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"MAXIMUM POWER POINT TRACKING FOR SOLAR PV ARRAY BY USING PETURB AND OBSERVE, INCREMENTAL CONDUCTANCE, CUCKOO SEARCH, GREY WOLF OPTIMIZATION TECHNIQUES."

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Abstract: Increasing concerns about climate change and sustainability, the adoption of renewable energy sources like solar power is on the rise worldwide. Solar energy has emerged as a prominent renewable energy source due to its abundance, accessibility, and environmental friendliness. Maximum Power Point Tracking (MPPT) techniques play a crucial role in optimizing the efficiency and output of photovoltaic (PV) solar systems by continuously tracking the maximum power point of the PV array. Various MPPT algorithms such as Perturb and Observe (P&O), Incremental Conductance (INC), and Fractional Open-Circuit Voltage (FOCV) are extensively discussed and applied in literature for improving the performance of PV systems. Researchers and practitioners have explored and implemented these MPPT algorithms in real-world PV systems to enhance energy harvesting efficiency and maximize power output. Partial shading in PV arrays can significantly reduce overall system efficiency and lead to mismatch losses. Advanced MPPT algorithms are employed to mitigate the impact of partial shading, ensuring optimal performance and energy yield from solar installations. In this project we will apply various techniques and algorithms like PandO, Incremental conductance for MPPT of solar PV systems and also we will compare the tracking efficiency of all these methods and we will extend the work to partial shading conditions also.

Index Term: Matlab, MPPT, Perturb and Observe, Incremental Conductance, Cuckoo search and Grey wolf optimization.

I. INTRODUCTION

Energy has the great importance for our life and economy. The energy demand has greatly increased due to the industrial revolution. Fossil fuels have been started to be gradually depleted. The sustainability of our civilization is seriously threatened. On the other hand the greenhouse gas emissions are still increasing due to the conventional generation of energy. It is a really global challenge to reduce carbon dioxide emissions and ensuring secure, clean and affordable energy, and to achieve more sustainable energy systems. Renewable energy sources are considered as a perfect option for generating clean and sustainable energy. There are many sources of renewable energy such as solar energy, wind energy, etc. Photovoltaic (PV) system has taken a great attention by the researchers where it appears to be one of the most promising renewable energy sources. Solar energy is a clean, maintenance-free, pollution free. However, two important factors limit the implementation of photovoltaic systems. These are high installation cost and low efficiency of energy conversion. In order to reduce photovoltaic power system costs and to increases the utilization efficiency of solar energy, the maximum power point tracking system of

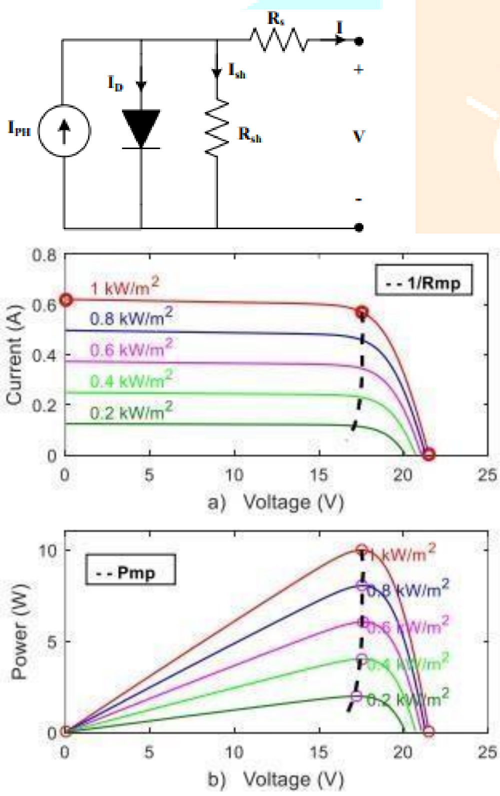

fig: solar pv Maximum power outputs

referred to as MPPT, is a system used to extract the maximum power of the PV module to deliver it to the load, and the efficiency is increased. 2 PV systems are dependent power sources with nonlinear I-V characteristics under different environmental (isolation, temperature, degradation) conditions. In addition, they have high fabrication cost and low energy conversion efficiency. PV arrays have non-linear I– V characteristics and output power depend on atmospheric conditions. In photovoltaic module there is one single point at any given point of time where maximum power is drawn, so to locate this point and operate MPPT module always near that point. The process of doing this to always trying to maintain the operating point of PV panel at maximum power point is calledmaximum power point tracking (MPPT). MPPT is a technique

employed to extract maximum power available from the PV source, as location of MPP keeps on varying with changing atmospheric conditions. The MPP tracker traces, PV operating voltage corresponding to MPP and locks the operating point at MPP and extract maximum power from the PV array.

II LITERATURE REVIEW

Maximum Power Point Tracking (MPPT) methods utilizing Perturb and Observe (P&O) algorithm, Incremental Conductance method, Cuckoo Search algorithm, and Grey Wolf Optimizer (GWO) algorithm. Maximum Power Point Tracking (MPPT) is crucial in solar energy systems to ensure optimal power extraction from photovoltaic (PV) panels. Various MPPT techniques have been developed to enhance efficiency and adaptability to changing environmental conditions. The Perturb and Observe (P&O) algorithm is one of the most widely used MPPT 3 techniques due to its simplicity and effectiveness. It perturbs the operating point of the PV system and observes the resulting change in power to determine the direction towards the maximum power point (MPP). However, P&O suffers from oscillations around the MPP under dynamic weather conditions and may take longer to converge. The Incremental Conductance method improves upon P&O by considering the instantaneous conductance of the PV system. It adjusts the operating point based on the comparison between the incremental conductance and the instantaneous conductance, leading to faster and more accurate tracking of the MPP. However, it requires more computational resources compared to P&O. Cuckoo Search algorithm, inspired by the brood parasitism of some cuckoo species, is a nature-inspired optimization algorithm. It simulates the breeding behavior of cuckoos to search for the global optimum. In the context of MPPT, Cuckoo Search optimizes the control parameters of the PV system to maximize power output. It exhibits good convergence properties and robustness against local optima. Grey Wolf Optimizer (GWO) algorithm is another nature-inspired optimization technique inspired by the social hierarchy and hunting mechanism of grey wolves. It mimics the hunting behavior of wolves to iteratively update the position of potential solutions. GWO has shown promising results in various optimization problems, including MPPT in solar PV systems. It efficiently explores the search space and converges towards the MPP with fewer iterations compared to traditional algorithms. 4 In recent studies, researchers have compared the performance of these MPPT techniques under different operating conditions, including variations in irradiance and temperature. They have also proposed hybrid approaches that combine multiple algorithms to achieve improved efficiency and robustness. Overall, the literature demonstrates ongoing research efforts to enhance the performance of MPPT techniques in solar energy systems, with a focus on improving accuracy, convergence speed, and adaptability to changing environmental conditions.

III DISCRIPTION OF SYSTEM (SOLAR PV SYSTEM):

Solar photovoltaic (PV) systems harness sunlight to generate electricity, offering a sustainable and renewable energy solution. Comprising solar panels, inverters, and mounting structures, PV systems convert sunlight into usable electrical power. They provide clean energy with minimal environmental impact, reducing reliance on fossil fuels and mitigating greenhouse gas emissions. PV systems are versatile, scalable, and suitable for various applications, including residential, commercial, and utility-scale projects. With ongoing technological advancements and decreasing costs, solar PV systems are becoming increasingly accessible and economically viable, contributing significantly to the global transition towards clean and sustainable energy sources.Solar PV System. 2.2 Modelling of Solar System Modeling solar systems involves creating mathematical representations to simulate their behavior and performance, crucial for designing efficient and reliable solar energy 7 systems. Various modeling approaches are employed, each with distinct methodologies and applications. Empirical commonly used numerical approaches to analyze heat transfer and fluid flow within solar thermal systems, optimizing design and performance. Additionally, System Dynamics models simulate interactions between system components, enabling holistic assessment and optimization of solar energy systems' performance and integration with other renewable energy sources. Overall, modeling plays a crucial role in understanding, optimizing, and advancing solar energy technologies. By combining empirical, analytical, and numerical approaches, researchers and engineers can develop accurate and versatile models to facilitate the design, operation, and integration of solar systems into diverse energy

DC-DC BOOST CONVERTER

A DC-DC boost converter is an electronic circuit that converts a DC voltage at a lower level to a higher level. It is commonly used in many applications, such as power supplies, battery chargers, and LED drivers. 13 The boost converter operates by using a switching element, usually a transistor, to switch the input voltage to an inductor. When the transistor is turned on, the current flows through the inductor and stores energy. When the transistor is turned off, the inductor releases the stored energy into the output capacitor and load, which increases the output voltage. The boost converter can be controlled by adjusting the duty cycle of the switching element. A higher duty cycle results in a higher output voltage, and a lower duty cycle results in a lower output voltage. The output voltage can be regulated by a feedback loop that compares the actual output voltage to a reference voltage and adjusts the duty cycle accordingly. The efficiency of the boost converter can be improved by using a synchronous rectifier, which replaces the output diode with a transistor that switches on at the right time to reduce power losses. Other techniques, such as softswitching and multi-phase control, can also be used to improve efficiency and reduce noise.

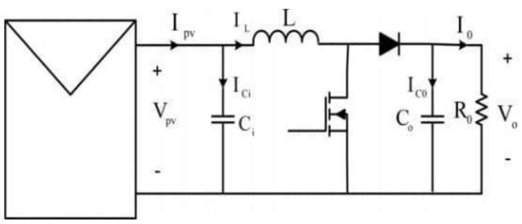

Fig: pv connected boost converter

PERTURB AND OBSERVE METHOD:

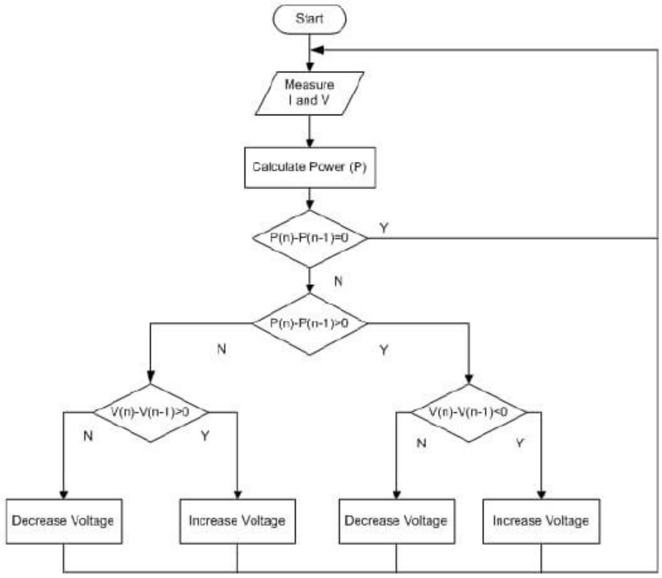

Fig:Flowchart of perturb and observe algorithm

landscapes, contributing to the global transition towards sustainable and renewable energy.the effects of the size of the increment on the performance of the P&O method. The small increments tend to make the algorithm more stable and accurate when the operating conditions of PV array change. Large increments tend to make the algorithm confused the there is a discussion about the effects of the size of the increment on the performance of the P&O method. The small

models rely on historical data and statistical analysis to forecast energy output based on past performance and environmental conditions. These models are simple and practical but may lack accuracy under varying circumstances. Analytical models utilize mathematical equations to describe system dynamics, considering factors such as solar irradiance, temperature, and panel characteristics. These models offer insights into system behavior but may require simplifications that limit their accuracy in complex scenarios. Numerical models employ computational techniques to solve complex equations governing solar system behavior, providing detailed simulations under various conditions. Finite Element Method (FEM) and Computational Fluid Dynamics (CFD)P&O MPPT method. As the name says, the algorithm based on the observation of the array output power and on the perturbation of the power based on increments of the array voltage or current. The algorithm continuously increments or decrements the reference current or voltage based on the value of the previous power sample. The P&O method claimed to have slow dynamic response and high steady state error [10]. In fact, the dynamic response is low when a small increment value and a low sampling rate employed. Low increments are necessary to decrease the steady state error because the P&O always

makes the operating point oscillate near the MPP, butnever at the MPP exactly. The lower the increment, the closer the system will be to the array MPP [11]. The greater theincrement, the faster the algorithm will work, but the steady state error will be increased. Considering that a low increment is 18 necessary to achieve a satisfactory steady state error, the algorithm speed may be increased with a higher sampling rate
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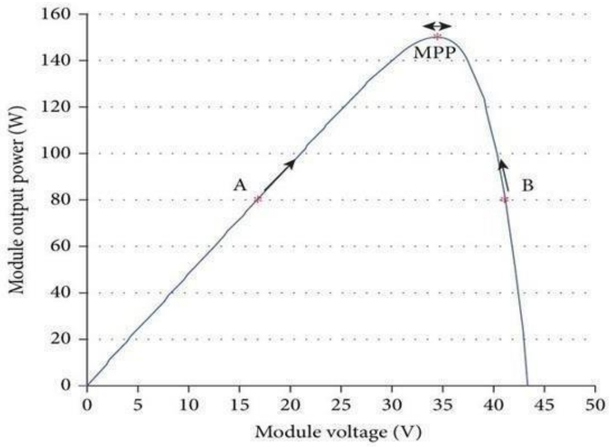


Fig: Solar panel characteristics curve showing MPP at operating points A and B.

increments tend to make the algorithm more stable and accurate when the operating conditions of PV array change. Large increments tend to make the algorithm confused since the response of the converter to large voltage or current variations will cause oscillations, overshoot and the settling time of the converter itself confuses the algorithm. The direct duty-cycle control is employed in a great number of works related to DC-DC converters for PV applications.

INCREMENTAL CONDUCTANCE:

The incremental conductance algorithm is an energy optimization strategy that provides fast dynamic response and well-regulated photovoltaic (PV) output voltages. In addition, the number of parameter needed to be monitored are significantly lower than other algorithms, making the implementation much more streamlined and cost effective.

the algorithm of the Incremental conductance MPPT method.The incremental conductance method works by continuously monitoring the instantaneous output power and the change in output power with respect to changes in the operating voltage and current. When the change in power reaches zero, the operating point of the PV system is at the maximum power point. The theory behind the incremental conductance method (IC) [16] is to determine the terminal voltage of the PV module by measuring and comparing the incremental and instantaneous conductance of the PV module. If it is observed that the incremental conductance is equal to the instantaneous conductance, it indicates that the maximum power point is found. It has been observed that within operating limits, output power increases with increasing terminal voltage of the PV module (slope of the power curve is positive, (dP/dV >0). On the contrary, at operating points past MPP there is a decrease in the output power with an increase in terminal voltage of the PV modules (the slope of the 24 Therefore, MPP is achieved when the incremental conductance is equal to the negative of the instantaneous conductance. The power-voltage curve characteristic shows that: when the voltage is smaller than MPP, dP/dV>0, so dI/dV>-I/V; when the voltage is bigger than MPP, dP/dV<-I/V . Thus, a tracker can know where 25 it

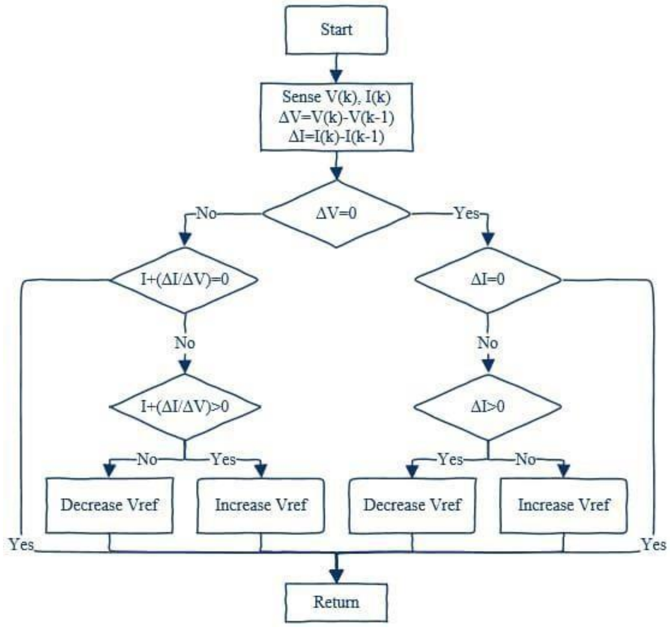


fig: flow chart of IC method

on the power-voltage curve by calculating the relation of the change of current/voltage and the current voltage themselves. Initialize the MPPT algorithm: Set the initial voltage and current values to their minimum values. 2. Read the voltage and current values from the solar panel. 26 3. Calculate the power output of the solar panel using the voltage and current values. 4. Determine the sign of the incremental conductance value (dP/dV). If the incremental conductance is positive, the operating point is to the left of the MPP; if the incremental conductance is negative, the operating point is to the right of the MPP. 5. If the incremental conductance is zero, the system has reached the MPP. 6. Adjust the voltage reference value based on the sign of the incremental conductance. If the incremental conductance is positive, increase the voltage reference value; if the incremental conductance is negative, decrease the voltage reference value. 7. Go back to step 2 and repeat the process until the system rea

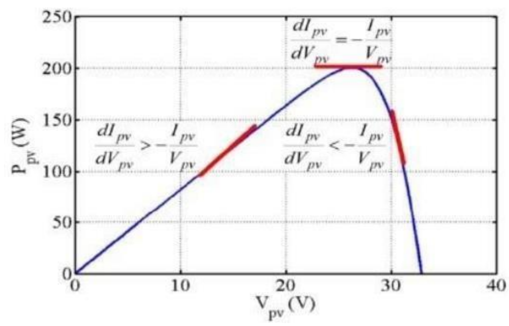


Fig:schematic representation of the power curve and the slope at the maximum power point

Once the MPP is reached, maintain schematic representation of the power curve and the slope at the maximum power point.

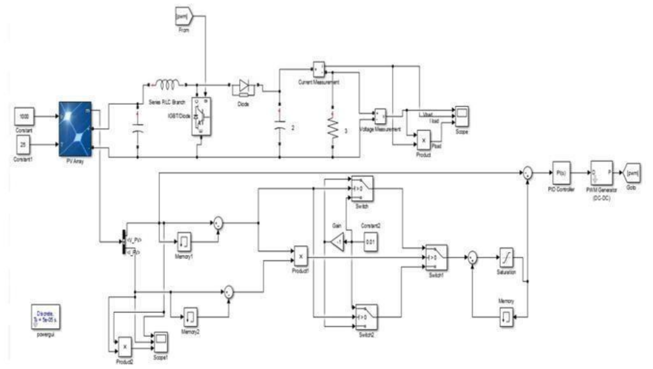


Fig:simulation diagram mppt using by p & o method

marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel [13, 14]. Consider A and B as two operating points. As shown in the figure below, the point A is on the left hand side of the MPP. Therefore, we can move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation, the value of ΔP becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP. This technology is essential for maximizing the return on investment in solar power installations, particularly in areas with fluctuating weather conditions or partial shading.

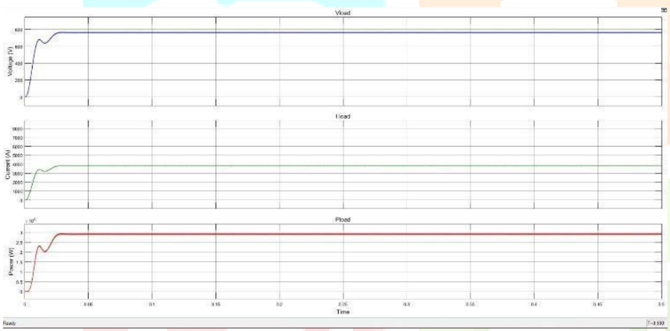


Fig:output curve of p&o

shows the simulation diagram of P&O method. As we know the P-V and I-V characteristics of a PV cell will be varying with respect and irradiance. Initially the irradiance of 1000kw/m2 applied to the PV panel The PV Array designed for generating 3MW power. So we choose sun power panel rating is SPR-445J, Then it shows maximum power point voltage is 76.7V. here, we connect 1349 parallel string and five series strings to a panel and the operating voltage of 383.5V. A boost converter used to step up the input voltage, current, power and the code for P&O algorithm written in the MATLAB function block. The Two inputs to the MATLAB function block are V_ PV and I_PV and output is D whereas, V, I, D indicates the instantaneous values of voltages, current, and duty ratio whereas, v, i, d indicates the previous values of voltages, current, and duty ratio which can be used from a unit time delay. The output from MATLAB function block i.e. (duty ratio) applied to the PWM Generator. The output voltage , current and power waveforms of P&O algorithm is shown in the below Fig.3.4. It indicates that the output voltage, current and power of PV 21 panel are varying with respect to time in seconds. The boost converters used in the Power curve and the slope at the maximum simulation it stepped up in the input voltage and the power is almost same.

CUCKOO SEARCH METHOD:

Cuckoo Search (CS) algorithm, inspired by the breeding behavior of cuckoos, is employed for Maximum Power Point Tracking (MPPT) in solar PV arrays. Through mimicry of the brood parasitism strategy, CS efficiently optimizes the parameters to track the maximum power point, enhancing the energy extraction from solar panels. Its utilization in MPPT ensures robust performance and adaptability, contributing to the optimization of solar power systems for enhanced efficiency and sustainability. shows the algorithm of the The Cuckoo Search (CS) algorithm, inspired by the breeding behavior of cuckoos, operates on the principle of searching f

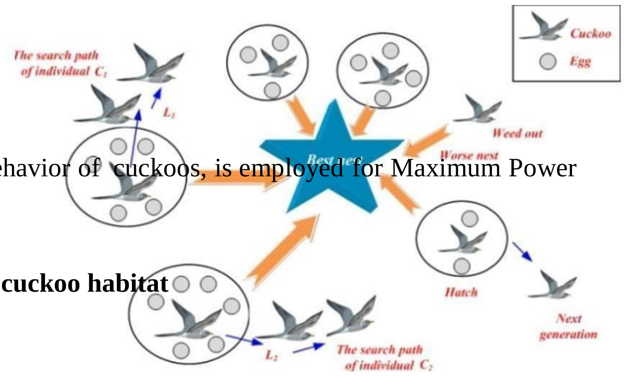


fig:cuckoo habitat

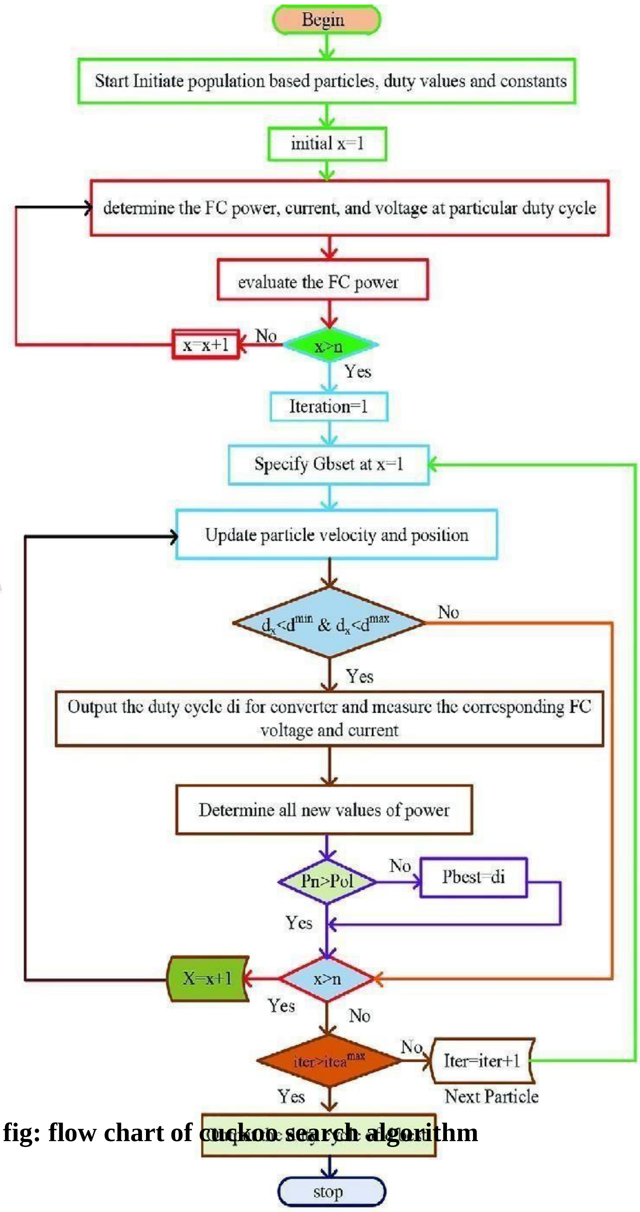


fig: flow chart of cuckoo search algorithm

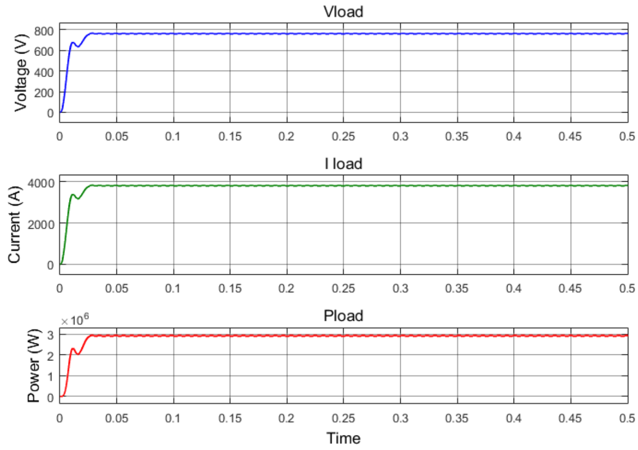


Fig:power output curve of cuckoo search algorithm

power point (MPP) by iteratively adjusting the parameters of the system. Initially, a population of solutions, represented as cuckoo eggs, is randomly generated within the search space. Through a process of evaluation, the fitness of each solution is determined based on its ability to track the MPP. The eggs with higher fitness values, representing promising solutions, are retained, while less promising ones are discarded. Additionally, inspired by the brood parasitism strategy, some eggs may be replaced by new solutions generated through a combination of exploration and exploitation strategies. This iterative process continues until convergence criteria are met, resulting in the identification of the optimal solution for MPPT in the solar PV 31 array. Through this approach, CS facilitates efficient and effective tracking of the MPP, thereby maximizing the energy extraction from the solar panels.

Initialization: Begin by initializing parameters such as population size, maximum iterations, and search space bounds. 5.2.2 Generate Initial Solutions: Randomly generate initial solutions (cuckoo 33 eggs) within the defined search space. 5.2.3 Evaluate Fitness: Evaluate the fitness of each solution based on its ability to track the Maximum Power Point (MPP) of the solar PV array. 5.2.4 Update Best Solution: Identify the best solution (egg) based on fitness evaluation. 5.2.5 Generate New Solutions: Employ exploration and exploitation strategies to generate new solutions. 5.2.6 Replace Eggs: Replace some eggs in the nest with the new solutions, mimicking the brood parasitism behavior. 5.2.7 Evaluate Convergence: Check convergence criteria such as maximum iterations reached or satisfactory fitness achieved. 5.2.8 Termination: If convergence criteria are met, terminate the algorithm; otherwise, return to step 3.

5.2.9 Output: Output the best solution found, representing the optimized parameters for MPPT in the solar PV array The Cuckoo Search (CS) method offers a robust and efficient approach for Maximum Power Point Tracking (MPPT) in solar PV arrays. By mimicking the behavior of cuckoos, CS optimizes parameters to enhance energy extraction. Its effectiveness lies in its ability to adaptively search for the optimal solution, ensuring improved system performance and sustainability. 34 5.3 Simulation results and discussions The figure 5.3 shows the simulation diagram of CS method. As we know the P-V and I-V characteristics of a PV cell will be varying with respect to temperature and irradiance.

Drawbacks of Cuckoo Search algorithm:

This method has several advantages, such as fast response and good tracking accuracy, but it also has some disadvantages, including: 5.4.1 Premature Convergence: CS may converge to suboptimal solutions prematurely due to its exploitation-heavy nature, limiting its ability to explore the entire search space. 5.4.2 Parameter Sensitivity: CS performance is highly dependent on parameter settings, requiring careful adjustment for different optimization problems. 36 5.4.3 Lack of Scalability: CS may struggle to scale effectively to highdimensional or complex search spaces, hindering its applicability in certain scenarios. 5.4.4 Limited Diversity: The algorithm's reliance on a single exploration strategy may lead to limited exploration of diverse solutions, potentially missing global optima.

GREY WOLF OPTIMIZATION:

Grey Wolf Optimization (GWO) is gaining traction in Maximum Power Point Tracking (MPPT) for solar PV arrays. By emulating the hunting behavior of grey wolves, GWO efficiently explores the solution space. In MPPT applications, GWO dynamically adjusts the operating point of the PV array to maximize power output, enhancing energy harvesting efficiency. Through its iterative process of searching and updating, GWO offers a promising approach for optimizing the performance of solar PV systems, contributing to renewable energy advancement inspired by the social structure and hunting tactics of grey wolves, has emerged as a powerful tool for Maximum Power Point Tracking (MPPT) in solar PV arrays. In MPPT. GWO dynamically adjusts the operating point of the PV array to extract maximum power from varying environmental conditions. By mimicking the collaborative hunting behaviors of a wolf pack, GWO iteratively updates potential solutions toward the optimal point. Alpha, beta, delta, and omega wolves symbolize candidate solutions, with the algorithm steering them toward the global maximum power point. Through this collective and adaptive approach, GWO efficiently explores the solution space, ensuring effective MPPT even under partial shading or rapid changes in irradi

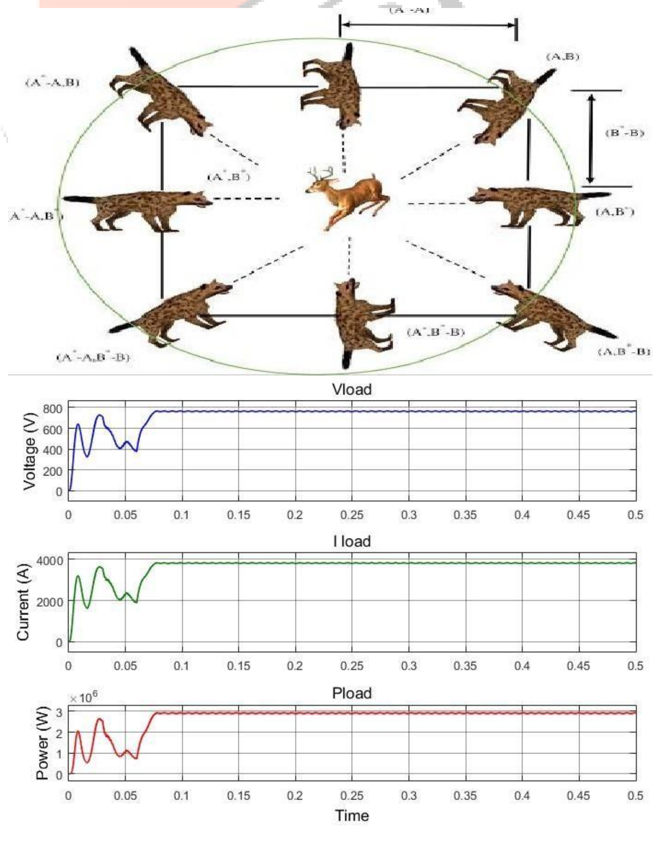
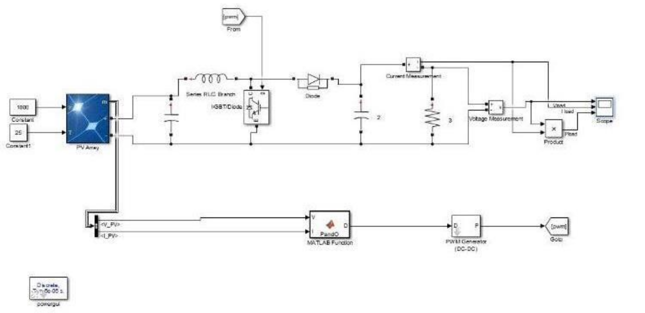


Fig: Grey wolf optimization & power output of grey wolf optimization

Comparative analysis



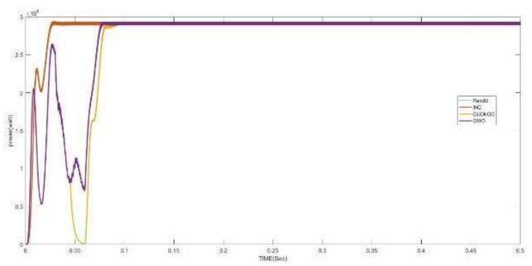


Fig:Comparision between p&o increment conductance,cuckoo search,grey wolf optimization power output curves

The boost converter is used to step up the input voltage, current ,power and the code for GWO algorithm is written in the MATLAB function block. The Two inputs to the MATLAB function block are V_PV, I_PV and output is D whereas, V, I, D indicates the instantaneous values of voltages, current, and duty ratio whereas, v, p, d indicates the previous values of voltages, current and duty ratio which can be used from a unit time delay. The output from MATLAB function block i.e. (duty ratio) is applied to PWM. The output voltage, current and power waveforms of GW algorithm is shown in the below Fig.6.4. It indicates that the output voltage, current and power of PV panel are 43 varying with respect to time in seconds.

REFERENCES:

[1] Mahesh, P. Venkata, S. Meyyappan, and Rama Koteswara Rao Alla. "A new multivariate linear regression MPPT algorithm for solar PV system with boost converter." *ECTI Transactions on Electrical Engineering, Electronics, and Communications* 20.2 (2022): 269-281.

[2] Mahesh, P. Venkata, S. Meyyappan, and RamaKoteswara Rao Alla. "Maximum power point tracking using decision-tree machine-learning algorithm for photovoltaic systems." *Clean Energy* 6.5 (2022): 762-775.

[3] Mahesh, P. Venkata, S. Meyyappan, and R. Alla. "Maximum power point tracking with regression machine learning algorithms for solar PV systems." *International Journal of Renewable Energy Research* 12.3 (2022): 1327-1338

[4] Mahesh, P. Venkata, S. Meyyappan, and RamaKoteswaraRao Alla. "Support Vector Regression Machine Learning based Maximum Power Point Tracking for Solar Photovoltaic systems." *International journal of electrical and computer engineering systems* 14.1 (2023): 100-108.

[5] L.A Zedah; Outline of New Approach of the Analysis of Complex System and Decision Processes; 1963, IEEE Transactions System, Man, Cybern. Vol. SMC-3, no.1, pp.146-151.

[6] Tekeshwar Prasad Sahu, T.V. Dixit and Ramesh Kumar; Simulation and Analysis of Perturb and Observe MPPT Algorithm for PV Array Using ĊUK Converter; ISSN 2231- 1297, Volume 4, Number 2 (2014), pp. 213-224.

[7] Srushti R. Chafle, Uttam B. Vaidya ;Incremental Conductance MPPT Technique FOR PV System; International Journal of Advanced Research in Electrical,Electronics and Instrumentation Engineering ;Vol. 2, Issue 6, June 2013;ISSN : 2320 – 3765. 49

[8] Md Fahim Ansari , S. Chatterji & Atif Iqbal; A fuzzy logic control scheme for a solar photovoltaic system for a maximum power point tracker ;International Journal of Sustainable Energy;19 April 2010;pp:245-255.

[9] P. Venkata Mahesh, S. Meyyappan, and Rama Koteswara Rao Alla “A New Multivariate Linear Regression MPPT Algorithm for Solar PV System with Boost Converter” ECTI on Electrical Engineering, Electronics, and Communications vol.20, no.2 june 2022.

[10] M. C. Cavalcanti, K. C. Oliveira, G. M. S. Azevedo, and F. A. S. Neves. Comparative study of maximum power point tracking techniques for photovoltaic systems. Brazilian Journal of Power Electronics, SOBRAEP, 12(2):163–171, 2007.

[11] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli. Optimizing dutycycle perturbation of P&O mppt technique. In IEEE PESC’04, vol. 3, 2004.

[12] L.A Zedah, “Outline of New Approach of the Analysis of Complex System and Decision Processes”, 1963, IEEE Transactions System, Man, Cybern. Vol. SMC-3, no.1, pp.146-151.

[13] M.G.Jaboori, M.M.Saied, and A.A. Hanafy, " A contribution to the simulation and design of photovoltaic systems", IEEE Trans.Energy Conv., vol 6, pp.401-406, Sep. 1991.

[14] T. Tafticht, K. Agbossou, M. L. Doumbia, and A. Cheriti, ´ “An improved maximum power point tracking method for photovoltaic systems,” Renewable Energy, vol. 33, no. 7, pp. 1508–1516, 2008.

[15] S. Kazmi, H. Goto, O. Ichiokura, and H. J. Guo, “An improved and very e fficient MPPT controller for PV systems subjected to rapidly varying atmospheric conditions and partial shading,” in Proceedings of the Power Engineering Conference, pp. 1–6, Adelaide, Australia, September 2009. 50

[16] D. P. Hohm and M. E. Ropp, “Comparative study of maximum power point tracking algorithms,” Progress in Photovoltaics: Research and Applications, vol. 11, no. 1, pp. 47–62, 2003.

[17] T. Esram and P. L. Chapman, “Comparison of photovoltaic array maximum power point tracking techniques,” IEEE Transactions on Energy Conversion, vol. 22, no. 2, pp. 439–449, 2007.

[18] E. Roman, R. Alonso, P. Iba ´ nez, S. Elorduizapatarietxe, and ˜ D. Goitia, “Intelligent PV module for grid-connected PV systems,” IEEE Transactions on Industrial Electronics, vol. 53, no. 4, pp. 1066–1073, 2006.

[19] C. Larbes, S. M. A¨ıt Cheikh, T. Obeidi, and A. Zerguerras, “Genetic algorithms optimized fuzzy logic control for the maximum power point tracking in photovoltaic system,” Renewable Energy, vol. 34, no. 10, pp. 2093–2100, 2009. [20] Erickson, Robert W., and Dragan Maksimovic. Fundamentals of power electronics.Springer Science & Business Media, 2007.