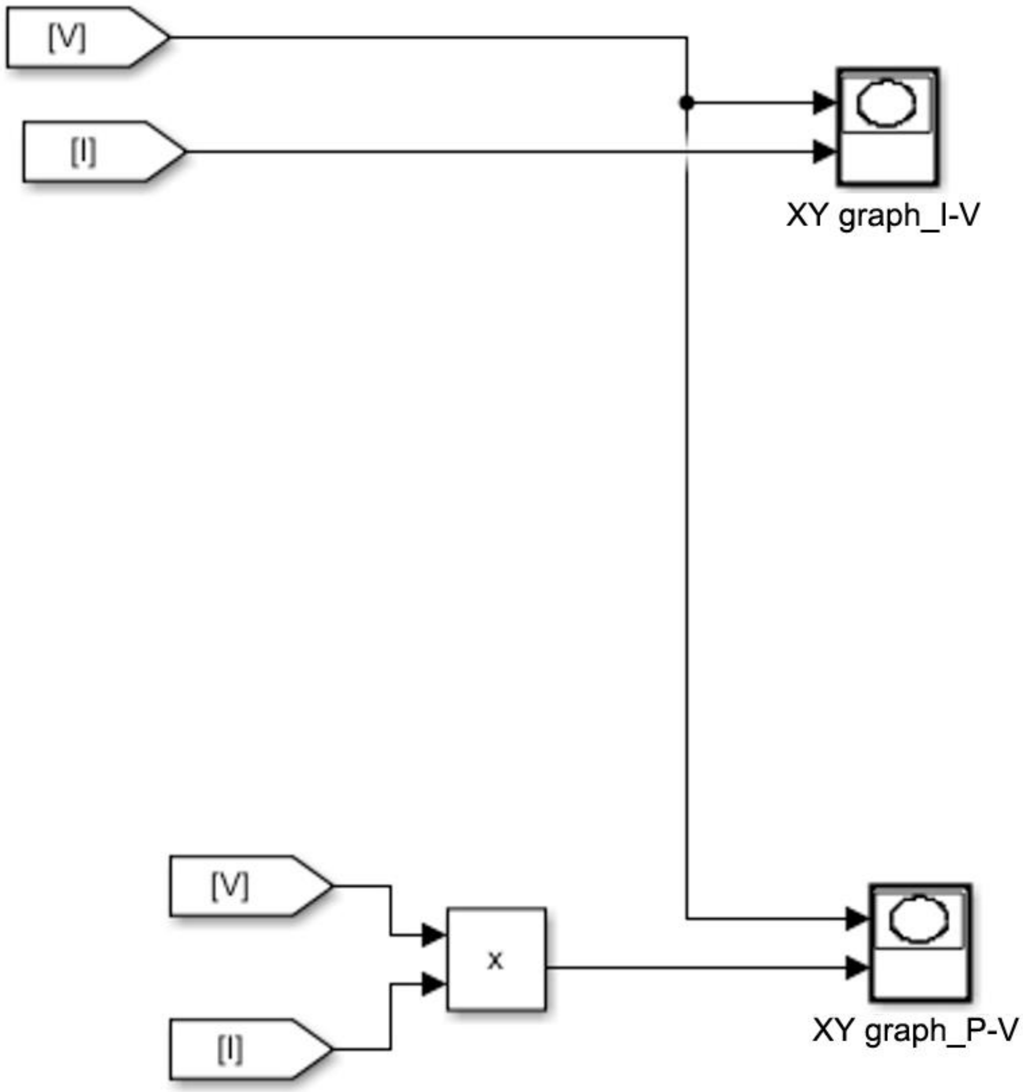

Figure 10. Solar PV MPPT graph plotter.

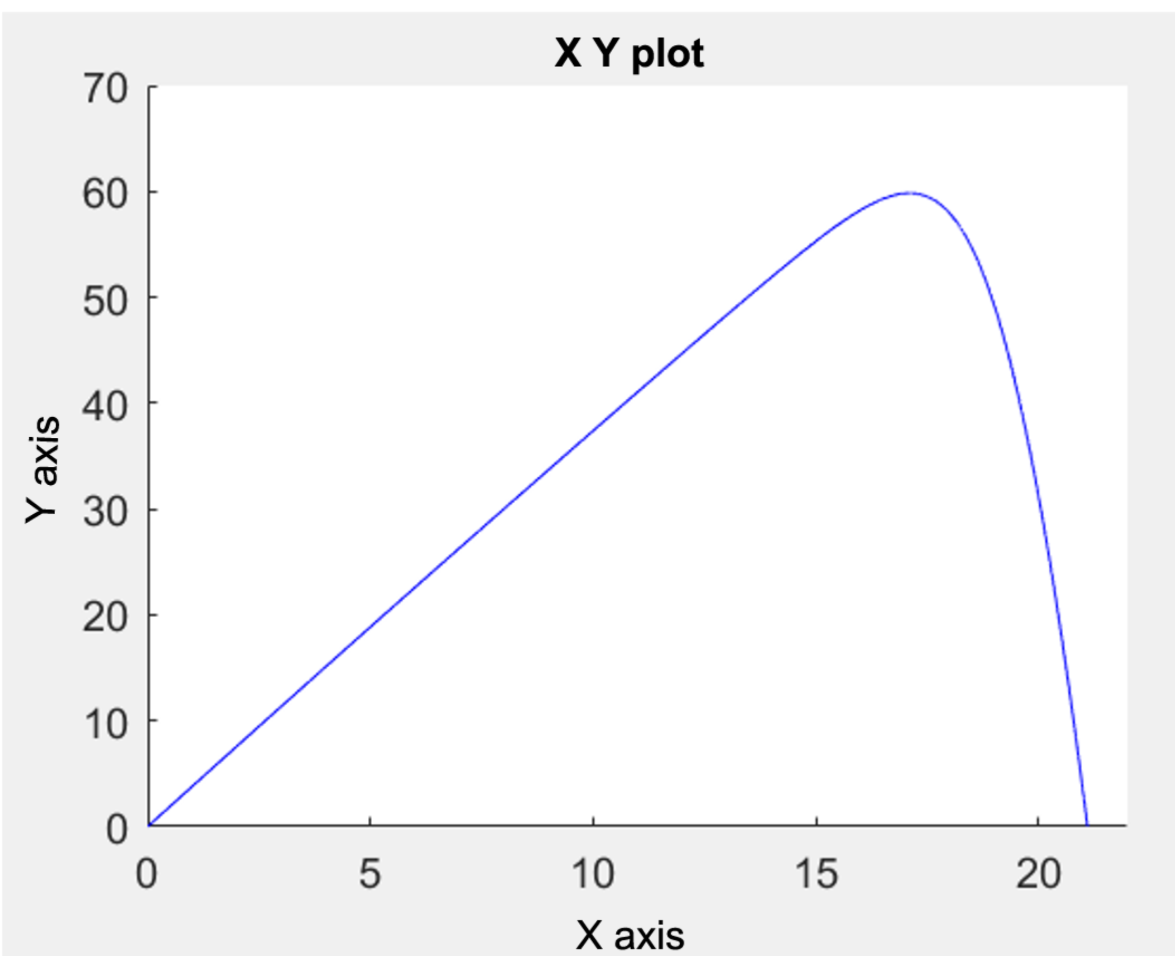

Figure 11. Proposed MPP tracking line.

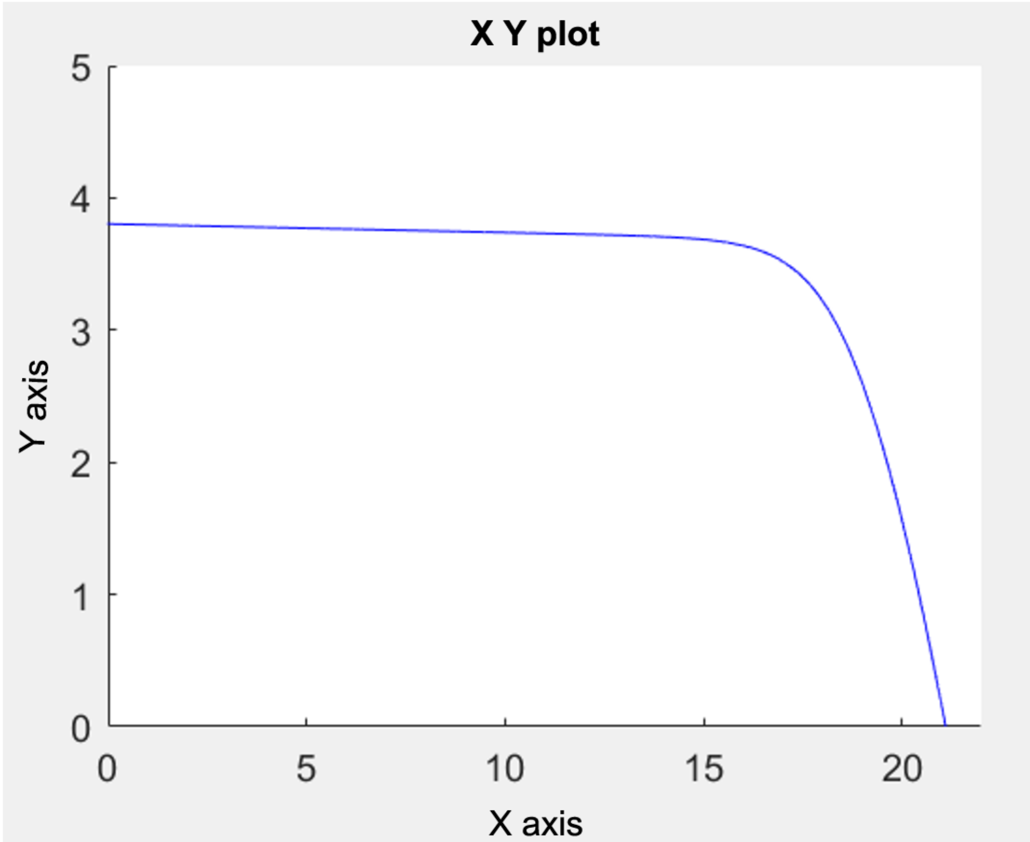

Figure 12. IV Graph of MPP tracking.

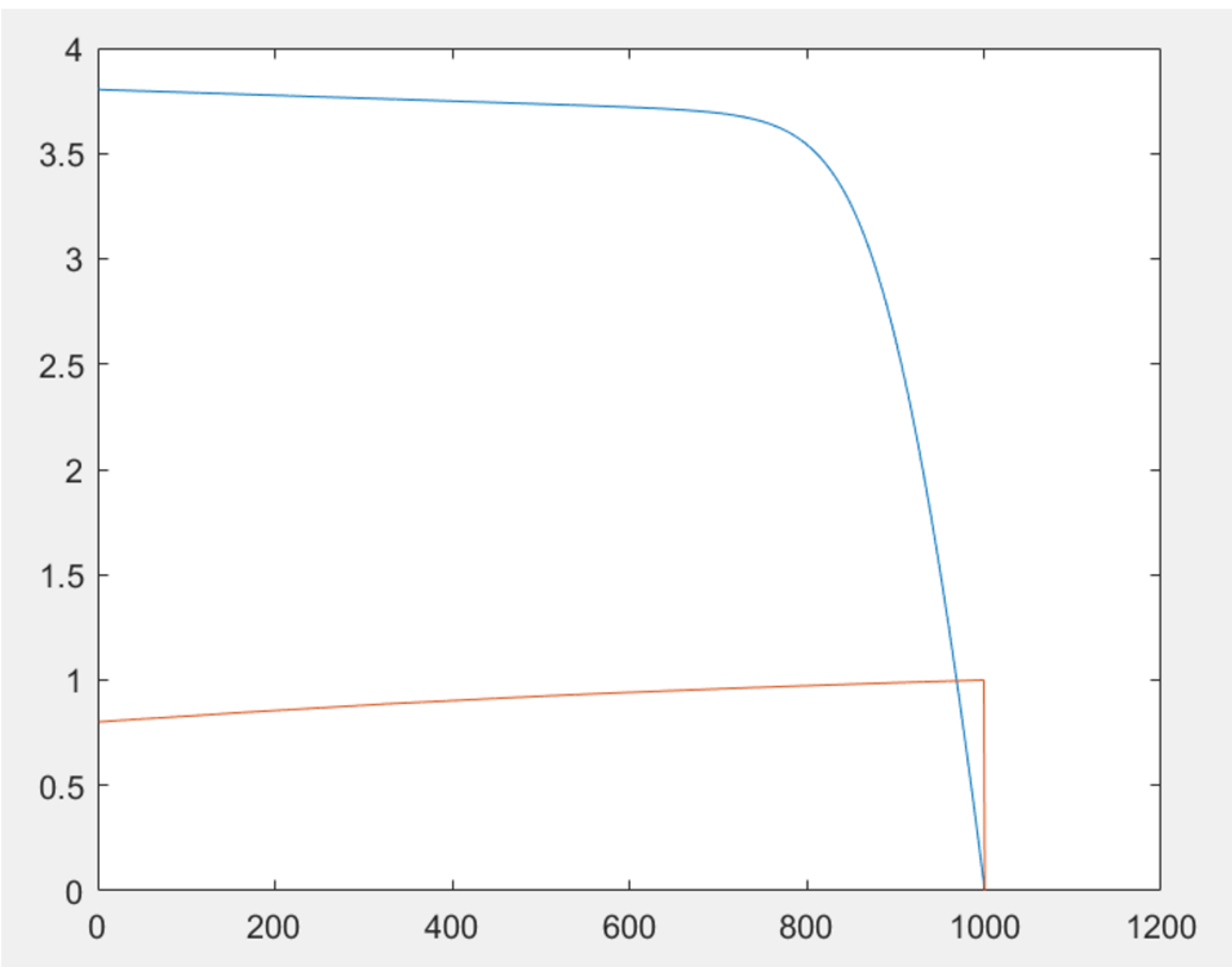

Figure 13. VI Plot curve for an propsed MPP tracking.

It is obvious that in Figure 9 and Figure 10, PV array receives two different radiation intensities, the sunlight of the shaded PV panels is only 400W/m². There is a voltage difference between the panel 1 and panel 2, which will turn on the bypass diodes of panel 2. Thus, there will be two MPPs on the

P- V characteristic of the PV array, as shown in Figure 12 and Figure 13. In this case, the GMPP is located at GP_1. In next iteration three PV panels of the PV array receive three different sunlight, which leads to MPPs on the P-V characteristic curve and the GMPP is now located at GP_2, as shown in Figure 12. Suppose If PV array works without any shading, so in there is only one power peak on the P-V characteristic curve get decreases [2, 12].

The Distributed proposed MPPT algorithm starts by initializing the duty cycles of the buck converter, which are noted as d_{ij} (i = 1,2,…N). The corresponding power at each duty cycle can be calculated by

$$P({d_i}^{j+1}) = V.I. \qquad (5)$$

The maximum fitness value will be saved and its corresponding duty cycle is set as I_{best}. According to the definition of *mppt_g*$^{i}_{best}$ it need to satisfy the following relation.

$$P(mppt\_g^{j}{}_{best}) \geq P(I^{j}{}_{best}) \qquad (6)$$

The mathematical expression of the Overall distribution of proposed MPPT algorithm is given in cauchy Random variable principles. Probability density function (PDF) of a Cauchy random variable is given by.

$$f_x(x; x_0; \gamma) = \frac{1}{\pi\gamma\left[1+\left(\frac{x+x_0}{\gamma}\right)^2\right]} \qquad (7)$$

Where:

x_0 is the location parameter (the peak of the distribution).

γ gamma is the scale parameter (the half-width at half-maximum).

Cumulative density function (CDF) of a Cauchy random variable is given by.

$$F_x(x) = \frac{1}{2} + \frac{1}{\pi} tan^{-1}\left(\frac{x-\mu}{\lambda}\right) \qquad (8)$$

Assume x is chosen as 0, because the position of particles d_{ij} in the proposed MPPT algorithm is a linear change of Cauchy, *dij* has the same distribution rule as Cauchy.

If the median m is of continuous random variable then.

$$\int_{-\infty}^{+\infty} f_x(x)dx = \int_{m}^{+\infty} f_x(x)dx = \frac{1}{2} \qquad (9)$$

The duty cycles are distributed around *mppt_g*$^{i}_{best}$ within a region of radius R (R ∈ [0,1]), which follows the Cauchy distribution. R is reduced by a shrinking coefficient α. when γ is smaller and the probability of particles in Cauchy distribution is more dispersed when γ is greater.

Although the AI-based proposed MPPT algorithms can be used to accurately capture the GMPP.They are sensitive to initial condition. Optimizing the initial values using a variety of measures can improve the performance of the AI-based MPPT algorithms. In the following, an Overall distribution of proposed MPPT algorithm will be shrinked at the search region of GMPP, which obtains the initial particles for the AI-based proposed MPPT algorithms. Therefore algorithms are able to complement each other and achieve a better MPPT performance.

In order to thoroughly compare the tracking performances of these proposed MPPT algorithms, a variable P_{avg} is introduced to represent the average output power of the PV system with MPPT algorithm during time duration T. P_{avg} can be expressed in (10)

$$P_{avg} = \frac{\int_0^T p.dt}{T} = \frac{\sum_{j=1}^{Num} p_i.\Delta t}{Num.\Delta t} \qquad (10)$$

Further, the tracking performances of these three MPPT algorithms can also be described by MPPT efficiency η, which can be calculated by.

$$\eta = \frac{P_{output\ of\ stable\ PV}}{P_{Theoritical\ Maximum\ output\ power\ of\ the\ PV}} X100 \qquad (11)$$

4. Conclusion and Future Scope

In this paper Distributed proposed MPPT protocol has been framed-out for the optimization and predictive maximization of power point tracking Through simulations using MATLAB and higher effectiveness and accuracy of the proposed MPPT algorithm in solar PV systems is demonstrated using simulink using Artificial Intelligence technique. The Overall distribution of proposed MPP algorithm can rapidly find the small region that contains the Global MPP without any information about the PV array and thus has a fast MPPT speed. PV system output more power and have lower power fluctuation in comparison with the existing MPPT algorithms.

References

[1] T. S. Babu, N. Rajasekar, and K. Sangeetha, "Modified particle swarm optimization technique based maximum power point tracking for uniform and under partial shading condition," *Applied Soft Computing*, vol. 34, pp. 613-624, 2015. https://doi.org/10.1016/j.asoc.2015.05.029

[2] H. Li, D. Yang, W. Su, J. Lü, and X. Yu, "An overall distribution particle swarm optimization MPPT algorithm for photovoltaic system under partial shading," *IEEE Transactions on Industrial Electronics*, vol. 66, no. 1, pp. 265-275, 2018. https://doi.org/10.1109/tie.2018.2829668

[3] A. K. Podder, N. K. Roy, and H. R. Pota, "MPPT methods for solar PV systems: a critical review based on tracking nature," *IET Renewable Power Generation*, vol. 13, no. 10, pp. 1615-1632, 2019. https://doi.org/10.1049/iet-rpg.2018.5946

[4] E. Mendez, A. Ortiz, P. Ponce, I. Macias, D. Balderas, and A. Molina, "Improved MPPT algorithm for photovoltaic systems based on the earthquake optimization algorithm," *Energies*, vol. 13, no. 12, p. 3047, 2020. https://doi.org/10.3390/en13123047

[5] N. Singh, K. K. Gupta, S. K. Jain, N. K. Dewangan, and P. Bhatnagar, "A flying squirrel search optimization for MPPT under partial shaded photovoltaic system," *IEEE Journal of Emerging and Selected Topics in Power Electronics*, vol. 9, no. 4, pp. 4963-4978, 2020.

[6] K. Y. Yap, C. R. Sarimuthu, and J. M.-Y. Lim, "Artificial intelligence based MPPT techniques for solar power system: A review," *Journal of Modern Power Systems and Clean Energy*, vol. 8, no. 6, pp. 1043-1059, 2020.

[7] M. Naseem, M. A. Husain, J. D. Kumar, M. W. Ahmad, A. F. Minai, and A. A. Khan, "Particle swarm optimization based maximum power point tracking technique for solar PV system under partially shaded conditions," in *2021 International Conference on Control, Automation, Power and Signal Processing (CAPS)*, 2021: IEEE, pp. 1-6.

[8] A. Hassan, O. Bass, and M. A. Masoum, "An improved genetic algorithm based fractional open circuit voltage MPPT for solar PV systems," *Energy Reports*, vol. 9, pp. 1535-1548, 2023. https://doi.org/10.1016/j.egyr.2022.12.088

[9] D. Kumar *et al.*, "A novel hybrid MPPT approach for solar PV systems using particle-swarm-optimization-trained machine learning and flying squirrel search optimization," *Sustainability*, vol. 15, no. 6, p. 5575, 2023.

[10] M. A. E. Mohamed, S. Nasser Ahmed, and M. Eladly Metwally, "Arithmetic optimization algorithm based maximum power point tracking for grid-connected photovoltaic system," *Scientific Reports*, vol. 13, no. 1, p. 5961, 2023. https://doi.org/10.1038/s41598-023-32793-0

[11] M. A. Azad *et al.*, "A particle swarm optimization–adaptive weighted delay velocity-based fast-converging maximum power point tracking algorithm for solar PV generation system," *Sustainability*, vol. 15, no. 21, p. 15335, 2023. https://doi.org/10.3390/su152115335

[12] F. Mahjabeen, "Artificial intelligence based MPPT techniques for solar power system: A review," *Asian Journal of Mechatronics and Electrical Engineering*, vol. 3, no. 1, pp. 27–40, 2024.