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Department of Electrical-Electronic Engineering

A MODIFIED HYBRID ALO–PSO-BASED MAXIMUM POWER POINT TRACKING FOR PHOTOVOLTAIC SYSTEM

Master Thesis

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Supervised

Asst. Prof.Dr. Yusuf Gürcan ŞAHIN

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Turkish Abstract	**:**	Yenilenebilir enerji kaynakları, çevreyi kirletmediği, az bakım gerektirdiği ve kurulumu kolay olduğu için elektrik üretimi için umut vericidir. Bununla birlikte, güneş fotovoltaik (PV) hücrelerinin özellikleri doğrusal değildir ve hava ve çevre koşullarına bağlıdır. Bir PV sisteminin güç çıkışını en üst düzeye çıkarmak için, sistemi güneş radyasyonu ve diğer çevresel faktörlerdeki değişikliklere hızlı ve doğru bir şekilde ayarlayabilen bir maksimum güç noktası izleme (MPPT) denetleyicisi kullanmak esastır. Bu tez, gerçekçi güneş radyasyonu koşulları altında bir PV sistemi için karınca aslanı optimizasyonu (ALO) ve parçacık sürüsü optimizasyonunu (PSO) birleştiren

hibrit bir MPPT algoritması önermektedir. Algoritma, toplam güneş paneli sayısına ve talep yüküne dayalı olarak bir DC-DC dönüştürücü için uygun bir görev döngüsünü hesaplar. Önerilen algoritma, MPP'ye ulaşmak için %99,97'nin üzerinde verimlilik, %0,25'lik düşük dalgalanma, sıfır salınım ve 0,013s'lik hızlı yanıt süresi ile yüksek performans elde ediyor.

Önceki çalışmalarla karşılaştırıldığında, bu algoritma gelişmiş yanıtlar, verimlilik, güvenilirlik, karmaşıklık ve maliyet performansı sunar. Sistemin sağlamlığını doğrulamak için PV sistemi, Matlab (R 2021a) Simulink kullanılarak EN50530 Avrupa standardı testine tabi tutuldu. Sistem dört koşul altında test edilmiştir: standart test koşulu (STC), ışınlama değişimi, sıcaklık değişimi ve eş zamanlı sıcaklık ve ışınlama değişimleri.

Sonuçlar, önerilen hibrit ALO-PSO MPPT algoritmasının, değişen çevresel koşullar altında PV sistemlerinde güç çıkışını en üst düzeye çıkarmak için verimli ve güvenilir bir yöntem sunduğunu göstermektedir.

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Dedication

I pray to the Almighty God to count this work towards the total of my father's good deeds and dedicate the fruits of this effort to the soul of my dear father, who God chose before he saw my joy. I dedicate the fruits of this effort to his memory. And to my dear father, may you always know that you have been and continue to be the guiding light on the road to my success! And to everyone who stood by my side, helped me out, and boosted my confidence! I want to dedicate the fruits of this joy to the people whose hearts used to rejoice in my happiness, including my loved ones and my close friends.

Fanan Riyadh Mohsin

DECLARATION

I hereby declare that in the preparation of this thesis, scientific ethical rules have been followed, the works of other persons have been referenced in accordance with the scientific norms if used, there is no falsification in the used data, any part of the thesis has not been submitted to this university or any other university as another thesis.

Fanan Riadh Mohsin
05/09/2023

TO ISTANBUL GELISIM UNIVERSITY
THE DIRECTORATE OF GRADUATE EDUCATION INSTITUTE

The thesis study of Fanan AL-SHAKHLI titled as A Modified Hybrid ALO-PSO-Based Maximum Power Point Tracking For Photovoltaic Systems has been accepted as MASTER in the department of Electrical-Electronic Engineering by out jury.

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Director of the Institute

SUMMARY

Renewable energy sources are promising for generating electricity because they are non-polluting, low maintenance, and easy to install. However, the characteristics of solar photovoltaic (PV) cells are nonlinear and depend on weather and environmental conditions. To maximize the power output of a PV system, it is essential to use a maximum power point tracking (MPPT) controller, which can quickly and accurately adjust the system to changes in solar radiation and other environmental factors.

This thesis proposes a hybrid MPPT algorithm that combines ant lion optimization (ALO) and particle swarm optimization (PSO) for a PV system under realistic solar radiation conditions. The algorithm calculates a suitable duty cycle for a DC-DC converter based on the total number of solar panels and the demand load. The proposed algorithm achieves high performance, with an efficiency of over 99.97%, a low ripple of 0.25%, zero oscillation, and a fast response time of 0.013s to reach the MPP.

Compared to previous works, this algorithm offers improved responses, efficiency, reliability, complexity, and cost performance. To validate the system's robustness, the PV system was subjected to the European standard test EN50530 using Matlab (R 2021a) Simulink. The system was tested under four conditions: standard test condition (STC), irradiation variation, temperature variation, and simultaneous variations of temperature and irradiation.

The results show the proposed hybrid ALO-PSO MPPT algorithm offers an efficient and reliable method for maximizing power output in PV systems under changing environmental conditions.

ÖZET

Yenilenebilir enerji kaynakları, çevreyi kirletmediği, az bakım gerektirdiği ve kurulumu kolay olduğu için elektrik üretimi için umut vericidir. Bununla birlikte, güneş fotovoltaik (PV) hücrelerinin özellikleri doğrusal değildir ve hava ve çevre koşullarına bağlıdır. Bir PV sisteminin güç çıkışını en üst düzeye çıkarmak için, sistemi güneş radyasyonu ve diğer çevresel faktörlerdeki değişikliklere hızlı ve doğru bir şekilde ayarlayabilen bir maksimum güç noktası izleme (MPPT) denetleyicisi kullanmak esastır.

Bu tez, gerçekçi güneş radyasyonu koşulları altında bir PV sistemi için karınca aslanı optimizasyonu (ALO) ve parçacık sürüsü optimizasyonunu (PSO) birleştiren hibrit bir MPPT algoritması önermektedir. Algoritma, toplam güneş paneli sayısına ve talep yüküne dayalı olarak bir DC-DC dönüştürücü için uygun bir görev döngüsünü hesaplar. Önerilen algoritma, MPP'ye ulaşmak için %99,97'nin üzerinde verimlilik, %0,25'lik düşük dalgalanma, sıfır salınım ve 0,013s'lik hızlı yanıt süresi ile yüksek performans elde ediyor.

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ABBREVIATIONS

ABC	**:**	Artificial Bee Colony
AC	**:**	Alternating Current
ACO	:	Ant Colony Optimization
Amp.	:	Ampere
ANN	:	Artificial Neural Network
CCM	:	Continuous Conduction Mode
CE	:	Change of Error
CS	:	Cuckoo Search
CV	:	Constant Voltage
D.C	:	Direct Current
DCM	:	Discontinuous Conduction Mode
DFO	:	Dragonfly Optimization
E	:	Error
EN50530	:	European Standard Test
f	:	Frequency
FFA	:	Firefly Algorithm
FLC	:	Fuzzy Logic Control
GMPP	:	Global Maximum Power Point
GP	:	Global Peak
GWO	:	Grey Wolf Optimizer
HC	:	Hill-Climbing
HGWOSCA	:	Hybrid Grey Wolf Optimizer Sine Cosine Algorithm
INC	:	Incremental Conductance
ISSA	:	Improved Squirrel Search Algorithm
KVL	:	Kirchhoff Voltage Law
LCD	:	Liquid Crystal Display
LMP	:	Local Maximum Point
LRCM	:	Linear Reoriented Coordinates Method
MCA	:	Musical Chairs Algorithm
MGWO	:	Modified Grey Wolf Optimization
MPO	:	Modified Perturbation and Observation
MPP	:	Maximum Power Point
MPPT	:	Maximum Power Point Tracking
MSCO	:	Modified Sine-Cosine Optimized
OCV	:	Open- Circuit Voltage
OTCA	:	Optimized Ten Check Algorithm

P&O	:	Perturbation and Observation
P.C.B.	:	Printed Circuit Board
PCPIO	:	Parallel and Compact Pigeon-Inspired Optimization
POS	:	PV Output Senseless
PSC	:	Partial Shading Condition
PSO	:	Particle Swarm Optimization
PV	:	Photovoltaic
RCC	:	Ripple Correlation Control
RES	:	Renewable Energy Sources
RIO	:	Roach Infestation Optimization
RRD	:	Reverse Recovery Diode
SAPSO	:	Simplified Accelerated Particle Swarm Optimization
SCC	:	Short- Circuit Current
Sec.	:	Second
SEPIC	:	Single-Ended Primary Inductor Converter
SL	:	Switched Inductor
SMC	:	Sliding Mode Controller
SOSMO	:	Second Order Sliding Mode Observer
SSA	:	Salp Swarm Algorithm
STC	:	Standard Test Condition

LIST OF SYMBOLS

Symbols	:	Definitions
$\vec{X}_P$	:	Prey Position
Δ_{iL}	:	Ripple Factor
$\vec{D}$, $\vec{C}$ and $\vec{A}$	:	Coefficient Vectors
I_0	:	Diode Reverse Saturation Current
I_{in}	:	Input Current
I_{out}	:	Output Current
I_{sh}	:	Shunt Current
I_D	:	Diode Current
I_{PV}	:	Output from Photoelectric Current
V_{in}	:	Input Voltage
V_{out}	:	Output Voltage
$\vec{X}$	:	Position Of The Grey Wolf
X_g	:	Global Candidate Solution
η_{mppt}	:	Maximum Power Point Tracking Efficiency
C_1, C_2	:	Acceleration Parameters
G_{best-i}	:	Best Particle Location
I_{mpp}	:	Maximum Power Point Current
$I_{out(min)}$	:	Minimum Output Current
I_{ph}	:	Photoelectric Current
I_{sc}	:	Short Circuit Current
I_{total}	:	Total Current
P_{best-i}	:	Optimal Particle Location
P_i	:	Probability Criteria
P_{max}	:	Maximum Power
P_{total}	:	Total Power
R_s	:	Series Resistor
R_{sh}	:	Shunt Resistor
T_{ij}	:	Pheromone's Concentration
T_{off}	:	Off Time
T_{on}	:	On Time
U_d&L_d	:	Upper And Lower Limit For The Dimension Issue
V_{DC}	:	Output Voltage From The Boost Converter

V_L	:	Inductor Voltage
V_N, G_N, T_N	:	Voltage, Irradiation, And Temperature, Respectively
V_{PV}	:	Input Voltage From PV Array To Boost Converter
V_{id}	:	New Food Sources
$V_{in(min)}$	:	Minimum Input Voltage
V_{mpp}	:	Maximum Power Point Voltage
V_{pv}	:	Voltage Throughout The Diode
V_{total}	:	Total Voltage
X_i	:	Position Of The Cuckoo Bird At Iteration i
r_1, r_2	:	Random Variables
$\oplus$	:	Input Multiples
Δ	:	Delta
ΔT_{ij}	:	Change In Pheromone Concentration
A	:	Number Of Iterations
C	:	Capacitance
D	:	Dimension
dI	:	Derivative Current
dP	:	Derivative Power
dV	:	Derivative Voltage
F	:	Farad
Fs	:	Switching Frequency
G	:	Irradiation
H	:	Henry
Hz	:	Hertz
I	:	Current
I	:	Iteration
J	:	Joule
K	:	Boltzmann's Constant
K	:	Kilo
L	:	Inductance
M	:	Milli
N	:	Negative
P	:	Power
pcs	:	Piece
Q	:	Electron Charge
R	:	Resistance
R	:	Random Number Between (0 to 1)

T	**:**	Temperature
T	**:**	Current Iteration
V	**:**	Voltage
v, u	**:**	Random Numbers
W	**:**	Weight
W	**:**	Omega
Wh	**:**	Watt Hour
X	**:**	Position
Γ	**:**	Gamma function
Δ	**:**	Limitation For Voltage Ripple
Λ	**:**	Exponent Of Lévy Flight
M	**:**	Micro
D	**:**	Duty Cycle
Ω	**:**	Ohm
μ	**:**	Membership Function
ρ	**:**	Pheromone Concentration Rate
$\boldsymbol{\alpha}$	**:**	Alpha
$\boldsymbol{\beta}$	**:**	Beta
$\boldsymbol{\delta}$		Delta

PREFACE

A photovoltaic system is a type of renewable energy system that converts sunlight in to electricity. PV systems can be used for a variety of applications, such as powering homes, powering remote off-grid locations, and providing electricity to utility power grids. PV system can face several issues that can affect performance and efficiency. Some common issues include: shading from trees, buildings or other objects can reduce amount of sunlight that reaches the PV modules. Temperature: the efficiency of PV modules decreases as the temperature increases, that's why that the PV system has non-linear characteristics . Controlling photovoltaic system is challenging due to their non-linear characteristics as a results the PV system must have a flexible controller that can adapt to the changing weather conditions . The focus of this thesis is to enhance the performance of renewable energy sources through the implementation of intelligent control techniques. Specifically , the study aims to apply these techniques to the problem of optimizing power output of the PV system under variable weather conditions. The thesis propose a new MPPT technique called ALO (Ant Lion Optimizer) the proposed technique uses a hybrid ALO and PSO to increase the efficiency of solar system. The simulation results show

INTRODUTION

A Photovoltaic (PV) system is a type of renewable energy system that converts sunlight into electricity. It consists of PV modules, also known as solar panels, which contain solar cells that convert sunlight into direct current (DC) electricity. The PV modules are typically made up of semiconductor materials, such as silicon, that absorbs the photons from sunlight and creates an electric current. The DC electricity generated by the PV modules is then sent to an inverter, which converts the DC electricity into alternating current (AC) electricity that can be used to power homes and buildings. The inverter also ensures that the voltage and frequency of the AC electricity are compatible with the grid power. PV systems can be used for a variety of applications, such as powering homes, powering remote off-grid locations, and providing electricity to utility power grids(B. Turley, A. Cantor, K. Berry, S. Knuth, D. Mulvaney, and N. Vineyard .2015)(N. Bekirsky, C. Hoicka, M. C. Brisbois, and L. R. Camargo .2022).

They can also be used in combination with other energy storage systems, such as batteries, to provide energy during periods of low sunlight or power outages. PV systems are becoming increasingly popular due to their ability to generate clean, renewable energy and reduce dependence on fossil fuels. They are also relatively simple to install and maintain, and have low operating costs(M. Sarvi and A. Azadian. 2022).

In December 2015, a climate change conference was held where 195 countries agreed to a goal of reducing global temperatures by 2°C. This highlighted the increasing significance of solar energy(M. Yaqoob, H. Abubakr, J. M. Alcala, A. Lashab, J. M. Guerrero, and J. C. Vasquez.2022). According to the climate action tracker, in order to keep global warming to 1.5°C, the world must cut 144 Gt of emissions by 2025, which is attributed to the top 32 polluters who account for 80% of overall emissions(C. G. Villegas-Mier, J. Rodriguez-Resendiz, J. M. Álvarez-Alvarado, H. Rodriguez-Resendiz, A. M. Herrera-Navarro, and O. Rodríguez-Abreo.2021). The Renewable Energy Corporation projects that an additional 4800 GW of solar power will be necessary to reach this goal by 2025. Research from the Fraunhofer Institute for Solar Energy Systems predicts that solar energy will supply 40% of global electricity consumption by 2025(C. G. Villegas-Mier, J. Rodriguez-Resendiz, J. M. Álvarez-Alvarado, H. Rodriguez-Resendiz, A. M. Herrera-Navarro, and O. Rodríguez-Abreo.2021)(C. Restrepo, N. Yanẽz-Monsalvez, C. González-Castaño, S. Kouro, and J. Rodriguez.2021).

PV systems can face several issues that can affect their performance and efficiency. Some common issues include: Shading from trees, buildings, or other objects can reduce the amount of sunlight that reaches the PV modules, which can decrease the power output of the system. Temperature: The efficiency of PV modules decreases as the temperature increases. If the PV modules get too hot, they can become damaged and their performance can be reduced. Dirt and debris: Dust, dirt, and debris can accumulate on the surface of the PV modules, which can reduce the amount of sunlight that reaches the solar cells. Aging: Over time, the performance of PV modules can degrade due to factors such as UV radiation and temperature changes (A. Gupta, K. Gupta, and S. Saroha.2020).

The electrical behavior of a PV system is described by the I-V curve, which shows the relationship between the current and voltage of the system. The I-V curve is a non-linear curve and has a unique point known as the maximum power point (MPP). The MPP is the point on the I-V curve where the system produces the maximum power. The MPP is affected by several factors, such as temperature, irradiance and shading(B. Bendib, H. Belmili, and F. Krim. 2015)

To investigate the maximum power point under rapidly weather condition, a MPPT algorithm can be used. It can adapt the operating point of the PV system quickly to changing weather conditions, such as changes in sunlight intensity and temperature(S. Yuvarajan and S. Xu pp. III-III).

There are several traditional and intelligent methods that are commonly used in Maximum Power Point Tracking (MPPT) for PV systems. Some of the traditional methods include: Perturb and Observe (P&O) method(R. John, S. S. Mohammed, and R. Zachariah.2017) this is one of the most widely used MPPT methods. It involves slightly perturbing the operating point of the PV system and observing the changes in power output. The operating point is then adjusted until the maximum power point is reached.

Incremental Conductance (IC) method(A. Nigam and A. K. Gupta.2016)this method uses the slope of the power-voltage curve to track the maximum power point. It involves measuring the incremental conductance of the PV system, which is the derivative of the power-voltage curve, and adjusting the operating point until the maximum power point is reached

Hill Climbing method(W. Zhu, L. Shang, P. Li, and H. Guo. 2018) this method is based on the idea of climbing a hill to reach the peak. It starts at an initial operating point and moves in the direction of the slope of the power-voltage curve until the maximum power point is reached.

Intelligent methods are based on machine learning, such as Artificial Neural Network (ANN) based algorithm, Fuzzy Logic(S. Messalti.2015), and Particle Swarm Optimization (PSO).

ANN-based MPPT this method uses artificial neural networks to model the behavior of the PV system and predict the maximum power point. It can improve the performance of the MPPT algorithm by reducing the number of iterations required to reach the maximum power point.

Fuzzy Logic MPPT this method uses fuzzy logic to model the behavior of the PV system and track the maximum power point. It can improve the performance of the MPPT algorithm by taking into account the uncertainty and non-linearity of the PV system.

PSO-based MPPT this method uses particle swarm optimization to track the maximum power point of the PV system. It can improve the performance of the MPPT algorithm by reducing the number of iterations required to reach the maximum power point and by avoiding local maxima.

In addition to meta-heuristic algorithms, other optimization approaches such as a Hybrid method that combine the advantages of different optimization techniques have also been used to overcome difficulties related to partial shading in PV arrays. These approaches are based on the ability of these methods to learn from historical data and accurately predict the optimal operating point under different weather conditions. For example, ANN-based MPPT methods use a trained neural network to predict the MPP based on measured system parameters such as the PV array voltage and current, and ambient temperature. Similarly, Fuzzy Logic-based MPPT(A. G. Al-Gizi and S. J. Al-Chlaihawi.2016) methods use a set of fuzzy rules to determine the optimal operating point under changing environmental conditions(S. Mohanty, B. Subudhi, and P. K. Ray.2016).

The literature shows that there are several optimization approaches that have been developed to overcome difficulties related to partial shading in PV arrays, including meta-heuristic algorithms, ANN, FL, and hybrid methods. Each approach has its own advantages and disadvantages, and the choice of method depends on the specific requirements of the application and the available resources.

CHAPTER ONE

LITRETURE REVIEW

1.1 Literature Review

There have been many studies and articles published in the field of optimization MPPT methods for PV systems. These studies demonstrate the ongoing research in the field of optimization MPPT methods for PV systems, and the various optimization techniques and algorithms that have been proposed to improve the performance of PV systems and overcome the challenges related to partial shading and rapidly changing weather conditions. Here are a few examples of recent studies:

M. A. S. Masoum et al., 2016 This study presents a hybrid MPPT algorithm that combines the advantages of genetic algorithms and particle swarm optimization for maximum power point tracking in PV systems. The hybrid algorithm uses the genetic algorithm to generate the initial population of candidate solutions and the particle swarm optimization to perform the local search. The proposed algorithm has been tested on a simulated PV system and compared its performance to that of a standard P&O MPPT algorithm and a standard genetic algorithm. The results showed that the proposed hybrid algorithm had a faster convergence time and better tracking performance than the other algorithms.

(Y. Li et al., 2017): In this study, proposed a new MPPT method based on a modified cuckoo search algorithm, which is a meta-heuristic optimization algorithm inspired by the behavior of cuckoo birds. The proposed method uses the cuckoo search algorithm to optimize the operating point of the PV system and adapts itself to the changing environmental conditions. The authors of the study have tested the proposed algorithm on a simulated PV system and compared its performance to that of a standard P&O MPPT algorithm and a standard cuckoo search algorithm. The results showed that the proposed method had a faster convergence time and better tracking performance than the other algorithms.

Z. Li et al., 2018: This study presents a hybrid MPPT method that combines the differential evolution algorithm with a perturb and observe method. The proposed method uses the differential evolution algorithm to generate a set of candidate solutions, and then the perturb and observe method is used to fine-tune the operating point of the PV system. The authors of the study have tested the proposed algorithm on a simulated PV system and compared its performance to that of a standard P&O MPPT algorithm and a standard differential evolution algorithm. The results showed that the proposed method had a faster convergence time and better tracking performance than the other algorithms.

S. Gao et al., 2019 : This study presents a hybrid MPPT algorithm that combines the advantages of artificial neural networks and improved particle swarm optimization for maximum power point tracking in PV systems. The proposed algorithm uses an artificial neural network to predict the MPP, and then the particle swarm optimization is used to fine-tune the operating point of the PV system. The authors of the study have tested the proposed algorithm on a simulated PV system and compared its performance to that of a standard P&O MPPT algorithm and a standard artificial neural network. The results showed that the proposed method had a faster convergence time and better tracking performance than the other algorithms.

Chao and Hsieh,2019 this article examined the performance of certain sections of a PV module array when exposed to shading, and then applied an advanced version of the particle swarm optimization (PSO) method to locate the highest point of power output, referred to as the global MPP, in a curve with multiple peaks. They improved the accuracy of the PSO algorithm by incorporating elements of the artificial bee colony (ABC) method. Through simulations, the authors demonstrated the effectiveness of their approach in accurately tracking the global MPP.

Mokhlis et al., 2020 In this article, proposed a hybrid approach called ANN-IFLC (Artificial Neural Network-Integral Feedback Linearization Controller) for MPPT in photovoltaic systems. This method has been compared to other commonly used MPPT techniques such as Incremental Conductance, Perturb and Observe, and found that the ANN-IFLC method performed more accurately and quickly. furthermore it , found that the performance of the ANN-IFLC method was on par with the Integral Sliding mode controller (ISMC) method. Also stated that controllers such as FLC, BSC and SMC which are robust in nonlinear systems, when combined with ANN, can give good results. Furthermore, it the use of ANN-IFLC and showed through simulations that the ANN-ISMC method was able to track the MPP accurately and quickly in a PV system with a Boost converter with a tracking time of 1.2s.

Viswambaran et al.,2020 In this article, the authors aimed to use Artificial Neural Networks (ANN) to model the nonlinear dynamic behavior of PV panels and to identify the optimal training algorithm and network architecture for developing an MPPT controller for a PV system.

They evaluated different network training functions and found that the Levenberg-Marquardt (LM) technique was the most appropriate for this task. They trained different neural network designs to track the MPP and compared their performance using metrics such as regression coefficient and mean square error. They found that feed-forward networks performed better, with faster convergence, lower mean square error, and higher regression coefficient. The proposed ANN-based MPPT technique is capable of monitoring the MPP under various environmental conditions and due to the high generalization capability of ANNs, it can also avoid getting stuck at local maxima.

Eltamaly et al., 2020 This article examines the use of particle swarm optimization (PSO) as a method for maximum power point tracking (MPPT) in photovoltaic (PV) systems that experience partial shading. The authors found that while PSO is effective in this application, it can have a slow convergence time and may converge prematurely. To improve its performance, they propose a technique to boost the performance of PSO when used as an MPPT. The simulation results indicate that this approach is successful.

Premkumar et al., 2021 This article introduces a new method for harvesting the highest output power from a solar PV panel or array under partial shade conditions (PSCs). The hybrid method combines the perturb and observe (P&O) technique with the salp swarm algorithm (SSA) to create a hybrid MPP tracking algorithm. The proposed hybrid SSA algorithm, called HSSA, outperforms other hybrid algorithms found in literature such as the hybrid grey-wolf-optimization (HGWO) and hybrid whale-optimization algorithm (HWOA). SSA uses the P&O method to search for the MPP in the projected search space. The authors used simulation tools in MATLAB/Simulink to model the proposed hybrid method and compared its performance to standalone P&O, WOA and GWO. The simulation results showed that the hybrid tracking algorithm has high tracking performance.

Mahmoud N. Ali et al.,2021 This paper presents a new design for a fuzzy logic-based algorithm that adjusts the step size of the incremental conductance (INC) maximum power point tracking (MPPT) method for PV systems. The proposed method uses a variable voltage step size that is determined by the degree of increase or decrease in the power-voltage relationship. To vary the step size of the duty cycle, a fuzzy logic system is developed based on the location of the fuzzy inputs in five regions around the point of maximum PV power. The fuzzy inputs are based on the slope of the power-voltage relationship, such as the current-voltage ratio and its derivatives, and appropriate membership functions and fuzzy rules are designed. The proposed method was verified and tested through simulation of a grid-connected PV system model. The simulation results show an improvement in the static and dynamic responses compared to the traditional INC method under various environmental conditions. Additionally, it increases the output DC power and reduces the time to reach steady state with changing environmental conditions.

Rambabu Motamarri et al., 2021 In this study, the authors propose a new MPPT method that utilizes a modified grey wolf optimization (MGWO) algorithm to extract the global peak (GP) for PV systems under partial shading conditions. The proposed method aims to overcome the limitations of traditional techniques by providing faster convergence and the ability to re-initialize parameters in dynamic conditions. However, it should be noted that the proposed method does not address issues such as high ripple, high oscillation, high overshoot, high cost, and increased system complexity. Additionally, the performance of the system has not been tested under the European standard test EN50530.

I. Dagal et al.,2022 In this study the proposed technique utilizes the strengths of both PSO and SSO, to accurately track the global maximum power point (MPP) in the PV system. By combining the two optimization models, the technique is able to efficiently charge the battery while also maintaining the highest level of efficiency. The use of the buck-boost converter and FOPID controller in the system further improves the overall performance and effectiveness of the MPPT mechanism. The authors have shown that the proposed technique can achieve better results than traditional PSO or SSO methods alone, through simulation and experimental studies.

Muhammad Mateen Afzal Awan et al., 2022 The article presents a new approach for determining the maximum power point (MPP) in PV systems called the optimized ten-check algorithm (OTCA). This method boasts high efficiency, quick response to changing weather conditions, minimal oscillation, a straightforward design, simple calculations, and low memory requirements. However, it doesn't address issues of high ripple, excessive overshoot, and high costs, and it has not been tested according to the European standard test EN50530 to confirm its performance.

Babes, B et al., 2022 This article describes a new method for MPPT control in PV systems that combines an ant colony optimization algorithm with an artificial neural network. The ACO algorithm is used to optimize the weights and biases of the ANN, and the resulting controller is able to accurately track the MPP of a PV array under varying irradiance conditions. Simulation results show that this hybrid controller improves the performance of the PV system and overcomes the limitations of traditional MPPT methods.

Chittaranjan Pradhan et al., 2022 This paper proposes a new method for tracking the maximum power point (MPP) in a photovoltaic (PV) system under various environmental conditions. The technique is called the roach infestation optimization (RIO) algorithm and is designed to be highly efficient, fast-acting, and accurate. However, the method does not address issues such as high ripple, high oscillation, and high overshoot, and the system has not been tested according to the European standard test EN50530 to verify its performance.

1.2 Problem Statement

The focus of this research will be to enhance the performance of renewable energy sources through the implementation of intelligent control techniques. Specifically, the study aims to apply these techniques to the problem of optimizing power output in PV systems under varying conditions. Despite the potential benefits, there is limited research on the use of intelligent control methods such as fuzzy logic and neural networks for MPPT in photovoltaics(F. Belhachat and C. Larbes.2018). This study aims to explore their potential for improving the efficiency of PV systems.

The stability of a power grid can be negatively impacted by fluctuations in the output power of a PV system caused by changing weather conditions(C. Hussaian Basha, V. Bansal, C. Rani, R. Brisilla, and S. Odofin.2020). To address this, it is important to develop a hybrid control system for managing PV power when it is connected to the utility grid, particularly for large-scale PV plants where weather conditions are highly variable(C. Pradhan, M. K. Senapati, N. K. Ntiakoh, and R. K. Calay.2022).

PV systems, like any other electrical equipment, are vulnerable to failure due to unforeseen events. The most common type of failure occurs when weather conditions change suddenly, leading to a significant change in the DC voltage of the PV array. This can cause damage to the PV power conversion system and shorten the lifespan of the PV array. To address these challenges, control systems have been developed to improve average tracking efficiency, stability, and manage power flow under various weather conditions. Among the various strategies employed, MPPT based on artificial intelligence techniques is considered to be the most effective for a nonlinear system like PV(F. Belhachat and C. Larbes . 2018).

The focus of this thesis is to address the challenges faced in maximum power point tracking (MPPT) for photovoltaic (PV) systems. The conventional MPPT methods have limitations such as slow response due to fixed-step change, high ripple and high oscillation due to changes in the maximum power point (MPP). To overcome these limitations, the thesis proposes a new MPPT technique called Ant lion optimizer (ALO) MPPT. The proposed technique uses a hybrid Ant lion optimizer and particles swarm optimization (PSO) to increase the efficiency of solar systems. The simulation results show that the proposed technique is able to find the global power points faster and performs better than traditional MPPT techniques in terms of convergence rate and efficiency.

1.3 Thesis objectives

1. Design and simulate the traditional MPPT, such as IC and P&O algorithms, to discover the limitation and disadvantages to avoid them in the modified proposed MPPT strategy under critical weather conditions.
2. Design and simulate the particle swarm optimization (PSO) based maximum power point tracking with PV array, including 12 panels, and exam it under different conditions. The simulation results prove that the PSO has outstanding over the traditional MPPT strategies.
3. The PSO-based MPPT suffers from rapid changes in the weather conditions due to the need for an accurate initial duty cycle; the hybrid particle swarm optimization and Ant Lion Optimizer (ALO-PSO) have been combined to solve this issue and capture the maximum power from the PV system.
4. The proposed MPPT strategies have been simulated using the Matlab R2021a version, and the simulation outcomes demonstrated the ALO-PSO has outstanding performance and improved the efficiency of the PV system in terms of fast response, lower ripple, and higher efficiency.

1.4 Thesis layout

This thesis is divided into five chapters, which are organized as follows:

Chapter One: This chapter starts with a general description of photovoltaic technology and then goes on to discuss the reasons, goals, and objectives of the research. It also highlights the contributions made by the thesis. Lastly, the chapter includes a list of publications that have resulted from the research.

Chapter Two: provides a short history of photovoltaic energy, followed by an explanation of the basics of the maximum power point tracking approach. It then provides a theoretical background on commonly used MPPT methodologies. Finally, the text compares and categorizes these methodologies based on their common features**.**

Chapter Three: covers the modeling, structure, and control of a photovoltaic system. It suggests starting with the modeling of a PV cell, then moving on to the configuration of a PV array. The text then discusses different topologies of PV systems and the use of a DC-DC boost converter. The control strategy for the PV system is discussed, along with the concept and design of ALO algorithms using PSO. Also concludes with the construction of a PV system model using MATLAB-SIMULINK.

Chapter Four: This chapter provides a comparison of the methodologies discussed in the thesis based on their fundamental characteristics. It concludes with an evaluation of the efficiency of the proposed method using the EN 50530 standard test under various weather conditions.

Chapter Five : summarizes the key findings of the study and provides suggestions for additional research that could be done to build on the work presented.

CHAPTER TWO

THEORETICAL BACKGROUND OF THE PV SYSTEM AND MAXIMUM POWER POINT TRACKING

2.1 Introduction

The structure of a photovoltaic system is covered in this chapter, including its production, control, storage, and consumption, as well as the basic concepts, physical and mathematical models of the photoelectric cell, DC/DC converter, control devices, storage components, the mathematical model of storage, AC/DC transformer, and a detailed analysis of each component**.**

2.2 Theoretical Background of The PV System

Solar panels produce electricity through the photoelectric effect, which was first observed by French physicist Edmund Becquerel in 1839. He discovered that some materials produced an electrical current when exposed to light. This is accomplished by combining two layers, one of which is made of a semiconducting material with a low number of electrons. When the panels are exposed to sunlight, photons are absorbed by the significant layers and stimulate the electrons to move from one layer to the other, generating an electrical charge(A. Belkaid, I. Colak, and O. Isik.2016).

The fast-growing population, the depletion of traditional fuel sources, and increasing environmental concerns have emphasized the need to explore renewable energy options. Solar energy is one of the attractive renewable energy sources due to its several advantages, such as being environmentally friendly, requiring minimal upkeep, being easy to build, and offering an unlimited energy source from the sun(A. Trivedi, A. Gupta, R. K. Pachauri, and Y. K. Chauhan.2016).

Recent global achievements have encouraged academic researchers in the solar system field to address the fundamental challenges facing the industry, including the efficiency of energy conversion in photovoltaic (PV) systems. The efficiency of a PV system is determined by the amount of electricity it generates compared to the amount of incident irradiation. Silicon (Si) crystalline cells and modules have an efficiency of 26.3% and a module efficiency of 24%(S. Mohanty, B. Subudhi, and P. K. Ray. 2016). To maximize the limited efficiency of the Si material, a control strategy known as Maximum Power Point (MPP) is employed. Perturb and observe (P&O) and incremental conductance (IC) are two popular Maximum Power Point Tracking (MPPT) algorithms used in photovoltaic (PV) systems(S. Mohanty, B. Subudhi, and P. K. Ray.2016)(M. H. Zafar et al. 2021).

Perturb and Observe (P&O) is a simple and commonly used MPPT algorithm that works by slightly changing the operating point of the PV system and monitoring the power output. The operating point is then adjusted in the direction of the maximum power point(M. M. A. Awan, M. Y. Javed, A. B. Asghar, and K. Ejsmont.2022)(S. Padmanaban et al.2019).

Incremental Conductance (IC) is a more sophisticated MPPT algorithm that continuously adjusts the operating point of the PV system based on the rate of change of the photocurrent with respect to the photovoltage. It uses the derivative of the I-V curve to determine the maximum power point. IC is a faster and more precise MPPT algorithm compared to P&O, but it requires more processing power and is more complex to implement(M. Sarvi and A. Azadian. 2022)(M. Mokhlis, M. Ferfra, H. A. Vall, C. C. Ahmed, and A. Taouni,2020).

But the P&O method struggles to track the maximum power point (MPP) in rapidly changing conditions due to its slow convergence speed. It takes into account current and voltage fluctuations and adjusts to changes in irradiation. In comparison, the IC MPPT is more complex, but also has its limitations such as the challenge of determining the step size and the possibility of oscillations. An alternative to P&O and IC is to determine MPP using basic methods such as the short circuit and fractional available voltage methods, which involves estimating short circuit voltage and open circuit current(S. Ravyts et al.,2020.).

Controlling photovoltaic (PV) systems is challenging due to their nonlinear characteristics. As a result, the PV system must have a flexible controller that can adapt to changing weather conditions(R. Shah, N. Mithulananthan, R. Bansal, and V. Ramachandaramurthy, 2015). To track the maximum power point (MPP) accurately and in real-time under various operational conditions, a reliable and straightforward controller is necessary. Traditional MPPT methods struggle to provide effective and adaptive control under changing environmental conditions. There are various discussed methods to overcome this, such as particle swarm optimization (PSO)(H. Renaudineau et al., 2014) grey wolf optimizer(GWO)(S. Mohanty, B. Subudhi, and P. K. Ray,2015), cuckoo search(CS)(J. Ahmed and Z. Salam,2014) , and fuzzy logic and ANN-based methods. However, these methods have high computational complexity, making them less practical for application compared to traditional methods.

ANN-based maximum power point tracking (MPPT) methods can only be applied to large photovoltaic (PV) panels because they require a large amount of data for training, including different levels of irradiance, temperatures, and partial shading conditions. Additionally, metaheuristics-based methods may experience a delay in convergence and could even prematurely converge in rapidly changing environmental conditions(S. A. Rizzo and G. Scelba,2015). Fuzzy logic control (FLC) is a low-complexity control method that has similar efficiency to ANNs, but it requires optimization of the FLC rule table, which necessitates a comprehensive understanding of how PV systems work.

To address these limitations, researchers have explored combining different techniques. In[K. Sundareswaran, V. Vigneshkumar, P. Sankar, S. P. Simon, P. S. R. Nayak, and S. Palani, pp. 187-200, 2015], the membership functions and rules of FLC were optimized using PSO. In, an FLC combined with a Hopfield artificial neural network (ANN) was proposed to overcome the static fuzzy rule table. Another approach, the Bat algorithm, is used to base MPPT on a grey wolf optimizer. Machine learning is also a key aspect of these efforts.

The use of artificial intelligence (AI) combined with other techniques is widespread in MPPT. However, complex MPPT systems have limited use because of declining solar cell prices. Many researchers are working to improve this.

The MPPT in a PV system increases the efficiency by operating at the Maximum Power Point (MPP), where the system produces maximum power from the highest amount of solar radiation that hits the PV array. It functions as a DC-DC converter, converting high-voltage energy to lower voltage. When the output voltage is lower than the input voltage, the output current is greater than the input current, resulting in a constant product of voltage and current (V*I). The PWM-based charge controller adjusts the duty ratio of switches to charge the battery with a constant voltage(M. F. Jalil, S. Khatoon, 2022).

2.3 Main Components of a Solar System

Solar panels are the central component of solar power systems, and they come in different shapes and sizes. They generate electricity by converting sunlight into electricity, with more energy produced when exposed to more sun, and less energy generated in the shade. Solar panels are created by connecting individual photovoltaic cells. Each cell produces about half a volt, but when connected in series, it results in a higher usable voltage. 12-volt panels, with a power rating of 150 watts or less, are classified as 12-volt panels, while more powerful panels are classified as 24-volt panels. Under load, 12-volt panels produce approximately 14-18 volts. A single solar panel can charge a 12-volt battery(M. H. Zafar, U. A. Khan, and N. M. Khan,2021).

A charge controller is an electronic device used in solar power systems to regulate the flow of electricity from the solar panels to the battery. Its primary function is to ensure that the battery is not overcharged or undercharged, which can damage the battery and reduce its lifespan. The charge controller monitors the voltage and current of the battery and regulates the flow of electricity accordingly. It also prevents reverse current flow from the battery to the solar panels, which can drain the battery at night. Some charge controllers also have additional features such as LED displays, adjustable charging parameters, and battery protection(D. Verma, S. Nema, R. Agrawal, Y. Sawle, and A. Kumar, 2022).

The choice of charge controller depends on the goal of increasing the charging capacity. For this purpose, an MPPT controller may be selected, but it's important to consider the specifications of each type. MPPT is suitable for low-temperature environments as it can capture the increase in voltage to charge batteries, providing more charge than a PWM controller. In contrast, a PWM controller is not able to pick up the voltage increase and charges with an amount similar to the battery's voltage. PWM controllers are often used in small photovoltaic systems as the benefits of using MPPT in these systems are minimal. PWM controllers are less expensive than MPPT but also less efficient. In specific conditions, MPPT can produce more energy in a photovoltaic system with a certain number of solar panels compared to a system using a PWM controller for the same design and number of panels(C. Osaretin and F. Edeko,2015).

The battery is responsible for storing and discharging energy as needed. There are various types of batteries, but lead-acid batteries are the most common for use with solar systems. Most batteries have a voltage of 12 volts, 24 volts, or 48 volts. Batteries can be connected like solar cells to produce different voltage values, with many batteries connected in series to increase both the battery bank's capacity and voltage. Some batteries are connected in parallel to only increase the power of the battery bank while keeping the same voltage. Solar panels produce direct current (DC) electricity with a voltage of 12 or 24 volts.

Solar cells are made from thin slices of silicon semiconductor material that have been doped to create an electron imbalance. The silicon chips are then arranged together to form a solar cell. The electrical current flows through conductive metal strips on the cells. When a photon collides with a solar cell, it can be reflected, transmitted, or absorbed. The creation of electric current occurs when silicon absorbs a photon. The produced current increases as the number of photons or the intensity of light absorbed by the solar cell increases. Solar cells generate the most power from direct sunlight, but they can also produce electricity on cloudy days and some systems may produce minimal amounts of electricity on bright moonlit nights. Individual solar cells generate only a small amount of electricity, so they are connected to form a solar panel or photoelectric unit to produce useful amounts of energy(R. A. Marques Lameirinhas, J. P. N. Torres, and J. P. de Melo Cunha ,2022).

2.4 Work of PV cell

The construction of PV cells involves the use of p-type and n-type silicon components. P-type materials are made by adding elements such as gallium or boron into silicon, which have one electron in their outer energy level. This causes an electron to move to the silicon and creates an electron vacancy, or "holes." On the other hand, n-type silicon is made by adding elements such as phosphorus, which has five electrons in its outer level. This creates a free electron and generates the electrical current in the PV cell. The voltage produced by a single cell is low, about 0.7V, so multiple cells are connected in series to increase the overall voltage and form a PV module. These modules are then connected in parallel to produce more current and provide the necessary power to the load, forming a PV array(K. Ramani, M. A. J. Sathik, and S. Sivakumar,2015). Figure.2.2 depicts the general structure of a cell, module, and array.

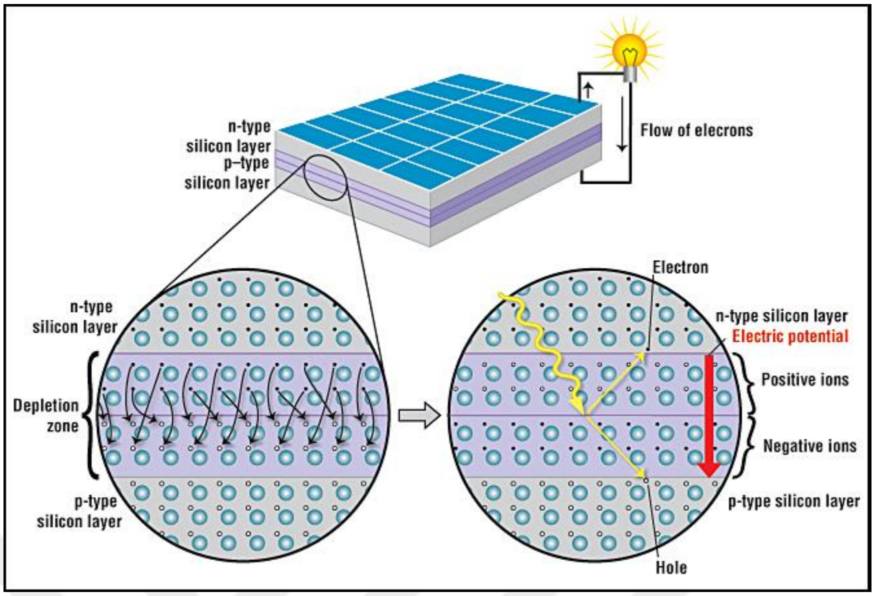


Figure 2.2 layers of silicon in a photovoltaic cell(V. Franzitta, A. Orioli, and A. Di Gangi,2016).

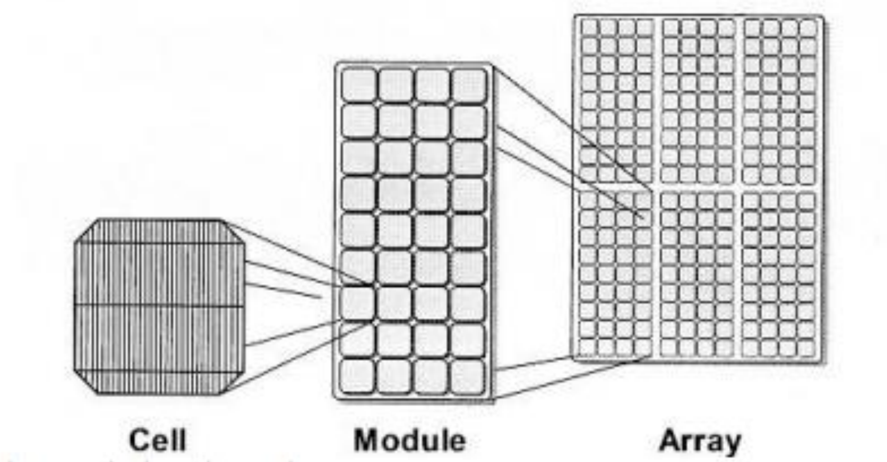


Figure 2.3 PV cell, module, and array structure

2.5 Single-diode PV Cell

The equivalent circuit shown in figure 2.4 represents a photovoltaic (PV) cell module, referred to as a single-diode model. This model takes into account a slight recombination loss in the depletion zone and is favored for its simplicity in many PV applications(V. L. Brano, A. Orioli, G. Ciulla, and A. Di Gangi, 2010). In an ideal scenario, the circuit consists of a photocurrent source and diode connected in parallel. However, in real-life PV cell operation, the impact of losses in silicon materials such as voltage drop and leakage current losses is accounted for by including series and shunt resistors in the PV cell circuit(M. G. Villalva, J. R. Gazoli, and E. Ruppert Filho,2015). Finally, semiconductor theory defines PV cell or module output current as follows:

$$I_L = I_{ph} - I_s \left[exp\left(\frac{q\,V}{\alpha\,V_{th}} \right) - 1 \right] - \frac{V + R_s\,I_L}{R_{sh}} \tag{2.1}$$

Where:

V is the voltage of the PV,

$V_{th} (= N_s K\,T/q)$ is the thermal voltage,

N_s is the number of series cells,

T is the temperature in °C,

K *is the Boltzmann constant,* R_{sh} and R_s are the shunt and series resistors,

I_{ph} is the photocurrent source,

I_s represents the saturation current,

α is the diode constant, and q is the charge of an electron.

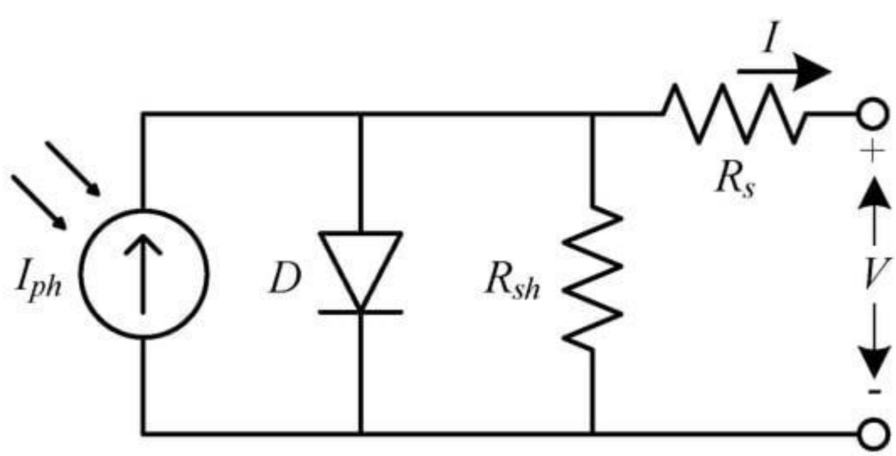


Figure 2.4 Single–diode model PV circuit.

The STC information listed in the datasheet for the PV panel gives the nameplate specifications, including open-circuit voltage (V_{oc}) short circuit current (I_{sc}), maximum voltage (V_{mp}), maximum current (I_{mp}), temperature coefficient for open-circuit voltage (K_v), temperature coefficient for short circuit current (K_i), and maximum power (P_{mp}).

In addition, the electrical properties of the PV panel, or cell behavior, can be determined from three points on the I-V and P-V curves, as shown in figure 2.4, with reference to the Saturation Test Conditions (STC) of temperature and solar shading. The operating point on the P-V or I-V graph determines the performance of the PV module, and the Maximum Power Point (MPP) changes based on the load.

The photocurrent of the PV module I_{ph} is proportional to the amount of irradiance and affected by the ambient temperature, as described in Eq 2.2:

$$I_{ph} = \left(I_{phn} + K_i \Delta T\right) \frac{G}{G_n} \tag{2.2}$$

Where:

I_{ph} is the variation in the source of photocurrent of the PV module with temperature and solar irradiance can be described by the equation $\Delta T = T - T_n$ ($T_n = 25°C$), G is the fall of irradiance on the module, respectively. In modeling the PV module, it is generally assumed that (I_{ph}) is equal to the short circuit current (I_{sc}), considering the low series resistance and high parallel resistance in fundamental PV modules.

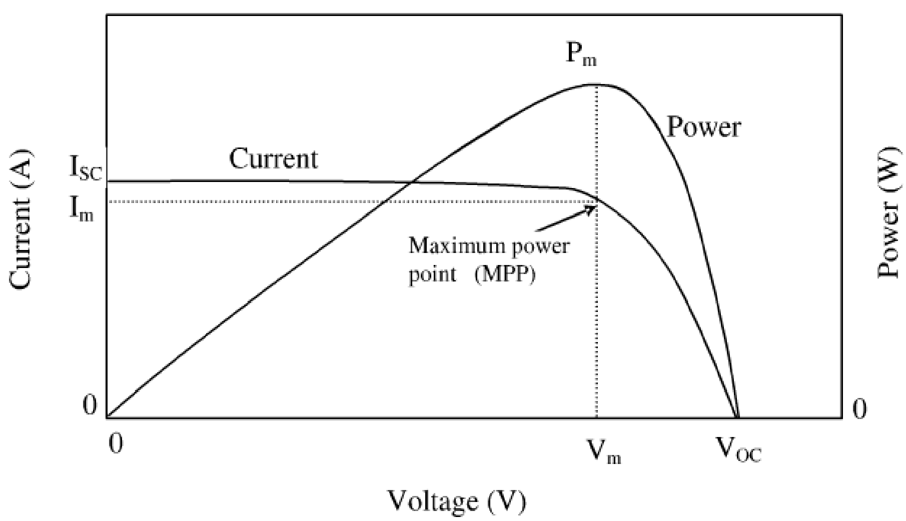


Figure 2.5 P-V & I-V characteristics of PV cell.

The saturation current in a diode may be determined with the use of the following equation:

$$I_s = I_{sn} \left(\frac{T_n}{T}\right)^3 exp\left[\frac{qE_g}{\alpha K}\left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (2.3)$$

WhereI_{sn} represents the reverse saturation current at a constant temperature of 25℃, and E_g refers to the band-gap energy with a value of 1.12. The reverse saturation current can also be expressed as follows.

$$I_{sn} = \frac{I_{scn}}{exp\left[\frac{V_{ocn}}{\alpha\, V_{th}}\right] - 1} \quad (2.4)$$

The open circuit voltage can be expressed as equation (2.5) and is influenced greatly by temperature changes due to the negative sign of the coefficient factor K_v [59].

$$V_{oc} = V_{ocn} + K_v\, \Delta T \quad (2.5)$$

Where V_{ocn} the open-circuit voltage at STC.

2.6 DC-DC Converter Modelling

A DC/DC converter is needed to stabilize the unstable power output of photovoltaic panels, due to fluctuating weather and temperature, and to increase the efficiency of the photovoltaic system by providing the required voltage for the loads. Unlike regular transformers, DC/DC converters convert voltage levels without consuming or adding voltage and do not require insulation between input and output, as they do not need alternating current waveforms. The different types of DC/DC converters are non-isolated, buck converter, boost converter, buck-boost converter, Cuk converter, and single-ended primary inductance converter (SEPIC)(R. H. Tan and L. Y. Hoo,2015).

2.6.1 Boost Converter

The boost converter is a type of DC/DC converter that increases the input voltage to a higher level at the output. It is composed of an inductor, switch, diode, and capacitor, with capacitors added at the output to reduce the ripple effect. The boost converter is controlled using pulse width modulation (PWM), which turns the switch on and off at a high frequency to regulate the output voltage (M. Premkumar, C. Kumar, 2021). The power circuit and switching states of the boost converter are shown in figures 2.6, 2.7, and 2.8.

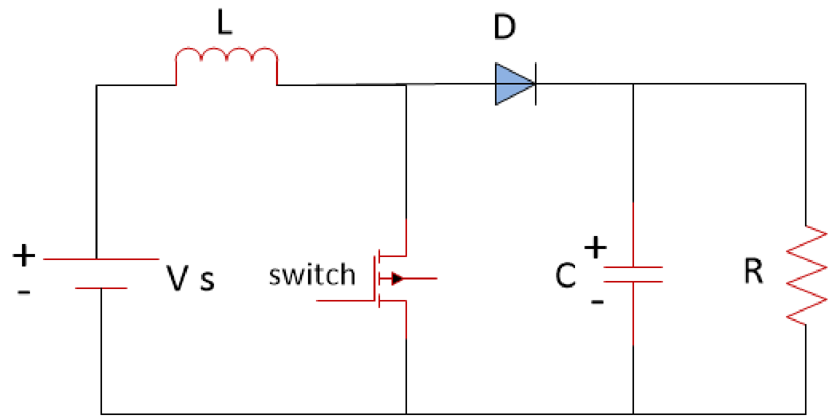


Figure 2.6 Internal structure of Boost converter.

The following describes the voltage path through the switch while it is in the "on" state. by first increasing the inductor current

$$V_L = V_{IN} \tag{2.6}$$

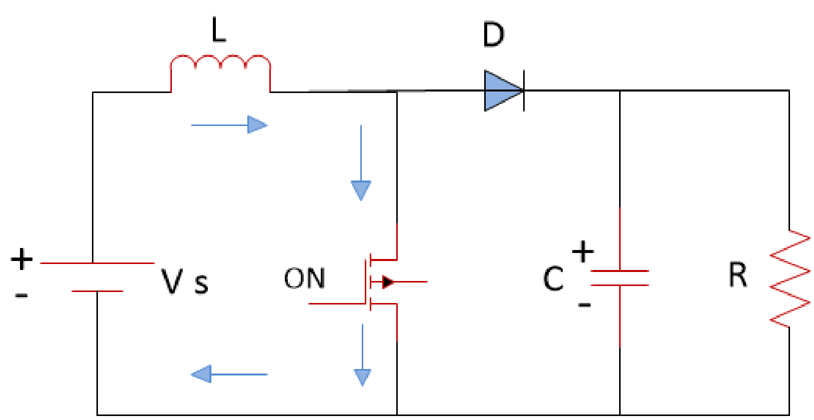


Figure 2.7 ON-state boost converter.

The following mathematical equation describes the flow of voltage in an inductor and a capacitor while the switch is in its off state

$$V_L = V_{IN} - V_o \qquad (2.7)$$

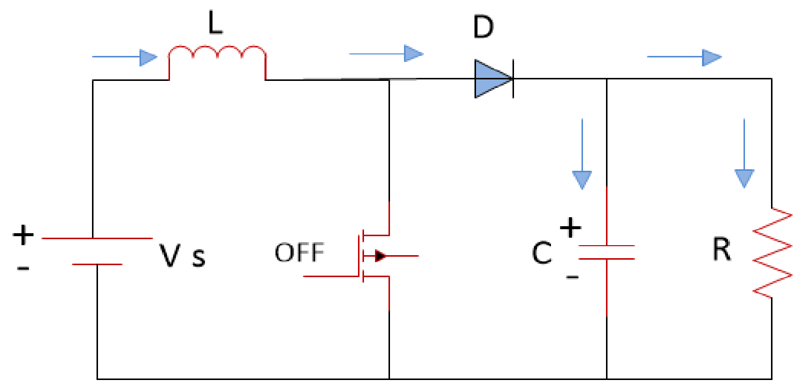


Figure 2.8 OFF-state boost converter.

2.6.2 Buck converter

The Buck Converter is a type of DC/DC converter that typically includes two switches (diode and transistor), an inductor, and a capacitor, as shown in Figure 2.9. It serves as a transformer between the voltage source and the main network or storage (batteries and supercapacitors) and is used to lower the high network voltage to the source voltage or storage voltage for synchronization purposes.

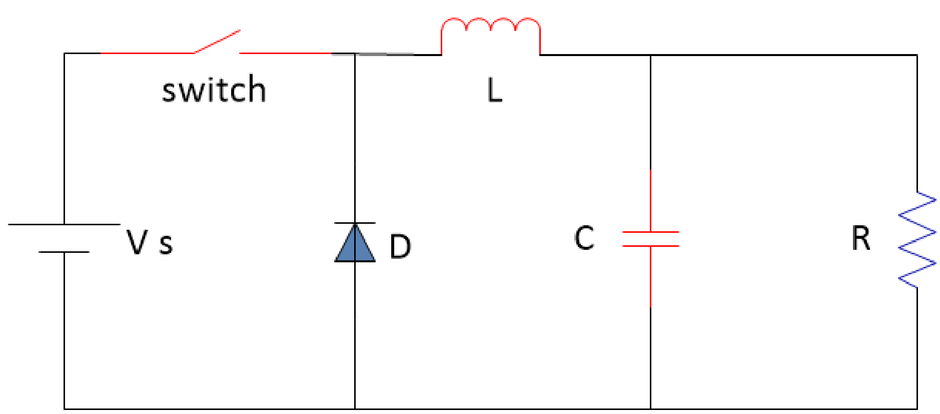


Figure 2.9 Internal structure of Buck converter.

Energy flow during an ON/OFF cycle is shown in figures 2.10 and 2.11. The inductance will be charged when the switch is in its closed ON -State and allowing electricity to flow through it.

$$V_L = V_{IN} - V_o \tag{2.8}$$

When the switch is closed, a linear increase in current is seen across the inductance, and the diode prevents the flow of reverse voltage (ON-state)

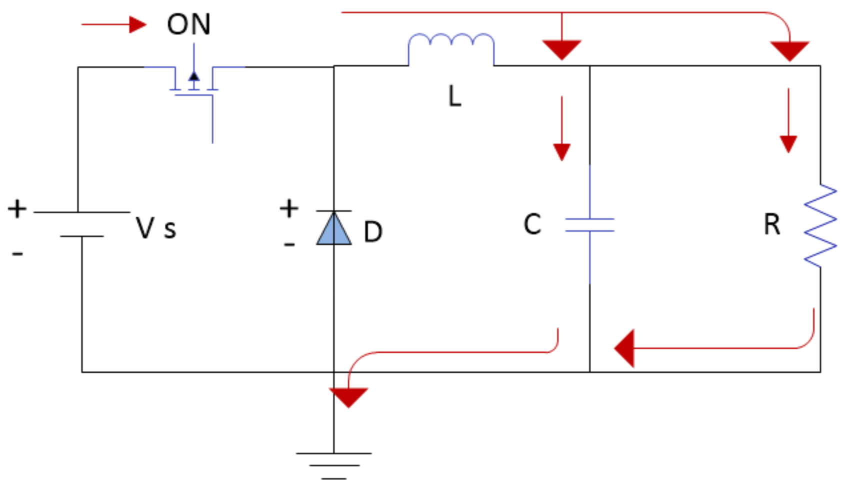


Figure 2.10 ON-State buck converter.

Diode is biased forward and electricity flows through it when the switch is in the off state.

$$V_L = -V_o \tag{2.9}$$

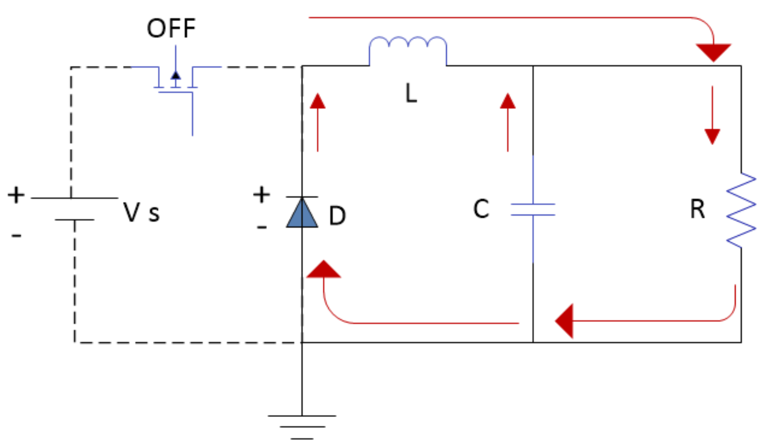


Figure 2.11 OFF-State buck converter.

2.6.3 Buck -Boost Converter

DC/DC converters, also known as choppers, are smaller and have fewer components compared to other converters. They operate by having a constant voltage during certain periods (duty cycle) and are similar to alternating voltage. The output voltage can be higher or lower than the input voltage depending on the duty cycle value. The circuit includes a switch, inductor, capacitor, and reverse diode. The inductor and capacitor filter the output wave and remove harmonics. The buck-boost converters provide efficient solutions as they can raise or lower voltage using minimal components, offer low duty cycle, high efficiency over a wide range of input and output efforts, and are less expensive compared to other converters.

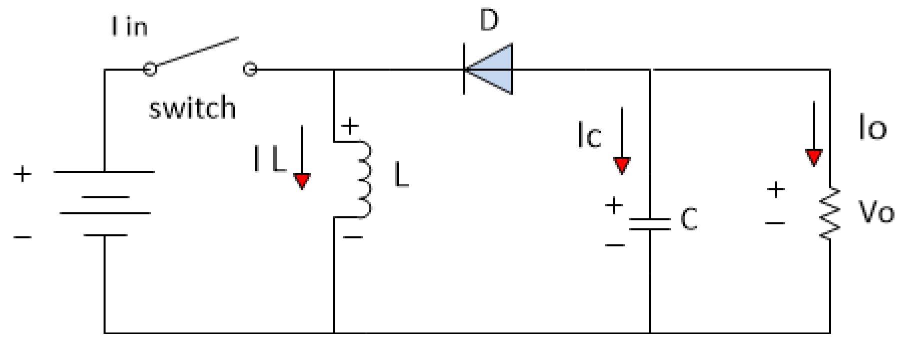


Figure 2.12 buck-boost converter.

The buck-boost converter is not isolated, lacking insulation between the input and output sides, making it unsuitable for certain applications. Additionally, the output voltage is the inverse of the input voltage, which may not be desired in some applications. However, the buck-boost converter can help protect batteries by preventing overcharging when the load current is low and excessive current draw, extending battery life. Buck-boost converters are widely used in battery-powered systems where input voltages vary greatly, starting from a full charge and decreasing as the battery is depleted.

2.7 Maximum Power Point Tracking (MPPT)

MPPT is an electronic technique used in solar energy systems to optimize the amount of power harvested from a solar panel by matching the electrical load to the maximum power point of the panel. This ensures that the panel operates at its most efficient voltage and current, resulting in increased energy output and improved system performance. The MPPT is divided into three main branches traditional, intelligent, and hybrid strategies as shown in figure 2.13.

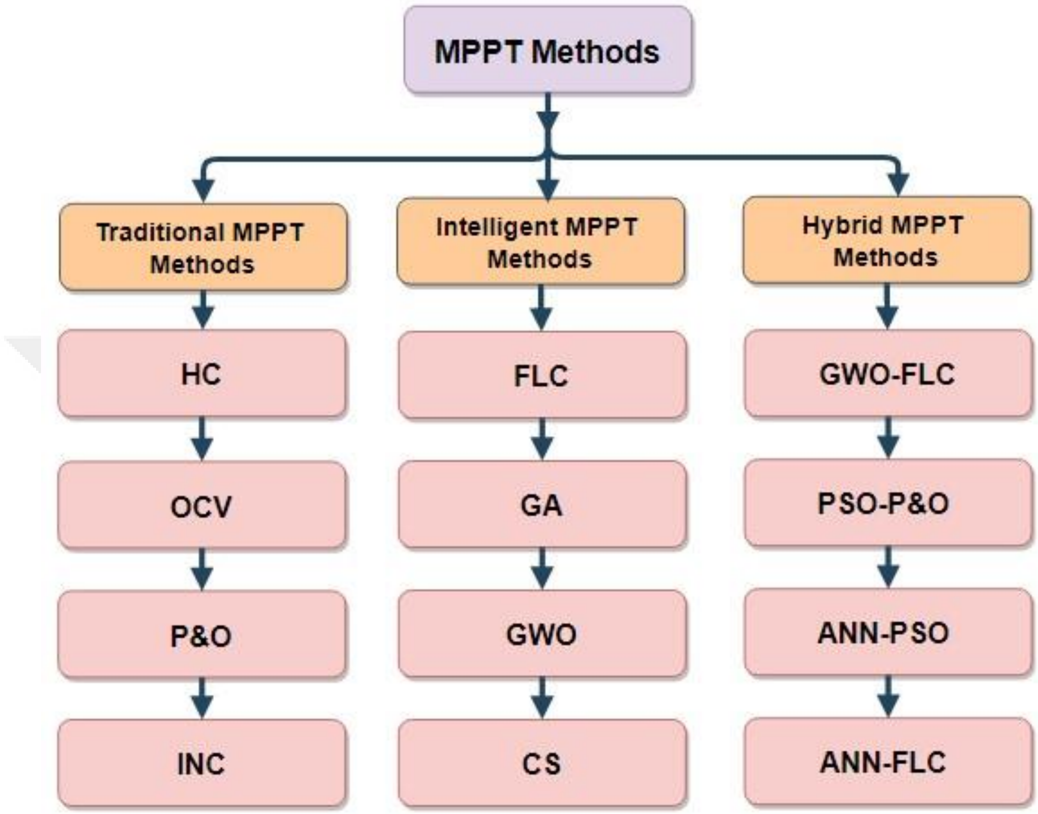


Figure 2.13: Classification of MPPT strategies.

MPPT is needed in photovoltaic (PV) systems for the following reasons:

1. Improving energy efficiency: MPPT ensures that the solar panel operates at its most efficient voltage and current, resulting in increased energy output and improved system performance.
2. Maximum power utilization: MPPT allows for the maximum power to be extracted from the panel, which improves the overall energy yield of the system.
3. Adapting to changing conditions: MPPT dynamically adjusts the operating point of the panel to track changes in weather conditions, ensuring that the maximum power is always being extracted.
4. Increasing battery life: MPPT regulates the voltage and current to prevent overcharging or discharging of the battery, which can significantly extend the battery life.

5. Increasing system reliability: MPPT enhances the overall stability and reliability of the system by reducing stress on the components and reducing the risk of system failure.

2.7.1 Traditional MPPT

There are multiple conventional MPPT techniques, including Constant Voltage (CV), Short Circuit Current (SCC), Open Circuit Voltage (OCV) [68], Hill Climbing (HC) [69], Perturb & Observe (P&O), Incremental Conductance (INC), Ripple Correlation Control (RCC), among others. In the following section, a brief overview of P&O and INC will be provided.

2.7.1.1 Perturb &Observe (P&O) algorithm

The P&O method is a commonly used Maximum Power Point Tracking (MPPT) algorithm for photovoltaic (PV) systems. It works by perturbing the operating point of the PV array and observing the resulting change in power output, the flowchart of the P&O method is shown in figure 2.14. The operating point is then adjusted in the direction that increases the power output, and the process is repeated until the maximum power point is reached. The algorithm is simple, fast, and efficient, making it a popular choice for MPPT in PV systems. The principle of operation P&O curve is shown in figure 2.15.

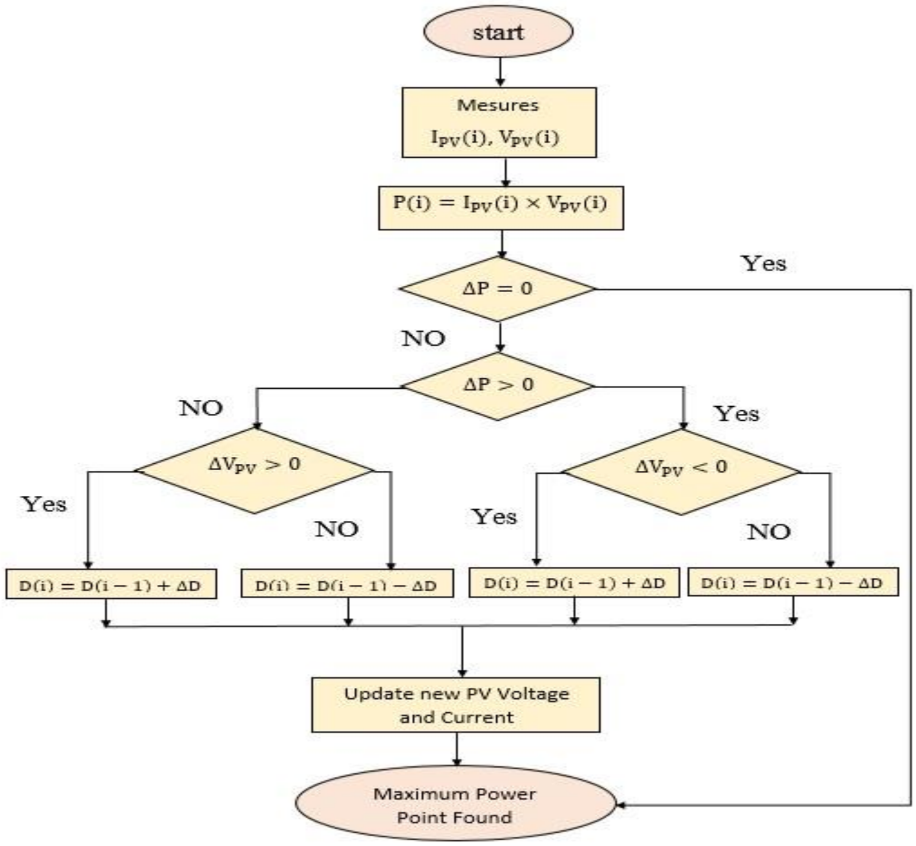


Figure 2.14: Flowchart of P&O method.

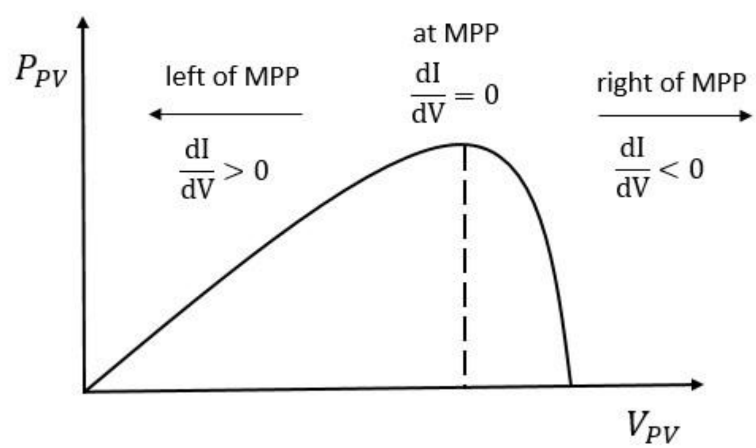


Figure 2.15: The principle of operation P&O curve.

The mathematical equations of the P&O technique are shown below at MPP $\{\frac{dp}{dv} = 0$ (2.10)

left of MPP $\{\frac{dp}{dv} > 0$ (2.11)

right of MPP $\{\frac{dp}{dv} < 0$ (2.12)

2.7.1.2 Incremental Conductance (INC) algorithm

The INC algorithm is another commonly used Maximum Power Point Tracking (MPPT) algorithm for PV systems. It works by continuously monitoring the current and voltage at the maximum power point and adjusting the operating point of the PV array to maintain maximum power. The algorithm uses the slope of the power-voltage (P-V) curve to determine the direction of the operating point adjustment, and the incremental conductance to calculate the size of the adjustment, the principle of operation INC curve is illustrated in figure 2.16. The INC algorithm is fast, efficient, and robust, making it a popular choice for MPPT in PV systems. The flowchart of the INC method is shown in figure 2.17.

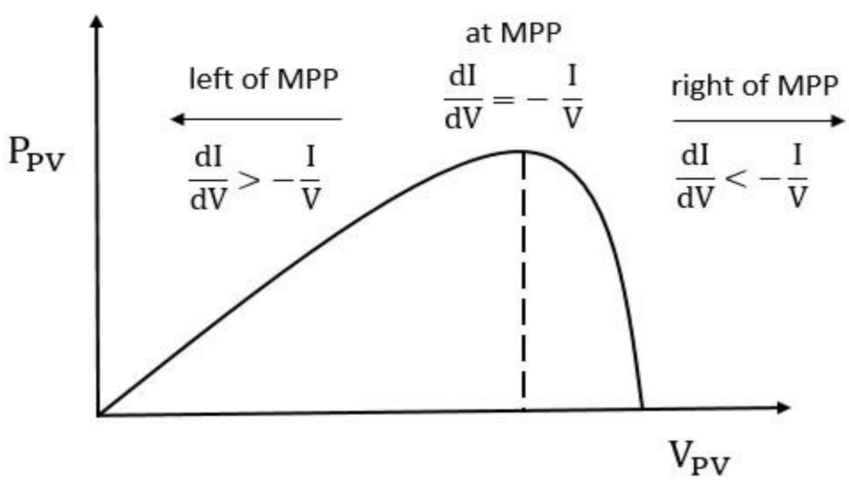


Figure 2.16: The principle of operation INC curve.

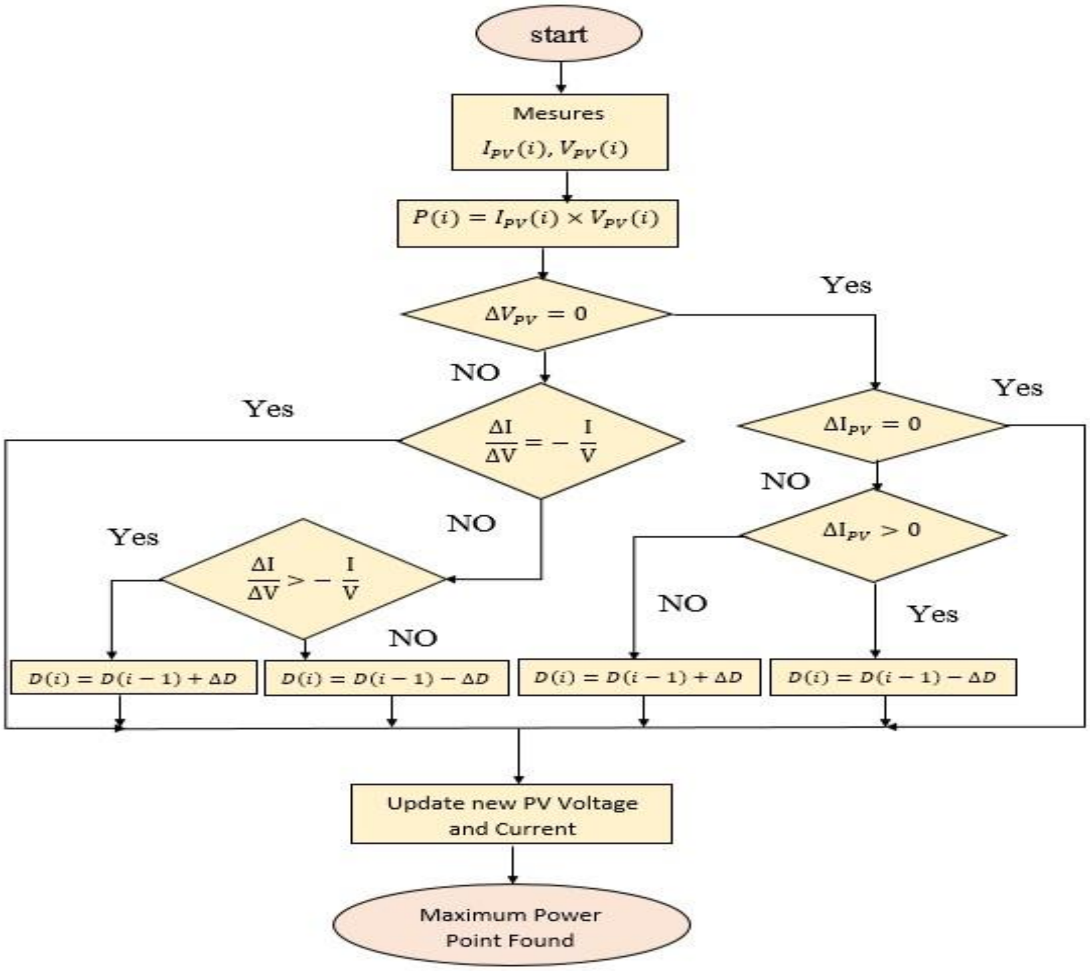


Figure 2.17: Flowchart of INC method(A. Belkaid, I. Colak, and O., 2016).

The mathematical equation described below

$$\frac{\mathrm{dp}}{\mathrm{dv}} = \frac{d(VI)}{\mathrm{dv}} = I + V\frac{\mathrm{dI}}{\mathrm{dv}} = 0 \quad (2.13)$$

$$\frac{\mathrm{dI}}{\mathrm{dV}} = -\frac{\mathrm{I}}{\mathrm{V}} \cong \frac{\Delta\mathrm{I}}{\Delta\mathrm{V}} \quad (2.14)$$

$$\text{at MPP } \{\frac{\mathrm{dI}}{\mathrm{dV}} = -\frac{\mathrm{I}}{\mathrm{V}} \quad (2.15)$$

$$\text{left of MPP } \{\frac{\mathrm{dI}}{\mathrm{dV}} > -\frac{\mathrm{I}}{\mathrm{V}} \quad (2.16)$$

$$\text{right of MPP } \{\frac{\mathrm{dI}}{\mathrm{dV}} < -\frac{\mathrm{I}}{\mathrm{V}} \quad (2.17)$$

2.7.2 Intelligent MPPT

There are various approaches referred to as intelligent MPPT the most common methods will be illustrated.

2.7.2.1 Fuzzy Logic Controller (FLC) Algorithm

FLC is a mathematical method that uses fuzzy set theory to represent human reasoning and decision-making in a form that a computer can understand and use to control a system. An FLC-based MPPT algorithm for a PV system uses fuzzy logic to determine the optimal operating point for the PV system to maximize the power output. The FLC algorithm takes inputs such as the PV voltage and current, and based on a set of predefined rules, it outputs the operating conditions that result in the maximum power output(V. Subramanian, V. Indragandhi, R. Kuppusamy, and Y. Teekaraman,2021).

Advantages of FLC for PV system-based MPPT:

1. Efficient tracking: FLC provides efficient and accurate tracking of maximum power point (MPP) for a PV system.
2. Robust performance: Fuzzy logic provides robust performance and stability even in the presence of changes in temperature and irradiance.
3. Easy tuning: FLC is easy to tune and can be adjusted according to the system's requirements.
4. Faster convergence: FLC has faster convergence compared to other MPPT methods, resulting in higher power extraction from the PV system.

Disadvantages of FLC for PV system-based MPPT:

1. Complexity: FLC is a complex method and requires a high level of expertise to implement and maintain.
2. Computational requirements: FLC requires higher computational resources compared to other MPPT methods, which can affect system performance and efficiency.
3. Sensitive to parameters: FLC is sensitive to parameters, and the performance of the system can be affected if the parameters are not properly set.

4. Dependence on model: FLC performance depends on the accuracy of the model used to describe the PV system, which can result in inaccurate tracking of the MPP if the model is incorrect.

There are two input variables to the PV system error (E) and change of error (CE), explains in the equation below

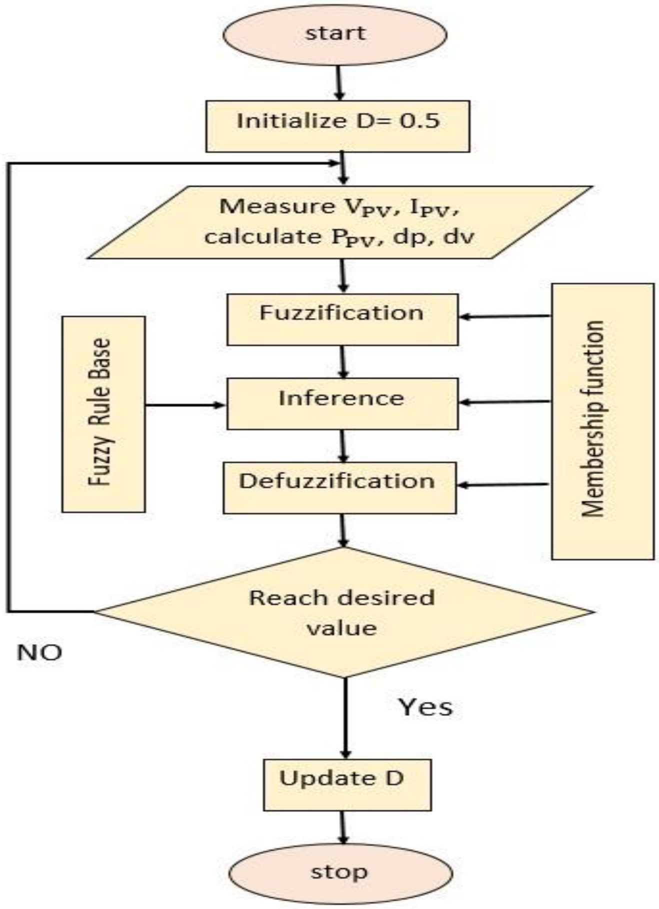
$$E(n) = \frac{P_{PV}(n) - P_{PV}(n-1)}{V_{PV}(n) - V_{PV}(n-1)} \quad (2.18)$$

$$CE(n) = E(n) - E(n-1) \quad (2.19)$$

In a PV system, the flowchart shown in figure 2.18 and the output from the defuzzification is the duty cycle described in the equation below

$$D = \frac{\sum_{i=1}^{n} \mu(D_i) - D_i}{\sum_{i=1}^{n} \mu(D_i)} \quad (2.20)$$

Where the μ is the membership function, D is the duty cycle and i iteration.



2.7.2.2 Artificial Bee Colony (ABC) Algorithm

ABC Algorithm is a nature-inspired optimization algorithm that can be used for MPPT in PV systems. ABC is based on the behavior of bees in a colony and is designed to simulate the search behavior of bees for nectar sources. In MPPT, the algorithm is used to search for the MPP in a PV system.

ABC works by dividing the search process into two phases: exploration and exploitation. In the exploration phase, the algorithm generates new solutions randomly and updates the search space. In the exploitation phase, the algorithm evaluates the solutions and updates the best solutions found so far. The algorithm continues this process until a stopping criterion is met, such as a maximum number of iterations or reaching a minimum error threshold (C. González-Castaño, C. Restrepo, S. Kouro, and J. Rodriguez,2021.).

ABC is a simple and easy-to-implement algorithm that provides global optimization for MPPT. However, it can have slow convergence and be sensitive to the parameters used in the algorithm, making it difficult to fine-tune for optimal performance in PV systems. Despite these limitations, ABC is a suitable choice for MPPT in PV systems with limited computational resources and has been shown to provide robust performance and stability even in the presence of changes in temperature and irradiance. figure 2.19 clarify the flowchart of the ABC algorithm.

To track the GMPP of the PV system with the employment of the ABC algorithm is done by assuming each employed bee has only one food source as in the following equation.

$$X_i^t = [X_{i1}^t, X_{i2}^t, X_{i3}^t, \dots X_{iD}^t]^T \tag{2.21}$$

Where X_i^t Represent the position of food sources; i act as the current iteration; t max time for the searching for the efficient location food sources.

The following equation explains creating random food sources.

$$X_{id}^t = L_d + r(U_d - L_d) \tag{2.22}$$

Where $U_d \& L_d$ Represent the upper and lower limit for the dimension issue; r is a random number between (0 to 1) [P. Verma et al.,p. 2419, 2021.].

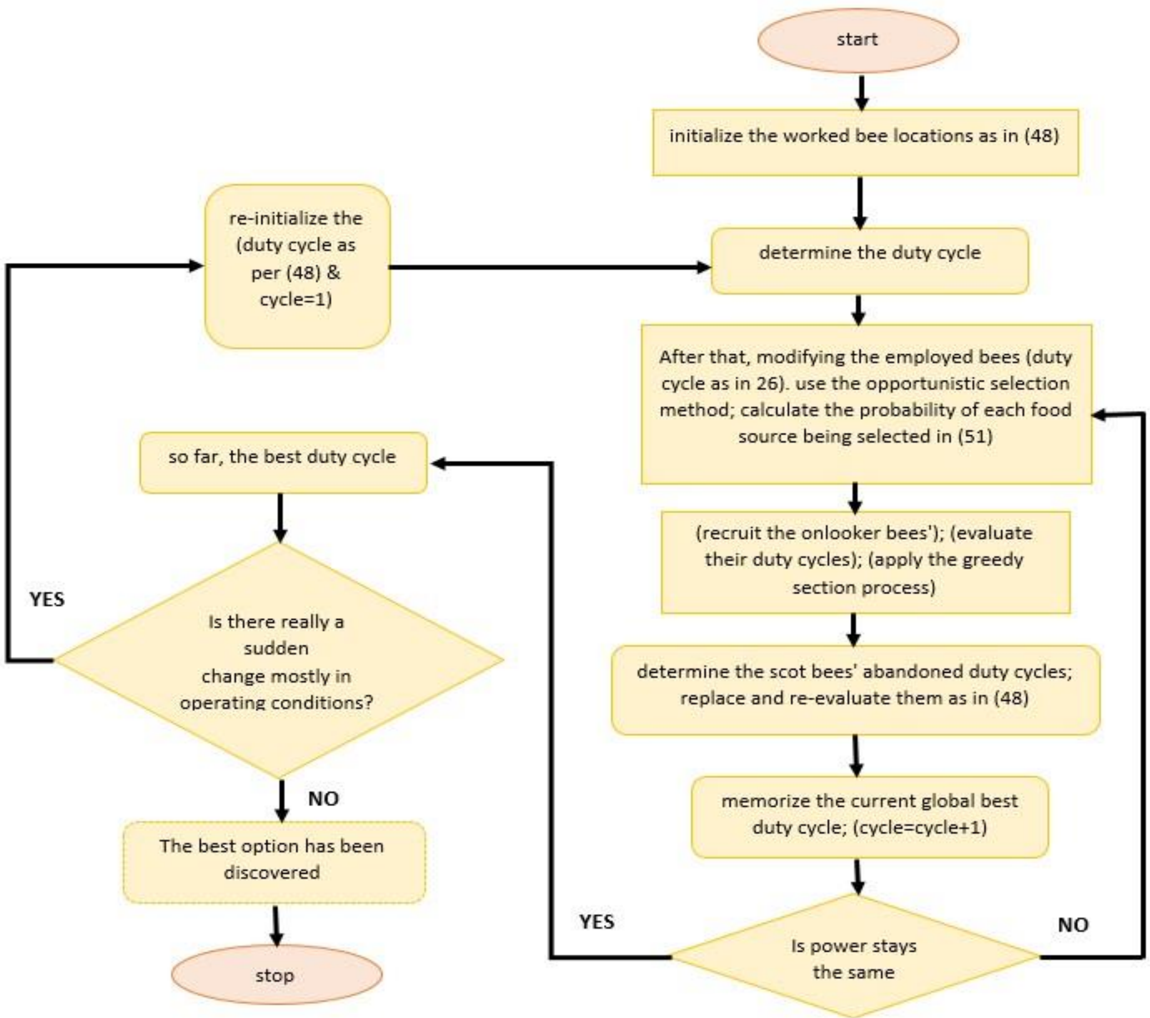


Figure 2.19: The ABC method flowchart (P. Verma et al., 2021.).

The employed bees, in the next step seeking to the food sources V_i closed to X_i in a random dimension d as in the equation below

$$V_{id} = X_{id} + \beta\left(X_{id} - X_{jd}\right) \tag{2.23}$$

Where the new food sources act as V_{id}; j is a random vector that should $\left[i \neq j \in \left(1,2,3,\ldots,N_p\right)\right]$; β is a random value between (1 to -1).

The below probability criteria P_i are used to share the information from the employed bees to onlooker bees

$$P_i = \frac{Fitness_i}{\sum_{n=1}^{N_p} Fitness_n} \tag{2.24}$$

The following table 2.1 clarifies the intelligent methods with merits and demerits

Table 2.1: The difference between swarm intelligent methods based on meta-heuristic approaches(L. Goel, 2020).

MPPT Methods	Author Name	Classification	Advantages	Disadvantages
PSO	Kennedy	Swarm intelligence	Fast calculation capability; MPP location for any P–V curve may be readily determined regardless of environmental conditions; strong dynamic response; and reliability.	The tracking speed is slow, and the initial parameters must be carefully chosen.
ACO	Dorigo	Swarm intelligence	Convergence is independent of initial conditions, and the rate of convergence is done fast.	Implementation can be complex.
ABC	Karaboga	Swarm intelligence	Convergence occurs quickly. There are only a few control parameters.	Implementation can be complex.

GWO	Mirajlili	Swarm intelligence	fast-tracking speed, high efficiency, and eliminates transitory oscillations.	The initialization process is difficult

2.7.3 Hybrid MPPT

Hybrid MPPT refers to a combination of multiple MPPT methods in a single system to improve the performance and efficiency of PV systems such as PSO-P&O, PSO-SMC , ANN-IC, GWO-PO, GWO-FLC, ANN-FLC, ANN-PSO, PSO-GA, and other hybrid MPPT methods.

The goal of hybrid MPPT is to overcome the limitations of individual MPPT methods and provide a more efficient and reliable way of tracking the MPP of a PV system. Advantages of hybrid MPPT include improved accuracy and efficiency in tracking the MPP, faster convergence, and robust performance even in the presence of changes in temperature and irradiance. However, hybrid MPPT can also be complex to implement and requires a high level of expertise to design and maintain. In conclusion, hybrid MPPT can provide a more efficient and reliable way of tracking the MPP in PV systems compared to individual MPPT methods, but requires careful design and implementation to achieve optimal performance.

CHAPTER THREE

DESIGN A PV SYSTEM BASED ON OPTIMIZER ALGORITHMS : SIMULATION CIRCUITS

3.1 Introduction

This chapter introduces the proposed configuration and the demand load calculation that will be used to design the PV system sizing. The configuration of the proposed with all its components explain with datils. The structure of the proposed hybrid is discussed in the second section of the chapter.

3.2 Demand Load Calculation

To properly design the photovoltaic (PV) system depicted in Figure 3.1 and determine the correct size for each component, the demand load must be calculated. The load requirements must be factored in when selecting the size of the PV panels. The thesis uses a residential house as a sample load and examines the daily usage for each type of load. The demand load is broken down into categories in Table 3.1.

Table 1.1: Consume appliances per day.

Consumer appliances (day)				
Appliances	**Hours (h)**	**Power (W)**	**NO. Appliances**	**Energy (Wh/day)**
Microwave oven	0.8	800	1	640
Refrigerator	9	183	1	1,647
Television	3	70	2	420
Clothes Washing Machine	2	600	1	1,200
Floor Standing Air Conditioner	8	3,200	1	25,600
Ceiling Fan	10	75	4	3,000
Fluorescent Tube	5	30	2	300
Fluorescent Lamp	5	11	2	110

Bulb	5	60	2	600
Total				33,337

The total load (Wh)= $33{,}337 \times 1.25$ (3.1)

Where 1.25 acts as a design safety limit[R. A. Mohammed, S. A. Hamoodi, and A. N. Hamoodi, pp. 782-789, 2021.].

The total load (Wh)= 41671.25 Wh.

3.3 PV sizing

The mathematical calculations are obtained according to the theoretical total daily energy.

Total Power= $\frac{\text{Total Load}}{\mathit{Sun\ Arc\ Rate}} = \frac{41671.25\ \text{Wh}}{6.5\ h} = 6410.9615\ W.$ (3.2)

Power of PV model= $540\ W.$

Then,

No. of PV modules= $\frac{\text{Total Power}}{\text{Power of PV model}} = \frac{6410.9615\ W}{540\ W}$ (3.3)

$$= 11.8721 \approx 12\ pcs.$$

3.4 Proposed system Configuration

The proposed setup includes three components: PV panels, DC/DC boost converters, and the proposed maximum power point tracking (MPPT) strategies, as shown in Figure 3.1. The photovoltaic system has a 12-panel array set up in three parallel strings, each made up of four panels connected in series based on power demand calculations. The total output power of the system is around 6480W (12 panels x 540W per panel), with each panel having a capacity of 540W and 110 cells. The specifications of the PV panels can be found in Table 3.2. The design, mathematical modeling, and analysis of each component are discussed in separate sections, including the introduction of optimizer algorithms like particle swarm optimization (PSO) and ant lion optimization (ALO) and how they are used in the MPPT controller to address varying conditions.

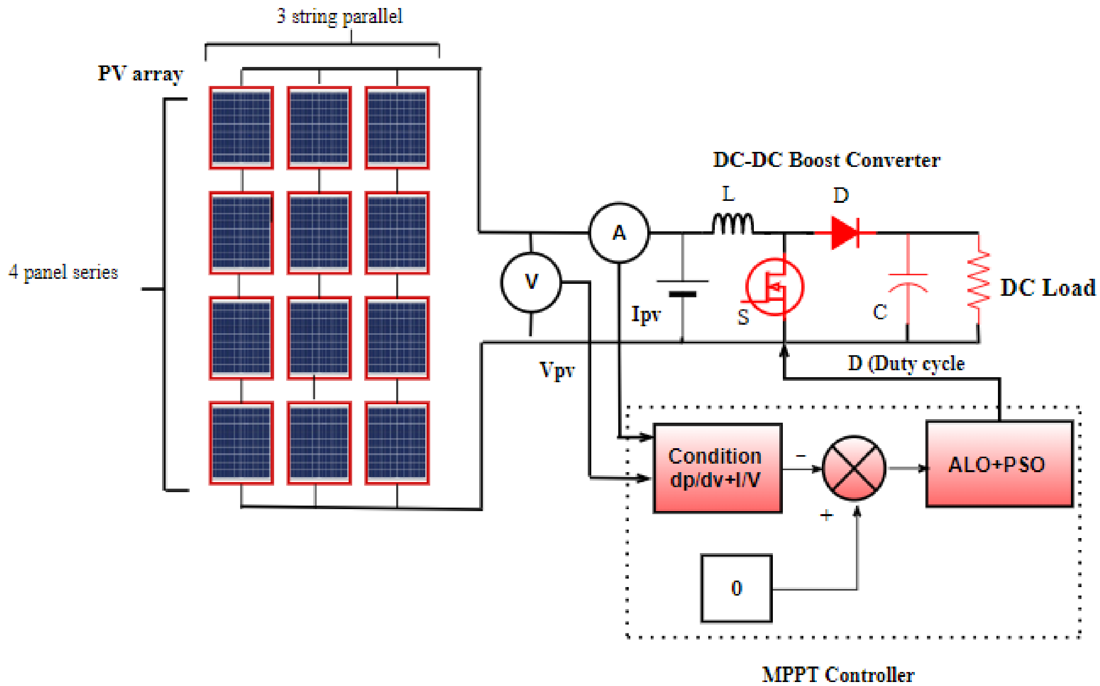


Figure 3.1: The block diagram of the PV system.

Table 3.2 PV calculations

Characteristic	Value
Maximum power (P_{max})	540 W
Cell number	110
Nominal open circuit voltage (V_{oc})	37.5 V
Maximum power voltage (V_{max})	31.2 V
Nominal short circuit current (I_{sc})	18.41 A
Maximum power current (I_{max})	17.33A
Diode ideality factor	0.4628
Temperature Coefficient (I_{sc})	0.04
Temperature Coefficient (V_{oc})	-0.25

3.5 DC/DC Boost Converter

The purpose of MPPT (Maximum Power Point Tracking) is to determine the maximum output of a photovoltaic (PV) module through a DC/DC boost converter. This calculation allows for the load impedance to be matched with the PV module, resulting in the most efficient energy transfer. which is given as follows:

$$Z_{Load} = \frac{V_o}{I_o} \tag{3.4}$$

The MPP (Maximum Power Point) is achieved when the impedance at the input side is equal to the impedance at the load side, represented by V_o and I_o respectively. This definition allows for the optimal impedance for photovoltaic (PV) operation to be determined:

$$Z_{opt} = \frac{V_{MPP}}{I_{MPP}} \tag{3.5}$$

Where:

V_{MPP} , I_{MPP} ; The maximum values of voltage and current for the photovoltaic (PV) system respectively. If the load line moves away from the MPP (Maximum Power Point), the controller will respond by bringing it back to the MPP region. This is shown in figure 3.2.

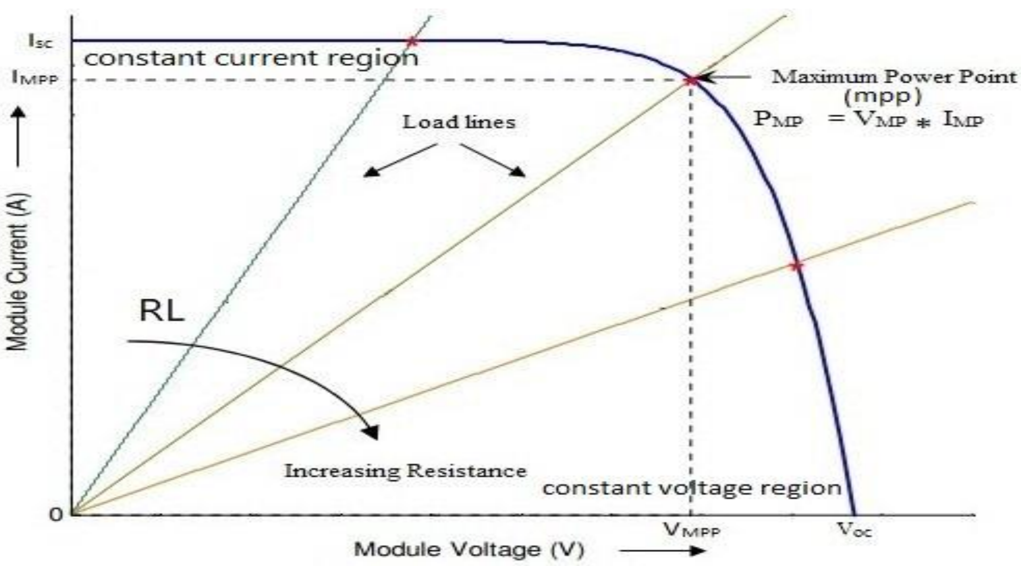


Figure 3.2 Load lines of the I-V curve of the PV module

paraphrase (However, as illustrated in figure 3.1, the DC/DC boost converter is commonly employed in PV applications such as MPPT controllers. Figure 3.3 depicts the boost converter's electrical circuit, which includes an inductor, a single diode, semiconductor switches such as a MOSFET or IGBT, and the capacitors at the input and output sides(M. Sharifzadeh, H. Vahedi, and K. Al-Haddad, 2018).(M. Bakkar, A. Aboelhassan, M. Abdelgeliel, and M. Galea, 2021). The waveforms of a boost converter triggered by a PWM signal are shown in figure 3.4.

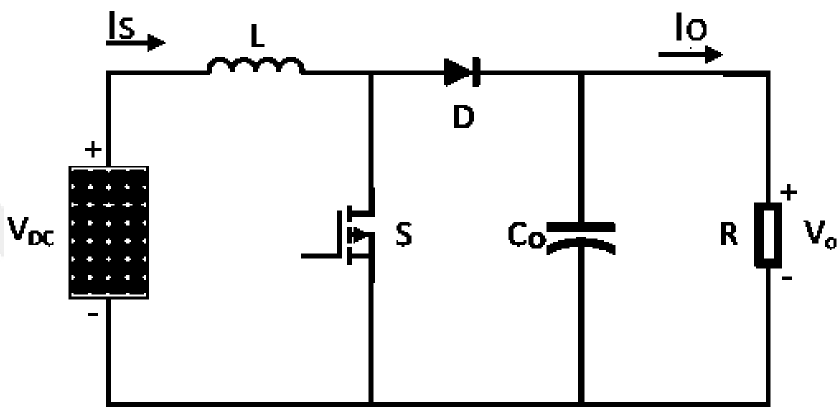


Figure 3.3 Electrical circuit of the boost converter.

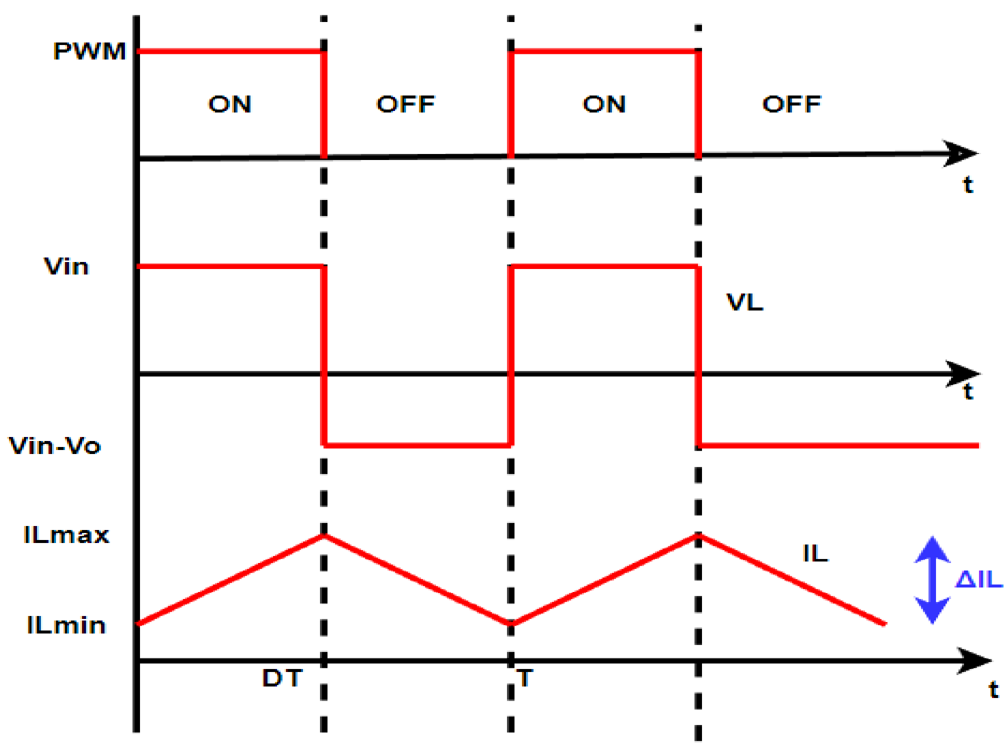


Figure 3.4 The boost circuit's PWM waveforms when in CCM mode.

The boost converter has a voltage output that is represented by

$$V_o = \frac{1}{1-d} V_{in} \tag{3.6}$$

To design a suitable boost converter, it is assumed to have 95% efficiency, so losses cannot be considered. Therefore, the output power (P_0) is equal to the input power (P_{in}). The input current can then be:

$$I_O = \eta I_{in} \ (1 - d\ ) \tag{3.7}$$

Where $I_{in} = I_L$ and $\eta = \frac{P_o}{P_{in}}$ is the efficiency of the boost converter. The duty cycle may be written using the following equation:

$$d = 1 - \frac{\eta \times V_{in}}{V_o} \tag{3.8}$$

The parameters of the boost converter in Continuous Conduction Mode (CCM)

may be calculated according to Eq 3.9.

$$L = \frac{V_{in}\ d}{f_s\ \Delta I_L} \tag{3.9}$$

Where f_s is the switching frequency, and $\Delta I_L = 0.3 I_L$.

The output capacitor may be determined according to the following equation:

$$C_O = \frac{I_o\ d}{f_s\ \Delta V_o} \tag{3.10}$$

Where $\Delta V_o = r \times V_O$ and $r = 0.5\%$. Therefore, C_O must be larger than the calculated value to maintain the output voltage ripple within the desired limits for the boost converter. The input capacitor, crucial for separating the PV power and decreasing voltage harmonics, can be determined using the following Eq:

$$C_{in} = \frac{d \times V_{in}}{8 \times {f_s}^2 \times L \times \Delta V_C} \tag{3.11}$$

Where $\Delta V_c = r \times V_{in}$ and $r = 1\%$.

In a conclusion, the parameters of the boost converter circuit are calculated using previously defined equations for one photovoltaic panel. The total number of panels is 12, arranged in three parallel strings of four series-connected modules each, forming the desired PV array. The combined power output is 6480W, with a PV voltage of 150V. The design of each boost converter is detailed in table 3.3.

Table 3.3 The boost converter simulation parameters

Parameters	Value	Unit
L	0.67	mH
C_{out}	100	μF
f_s	50	kHz
C_{in}	100	μF
d_{max}	0.5003	-

3.6 Design a Proposed MPPT Strategy Based on Hybrid ALO and PSO

3.6.1 Particle Swarm Optimization Algorithm (PSO)

The PSO algorithm is a powerful calculation method for PV systems based on MPPT. It operates by considering velocity and position to define each particle. Each particle represents the best solution, but the leader particle represents the global best solution. The particles follow the leader to reach optimal performance. In the search space, the particle distribution is random. During each iteration, particles update themselves using the best personal value (individual estimate of the solution) and the best global value (collective estimate of the solution)[A. Fathy, A. B. Atitallah, D. Yousri, H. Rezk, and M. Al-Dhaifallah , pp. 5603-5619, 2022.]. The flowchart of the PSO method is shown in figure 3.5.

The velocity and location of particles are modified according to the following formulas:

$$V_n(k+1) = wV_n(k) + s_1\rho_1(P_{p,best-k} - X_n(k)) + s_2\rho_2(P_{g,best} - X_n(k) \quad (3.12)$$

$$X_n(k+1) = X_n(k) + V_n(k+1) \quad (3.13)$$

n=1,2,3,…,N

where: k is the number of iterations; X_n denotes the nth particle's position; V_n means the nth particle's velocity; and w indicates the inertia burden. The social and cognitive acceleration coefficients are denoted by s_1 and s_2, respectively; The arbitrary variables ρ_1, ρ_2 are uniformly distributed between zero and one, and their assessments are uniformly distributed between zero and one; $P_{p,best-i}$ is the nth particle's individual optimal position at the kth iteration; $P_{g,best}$ denotes the swarm–optimum position. If an extempore scenario, such as the initialization requirement in Equation below was satisfied, the technique update is in line with the equations.

$$\mathrm{Ft}(X_{n-k}) > Ft(P_{p,best-k}) \tag{3.14}$$

$$P_{p,best-k} = X_{n-k} \tag{3.15}$$

Ft indicates the target function that must be maximized.

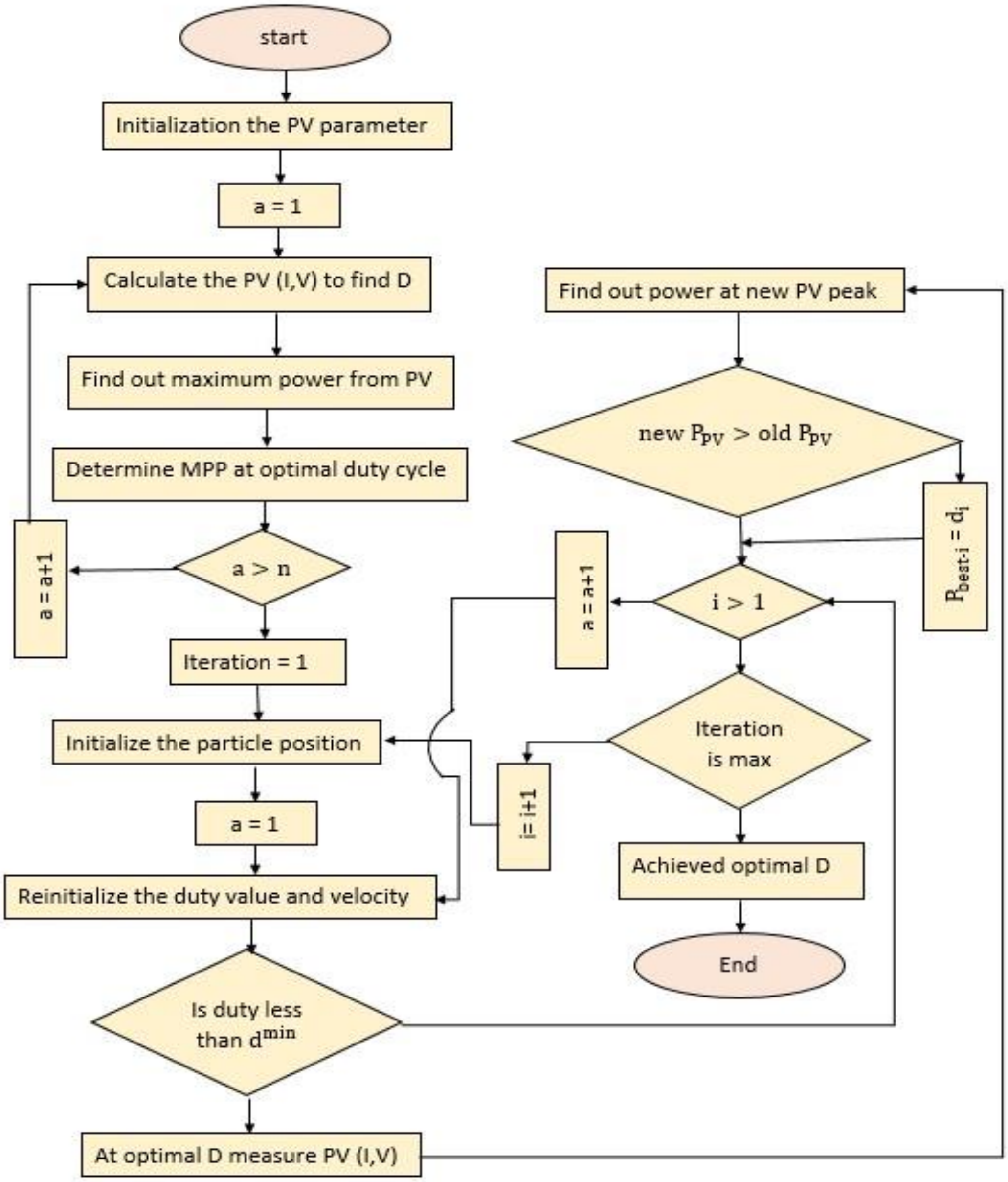


Figure 3.5 Flowchart of PSO method

3.6.2 Ant-Lion Optimization Algorithm

Recently, many algorithms have been influenced by natural creatures, including ALO (proposed by Mirjalili in 2015)[S. Mirjalili, pp. 80-98, 2015.], which is based on the hunting behavior of antlions. Antlions create a cone-shaped hole in the ground by moving in a circular pattern and discarding gravel. They then hide at the bottom of the hole and wait for insects, such as ants, to fall in and become trapped. Once the antlion detects its prey, it will try to retrieve it, drag it under the sand, and consume it. Afterwards, the antlion cleans its hole and prepares for the next hunt.

ALO is structured mathematically in five main steps, including random ant movement, trapping in ant-lion holes, trap construction, ant sliding towards the ant-lion, prey consumption, and trap reconstruction. The important parameters in ALO are summarized as follows:

n: is the number of ants;

m: is the number of ant-lions;

f: is a fitness function;

The position of ant i is represented by Y_i = (y_{i1}, y_{i2},…. y_{id}), where y_{ij} is the value of the j^{th} dimension of ant i.

The position of all ants is represented by X_{ant} = [Y_1, Y_2,.... Y_d], while X_{ant} $[i,j]$ represents the value in the j^{th} dimension of ant i.

The fitness function value for each ant is represented by f(X) = (f (Y_1),f (Y_2)...f ($Y_{d)}$).

The position of ant-lion i is represented by Z_i = (Z_{i1}, Z_{i2},…. Z_{id}), where Z_{ij} is the value of the j^{th} dimension of ant-lion i.

The position of all ant-lions is represented by X_{ant} = [Z_1, Z_2,.... Z_d] where X_{ant} $[i,j]$ represents the value in the j^{th} dimension of ant-lion i.

The fitness function value for each ant-lion is represented by f(Z) = (f (Z_1),f (Z_2)...f ($Z_{d)}$).

2.6.2.1 Ant Movement Model:

The movement of ants is based on random walking. In each iteration, each ant generates a random number between 0 and 1 using a uniform distribution, referred to as "rand." The ant then moves one step forward (+1) or backward (-1) in all dimensions. If the "rand" number is greater than or equal to 0.5, the ant moves forward, otherwise it moves backward. This results in a random walk in each iteration "t". If the starting position of ant i is set to zero, after "n" steps, the position of the ant is updated as follows:

$$[Y_i^0, Y_i^1, Y_i^2, \ldots.\ Y_i^n] \tag{3.16}$$

where "Y_i^k" is the accumulated sum of "k" step random walk in one iteration, and the position of ant i in iteration "t" is equal to "Y_i^n". In other words, $Y_i(t) =$ "Y_i^k". However, since the movement space of ants is limited or bounded, i.e., confined within the search space, the position of the ants cannot be directly updated. To ensure that the position of each ant remains within the search space during each step of the random walk,

since convert $Y_i^k = \frac{(Y_i^k - a_i)}{(b_i - a_i)}$ in the range

the value is transferred to the range $[c_i, d_i]$ by multiplying by $(d_i - c_i)$ and adding c_i, where a_i is the minimum value of the random walk in the i^{th} dimension and b_i is the maximum value. The positions of all ants are saved in a 2D array as follow X_{ant} = $[Y_1, Y_2, ... Y_d]$.

The positions of ant-lions are also stored in a similar way as ants. The array antlion X_{ant} = $[Z_{1,k}, Z_{2,k}, ... Z_{d,k}]$ is a 2D array where antlion $Z_{k,j}$ represents the value in the i^{th} dimension of ant-lion k.

During optimization, a fitness function f is used to assign each ant. The fitness function for the i^{th} ant or antlion is represented by f (,).

2.6.2.2 Ant Trapping in Ant-Lion Holes:

Ants' movements are impacted by ant-lion traps. When an ant (designated as " i ") enters the trap of a specific ant-lion (designated as " j "), its movement is governed by the following equations:

$\mathrm{C_i^t = Z_i^t + C^t}$ $\quad$ $\mathrm{D_i^t = Z_i^t + D^t}$

The variables "$\mathrm{C_i^t}$" and "$\mathrm{D_i^t}$" represent the minimum and maximum values of all variables, respectively, at iteration "t^{th}", while "$\mathrm{C^t}$" and "$\mathrm{D^t}$" are the minimum and maximum values of all variables for ant "i".

"$\mathrm{Z_i^t}$" represents the position of ant-lion "t^{th}" at iteration "j^{th}". Ant " i " moves randomly within a hypersphere defined by vectors "C_i" and "D_i" around the selected ant-lion.

2.6.2.3 Building Traps:

To increase the chances of capturing ants, a roulette wheel is employed to identify the strongest ant-lions.

2.6.2.4 Moving Ants toward Ant-Lions:

Once an ant enters a trap, the ant-lion begins to push sand outward from the center of its hole, causing the ant to move closer to the ant-lion and making it difficult for the ant to escape. This action is modeled by decreasing "C_i" and "D_i", which reduces the radius of the ant's random movement within a hypersphere. The following equations update these parameters:

$$\mathrm{C}^{\mathrm{t}} = \frac{(\mathrm{C}^{\mathrm{t}} \times T)}{(10^{\mathrm{w}} \times t)} \qquad \mathrm{D}^{\mathrm{t}} = \frac{(\mathrm{D}^{\mathrm{t}} \times T)}{(10^{\mathrm{w}} \times t)} \tag{3.17}$$

Where "t" represents the iteration number, "C^{t}" and "D^{t}" are the minimum and maximum values of all variables at iteration "t^{th}", "T" is the maximum iteration number, and "w" is a constant parameter that is calculated based on the iteration number according to the following equation:

$$w = \begin{cases} 2 & t > 0.1T \quad , \\ 3 & t > 0.5T \quad , \\ 4 & t > 0.75T \quad , \\ 5 & t > 0.9T \quad , \\ 6 & t > 0.95T \quad , \end{cases} \tag{3.18}$$

2.6.2.5 Capturing Ants and Rebuilding Traps:

When an ant reaches the bottom of the trap, the ant-lion eats it, completing its hunting process. The final step involves updating the position to the latest position as follows:

$$\mathrm{Z}_{\mathrm{j}}^{\mathrm{t}} = \mathrm{Y}_{\mathrm{i}}^{\mathrm{t}} \quad \mathrm{f}(\mathrm{Y}_{\mathrm{i}}^{\mathrm{t}}) > \mathrm{f}(\mathrm{Z}_{\mathrm{j}}^{\mathrm{t}}) \tag{3.19}$$

where t is the current iteration.

2.6.2.6 Elitism:

How are the best solutions maintained throughout the iterations in evolutionary algorithms? Elitism is a crucial aspect of these types of algorithms. It influences the movement of ants by linking it to the selected ant-lion. The position of the ant is determined by averaging random movements around the chosen ant-lion. The equation below displays this effect:

$$\mathrm{Y}_{\mathrm{i}}^{\mathrm{t}} = \frac{(\mathrm{R}_{\mathrm{A}}^{\mathrm{t}} + \mathrm{R}_{\mathrm{E}}^{\mathrm{t}})}{2}, \tag{3.20}$$

$\mathrm{R}_{\mathrm{A}}^{\mathrm{t}}, \mathrm{R}_{\mathrm{E}}^{\mathrm{t}}$ are the random walks performed near the ant-lion, located by the roulette wheel.

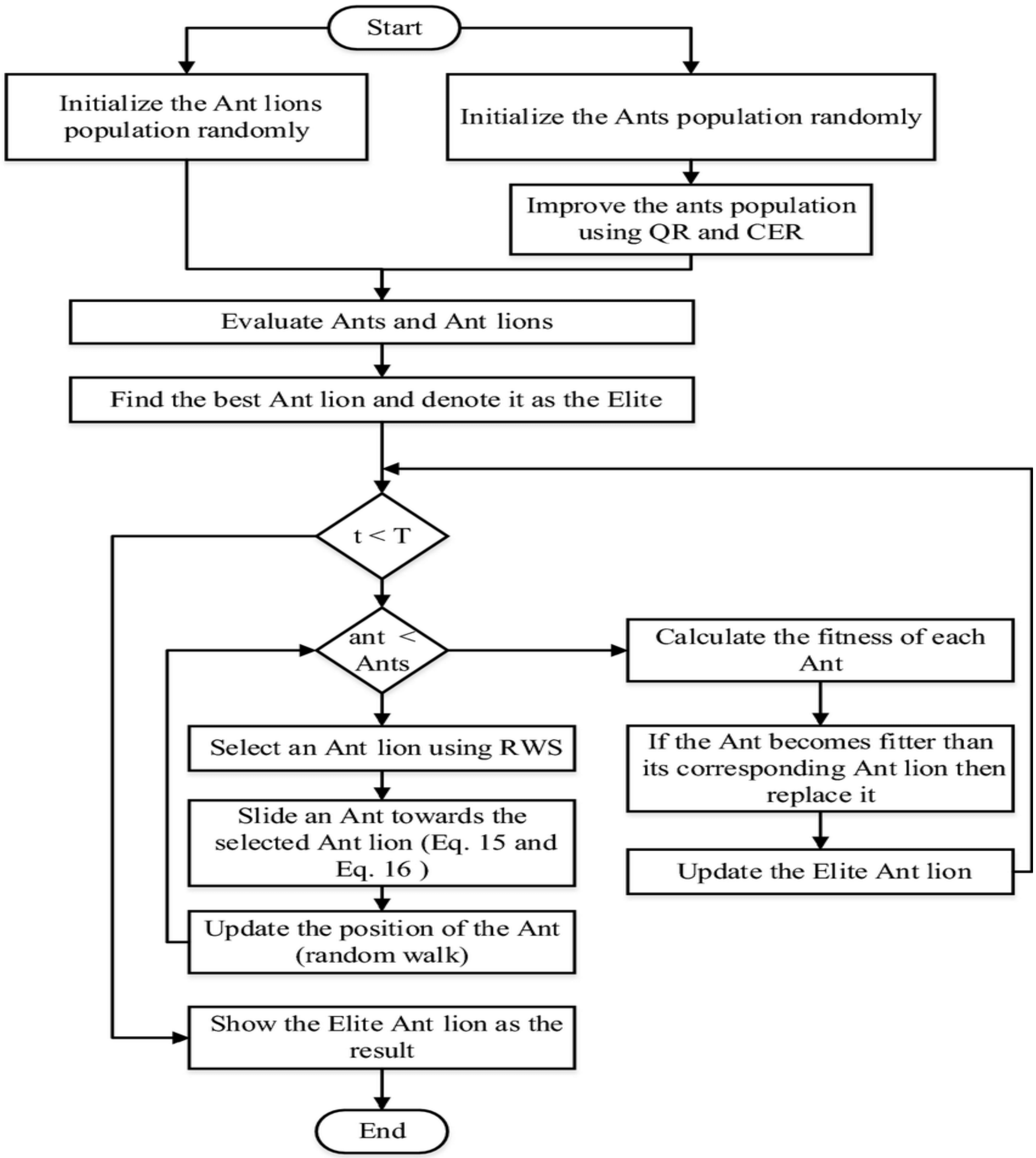


Figure 3.6 The flow chart of Ant Lion Optimizer(V. R. VC, 2018.).

3.7 Proposed MPPT Based on hybrid ALO with PSO

A crucial problem in both conventional MPPT and some intelligent MPPT methods is their reliance on fixed changes in the duty cycle, leading to slower tracking and fluctuations. To resolve this challenge, the ALO proposes utilizing a variable step size for PSO and the PSO proposes a new duty cycle based on the step change as determined by equation 3.21.

$$\mathrm{D}(\mathrm{i}+1)=\mathrm{D}(\mathrm{i})\pm\Delta\mathrm{D} \tag{3.21}$$

Di+1 represents the new duty cycle, ΔD represents the position that provides accurate duty in each iteration, and Di serves as the duty cycle at each iteration.

In this section, a hybrid optimization algorithm is presented that combines the strengths of Particle Swarm Optimization (PSO) and Ant lion optimization Algorithm (ALO). PSO excels at exploring the search space, but struggles with finding the optimum local solution and converging. ALO, on the other hand, overcomes these weaknesses. By combining the two algorithms, a balance between exploration and exploitation is achieved, yielding the benefits of both. PSO is utilized in the global search due to its fast convergence in exploration, while ALO is employed in the local search due to its fine-tuning in exploitation. A flowchart of the proposed hybrid algorithm of ALO and PSO is illustrated in figure 3.6. The details of this hybrid algorithm will be discussed in the following.

Step 1: Initialization:

1.1: Set the input parameters for the hybrid algorithm.

1.2: Randomly assign positions and velocities to particles within a specified range.

1.3: Evaluate the fitness and determine the global and personal best particles (g_{best} and b_{best}).

Step 2: This step encompasses the exploitation and exploration phases, which are based on the local best positions of the particles and the global best of the swarm.

2.1: Exploitation phase: During this phase, the algorithm compares the fitness of a particle with the best global value observed so far using Eq 3.22.

$$\mathrm{f(i,t)}=\begin{cases} true & f(P_i^t)\le f\left(g_{best}^{t-1}\right), \\ false & f(P_i^t)> f\left(g_{best}^{t-1}\right), \end{cases} \tag{3.22}$$

When P_i^t represents the i^{th} particle in its current state t , if $f(i,t)$ this state is determined to be true, the local search will continue and the particle will be manipulated through a simulated ALO.

The current position is then stored in X_{temp}. The new position is evaluated using the ant-lion algorithm, and the velocity is calculated using Eq 3.23.

$$Vi_d(t+1) = Xi_d(t+1) - Xi_{temp}, \tag{3.23}$$

If f(i,t) is false, the particle will be manipulated by PSO and PSO will continue its standard process using this particle according to equations 3.12 and 3.13. The minimum and maximum velocities, V_{min} and V_{max}, are applied to restrict the next movement of the particle. These velocities are randomly set at the start of the proposed hybrid algorithm within a certain range. A linear decreasing inertia weight is employed, which is calculated using equation 3.24.

$$w = w_i - \left(\frac{w_i - w_f}{n}\right) * t, \tag{3.24}$$

Where: n and t represent the maximum number of iterations and the current iteration, respectively. w_i and w_f stand for the initial and final values of the linearly decreasing inertia weight. This weight is updated dynamically to enhance the global search ability of the particle and to prevent premature convergence, where improvements are made based on previous personal bests.

Exploration phase: The calculation of the fitness function and examination of the range restrictions for all particles and ant-lions occur. After the fitness function is determined, the best solutions (and) are updated

Step 3: The hybrid algorithm will end when the maximum number of iterations (n) has been reached. The result of the proposed hybrid algorithm will be the identification of the global best particle (g_{best} and its fitness value).

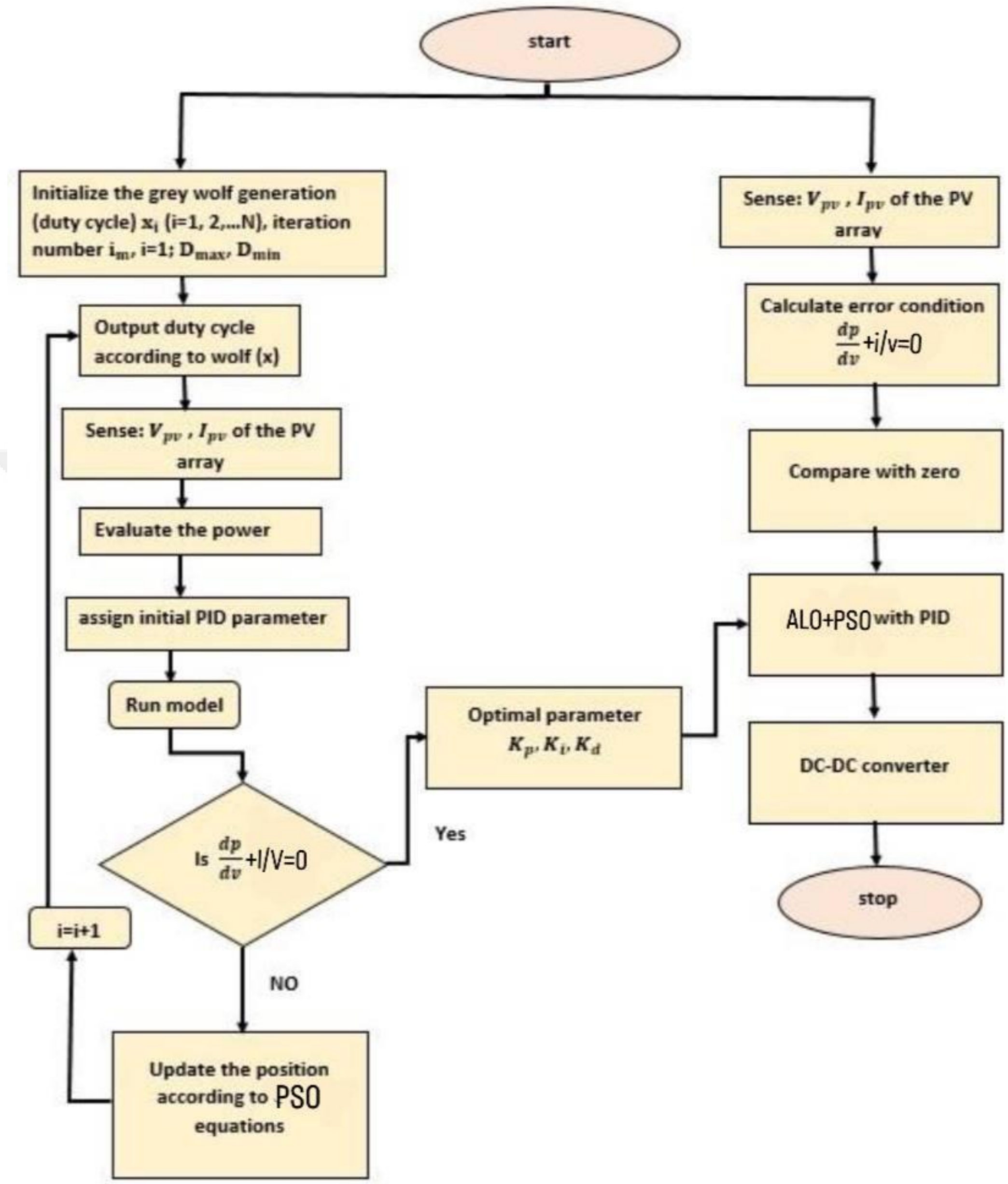


Figure 3.7 The flowchart of ALO-PSO method.

3.7 Summary

Initially, the capacity of the photovoltaic module was calculated based on the energy consumption of the load. The design of the DC/DC boost converter and the proposed MPPT method was introduced and thoroughly examined. The validity of the MPPT approach for a solar system was tested using MATLAB/Simulink software, and the results of the simulation can be found in Chapter 4.

CHAPTER FOUR

ANALYSIS OF SIMULATION RESULTS

4.1 Introduction

This chapter examines the efficacy of the proposed hybrid MPPT for obtaining the maximum amount of energy from a PV system in non-uniform environments. The proposed system has been tested under a variety of situations, including normal operation, variable irradiations, temperatures, and combined irradiation and temperature, as well as sinusoidal conditions. Additionally, various MPPT algorithms such as the P&O and IC algorithms have been evaluated to demonstrate the capability of MPPT in extracting maximum power even in challenging conditions.

Simulink and the m-file in MATLAB can be used to create a hybrid system (R2021a). MATLAB's Simulink will be used to synthesize the ideas presented earlier in the system validation design and simulation, such as the design of a solar panel plant, a DC-DC converter, and MPPT with a resistive load.

4.2 Results and Discussion

In conclusion, the effects of varying temperature and irradiation on an array PV system can be seen in the I-V and P-V curves of the system. These curves demonstrate how the current, voltage, and power of the system change as radiation and temperature levels fluctuate.

Case one: (normal operation test)

Under simulated Standard Test Conditions (STC) of 1000W/m2 and 25°C, the results of the proposed intelligent MPPTs, such as the PSO-based MPPT and hybrid ALO with PSO-based MPPT, were compared to traditional MPPTs. It was shown that the proposed algorithms had a more rapid and efficient response when it came to the current, voltage and power output of the PV system. Figures 4.1, 4.2 and 4.3 revealed that the ALO-PSO had the best dynamic reaction, arriving at the maximum power point in a shorter time than the traditional methods. However, the P&O and IC algorithms were found to be the least viable due to their large oscillations around the MPP, which led to a reduction in the generated output power. To address this issue, the hybrid intelligent MPPT was proposed to increase the duty cycle step size, thus improving efficiency.

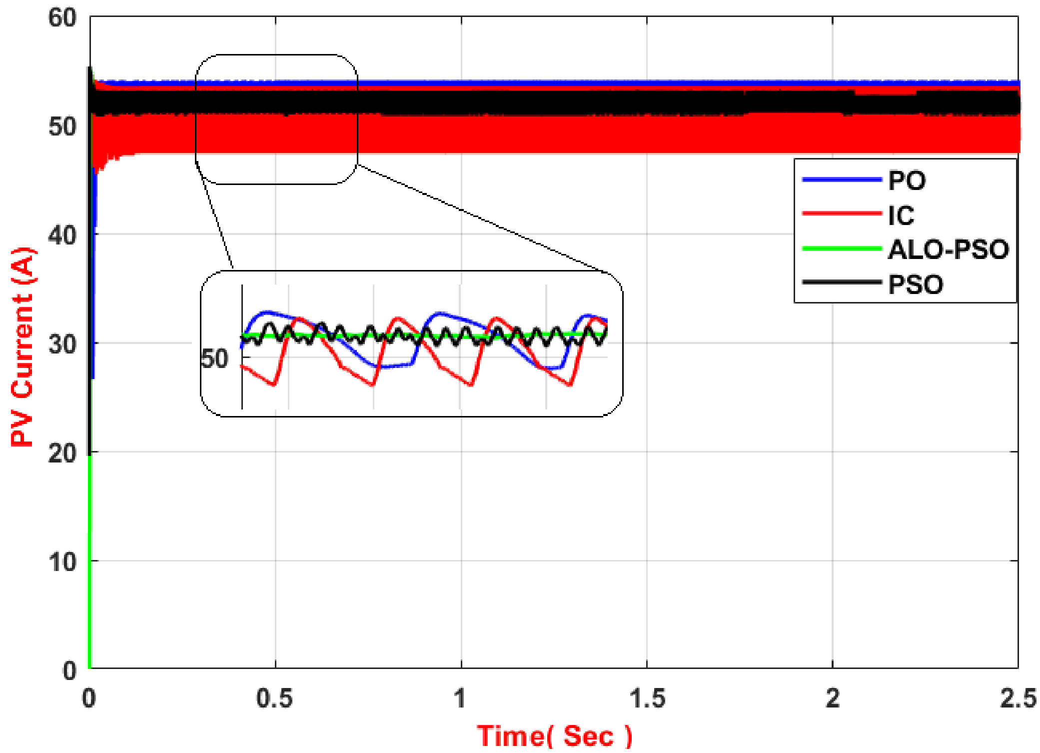


Figure 4.1 the dynamic response of the PV current at STC

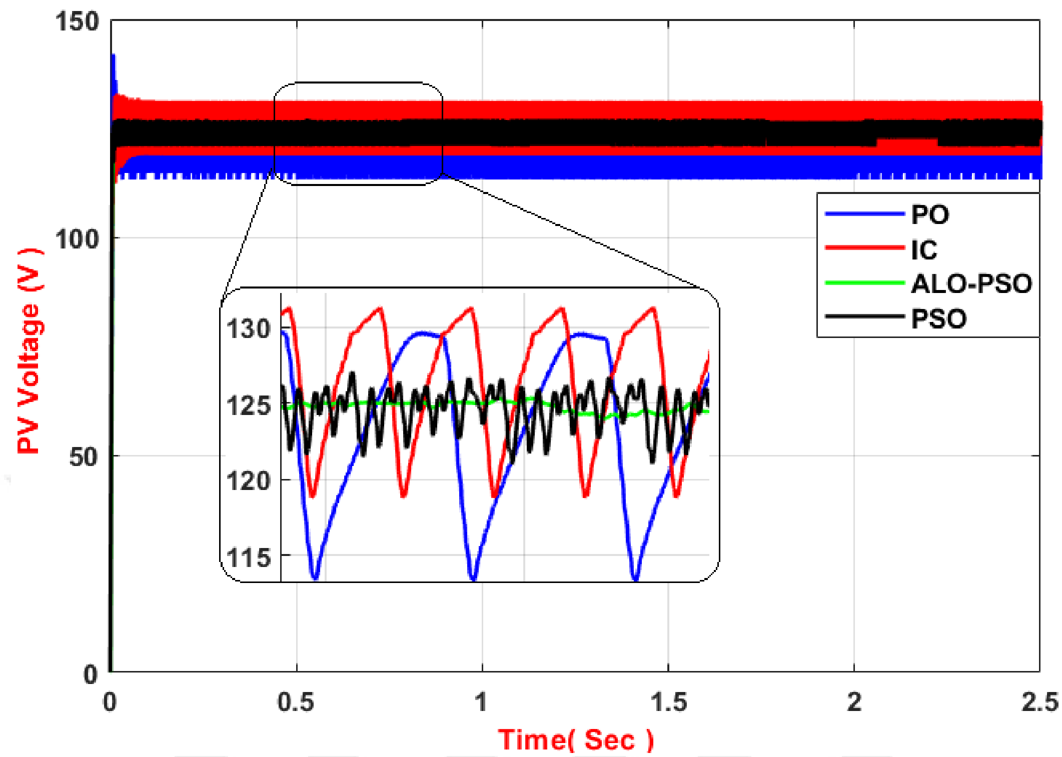


Figure 4.2 the dynamic response of the PV voltage at STC

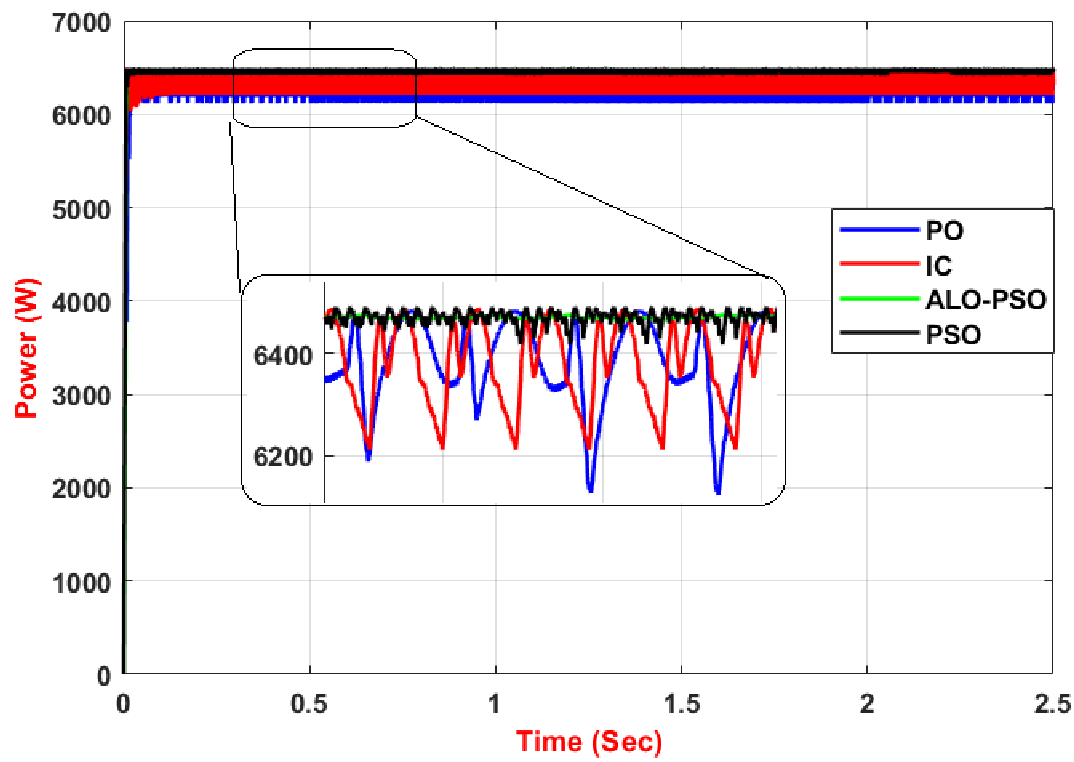


Figure 4.3 the dynamic response of the PV power at STC.

The provided P-V curve in Figure 4.4 demonstrates the effectiveness of the ALO-PSO-based MPPT algorithm in quickly achieving its maximum power output without any oscillations and with only a minimal amount of ripple. This is evidenced by the nearly linear trend of the curve, indicating that the algorithm is able to accurately and rapidly track the optimal operating point.

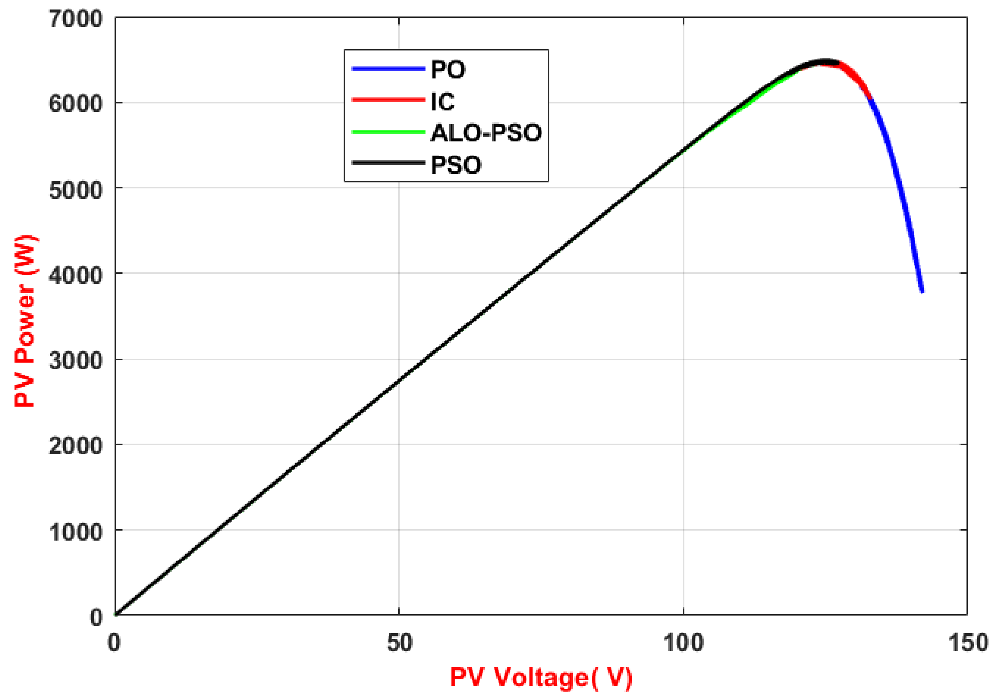


Figure 4.4 the P-V characteristic curve.

Case Two :(Irradiation Variation)

Even if a controller's MPPT tracking efficiency is excellent in a fixed state, it can significantly decrease when exposed to rapidly changing environmental conditions, particularly when there is irradiation. Therefore, it's crucial to evaluate performance even in constantly shifting surroundings. This section talks about the environmental conditions that change almost daily, with the temperature remaining constant, but the irradiance changing constantly. The profile for this scenario is depicted in Figure 4.5. It's worth noting that the variation occurs between a low irradiation level of 500 W/m2 and the highest possible irradiation level of 1000 W/m2. Additionally, the temperature is maintained at Standard Test Condition (STC) levels of 25C during irradiation variations.

Based on the information provided, it appears that the Hybrid ALO and PSO algorithm MPPT controllers are superior to other MPPT controllers, including conventional P&O, IC, and MPPT-based PID algorithm, in terms of their ability to quickly track the maximum power point (MPPT) despite rapidly varying irradiation. These controllers also have minimal period, lower ripple, and do not exhibit oscillation or overshoot.

The figures mentioned (4.6, 4.7, and 4.8) likely show the responses of the various MPPT controllers to changes in irradiation, with PV current, voltage, and maximum power plotted as functions of time or irradiation intensity. Based on these plots, it appears that the Hybrid ALO and PSO algorithm controllers are able to more accurately and quickly adjust the system to changing irradiation conditions, resulting in higher power output and more stable operation.

Overall, this suggests that the Hybrid ALO and PSO algorithm MPPT controllers may be a good choice for applications where rapid and accurate MPPT is critical, such as solar power generation systems. However, it's important to note that the specific performance of these controllers may depend on various factors, including system design, environmental conditions, and other application-specific factors.

based on the information provided, it appears that the proposed MPPT approach using ALO-PSO was successful in tracing the commanded PV currents and voltages with lower ripple and maximum undershoot compared to the traditional-based MPPT. Additionally, the proposed MPPT controller was able to monitor and respond to changes in irradiation levels, which traditional and intelligent MPPT controllers may not be able to do effectively. Overall, the suggested MPPT controller was able to maintain the set-point and prevent the system response from straying from it, which is a desirable outcome in photovoltaic systems.

Figure 4.9 demonstrates that the proposed ALO-PSO approach has successfully achieved maximum power point tracking without oscillation and with a higher steady state compared to other approaches. This means that the proposed approach was able to efficiently locate and maintain the optimal operating point of the photovoltaic system without any unnecessary oscillation or fluctuations. This is a desirable outcome as it helps to maximize the power output of the system while also maintaining stability and reliability.

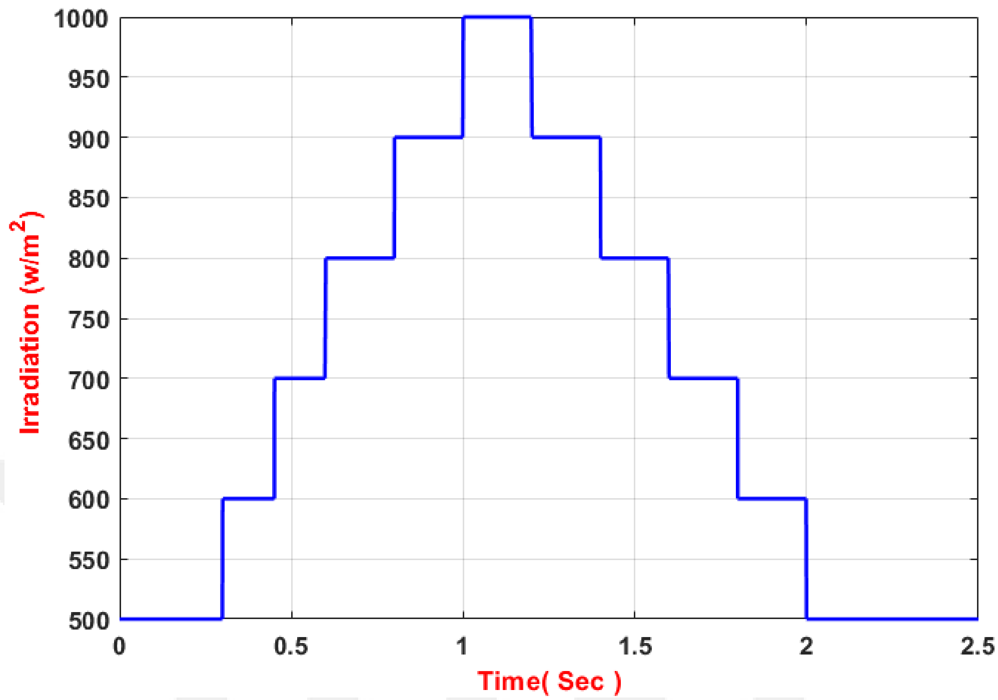


Figure 4.5 non-uniform irradiance

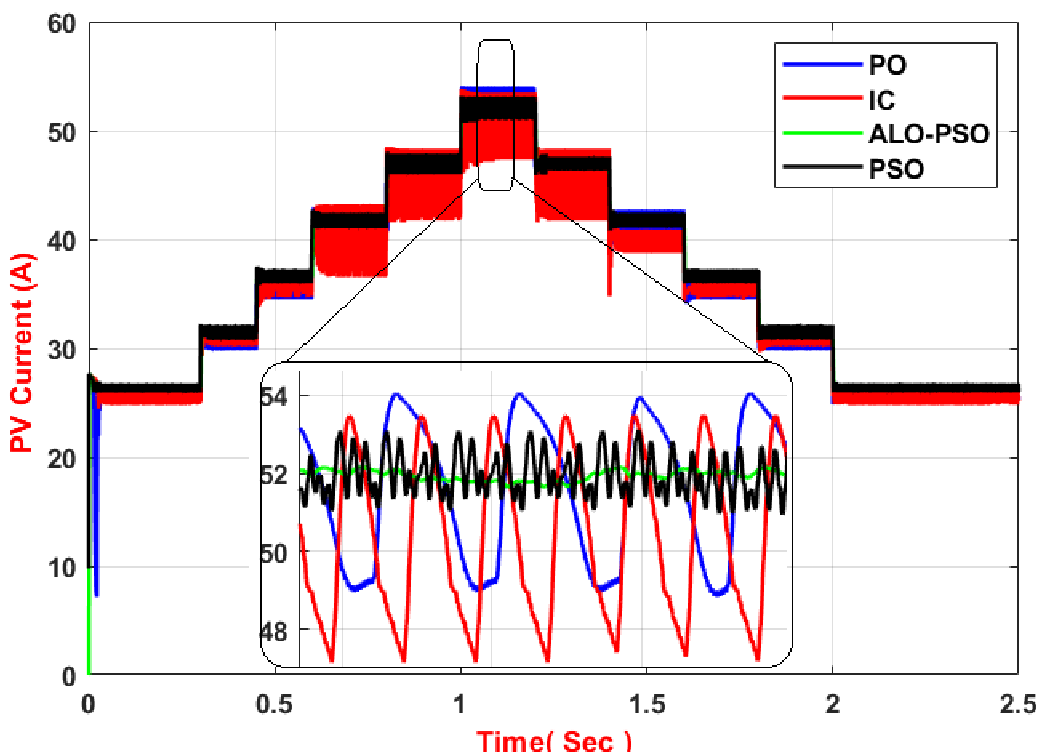


Figure 4.6 the dynamic response of the PV current under variation irradiation &constant temperature

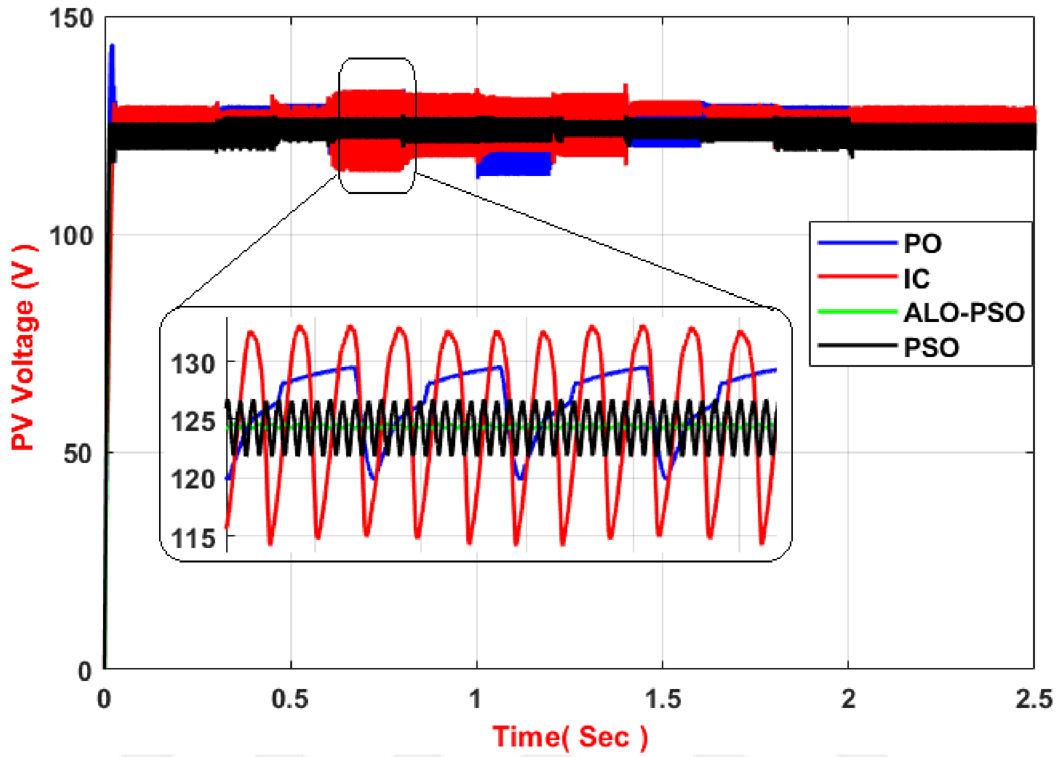


Figure 4.7 the dynamic response of the PV voltage under variation irradiation &constant temperature

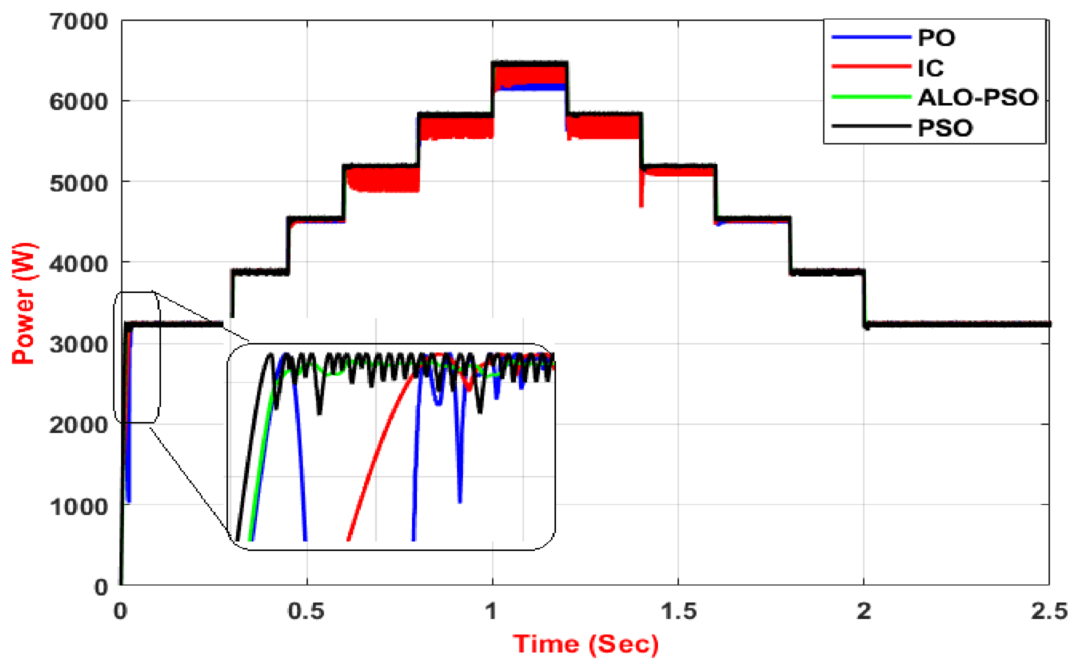


Figure 4.8 the dynamic response of the PV power under variation irradiation &constant temperature

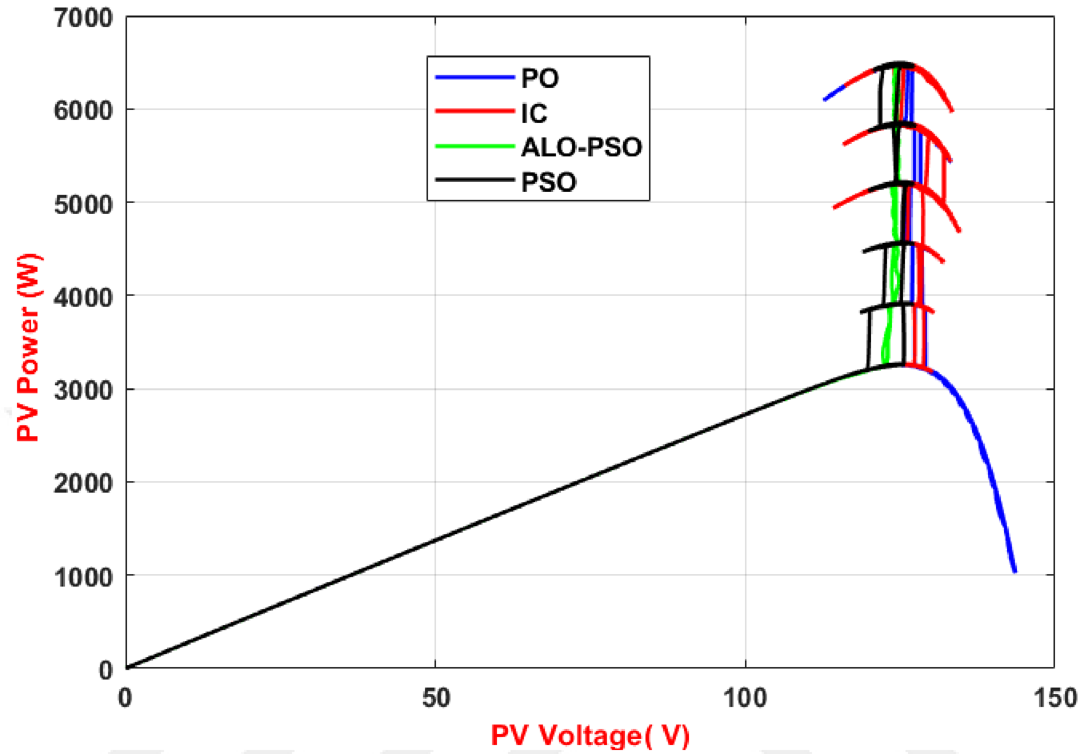


Figure 4.9 The P-V curve under variation irradiation &constant temperature

4.3 Temperature Variation

the temperature fluctuations did not have a significant impact on the performance levels of the MPPT controllers. This suggests that the proposed ALO-PSO approach is robust and effective in maintaining optimal power output even under varying temperature conditions. Figures 4.10, 4.11, and 4.12 further demonstrate that the proposed ALO-PSO controller has a lower undershoot than traditional-based MPPT controllers. This indicates that the proposed approach is able to more accurately track the maximum power point and prevent the system from deviating too far from the set-point. Additionally,

Figure 4.13 demonstrates that the proposed ALO-PSO approach still offers minimal ripple and the least amount of energy loss under daytime heat conditions. This suggests that the proposed approach is able to maintain stable and efficient power output even under challenging temperature conditions. The MPPT responses obtained for the PV array power and the P-V curve further support this, as they do not show significant variations in performance in response to temperature variations. This indicates that the proposed approach is robust and effective in maintaining optimal power output even under varying temperature conditions, which is an important factor in ensuring the reliability and longevity of photovoltaic systems.

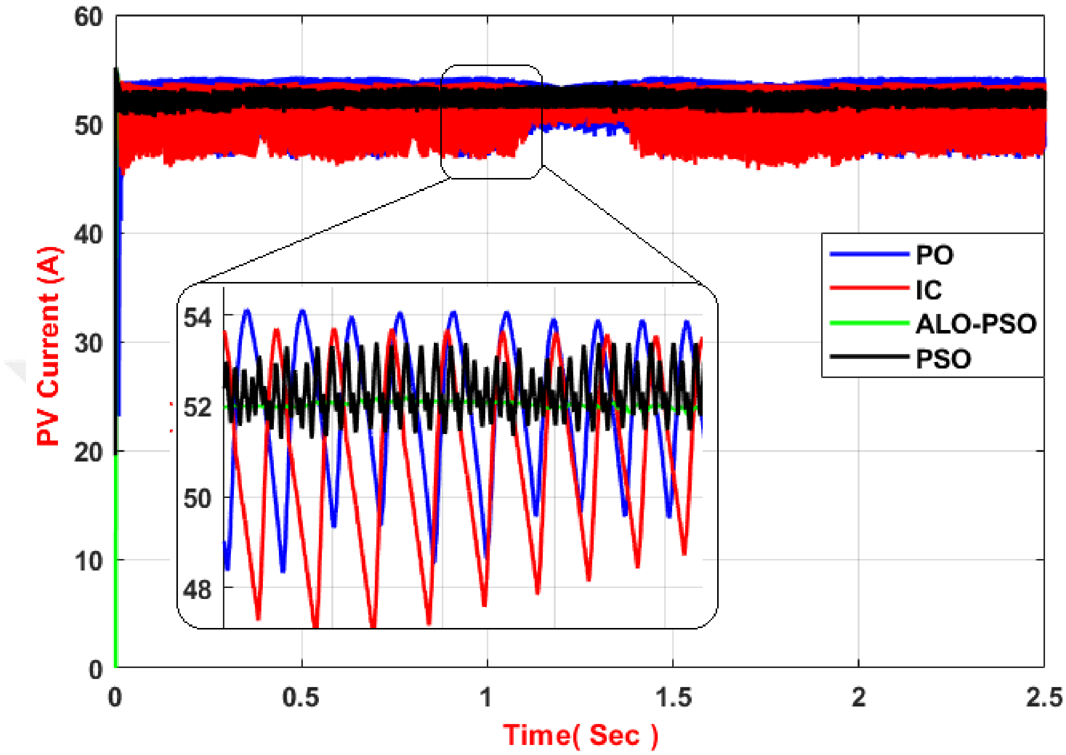
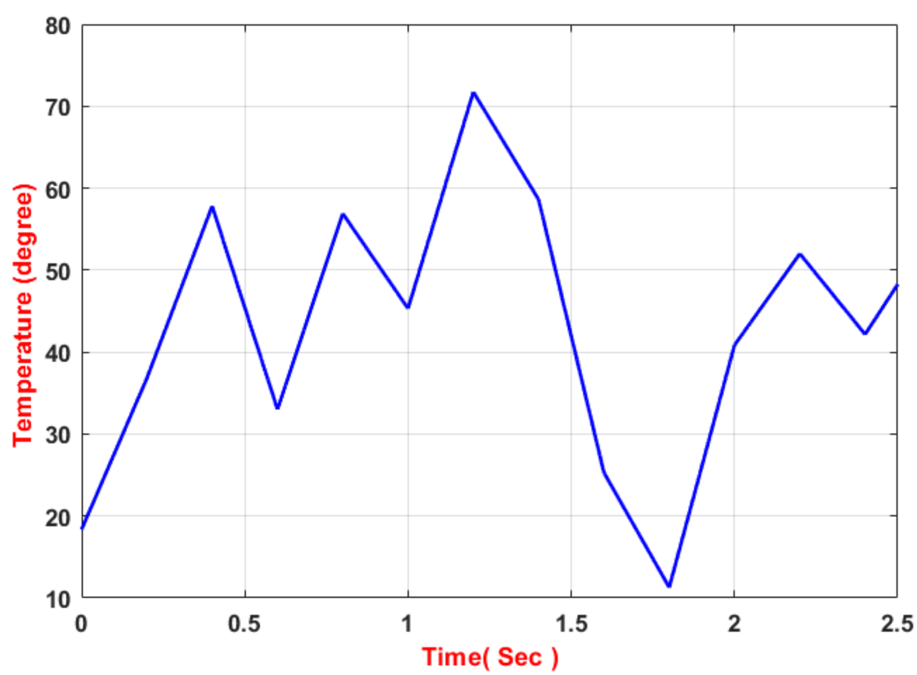
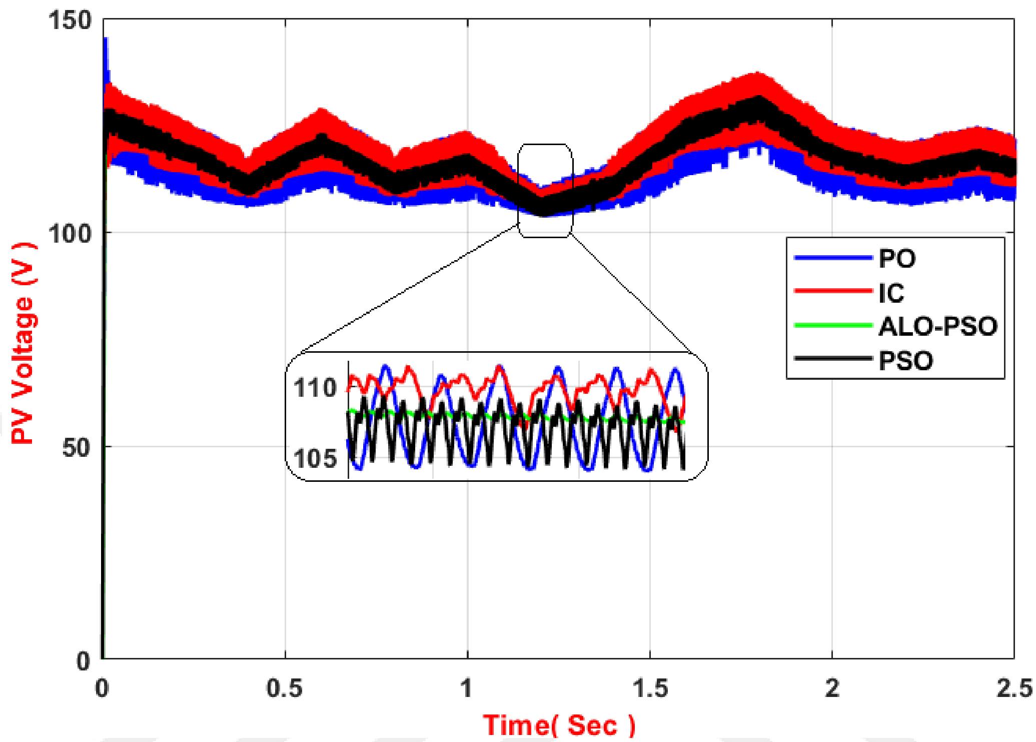


Figure 4.10 the dynamic response of the PV current under variation irradiation &constant temperature



(a) Temperature profile



(b)PV voltage

Figure 4.11 the dynamic response of the PV voltage under variation irradiation &constant temperature

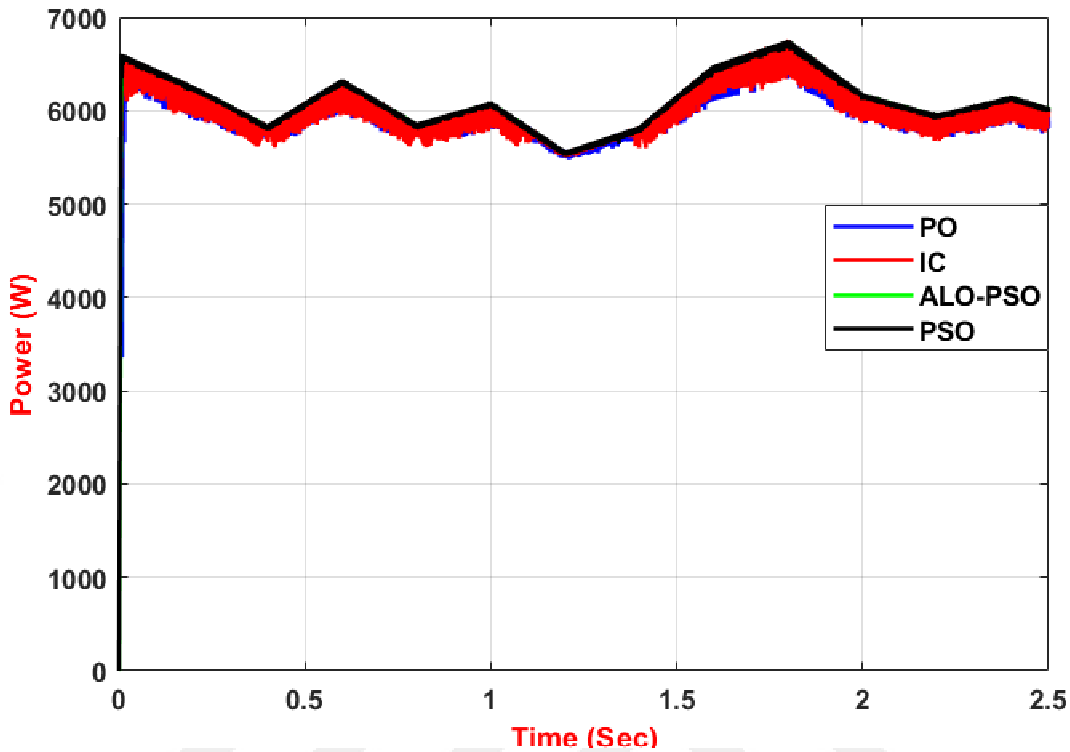


Figure 4.12 the dynamic response of the PV power under variation irradiation &constant temperature

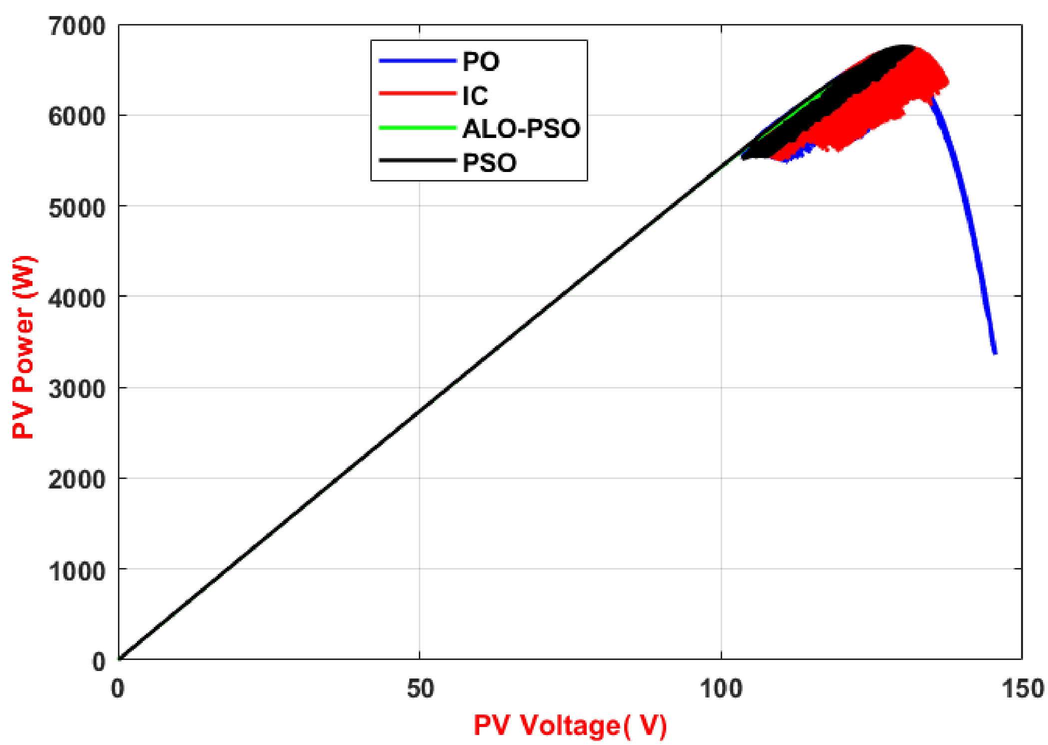


Figure 4.13 the P-V curve under variation irradiation &constant temperature

4.4 Simultaneous Variations of Temperature and Irradiation

which is able to effectively track and maintain the optimal power output even under unpredictable and abrupt changes in irradiance and temperature. Figures 4.14 and 4.15 demonstrate the complex and varied nature of the test profile, which includes both gradual and abrupt changes in environmental conditions. Despite this challenging profile, the proposed ALO-PSO approach is able to achieve the least amount of undershoot and quick tracking to random changes in temperature and irradiance, as demonstrated in Figures 4.16, 4.17, and 4.18. These results suggest that the proposed ALO-PSO approach is a robust and effective method for achieving maximum power point tracking in photovoltaic systems under a wide range of environmental conditions, even when these conditions are unpredictable and varied. Overall, the findings presented in these figures provide strong evidence for the efficacy of the proposed ALO-PSO approach and highlight its potential for improving the performance and reliability of photovoltaic systems.

The findings presented in Figure 4.19 demonstrate that the proposed ALO-PSO based MPPT controller causes a significantly smaller ripple for steady-state conditions compared to the other MPPT controllers. This is particularly evident in the magnified region, where the ripple in the proposed ALO-PSO based MPPT controller is almost negligible. This suggests that the proposed approach is able to maintain a more stable and consistent power output under steady-state conditions, which is an important factor in ensuring the reliability and longevity of photovoltaic systems. Additionally, as mentioned, the proposed MPPT approach also has a better response than the other MPPT approaches, further supporting its efficacy and potential for improving the performance of photovoltaic systems. Overall, these results provide strong evidence for the superiority of the proposed ALO-PSO based MPPT controller, particularly under steady-state conditions.

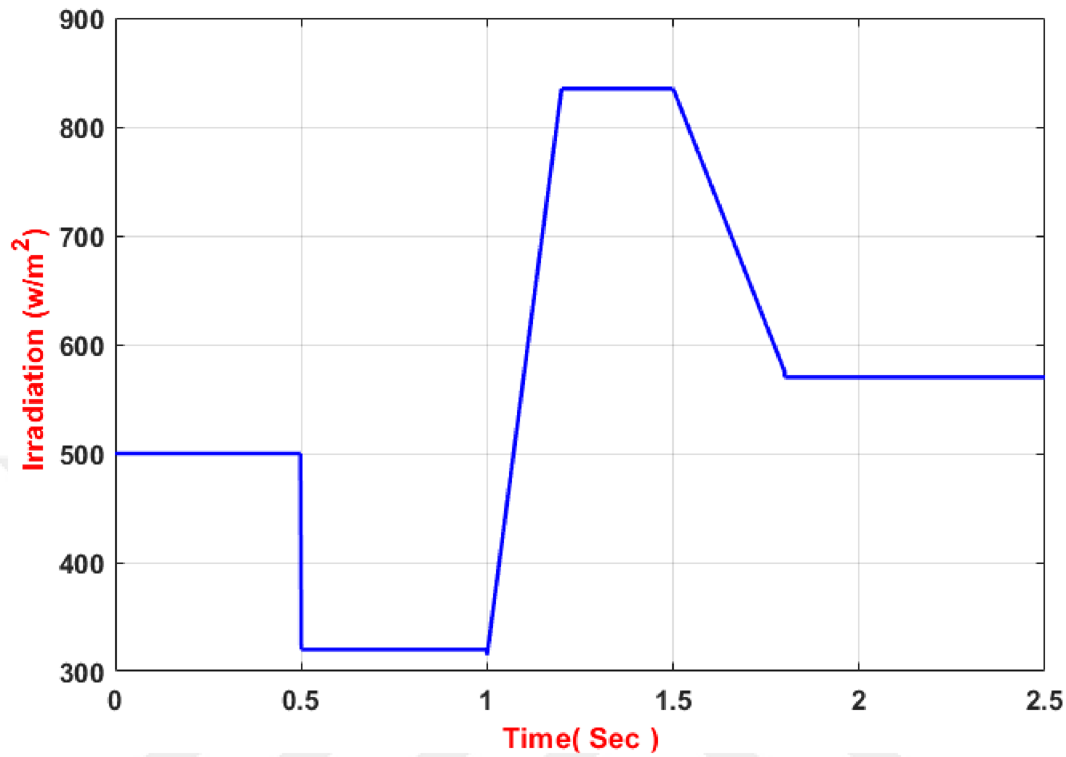


Figure 4.14 Profile of irradiance

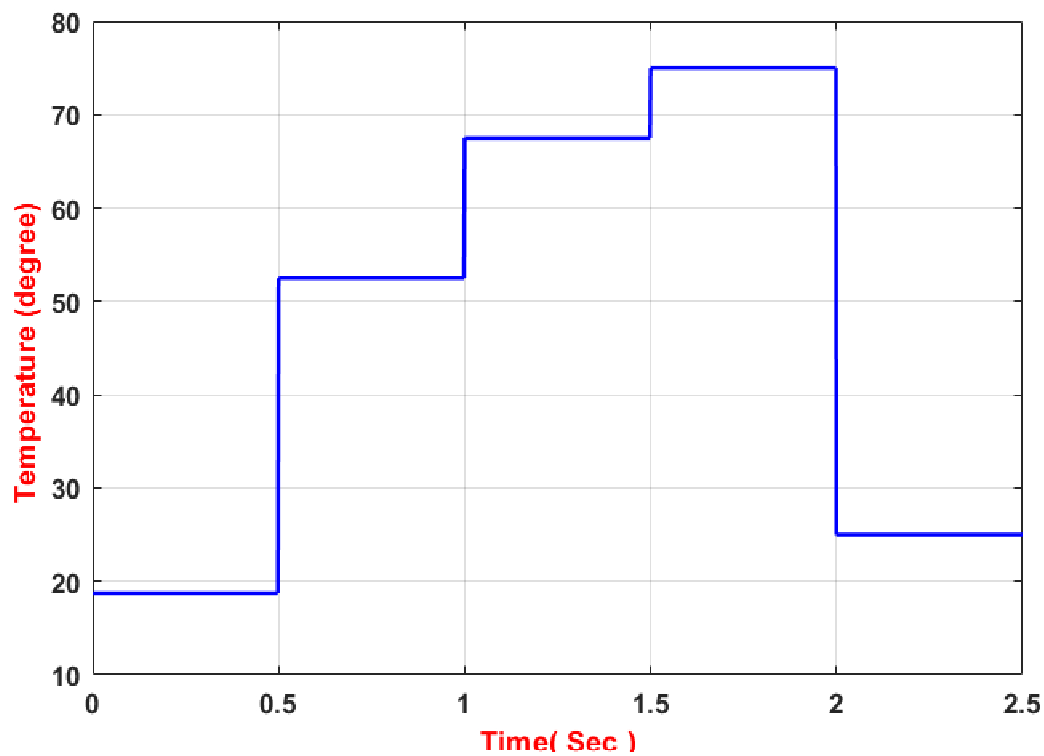


Figure 4.15 Profile of variable temperature

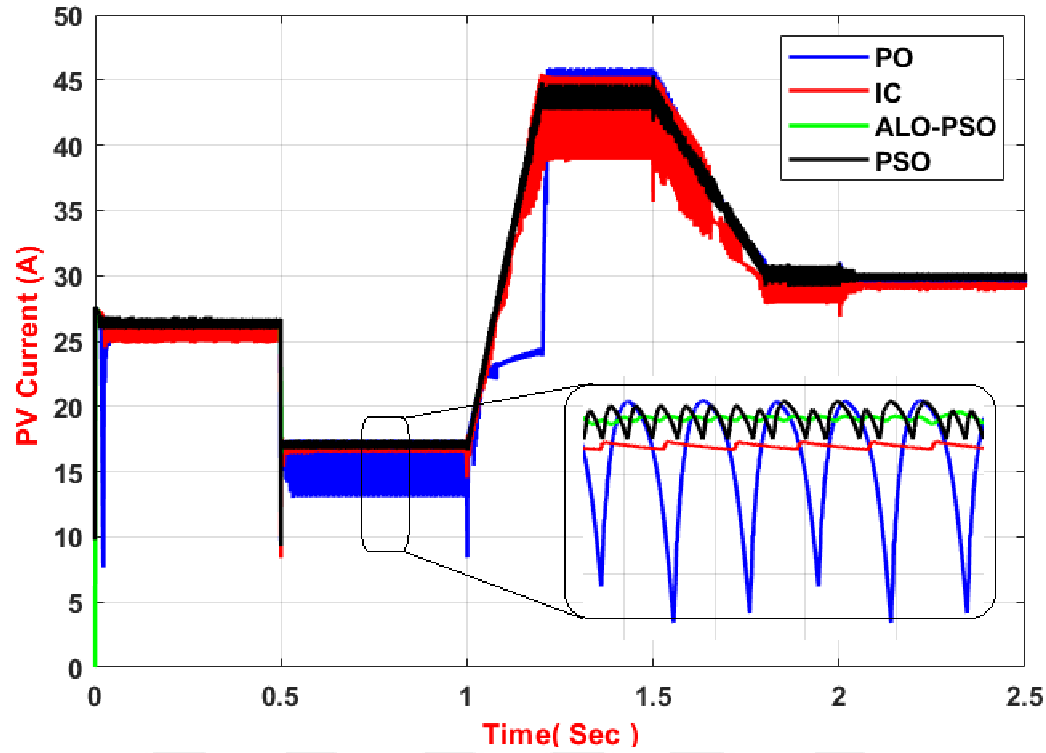


Figure 4.16 dynamic response of the PV current under variation temperature &irradiance

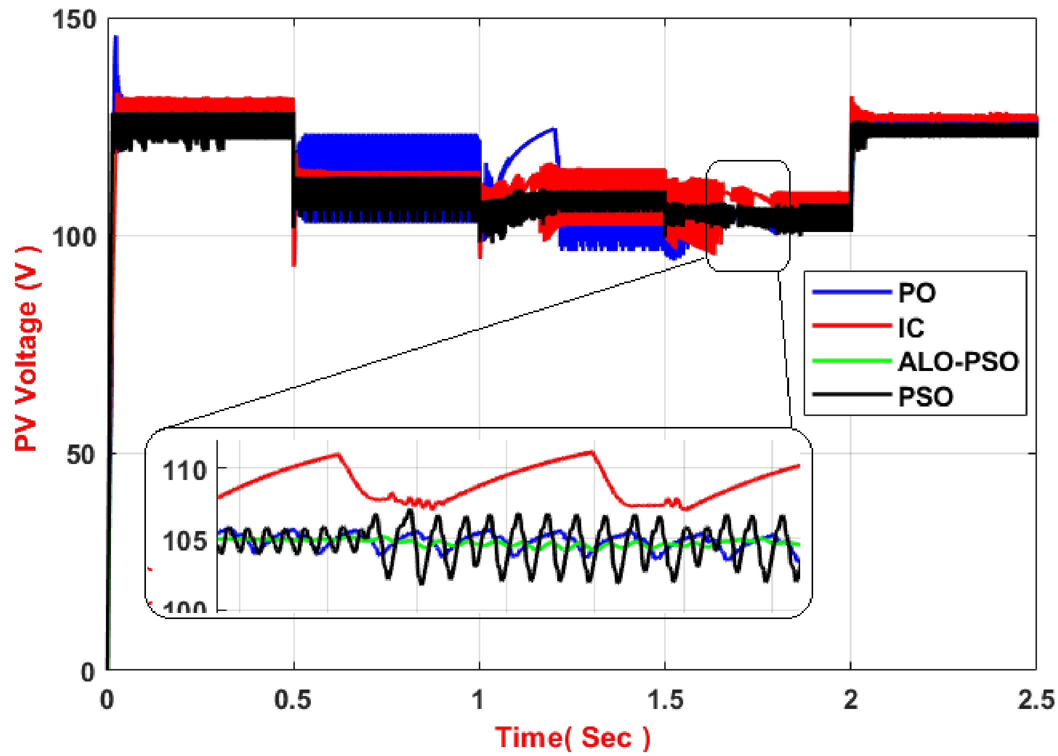


Figure 4.17 dynamic response of the PV voltage under variation temperature &irradiance

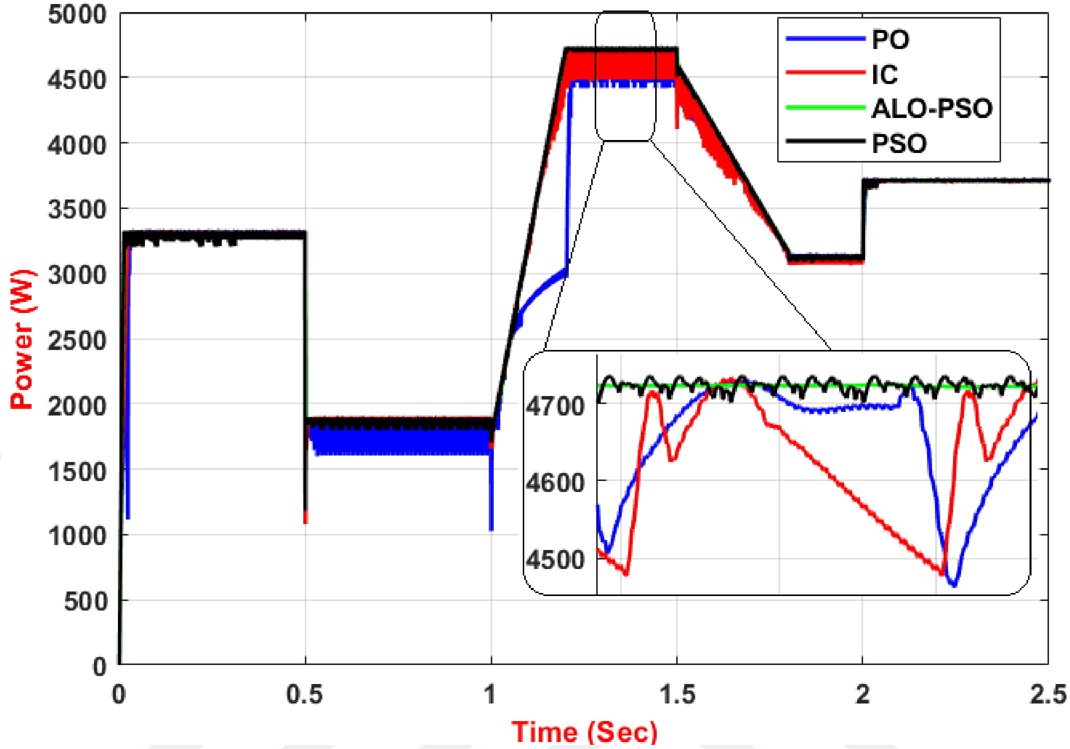


Figure 4.18 dynamic response of the PV power under variation temperature &irradiance

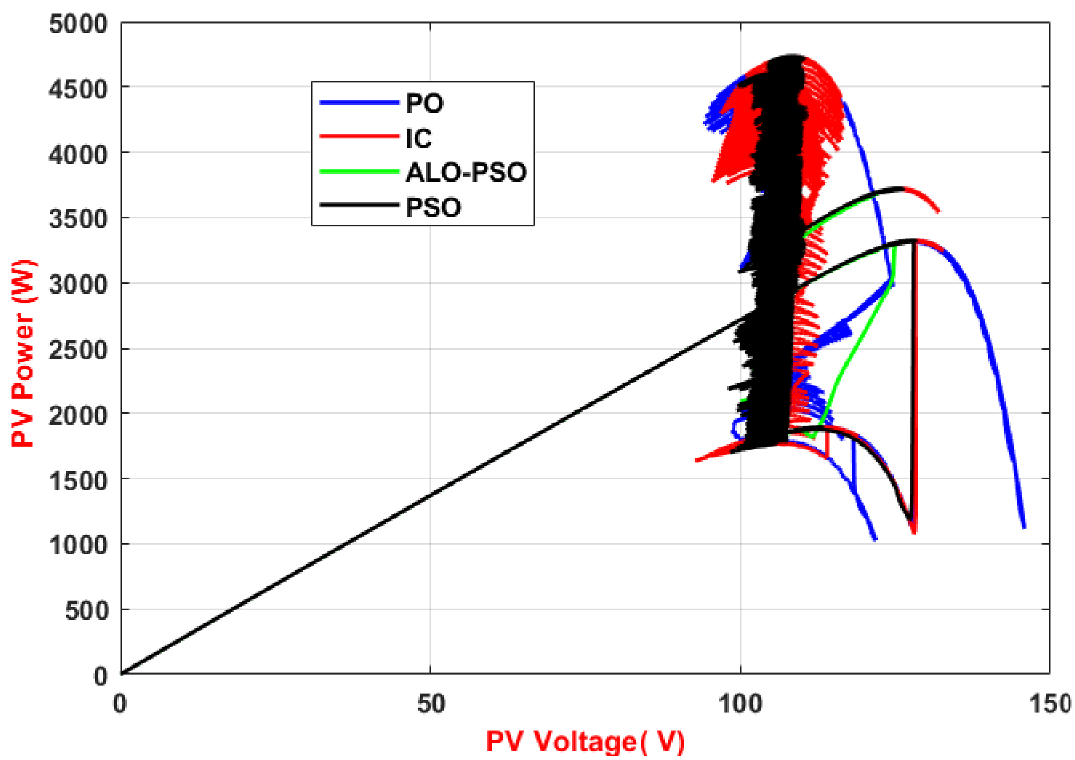


Figure 4.19 P-V curve under variation temperature &irradiance.

The use of various performance indices in the tests provides a comprehensive assessment of the behavior of the proposed ALO algorithm compared to other algorithms under different operating conditions. These indices allow for a quantitative evaluation of the numerical performance of the algorithms, which can be useful in determining the strengths and weaknesses of each approach.

In particular, the analysis of the hybrid electronic speed control system that uses the proposed ALO algorithm indicates that it has an outstanding tracking speed. This suggests that the algorithm is able to quickly and accurately respond to changes in operating conditions, which is a crucial factor in ensuring the efficiency and reliability of the system. Additionally, the results show that the proposed ALO algorithm performs significantly better in terms of both efficiency and power quality performance compared to conventional algorithms. This suggests that the proposed approach has the potential to significantly improve the overall performance of electronic speed control systems, which could have important practical implications in a range of applications.

CONCLUSION

The use of the maximum power point tracking (MPPT) technique is essential for maximizing the output power of a photovoltaic (PV) system. This technique helps the system to operate at the maximum power point (MPP) of the PV array, which is the point at which the array produces the highest amount of power.

In this research, a hybrid Ant lion Optimization Algorithm (ALO) with particle swarm Optimization (PSO) has been proposed for improving the performance and efficiency of the PV system. ALO and PSO are two optimization techniques that are commonly used for improving the performance of PV systems. The boost DC-DC converter is utilized in this research for improving the consistency and dependability of the PV power conversion, particularly during rapid shifts in weather conditions. A boost converter is a type of DC-DC converter that increases the voltage of the input signal to a higher level. The boost DC-DC converter has several advantages over the conventional boost converter. For example, it provides a higher output voltage, which is useful for applications that require a higher voltage level. It also has a lower input current ripple, which results in better efficiency and stability.

The following summarizes the study scope, significant contributions, and conclusions.

1- The study proposes a hybrid optimization approach that combines the Ant lion Optimization Algorithm (ALO) with Particle Swarm Optimization (PSO) to enhance the performance of a PV system. The hybrid approach is shown to have better convergence speed, accuracy, and stability than traditional optimization methods.

2- The study introduces a boost DC-DC converter as a more reliable alternative to conventional boost converters for PV power conversion. The boost DC-DC converter is shown to provide higher output voltage and lower input current ripple, resulting in better efficiency, stability, and reliability of the PV system.

3- Additionally, the study highlights that the ALO-PSO-PID hybrid MPPT controller outperforms traditional MPPT controllers such as P&O, IC and PI-based MPPT, and FPIbased MPPT in terms of tracking efficiency, speed, and stability. The proposed hybrid MPPT controller has a simple structure, is easy to implement in real-time, and has robust performance. The study findings demonstrate that the ALO-PSO-PID hybrid MPPT controller is an effective approach for improving the performance and reliability of PV systems.

Recommendations for Future Work

1- Another issue that needs to be addressed is the need for better data collection and monitoring. This will enable researchers to evaluate and compare the performance of different types of MPPT controllers, as well as assess the performance of the PV system under different weather conditions. Additionally, data collection and monitoring will enable researchers to develop an efficient and reliable control strategy for PV systems that can be implemented in the field.

2- Battery storage is an integral part of any PV system. Research into improved battery storage and energy management strategies should be conducted to ensure that the PV system can provide energy over extended periods of time, particularly in cases of short-term power outages.

3- Finally, the cost of MPPT controllers and PV systems must be reduced in order to make them accessible to more people. This can be achieved by increasing the efficiency of the controllers and by introducing new technologies and materials that reduce the cost of production.

4- in order to achieve the optimal operation of a grid-connected PV system. To select the suitable MPPT for a grid-connected system, it is essential to assess proposed strategies through testing and evaluation of their performance.

5- The economic dispatch problem in a PV system must be addressed in order to optimize the performance of a grid-connected system. To select the best MPPT for this purpose, it is necessary to evaluate proposed strategies by testing them and assessing their performance. This will help determine which strategy is most suitable for achieving the optimal power generation of a solar power plant while minimizing the capital cost associated with the system. Therefore, it is essential to test the proposed MPPT strategies with a grid-connected system and analyze their performance in order to choose the best option.

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APPENDICES

Appendix A: Simulink model and matlab code of P&O MPPT strategy

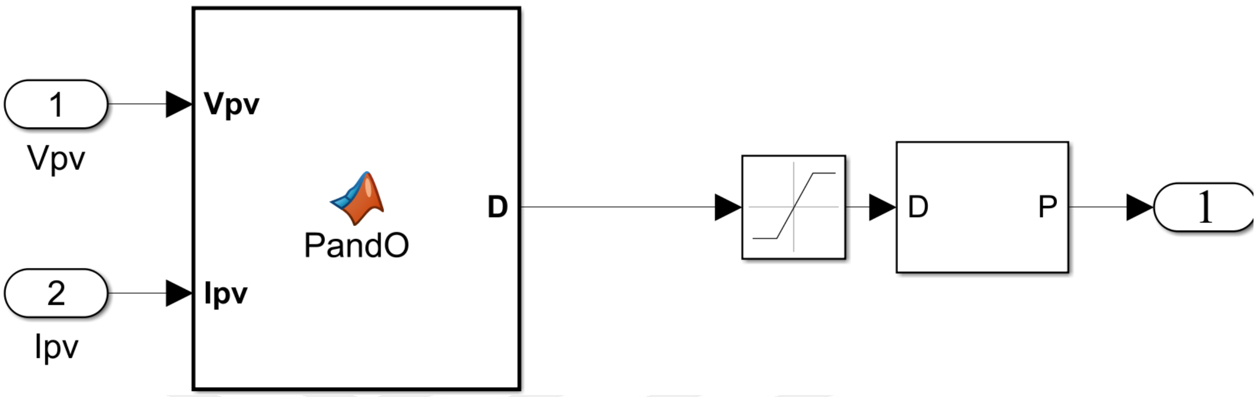

Figure 1. Simulink model of P&O strategy

```
function D = PandO(Vpv,Ipv)

persistent Dold Pold Vold


if isempty(Dold)
    Dold = 0.35;
    Vold = 31;
    Pold = 540;
end


deltaD = 0.003;

Ppv = Vpv*Ipv;

if (Ppv-Pold) ~= 0
    if (Ppv-Pold) > 0
        if (Vpv-Vold) > 0
            D = Dold - deltaD;
        else
```

```
                D = Dold + deltaD;
            end
        else
            if (Vpv-Vold) > 0
                D = Dold + deltaD;
            else
                D = Dold - deltaD;
            end
        end
    else
        D = Dold;
    end

    Dold = D;
    Vold = Vpv;
    Pold = Ppv;
```

Appendix B: Simulink model and matlab code of IC MPPT strategy

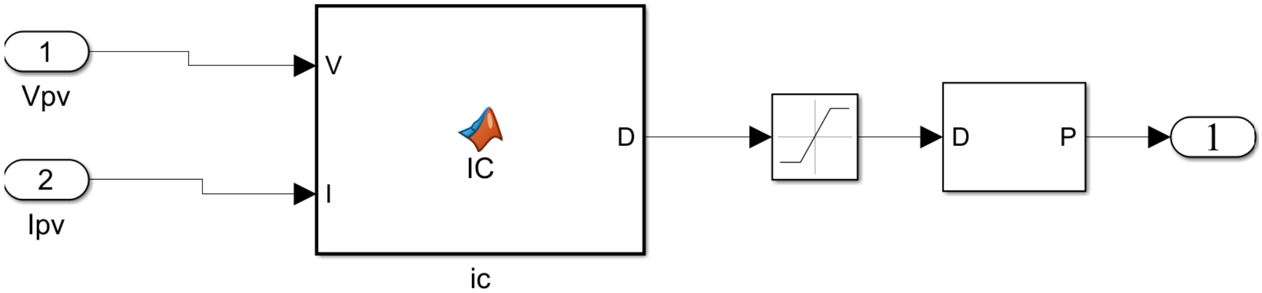

Figure 1. Simulink model of IC strategy

```
function D  = IC(V, I)


Dinit = 0.35;  %Initial value for D output
Dmax = 0.65;   %Maximum value for D
Dmin = 0.05;   %Minimum value for D
deltaD = 0.001; %Increment value used to increase/decrease the duty cycle D


persistent Vold Pold Dold Iold M;

dataType = 'double';

if isempty(Vold)
    Vold=31;
    Pold=540;
    Iold=0;
    Dold=Dinit;
    M=1;
end
```

```
P= V*I;
dV= V - Vold;
dP= P - Pold;
dI= I - Iold;
M=abs(dP);

if M < 0.005
    D=Dold;
else
    if dV == 0
        if dI == 0
            D=Dold;
        elseif dI>0
            D=Dold - (M*deltaD);
        else
            D=Dold + (M*deltaD);
        end
    else
        if dI/dV == -I/V
            D=Dold;
        elseif dI/dV>-I/V
            D=Dold - (M*deltaD);
        else
            D=Dold + (M*deltaD);
        end
    end
end

if D >= Dmax | D<= Dmin
    D=Dold;
end

Dold=D;
Vold=V;
Pold=P;
Iold=I;
```