REPUBLIC OF TURKEY

ALTINBAŞ UNIVERSITY

Institute of Graduate Studies

Electrical and Computer Engineering

MPPT SYSTEMS SIMULATION AND ALSO DESIGN MICRO CUBE SATELLITE APPLICATION

Khalifa Mohamed Khalifa SHAOUT

Master's Thesis

Supervisor

Prof. Dr. Galip CANSEVER

Istanbul, 2022

MPPT SYSTEMS SIMULATION AND ALSO DESIGN MICRO CUBE SATELLITE APPLICATION

Khalifa Mohamed Khalifa SHAOUT

Electrical and Computer Engineering

Master's Thesis

ALTINBAŞ UNIVERSITY

2022

The thesis titled MPPT SYSTEMS SIMULATION AND ALSO DESIGN MICRO CUBE SATELLITE APPLICATION prepared by KHALIFA MOHAMED KHALIFA SHAOUT and submitted on 20/05/2022 has been **accepted unanimously** for the degree of Master of Science in Electrical and Computer Engineering.

____

Prof. Dr. Galip CANSEVER

Supervisor

Thesis Defense Committee Members:

Prof. Dr. Galip CANSEVER	Faculty of Engineering and Architecture, Altinbas University	__________________
Asst. Prof. Dr. Doğu Çağdaş ATİLLA	Faculty of Engineering and Architecture, Altinbas University	__________________
Asst. Prof. Dr. Levent UCUN	Faculty of Control and Automation Engineering, Yıldız Technical University	__________________

I hereby declare that this thesis meets all format and submission requirements of a Master’s thesis.

Submission date of the thesis to Institute of Graduate Studies: ___/___/___

I hereby declare that all information data presented in this graduation project has been obtained in full accordance with academic rules and ethical conduct. I also declare all unoriginal materials and conclusions have been cited in the text and all references mentioned in the Reference List have been cited in the text, and vice versa as required by the abovementioned rules and conduct.

Khalifa Mohamed Khalifa SHAOUT

Signature

DEDICATION

First I would like to Allah Almighty for the power of mind , health, strength , guidance knowledge and skills to complete this study .This thesis is wholeheartedly dedicated to my beloved father, who have been my source of inspiration, he tells me that" every success in your life will be best gift for me". To my mother, who have been supporting me with the kind and pure love.

PREFACE

I would like to thank my supervisor Prof. Dr. Galip CANSEVER for all support during my study. It's great pleasure to express my deepest gratitude to my friends who have shared with me best moments during my study for the Master degre.

ABSTRACT

MPPT SYSTEMS SIMULATION AND ALSO DESIGN MICRO CUBE SATELLITE APPLICATION

Shaout, Khalifa Mohamed Khalifa

M.Sc., Electrical and Computer Engineering, Altınbaş University,

Supervisor: Prof. Dr. Galip CANSEVER

Date: 05/2022

Pages: 93

The demand for electricity is increasing with the highest measure of all energy consumption worldwide due to overall socio economic growth. The conversion of solar radiation directly into electrical energy using the PV cells possesses a number of important benefits. However, its expert extraction contributes the execution of certain challenges, like fluctuation in energy, high capital, and reduced efficiency in conversion of energy. The inequality among source and load characteristics limits the accessibility of maximum possible power delivery to load, and finally results in considerable loss of power. An electronic circuitry used to match the characteristics of module with respect to maximum power to avoid such power loss is termed as maximum power point tracker (MPPT). Modern literature discloses that the efforts in research aims in enhancing the power output generated from module by means of MPPT. The major contribution of this research is the development of a hybrid Bat-Cat optimization tuned Sugeno fuzzy Logic controller (BT-CT-based sugeno FLC) for the optimization of MPPT in the hybrid energy systems. The proposed BT-CT optimization algorithm inherits the characteristic features of placenta mammals and the tracing cats in such a way to balance the trade-off between the phases, such as exploration and exploitation. In other words, the proposed optimization algorithm helps in achieving the Maximum power point (MPP) by attaining the global optimal solution. The system model of the

proposed setup comprise of PV array, Boost converter, RL filter, Inverter, Bidirectional DC-DC control, battery control, in addition with the proposed optimization tuned controller. The efficiency of the proposed method of MPPT is analyzed for different irradiance levels by maintaining constant temperature. The results are analyzed in terms of varying reference voltage and population size in such a way to reveal the performance of the proposed method for different irradiance levels. Finally, the results of the proposed BT-CT-based Sugeno FLC are compared with the existing methods of MPPT in such a way to reveal the superiority of the proposed method in tracking the MPP from PV array. The maximum power tracked using the proposed BT-CT-based Sugeno FLC is 7600W, even at varying irradiance levels.

Keywords: Maximum Power Point Tracker, Hybrid Energy Systems, Fuzzy Logic.

TABLE OF CONTENTS

Pages

LIST OF FIGURES

Pages

ABBREVIATIONS

ML	:	Machine Learning
NLP	:	Natural Language Processing
MPPT	:	Maximum Power Point Tracking
FLC	:	Fuzzy Logic Controller
MPP	:	Maximum Power Point
PID	:	Potential Induced Degradation
INC	:	Incremental Conductance
HHO	:	Harris Hawkins Optimization
PSO	:	Particle Swarm Optimization
EKF	:	Extended Kalman Filter
RFA	:	Random Forest Algorithm
CSO	:	Cat Swarm Optimization
MPSO	:	Modified Partical Swarm Optimization
ACO	:	Ant Colony Optimization

1. INTRODUCTION

During the current decade, the raising energy demand due to the population exploitation is one of the most significant issues all over the world. It is stated that 85% of the total energy demands are satisfied through the non- renewable resources, such as fossil fuels. Now-a-days, there is depletion in the traditional sources of energy, such as coal, crude oil and fossil fuels due to the over exploitation of the human beings. Furthermore, the utilization of these fossil fuels results in the emission of green house gases, such as carbon, sulfur oxide, nitrous oxide and methane [19], [20], which threatens all the living organisms both physiologically and economically [22] [21] [9]. The awareness about the environment and the enhancing energy demand results in the replacement of the conventional non-renewable energy with the sustainable energy, such as solar energy, tidal energy, geo-thermal energy, wind energy, and so on [23][24][25][26][4]. These sustainable energy are both eco-friendly and cost-efficient as it never diminishes and is safer to the environment. Among all the sources of energy, solar energy is considered as the dominant source among the sustainable energy due to its simplicity and diverse applications.

1.1 SOLAR ENERGY

The solar energy is one of the sustainable resources of energy, which is obtainable anywhere and it is available from the sunrise to sunset. The solar energy is the eco-friendly source of energy as it does not emit any harmful gases. The solar energy is one of the better replacements of the traditional fossil fuels as it reduces the air pollution to the greater extent. The reduction in air pollution further reduces the acid rain formation, respiratory ailments and soil destruction. The emissions are also greatly reduced by the solar system as it does not emit any harmful gases, such as CO2. Moreover, the solar energy possesses the maximum power density among all the sustainable resources [28]. Additionally, the life span of the solar plant is more than 25 years and on the other hand, it is interesting to note that the lifetime of the solar plant can be extended to 100 years with the aid of some technical advancements [29] [27]. One of the best options for preserving the solar energy can be done from the roof top of the buildings and house, which makes them available till the presence of sunlight [18]. Hence, the solar energy plays a vital role in energy distribution.

Some desired characteristics of the solar energy that makes them dominant among the other sustainable energies are enlisted below:

i. The technological escalations adapted in the solar energy results in the enhancement of efficacy of the solar energy.
ii. The solar energy is more sustainable than the other renewable resources, such as wind energy and hydro power energy.
iii. The low maintenance is yet another desired characteristic of the solar energy, which makes them dominant among the other energy sources.
iv. The solar energy does not induce carbon dioxide, dust or any toxic gases, which is responsible for the environmental pollution as it is a spotless energy resource.
v. The minimum carbon foot print, low maintenance and uncomplicated installation are the desired qualities that increase the efficiency of the system [30].
vi. The solar energy can be integrated in the roof-top of the buildings thus it reduces the area of installation. The hydro power and the wind power require more area for installation.
vii. It is applicable for the large scale industries as it reduces the maintenance cost and the electricity bills.

Due to the aforementioned features, the solar system is widely utilized in various applications mainly, in the household appliances, telecommunication, water pumping stations, and charging stations [31] [33] [34] [84]. Yet, there are some limitations in the Solar system, which drives them to adapt the dynamic PV cells, are elaborated below.

i. The main drawback of the solar energy is that it can generate the electricity in the presence of sunlight only, which may cause the energy shortage during the monsoon and the cloudy days [3].
ii. The proper utilization of the solar energy is the main concern as the solar system generates the solar power only during the sunny days. Hence, accumulating the excess electricity generated by the solar system in the daytime is the pre-requisite of an efficient solar system.
iii. The high installation cost is also the main drawback of the solar system, which can be reduced by the efficient grid system.

Thus to overcome the limitation of the traditional solar system the Photovoltaic cells, which provides strong non-linear characteristics are implemented in the solar system.An efficient power grid reduces the power dissipation in the solar system and it provides the uninterrupted power supply regardless of the climatic conditions. Hence, an economical and eco-friendly power grid system is utilized in Photovoltaic (PV) systems in order to obtain uninterrupted power supply [7]. In the grid system, the surplus energy generated by the solar power is collected and reserved in the grids. An inverter is utilized in this system so as analyze frequency, voltage and the waveform.

In the power system, power grids play a prominent role and render the cost effective Stand-alone systems in contrast to the power cables [34]. While comparing with distinct power source the Hybrid stand-alone systems are more energy efficient [35]. In stand-alone systems, the PV system is the substantial energy source [36]. A amalgamated PV battery that depends on the diesel is utilized for the field where the solar radiation is curtailed in the winter season. [34] [2].

1.2 CATEGORIZATION OF THE SOLAR ENERGY

The solar energy is generally characterized into two different categories, such as passive solar and the active solar energies [37] with respect to the gathering and distributing capacity of the solar panels. The active solar energy comprised of the utilization of photovoltaic system [38], and the concentrated solar power to enhance the energy efficiency of the system.

As mentioned-before, the photovoltaic is one of the leading techniques, which are used to generate the electric power with the aid of solar cells. The photovoltaic based Solar system is an eco-friendly system, which restrains the emission of the green house gas in great extent. Furthermore, due to the advancements in the solar system reduce the maintenance cost and the operating cost in a great extent. The high energy demands are also manipulated through the PV solar system as it reserves the surplus of energy from the solar panels.

The solar energy perforation level is enhanced with the photovoltaic system. The photovoltaic system comprised of solar panels consolidated with regulator and other hardware. The PV system is one of the pre-eminent methods utilized in the solar panels to generate the electric power by utilizing the solar cells. On the other hand, the solar tracking system is utilized in the PV system to enhance the overall system performance. The PV solar system contributes with 1% of the total electricity generation all over the world and it is expected that by 2020, more than 45% of total energy demands are satisfied through the energy generated from the PV solar system [39] [1]. Hence, the solar PV system becomes the significant research topic, which mitigates the environmental demolition. Though the PV system posses some advantages, they experience some critical issues, such as fault diagnosis, energy efficiency and rate of return issues. There are two main issues to be resolved in the PV solar system: the primary issue is that the solar system relies on the various environmental conditions for tracking the maximum power point. The environmental conditions [40][41] [1], such as temperature, shadows, dirt, sunlight and spectral of sunlight influence the characteristic features of the PV Solar system, which in turn degrades the production of the system. The Potential Induced degradation (PID) [42] is yet another issue, which delimits the performance of the solar PV systems. The voltage variation is the main reason for the PID issues, which can be restrained through the proper grounding of the negative pole of the inverter. The proper energy storage system is required to store the excess energy generated through the PV systems in order to utilize these excess energy in the near future. Furthermore, in the PV solar system, the electricity generated is in the form of DC supply and need to be converted to the AC supply [43]. The conversion process reduces the efficiency of the system and thus, requires power optimization so as to reduce the performance degradation due to the conversion.

1.3 ARCHITECTURE OF THE SOLAR PV SYSTEM

The architecture of the PV solar system [44] is demonstrated in the figure 1.1. The framework consists of the photothermic module, photovoltaic modules, Electric storage units, and the distribution system.

1.3.1 Photothermic Module

Photothermic module is utilized to convert the light energy from the solar energy into heat energy. The solar convectors, such as parabolic trough, compound parabolic and the evacuated tubes are considered as the convectors that generate the heat energy.

1.3.2 Photovoltaic Module

The solar light is gathered from the sun and these gathered solar lights are utilized to produce the electricity. The traditional silicon solar is the widely-used photothermic module, which posses the efficiency of about 25% and it is not suitable for curved surface. The thin film solar module is the advanced solar modules that are flexible, but they suffer from limited lifetime and low efficiency.

1.3.3 Inverter

The energy generated from the sun is always in the DC power, which is converted into the AC power that ensures the applicability of the solar energy for both household and the business applications.

1.3.4 Electric Storage

As discussed earlier, the solar system generates the electric energy in the presence of sunlight and the excess amount of energy is generated under the sunny conditions. Hence, an efficient battery is utilized in the PV solar grids to store the excess power precipitated from the sunlight. The surplus power generated from the solar system is stored in the photovoltaic cells for the future use.

1.3.5 Distribution System

The well-organized distribution system is required for the proper allocation of the energy generated from the PV solar system to various substations. The reliability and accessibility of the demanded power and proper voltage are the features needed for the better distribution system. The variation of the load is the prime reason behind the voltage fluctuation, which restrains the efficiency of the distribution system.

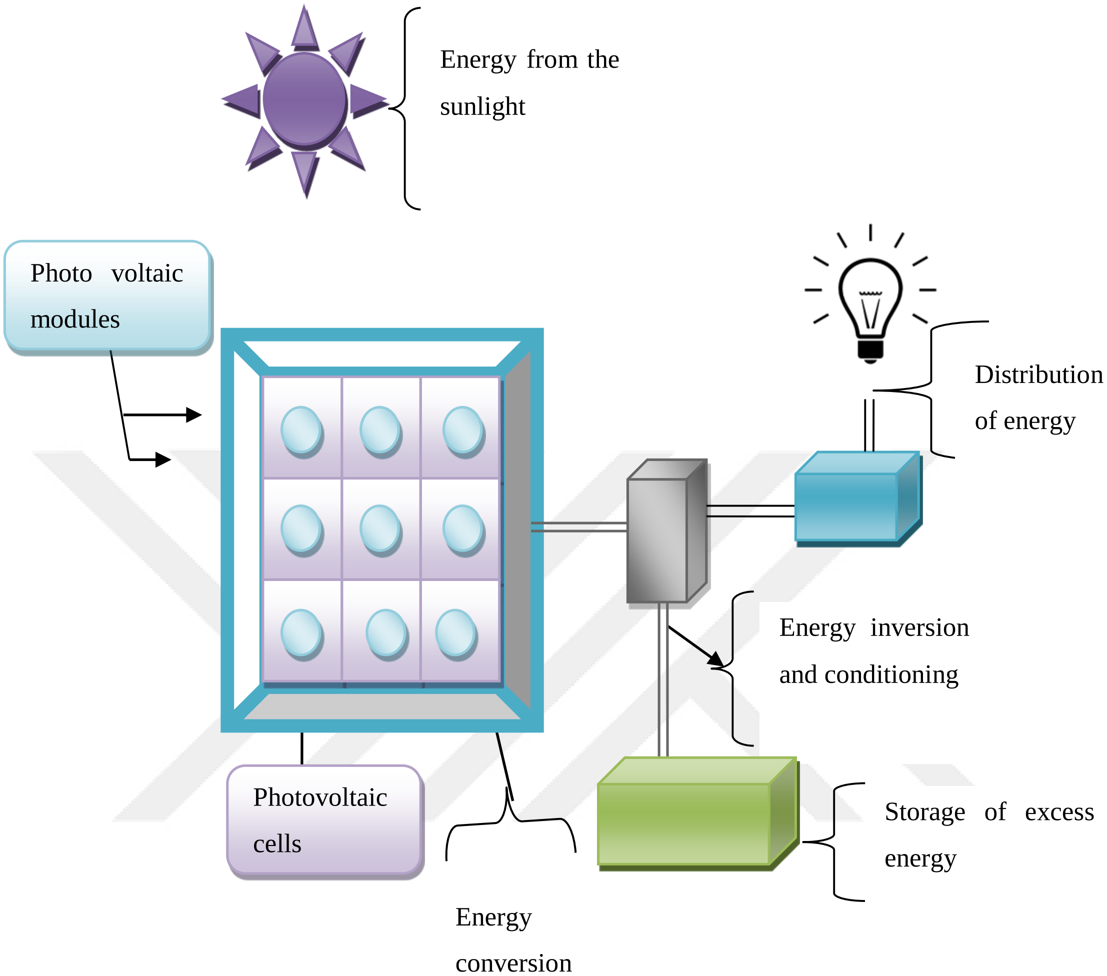


Figure 1.1: Architecture of PV Solar System.

1.4 APPLICATION OF PHOTOVOLTAIC CELLS

Figure 1.2 illustrates the applications of the PV systems. The PV system renders its applications in various domains, such as military application, stand-alone applications, building related applications, solar form and the remote location.

Military application: The portable PV systems are utilized by the soldiers to charge the electric equipment used for their regiments. This portable PV system thus helps the soldiers in the critical situations.

Remote location: The PV system is utilized in the remote location-related applications, such as health clinics, light house, oil platforms and desalinization techniques.

Solar farm: The PV systems are used to generate immense power of about megawatts power with the aid of sun- tracking system.

Stand-Alone power: The PV system is also utilized in stand-alone power systems, such as transmitters, traffic signs, irrigation pumps and parking meters.

Power in space: A well-organized PV system is used to supply power for spacecrafts and the space stations. The PV is also regarded as the power source for satellites, which revolves the earth's orbits.

Building-related requirements: The PV is also installed in the roof-top of the buildings to meet the electricity requirements [45]**.**

It is already discussed that the PV solar energy relies on the various computing position, such as temperature, dirt, irradiance, shadow and the spectral of light [46] [5]. All the above-mentioned issues make the system more complex to work at the maximum output power point. The main challenge in the PV solar system is to attain the equilibrium operating point in which the maximum power point matches the load demands [40][1].Various researchers concentrates to restrain the power loss of solar PV system by determining the maximum power point. Tracking the maximum power point of the PV system is considered as the complex process due to the ambient temperature, solar irradiance and stochastic nature of the load. Therefore, a well-organised tracking controller is required to track the maximum power point (MPP) [47] [6].

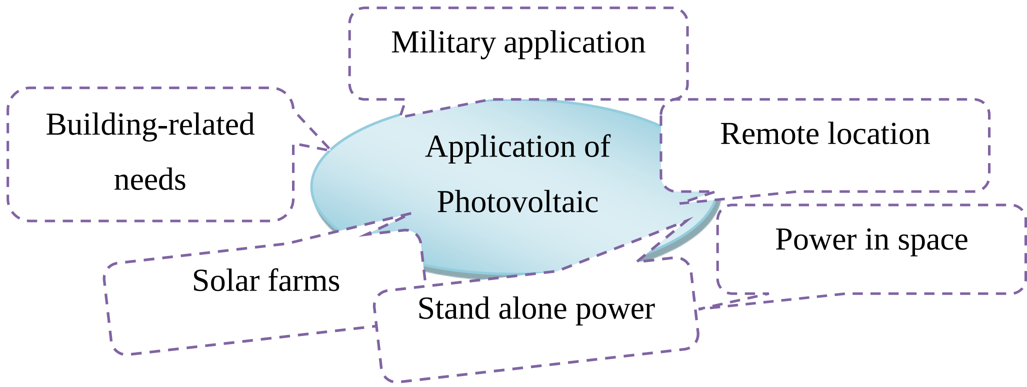


Figure 1.2: Application of Photovoltaic Cells.

The MPPT is the electronic framework, which offers the obligation cycle to the rectifier or the electric converter to the maximum power production [6]. The maximum power point tracking systems are widely categorized into three broad classifications, such as offline technique, online technique and the hybrid techniques [48]. The traditional methods are based on the co-relation between the voltage and the current at the extreme point [49]. The offline methods fail to track the maximum power where there is a variation in the climatic conditions [50]. Hence, to obtain the accurate MTTP the online methods, such as incremental conductance approach (InCond) [53], hill climbing approach [52] and perturbation and observation (P&O) [51] approach are used. Additionally, the artificial techniques such as Fuzzy logic control techniques (FLC), particle swarm optimization (PSO), Fibonacci search techniques, Genetic Algorithm and neural network techniques (ANN) [53]-[58][7] are applied for the MPPT. The Grey wolf optimization is one of the most modernised versions of meta-heuristic algorithm used to track the MPP in [2].

The P&O enhancement procedure is considered as the mainstream technique inferable due to its viability, effortlessness and simplicity of execution. Furthermore, the P&O system is applicable for any PV solar systems as it independent on the properties of the PV systems. The P&O system generally compares the variation in the voltage in accordance to the current to recognize the maximum power. A slight influence is presented in the board voltage in order to accomplish variations in the output power in the PV framework. The yielded power is recorded consistently and compared with the power obtained previously. If the power increases then, the voltage follows the same direction otherwise, the influences will be transferred. The unsettling influence in the voltage is accomplished by the obligation pattern of the DC-DC converter [7]. However, the voltage fluctuations are experienced in tracking the maximum power in the wide-range PV system. The voltage is the main reason behind the power dissipation [59]. An incremental conductance (INC) [60] method is used as an alternative technique to P&O so as to restrain the power dissipation issues. This strategy utilizes steady estimation steps, which makes it conceivable to follow the MPP by estimating the proportion between immediate conductance and INC estimations of the PV framework power. Now-a-days, researchers provide more attention in designing the appropriate MPPT controller [60]-[65]. In the above-mentioned techniques, such as P&O and the INC [69], the practical and the theoretical values are estimated and compared so as to determine the maximum power [66] [67]. On the other side, two MPPT methods called neural and the fuzzy control system [68] are evaluated to obtain the maximum power. The particle Swarm optimization (PSO) [70] is also utilized so as to obtain the optimal power, which leads to enhance the overall efficiency, simplicity and reduce in the cost price. Yet, it fails to achieve better performance at the varying atmospheric conditions [8]. These MPP tracking method fails to produce the accurate results in the partial shading condition.

The intelligence system, such as FLC and GRNN presented for effective tracking MPP under the partial shading condition. Yet the FLC requires the well–structured directives to collaborate with different operating conditions and also to restrain the issues related to the partial shading condition. The Harris Hawkins optimization (HHO) optimization is one of the bio-inspired algorithm presented in [3] for the proper tracking of MPP. The coordination of HHO-based MPPT strategy with PV inverter ideally improves the energy harvesting capacity. Though the HHO enhances the harvesting capacity, it suffers from the drawback, such as low accuracy and the slow convergence rate. To attain the high intermittence area, the hybrid techniques, such as amalgamating the FLC with BAT optimization [5], FLC with Grasshopper optimization [6], FLC with PSOGA are adapted yet the computational complexity makes them unfit for MPP tracking.

1.5 OVERALL RESEARCH QUESTIONS

The research questions are:

i. Enumerate the significance of the hybrid energy system over the PV systems in the power generation.

ii. What is the inspiration behind developing a new sugeno fuzzy controller for the hybrid energy systems.
iii. Whether the in-depth analysis is initiated for the BAT-based sugeno fuzzy controller in the power optimization applications of the PV systems.
iv. What kind of extension would assist the performance boosting criterion of the hybrid energy system when compared with the bat-based FLC.
v. Have the justification of the new controller done with the existing controller for highlighting the importance of the developed model.

1.6 RESEARCH OBJECTIVES

The major objectives of the research include:

i. To study and analyze the need for the hybrid energy systems inspite of the PV systems.
ii. To study and analyze the various power optimization models of the PV systems.
iii. To study and understand the BAT-based sugeno fuzzy controller for power optimization in the PV systems.
iv. To design and develop a BT-CT-based Sugeno FLC for the implementing in the hybrid energy system for enhancing the power optimization capabilities.
v. To implement and justify the effectiveness of the proposed control scheme through the comparative analysis of the developed controller with the existing control schemes.

1.7 CONTRIBUTION OF THE RESEARCH

The major contributions of the system:

i. The research contribution in the hybrid energy system is significantly important for enabling the effective power optimization in the system for which a BT-CT-based sugeno fuzzy logic controller is designed.
ii. The proposed BT-CT-based sugeno fuzzy logic controller is developed through the integration of the proposed BT-CT with the sugeno FLC for optimizing the membership rules, which directly solves the MPPT issue associated with the power optimization.

iii. The proposed BT-CT algorithm is developed through hybridizing the bat and cat characteristics in order to enhance the effective remuneration between the exploration and exploitation phases thereby, improving the global optimal convergence.

1.8 ORGANIZATION OF THE RESEARCH

The organization of the research follows:

The background of the research is discussed in detail along with the working modulo and applications of the system in the chapter 1.

Chapter 2 details the review of the existing methods employed for the power optimization in the PV systems along with the challenges of the existing models. The major gaps of the research are enumerated in the chapter in detail.

Chapter 3 details the motivation behind the research with the discussion on the need for the hybrid energy system and an effective controller for the power optimization of MPPT systems.

Chapter 4 structures the proposed model and discusses the hybrid system with the justification as various case studies.

Chapter 5 enumerates the comparative analysis of the existing systems with the proposed system in order to justify the effectiveness of the developed system in the maximum power optimization of the hybrid energy system.

Chapter 6 concludes the research with the discussion on the main achievements and future dimensions of the research.

2. LITERATURE SURVEY

2.1 INTRODUCTION

The PV solar system is one of the sustainable and eco- friendly energy resources, which is considered as the best replacement for the traditional non-renewable resources. The tracking of the maximum power point is the significant task to be carried out in PV system so as to enhance the power generation of the solar grids. The detailed review of some of the conventional methods used for MPPT is elaborated in this chapter along with the merits and their limitations.

2.2 LITERATURE REVIEW

The Advanced machine learning techniques utilized in the MPP tracking is enlisted below, where the methods enumerate the interaction between the machines and the humans. The machine learning-based MPPT techniques utilized for the review is mentioned in the following categorization chart. Figure 2.1 depicts the categorization chart of the existing MTTP method.

2.2.1 Categorization Chart

The categorization chart demonstrating the various approaches employed for MPPT is demonstrated below.

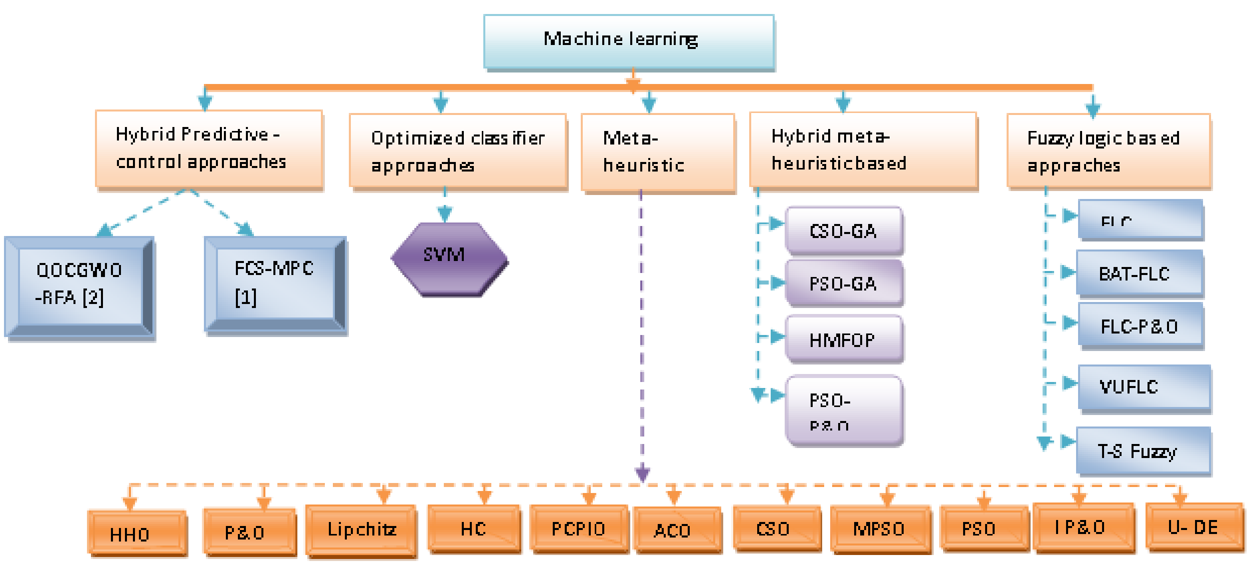


Figure 2.1: Categorization chart of the Existing MTTP Methods.

2.2.2 MPP Tracking Based on Hybrid Predictive Control Approach

Mostafa Ahmed *et al.* [1] extracted the extreme power obtained from the PV source by utilizing the finite control set model predictive control (FCS-MPC) together with enhanced kalman filter (EKF). The integration of FCS-MPC and the EKF increases the robustness and the reliability of the entire system as it restrains the requirements of sensors such as voltage and current. The method promoted the minimal installation and the maintenance cost as it does not possess any sensors. The system exhibits enhanced performance for both the transient state and the steady state. Furthermore, this system yields the higher efficiency and the fast tracking speed than the other traditional techniques at certain operating point. The complexity experienced during the implementation process is the main drawback of the FCS-MPC system.

Arther jain *et al.* [2] preferred a dynamic and efficient hybrid technique in the solar PV array so as to maximize the power of the load. The hybrid technique called QOCGWO –RFA technique is used, which is developed through integrating two well-organized methods, such as Random Forest Algorithm (RFA) and the Quasi Oppositional Chaotic Grey wolf Optimizer (QOCGWO). QOCGWO upgrades the specific obligation cycles needed for the DC-DC converter of SPV dependent on the current and voltage boundaries. RFA is utilized in this research so as to estimate the control signals with respect to the active and reactive power deviations in the voltage source inverter. The main constrains in the PV system, such as external disturbances and the load disturbances are reduced through the QOCGWO-RFA system. The over-fitting of the system requires the appropriate tuning, which is one of the main issues that are experienced in the QOCGWO-RFA system.

2.2.3 MPP Tracking Based on Meta -Heuristic Approach

Majad Mansoor *et al.* [3] utilized an advanced Harris hack optimization (HHO) in order to track the extreme power PV system within various atmospheric conditions. The average power of the PV system is enhanced by 3 to 4% through the faster tracking performance and the least oscillations. The MPPT and the HHO of the PV system restrains the issues of the PS and the random oscillations. Because of the great proficiency of HHO, the cleaner sun-powered energy can be used more effectively, which adds to the techno-monetary achievability of sunlight based PV frameworks. The coordination of HHO MPPT strategy with PV inverter ideally improves the energy harvesting capacity. The main drawback of the Harris hawk optimization is slow convergence speed and low accuracy.

Ai-Qing Tian *et al.* [11] preferred the pigeon-inspired optimization algorithm, an advanced pattern of the meta-heuristic algorithm to determine the MPP. The newly formed algorithm which is inspired by the characteristic features of the pigeon is thus named as Parallel and Compact Pigeon-Inspired optimization (PCPIO). The PCPIO has the ability to handle the issues that restricts the tracking system to attain the wide-range maximum power. The PCPIO system determines the MPP rapidly and more accurately. The characteristic features of the PSO and the advanced pigeon algorithm is evaluated in the PCPIO methods in order to find the better optimization solution. The multi-peak output qualities of the PV arrays under complex environmental circumstances are evaluated in the article and intimate the significance of the revamped PIO algorithm with the incremental conductivity (INC) method in tracking the maximum power. The PIO method increases the rapidness of the system, further the INC is employed to detect the best power point. Improved accuracy, extended intermittent coverage are the main advantage of the PCPIO algorithm. The computational complexity is the main issue encountered in the PCPIO algorithm adversely affect the performance of the system.

Ali M. Eltamaly [12] tracked the MPP in the solar PV system under partially shaded condition with the aid of swarm intelligence. The cuckoo search algorithm is one of the efficient swarm intelligence techniques, which is used to avoid the restrictions of the existing technique. The advanced CSO satisfies the main requisites of the MPPT such as, reduction in the cost of controller, controlled rejection rates, short intermitting time, low fluctuation at the steady-state and reduced computational complexity. The advanced CSO preferred by the Ali M. Eltamaly achieves the zero rejection rates, lower intermitting time less than 0.75s and zero fluctuations in the steady state condition. Furthermore the logics utilized in the advanced CSO are very simple thus the reduction in computational complexity is attained. The slow intermittent rate is the hectic challenge to be restrained in the advanced CSO algorithm.

Mazen Abdel-Salam *et al.* [9] presented an advanced methodology to track the MPP based on P&O techniques. The advanced P&O methodology relies on the climatic factors like irradiance and temperature. The advanced methodology comprised of various climatic condition such as Ropp profile of irradiance, ramp variation of irradiation and the step variation of irradiance for the efficient tracking of the maximum power. The dissipation of the accessible energy is one of the major drawbacks in the methodology due to the fluctuation in the peak power point.

AI-wesabi Ibrahim *et al.*[14] evaluated the yield qualities of the PV framework in the influence of partial concealing condition, to present an improved extreme force point tracking strategy. The efficiency of the traditional methods is negatively affected by the partial concealing condition, which produce pinnacles in the PV curves. The revamped version of PSO so called modified PSO (MPSO) is utilized in the framework to enhance the yield power of the PV framework, irrespective of the abnormal conditions. The revamped PSO system efficiently tracks the global high yield power of the PV framework with high stability. The local intermittent area and the local optimum issues are the main drawback, which curbs the function of the MPPT system.

Rakesh Kumar Phaden *et al.* [15] utilized the adapted version of the ant colony optimization (ACO) which posses direct obligation cycle controlling ability to manage the MPP in PV system. A simple and eminent technique to reinitialize the insect to filter for the new MPP is recommended to speed up, bringing about unrivalled unique reaction. The robust feature, rapid response and enhancement in the tracking speed make the system superior over the conventional methods. Furthermore the system is found to be effective in tracking GMPP for the different climatic condition such as substantial insolation variation and the partial concealing condition. The low cost and simplicity are the other desired qualities of the adapted ACO method. The adapted ACO is not suitable for the large sale issues.

Peng Zhang and Huibin sui [68] presented an upgraded Differential Evaluation algorithm by contemplating the yield attributes of PV exhibits under fractional concealing conditions. To follow the GMPP of PV clusters, the work presents the ideal transformation methodology, versatile scaling features and the cross features under the influence of PSC by utilizing numerical conditions. High intermitting speed and reduced oscillation loss are the main advantages of the upgraded DE algorithm. The complex strategy and the substandard search quality are the main advantages of the system.

Hongda Liu *et al.* [71] used the reconfiguration algorithm on PV array method to tackle the issue that the yield power is influenced by the halfway concealing. By changing the association method of the PV cluster, shadow restricted PV exhibit by streamlining calculation can accomplish ideal conveyance of shadows, maximally accomplish the yield force of PV exhibit easily under the state of shadow and improve the yield force of the entire PV. Furthermore it increases the multi peak criterion by eliminating the local peak value.

Another strategy is presented by Mohammad H. Moradi *et al.* [72] to improve the exhibition of greatest force point tracking in solar oriented PV boards. The algorithm is the integration of two loops, set point count and the fine tune loops. First the set point circle approximates the most extreme force utilizing disconnected computation of the open circuit voltage. The specific measure of the greatest force will, at that point, be followed by the fine tuning loop which depends on P&O technique. The proposed strategy displays worthy effectiveness and incredible execution during startup time and because of fast changes in barometrical conditions. Effortlessness, restricted equipment necessities and low execution costs are among the upsides of the algorithm.

Wenfan Li *et al.* [70] utilized one of the modern technology known as Lipschitz optimization to track the MPP in the solar PV boards. The advantage is that it is adaptable to any climatic condition and provides the optimal power under PSC. Furthermore the enhanced tracking efficiency and the speed considered as the merits of the system. The increased number of functional evaluations is the main drawback of the system.

Mr. Amol V. Atpadkar *et al.* [76] presented the appropriate method for tracking the MPP with the aid of Hill climbing optimization. The working point should be chosen to get the greatest force there by utilizing the most extreme radiations of the sunlight based energy. The Hill climbing optimization is utilized for improvement of the framework to give the greatest force from the nearby planetary group under ordinary and the incomplete concealing conditions. The local maximum is the main issues that are faced in the HC method.

Mohammad Sarvi *et al.* [74] presents a extreme force tracking (MPPT) with the aid of PSO technique for PV frameworks under the influence of the partial concealed condition. The exhibition of the proposed strategy is contrasted and irritate and notice (P&O), improved P&O, voltage-dependent most extreme force point tracking and current-dependent greatest force point tracking calculations, particularly, under part of the partial shading condition. The deep evaluation in the P&O based MPPT algorithm provides high exactness in tracking the extreme power point under various insolation, temperature and part of the fractional shading , and it provides impressive results while considering the other conventional methods. Likewise under quickly changing barometrical conditions, the P&O calculation is separated. PSO prevail better execution in terms of tracking accuracy, and furthermore the methodology achieves high convergence speed. Yet, the PSO based MPP tracking system suffers from low convergence rate.

Alireza Ramyar *et al.* [76] presented the hill climbing method for tracking the extreme power in PV system under both the uniform and partial shading condition. The hill climbing method is used to analyze the irradiance pattern of the solar panels in order to track all extreme power points. It isn't fit to issues where the estimation of the heuristic capacity drops off abruptly when the solution might be in sight.

Yingquan Zou *et al.* [10] utilized the modified MPPT algorithm for the effective tracking of the MPP in the PV system under the restricted shadowed condition. The revamped version of the traditional P&O system is engrossed in the algorithm so as to determine the best power point in the PV systems. The PV array output is directly enhanced through the adopted differential flatness control and the fuzzy logic is employed to track the suitable voltage. The exactness, fastness and the robustness are the desirable qualities of the revamped MPPT algorithm. Power failure and the lack of efficiency are the prime issues encountered in the revamped MPPT algorithm.

A nature-influenced metahuristic frame work so called bat algorithm (BA) is utilized by Mehdi Seyedmahmoudian *et al.* [79] to track MPP under the influence of fractional shading methods. The performances of the PV system under various fractional shading condition is analyzed and the effectiveness of the bat algorithm in tracking the extreme power point of the system. The reliability, fastness, sustainability and the efficiency is the considered as the prime advantage of the system, which makes them preferable for various PV systems. Even though the BA posses the aforementioned advantages it experience delay in attaining the converge rate.

L. Piegari and R. Rizzo [80] preferred a versatile algorithm based P&O MPPT algorithm to improve the proficiency of PV frameworks. The calculation has been set up to diminish the principle issues that emerge in using customary P&O calculations: dynamic reaction and consistent state steadiness. The calculation is versatile and furthermore the estimations are delicate to the parameter variation. Furthermore, some lab tests on a low force board have been performed giving test legitimacy to the adequacy of the P&O calculation. The rpidly changing climatic condition creates adverse effects in adaptive P&O MPPT algorithm.

The data handled technique is utilized by Chao Huang *et al.*[82] for tracking the extreme force of the PV system. The data driven system consists mainly of two-overlaps that aids the PV system in order to restrain the issues that related to the varying fractional concealing condition. A minimized data-driven system is utilized in the fractional concealing condition so as to create the power-voltage curve (P-V) model. An advanced cubic spline is utilized to upgrade the P-V curve model, which comprised of multiple peaks to obtain GMPP under the influence of the fractional concealing condition. The data drive MPP tracking system is the enhancement in the efficiency of the MPPT in PV system. Misinterpretation due to the false data is the prime issue experienced in the data-driven system.

Kinattingal sundareswaran *et al.*[83] utilized the amalgamated optimization algorithm , which incorporates the traditional GA algorithm and conventional P&O algorithm. The amalgamated model guarantees better intermitting area so as to track the GMPP accurately and efficiently. The latency is also minimized in the amalgamated GA and P&O algorithm, which determines the global intersection with minimum time. The pre-mature convergence is the main issues encountered with amalgamated optimization algorithm.

Kheldoun *et al.* [86] presented Golden-Section algorithm for effective tracking of the extreme power point in the PV frameworks. The Golden-Section strategy intermits the maximum power through the stretch contracting process. At first, two focuses are chosen from the hunt space whose limits are known, assessed then another point is created in the same manner. The algorithm produces another limited span, restricted by the new point and one of the underlying focuses as indicated by the assessment results. The algorithm quits iteration (span contracting) when the stretch turns out to be adequately little and the photovoltaic framework is compelled to work at the normal estimation of the last discovered span without annoying either the voltage or the obligation cycle. This force the PV framework joins quickly to the most extreme force point in short of voltage or force motions around the greatest force point consequently lower energy squander. The Golden-Section algorithm is further utilized as the global hunt algorithm for the effective tracking of the GMPP. There is no instruction in the algorithm to pick up the best solution, when various zeros or optima exist in the system.

Lian Lian Jiang *et al.* [87] presented the advanced MPPT method, based on the ACO algorithm. The ACO- based MPP technique is found to be efficient under different fractional shading condition. The less number of recitations is required for this method to obtain the convergence. The convergence thus obtained is unrelated to the initial conditions. The extended time requirement of the algorithm due to the substantial solution space is the main issue encountered in the ACO based power tracking system.

Yasser E. Abu Eldahab *et al.* [89] preferred the GA based extreme power tracking system to maintain the better features and to elude the limitations of the traditional P&O method. The genetic algorithm is employed in the research in order to obtain most proficient power extraction. The PI regulator based MPPT, provides somewhat lower productivity, while the MPPT with unsupervised control strategy has the most reduced effectiveness. Another significant benefit of the strategy is that, the MPP can be reached straightforwardly with practically extremely restricted swing in the inceptive stage. Consequently, the framework is found to be well balanced. The time-consumption is one of the limitations found in the GA based technique which affects the efficiency of the system.

2.2.4 MPP Tracking Based on Fuzzy Logic Approach

Mohammad Hasan Parvanesh *et al.*[5] preferred a hybrid strategy, which make use of fuzzy logic (FLC) for the efficient tracking of the maximum power point. The accurate adaptations and the work point estimation are two constituents presented in the system to estimate the MPP. The comparison of the aforementioned components is presented in the method so as to determine the appropriate maximum power. From the comparative description the accurate estimation of the maximum power is obtained. Low implementation cost, minimum hardware requirements and the enhanced efficiency makes the system more dynamic in solar PV systems. Yet, the lower tracking efficiency and the low converge speed are the drawback of the FLC system.

Laxman Bhukya *et al.*[6] utilized the FLC , which is based on the efficient Grasshopper optimization to track the maximum power of the system. The grasshopper optimization is employed in the FLC to regulate its membership function so as to restrain the uncertainties experienced in this system. The temperature and the irregular irradiance are considered as the prime factor behind the formation of uncertainties. Hence, the efficacy of the FLC method based on the grasshopper optimization is evaluated under rapid changing temperature and irradiance. The grasshopper optimization handles the constraints such as steady-state oscillation, lower intermitting speed and the lower tracking efficiency that are experienced by the FLC methods. Still the method experiences complexities in the implementation process as it performs the operation such as defuzzification and the fuzzification process. Further the grasshopper based FLC system requires more storage process to track the exact power point under the partial shading conditions.

Majid Dehghani *et al.*[8] suggested a novel method to effectively track the MPP in solar system based on the FLC, which it is optimized by the integration of two well organised algorithm known as genetic algorithm and the particle swarm optimization. The ratio and the derivative of the power variations are considered as the input of the FLC system and the duty cycle is the output of this method. The optimization issues encountered in the FLC such as fuzzy rules and the fuzzy membership functions are efficiently controlled by the integrated Particle Swarm algorithm-genetic algorithm (PSO-GA).This PSO-GA algorithm possess the advantage like rapid reaction rate along with better accuracy rate on comparing the controllers utilized in the system. The accuracy of the PSO-GA based controller is improved to about 2-8% of the output power of PV, while compared to other controllers with different temperature and irradiance. Thus the FLC controller based on PSO-GA tracks the MPP with more accuracy. Yet, the computational complexity due to the high dimensional data is the main drawback of the system.

Mahlaga Mahadavi *et al.*[77] presents the superior efficient tracking method to track the extreme power produced by the PV systems. The method integrates both the analytical skills of the ANN and the course-grained data handling skill of the Fuzzy logic and the system is known as Adaptive Neuro- FIS (ANFIS) method. It can deal with non-straight and time shifting issues subsequently making it reasonable for exact greatest force point tracking to guarantee PV frameworks work effortlessly. It ought to be brought up that a few parameters are precluded in the ANFIS to improve on the case. For instance, the shunt opposition in PV model, which is the main parameter to increase the efficacy of the system, is not considered in the method. The climate condition is another parameter which ought to be considered, particularly in concealed or controversial conditions.

Yiwang Wang *et al.*[78] used the Variable universe fuzzy logic control (VUFLC) for the for tracking the MPP of the PV system, which relies on the temperature variance of the PV panels. The expansion and contract factor of the VUFLC is regulated in accordance to the atmospheric temperature variance in the PV module. The impact of temperature variation is PV board is greatly reduced by the regulation factor utilized in the VUFLC, which increase the accuracy and speed of the MPP tracking. Further the tracking efficiency of the solar PV panels is greatly reduced by the VUFLC method. The complexity involved in fuzzification and the de-fuzzification process is the main drawback of the VUFLC system.

D. Ounnas *et al*.[81] presented a advanced MPP tracking method, which is based on the Takagi-Sugeno fuzzy model (T-S) fuzzy model to extract maximum power from the solar PV system. A conventional DC-DC enhanced converter is utilized in the T-S fuzzy model to manage the yield power from the PV board. A MPPT regulator based on fuzzy logic is modelled by constructing the feedback regulator and the most favourable reference model to obtain the maximum PV output voltage. The vulnerabilities of the design model is controlled by the Fuzzy model. Setting the accurate guidelines and enlistment capacities in the fuzzy is the problematic endeavour in the system.

2.2.5 MPP Tracking Based on Hybrid Fuzzy Logic Approach

Zhen pan *et al*. [4] presented a combinational technique to track the MPP, which is depending on the BAT optimization and the fuzzy controller. The fuzzy logic controllers are employed in the MPPT methods in order to make them sustainable in all environmental conditions. The PV frame work is furnished with the MPPT procedure thus it works manually with an electrical energy repository framework, which is reliable to the lead acid accumulator. A balanced power output is obtained through this hybrid technique as it compensates the irregular solar power production. To provide a sustainable energy the BAT-FLC reliable system is needed to be integrated with PV inverter.

Khaled Batainesh and Naser Eid *et al.*[73] presents a hybrid techniques , which combines FLC with the P&O method for the efficient tracking of extreme power point of the PV under variable climatic conditions. NFIS is utilized to boost both the parameter and the associative performance of the FLC. The region of FLC is utilized to determine the range of the extreme power of the PV board. The advantages and limitations of the both the FLC and the P&O method is analyzed to minimize the limitation of the hybrid strategy. The hybrid technique is evaluated under various weather conditions and proves to be adaptable in different environments. The hybrid method traces out the MPP within limited time than the other methods.

The two advanced controllers are presented by A. M. Zein Alabedin *et al.*[90], which is reliable on fuzzy logic and the ANN. Fuzzy logic based regulators are straightforward, simple to carry out, and does not relies with the information on the numerical model of the framework. Neural organizations are widely known as the general approximators for non-straight powerful framework. Hence, they can be utilized to compute the reference boundaries of the greatest force point. The two regulators are evaluated under factor natural elements to contemplate their tracking efficiency. Fluffy rationale was discovered to be a basic, and simple to execute instrument for MPPT. In any case, its transient exhibition was moderate and remembered variances for the yield power. Then again, neural organizations showed an amazing exhibition when applied with conventional P&O MPPT methodology. The planned neural organization had the option to precisely gauge the most extreme force age under factor climatic conditions which helped in speeding up and eliminating the force changes. The Fuzzy strategies are needed to be incorporated with fluffy rationale regulator with power assessment utilizing neural organization the ANN in order to boost the energy harvesting. A well-organized processor with parallel processing power is required in the ANN to track the extreme power point.

M. Zein Alabedin *et al.*[90] utilized the Fuzzy logic control and the Artificial Neural Network (ANN) for the effective tracking of the extreme power of the PV solar system. The Fuzzy logic is the manageable and the tools are uncomplicated to implement. However the fluctuations occurred in the output power and the slow performance are the prime factors that deteriorate the performance of the system. The ANN is devised to accurately determine the extreme power of the PV grids. The ANN enhances the detection speed and removes the output power fluctuations.

2.2.6 MPP Tracking Based on Hybrid Meta-Heuristic Approach

The hybrid algorithm, which is the integration of both the cuckoo search algorithm and the genetic algorithm (CSO-GA) is preferred by Nabil A.Ahmed *et al.*[7] . This hybrid algorithm provides the best control parameters to track the maximum power point. This algorithm is used to tune the regulators in P&O MPPT method, in which the conventional methods fail to tune the parameters due to the nonlinearity and the wide distinction in the system parameter. The low intermitting speed and oscillations experienced in the MPP are effectively restrained by the hybrid genetic algorithm and the cuckoo search algorithm. The poor ability of determining the local optima and the articulation of the fitness parameter are the main drawback experienced in this technique.

Saber Arabi Nowdeh *et al.*[69] preferred the well organized method for extreme power tracking in the PV system so called hybrid moth flame optimizer Perturb and observe method (HMFOPO). The HMFOPO is the amalgamated algorithm which is the integrated form of both the MFO and P&O achieves the peak power in the PV module. The P&O is implemented in the best moth which was estimated by the MFO algorithm to obtain a best photovoltaic curve. Hence, the amalgamation of the two algorithms improves the accuracy, attain speed convergence rate and enhance efficiency to track MPPT. The main drawback is that it is highly sensitive to parameters.

Hadeed Ahmed Sher *et al.*[75] presented a hybrid method in order to track the extreme power of the PV system through amalgamating P&O method with the fractional short circuit current (FSCC).The hybrid method enables to detect the aggressive climatic condition more precisely while compared to the conventional methods. Furthermore, under gradually changing climate condition the algorithm tracks the most extreme force point (MPP) utilizing the P&O MPPT. Along these lines, the proposed technique encounters less disconnected (hamper) estimations and henceforth, better energy utilization is achieved. The hybrid MPPT strategy requires low computational time because of FSCC and precise due to P&O technique.

2.2.7 MPP Tracking Based on The Optimized Classifier Approach

Mean Takruri [13] deliberated various techniques employed to track the MPP in the solar PV panels. From the extensive evaluation it is clear that MPP is vulnerable to the external factors such as irradiation and the temperature. Hence, a futuristic method is established to maximize the yield power of the PV panels while attached to the DC/DC boost adapter under various load condition. AI procedures were utilized to anticipate the ideal reference voltage of the PV board by any means of climatic conditions to serve as a source of perspective for a PID regulator that guaranteed that the DC/DC boost adapter gave a steady yield voltage and most extreme force under various climate conditions and loads. The preferred AI framework was tried on an exploratory photovoltaic dataset accumulated from Spain. The method is found to be Robustness against the internal and the external disturbance. The SVM based credential potential generator is found to be most preferred generator due to its dominance against other methods. Yet, the presence of noise in the training data adversely affects the performance of the generator.

Stefan Daraban *et al.* [88] utilized the modified GA to track the extreme power point in the solar PV system. The GMPTT algorithm is adapted in the system so as to enhance the energy gathering capacity. The P&O algorithm is integrated with the GA function to generate the modified GMPPT. By implanting a basic MPPT calculation (P&O) inside the construction of the GA, the populace size and the quantity of cycles are diminished, in this manner finding the MPP (most extreme force point) in a more limited time. The parameters such as number of emphasis, size of the population and the number of qualities are normalized to obtain the final solution.   A macro model is utilized to average the genuine DCeDC converter and diminish the calculation weight of the test system, which in turn reduces the execution time. The GMPPT algorithm and the control part were carried out on a DSP (computerized signal processor) and tried on a trial limited scope photovoltaic framework. The main drawback is that the system fails to produce the optimal randomized number. Hence, the new computation based on the Chaos theory is needed to be introduced in the system so as to produce the best randomized number. Furthermore, the GA is the time consuming process and it is computationally expensive. The complexity is experienced in designing the objective functions and to obtain the appropriate operators.

Yi-Hua Liu *et al.*[85] utilized the neural network based two digital MPPT algorithm methods for the rapid changing environmental condition. The enhancement in the tracking speed is obtained in the method as it utilize the fast-moving voltage regulation loop, results in the obtaining improved tracking efficiency. The implementation is achieved with the aid of low cost controller as it posses few multiplication and the addition process. Increased in the tracking efficiency is the prime advantage of the system as it restrains the fluctuations around the MPP. The MPPT algorithm is adapted for all kinds of power converters and it is easily cop up with any voltage modulation loop. Yet, the computational expensive and extended processing time is the hectic issues related to the NN-based digital MPPT algorithm.

2.3 RESEARCH GAPS

i. The main challenge in the FCS-MPC [1] system integrated with the Kalman filter lies in reducing the computational complexity due to the huge implementation process.

ii. The over fitting of the system , which require the appropriate tuning of the parameter are the main issue that encountered in the MPPT tracking with QOCGWO-RFA system [2].

iii. The slow convergence rate and the low speed are the prime issue to be handled in the HHO MPPT strategy, furthermore it requires an efficient PV inverter for the enhancement of the energy harvesting efficiency [3].

iv. In the FLC-BAT optimization technique need to be integrated with the suitable PV inverter to obtain sustainable energy [4] and to cop up with practical application.

v. The low tracking efficiency and the low convergence rate are the main issues that degrade the performance of the FLC based MTTP tracking [5].

vi. The complexities arises during the defuzzification and the fuzzification process are the main issues to be restrained in the FLC [6] system.

vii. The poor ability of determining the local optima and the articulation of the fitness parameter are the main drawback experienced in the CSO-GA [7] technique.

viii. The computational complexity due to the processing of high dimensional data is the main issues related to the PSO-GA [8] based MTTP technique.

ix. The dissipation of the accessible energy is one of the major drawbacks in the P&O methodology [9] due to the fluctuation in the peak power point.

x. The main issue faced in the revamped MPPT algorithm is the constant power failures and the lack of efficiency [10].

xi. The computational complexity is the main issue encountered in the PCPIO [11] algorithm, which negatively influence the performance of the MPPT system.

xii. The low intermittent rate is considered as the prime issue in the advanced CSO based MTTP technique [12], which curbs the performance of PV MTTP method.

xiii. The presence of the noise in the training data is one of the main issue which effects the efficiency of the tracking power in the SVM based MTTP [13] strategy.

xiv. The local intermittent area and the local optimum issues are the main drawback, which curbs the function of the MPPT based on MPSO technique [14].

xv. Though low cost and simplicity are the desired qualities of the adapted ACO method is not preferable for the large sale issues [15].

xvi. The substandard research quality and the enhanced perplexity are the main issues that deteriorate the performance of the DE algorithm [68] for the tracking the MPP in the PV cells.

xvii. Though the HMOFOPO [69] method attains high accuracy and the speed convergence, it suffers from the deterioration in their detection performance as it is sensitive to the parameters.

xviii. To attain the highest detection accuracy the Lipchitz optimization [70] for the MPP tracking are subjected to various functional evaluation. Hence the increased number of functional evaluation in the main drawback of the Lipchitz optimization.

xix. Misinterpretation due to the false data is the prime issue experienced in the data-driven system utilized for tracking MPP in the solar panels [82].

xx. Setting the accurate guidelines and enlistment capacities in the fuzzy is the problematic endeavour experienced in TS-Fuzzy method for tracking of MPP in PV grid system [81].

xxi. Handling the issues that are related to the local maxima is considered as the hectic challenge experienced in the Hill climbing optimization [76].

xxii. The extensive time consumption is the prime challenge experienced in the reconfiguration of PV arrays based on GA algorithm [71].

xxiii. The deterioration of the energy is the hectic challenge experienced in the traditional P&O utilized in the fine tuning of MPP tracking system [72].

xxiv. The complexity involved in fuzzification and the de-fuzzification process is the main drawback of the VUFLC system [78].

xxv. Even though the BA based extreme power tracking system posses the advantages such as reliability, fastness, sustainability and the efficiency it experience delay in attaining the converge rate [87].

xxvi. The rapidly varying climatic condition creates adverse effects in adaptive P&O MPPT algorithm [88].

2.4 CONCLUSION

This chapter elucidates the brief reviews of various existing methods, which is utilized to track the maximum power in PV system with their advantages and the limitations. The challenges that are encountered in the traditional methods are briefly explained in the chapter, which aids to develop a well-organized MPP tracking system in PV solar system.

3. MOTIVATION

3.1 BACKGROUND

The hybrid energy system is a basic need and the inspiration behind the application of the hybrid system is enumerated below. When working with the PV systems, the drawback is associated with the operation of the highest power under the influence of various conditions requires a constructive algorithm known as MPPT. This problem has detained the attention over the present years due to its important function in operating the PV system in an effective manner. It is important to realize that the independent solar PV panel fails to satisfy the expected target in the production of power due to the absence of irradiation at night and the varying solar irradiance throughout the day. As such, continuous generation of power is not possible without additional storage system, whereas battery energy storage (BES) systems are most commonly used. This may help in alleviating the instability of the power output from solar PV system and stabilize the power in a feasible way. Thus, introducing effective controllers to make in use of the accessible power and to effectively manage the power allocation among the elements and the main network is of the main concern. MPPT techniques facilitate the transfer of maximum power from the PV system to the load by setting of duty cycle of the converters optimally. Optimization algorithms are playing a vital role in the control of MPPT techniques when used with intelligent control based MPPT strategies. However, controlling the Sugeno Fuzzy based MPPT is difficult with the management of membership function using a single optimization technique, like BAT optimization technique due to its poor convergence characteristics. In order to rectify this limitation, hybrid optimization techniques can be introduced by combining the characteristics of two or more optimization algorithm in such a way to complement the drawbacks associated with each single optimization algorithm. Let us take a deep insight into the system with the bat optimization algorithm.

3.2 EXISTING SYSTEM WITH THE BAT-BASED MPPT FOR THE HYBRID ENERGY SYSTEMS

The block diagram of the existing system is shown in figure 3.1. Here, the sugeno fuzzy based MPPT controller is tuned using the BAT optimization algorithm that experienced the major drawback of poor convergence rate. In addition, the parameter tuning and the performance of the system is not satisfactory, while using the BAT optimization algorithm due to the poor convergence phenomenon of the bat algorithm.

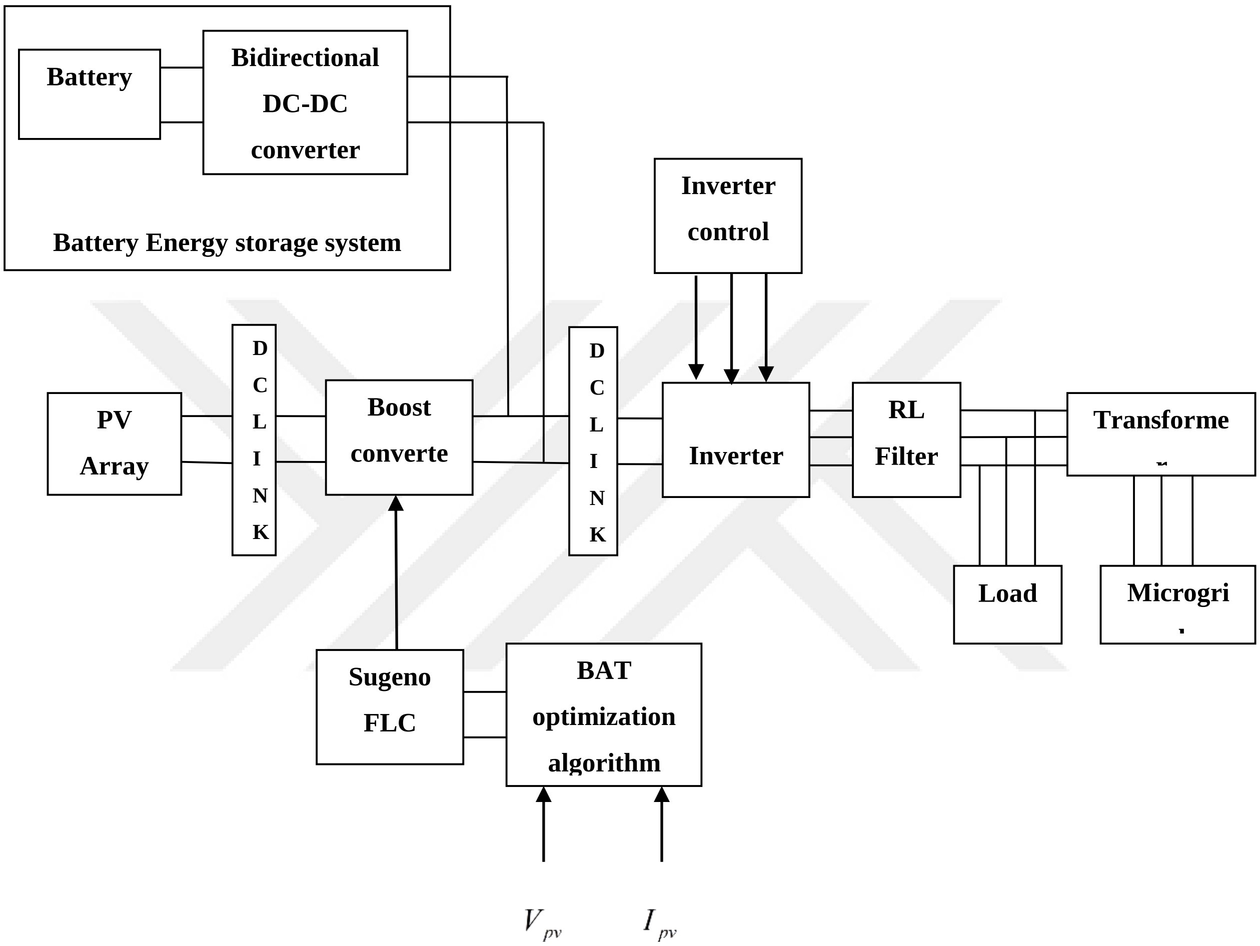


Figure 3.1: Existing Method of MPPT Based on BAT-Based Sugeno Fuzzy Controller.

3.3 CONCLUSION

This chapter deliberates the need for the development of the advanced controller of Bat-FLC for the extraction of MPPT in the hybrid energy system comprising of PV panel and BES system. The drawbacks associated with the existing method of MPP tracking is detailed to obtain a clear view for the development of the proposed strategy in such a way to rectify the limitations from the existing method.

4. HYBRID BAT-CAT OPTIMIZATION ALGORITHM TUNED SUGENO FUZZY CONTROLLER FOR MAXIMUM POWER POINT TRACKING IN GRID CONNECTED PHOTO VOLTAIC SYSTEM

4.1 INTRODUCTION

This chapter introduces a control strategy for a hybrid power generation system, comprised a PV panel and a BSS System. The initial of PV systems is significantly increasing and it has been endlessly demanding to reduce the cost of production. Numbers of research works have been dedicated to design efficient strategies for the maximization of power output of these systems. As a result, a well-organized strategy known as maximum power point tracking (MPPT) for solar PV systems was introduced. This research make in use of the sugeno fuzzy controller, the membership function of which is controlled using the hybridised BT-CT optimization algorithm in such a way to extract the MPP. The proposed strategy is termed as BT-CT- sugeno Fuzzy. With the use of the proposed BT-CT optimization algorithm that inherits the characteristic features of the creatures, such as placental mammals and the tracing cats, the social hierarchy of the input and output are set autonomously. The outcomes of the proposed BT-CT- sugeno Fuzzy technique are evaluated in terms of reference voltage and population size by varying the solar irradiance at constant temperature. The PV system is operated jointly with a BSS System in such a way to provide continuous power supply throughout the day. The efficacy of the proposed method is analyzed by comparing it with the conventional techniques in such a way to prove the superiority of the proposed method.

4.2 SYSTEM MODEL OF PROPOSED BT-CT-BASED CONTROL STRATEGY FOR HYBRID ENERGY SYSTEM

The system model of the hybrid energy system consists of PV array, Boost converter, Inverter, RL filter, battery control, Bidirectional DC-DC control, and the proposed BT-CT optimization-based sugeno fuzzy controller. This research introduces a control strategy for a hybrid power generation system, which comprised of a PV panel and a BSS System working in the grid-connected mode. The important function of the BSS System is the charging and discharging characteristics for the stabilization of power distributed to the load. The BES system absorbs power during the excess flow of power from the PV power generation and inserts it to the grid during shortfall. The significances of the proposed strategy are discussed as below:

i. Developing a combinatorial FLC and BT-CT for the extraction of MPP from the PV system.

ii. The proposed MPPT strategy is effective in dealing the divergent conditions and improves convergence speed, and efficiency, and reduces the steady-state oscillations in the network.

iii. Proves the superiority of the proposed MPPT algorithm by comparing its performance with the conventional techniques of MPPT.

iv. Acquiring a stable and reliable output from PV and improving the dynamic performance in grid-connected mode with the use of a BSS System. The diagrammatic representation of the proposed model is illustrated in figure 4.1.

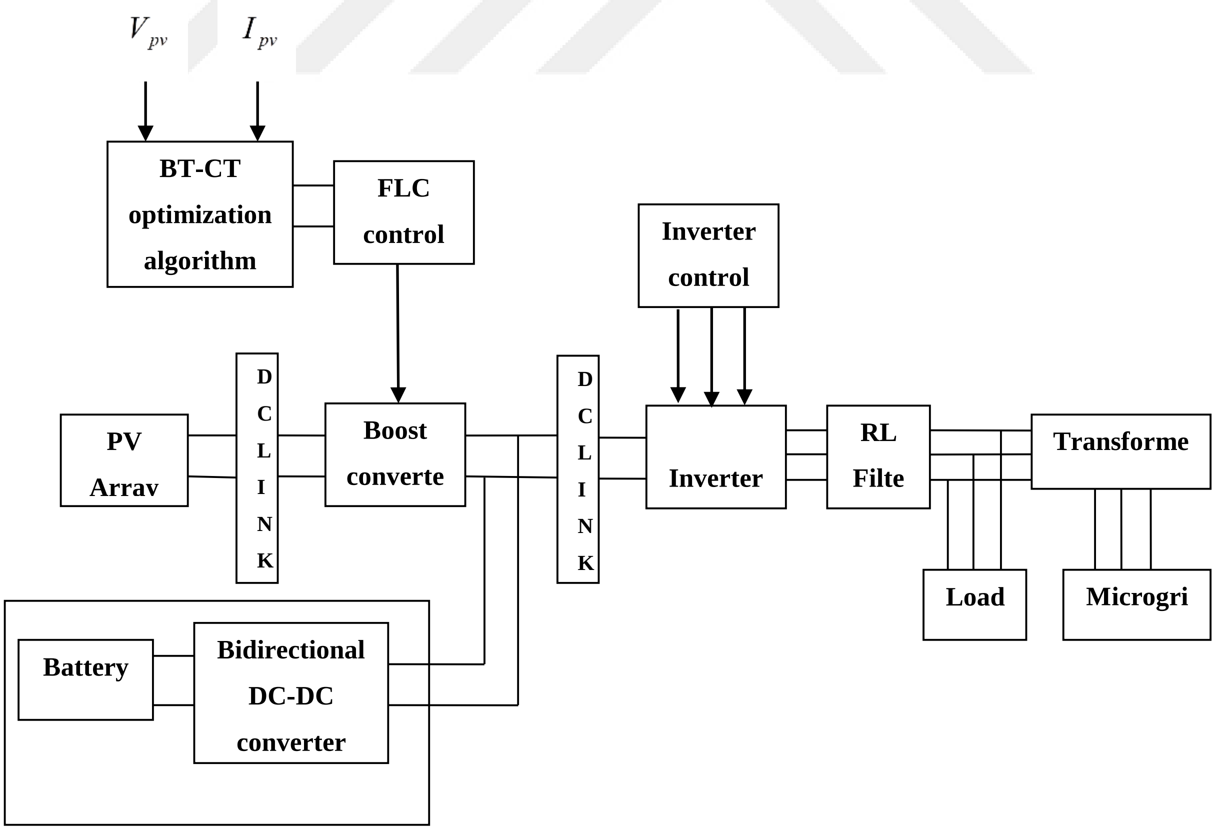


Figure 4.1: Block Diagram of The Proposed System.

4.2.1 PhotoVoltaic System

The PV panel is generally associated with the presence of multiple cells that are interconnected either in series or parallel. When the number of series connections increase, the voltage increases, and when the number of parallel connections increases, the current increases. The current across the PV panel is expressed as,

$$I_{pv} = I_{ph} - I_{pv0}\left[\exp\left(\frac{q(V_{pv}+I_{pv})}{nKT}-1\right)\right]-\left(\frac{V_{pv}+R_s I_{pv}}{R_{sh}}\right) \tag{4.1}$$

where, R_s indicates the series resistance, R_{sh} represents the shunt resistance, I_{ph} is the photocurrent pertaining to the PV cell, n represents the ideality factor of the p-n junction, T is the temperature and K is the Boltzmann constant. The system analyzed in this research for the solar PV panel is based on the SunPower SPR-305E-WHT-D comprising of five series modules and five parallel strings. The maximum solar irradiance is $1000W/m^2$ and the temperature considered is 25^oC. The maximum capacity of the PV array is $7631\ W$ with 5×5 modules.

4.2.2 Battery Energy System

Due to the uncertain and intermittent characteristics of the output from solar power with the extremely variable demands of load, lead acid battery is used for the storage of power in the proposed system in such a way to make in use the maximum capacity of the battery. The lead acid battery is designed with suitable choice of parameters, and the value of State of charging (SOC) is set to be 60%. The maximum storage capacity of the lead acid battery used in this research is 312.5 W, and gets charged above the nominal voltage of 240 V. The equations indicating charging and discharging of battery is expressed as,

$$V_{ch} = V_0 - Ri - \left[K\frac{Q}{it-0.1Q}\right]i^* - \left[K\frac{Q}{Q-it}\right]it + Exp(t) \tag{4.2}$$

$$V_{dch} = V_0 - Ri - \left[K\frac{Q}{Q-it}\right](it+t^*) + Exp(t) \tag{4.3}$$

where, V_{ch}, V_{dch} are the battery voltage, V_0 is the constant voltage of battery in $volts$, is K represents the polarization resistance in ohm, Q is the capacity of battery in Ah, it is the actual battery charge in Ah, R indicates the internal resistance in ohm, i is the battery current in Ampere, and i^* is the filtered current.

4.2.3 MPPT Control Strategies for Maximal Power Point Tracking in The PV System

PV panels may receive non-homogeneous irradiation owing to passage on tree or cloud, which is termed as partial shading effect. This factor minimizes the output of the PV panel considerably leading to the creation of multiple peaks in the P-V characteristics. Hence, it is necessary to operate the PV at Global MPP to make in use of the maximum power available. Thus, the MPPT controllers are used in such a way to track the maximum power to be fed to the microgrid. To attain MPP, number of conventional MPPT algorithmic strategies, such as Incremental Conductance (INC), Perturb and Observe (P&O), and Hill Climbing methods, and so on are used. However, there arise certain drawbacks with the usage of these techniques, such as repetitive perturbations, increased steady state oscillations and reduced efficiency in conversion. The above stated methods are inefficient in detecting the global point and may get converge within the local MPP, leading to reduced usage of total power from the PV array. Hence, as an alternative to the conventional strategies to prevail over the limitations, another class termed as bio-inspired techniques are introduced. These techniques are developed based on the biological characteristics of swarm movement, such as ants and other insects. The proposed research make in use of the proposed optimization algorithm, which is developed through the combined characteristics of placental mammals and the tracing cats, to tune the membership function of the sugeno FLC in such a way to track the MPP from the PV panel.

4.2.4 Boost Converter

The important application of boost converter is the regulated dc power supplies and the regenerative braking of dc motors. In boost converter, the output voltage is always higher than that of the input voltage.

4.2.5 Microgrid

Microgrids progress with the escalating penetration of the sources of renewable energy to the system and with the consideration of constraints related to transmission capacity and line losses during the conduction of electric power over long distances. Microgrids allow the generation to be placed near the load centers with enhanced control and management to guarantee active power distribution with increased reliability.

4.3 OPTIMIZATION TUNED SUGENO FUZZY LOGIC CONTROL IN MPPT

FLC possess broad collection of purposes in the field of sustained energy. The usage of FLC has been improved due to its simplicity, robustness, efficiency in case of imprecise inputs, absence of precise mathematical model and the capability to deal with nonlinearity [92]. FLC acts as controller to attain the MPP from the PV modules even under varying weather patterns. The progression of FLC is divided as three sections, such as fuzzification, assessment of rule and defuzzification. In this section, the optimal design of Sugeno FLC based on BT-CT optimization algorithm is proposed. The membership function of the Sugeno FLC is tuned optimally using the proposed BT-CT optimization algorithm in such a way to track the maximum power point from the solar power system. The basic structure of a sugeno FLC is depicted in figure 4.2.

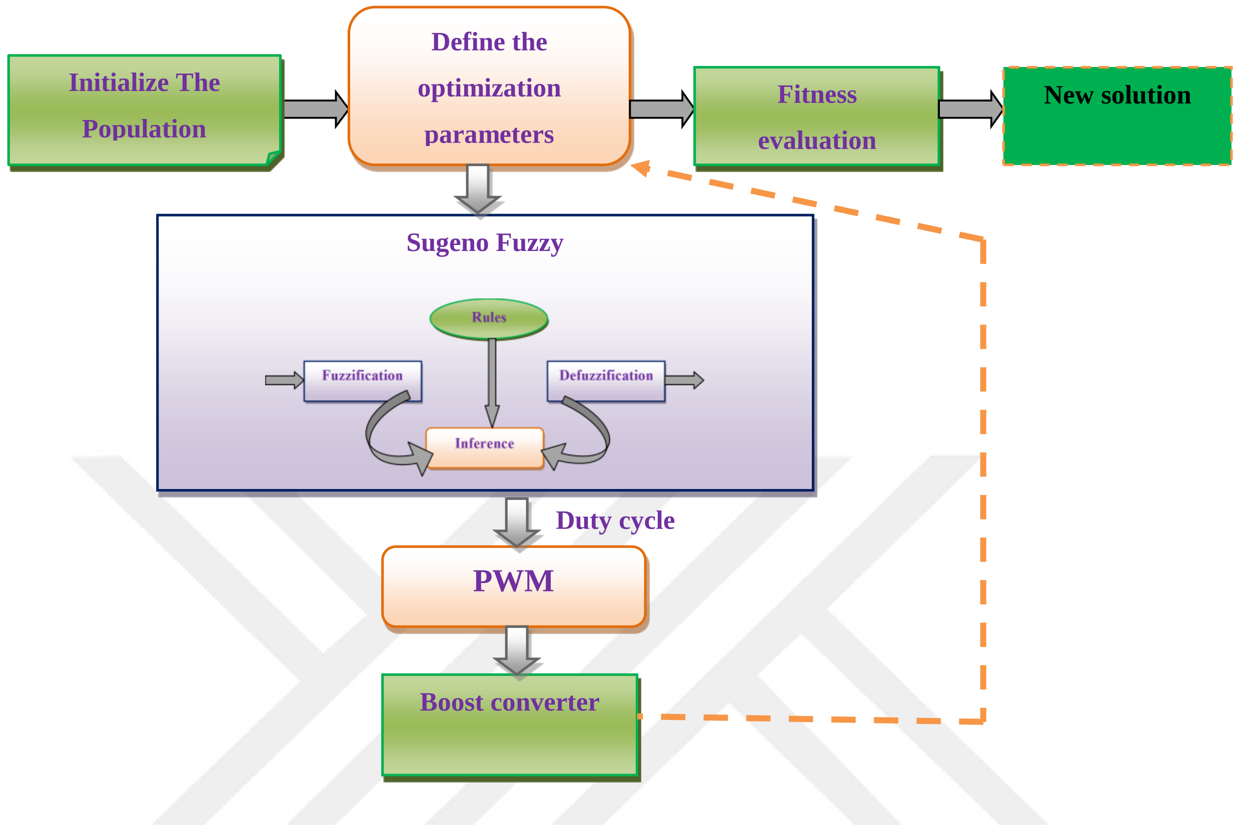


Figure 4.2: Structure of Sugeno Fuzzy logic control.

4.3.1 Sugeno FLC

Due to the difficulty and insecurity of real-world applications, like power system, the usage of human knowledge based FLCs are required in control systems. There are two kinds of FLCs, namely Mamdani type that needs human knowledge, and the Sugeno type that can be modelled using the optimization algorithms and shows number of advantages over the Mamdani type FLC. The Fuzzy inference generally consists of the steps, such as fuzzification, rule base, and defuzzification.

4.3.1.1 Fuzzification

The first step involved in the processing of the FLC is the fuzzification step that makes in use of the crisp input, such as variation in voltage, and merges it with the stored membership function to generate the inputs of fuzzy. In order to convert the crisp inputs as fuzzy inputs, the membership function is initially allocated for each input. After the allocation, fuzzification takes the inputs from real-time and matches with the stored membership function to generate the values for fuzzy input.

Consider, the two data inputs to the FLC be $e(k)$ and $\Delta e(k)$, where $e(k)$ is the error and $\Delta e(k)$ is the change in error. The data is forwarded to the fuzzy sets between $[0,1]$ using the membership function (MF). The Gaussian MF highly adaptable for the proposed BT-CT optimization algorithm is used in this research. The delivery of the input by way of the Gaussian MF is expressed as,

$$\alpha(n) = e^{\left(-0.5\left[\frac{n-i}{\beta}\right]^2\right)} \tag{4.4}$$

where, n indicates the FLC input, i indicates the mean, and the standard deviation of the Gaussian function is represented as β.

4.3.1.2 Evaluation of Rules

The fuzzy rules that are used in the sugeno FLC are the if-then conditional statement, which is expressed as,

$$\text{If } n_1 \text{ is } \alpha_1(n_1) \text{ and } n_2 \text{ is } \alpha_2(n_2)\text{, then } r = f(n_1, n_2) \tag{4.5}$$

The logic relation among the input means to evaluate the minimum MFs of the input is expressed as,

$$K = \min(\alpha_1(n_1), \alpha_2(n_2)) \tag{4.6}$$

The parameter r represents the output of the rule, and it is a function of n_1 and n_2.

4.3.1.3 Defuzzification

The final step in FLC is the defuzzification, where the expected measure is obtained with the isolation of the crisp value to produce the output fuzzy set. The output of the sugeno FLC is evaluated mathematically as,

$$r = \frac{\sum_{s=1}^{j} K_s r_s}{\sum_{s=1}^{j} K_s} \tag{4.7}$$

The structure of proposed Sugeno FLC control is shown in figure 4.3.

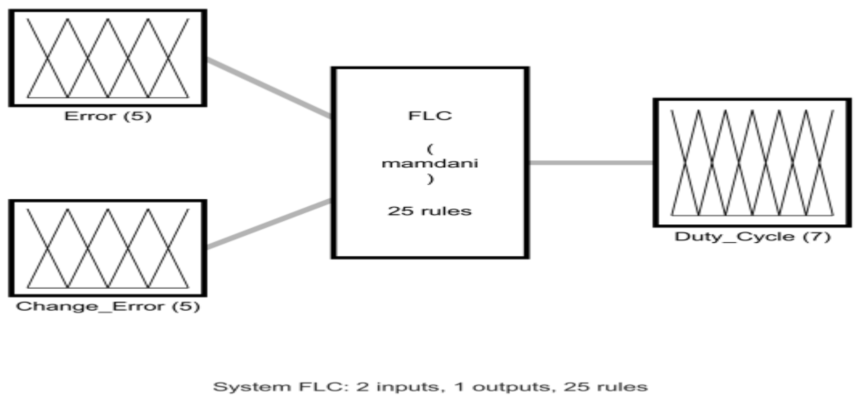


Figure 4.3: Proposed Fuzzy Logic Control.

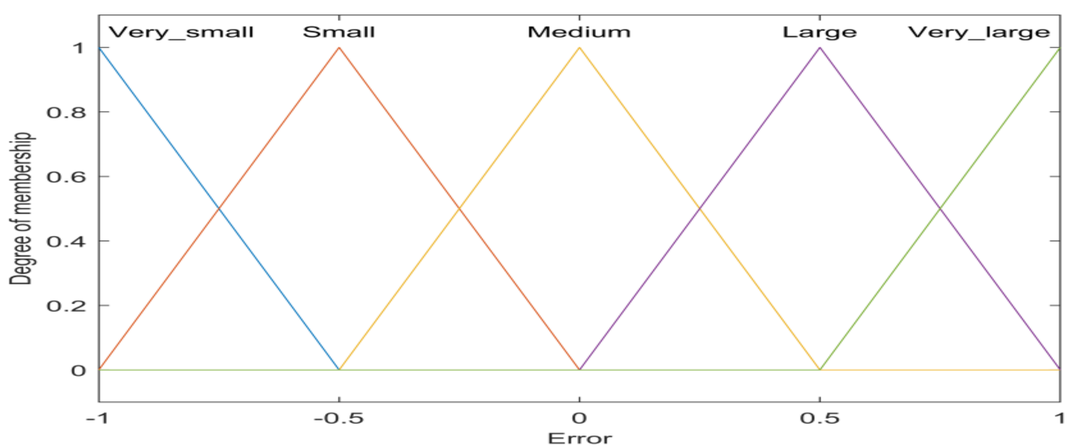


Figure 4.4: Membership Function in Terms of Error.

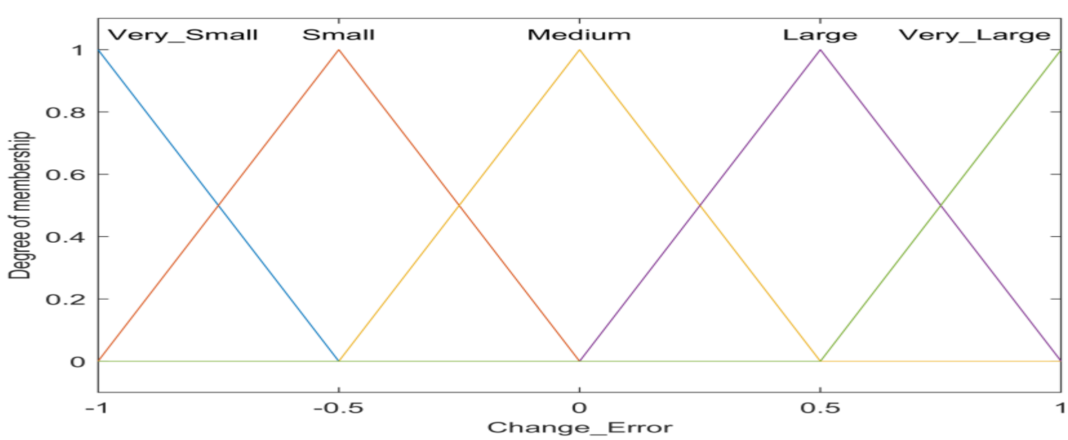


Figure 4.5: Membership Function in Terms of Change in Error.

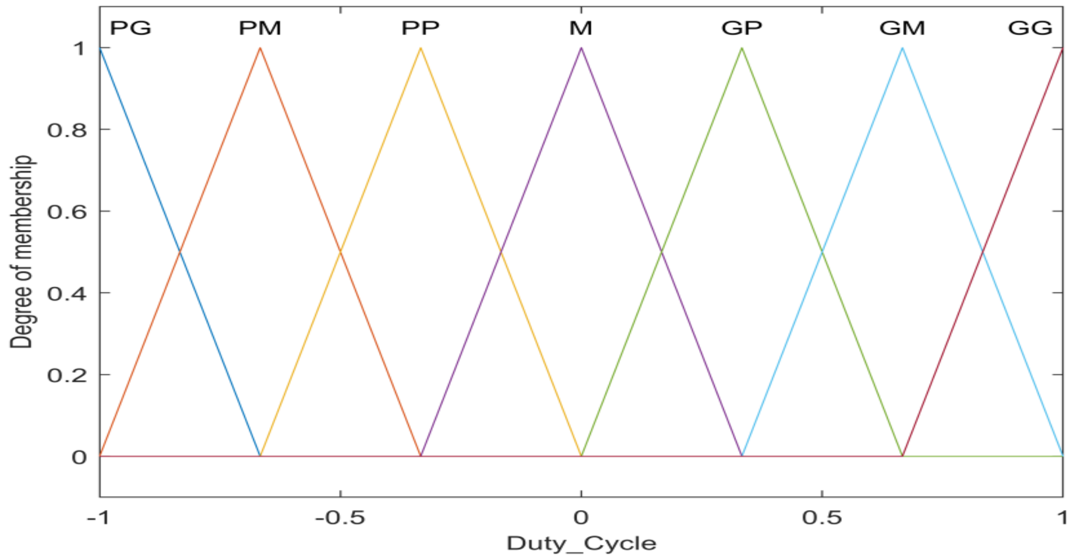


Figure 4.6: Membership Function in Terms of Duty Cycle.

The membership functions in terms of error, change in error, and duty cycle are depicted in figure 4.4, figure 4.5, and figure 4.6, respectively.

4.4 PROPOSED HYBRID BAT-CAT OPTIMIZATION ALGORITHM

The most important advantage of using the characteristics of Placental mammals is its flexibility and simplicity. The features of the placental mammals can be used to solve broad level of optimization problems with its flexible characteristics. On the other hand, the characteristics of tracing cats are efficient in maintaining a better trade-off between the phases, such as exploration and exploitation in order to find the global optimal solutions. The basic principles and the procedure of the placental mammals are deliberated as below.

4.4.1 Reason for Proficiency of Placental Mammal

There are various causes for the victory of Placental mammal-based algorithms, of which some of the key points are discussed as below.

Frequency modification: Placental mammals generally makes in use of the concept of echolocation and frequency modification to find the solutions for the optimization problems. Due to the inefficiency of echolocation, to copy the real characteristics in real time, modifications in frequency are made. This functionality leads to certain characteristics analogous to some of the important characteristics of harmony search Algorithm (HSA) and particle swarm optimization (PSO). Hence, BA exhibits the benefits of other algorithms that follow the features of swarm based models.

Mechanical zooming: One of the most unique characteristics of BA is its zooming capability in searching the better solutions automatically. This characteristic is made by making a move from exploration to local rigorous exploitation. This leads to increased convergence speed even at the initial stages of computation as compared to other algorithms

Parameter management: Unlike the other meta-heuristic algorithms that use pre-tuned fixed parameter values, BA possesses the control over its parameters while preceding the algorithm. This approach leads the algorithm to move from exploration phase to exploitation phase automatically, when moving towards the optimal solution. In addition to the above stated advantages, BA has the property of global convergence and is capable of solving large-scale problem in an efficient manner. The characteristics of BA is explained as below,

4.4.2 Echolocation of Placental Mammals

Of the different varieties of Placental mammals, most of the varieties follow the property of echolocation particularly, the microbats. The echolocation property is used to help the Placental mammals to avoid obstacles, find food, and locate the place to sleep in the dark. The pulses of the Placental mammals differ in properties and are connected with their trapping techniques, based on the types. Most of the Placental mammals produce, short frequency-modulated signals in 25 kHz to 150 kHz of frequency lasting for about 8 milliseconds to 10 milliseconds. The Placental mammals are capable of identifying the three dimensional environment by using the delay in time among their ears and variations in loudness.

4.4.3 Rules Based on Placental Mammals

Depending on the basic characteristics of the BA, the author in [93] modeled the BA with the use of three idealized rules, such as,

i. All Placental mammals find the distance using the concept of echolocation, and they know the difference among the background wall and the prey in a supernatural way.

ii. All Placental mammals fly at the velocity of k_a in position i_a with the frequency of w and loudness L_0 to find the food. They modify the wavelength automatically and lead the rate of pulse emission as $e \in [0,1]$, based on the nearness of the target.

iii. The loudness of the sound produced by the Placental mammals may differ due to various aspects, but assume that it varies from the large positive L_o to a minimum constant measure $L_{\min}$.

4.4.4 Motion of Placental Mammals

The Placental mammals are assumed to fly with a velocity of k_a^s in the position i_a^s at s^{th} iteration in a search space of d-dimension. The best Placental mammal among the entire population is considered as the best solution i^*. Hence, the update equation for k_a^s and i_a^s based on the above described rules are given as,

$$w_a = w_{\min} + \left(w_{\max} - w_{\min}\right)u \tag{4.8}$$

$$k_a^s = k_a^{s-1} + \left(i_a^{s-1} - i^*\right)w_a \tag{4.9}$$

$$i_a^s = i_a^{s-1} + k_a^s \tag{4.10}$$

where, u is a random vector of uniform distribution that varies between 0 and 1. All the Placental mammals are assumed to possess a frequency that changes between $w_{\min}$ and $w_{\max}$. Hence, the BA is stated as a frequency-based algorithm to attain an enhanced balance between the exploitation phases and exploration phase. The auto-zooming and the loudness characteristics of the BA are provided for enhanced results with the rate of pulse emission and the loudness of the Placental mammals, respectively.

4.4.5 Local Search Capability of Placental Mammals

In order to enhance the local search capacity of the Placental mammals, a structure is designed to improve the solution near the generated solution.

$$i_{a,pm}^{s+1} = i_{a,pm}^{s} + \rho L^{s} \tag{4.11}$$

where, $i_{a,pm}^{s}$ is a solution of high quality selected by some strategy, like roulette wheel, L^{s} is average measure of loudness of all Placental mammals at s^{th} iteration and ρ is the randomly developed value that varies from -1 to 1.

4.4.6 Deviation of Pulse Rates and Loudness

The values of loudness and the rate of pulses are varied at the process of iteration to balance the phases and to move to the exploitation phase when it is needed to move. The loudness of the Placental mammal decreases, whereas the pulse emission rate increases as soon as the Placental mammal finds its prey. The value of loudness can be selected between $L_{\min}$ nad $L_{\max}$, and the assumption of $L_{\min} = 0$ represents that the Placental mammal found its prey and stops producing sounds. Hence, the value of L using these assumptions are formulated as,

$$L^{s+1} = \beta L^{s} \tag{4.12}$$

$$e_{a}^{s+1} = e_{a}^{0}\left[1 - \exp\left(-\eta s\right)\right] \tag{4.13}$$

where, β and η are the constant. For any value $0 < \beta < 1$ and $\eta > 0$,

$$L_{a}^{s} \to 0 \tag{4.14}$$

$$\eta_{a}^{s} = \eta_{a}^{0} \quad \text{as } s \to \infty \tag{4.15}$$

In case of simple problems, the value of β can be assumed to be equal to η. The algorithm designed with the characteristics of the Placental mammal possesses the advantage of rapid convergence even at a starting stage by moving to exploitation from the phase of exploration. This leads to the generation of solution in less period of time. However, switching to exploitation stage by varying L and e too quickly leads to stagnation after initial stage. Hence, in order to enhance the performance, the characteristics of the tracing cats are integrated with the features of the Placental mammal in such a way to boost the diversity of the solutions.

According to biology, there are nearly about thirty-two varieties of species in feline, for instance tiger, leopard, cat and so on. The living atmosphere of feline may differ in certain aspects, but there is some similarity between the characteristics of the group of feline. For the wild felines, the hunting feature exhibits the endurance of their races, but in case of indoor cats, it is curious about the moving things. The cats possess increased curiosity, but stay inactive most of the time. They spend more time to rest, but are highly alert even at rest with its eyes open screening around. Cats are appeared to be lazy, but they are cunning and smart. There are two modes of operations detailing the features of the cats, such as seeking mode and the tracking mode. The seeking cats are the one able to remain calm, but alert even at rest screening the surrounding. But, the tracing cats are the one that plans a way to catch its prey by tracing the prey [94]. The characteristics of the tracing cats are more capable to be inherited with the characteristics of the Placental mammal in such a way to find the MPP in grid connected PV-battery system.

The standard equation for formulating the characteristics of the tracing cats is expressed as,

$$i_{a,tc}^{s+1} = i_{a,tc}^{s} + y_a^{s+1} \tag{4.16}$$

$$i_{a,tc}^{s+1} = i_{a,tc}^{s} + y_a^{s} + g * h * \left(i_a^B - i_{a,tc}^{s}\right) \tag{4.17}$$

where, $i_{a,tc}^{s}$ is the position of the tracing cat at s^{th} iteration, $i_{a,tc}^{s+1}$ is the position of the tracing cat at $(s+1)^{th}$ iteration, y_a^{s+1} is the velocity of the tracing cat at which it traces the prey, i_a^B is the position of the tracing cat possessing best fitness measure, h is a constant, and g is a random measure that varies between 0 and 1.

Finally, the position of the Placental mammal based on the distance and velocity parameters are modeled based on [91] as,

$$i_a^{s+1} = 0.5 i_{a,pm}^{s+1} + 0.5 i_{a,tc}^{s+1} \tag{4.18}$$

$$i_a^{s+1} = 0.5 i_{a,pm}^{s+1} + 0.5 i_{a,tc}^{s+1} \tag{4.19}$$

$$i_a^{s+1} = 0.5\left(i_{a,pm}^{s} + \rho L^{s}\right) + 0.5\left(i_{a,tc}^{s} + y_a^{s} + g * h * \left(i_a^B - i_{a,tc}^{s}\right)\right) \tag{4.20}$$

$$i_a^{s+1} = i_{a,pm}^s [0.5 + 0.5 - g * h] + 0.5 \rho L^s + 0.5 [y_a^s + g * h * i_a^B] \quad (4.21)$$

$$i_a^{s+1} = i_{a,pm}^s [1 - g * h] + 0.5 \rho L^s + 0.5 [y_a^s + g * h * i_a^B] \quad (4.22)$$

The above equation is the update equation of the proposed BT-CT algorithm that inherits the characteristic features of the Placental mammal and the tracing cats.

4.4.7 Principle of Algorithm Based on Placental Mammal

The basic features of Placental mammal are used for providing continuous optimization solutions to problems. However, to handle the combinatorial problems in an effective way, some changes are required to be performed. The important step is to change continuous esteemed locations of Placental mammals as binary esteems with the use of a sigmoid function as,

$$S(i_a^s) = \frac{1}{1 + \exp[i_a^s]} \quad (4.23)$$

That results in,

$$i_a^s = \begin{cases} 1, & S(i_a^s) > \alpha \\ 0, & Otherwise \end{cases} \quad (4.24)$$

where, α is the random value that varies between 0 and 1.

4.4.8 Algorithmic Steps of Proposed BT-CT Algorithm

The steps followed by the working principle of the proposed BT-CT algorithm is described as below,

Step 1: Initialization of population:

The location i_a^s and the speed of the Placental mammal k_a^s are initialized, where $a = (1,2,..., X)$ is the total number of Placental mammal.

Step 2: Initialization of loudness and pulse rates:

The pulse rate e_a^s and the loudness L^s are initialized for all the Placental mammals in the population.

Step 3: Describe frequency of pulse:

The pulse frequency of each Placental mammal is defined between the range $w_{\min}$ to $w_{\max}$

Step 4: Update of position

The location is updated using equation (4.11) for all the Placental mammals in the population at the iteration s.

Step 5: Generation of local solution

Choose a location from the best solution for the condition, $rand > e_a^s$ and produce a local solution near the best solution using equation (4.13).

Step 6: Evaluation of fitness

Evaluate the fitness for all the Placental mammals in such a way to sort the Placental mammals based on their fitness measure. If $rand < L^s$ and $w\left(i_a^s < i_a^B\right)$, save the obtained solution as the best solution . Otherwise update the fitness measure, e_a^s and L^s using equation (4.14) and equation (4.15) and rank the Placental mammals to obtain the best solution i_a^B using equation (4.24).

Step 7: Termination

Repeat the steps for all the number of iterations till the termination criteria is satisfied. The Pseudocode of the proposed BT-CT algorithm is deliberated as below.

Pseudocode of BT-CT algorithm:

Sl. No	Pseudo code of proposed Coy-GWO optimization algorithm
1	Input: k_a^s, where $a = (1,2,..., X)$
2	Output: i_a^B
3	Initialize the population of Placental mammals
4	Initialize pulse rate e_a^s and loudness L^s
5	Describe pulse frequency between the range $w_{\min}$ to $w_{\max}$
6	For all X
7	{
8	Update the position using equation (4.10)
9	If $rand > e_a^s$,
10	Produce a local solution near the best solution using equation (4.12).
11	End if
12	If $rand < L^s$ and $w(i_a^s < i_a^B)$
13	Save the obtained solution as the best solution
14	Else
15	Update fitness, e_a^s and L^s
16	Update the best solution i_a^B using equation (4.24)
17	End if
18	$s = s + 1$
19	}
20	Return i_a^B

4.5 RESULTS AND DISCUSSIONS

This section discusses the results of the proposed BT-CT-based Sugeno FLC obtained from the MATLAB/Simulink platform.

4.5.1 Performance Analysis

The performance of the proposed BT-CT-based sugeno FLC is analyzed in terms of varying reference voltage and varying training percentage with three conditions of irradiances.

4.5.1.1 Performance in Terms of Varying Reference Voltage

The results in this section are analyzed in terms of varying reference voltage at three cases of irradiance levels in such a way to check the effectiveness of the system for varying reference voltages.

Case-1: In this scenario, the irradiance level is maintained constant at $1000 W/m^2$, and the corresponding battery power, PV power, VI characteristics, and the PV characteristics for varying reference voltage are analyzed. Figure 4.7 shows the irradiance of PV that is maintained constant at $1000 W/m^2$.

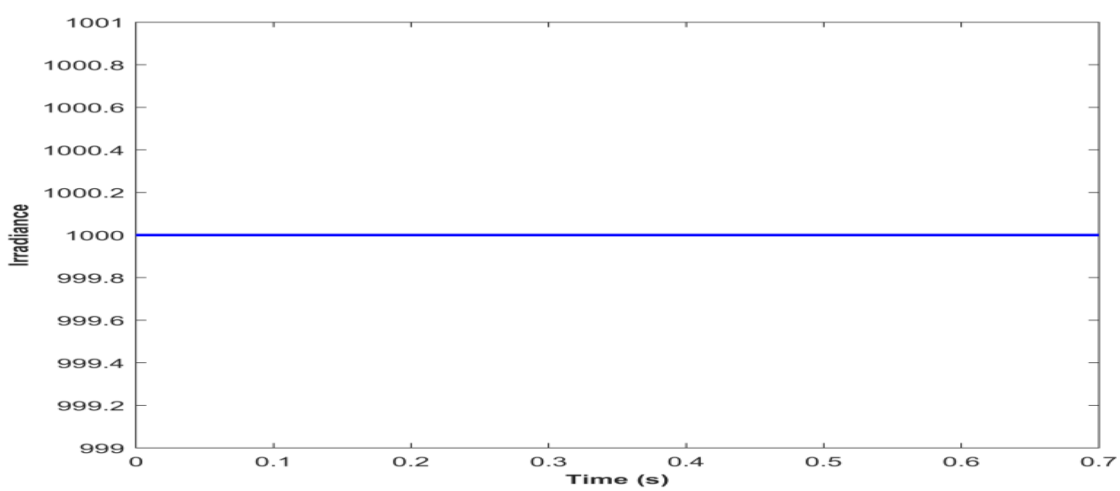
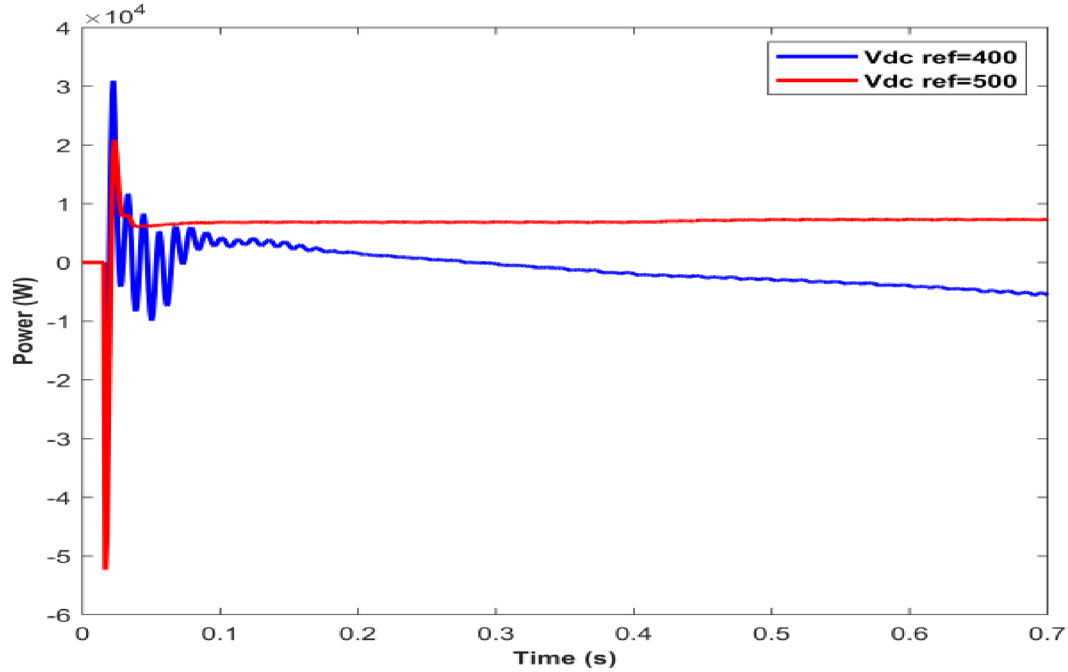
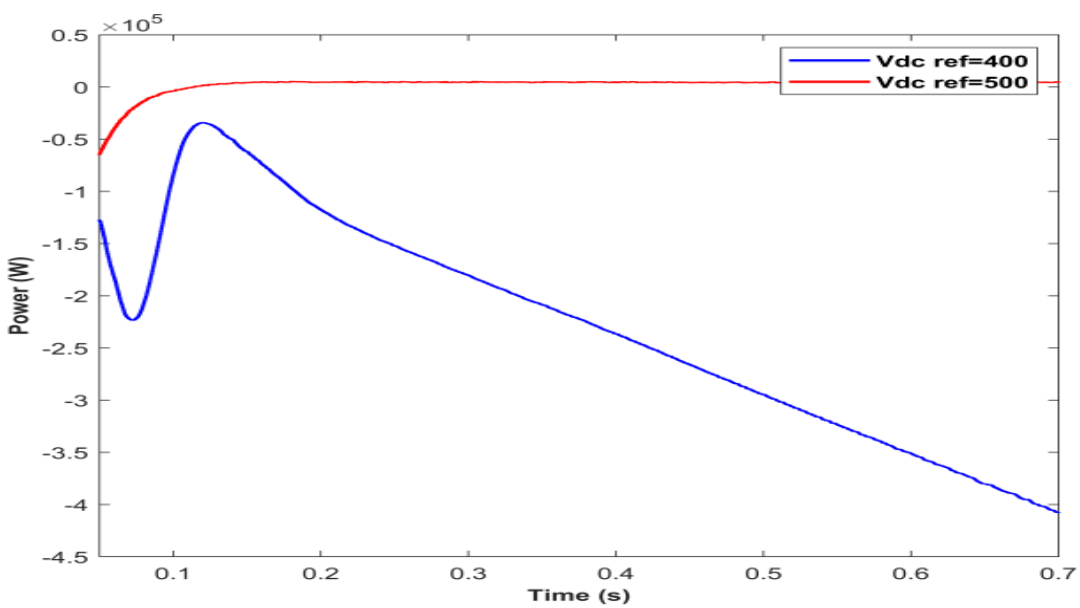


Figure 4.7: Irradiance Curve at case-1.



(a)

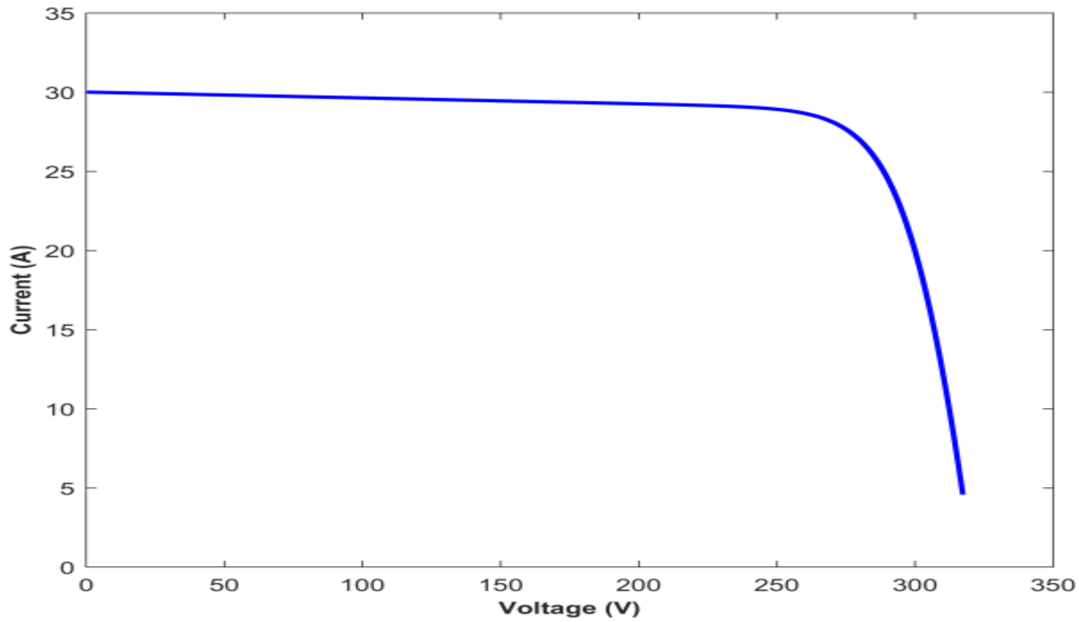


(b)

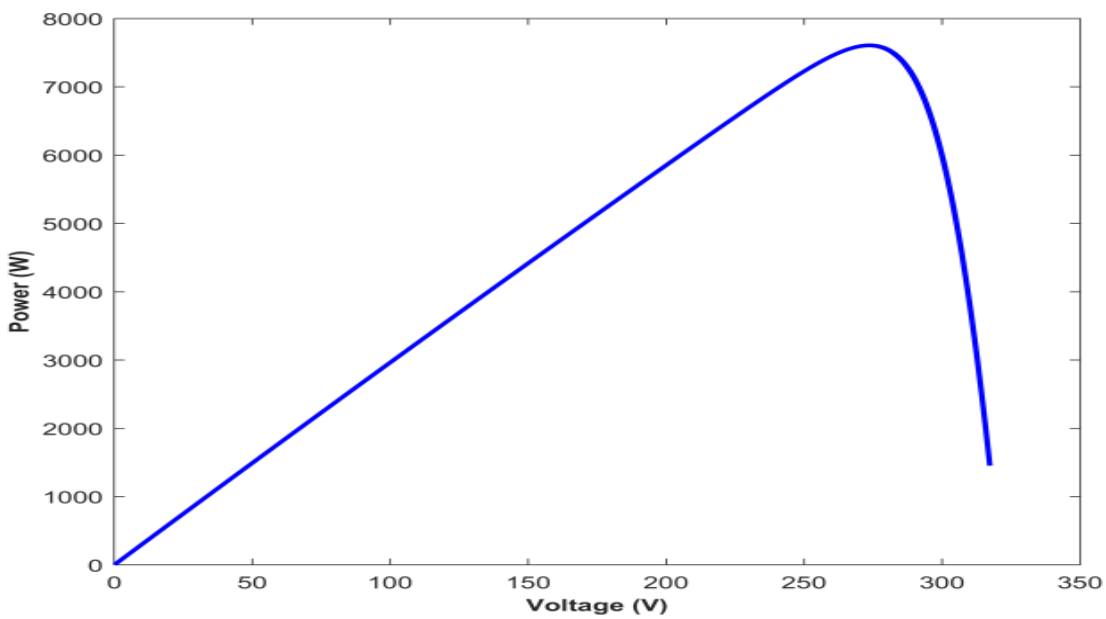
Figure 4.8: PV power and Battery power characteristics for case-1, (a) PV power, and (b) Battery power.

Figure 4.8 shows the PV power curve characteristics and battery power characteristics for constant irradiance of $1000W/m^2$. Figure 4.8 (a) shows the PV power characteristics. When the reference voltage is 400 V, the power generated is 2648.15 W at time 0.15 sec. Similarly, when the reference voltage is 500 V, the power generated is 6882.12 W at time 0.15 sec. Figure 4.8 (b) shows the battery power characteristics for constant irradiance of $1000W/m^2$. When the reference voltage is 400 V, the power generated is -117808.83 W at time 0.2 sec. Similarly, when the reference voltage is 500 V, the power generated is 4421.64 W at time 0.2 sec.

Figure 4.9 shows the V-I characteristics and P-V characteristics for constant irradiance of $1000W/m^2$. Figure 4.9 (a) shows the V-I characteristics for constant irradiance of $1000W/m^2$. At time 0.06 sec, the voltage across the current of 30 A is 0.1502 V. The voltage across the current of 28.91A is 250.1 V at time 0.57 sec. Figure 4.9 (b) shows the P-V characteristics for constant irradiance of $1000W/m^2$. At time 0.06 sec, the power across the voltage of 261.77 V is 6328.01 W. The power across the voltage of 267.92V is 7572 W at time 0.69 sec, which is the maximum possible power that can be attained using the proposed strategy of MPPT.



(a)



(b)

Figure 4.9: V-I and P-V characteristics for case-1, (a) V-I characteristics, (b) P-V characteristics.

Case-2:

In this scenario, the irradiance level is varied from 0 W/m^2 to 200 W/m^2 till 0.2 sec, 200 W/m^2 to 600 W/m^2 till 0.4 sec, 600 W/m^2 to 200 W/m^2 till 0.55 sec, and finally 200 W/m^2 to 1000 W/m^2 till 0.7 sec, and the corresponding battery power, PV power, VI characteristics, and the PV characteristics are analyzed. Figure 4.10 shows the irradiance of PV in case-2.

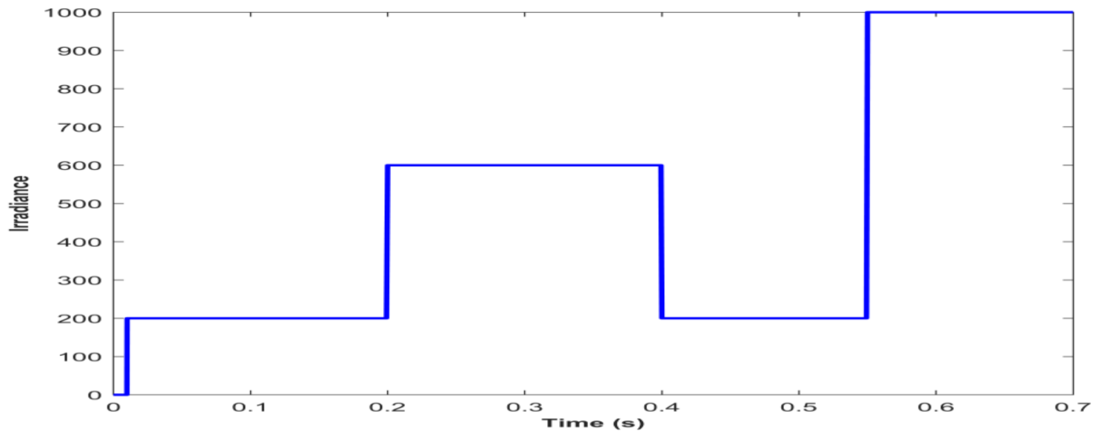
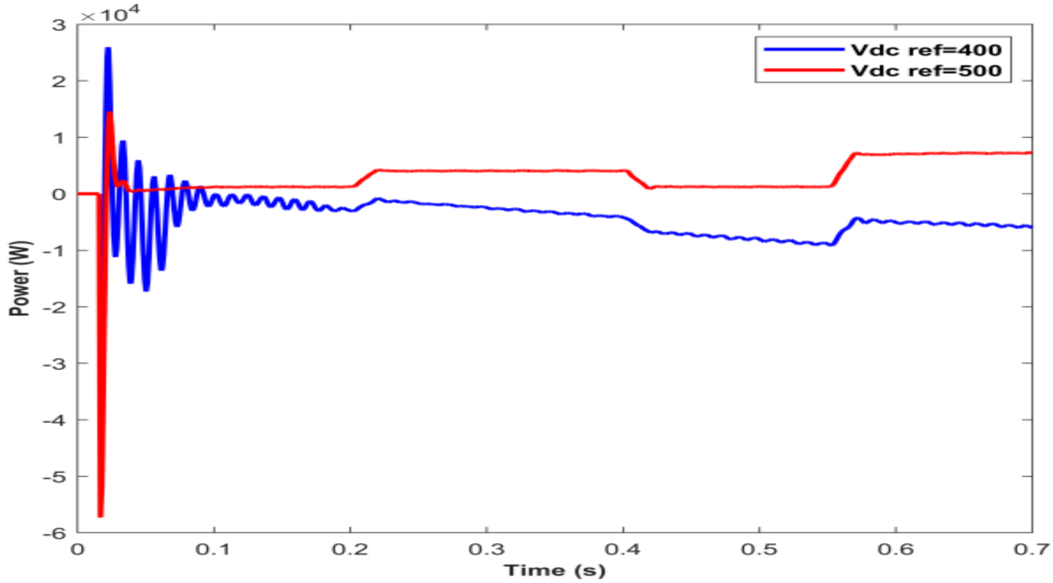
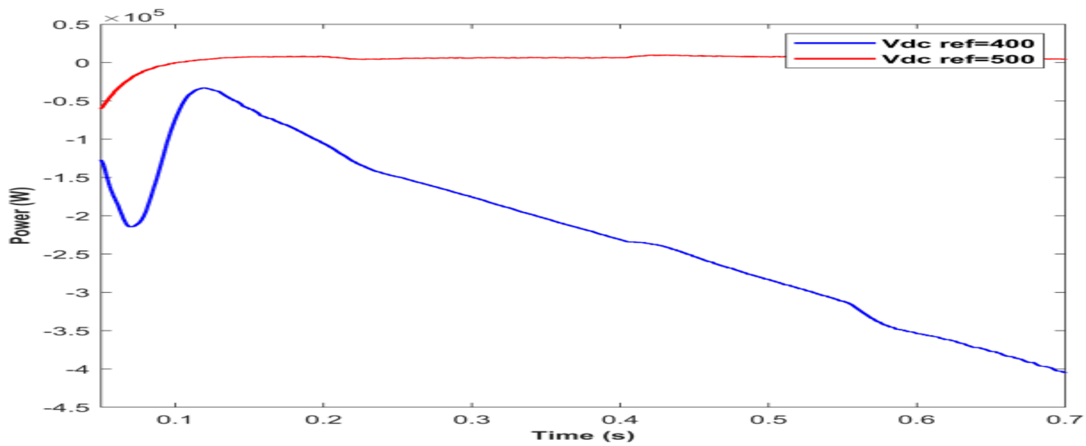


Figure 4.10: Irradiance Curve at Case-2.

Figure 4.11 shows the PV power characteristics and the battery power characteristics for the irradiance in case-2. Figure 4.11 (a) shows the PV power curve characteristics for the irradiance in case-2. When the reference voltage is 400 V, the power generated is -2180 W at time 0.15 sec. Similarly, when the reference voltage is 500 V, the power generated is 1222.05 W at time 0.15 sec. Figure 4.11 (b) shows the battery power characteristics for the irradiance of case-2. When the reference voltage is 400 V, the power generated is -105528.29 W at time 0.2 sec. Similarly, when the reference voltage is 500 V, the power generated is 7822.66 W at time 0.2 sec.

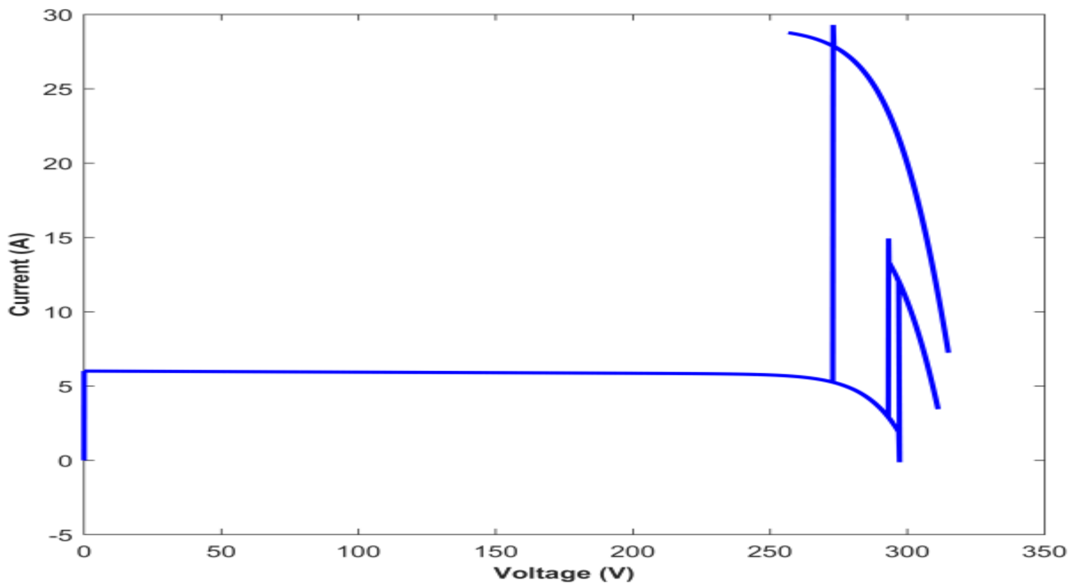


(a)

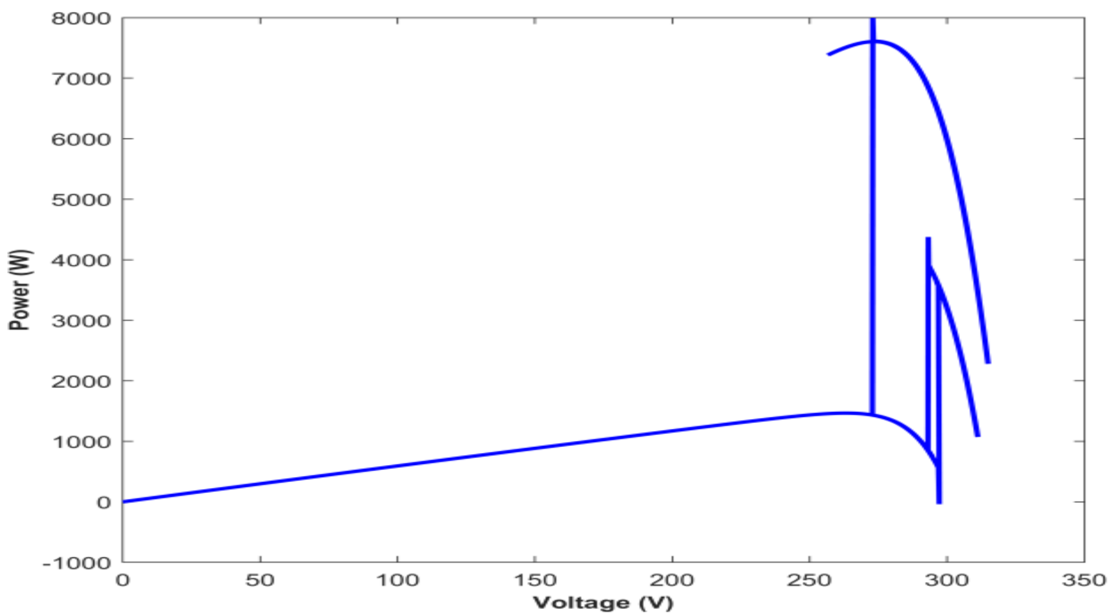


(b)

Figure 4.11: PV power and Battery power characteristics for case-1, (a) PV power, (b) Battery power.



(a)



(b)

Figure 4.12: V-I characteristics and PV characteristics for case-2, (a) V-I characteristics, (b) P-V characteristics.

Figure 4.12 shows the V-I characteristics and the PV characteristics for irradiance of case-2. Figure 4.12 (a) shows the V-I characteristics for irradiance of case-2. At time 0.06 sec, the voltage across the current of 2.88 A is 293.19 V. The voltage across the current of 2.75 A is 293.74 V at time 0.17 sec. Figure 4.12 (b) shows the P-V characteristics for irradiance of case-2. At time 0.06 sec, the power across the voltage of 293.19V is 845.73W. The power across the voltage of 269.33V is 7586.07W at time 0.69 sec, which is the maximum possible power that can be attained using the proposed strategy of MPPT in case-2.

Case-3: In this scenario, the irradiance level is varied from 0 W/m^2 to 200 W/m^2 till 0.2 sec, 200 W/m^2 to 500 W/m^2 till 0.4 sec, 500 W/m^2 to 800 W/m^2 till 0.4 sec, and finally maintained at 800 W/m^2 till 0.7 sec, and the corresponding battery power, PV power, VI characteristics, and the PV characteristics are analyzed. Figure 4.13 shows the irradiance of PV in case-3.

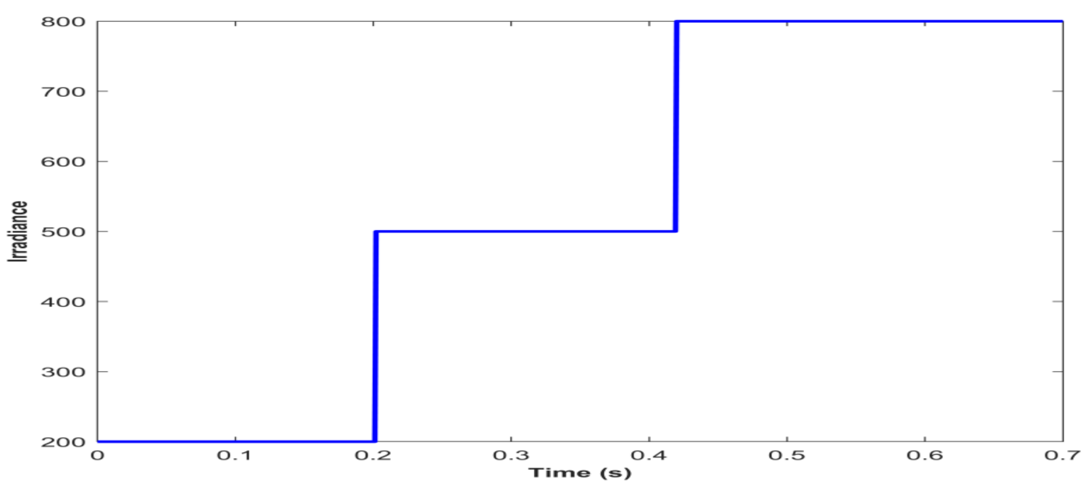
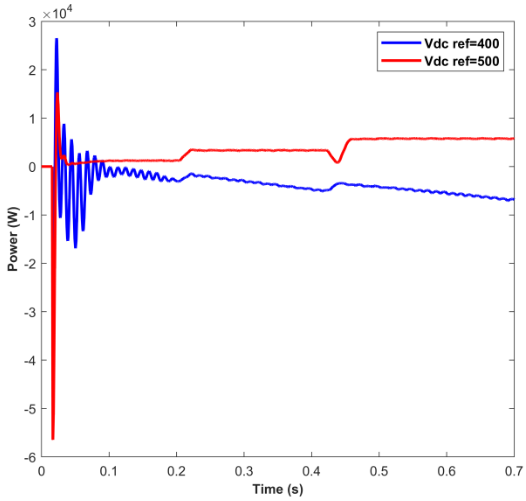
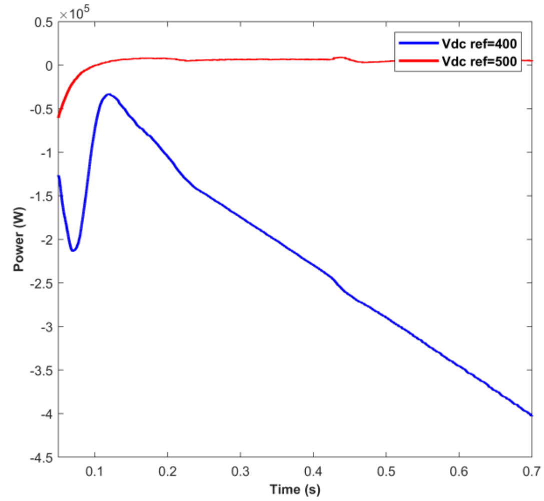


Figure 4.13: Irradiance curve at case-3.

Figure 4.14 shows the PV power curve characteristics and the battery power curve for the irradiance in case-3. Figure 4.14 (a) shows the PV curve characteristics for the irradiance in case-3. When the reference voltage is 400 V, the power generated is -1094.4 W at time 0.15 sec. Similarly, when the reference voltage is 500 V, the power generated is 1258.2 W at time 0.15 sec. Figure 4.14 (b) shows the battery power characteristics for the irradiance of case-3. When the reference voltage is 400 V, the power generated is -10507 W at time 0.2 sec. Similarly, when the reference voltage is 500 V, the power generated is 6874.6 W at time 0.2 sec.



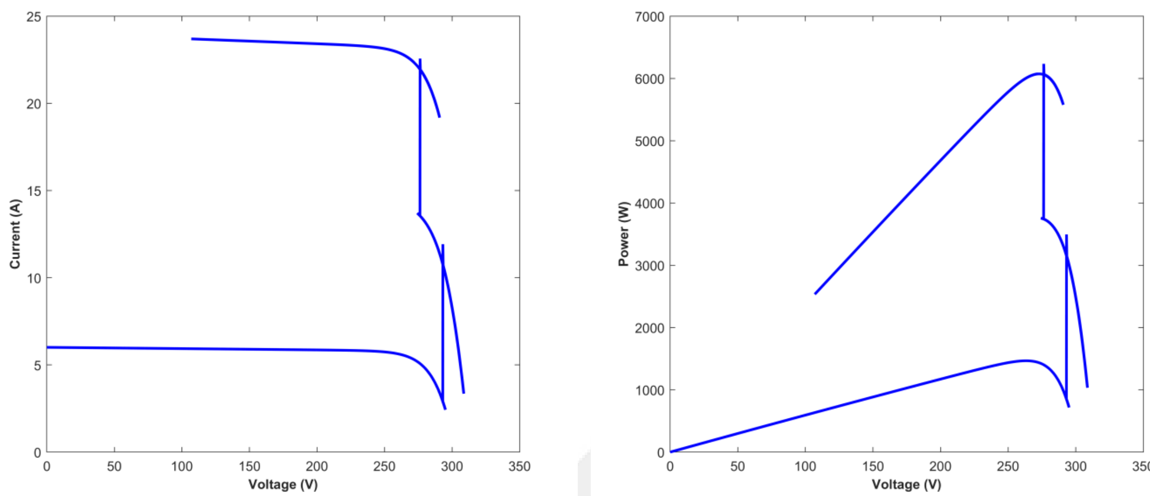
(a)



(b)

Figure 4.14: PV Power Characteristics and Battery power Characteristics in Case-3, (a) PV Power, and (b) Battery Power.

Figure 4.15 shows the V-I characteristics and the P-V characteristics for irradiance of case-3. Figure 4.15 (a) shows the V-I characteristics for irradiance of case-3. At time 0.4 sec, the voltage across the current of 9.4 A is 296.98 V. The voltage across the current of 22.81 A is 293.74 V at time 263.17 sec. Figure 4.15 (b) shows the P-V characteristics for irradiance of case-3. At time 0.6 sec, the power across the voltage of 254.4V is 5866.9 W. The power across the voltage of 263.17V is 6003.55W at time 0.69 sec, which is the maximum possible power that can be attained using the proposed strategy of MPPT in case-3.



(a)	(b)

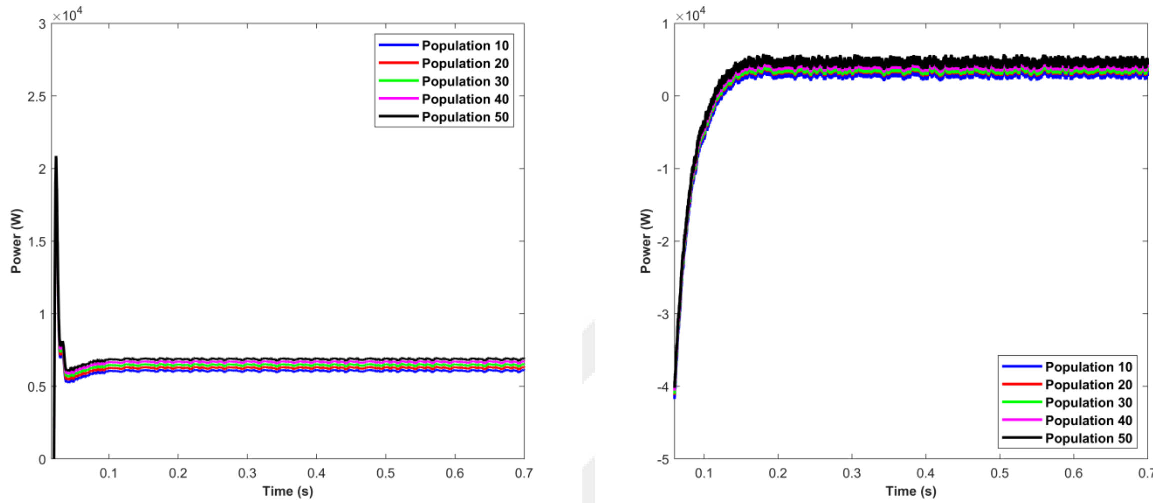
Figure 4.15: V-I Characteristics and P-V Characteristics for Case-2, (a) V-I Characteristics, and P-V Characteristics.

4.5.1.2 Performance in Terms of Varying Population Size

The results in this section are analyzed in terms of varying population size at three cases of irradiance levels in such a way to check the effectiveness of the system for varying reference voltages.

Case-1:

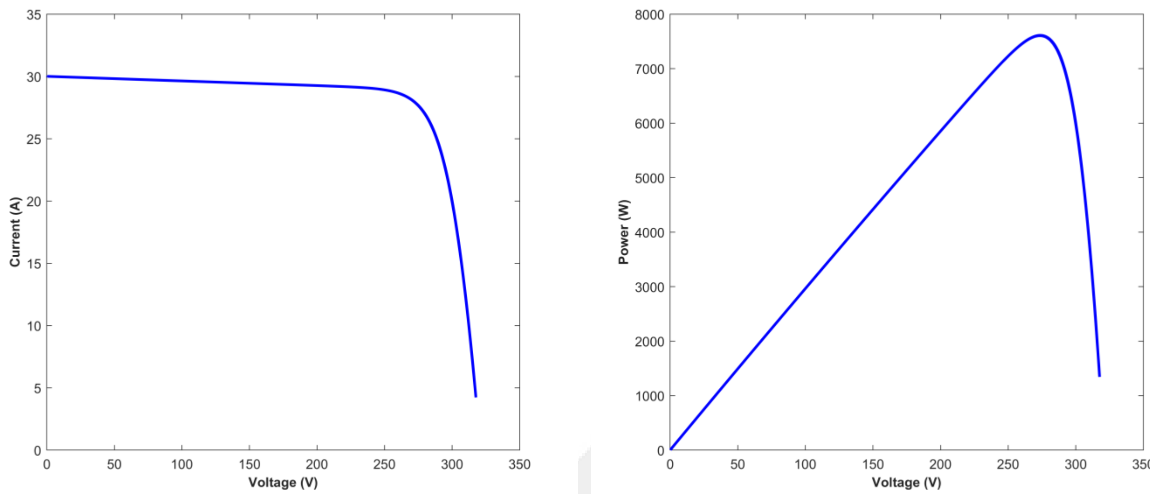
In this scenario, the irradiance level is maintained constant at $1000W/m^2$, and the corresponding battery power, PV power, V-I characteristics, and the P-V characteristics for varying population size are analyzed. Figure 4.16 shows the PV power and Battery power characteristics of the proposed model in terms of varying population size. Figure 4.16 (a) depicts the PV power characteristics in case-1. When the population size is 10, the PV power generated across the time 0.1 sec is 5606 W. Similarly, when the population size is 30, the PV power generated across the time 0.1 sec is 6006 W. The PV power generated for the population size of 50 at time 0.1 sec is 6856 W. Figure 4.16 (b) depicts the battery power characteristics in case 1. When the population size is 10, the battery power generated across the time 0.1 sec is -4860W. Similarly, when the population size is 30, the PV power generated across the time 0.1 sec is -4458W. The PV power generated for the population size of 50 at time 0.1 sec is -4058 W.



(a) (b)

Figure 4.16: PV Power and Battery Power Characteristics for Case-1, (a) PV Power Characteristics, and (b) Battery power Characteristics.

Figure 4.17 shows the V-I and P-V characteristics of the proposed model in terms of varying population size. Figure 4.17 (a) depicts the V-I characteristics in case-1. At time 0.4 sec, the voltage across the current of 28.95 A is 247.81 V. The voltage across the current of 28.96 A is 247.01 V at time 0.6 sec. Figure 4.17 (b) shows the P-V characteristics for irradiance of case-3. At time 0.6 sec, the power across the voltage of 248.4V is 7189 W. The power across the voltage of 247V is 7154 W at time 0.69 sec, which is the maximum possible power that can be attained using the proposed strategy of MPPT in case-3.

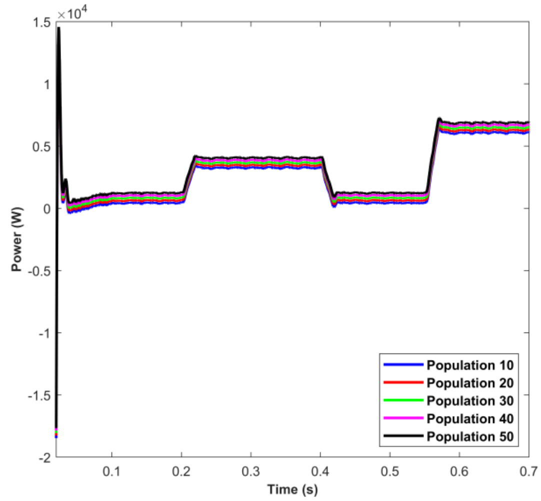


a)

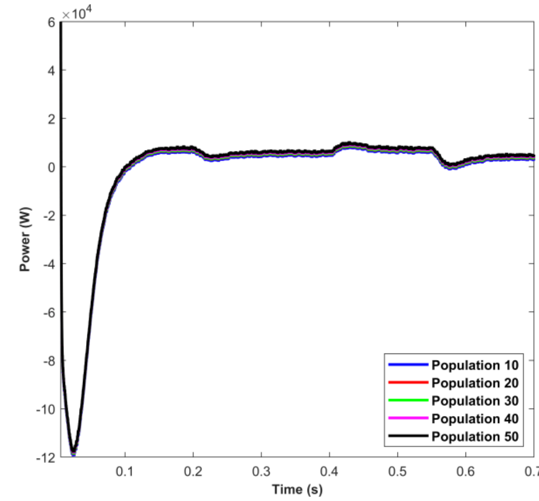
Figure 4.17: V-I Characteristics and P-V Characteristics for Case-1, (a) V-I Characteristics, and P-V Characteristics.

Case-2:

In this scenario, the irradiance level is varied from 0 W/m^2 to 200 W/m^2 till 0.2 sec, 200 W/m^2 to 600 W/m^2 till 0.4 sec, 600 W/m^2 to 200 W/m^2 till 0.55 sec, and finally 200 W/m^2 to 1000 W/m^2 till 0.7 sec, and the corresponding battery power, PV power, VI characteristics, and the PV characteristics are analyzed. Figure 4.18 shows the PV power characteristics and the battery power characteristics for the irradiance in case-2. Figure 4.18 (a) shows the PV power curve characteristics for the irradiance in case-2. When the population size is 10, the PV power generated across the time 0.1 sec is 147 W. Similarly, when the population size is 30, the PV power generated across the time 0.1 sec is 347 W. The PV power generated for the population size of 50 at time 0.1 sec is 1197 W. Figure 4.18 (b) depicts the battery power characteristics in case-2. When the population size is 10, the battery power generated across the time 0.1 sec is -965W. Similarly, when the population size is 30, the PV power generated across the time 0.1 sec is -564W. The PV power generated for the population size of 50 at time 0.1 sec is -164 W.



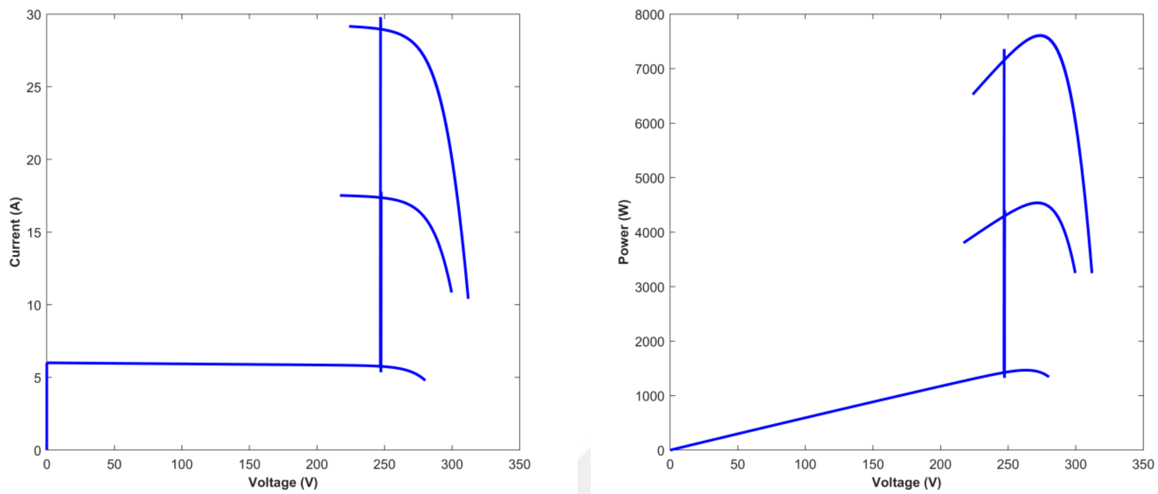
(a)



(b)

Figure 4.18: PV Power and Battery power Characteristics for Case-2, (a) PV Power, (b) Battery Power.

Figure 4.19 shows the V-I characteristics and the PV characteristics for irradiance of case-2. Figure 4.19 (a) shows the V-I characteristics for irradiance of case-2. At time 0.06 sec, the voltage across the current of 5.74 A is 249 V. The voltage across the current of 5.75 A is 248 V at time 0.17 sec. Figure 4.19 (b) shows the P-V characteristics for irradiance of case-2. At time 0.06 sec, the power across the voltage of 249V is 1433W. The power across the voltage of 247V is 7152W at time 0.69 sec, which is the maximum possible power that can be attained using the proposed strategy of MPPT in case-2.

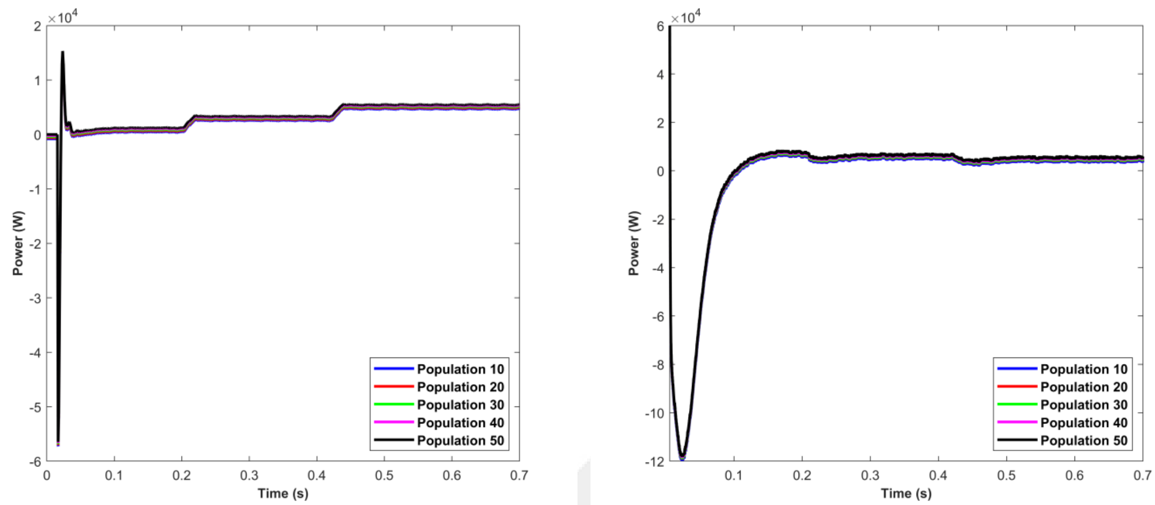


(a) (b)

Figure 4.19: V-I Characteristics and PV Characteristics for Case-2, (a) V-I Characteristics, (b) P-V Characteristics.

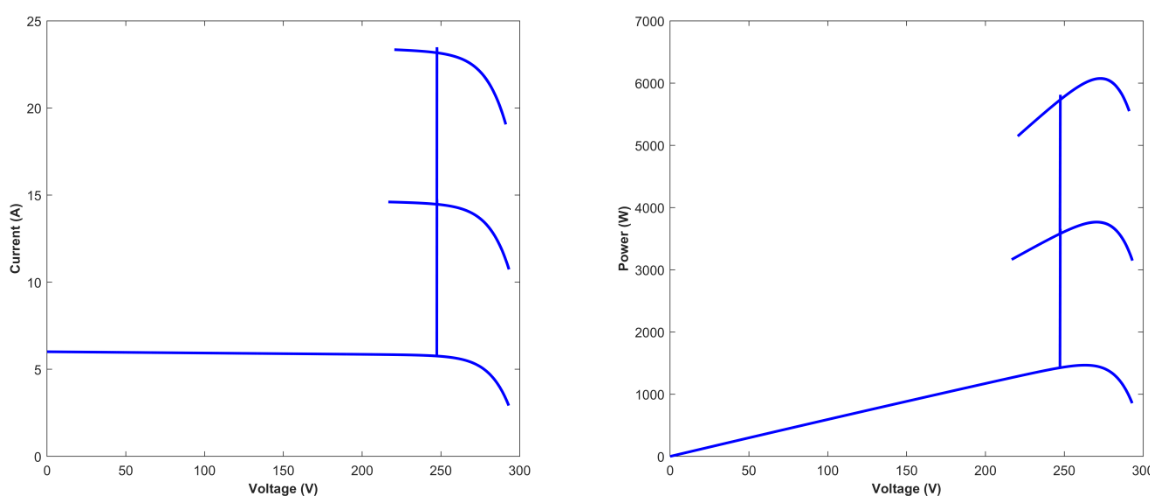
Case-3:

In this scenario, the irradiance level is varied from 0 W/m^2 to 200 W/m^2 till 0.2 sec, 200 W/m^2 to 500 W/m^2 till 0.4 sec, 500 W/m^2 to 800 W/m^2 till 0.4 sec, and finally maintained at 800 W/m^2 till 0.7 sec, and the corresponding battery power, PV power, VI characteristics, and the PV characteristics for varying population size are analyzed. Figure 4.20 shows the PV power curve characteristics and the battery power curve for the irradiance in case-3. Figure 4.20 (a) shows the PV curve characteristics for the irradiance in case-3. When the population size is 10, the PV power generated across the time 0.1 sec is 140 W. Similarly, when the population size is 30, the PV power generated across the time 0.1 sec is 340 W. The PV power generated for the population size of 50 at time 0.1 sec is 1190 W. Figure 4.20 (b) depicts the battery power characteristics in case-3. When the population size is 10, the battery power generated across the time 0.1 sec is -1297W. Similarly, when the population size is 30, the PV power generated across the time 0.1 sec is -897W. The PV power generated for the population size of 50 at time 0.1 sec is -497 W.



(a) **(b)**

Figure 4.20 PV power Characteristics and Battery Power Characteristics in Case-3, (a) PV Power, and (b) Battery Power.



(a) **(b)**

Figure 4.21: V-I Characteristics and P-V Characteristics for Case-3, (a) V-I Characteristics, and P-V Characteristics.

Figure 4.21 shows the V-I characteristics and the PV characteristics for irradiance of case-3. Figure 4.21 (a) shows the V-I characteristics for irradiance of case-3. At time 0.06 sec, the voltage across the current of 5.74 A is 250 V. The voltage across the current of 5.75 A is 248 V at time 0.17 sec. Figure 4.21 (b) shows the P-V characteristics for irradiance of case-3. At time 0.06 sec, the power across the voltage of 250V is 1436W. The power across the voltage of 247V is 5721W at time 0.69 sec, which is the maximum possible power that can be attained using the proposed strategy of MPPT in case-2.

4.6 SUMMARY

This chapter deliberates the analysis of the results obtained from the proposed BT-CT-based sugeno fuzzy logic controller in the extraction of maximum power point from the PV system. The results are analyzed for two conditions, such as varying reference voltage and varying population size for three cases of irradiance levels. The PV power output, battery power output, V-I characteristics, and the P-V characteristics of the system are analyzed to prove the effectiveness of the proposed BT-CT-based sugeno fuzzy logic controller in MPPT.

5. COMPARATIVE RESULTS

5.1 INTRODUCTION

In order to determine the effectiveness of the proposed BT-CT-based sugeno FLC controller in MPPT for hybrid energy systems, the proposed method is evaluated with the comparative methods, such as the conventional Perturb and Observe (P&O) method, Incremental Conductance (INC) method, FLC, Bat optimization tuned FLC (BAT-Fuzzy) method. The analysis is carried out in terms of PV power and battery power for three cases of irradiance measures.

Case-1:

In this scenario, the irradiance level is maintained constant at $1000 W/m^2$, and the corresponding battery power and PV power are analyzed.

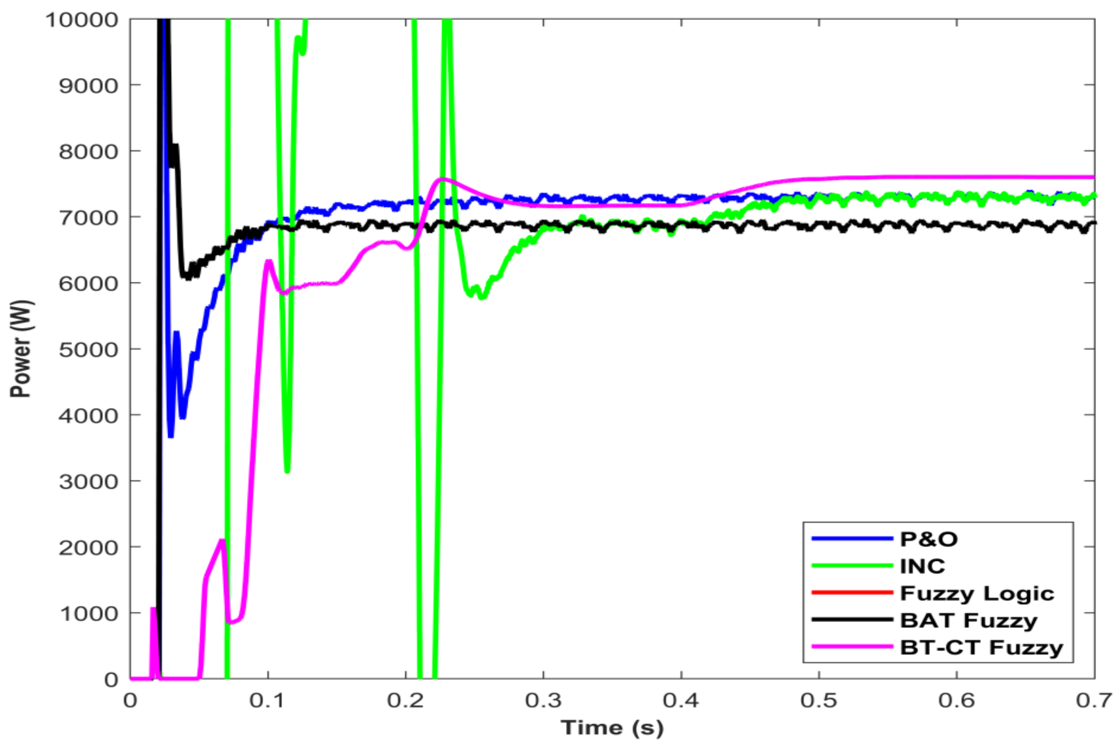


Figure 5.1: PV Power Obtained at Case-1.

Figure 5.1 shows the PV power obtained at constant irradiance of $1000W/m^2$. The PV power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based sugeno FLC at the time instance of 0.5 sec is 7328, 7269, 6883, 6883, and 7571, respectively. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.69 sec is 7300, 7311, 6891, 6891, and 7601, respectively.

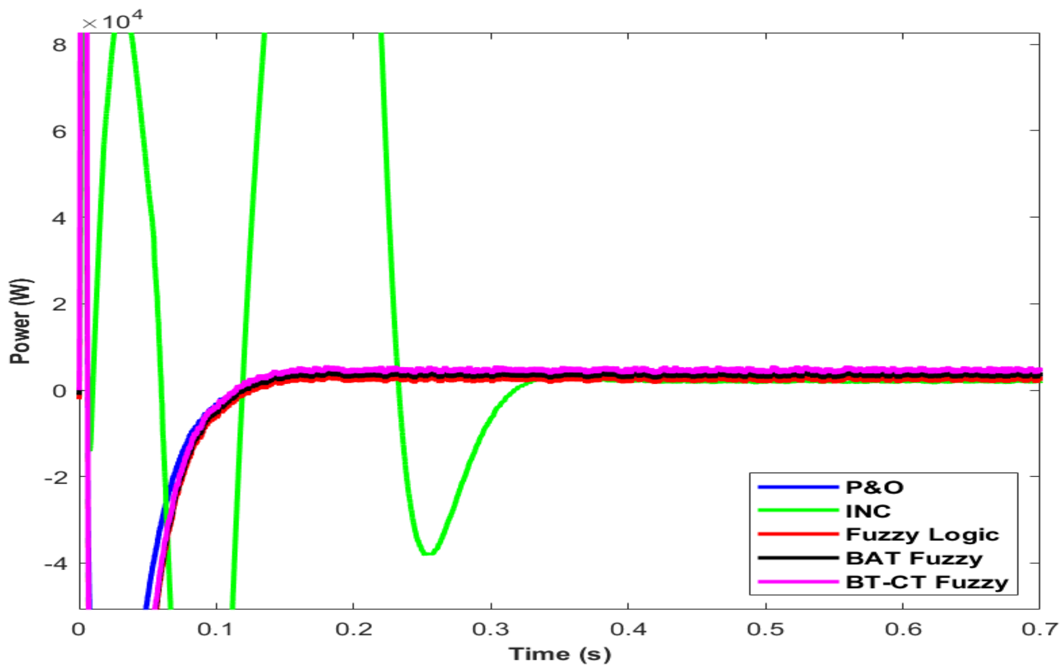


Figure 5.2: Battery Power Obtained at Case-1.

Figure 5.2 shows the battery power obtained at constant irradiance of $1000W/m^2$. The battery power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.5 sec is 3415, 1786, 3388, 3688, and 4489, respectively. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.7 sec is 3545, 1892, 3420, 3720, and 4521, respectively. Figure 5.3 depicts the bar chart representing the generation of power for the time period of 0 to 0.7 sec using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC and are compared with the real power generated using the PV system. The maximum actual power generated from the PV system is 7631 W. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC is 7300, 7311, 6891, 6891, and 7601, respectively.

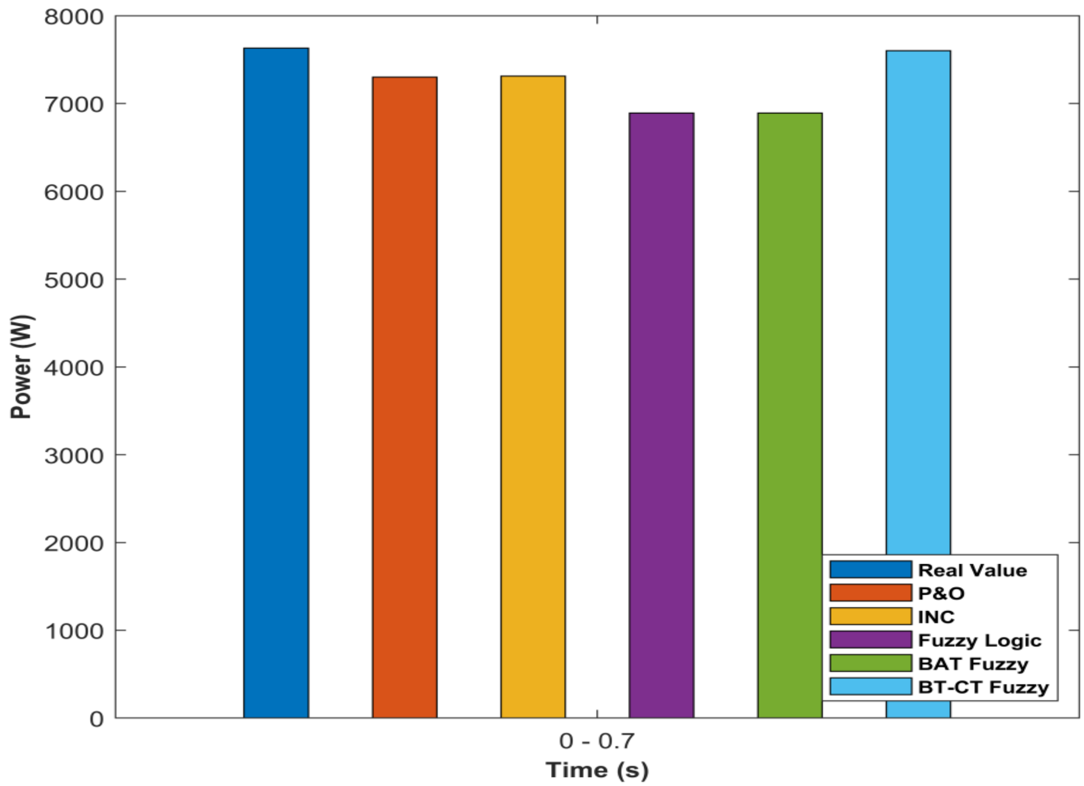


Figure 5.3: Comparative Analysis Using Bar Chart in Case-1.

Case-2:

In this scenario, the irradiance level is varied from 0 W/m^2 to 200 W/m^2 till 0.2 sec, 200 W/m^2 to 600 W/m^2 till 0.4 sec, 600 W/m^2 to 200 W/m^2 till 0.55 sec, and finally 200 W/m^2 to 1000 W/m^2 till 0.7 sec, and the corresponding battery power and PV power are analyzed. Figure 5.3 shows the PV power characteristics for the irradiance in case-2. Figure 5.4 shows the PV power obtained at the irradiance of case-2. The PV power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.5 sec is 868, 1227, 1025, 1226, and 1428, respectively. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.69 sec is 7262, 7283, 6677, 6878, and 7593, respectively.

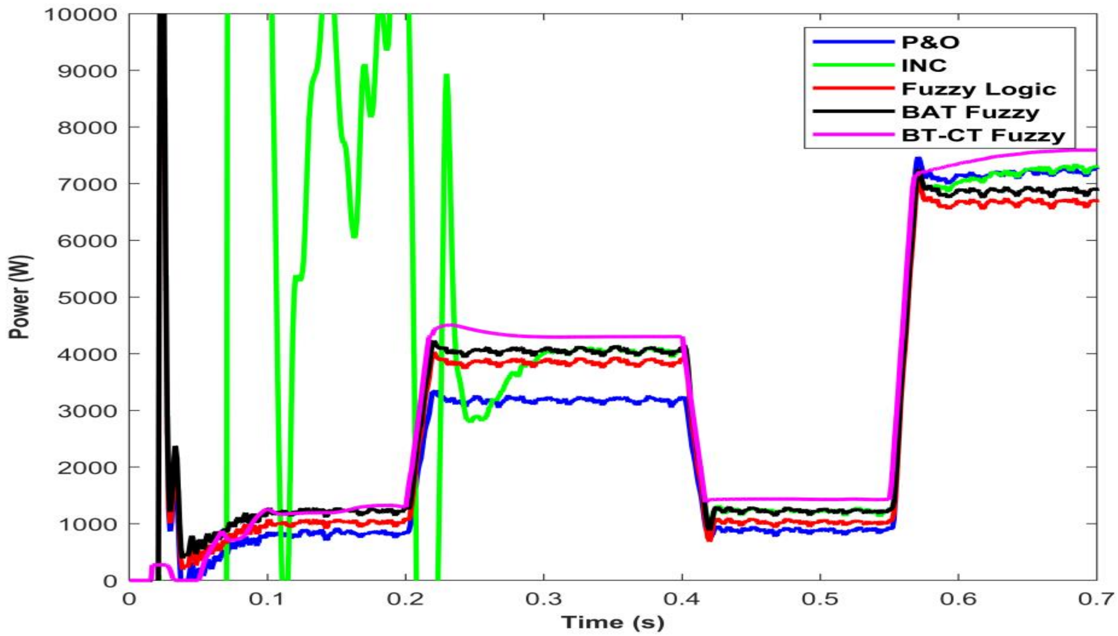


Figure 5.4: PV Power Obtained at Case-2.

Figure 5.5 shows the battery power obtained at the irradiance of case-2. The battery power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.5 sec is 6054, 3116, 6450, 6749, and 7550, respectively. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.7 sec is 3501, 1719, 3651, 3950, and 4751, respectively.

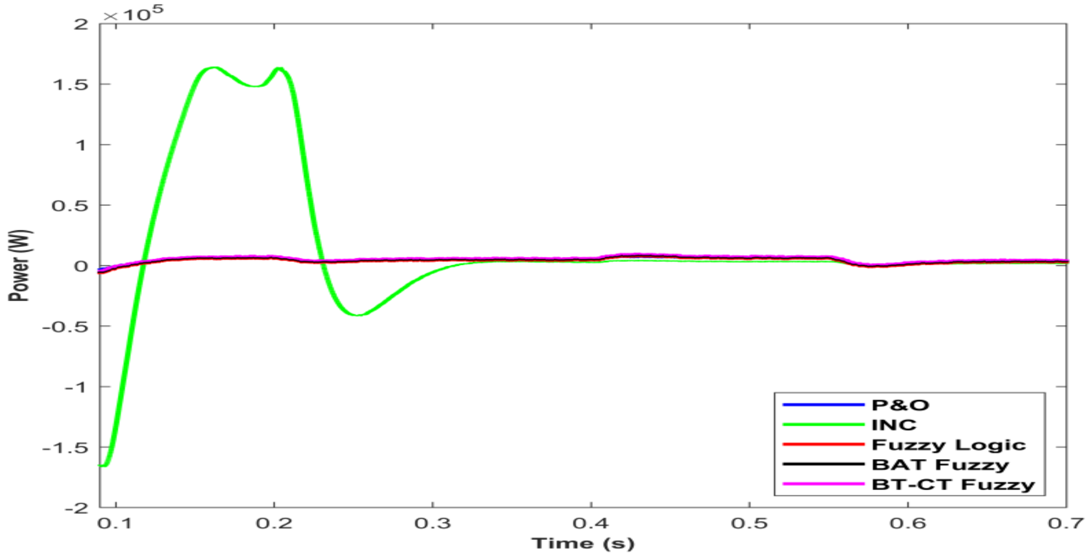


Figure 5.5: Battery Power Obtained at Case-2.

Figure 5.6 depicts the bar chart representing the generation of power using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC in case-2. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.015 to 0.2 is 868, 1227, 1025, 1226, and 1428, respectively. The real power generated at this instance is 1466 W. Similarly, the power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.2 to 0.4 is 3173, 4066, 3883, 4084, and 4301, respectively. The actual power generated using the PV system at this instance is 4536 W. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.4 to 0.55 is 868, 1227, 1025, 1226, and 1428, respectively. The actual power generated using the PV system at this instance is 1466 W. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.55 to 0.7 is 7300, 7311, 6891, 6891, and 7601, respectively. The actual power generated using the PV system at this instance is 7631 W.

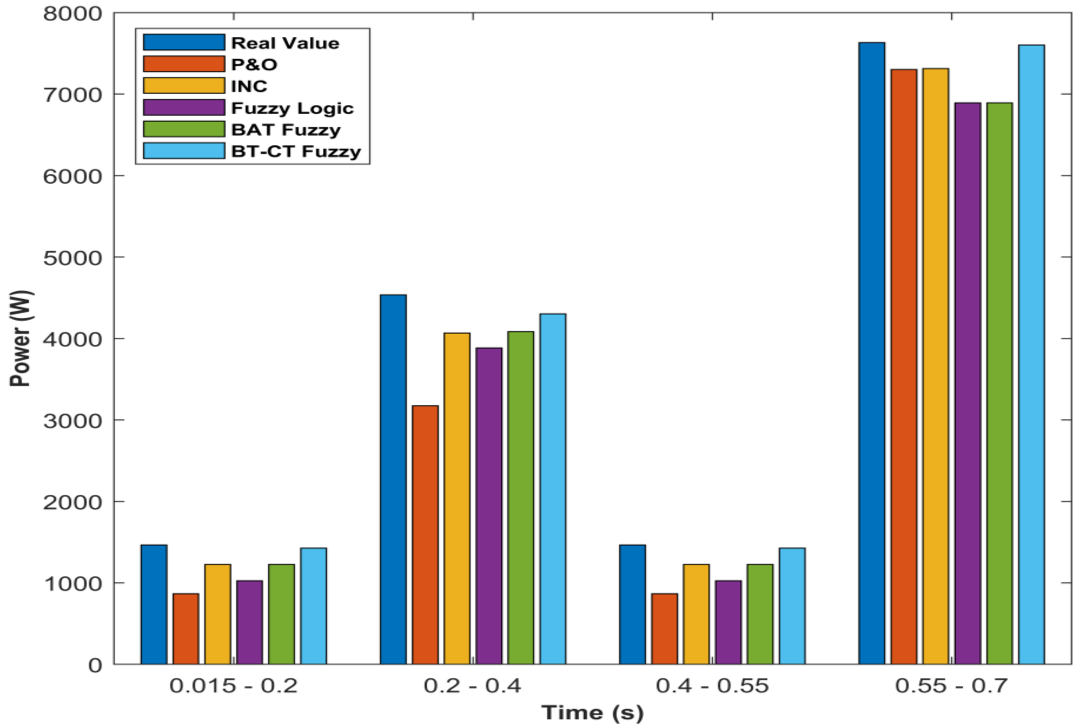


Figure 5.6: Comparative Analysis Using Bar Chart in Case-2.

Case-3:

In this scenario, the irradiance level is varied from 0 W/m^2 to 200 W/m^2 till 0.2 sec, 200 W/m^2 to 500 W/m^2 till 0.4 sec, 500 W/m^2 to 800 W/m^2 till 0.4 sec, and finally maintained at 800 W/m^2 till 0.7 sec, and the corresponding battery power and PV power characteristics are analyzed. Figure 5.6 shows the PV power curve characteristics for the irradiance in case-3. Figure 5.7 shows the PV power obtained at the irradiance of case-3. The PV power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.5 sec is 5452, 5731, 5165, 5424, and 1428, respectively. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.69 sec is 5757, 5789, 5234, 5492, and 7593, respectively.

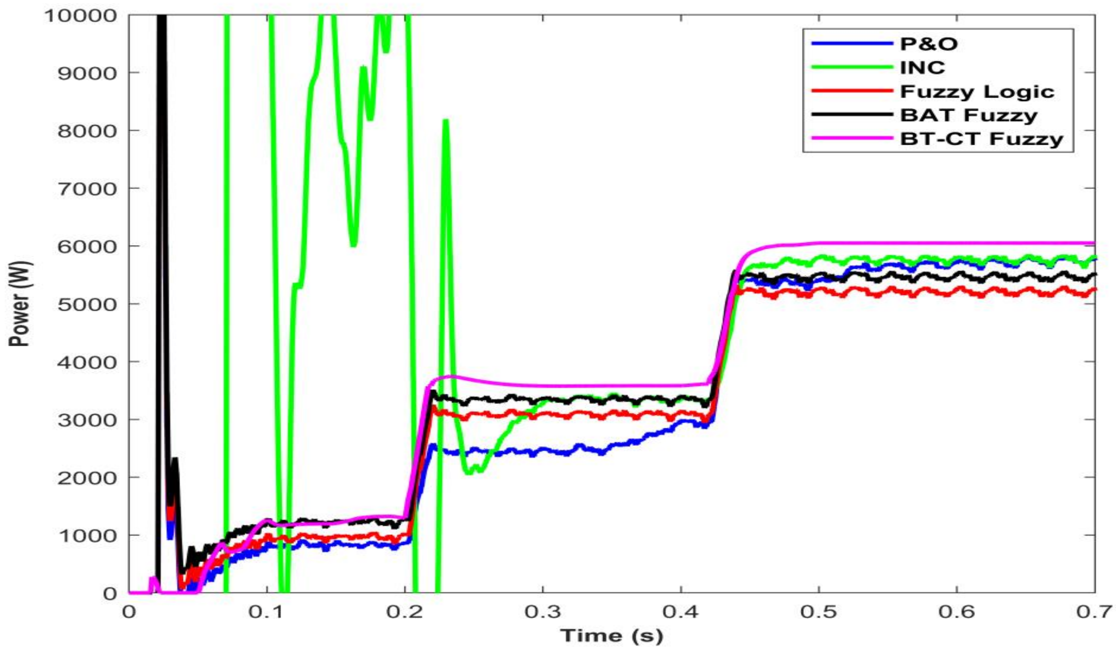


Figure 5.7: PV Power Obtained at Case-3.

Figure 5.8 shows the battery power obtained at the irradiance of case-3. The battery power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.5 sec is 3823, 1849, 5249, 6566, and 7166, respectively. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.7 sec is 3816, 2248, 5597, 7174, and 7774, respectively.

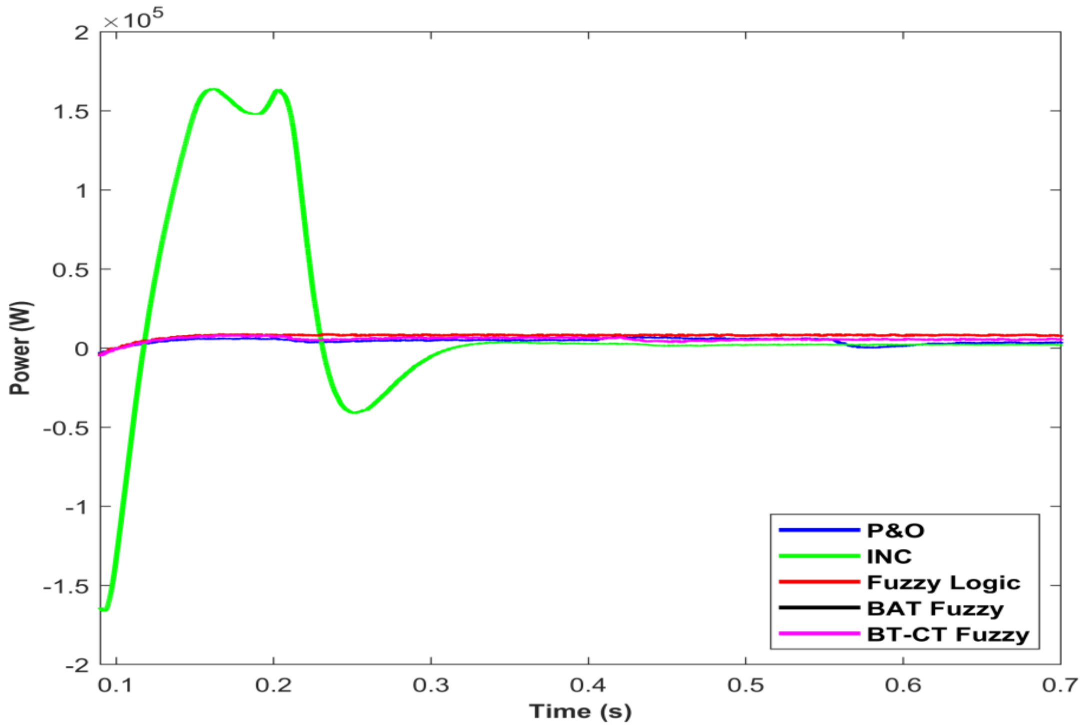


Figure 5.8: PV Power Obtained at Case-3.

Figure 5.9 depicts the bar chart representing the generation of power using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC in case-3. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0 to 0.2 is 773, 1580, 932, 1190, and 1714, respectively. The real power generated at this instance is 1466 W. Similarly, the power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.2 to 0.45 is 2387, 3291, 3039, 3297, and 3425, respectively. The actual power generated using the PV system at this instance is 3766 W. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.45 to 0.7 is 5756, 5789, 5233, 5492, and 5923, respectively. The actual power generated using the PV system at this instance is 6073 W.

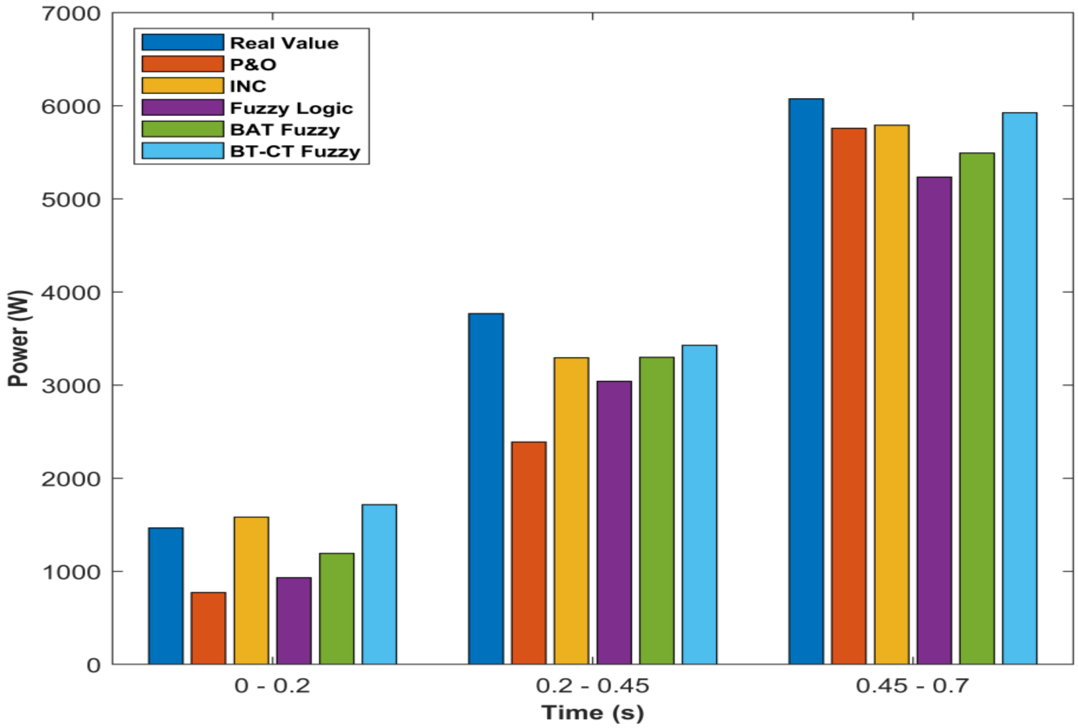


Figure 5.9: Comparative Analysis Using Bar Chart in Case-3.

5.2 SUMMARY

This chapter deliberates the comparative results obtained using the proposed BT-CT-based Sugeno FLC controller and the conventional methods of MPPT. The result implies the effectiveness of the proposed method in terms of PV power and battery power compared to the conventional methods in tracking the maximum power from the PV system in case of increased irradiance levels and the battery energy storage system in case of less irradiance levels. The results thus obtained are compared with the actual power generated from the PV system.

6. CONCLUSION

The increased energy demand and the reduced availability of fossil fuels have led to the search for sustainable alternatives. Harvesting of green energy resources is one of the better alternatives for fossil fuels, due to pollution free power generation. In particular, solar energy is the recently emerging alternative with increased efficiency to solve the problem of increased energy demand. Photovoltaic Electrical Power Generation System (PV-EPGS) involves in the conversion of solar energy into electrical energy. Generally, the PV system comprise of number of PV modules that are connected either in series and parallel. Under some circumstances, the PV panels may observe non-homogeneous irradiation due to the reason of passage of cloud or tree and so on. This may lead to significant reduction in power from the PV panel, and hence there is always a need to control the PV at global maximum power point (GMPP) to make in use of the maximum available power.

This research investigated the control system of a hybrid generation system, developed using the photovoltaic system and a battery operating in a hybrid structure, and the hybrid system is connected grid. In case of these hybrid systems, the maximum power point tracking algorithm is required in order to acquire the maximal power at some operating point. Hence, this research uses the Maximum power point tracking (MPPT) controller, which assures the maximal power point tracking. The important contribution of this research is the development of MPPT strategy based on Sugeno Fuzzy logic controller (Sugeno FLC), the membership function of which is controlled using a hybrid Bat-Cat (BT-CT) optimization algorithm. The error and the change in error are controlled in such a way to tune the duty cycle of the converter that in turn provides the maximum possible power from the PV panel.

6.1 DISCUSSION ON THE MAJOR FINDINGS

The proposed hybrid Bat-Cat optimization tuned Sugeno Fuzzy Logic controller (BT-CT-based sugeno FLC) outperforms the conventional techniques in terms of varying irradiance levels. The results are analyzed for different irradiance levels at constant temperature, in terms of varying population size and reference voltages. The maximum actual power generated from the PV system is 7631W. The power generated in case 1 at constant irradiance of $1000W/m^2$ using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC for the time instance of 0 to 0.7 is 7300, 7311, 6891, 6891, and 7601, respectively.

The power generated in case 2 using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.015 to 0.2 is 868, 1227, 1025, 1226, and 1428, respectively. The real power generated at this instance is 1466 W. Similarly, the power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.2 to 0.4 is 3173, 4066, 3883, 4084, and 4301, respectively. The actual power generated using the PV system at this instance is 4536 W. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.4 to 0.55 is 868, 1227, 1025, 1226, and 1428, respectively. The actual power generated using the PV system at this instance is 1466 W. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.55 to 0.7 is 7300, 7311, 6891, 6891, and 7601, respectively. The actual power generated using the PV system at this instance is 7631 W.

The power generated in case 3 using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0 to 0.2 is 773, 1580, 932, 1190, and 1714, respectively. The real power generated at this instance is 1466 W. Similarly, the power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.2 to 0.45 is 2387, 3291, 3039, 3297, and 3425, respectively. The actual power generated using the PV system at this instance is 3766 W. The power generated using the methods, such as P&O, INC, FLC, BAT-Fuzzy, and the proposed BT-CT-based Sugeno FLC at the time instance of 0.45 to 0.7 is 5756, 5789, 5233, 5492, and 5923, respectively. The actual power generated using the PV system at this instance is 6073 W. Hence, from the discussion, it is evident that the proposed BT-CT-based Sugeno FLC controller outperforms other comparative methods in terms of extraction of maximum power.

The simulation results exhibited the superior performance of the developed framework known as proposed BT-CT-based Sugeno FLC when compared with the other existing techniques, where the maximal power point is tracked effectively and efficiently with least oscillation at highest speed even under an abrupt change in the solar irradiance. Besides, the impact of temperature variations, different states of the partial shading conditions is discussed and the capability of the developed algorithm is analyzed. Furthermore, the capability of the presented algorithm in efficiently controlling the power flow between the electrical network and the hybrid system has been assessed, where it showed a fast transient response and enhanced stability.

6.2 FUTURE SCOPE

In spite of the excellent performance of the proposed method in MPPT, it still undergoes certain issues, like lack of irradiance during rainy reasons and reduced capacity of battery. Hence, the future work will be focused on using a combining two or more renewable energy resources in such a way to provide continuous power supply. Hybridizing wind energy conversion system with the PV panel complement each other during day and night for the continuous generation power supply to the grid. In addition, usage of some other hybrid optimization technique can be made for enhancing the performance of the sugeno FLC in terms of computation time. Intelligent techniques, other than sugeno FLC can also be used to handle the drawbacks associated with the sugeno FLC, like the dependence of human expertise and to obtain accurate results.

REFERENCES

Ahmed, M., Abdelrahem, M., Kennel, R. and Hackl, C.M., 2020, "Maximum Power Point Tracking Based Model Predictive Control and Extended Kalman Filter Using Single Voltage Sensor for PV Systems", In Proceedings of the 29th IEEE International Symposium on Industrial Electronics (ISIE), pp. 1039-1044, 2020.

Jain, A.A., Rabi, B.J. and Darly, S.S., "Application of QOCGWO-RFA for maximum power point tracking (MPPT) and power flow management of solar PV generation system", International Journal of Hydrogen Energy, vol.45, no.7, pp.4122-4136, 2020.

Mansoor, M., Mirza, A.F. and Ling, Q., "Harris hawk optimization-based MPPT control for PV Systems under Partial Shading Conditions", Journal of Cleaner Production, vol.274, pp.122857, 2020.

Pan, Z., Quynh, N.V., Ali, Z.M., Dadfar, S. and Kashiwagi, T., "Enhancement of maximum power point tracking technique based on PV-Battery system using hybrid BAT algorithm and fuzzy controller", Journal of Cleaner Production, vol.274, pp.123719, 2020.

Parvaneh, M.H. and Khorasani, P.G., "A new hybrid method based on fuzzy logic for maximum power point tracking of photovoltaic systems", Energy Reports, vol.6, pp.1619-1632, 2020.

Bhukya, L. and Nandiraju, S., "A novel photovoltaic maximum power point tracking technique based on grasshopper optimized fuzzy logic approach", International Journal of Hydrogen Energy, vol.45, no.16, pp.9416-9427, 2020.

Ahmed, N.A., Abdul Rahman, S. and Alajmi, B.N., "Optimal controller tuning for P&O maximum power point tracking of PV systems using genetic and cuckoo search algorithms", International Transactions on Electrical Energy Systems, pp.e12624, 2020.

Dehghani, M., Taghipour, M., Gharehpetian, G.B. and Abedi, M., "Optimized fuzzy controller for MPPT of grid-connected PV systems in rapidly changing atmospheric conditions", Journal of Modern Power Systems and Clean Energy, 2020.

Abdel-Salam, M., El-Mohandes, M.T. and El-Ghazaly, M., "An efficient tracking of MPP in PV systems using a newly-formulated P&O-MPPT method under varying irradiation levels", Journal of Electrical Engineering & Technology, vol.15, no.1, pp.501-513, 2020.

Zou, Y., Yan, F., Wang, X. and Zhang, J., "An efficient fuzzy logic control algorithm for photovoltaic maximum power point tracking under partial shading condition", Journal of the Franklin Institute, vol.357, no.6, pp.3135-3149, 2020.

Tian, A.Q., Chu, S.C., Pan, J.S. and Liang, Y., "A novel pigeon-inspired optimization based MPPT technique for PV systems", Processes, vol.8, no.3, pp.356, 2020.

Eltamaly, A.M., "An Improved Cuckoo Search Algorithm for Maximum Power Point Tracking of Photovoltaic Systems under Partial Shading Conditions", Energies, vol.14, no.4, pp.953, 2020.

Takruri, M., Farhat, M., Barambones, O., Ramos-Hernanz, J.A., Turkieh, M.J., Badawi, M., AlZoubi, H. and Abdus Sakur, M., "Maximum Power Point Tracking of PV System Based on Machine Learning", Energies, vol.13, no.3, pp.692, 2020.

Ibrahim, A.W., Shafik, M.B., Ding, M., Sarhan, M.A., Fang, Z., Alareqi, A.G., Almoqri, T. and Al-Rassas, A.M., "PV maximum power-point tracking using modified particle swarm optimization under partial shading conditions", Chinese Journal of Electrical Engineering, vol.6, no.4, pp.106-121, 2020.

Phanden, R.K., Sharma, L., Chhabra, J. and Demir, H.İ., "A novel modified ant colony optimization based maximum power point tracking controller for photovoltaic systems", Materials Today: Proceedings, vol.38, pp.89-93, 2021.

Dollinger, B. and Dietrich, K., "Storage systems for integrating wind and solar energy in Spain", In proceedings of IEEE International Conference on Renewable Energy Research and Applications (ICRERA), pp. 361-365, 2013.

Sangwongwanich, A., Yang, Y. and Blaabjerg, F., "Development of flexible active power control strategies for grid-connected photovoltaic inverters by modifying MPPT algorithms", In proceedings of IEEE 3rd International Future Energy Electronics Conference and ECCE Asia (IFEEC 2017-ECCE Asia), pp. 87-92, 2017.

Erdil, E., Ilkan, M. and Egelioglu, F., "An experimental study on energy generation with a photovoltaic (PV)–solar thermal hybrid system", Energy, vol.33, no.8, pp.1241-1245, 2008.

Erdil, E., Ilkan, M. and Egelioglu, F., "An experimental study on energy generation with a photovoltaic (PV)–solar thermal hybrid system", Energy, vol.33, no.8, pp.1241-1245, 2008.

Ağbulut, Ü., "Turkey’s electricity generation problem and nuclear energy policy", Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, vol.41, no.18, pp.2281-2298, 2019.

Mosaad, M.I., abed el-Raouf, M.O., Al-Ahmar, M.A. and Banakher, F.A., "Maximum power point tracking of PV system based cuckoo search algorithm; review and comparison", Energy Procedia, vol.162, pp.117-126, 2019.

Ağbulut, Ü. and Sarıdemir, S., "A general view to converting fossil fuels to cleaner energy source by adding nanoparticles", International Journal of Ambient Energy, pp.1-6, 2019.

Luo, L., Abdulkareem, S.S., Rezvani, A., Miveh, M.R., Samad, S., Aljojo, N. and Pazhoohesh, M., "Optimal scheduling of a renewable based microgrid considering photovoltaic system and battery energy storage under uncertainty", Journal of Energy Storage, vol.28, pp.101306, 2020.

Ahmed, E.M., Aly, M., Elmelegi, A., Alharbi, A.G. and Ali, Z.M., "Multifunctional distributed MPPT controller for 3P4W grid-connected PV systems in distribution network with unbalanced loads", Energies, vol.12, no.24, pp.4799, 2019.

Rahimi, E., Rabiee, A., Aghaei, J., Muttaqi, K.M. and Nezhad, A.E., "On the management of wind power intermittency", Renewable and Sustainable Energy Reviews, vol.28, pp.643-653, 2013.

Naveen Shankarappa, Mufassireen Ahmed, Shashikiran N, Dr. H Naganagouda,"Solar Photovoltaic Systems – Applications & Configurations",International Research Journal of Engineering and Technology (IRJET), vol.4,no.8, pp.1851-1855, 2017.

Pearce, J.M., "Photovoltaics—a path to sustainable futures", Futures, vol.34, no.7, pp.663-674, 2002.

Smil, V., "Energy at the crossroads: global perspectives and uncertainties", Massachusetts Institute of Technology press, 2005.

Lakatos, L., Hevessy, G. and Kovács, J., "Advantages and disadvantages of solar energy and wind-power utilization", World Futures, vol.67, no.6, pp.395-408, 2011.

Agathokleous, R.A. and Kalogirou, S.A., "Status, barriers and perspectives of building integrated photovoltaic systems", Energy, vol.191, pp.116471, 2020.

Ahmed, J. and Salam, Z., "A Maximum Power Point Tracking (MPPT) for PV system using Cuckoo Search with partial shading capability", Applied Energy, vol.119, pp.118-130, 2014.

Fathabadi, H., "Novel stand-alone, completely autonomous and renewable energy based charging station for charging plug-in hybrid electric vehicles (PHEVs)", Applied Energy, vol.260, pp.114194, 2020.

Vezin, T., Meunier, S., Queval, L., Cherni, J.A., Vido, L., Darga, A., Dessante, P., Kitanidis, P.K. and Marchand, C., "Borehole water level model for photovoltaic water pumping systems", Applied Energy, vol.258, pp.114080, 2020.

Ma, T., Yang, H., Lu, L. and Peng, J., "Pumped storage-based standalone photovoltaic power generation system: Modeling and techno-economic optimization", Applied energy, vol.137, pp.649-659, 2015.

Gupta, R.A., Kumar, R. and Bansal, A.K., "BBO-based small autonomous hybrid power system optimization incorporating wind speed and solar radiation forecasting", Renewable and Sustainable Energy Reviews, vol.41, pp.1366-1375, 2015.

Singh, H.N. and Tiwari, G.N., "Monthly performance of passive and active solar stills for different Indian climatic conditions", Desalination, vol.168, pp.145-150, 2004.

Hua, C., Lin, J. and Shen, C., "Implementation of a DSP-controlled photovoltaic system with peak power tracking", IEEE transactions on industrial electronics, vol.45, no.1, pp.99-107, 1998.

Safari, A. and Mekhilef, S., "Incremental conductance MPPT method for PV systems", In proceedings of 24th Canadian Conference on Electrical and Computer Engineering (CCECE), pp. 000345-000347, IEEE, 2011.

Eltawil, M.A. and Zhao, Z., "MPPT techniques for photovoltaic applications", Renewable and sustainable energy reviews, vol.25, pp.793-813, 2013.

Salas, V., Olias, E., Barrado, A. and Lazaro, A., "Review of the maximum power point tracking algorithms for stand-alone photovoltaic systems", Solar energy materials and solar cells, vol.90, no.11, pp.1555-1578, 2006.

Pingel, S., Frank, O., Winkler, M., Daryan, S., Geipel, T., Hoehne, H. and Berghold, J., "Potential induced degradation of solar cells and panels", In proceedings of 35th IEEE Photovoltaic Specialists Conference, pp. 002817-002822, 2010.

Soh, L.Q. and Tiew, C.C.D., "Building of a portable solar ac & dc power supply", In proceedings of 5th International Conference on Intelligent Systems, Modelling and Simulation, pp. 445-451, 2014.

Reijenga, T.H. and Kaan, H.F., "PV in Architecture", Handbook of Photovoltaic Science and Engineering, second edition, John Wiley & Sons, Chichester, UK, pp.1043-1077, 2011.

Kalogirou, S.A. and Tripanagnostopoulos, Y., "Industrial application of PV/T solar energy systems", Applied Thermal Engineering, vol.27, no.8-9, pp.1259-1270, 2007.

Radjai, T., Gaubert, J.P., Rahmani, L. and Mekhilef, S., "Experimental verification of P&O MPPT algorithm with direct control based on Fuzzy logic control using CUK converter", International Transactions on Electrical Energy Systems, vol.25, no.12, pp.3492-3508, 2015.

Seyedmahmoudian, M., Horan, B., Soon, T.K., Rahmani, R., Oo, A.M.T., Mekhilef, S. and Stojcevski, A., "State of the art artificial intelligence-based MPPT techniques for mitigating partial shading effects on PV systems–A review", Renewable and Sustainable Energy Reviews, vol.64, pp.435-455, 2016.

Harrag, A. and Messalti, S., "Variable step size modified P&O MPPT algorithm using GA-based hybrid offline/online PID controller", Renewable and Sustainable Energy Reviews, vol.49, pp.1247-1260, 2015.

Ahmed, N.A., Miyatake, M. and Al-Othman, A.K., "Hybrid solar photovoltaic/wind turbine energy generation system with voltage-based maximum power point tracking", Electric power components and systems, vol.37, no.1, pp.43-60, 2008.

Ahmed, N.A., Miyatake, M. and Al-Othman, A.K., "Power fluctuations suppression of stand-alone hybrid generation combining solar photovoltaic/wind turbine and fuel cell systems", Energy Conversion and Management, vol.49, no.10, pp.2711-2719, 2008.

Jones, D.C. and Erickson, R.W., "Probabilistic analysis of a generalized perturb and observe algorithm featuring robust operation in the presence of power curve traps", IEEE Transactions on Power Electronics, vol.28, no.6, pp.2912-2926, 2012.

Motsoeneng, P., Bamukunde, J. and Chowdhury, S., "Comparison of Perturb & Observe and Hill Climbing MPPT schemes for pv plant under cloud cover and varying load", In proceedings of 10th International Renewable Energy Congress (IREC), pp. 1-6, 2019.

Liu, F., Duan, S., Liu, F., Liu, B. and Kang, Y., "A variable step size INC MPPT method for PV systems", IEEE Transactions on industrial electronics, vol.55, no.7, pp.2622-2628, 2008.

Salih, H.W., Wang, S. and Farhan, B.S., "A novel GA-PI optimized controller for MPPT based PV in a hybrid PV-diesel power system", In proceedings of 5th International Conference on Electric Utility Deregulation and Restructuring and Power Technologies (DRPT), pp. 1288-1293, 2015.

controller for a PV system with DC-DC boost converter", In proceedings of International Conference on Engineering & MIS (ICEMIS), pp. 1-6, 2017.

Farhat, M., Hussein, M. and Atallah, A.M., "Enhancement performance of a three phase grid connected photovoltaic system based on pi-genetic algorithm (pi-ga) controller", In proceedings of Nineteenth International Middle East Power Systems Conference (MEPCON), pp. 145-151, 2017.

Paul, S. and Thomas, J.,"Comparison of MPPT using GA optimized ANN employing PI controller for solar PV system with MPPT using incremental conductance", In proceedings of International Conference on Power Signals Control and Computations (EPSCICON), pp. 1-5, 2014.

Kim, D.H. and Cho, J.H., "Adaptive tuning of PID controller for multivariable system using bacterial foraging based optimization", In proceedings of International Atlantic Web Intelligence Conference, pp. 231-235, 2005.

O. Guenounou, B. Dahhou, and F. Chabour, “Adaptive fuzzy controller based MPPT for photovoltaic systems,” Energy Conversion and Management, vol. 78, pp. 843-850, 2014.

Ö. Çelik and A. Teke, “A hybrid MPPT method for grid connected photovoltaic systems under rapidly changing atmospheric conditions,” Electric Power Systems Research, vol. 152, pp. 194-210, Nov. 2017.

S. Belhimer, M. Haddadi, and A. Mellit, “A novel hybrid boost con- verter with extended duty cycles range for tracking the maximum power point in photovoltaic system applications,” International Journal of Hydrogen Energy, vol. 43, no. 14, pp. 6887-6898, Apr. 2018

A. F. Murtaza, M. Chiaberge, F. Spertino et al., “MPPT technique based on improved evaluation of photovoltaic parameters for uniformly irradiated photovoltaic array,” Electric Power Systems Research, vol. 145, pp. 248-263, Apr. 2017.

J. Ramos-Hernanz, J. M. Lopez-Guede, O. Barambones et al., “Novel control algorithm for MPPT with boost converters in photovoltaic systems,” International Journal of Hydrogen Energy, vol. 42, no. 28, pp.17831-17855, Jul. 2017.

J. Shi, W. Zhang, Y. Zhang et al., “MPPT for PV systems based on a dormant PSO algorithm,” Electric Power Systems Research, vol. 123, pp. 100-107, Jun. 2015.

L. Zhang, S. Yu, T. Fernando et al., “An online maximum power point capturing technique for high-efficiency power generation of solar photovoltaic systems,” Journal of Modern Power Systems and Clean Energy, vol. 7, no. 2, pp. 357-368, Mar. 2019.

M. A. Elgendy, B. Zahawi, and D. J. Atkinson, “Assessment of per- turb and observe MPPT algorithm implementation techniques for PV pumping applications,” IEEE Transactions on Sustainable Energy, vol. 3, no. 1, pp. 21-33, Jan. 2012.

F. Bouchafaa, I. Hamzaoui, and A. Hadjammar, “Fuzzy logic control for the tracking of maximum power point of a PV system,” Energy Procedia, vol. 6, pp. 633-642, Jun. 2011.

Peng Zhang and Huibin "Maximum Power Point Tracking Technology of Photovoltaic Array under Partial Shading Based On Adaptive Improved Differential Evolution Algorithm", Energies, vol.13, no.5, pp.1254, 2020.

Saber Arabi Nowdeh, Moghaddam, M.J.H., Nasri, S., Abdelaziz, A.Y., Ghanbari, M. and Faraji, I., "A New Hybrid Moth Flame Optimizer-Perturb and Observe Method for Maximum Power Point Tracking in Photovoltaic Energy System", In Modern Maximum Power Point Tracking Techniques for Photovoltaic Energy Systems, pp. 401-420, 2020.

Wenfan Li, Zhang, G., Pan, T., Zhang, Z., Geng, Y. and Wang, J., "A Lipschitz optimization-based MPPT algorithm for photovoltaic system under partial shading condition", IEEE Access, vol.7, pp.126323-126333, 2019.

Hongda Liu, Wan, L. and Pei, B., "Optimal scheme of PV array in partial shading: A reconfiguration algorithm", In proceedings of IEEE International Conference on Mechatronics and Automation, pp. 2105-2109, 2016.

Mohammad H. Moradi and Ali Reza Reisi "A hybrid maximum power point tracking method for photovoltaic systems", Solar Energy, vol.85, no.11, pp.2965-2976, 2011.

Khaled Batainesh and Naser Eid "A hybrid maximum power point tracking method for photovoltaic systems for dynamic weather conditions", Resources, vol.7, no.4, pp.68, 2018.

Mohammad Sarvi, Ahmadi, S. and Abdi, S., "A PSO- based maximum power point tracking for photovoltaic systems under environmental and partially shaded conditions", Progress in Photovoltaics: Research and Applications, vol.23, no.2, pp.201-214, 2015.

Hadeed Ahmed Sher, Murtaza, A.F. and Al-Haddad, K., "A hybrid maximum power point tracking method for photovoltaic applications with reduced offline measurements", In proceedings of IEEE International Conference on Industrial Technology (ICIT), pp. 1482-1485, 2017.

Alireza Ramyar, Iman-Eini, H. and Farhangi, S., "Global maximum power point tracking method for photovoltaic arrays under partial shading conditions", IEEE Transactions on Industrial Electronics, vol.64, no.4, pp.2855-2864, 2016.

Mahlaga Mahadavi, Li, L., Zhu, J. and Mekhilef, S., "An adaptive neuro-fuzzy controller for maximum power point tracking of photovoltaic systems", In TENCON IEEE region 10 Conference, pp. 1-6, 2020.

Yiwang Wang, Yang, Y., Fang, G., Zhang, B., Wen, H., Tang, H., Fu, L. and Chen, X., "An advanced maximum power point tracking method for photovoltaic systems by using variable universe fuzzy logic control considering temperature variability", Electronics, vol.7, no.12, pp.355, 2018.

Mehdi Seyedmahmoudian, Kok Soon, T., Jamei, E., Thirunavukkarasu, G.S., Horan, B., Mekhilef, S. and Stojcevski, A., "Maximum power point tracking for photovoltaic systems under partial shading conditions using bat algorithm", Sustainability, vol.10, no.5, pp.1347, 2018.

Piegari, L. and Rizzo, R., "Adaptive perturb and observe algorithm for photovoltaic maximum power point tracking", IET Renewable Power Generation, vol.4, no.4, pp.317-328, 2010.

Ounnas, D., Ramdani, M., Chenikher, S. and Bouktir, T., "An Efficient Maximum Power Point Tracking Controller for Photovoltaic Systems Using Takagi–Sugeno Fuzzy Models". Arabian Journal for Science and Engineering, vol.42, no.12, pp.4971-4982, 2017.

Chao Huang ,Wang, L., Zhang, Z., Yeung, R.S.C., Bensoussan, A. and Chung, H.S.H., "A novel spline model guided maximum power point tracking method for photovoltaic systems", IEEE Transactions on Sustainable Energy, vol.11, no.3, pp.1309-1322, 2019.

Kinattingal sundareswaran, K., Vigneshkumar, V. and Palani, S., "Development of a hybrid genetic algorithm/perturb and observe algorithm for maximum power point tracking in photovoltaic systems under non-uniform insolation", IET Renewable Power Generation, vol.9, no.7, pp.757-765, 2015.

Tat Luat Nguyen and Kay-Soon Low, "A global maximum power point tracking scheme employing DIRECT search algorithm for photovoltaic systems", IEEE transactions on Industrial Electronics, vol.57, no.10, pp.3456-3467, 2010.

Yi-Hua Liu, C.L., Huang, J.W. and Chen, J.H., "Neural-network-based maximum power point tracking methods for photovoltaic systems operating under fast changing environments", Solar energy, vol.89, pp.42-53, 2013.

Kheldoun, A., Bradai, R., Boukenoui, R. and Mellit, A., "A new Golden Section method-based maximum power point tracking algorithm for photovoltaic systems", Energy Conversion and Management, vol.111, pp.125-136, 2016.

Lian Lian Jiang, Maskell, D.L. and Patra, J.C., "A novel ant colony optimization-based maximum power point tracking for photovoltaic systems under partially shaded conditions", Energy and Buildings, vol.58, pp.227-236, 2013.

Stefan Daraban, Petreus, D. and Morel, C., "A novel MPPT (maximum power point tracking) algorithm based on a modified genetic algorithm specialized on tracking the global maximum power point in photovoltaic systems affected by partial shading", Energy, vol.74, pp.374-388, 2014.

Yasser E. Abu Eldahab, Saad, N.H. and Zekry, A., "Enhancing the maximum power point tracking techniques for photovoltaic systems", Renewable and Sustainable Energy Reviews, vol.40, pp.505-514, 2014.

A. M. Zein Alabedin, El-Saadany, E.F. and Salama, M.M.A., "Maximum power point tracking for photovoltaic systems using fuzzy logic and artificial neural networks", In proceedings of IEEE Power and Energy Society General Meeting, pp. 1-9, 2011.

Binu D; Kariyappa B.S, "Rider Deep LSTM Network for Hybrid Distance Score-based Fault Prediction in Analog Circuits", IEEE Transactions on Industrial Electronics, pp.1, 09 October 2020.

Lee and Chuen-Chien, "Fuzzy logic in control systems: fuzzy logic controller. I", IEEE Transactions on systems, man, and cybernetics, vol. 20, no. 2, pp. 404-418, 1990.

Yılmaz, Selim, and Ecir U. Küçüksille, "A new modification approach on bat algorithm for solving optimization problems", Applied Soft Computing, vol. 28, pp. 259-275, 2015.

Chu, Shu-Chuan, Pei-Wei Tsai, and Jeng-Shyang Pan, "Cat swarm optimization", In Pacific Rim international conference on artificial intelligence, pp. 854-858, 2006.