Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations using ANN optimized Fuzzy-PID controller

Binyam Beyene Tolera

A Thesis Submitted to

The Department of Electrical Power and Control Engineering
School of Electrical Engineering and Computing

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Electrical Power and Control Engineering (Control)

Office of Graduate Studies

Adama Science and Technology University

June, 2023
Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "Optimal Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations using ANN optimized Fuzzy-PID controller" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Binyam Beyene Tolera	________	______
Name of the Student	Signature	Date

RECOMMENDATION

I, the advisors of this thesis, hereby certify that I have read the revised version of the thesis entitled "Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations using ANN optimized Fuzzy-PID controller" prepared under our guidance by **Binyam Beyene Tolera** submitted in partial fulfillment of the requirements for the degree of Masters of Science in Electrical Power and Control Engineering (Control Engineering). Therefore, we recommend the submission of revised version of the thesis to the department following the applicable procedures.

Dr. Shubhashish Bhakta (Ph.D. Engg.)	____________	______________
Major Advisor	Signature	Date

APPROVAL SHEET

I, the advisors of the thesis entitled "Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations using ANN optimized Fuzzy-PID controller" and developed by **Binyam Beyene Tolera**, here by certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Dr. Shubhashish Bhakta	____________________	____________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Binyam Beyene Tolera** have read and evaluated the thesis entitled "Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations using ANN optimized Fuzzy-PID controller" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Masters of Science in Electrical Power and Control Engineering (Control Engineering).

Chairperson	Signature	Date
Internal Examiner	Signature	Date
Eternal Examiner	Signature	Date

Finally, approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
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Office of Postgraduate Studies, Dean	Signature	Date

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LIST OF ABBREVIATIONS

ANFS	Artificial Neural Fuzzy Inference System
ANN	Artificial Neural Network
DE	Differential Evolution
FA	Firefly Algorithm
FIS	Fuzzy Inference System
FL	Fuzzy Logic
FLC	Fuzzy Logic Controller
GA	Genetic Algorithm
GMMP	Global Maximum Power Point
GP	Global Peak
GSA	Gravitational Search Algorithm
I	Current
Kg	Kilogram
KW	Kilowatt
KWh	Kilowatt-hour
LP	Local Peak
MFs	Membership Functions
MPPT	Maximum Power Point Tracking
MW	Megawatt
NB	Negative Big
NM	Negative Medium
NM	Newton Meter
NS	Negative Small
P&O	Perturb and Observe
PB	Positive Big
PD	Proportional Derivative
PI	Proportional Integrator
PID	Proportional Integrator Derivative

PM	Positive Medium
PS	Positive Small
PSC	Partial Shading Condition
PSO	Particle Swarm Optimization
PV	Photovoltaic
PWM	Pulse Width Modulation
RMSE	Root Mean Square Error
RSE	Renewable Sources of Energy
SHPPs	Small Hydro Power Plants
V	Voltage

ABSTRACT

Electricity is the main source of energy all over the world. Today most of the energy used comes from fossil fuels. The constant exploitation of fossil fuels creates an adverse effect on the environment. Due to increasing energy demand and global warming identification and utilization of new renewable sources of energy site is crucial importance to reduce the energy shortage and fossil fuel dependency throughout the country. In this thesis the three PV configuration series, series-parallel and total cross tied are considered.

This thesis investigates Optimal Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations. An optimal maximum power point tracking of PV Configurations incorporation with adaptive neural network optimized fuzzy-PI controller are modeled, designed, and simulated by using MATLAB/Simulink software. A simulation result is observed by using a ANN based fuzzy-PI. It is observed from the MATLAB simulation results, the effects of system performance measuring variables by using ANN optimized fuzzy-PI controller are tested for different PV configuration and the TCT configuration is the better performed PV configuration. The effects of system performance measuring variables by using ANN optimized Fuzzy Logic PI controller are tested for different PV configuration and it have good controllable effect in the three configurations.

Generally, fuzzy-PI controller by itself is poor control system stability performance measuring variables, it only considers steady-state frequency error approaches to zero at various load changes. Therefore, both the transient and steady-state control system stability performance measuring variables in all the three configurations are improved by ANN optimized Fuzzy-PI controller. The controller works efficiently under all PV configurations because, this controller is suitable for complex, nonlinear, uncertain, higher-order, and time-delay systems.

Keywords: *Maximum Power Point Tracking (MPPT), Photovoltaic (PV), Fuzzy-PI Controller, MATLAB/Simulink, Renewable Energy Source*

CHAPTER ONE

INTRODUCTION

1.1. Background of the study

Nowadays, electricity is a crucial factor for the social and economic progress of any nation. It offers numerous benefits, including better healthcare, improved education, efficient transportation systems, enhanced communication networks, a higher quality of life, and stable economic conditions. Particularly in terms of economic development, energy usage plays a significant role in everyday activities of households, industries, hospitals, railways, universities, transportation, factories, companies, and other organizations. In areas where accessing the power grid is not feasible, solar power systems are extensively used. Renewable energy sources such as solar panels, steam, wind, biogas or biomass, and hydropower plants are employed to generate electricity.

Harnessing electricity from alternative solar photovoltaic sources is crucial for preserving the environment. (O. Parish, 2002). Solar energy is considered the most cost-effective and reliable among all non-conventional energy sources, and it is also environmentally friendly. In remote rural areas, access to power is limited due to the high cost of setting up transmission lines. Solar energy offers a more affordable and efficient solution while generating fewer emissions. However, to ensure a stable and dependable power system, renewable energy systems require storage mechanisms. These storage systems are necessary to meet energy demand during periods when renewable sources are unavailable, to reduce the time gap between peak load and maximum power production, to facilitate energy conversion, and to minimize the time difference between peak load and the highest power generated.

Solar photovoltaic (SPV) systems are widely used as a renewable energy source. They hold great promise as they can utilize the abundant solar energy to meet the increasing global energy needs. These systems are eco-friendly and require minimal maintenance, which makes them a preferred option for both residential and commercial use. However, despite technological improvements, there are still challenges that affect the efficiency of SPV systems, such as low conversion efficiency and dependence on sunlight intensity and environmental factors.(Q. A. e. al, 2019).

Shading is a common occurrence that negatively impacts the energy production of solar photovoltaic (SPV) systems. When shading occurs on the photovoltaic (PV) modules, it reduces the power generation capacity of the connected series string in the PV array, resulting in decreased overall power output. This reduction in power output is due to mismatch losses, causing the PV array to generate less power than its full potential, thus reducing its efficiency. The mismatch is caused by the shaded module behaving as a load instead of a source of energy within the array. Consequently, the shaded PV module experiences a significant increase in cell temperature, creating a localized hot spot that can permanently damage the module.

The existing conventional configurations for photovoltaic (PV) arrays, as mentioned in the literature, include series, parallel, series-parallel (SP), Total-cross-tie configuration (TCT), Bridge-link configuration (BL), and Honey comb (HC) configuration. (Lukaszewicz, 2001). The majority of photovoltaic (PV) systems are directly connected to solar arrays and utilize DC motors. While this setup is user-friendly, it tends to be inefficient and demands regular maintenance. On the other hand, PV systems that operate with an AC drive employ an inverter along with an AC motor.

The DC power generated by the solar array is increased and then supplied to an inverter, which converts it into AC power to drive the connected motor. The output power of a Photovoltaic (PV) array fluctuates depending on factors like sunlight intensity, shading, and temperature. To extract the maximum power from the PV array, a photovoltaic power system typically incorporates a maximum power point tracking (MPPT) controller. Additionally, the system may not respond promptly to sudden changes in temperature or sunlight intensity. In contrast, classical PID controllers are feedback controllers with fixed gains. (N. Mutoh, M Ohno, n.d.). They are unable to account for changes in process parameters and are not adaptable to environmental variations. A system controlled by a PID controller is less capable of promptly responding to significant and rapid changes in the system's state, resulting in a slower attainment of the desired set point.

In recent times, artificial intelligence-based approaches have been introduced as a means of enhancing control schemes. One such method is the fuzzy logic controller, which offers its own advantages, particularly in the development of maximum power point tracking (MPPT) algorithms. The membership function shape of fuzzy logic controllers can be adjusted to optimize the gap between the operating point and the maximum power point. Therefore, in this thesis, an artificial intelligence control technique combined with an MPPT controller is employed to enhance the energy conversion efficiency of the photovoltaic system. The proposed intelligent process incorporates expert knowledge that enables the extraction of maximum power from a PV module, even when faced with varying solar irradiation and temperature conditions. (Darla, n.d.).

1.2. Statement of the Problem

The availability of electricity worldwide is a crucial aspect of sustainable socio-economic development. However, a major obstacle, especially in remote rural areas, has been the lack of accessible electricity. Photovoltaic (PV) systems face challenges such as low conversion efficiency and reliance on atmospheric conditions. Additionally, the non-linear nature of the system and high initial investment requirements make it difficult to efficiently extract and utilize PV power. To overcome these challenges, efficient tracking and utilization techniques are needed to optimize power extraction and overcome the system's sensitivity to climatic conditions. While mechanical methods for maximum power point tracking (MPPT) are simple to implement, they struggle to cover large solar panel areas, such as in mini-grid or off-grid systems. Classical MPPT techniques have drawbacks like failure to track perturbations accurately, steady-state oscillations, and inability to track global MPPT under partial shade conditions. As a result, optimization techniques have been employed to effectively track global MPPT, reduce power loss, improve steady-state oscillation, and minimize settling time. Therefore, this thesis includes a comparison between classical MPPT methods (such as Incremental Conductance and perturb & observer) and more recent soft-computing techniques.

1.3. Objectives of the Study

1.3.1. General Objective

The general objective of this thesis is Optimal Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations using ANN Optimized Fuzzy-PID controller.

1.3.2. Specific Objectives

- To select the best renewable source of energy among the various renewable sources
- To compare different patter configuration array of Photovoltaic Performance
- To investigate and analyses the effect of irradiation and temperature changes on the output characteristics of the PV array and to optimize their effects.
- To develop control mechanism by using PID and Fuzzy Logic PID controller to increase the efficiency of the proposed system.
- Implement the proposed controllers using MATLAB/SIMULINK to test the overall system efficiency in different weather conditions.

- To analyze the simulation results and makes recommendation based on the finding of this research.

1.4. Significance of the Study

This study holds great importance for the society of Ethiopia on multiple fronts. The foremost and most significant aspect is to ensure optimal access to electricity for communities through solar power. This improved access to electricity has a transformative impact on the standard of living. It enables students to study at night, allows health centers to operate during nighttime, and eliminates the need for unhealthy kerosene lamps, thereby enhancing overall health conditions. Furthermore, optimal electrification has additional benefits such as reducing rapid deforestation, preventing soil erosion, promoting environmental protection, and reducing environmental pollution, which in turn contributes to the mitigation of global warming.

1.5. Scope of the Study

This thesis specifically examines the feasibility of solar photovoltaic (PV) as a renewable energy source compared to other options like biogas, water, and wind. It is important to note that this study does not involve practical implementation; instead, it focuses on forecasting mathematical models, designing, and simulating MPPT for Solar PV Configurations using Fuzzy Logic PID controller in the MATLAB/Simulink software.

1.6. Limitation of the Study

This thesis is constrained to simulating the system using the MATLAB/Simulink software, demonstrating the interactions among the various components. The decision to use simulation instead of implementing a real system is due to the challenges of obtaining the necessary components and the additional time and cost involved in creating a physical prototype.

1.7. Thesis Organization

This thesis paper is mainly divided into five chapters.

Chapter One: which is the introduction part that discusses about background, statement of the problem, objectives, significance, scope and limitations leading towards the completion as well as the contribution of the thesis.

Chapter Two: is a literature review part in which different kinds of literature are reviewed and the basic background theory briefly discussed related to the study.

Chapter Three: which is described the methodologies used for this study and mathematical modeling of the system of MPPT for Solar PV system is presented.

Chapter Four: which is a MATLAB simulation results and discussion parts of MPPT for Solar PV system are briefly described.

Chapter Five: which is the conclusion, recommendation, and future work have been discussed.

CHAPTER TWO

LITERATURE REVIEW

2.1. Theoretical Overview

Developing nations require affordable and dependable electricity to support their development goals. The pressing issues of climate change, environmental degradation, population growth, and the constant demand for electricity have highlighted the importance of renewable energy sources. Renewable energy systems (RSE) offer a suitable and environmentally friendly solution, particularly for providing electricity in remote rural areas. RSE offers several advantages over conventional sources, including reducing reliance on fluctuating oil prices, lowering fuel transportation costs, improving healthcare, boosting economic productivity, creating local job opportunities, combating climate change, and addressing poverty by utilizing local natural resources effectively.

Solar photovoltaic (SPV) systems have non-linear I-V (current-voltage) and P-V (power-voltage) characteristics that change with varying irradiation and temperature conditions. Consequently, the maximum power point (MPP) of the SPV module also varies. To efficiently transfer maximum power from the PV module to the load, an SPV module is typically used in conjunction with a DC-DC converter. Achieving impedance matching is crucial for maximizing power transfer, which is accomplished by adjusting the duty ratio of the pulse width modulation (PWM) signal provided to the converter switch. To track the optimal operating point of the module, an MPPT (maximum power point tracking) algorithm is usually employed.

In this paper, a boost converter along with FL-PID (fuzzy logic-proportional integral derivative) based MPPT ANN (artificial neural network) algorithms are utilized to track the MPP of the SPV module. Numerous MPPT techniques have been proposed in the literature, such as constant voltage, fractional short-circuit current, fractional open-circuit voltage, HC (hill climbing), P&O (perturb and observe), INC (incremental conductance), FL (fuzzy logic), and others. However, the P&O MPPT algorithm is commonly used due to its simplicity and ease of implementation. This algorithm introduces a slight perturbation in the duty ratio or duty cycle (D) of the PWM signal sent to the DC-DC converter switch, which in turn affects the power delivered by the module. If the power increases with the change in D, the perturbation is maintained in the same direction. Conversely, if a decrease in power occurs with the change in D, the change in the subsequent cycle will be in the opposite direction.(C. C. Hua and C. M. Shen, 1998).

The solar PV energy source has gained global recognition among various renewable energy sources due to its advantages such as low maintenance cost, long working life, noise-free operation, and environmentally friendly nature. However, the solar PV system faces challenges such as low conversion efficiency and high installation costs, which necessitate the effective utilization of available solar energy. Additionally, the nonlinearity of the PV system poses constraints on power generation. To address these challenges and improve the overall performance of the PV system, the maximum power point tracking (MPPT) scheme is crucial.

This study provides a comprehensive review of soft computing methods for MPPT controllers, considering their applications, benefits, and drawbacks. Various techniques such as fuzzy logic (FL), artificial neural network (ANN), probability, nonlinear predictor, chaos theory, evolutionary techniques like differential evolution (DE) and genetic algorithm (GA), and swarm optimization techniques like particle swarm optimization (PSO) and ant colony optimization (ACO) are reviewed. An improved PSO algorithm is discussed for simulating MPPT in partially shaded PV setups. Additionally, a comparison is presented for microcontroller applications based on traditional and modified techniques. The study proposes an intelligent hybrid optimization method based on PSO and shuffled frog leaping algorithm to track the global maximum power point (GMPP) under partial shading conditions. Various parameters are considered for designing a grid-integrated PV setup under variable weather situations using a PSO algorithm.

In the PV system, a boost converter is used, which regulates the operating voltage by adjusting the duty cycle of the converter. The pulse width modulation (PWM) technique is employed to operate the IGBT type of MOSFET. The boost converter comprises components such as an inductor, diode, input and output capacitors, load resistance, and a MOSFET. Different types of DC-DC converters, including buck, boost, and buck-boost converters, exist, but the boost converter is specifically considered in this PV system with the MPPT optimization technique for tracking the GMPP.(Jha et al., 2022). The input voltage is greater than the output. The output voltage of the converter is changed in accordance with the change in the duty cycle.

2.2. Photovoltaic System

The photovoltaic system is composed of interconnected components that are specifically designed to generate and deliver the required electricity from a small device to the load. Photovoltaic systems are classified into three main categories: grid-connected systems, standalone systems, and hybrid systems. These systems incorporate various energy sources such as PV arrays, diesel generators, and wind generators. In grid-connected and standalone systems, energy storage elements like batteries or supercapacitors may be employed to store excess energy during periods of ample sunlight. Hybrid and standalone systems are increasingly being utilized in rural areas. (H Patel and V Agarwal, n.d.).

Hence, the PV array system examined in this thesis serves as a standalone solution to address the immediate needs of individuals, particularly in rural areas. In a standalone system, the power generated by the photovoltaic array is directly supplied to the load without being connected to the utility grid. Solar energy is available almost everywhere on the planet, unlike other renewable resources such as hydropower and geothermal energy, which are location-dependent based on geographical features. Additionally, for off-grid applications, it is advantageous to have a portable, easily transportable, simple to install, and compact system like solar photovoltaic panels.

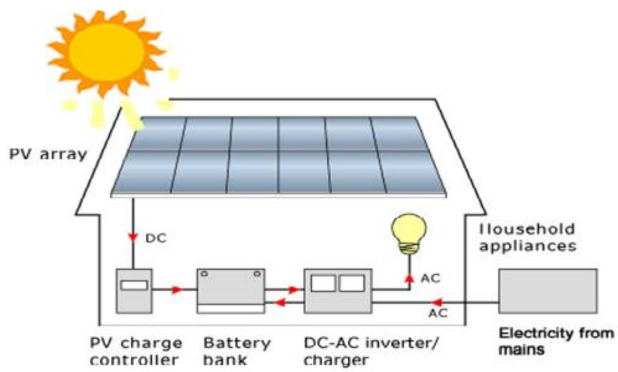

Figure 2.1

Figure 2. 1.Typical layout of MPPT solar PV system. (H Patel and V Agarwal, n.d.)

2.3. Solar Energy

The sun is not only the primary source of life but also the ultimate origin of all energy, with the exception of tidal and geothermal power. Even the energy stored in fossil fuels ultimately originates from the sun. Every hour, the sun emits a staggering amount of energy, approximately 174 trillion kilowatt-hours, to the Earth. To put it differently, our planet receives an astonishing 1.74 x 10^17 watts of power from the sun.("The, 2018). There are generally two methods of harnessing sunlight to generate electricity: photovoltaic (PV) systems and solar thermal systems. This thesis specifically focuses on the discussion of photovoltaic power systems, leaving out the examination of solar thermal systems.

2.3.1. Photovoltaic Power System (Solar Energy Conversion System)

Photovoltaic (PV) is a method that generates electrical power by converting solar radiation into direct current electricity using semiconductors that possess the photovoltaic effect. The basic building block of a PV system is a solar cell, which is relatively small and typically produces around 1 to 2 watts of power(A W. Leedy, LipingGuo, n.d.). Each solar cell operates similarly to a diode, with a p-n junction formed by semiconductor material. When the junction absorbs light, it can generate currents through the photovoltaic effect. The equivalent circuit of a solar cell can be represented by a current source in parallel with a diode that is forward biased, as illustrated in Figure 2.2.

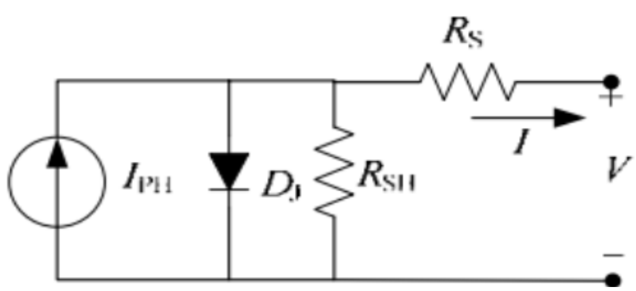

Figure 2.2.

Figure 2. 2.Equivalent electrical circuit of PV cell*(A W. Leedy, LipingGuo, n.d.)*

The circuit's output terminals are linked to the load, completing the connection. The current equation for the solar cell is expressed as follows: (A W. Leedy, LipingGuo, n.d.),

$$P = V \times I \qquad 2.1$$

Where, I $is\ cell\ current\ (A)$, V $is\ cell$ voltage (V), P $is\ cell\ output\ power$ (W)

In order to enhance the power output of PV cells, they are connected together to create larger units known as modules. These modules can then be interconnected to form even larger units called arrays. Figure 2.3 depicts this configuration as illustrated below:

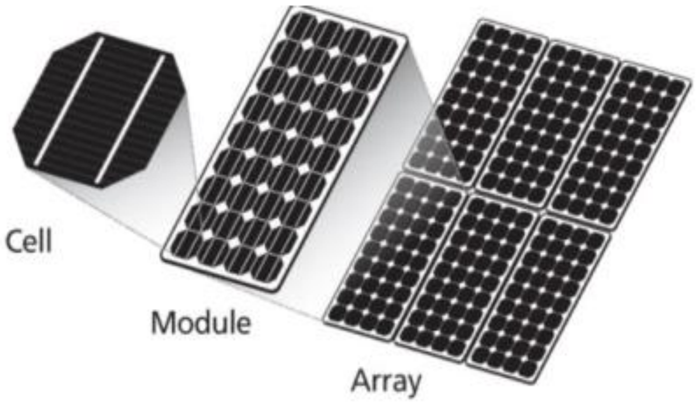

Figure 2. 3.PV cell, Module, and Array*(V.Agarwal, n.d.)*

PV cell: Photovoltaic systems consist of fundamental components known as photovoltaic cells, which are commonly referred to as solar cells. To provide protection, these solar cells are encapsulated within a protective laminate, thus forming photovoltaic modules.

PV module: A photovoltaic module, which is also referred to as a photovoltaic panel, consists of multiple individual cells. To enhance the voltage rating of the module or panel, the cells are commonly connected in a series configuration.

PV Array: An array is formed by combining several modules into a single system. To achieve the desired power ratings, modules can be connected in parallel or series, depending on the situation. This allows for increasing the energy output when the individual module's production is insufficient for specific purposes.

Figure 2.4 illustrates the equivalent circuit for a solar module that is organized into NP parallel branches and NS series branches.

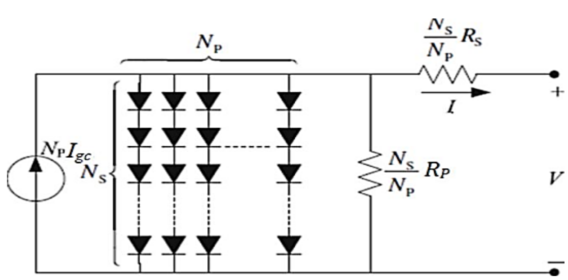

Figure 2.4.

Figure 2. 4.General equivalent circuit of PV module(V.Agarwal, n.d.)

The PV array is formed by connecting numerous solar cells in series or parallel to achieve the necessary current, voltage, and high power output. This construction allows for the creation of PV systems that can fulfill a wide range of electricity requirements, regardless of size. It is important to note that the electricity generated by PV systems relies on the presence of sunlight. Nevertheless, PV systems have demonstrated long-term durability, with many installations operating outdoors on Earth or in space for more than 30 years. (“, n.d.). It can be seen that a maximum power point exists on each output power characteristic curve.

2.3.2. Main PV Cell Types

Silicon is widely used in the industry for producing photovoltaic cells. There are four main categories of photovoltaic cells made from silicon, which are distinguished by their material structure and preparation method. These categories include Mono or Single-Crystalline Silicon, Polycrystalline or Multi-Crystalline Silicon, Amorphous Silicon, and String Ribbon Silicon. However, this particular work focuses on Mono or Single-Crystalline Silicon due to its efficiency, space efficiency, and longer lifespan compared to the other types. Mono or Single-Crystalline Silicon solar panels typically have an efficiency ranging from 14% to 22%.(A. Mondal and S. Yuvarajan, n.d.).

2.3.3. Electrical Characteristics of Photovoltaic Panel

Photovoltaic modules are commonly evaluated based on standard test conditions. These conditions encompass the following factors:

Cell temperature: The temperature used for cell testing under standard test conditions is set at 25°C, which may differ from the ambient air temperature.

Irradiance: It is a power or sunlight intensity that is described in watts per square meter falling on a flat surface. The measurement standard is expressed as 1,000 Watts/m^2 (W. D. Kellogg, M. H. Nehrir, G.Venkataramanan, n.d.).

2.3.4. Factors that Affect Reliability and Performance of PV Cell

Solar Cell Conversion Efficiency (η): The efficiency of a PV solar cell is determined by the ratio of the maximum output power it generates to the incident or input power. Several output parameters influence the efficiency of a solar PV cell, and they are defined as follows: (J. A. Gow and C. D. Manning, 2019).

$$\eta = \frac{V_{oc} \times I_{sc} \times FF}{P_{in}} \qquad (2.2)$$

where: FF = the fill factor. I_{sc} = the short circuit current, P_{in} = the incident light power on the device, and V_{oc} = open circuit voltage,

Short Circuit Current: The short-circuit current is obtained by connecting the negative and positive terminals of the cell, creating a short circuit. In this state, the voltage between the terminals is zero, indicating the absence of any load resistance. The value of the short-circuit current depends on the spectrum of the incident light and the density of photons.

Open Circuit Voltage: Open-circuit voltage refers to the voltage measured across the terminals of a solar PV cell when no load is connected. It represents the highest voltage that the cell can generate under any lighting condition. The open-circuit voltage is the maximum voltage observed when there is no current flowing through the external circuit.

Fill factor: Fill factor (FF) is an important aspect that determines the efficiency of a solar photovoltaic module. It is evaluated by examining the current vs. voltage curve of the module. To achieve maximum efficiency, it is crucial for the fill factor to be as high as possible and close to one. The fill factor value also serves as an indicator of the quality of the PV array; the closer it is to one, the more electricity the array can generate. However, the presence of parasitic components in the solar cell can lead to a decrease in the fill factor value. Typically, fill factor values range from 0.7 to 0.8. (E. M. Natsheh, 2013).This mathematical relationship represents the connection between theoretical power and maximum power. Figure 2.3 illustrates an I-V Curve that displays the varying fill factor of a solar cell.

$$FF = \frac{V_{mp} \; I_{mp}}{V_{oc} \; I_{sc}} \qquad (2.3)$$

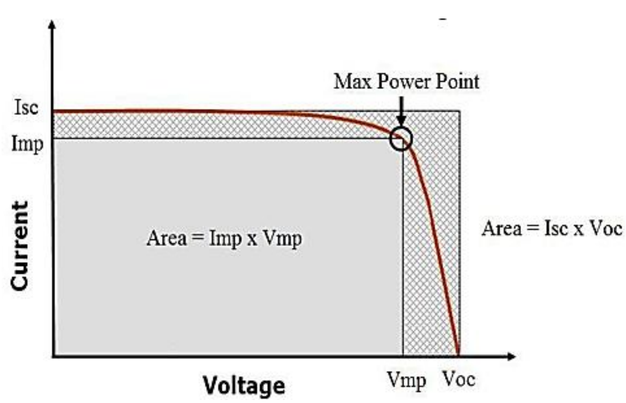

Figure 2. 5.I-V Curve with a varying fill factor of solar cell(E. M. Natsheh, 2013)

2.4. Types of PV Configuration Modules

To amplify the current, PV modules are interconnected in various configurations such as series, series-parallel, and total-cross-tied panel modules. This interconnection of modules, forming a combination of series and parallel connections, is referred to as a solar photovoltaic array or PV module array. The purpose of this configuration is to increase the overall current output. (Sumaiya, 2018).

2.4.1. Series Connection of Modules

In certain situations, the voltage needed for a power plant exceeds the capacity of a single PV module. To meet this voltage requirement, multiple PV modules are connected in series, allowing for the desired voltage level to be reached. This series connection of PV modules is similar to how multiple cells within a module are interconnected to achieve the required voltage level. By employing this series connection, both the voltage and power output of the module increase. In this arrangement, the negative terminal of one module is connected to the positive terminal of the next module.(Bidram, Ali, Davoudi, Ali, and Balog, 2012).

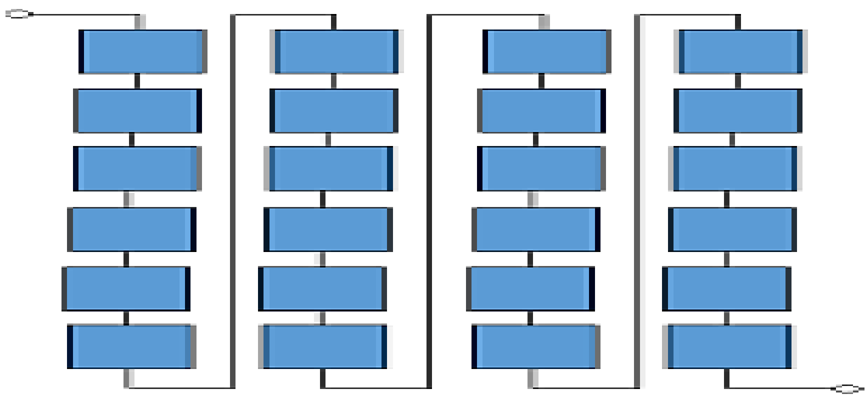

Figure 2. 6.PV panels connected in series configuration

2.4.2. Series-Parallel Connection of Modules

The series-parallel (SP) configuration is widely utilized and is achieved by connecting PV modules in a series to achieve the desired voltage level. These series-connected modules are then connected in parallel to increase the overall output current. To generate high power levels in the gigawatt range for large-scale PV system plants, it becomes necessary to connect modules in both series and parallel configurations.(WANG, Yaw-Juen and HSU, Po-Chun, 2009). In large PV plants, the modules are initially connected in series to create a PV module string, allowing the desired voltage level to be achieved. Subsequently, multiple strings are connected in parallel to attain the required current level for the entire system.

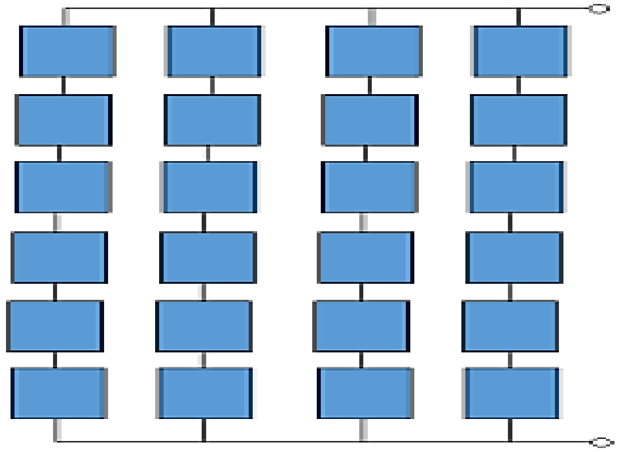

Figure 2. 7.PV panels connected in Series-Parallel configuration(WANG, Yaw-Juen and HSU, Po-Chun, 2009)

2.4.3. Total-Cross-Tied Connection of Modules

In the total cross tied (TCT) configuration, the modules are initially connected in parallel to create parallel-connected groups. These groups are then connected in series. This configuration ensures that the PV module is fully interconnected, allowing for optimal connectivity throughout the system.

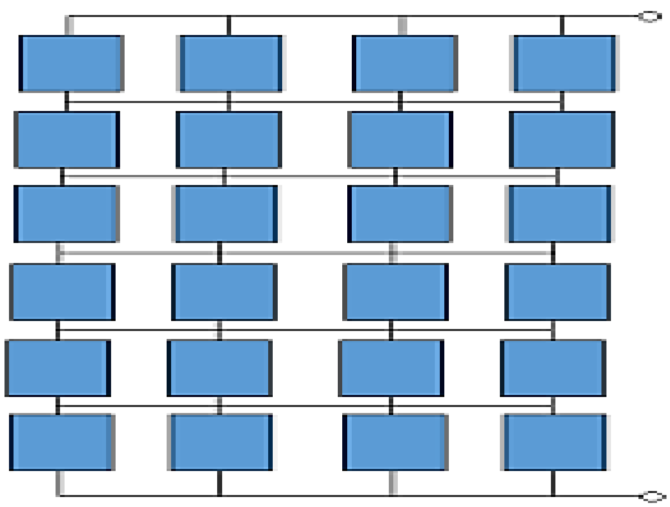

Figure 2. 8.PV panels connected in total cross tied (TCT) configuration(El-Dein, Mz Shams, Kazerani, Mehrdad, And Salama, 2013)

2.5. Maximum Power Point Tracking (MPPT) System

MPPT (Maximum Power Point Tracking) is a crucial component in photovoltaic generation as it ensures the system operates at high power efficiency by consistently maintaining the peak power point, even in changing weather conditions. Its primary function is to transfer the maximum power generated by the solar array to the load by aligning the source impedance with the load impedance. To achieve this, an MPPT system is implemented, which constantly tracks variations in the atmospheric conditions that affect the maximum power output of the solar array (Dunford, 2004).

The MPPT system is essentially an electronic device positioned between the PV array and the load. It incorporates a DC-DC switching power converter or DC-AC inverter, along with an MPPT control algorithm, enabling the PV system to deliver the maximum power possible to the load. As the solar panel generates power, the maximum achievable power fluctuates with changes in atmospheric conditions, and the electrical characteristics of the load may also vary. The primary objective of the MPPT system is to reconcile these two parameters by adjusting the duty ratio of the power converter.

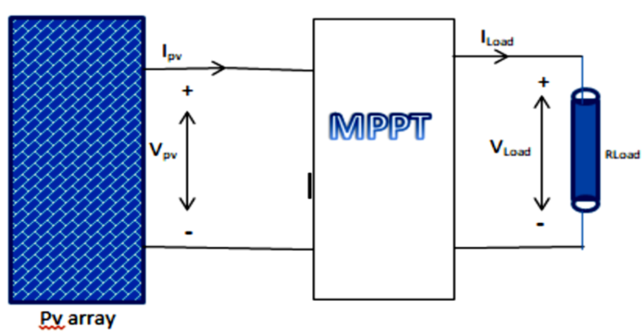

Figure 2. 9.Converter acting as a Maximum Power Point Tracker(Dunford, 2004)

2.5.1. Performance Specifications of MPPT Controller

When assessing the performance of a new or modified MPPT control algorithm, certain aspects such as dynamic response, steady-state error, and tracking efficiency are taken into account to ensure a successful design. These factors play a crucial role in evaluating the effectiveness of the algorithm in achieving accurate and efficient tracking of the maximum power point.

The dynamic response

The Response of a MPPT control algorithm needs to be fast to track the MPP during the rapid changes in the atmospheric conditions. The higher the tracking speed of the MPPT algorithm, the lower the loss in solar energy in the system

Steady-state error

Ideally, the MPPT control algorithm should identify the maximum power point (MPP) and ensure that the system remains operating at this optimal point for as long as possible. However, achieving this in practice is challenging due to the active perturbation process employed by MPPT algorithms and the continuous changes in solar insolation and temperature. As a result, it is difficult to maintain the system consistently at the MPP. This phenomenon has a detrimental effect on the overall efficiency of the PV system.

Tracking efficiency

Tracking efficiency plays a crucial role in assessing the effectiveness of an MPPT control algorithm in accurately tracking the maximum power point (MPP) and enhancing the overall performance of the PV system compared to alternative methods. As defined by T. Tafticht (2007), tracking efficiency is determined by comparing the actual power output of the PV array to the theoretical power that could have been generated during the same time period. This ratio provides a quantifiable measure of how efficiently the MPPT algorithm is able to track and utilize the available power from the PV array.

2.6. DC-DC Converter for Photovoltaic System

The switch mode DC-DC converter plays a crucial role in an MPPT system, serving as its primary component. These converters are commonly employed to transform unregulated DC inputs into controlled DC outputs at desired voltage and current levels. They are extensively utilized in various applications such as DC power supplies, DC motor drives, and as inputs to inverters. In the context of an MPPT system, the same converter is employed to achieve load matching for maximum power transfer. This is accomplished by regulating the input voltage at the MPP of the PV array through the control of the duty ratio (D).(Mohan, N., Undeland, T. M., & Robbins, 2002).

DC-DC converters are utilized to establish a connection between the photovoltaic module and an inverter. Their purpose is to ensure that the photovoltaic module consistently operates at its maximum power point, providing the desired input voltage level to the inverter. This is achieved through the control of the converter's duty ratio (D) using maximum power point tracking algorithms (MPPT).

In general, converters can be classified into two types: isolated and non-isolated converters. Isolated converters employ a small high-frequency electrical isolation transformer to create DC isolation between the input and output of the converter. The output voltage can be stepped up or down by adjusting the turns ratio of the transformer. Isolated converters, such as half bridge and full bridge configurations, are commonly used in switch mode power supplies.On the other hand, non-isolated converters do not incorporate an isolation transformer. They are frequently employed in DC motor drives, where isolation is not required for the specific application.(Mohan, N., Undeland, T. M., & Robbins, 2002). Non-isolated converters are classified into three types: step up (boost), step down (buck), and step up and step down (buck-boost).

2.6.1 Step-Down (Buck) Converter

This particular DC-DC converter operates in such a way that the average output voltage (Vo) it generates is consistently lower than the DC input voltage. The buck converter is specifically designed for voltage step-down purposes in PV applications. It is commonly employed for tasks like battery charging and water pumping systems within the realm of photovoltaics.

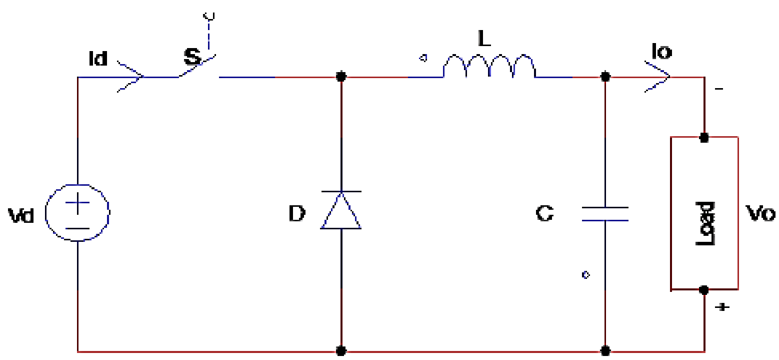

Figure 2. 10.Step-down Buck converter(Silva-Ortigoza, 2006)

2.6.2 Step-Up (Boost) Converter

Boost converters find application in various areas such as the regenerative braking circuit of DC motors and regulated DC power supplies. Unlike the buck converter, the boost converter operates in a manner where the output voltage is consistently higher than the input voltage.(Silva-Ortigoza, 2006). Hence, the step-up converter is suitable for implementation in MPPT systems that require the output voltage to be higher than the input voltage. This is particularly applicable in grid-connected systems, where the boost converter ensures a consistently high output voltage even when the PV array voltage decreases to low values.

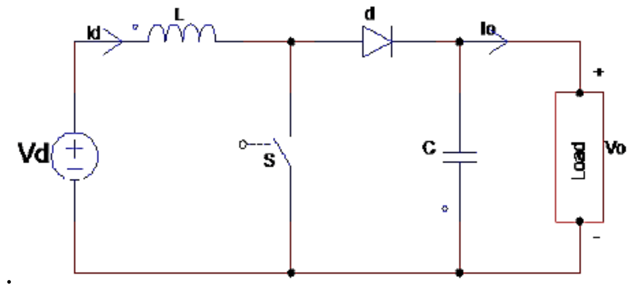

Figure 2. 11.Step-Up Boost Converter*(Silva-Ortigoza, 2006)*

2.6.3 Cuk (Buck-Boost) Converter

The Cuk converter can be derived from the Buck-Boost topology circuit through the application of the duality principle. By employing this principle, it becomes evident that the input circuit of the Cuk converter functions as a Boost converter, while the output circuit operates as a Buck converter.(E. Duran, 2008). Hence the Cuk converter is similar to the Buck-Boost converter, it provides a negative polarity regulated output voltage with respect to its terminal of the input voltage.

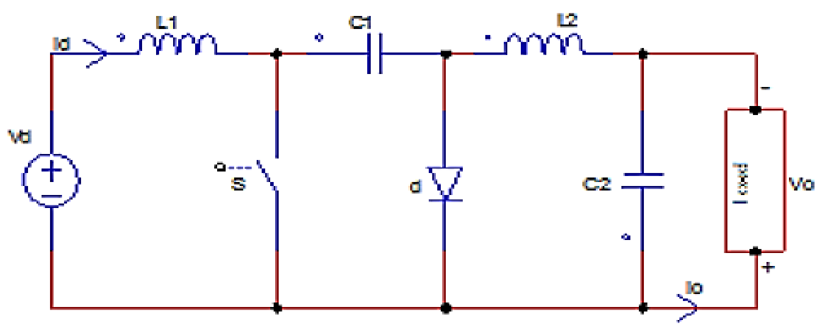

Figure 2.12.

Figure 2. 12.Cuk converter*(E. Duran, 2008)*

Various types of DC-DC converters have been extensively investigated in the literature to determine their suitability for the MPPT stage of PV systems. In this study, a boost converter was chosen for implementation. The DC-DC boost converter plays a crucial role in the PV inverter system as it significantly enhances the overall efficiency of the system. Operating with a higher input voltage reduces the required input current for a given power, resulting in lower losses. The boost converter is responsible for regulating and increasing the DC output voltage of the PV system.2.7. Maximum Power Point Tracking Control Algorithms

In recent years, numerous MPPT algorithms have been introduced for PV power systems with the aim of identifying the maximum power point (MPP) and enhancing system efficiency. These MPPT algorithms can generally be categorized into two types: indirect control, also known as "quasi tracking techniques," and direct control, also referred to as "true tracking techniques."”(V. Salas, 2006). In the indirect control techniques, the maximum power point (MPP) is determined by measuring the voltage and current of the PV array, the solar insolation, or by utilizing mathematical functions based on empirical data. However, these techniques are limited in their ability to accurately track the MPP under varying irradiation and temperature conditions. Examples of indirect control techniques include the look-up table technique, constant voltage technique, fractional open-circuit voltage, and fractional short-circuit current.

On the other hand, true tracking techniques possess the capability to locate the optimum operating point even when atmospheric conditions change. These techniques do not rely on prior knowledge or calculated data from the V-I characteristics of the PV array. The fractional open-circuit voltage and fractional short-circuit current methods utilize only one variable, either the PV array output voltage or current, respectively. Meanwhile, techniques like P&O and INC require both variables to determine the MPP.

Various types of controllers are available to regulate and optimize the performance of the system. These controllers play a role in managing, collecting, processing, and executing tasks to achieve the desired behavior of the system. Examples of conventional and intelligent controllers include PI, PD, PID, LQR, FLC, AFLC, ANFIS, MPC, and SMC. In this thesis, an intelligent Fuzzy-PID controller and a conventional PID controller are employed to design an optimal MPPT system for a solar PV system. The goal is to compare the stability of the control system and evaluate its performance.

2.7.1. Fuzzy Logic Controller

Fuzzy Logic Control (FLC) is an appealing approach for situations where precise mathematical formulations are challenging to obtain. The main reason is that every control system maps input values to corresponding output values. In general, a desired set of outputs is determined based on a given set of inputs. Fuzzy logic offers a valuable methodology for developing practical solutions to control complex systems. It is not mandatory to possess an exact model of these intricate systems in order to design and implement FLC.(Z. L. A., n.d.). It is sufficient to understand the general behavior of the system. When the variables are selected, the decision will be made through specific fuzzy logic functions.

The basic configuration of FLC consists of four main parts such as fuzzification, rule base, fuzzy inference systems, and defuzzification. To implement a fuzzy logic technique to a real application requires the following four main steps:

Fuzzification

Fuzzification is the procedure of transforming classical or crisp data values of control inputs into fuzzy data values using membership functions (MFs). These membership functions take the shape of triangles, trapezoids, bells, or other suitable forms, representing fuzzy linguistic variables. This conversion allows the data to align with the fuzzy set representation in the rule base. (T. Y. a. E. H. Mamdani., 1982).

Rule Base

In the rule-based form, linguistic variables are utilized as antecedents and consequents. The antecedents represent the conditions or inequalities that need to be fulfilled. On the other hand, the consequents are the outputs or inferences that are obtained when the antecedent conditions are satisfied. (A. S. Mamdani E. H., n.d.). The fuzzy rule-based system uses an if-then rule-based system given by, if antecedent, then consequent.

Fuzzy Inference System

Fuzzy inference systems (FISs) are an integral component of fuzzy logic systems, often referred to as fuzzy rule-based systems, fuzzy models, fuzzy expert systems, or fuzzy associative memories. FISs are responsible for formulating appropriate rules and making decisions based on these rules. They primarily rely on the principles of fuzzy set theory, fuzzy if-then rules, and fuzzy reasoning. FISs utilize "if...then" statements, with connectors such as OR or AND in the rule statements. While the basic FIS can accept either fuzzy or crisp inputs, the outputs it generates are typically fuzzy sets. (K. T. P. Hoang, n.d.). Combine membership functions with the control rules to derive the fuzzy output and arrange those outputs into a table called the lookup table. The control rule is the core of the fuzzy inference system and those rules are directly related to a human being’s intuition and feeling.

Defuzzification

The process of determining the corresponding output and input values and organizing them in a table is referred to as a lookup table. The output is then retrieved from the lookup table based on the current input, and the control output is converted from the linguistic variable back to a crisp variable. This final output is then sent to the control operator. This conversion is accomplished through a process known as defuzzification.(Hoang, n.d.). The defuzzification can reduce a fuzzy to a crisp single-valued quantity or as a set or convert to the form in which fuzzy quantity is present.

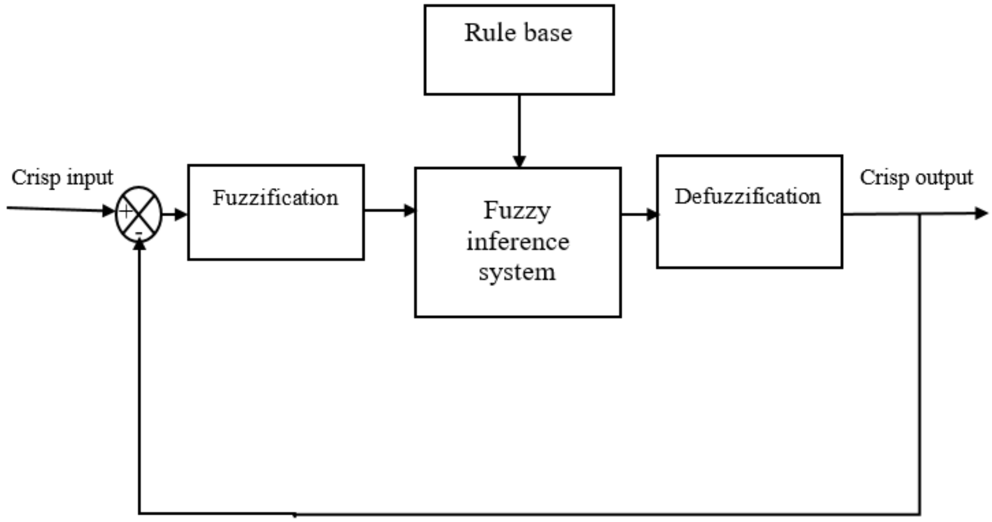

Figure 2. 13.Block diagram of fuzzy logic controller (Hoang, n.d.)

2.7.2. Conventional PID Controller

The PI and PID controllers are widely used conventional controllers that are readily available in commercial applications. PI controllers are employed to enhance the dynamic response of a system and minimize or eliminate steady-state errors. On the other hand, PID controllers consist of three key components: proportional, integral, and derivative terms. ("'Discrete PI and PID Controller Design and Analysis for Digital Implementation'. ".," 2011).

PID controllers are a fusion of PI (proportional-integral) and PD (proportional-derivative) controllers. The proportional term is responsible for addressing the present error, the integral term deals with the cumulative error, and the derivative term anticipates future errors..

$$u(t)=K_p\left(e(t)\right) + K_i\left(\frac{1}{K_i}\int_0^1 e(t)dt\right) + K_d(K_d\,\frac{de(t)}{dt}) \quad (2.4)$$

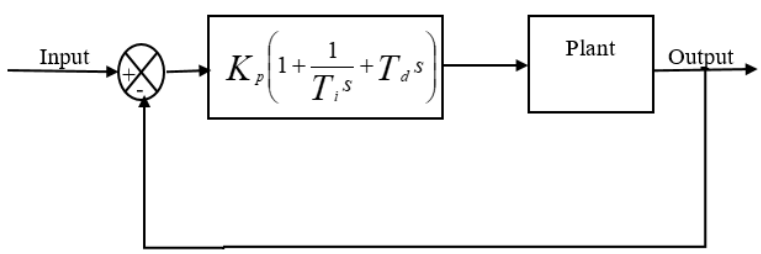

Figure 2. 14.Block diagram PID controller(K. H. Ang, G. Chong and Y. Li, 2005).

2.7.3. Artificial Neural Network

Artificial neural networks (ANNs) are machine learning techniques inspired by the biological nervous system. They consist of interconnected nodes, called neurons, that learn to perform tasks by adjusting the weights between them. These weights are modified using a learning algorithm, which guides the learning process. ANNs offer several advantages over other machine learning methods. They can handle complex and nonlinear relationships, work with numerical or analogue data, provide robust solutions, and do not require advanced mathematical knowledge from the user.In the context of solar panels, the output voltage and current vary nonlinearly with solar radiation levels, aging, and load current. ANNs can be trained using the backpropagation theorem to predict these variations. By analyzing previously recorded data, the ANN learns the relationship between input and output variables. This enables the ANN to handle complex systems with many interconnected parameters. Once trained, the ANN can approximate the input-output mapping of the system.However, there are challenges with ANNs. They require a significant amount of training data, which can be time-consuming and challenging to obtain, especially for complex systems. Furthermore, ANNs do not make autonomous decisions. They can only approximate the relationship between input and output variables, and their predictions may not always be accurate, particularly when dealing with new or unseen data.

2.8. Previous Works on MPPT for Solar PV System

This section reviews previous work that is directly or indirectly related to the idea of this thesis. Many studies have been conducted on standalone off-grid electricity generation in Ethiopia and other developing countries. The works reviewed in this section are generally categorized into three types: recently published journal papers, M.Sc. theses, and Ph.D. theses. Different methods and approaches have been used to evaluate various renewable energy resources, such as small hydro power, wind turbines, solar photovoltaic (SPV) systems, fuel cells, and hybrid systems. Some of the most relevant papers are reviewed in the following paragraphs. The rest are listed in the reference section and mentioned within the text.

The papers (H. A. F. M. M. M. S. S. Y. L. H. Hassan, n.d.; Nandiraju, n.d.) A PID controller was proposed to regulate the load frequency in hydro power systems with one or two power sources. The proposed PID controller tuning method was demonstrated to enhance load frequency control in a second-order, linear, and typically underdamped hydropower system model when subjected to a step load variation. It outperforms other conventional controllers in terms of performance.

Most existing PID tuning methods rely on manual adjustments where the user iteratively modifies the PID values until a satisfactory response is achieved. These methods are time-consuming and lack standardization. Although automated tuning methods exist, they mainly focus on overdamped systems and have not been directly applied to load frequency control (LFC) in hydropower systems.The simulation results of the PID controller in this study indicate significant steady-state frequency errors, lengthy settling time, extended rise time, and considerable overshoot when the load changes from small to large values. Consequently, the PID controller is not suitable for nonlinear, uncertain, complex, higher-order, and time-delay hydropower systems that require load frequency control for one or two power sources.

The papers (C. Dubey and Y. Tiwari, 2018; C. Lodha and V. Shukla, n.d.; M. H. Kebede, n.d.) A novel self-tuning fuzzy PI controller system model was proposed for wind power systems to address the limitations of traditional PI controllers. The performance of the system was evaluated by examining parameters such as rise time, overshoot, and settling time. This system model combines a conventional PI controller with a fuzzy controller in a third-order configuration, eliminating the need for a hydraulic amplifier servo mechanism to ensure stability in controlling the load frequency of the system.Simulation results demonstrate significant improvements in system adjustment time and overshoot, leading to enhanced control performance when the fuzzy self-tuning algorithm is applied to the conventional PI controller using 25 fuzzy rules. Notably, the steady-state frequency deviation ranges from 0 to 1 p.u. as the load varies from 25% to 95% over a time period of 0 to 400 seconds. However, the rise time, overshoot, and settling time remain relatively high.

The papers (L. E. Weldemariam, 2019; M. Shikur, n.d.)A study conducted by Mohammed Shikur in 2019 entitled on “Simulation, Modeling and Control of Distributed Hybrid Generation System” for Berehet Woreda.The primary objective of this thesis is to develop a model, conduct simulations, and implement control strategies for a hybrid power system connected to the grid. The system comprises various components including wind turbines, photovoltaic generators (PV), an alkaline water electrolyzer, a storage gas tank, and a solid oxide fuel cell (SOFC), with different system configurations explored. To achieve the goals of this study, different methodologies were employed.

The hybrid system was modeled and simulated using MATLAB/Simulink software. Data specific to the case study area were collected to perform optimization and financial analysis using the HOMER optimization software. The results obtained from HOMER indicated that the optimal configuration consisted of a 3,000 kW PV array, 20 Atlantics wind turbines, and a 2,000 kW fuel cell stack. The total net present cost (NPC) was calculated to be $7,645,000.00 with a cost of electricity (COE) of $0.188/kWh. It should be noted that the alkaline electrolyzer, which was not equipped with any controller, demonstrated drawbacks such as low current density, low efficiency, and high operational cost.The papers associated with this research focus on different aspects of the hybrid power system, covering topics such as modeling, simulation, optimization, and financial analysis.

(G. B. Huka, n.d.; M.Sharmila, C.K.Sundarabalan, J.Prince Joshva Gladson, n.d.) In a 2016 journal article titled "Compensation of Power Quality Issues using Fuel Cell with Electrolyzer/PV/Wind Turbine," M. Sharmila et al. present a model designed to address power quality problems in a wind-diesel hybrid system. The primary objective of this study is to mitigate the voltage variation and voltage flicker effects caused by wind turbines on the electrical grid. Through simulations, the authors demonstrate the effectiveness of the FC/ELZ system in compensating for flicker levels and voltage fluctuations.The results of the study indicate that the proposed system enhances the output power quality of the FCWT, thereby improving the reliability of the microgrid. Additionally, it helps reduce fuel consumption, pollution, and the need for fuel transportation to the microgrid, thus lowering fuel costs. However, it should be noted that, similar to the previous paper, this study also relies on a Genset as a backup power system, which has potential environmental impacts. Furthermore, since wind power alone cannot guarantee continuous power supply, the study does not incorporate any type of controller mechanism.

The papers (H. Abatcha, A. M. Jumba, 2018; S. Yuvarajan and J Shoeb, n.d.) In 2011, Gelma Boneya conducted a study on the design of a PV-Wind hybrid power generation system for remote areas in Ethiopia. The objective of the study was to provide electricity to a community comprising 100 households, a health center, and a school. Boneya argued that implementing cost-effective PV-Wind hybrid systems could significantly improve the lives of people in rural areas without access to the main grid. Using the HOMER software, various results were obtained depending on the level of renewable energy penetration. The study found that the cost of energy for the feasible hybrid system ranged from 30 to 40 cents per kilowatt-hour. Although this was higher than the current global and Ethiopian electricity tariffs, Boneya emphasized that the cost should not be the sole determining factor, considering the severe electricity shortage in the country and the limited electricity usage in rural areas. It was also recognized that both power supply and demand in such areas are unpredictable and subject to fluctuations over time. To effectively manage the variability in power supply and demand, including power intermittency, power peak shaving, and long-term energy storage, a supervisory control system was deemed necessary. However, it is worth noting that the study did not incorporate any specific control mechanism to address these phenomena.

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CHAPTER THREE

METHODOLOGY

3.1. Introduction

This chapter deals with the data collection, designing process of solar PV system, mathematical modeling for photovoltaic cell, designing and modeling of boost converter, fuzzy based ANN MPPT, and designing of inverter.

3.2. Methodologies

To achieve the overall goals and specific objectives of this study, various methods and techniques were employed, as depicted in Figure 3.1. The initial step involved reviewing relevant literature and conducting a comprehensive analysis. Subsequently, the necessary data for the research was collected and examined. The load demand of the system was determined, and a suitable PV module was selected. In order to obtain the desired output voltage, a DC-DC boost converter was designed. The overall methodology encompassed several distinct tasks that were executed to successfully fulfill the requirements of this thesis.

1. Literature review: This thesis relies on the prior research conducted by scholars in the field pertaining to the selected topic. To gather essential and relevant information, extensive literature review was conducted, encompassing various sources such as books, articles, papers, journals, published materials, and online resources specifically focused on MPPT for Solar PV configurations

2. Data collection: The necessary data for the design, modeling, and simulation of MPPT for Solar PV configurations was gathered from a diverse range of sources. These sources include books, papers, journals, online research, articles, published materials, previous works by other scholars, and even related videos were observed to gather comprehensive information.

3. Data analysis: The collected data is analyzed using established theoretical formulas to inspect, model, and design the feasibility of MPPT for Solar PV systems. This process involves a thorough examination of the data, applying proven formulas, and utilizing modeling techniques to assess the viability and effectiveness of the MPPT system for Solar PV applications.

4. Modeling and designing: the overall model and designs of the proposed fuzzy logic PID controller of MPPT for Solar PV configurations have been simulated using MATLAB/Simulink software depending on the data analysis to get the best optimizing solution.

5. Finally, paper documentation: the final work is showing the overall works of the thesis starting to ending including, MATLAB simulation results, conclusion, recommendation, and future work that have been made based on the research finding and the simulation studies.

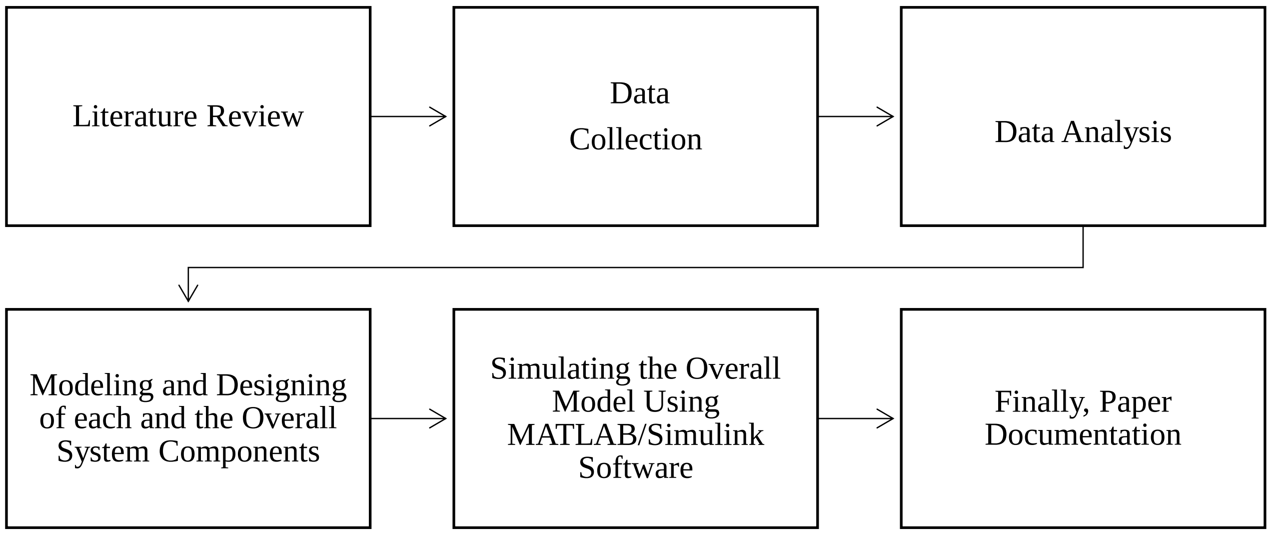


Figure 3. 1.Block diagram of overall methodologies to be followed for this thesis

3.3. Materials

For the system design and editing thesis documentation the following computer software's are used.

- Microsoft office 2019,
- Math Type 6.0 equation,
- MATLAB/2019a, and

Microsoft office is used for editing the thesis documentation. MathType 6.0 is used for writing mathematical equations in Microsoft office word and Power point presentation tools. MATLAB is used for simulation of the system design.

3.4. Mathematical Modeling of Solar PV System

The initial stage in designing and evaluating control systems is mathematical modeling, which involves expressing the system using equations like state-space, differential equations, and transfer functions. State-space modeling is a versatile method that can represent both linear and nonlinear systems. While solving differential equations can be complex and time-consuming, transfer function modeling is relatively straightforward in comparison. (M. Shikur, n.d.). A solar PV cell is represented as a p-n junction in its model. The behavior of the solar cell can be explained using a nonlinear model that includes components such as photocurrent, diode, parallel resistor, and series resistor. This model is depicted in Figure 2.2 as an equivalent circuit. The output current of the cell can be calculated using the following equation:

$$I = I_{ph} - I_d - I_{sh} \tag{3.1}$$

Where,

I is the output current

I_{ph} is a light-generated current or photocurrent,

I_d is the diode current and

I_{sh} is the shunt current.

According to Figure 2.2, the series resistance R_s comprises the resistance of the semiconductor material and the contact resistance of the cables. On the other hand, the parallel or shunt resistance R_p accounts for the leakage currents at the edges of the photovoltaic cell, where the ideal shunt reaction of the p-n junction may be diminished. Typically, this resistance is in the kilohm range and does not significantly impact the current-voltage characteristic.

$$I = I_{ph} - I_d \tag{3.2}$$

According to Shockley equation the diode current can be written as [59]:

$$I_d = I_s \left(\exp\left(\frac{V + IR_s}{V_t} \right) - 1 \right) \tag{3.3}$$

The amount of current produced by the solar cell is directly related to the intensity of solar radiation it receives. At night, the solar cell operates in reverse mode as a diode. However, when light shines on the solar cell, it generates a diode current. The behavior of the diode determines the current-voltage (I-V) characteristics of the cell. By utilizing the electrical properties of a p-n junction diode and applying circuit laws to Figure 2.2, equation (4.2) can be modified as follows:

$$I = I_{ph} - I_s \left(\exp\left(\frac{V + IR_s}{V_t} \right) - 1 \right) \tag{3.4}$$

$$V_t = \frac{mKT_C}{q} \tag{3.5}$$

Thus, equation (3.4) can be written as:

$$I = I_{ph} - I_s\left(\exp\left(q\left(\frac{V+IR_s}{mKT_C}\right)\right) - 1\right) \quad (3.6)$$

Where,

I_s is the cell saturation of dark current in A

V_t is the thermal voltage in V

K is the Boltzmann's constant ($1.38 * 10^{-23}$J/K)

q is the electronic charge ($1.6 * 10^{-19}$C)

T_C is the cell working temperature and

m is ideality factor, its value is dependent on PV technology and is listed in table 3.1 below.

Table 3. 1.Ideality factor m for different PV technology (A. Barnawi, 2016; A. Mondal and S. Yuvarajan, n.d.)

Technology	**Si-mono**	**Si-poly**	**a-si:H**	**a-si:H tandem**	**a-si:H triple**	**CdTe**	**CIS**	**AsGa**
m	1.2	1.3	1.8	3.3	5	1.5	1.5	1.3

In order to enhance the power output of a solar cell, multiple cells are interconnected in both series and parallel arrangements within a module. A photovoltaic (PV) array consists of several PV modules that are connected in series and parallel configurations to generate the desired voltage and current.

Referring to Figure 2.4 in chapter two, the equation representing the relationship between the current and voltage at the terminals of the cell module can be derived as follows(A. Mondal and S. Yuvarajan, n.d.):

$$I = N_p I_{ph} - N_p I_s\left(\exp\left(q\left(\frac{V+IR_s}{mKT_C N_S}\right)\right) - 1\right) \quad (3.7)$$

The photocurrent mainly depends on the solar insolation and cell's working temperature, which is described as (A. Barnawi, 2016)

$$I_{ph} = \left(I_{sc} + K_i\left(T_C + T_{ref}\right)\right) G \quad (3.8)$$

Where,

I_{sc} is the cell's short-circuit current at a $25^{\circ}{}_{C}$ and 1kW/m^2

K_i is the cell's short circuit current temperature coefficient

T_C is the cell operating temperature in Kelvin

T_{ref} is the cell's reference temperature and

G is the solar insolation in kW/m^2

Based on equation 3.8, the value of K_i, which is obtained from the manufacturer's data sheet, is negative. Consequently, as the temperature increases, the output current of the system decreases.

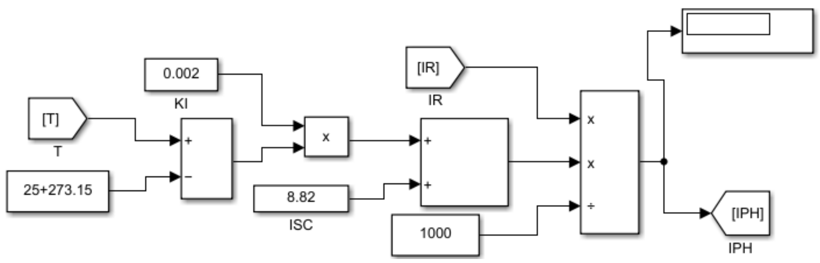


Figure 3. 2.Photo current Simulink model

As seen from equation (3.3) the diode current depends on saturation current.

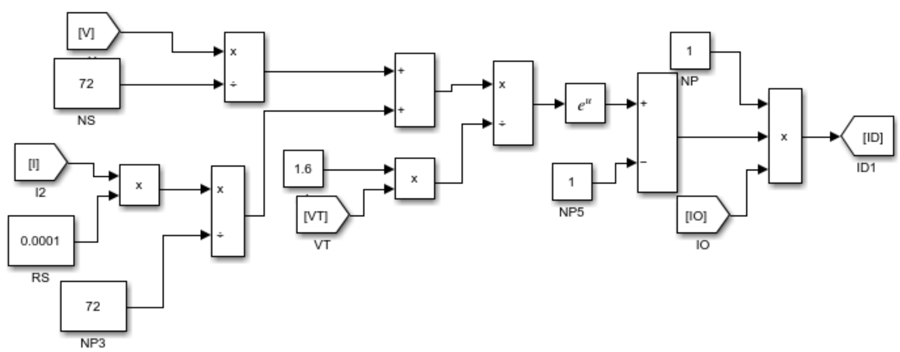


Figure 3. 3.Diode current Simulink model

On the other hand, the cell's saturation current varies with the cell temperature, which is described as [13, 17]:

$$I_s = I_{rs}\left(\frac{T_C}{T_r}\right)^3 \exp\left(\frac{qE_g}{mK}\left(\frac{1}{T_r} - \frac{1}{T_C}\right)\right) \quad (3.9)$$

And

$$I_{rs} = \frac{I_{sc}}{\exp\left(\frac{qV_{OC}}{KmT_C}\right) - 1} \quad (3.10)$$

Where,

I_{rs} is the cell's reverse saturation current at a reference temperature and a solar radiation

E_g is the bang-gap energy of the semiconductor used in the cell and

is the cells open circuit voltage.

From table 3.1, the value of ideality factor **m** is 1.2.

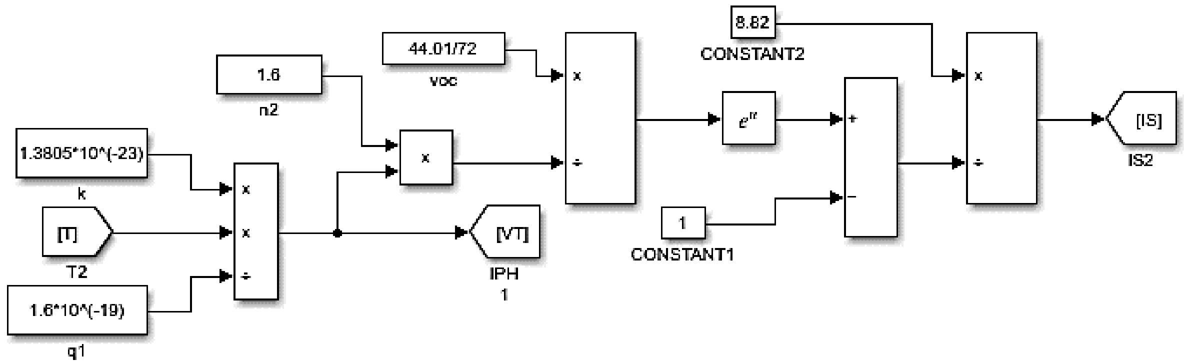


Figure 3. 4.Saturation current Simulink model

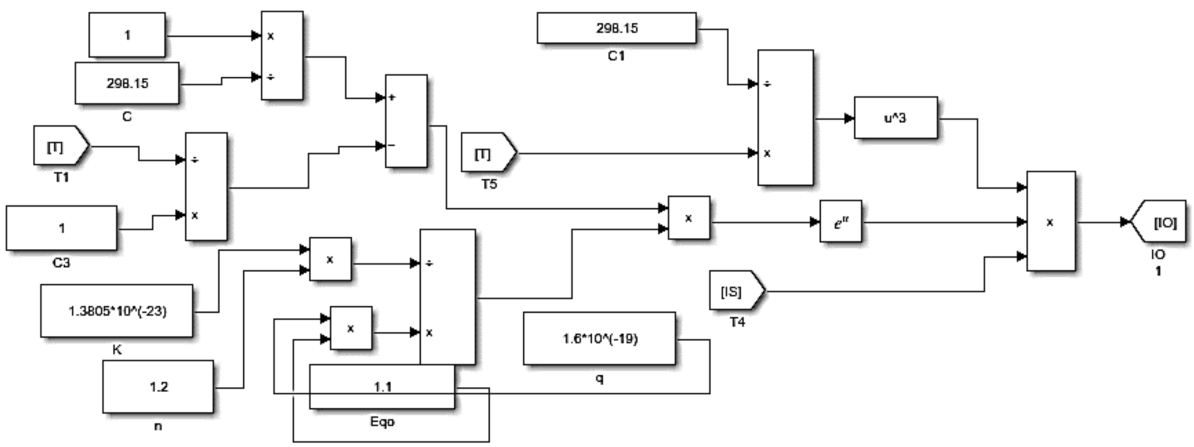


Figure 3. 5.Reverse saturation current Simulink model

The general MATLAB/Simulink model of the solar PV energy conversion system is given in figure below.

3.5. Modelling of Maximum Power Point Tracking Algorithms

The process of mathematically modeling Maximum Power Point Tracking (MPPT) entails creating an equation or expression that accurately represents the behavior of the PV system and the MPPT algorithm. The objective is to derive an equation that can predict the performance of the MPPT algorithm across various operating conditions.

A fundamental approach to modeling MPPT involves utilizing the current-voltage (I-V) characteristic curve of the solar panel. This curve depicts the correlation between the output current and voltage of the solar panel, considering a specific irradiance and temperature. The power output of the solar panel can be determined using the following equation:

$$P = IV \tag{3.11}$$

where P is the power output, I is the current, and V is the voltage.

The maximum power point (MPP) is the point on the I-V curve where the power output is at its maximum. The MPP can be obtained by solving the following equation:

$$dP/dV = 0 \tag{3.12}$$

This equation gives the voltage value at which the power output is at its maximum. However, due to the non-linear nature of the I-V curve, it is difficult to obtain an analytical solution for this equation.

One of the most common MPPT algorithms used in PV systems is the perturb and observe (P&O) algorithm. The P&O algorithm uses a perturbation technique to track the MPP of the PV system. The algorithm periodically perturbs the voltage or current of the system and measures the resulting power output. If the power output increases, the perturbation is continued in the same direction, otherwise, the direction of perturbation is reversed. This process is repeated until the MPP is reached(K. T. P. Hoang, n.d.).

The P&O algorithm can be modelled mathematically using the following equation:

$$V(t+1) = V(t) + Ksign(P(t) - P(t-1)) \tag{3.13}$$

where V is the voltage, P is the power output, and K is a constant that determines the step size of the perturbation. The sign function is used to determine the direction of the perturbation based on the change in power output.

MPPT using ANN optimized Fuzzy-PID Control is considered in this thesis due to its better performance, robust and simplicity in design, working with imprecise inputs, not needing an accurate mathematical model (require the complete knowledge of the operation of the PV system by the designer), and handling nonlinearity.

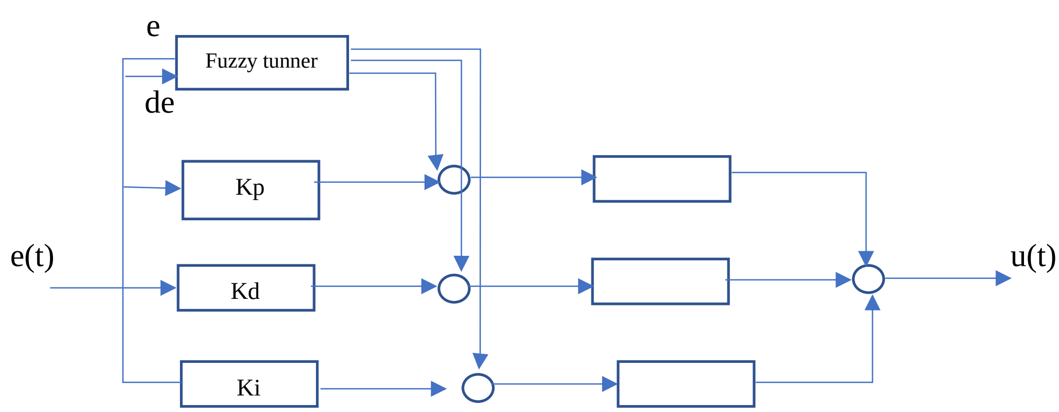
3.2.1. Fuzzy PID Control Based PV Maximum Power Point Tracking

The controller utilized in this system combines both fuzzy logic controllers and PID controllers. Fuzzy logic controllers allow for the rapid and accurate adjustment of PID controller parameters, enabling the PID parameters (Kp, Ti, and Td) to adapt to process changes caused by external disturbances. As a result, the equation for the PID parameters with adaptation, denoted as Equation 3.14, can be expressed

$$.K_p(t) = K_{p1}(t) + \Delta K_p \quad (3.14)$$

$$T_i(t) = T_{i1}(t) + \Delta T_i$$

$$T_d(t) = T_{d1}(t) + \Delta T_d$$



The fuzzy tuner produces three outputs, namely voltage, power, and duty cycle, for the try error fuzzy controller. The fuzzy logic MPPT algorithm can be described as follows:

MPPT, or maximum power point tracking, is a technique employed in photovoltaic (PV) systems to identify and track the maximum power point (MPP). The effectiveness of MPPT relies on both the MPPT control algorithm and the MPPT circuit. Typically, the MPPT control algorithm is implemented within the DC-DC converter, which serves as the MPPT circuit.

The proposed MPPT controller, based on fuzzy logic controller (FLC), comprises four key components: input/output membership functions (MFs), a fuzzy inference engine, fuzzy rules, and a defuzzifier. The fuzzy inference process employs Mandani's method, while the defuzzification uses the center of gravity to determine the output of the FLC, which represents the change in duty cycle.

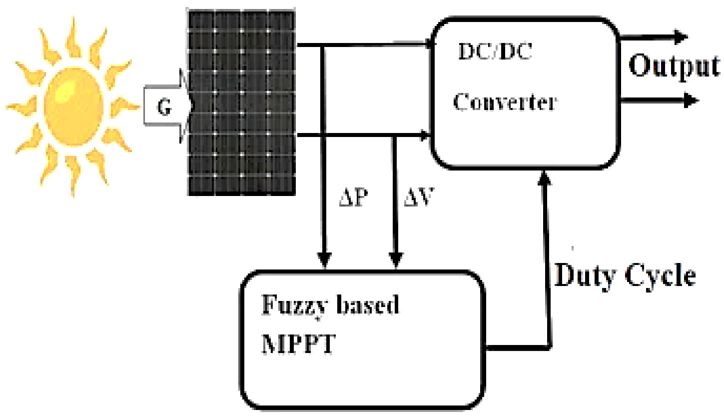


Figure 3. 6.Detailed block diagram of FLC-based MPPT controller

In this research, the proposed fuzzy logic controller (FLC) utilizes power variation (ΔP) and voltage variation (ΔV) from the solar cell as inputs, and the duty cycle (D) is chosen as the output of the FLC. The membership functions (MFs) in the FLC can have various shapes, such as triangular, trapezoidal, symmetric Gaussian function, generalized Bell curve, or sigmoidal function. For this study, triangular MFs are employed for both input and output variables. Triangular MFs are preferred due to their simplicity, making them suitable for low-cost microcontroller implementation.

The fuzzy controller takes two inputs: the power error and the rate of change of the error. The power error is the difference between the desired power output and the actual power output of the solar cell. The change in error represents how fast the power error is changing. The output of the fuzzy controller is the duty cycle variable, which is used to control the pulse width generation block. The power error can be calculated using the following equation:(Manjunath, n.d.),

$$E(k) = P(k) - P(k-1)$$
$$E(k) = V(k) - V(k-1) \quad (3.15)$$

The change in error is given by,

$$\Delta E(k) = E(k) - E(k-1) \quad (3.16)$$

The output of the fuzzy controller is the duty cycle,

$$(k) = D(k-1) - dD \quad (3.17)$$

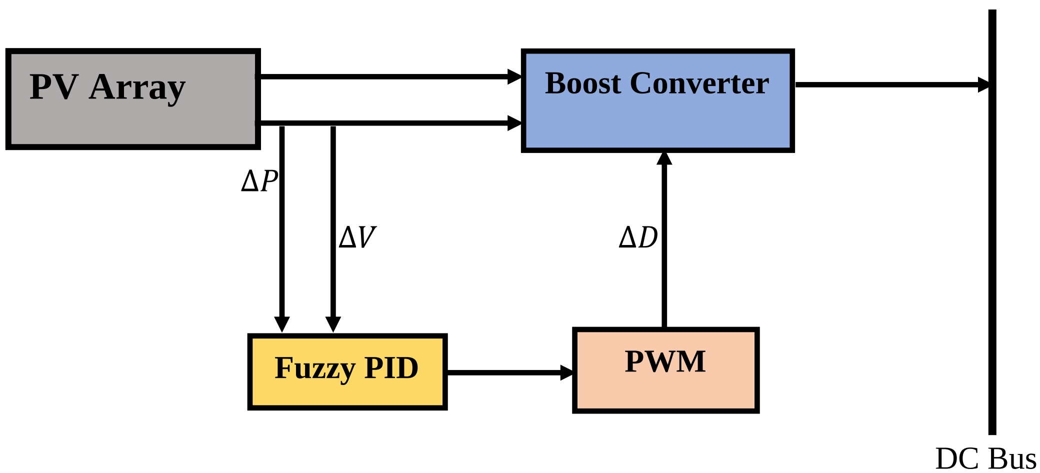


Figure 3.5. Schematic diagram of the proposed Fuzzy-PID MPPT

The fuzzy logic controller (FLC) takes two input variables at sampling instant k: power variation (ΔPpv) and voltage variation (ΔVpv). The output variable is the duty ratio (D) of the boost converter. The values of ΔPpv and ΔVpv can be calculated using the following equations:(Islam, 2006),

$$\Delta P_{pv} = G_p\left(P_{pv}(k) - P_{pv}(k-1)\right) \quad (3.18)$$

$$\Delta V_{pv} = G_V\left(V_{pv}(k) - V_{pv}(k-1)\right) \quad (3.19)$$

And the crisp value of the output variable ΔD (k) is computed by;

$$D(k) = D(k-1) + G_D \Delta D(k) \quad (3.20)$$

The scaling factors Gp, GV, and GD are used to normalize the values of ΔPpv(k), ΔVpv(k), and ΔD(k) in the fuzzy logic controller (FLC). These scaling factors are crucial in optimizing the performance of the FLC and can be determined through trial and error, tailored to the specific application. The normalized output signal D(k) is then sent to the system. The input variables ΔPpv and ΔVpv are divided into five fuzzy sets: PB (Positive Big), PS (Positive Small), ZE (Zero), NS (Negative Small), and NB (Negative Big). Similarly, the output variable D is divided into the fuzzy sets: PB (Positive Big), PS (Positive Small), ZE (Zero), NB (Negative Big), and NS (Negative Small). The algorithm is inspired by the perturbing and observing (P&O) method, and Figure 3.9 illustrates the membership functions and rule base corresponding to the inputs and outputs. The fuzzy rule database is divided into nine regions based on the characteristics of the P-V curve of the solar PV cell. Detailed analysis and discussions regarding these regions are provided below.

Region 1: When both the power and voltage decrease simultaneously at the same irradiance, the operating point of the solar cell will be on the left side of the maximum power point (MPP). By analyzing the variations in power and voltage, the decrease in the duty ratio can be determined.

Region 2: If the power output of the solar cell remains constant but the voltage output decreases, it is assumed that the operating point is at the maximum power point (MPP). In this case, the algorithm output would be set to ZE to avoid contradictions, as it cannot determine if the irradiance has increased or decreased.

Region 3: When the irradiance remains constant and both the power and voltage increase, the operating point will be on the right side of the MPP. The increase in the duty ratio can be determined by analyzing the changes in power and voltage. However, if the duty ratio command is too large, it can cause the operating point to move from the right side of the MPP to the left side, leading to contradictory outputs and fluctuations. Hence, the step size of the duty ratio should not be too large.

Region 4: This region is characterized by a constant voltage and decreasing power. Without changes in irradiance, the system cannot determine the location of the operating point relative to the MPP. Therefore, the output for this region is set to ZE to prevent contradictions, even if the irradiance changes.

Region 5: When both the power and voltage stabilize without further changes, it indicates that the system has successfully tracked and reached the MPP. The duty ratio remains unchanged, and the output is set to ZE.

Region 6: In this region, the power output of the solar cell increases while the voltage output remains constant. Similar to Region 4, the system cannot determine the operating point's position relative to the MPP without changes in irradiance. Hence, the output for this region is set to ZE to avoid contradictions.

Region 7: When the irradiance remains constant, the power output of the solar cell decreases, and the voltage output increases, the operating point is located on the right side of the MPP curve. The duty ratio is adjusted accordingly to match the changes in power and voltage.

Region 8: In this region, the power output of the solar cell remains constant while the voltage output increases. Assuming the irradiance remains constant, it is considered that the MPP has been reached, and the output is set to ZE. Even with changes in irradiance, the region cannot determine if it has increased or decreased, thus avoiding contradictions by setting the output to ZE.

Region 9: If both the power and voltage of the solar cell increase simultaneously with the same irradiance, it indicates that the operating point is on the left side of the MPP. The decrease in the duty ratio can be determined by analyzing the changes in power and voltage. However, if the duty ratio command is too large, it can cause the operating point to shift from the left side of the MPP to the right side. In such a case, both power and voltage should increase, and the duty ratio should be increased to track the MPP. This contradicts the need to reduce the duty ratio according to the fuzzy rules database. To prevent system fluctuations, significant changes in the duty ratio should be avoided.

Based on the above condition the overall rules are shown in table 3.2 below.

Table 3. 2.Complete rule base for the proposed FLC

Duty cycle (D)		**ΔP**				
		NB	**NS**	**ZE**	**PS**	**PB**
ΔV	**NB**	NB	NS	ZE	PS	PB
	NS	NS	NS	ZE	PS	PS
	ZE	ZE	ZE	ZE	ZE	ZE

	PS	PS	PS	ZE	NS	NS
	PB	PB	PS	ZE	NS	NB

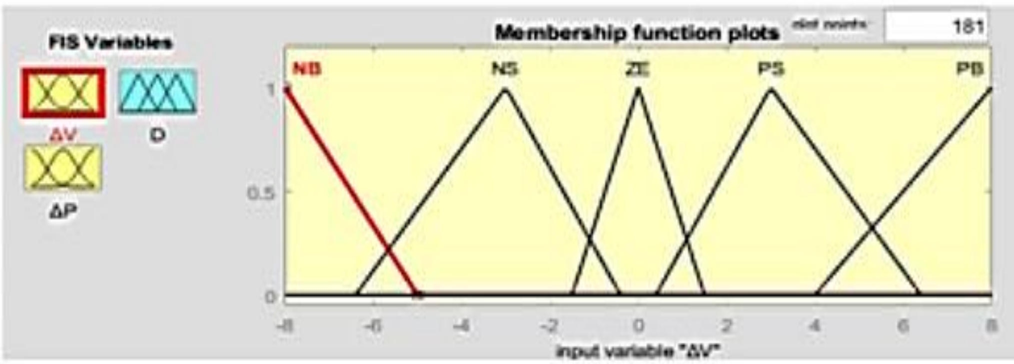


Figure 3. 7.Membership function for ΔV

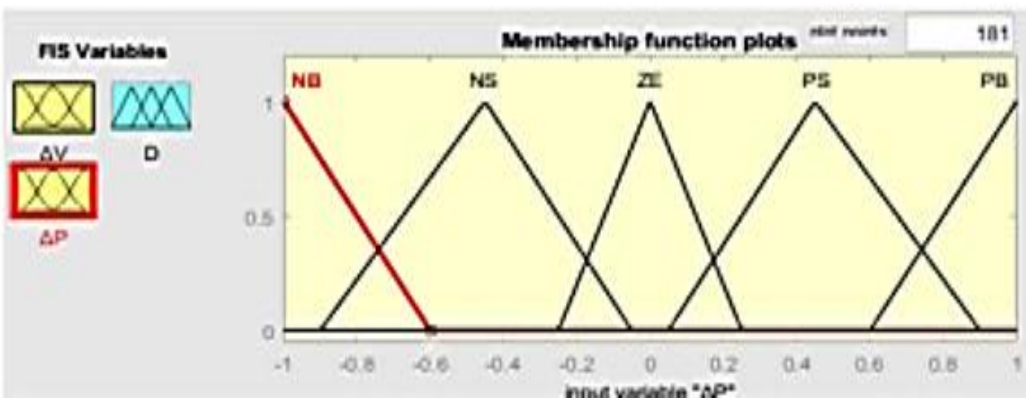


Figure 3. 8.Membership function for ΔP

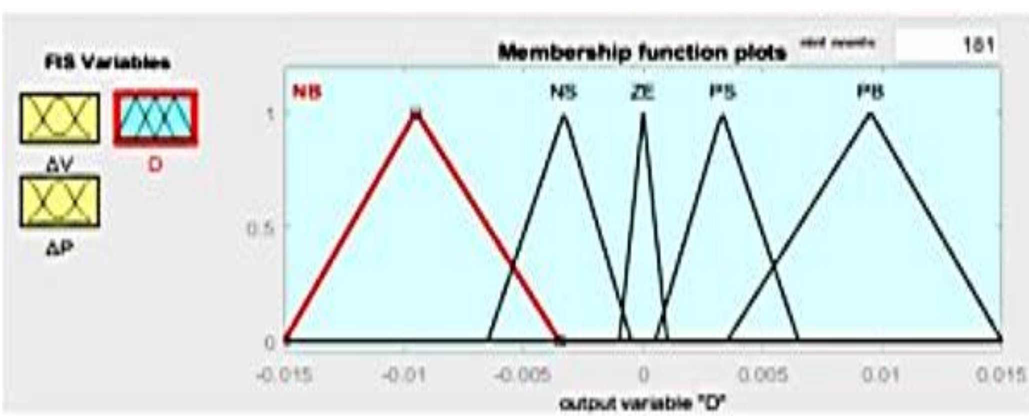


Figure 3. 9.Membership of duty ratio D and (d) rule base.

The process of Maximum Power Point Tracking (MPPT) involves regulating the duty cycle (D) of the DC-DC boost converter. The AC power is converted into DC power using an uncontrolled rectifier. The output of the fuzzy controller is then applied to the duty cycle (D) of the DC-DC boost converter and is scaled to a range of [-1, 1]. By adjusting the duty cycle, the aim is to achieve the maximum power output from the system.

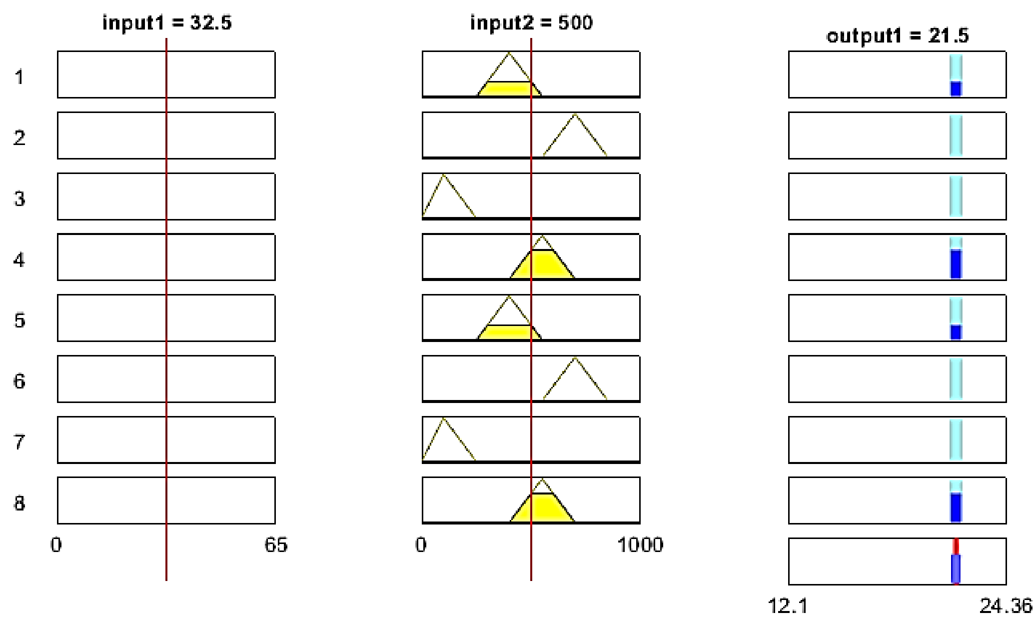


Figure 3. 10.Rule views of the control algorithm

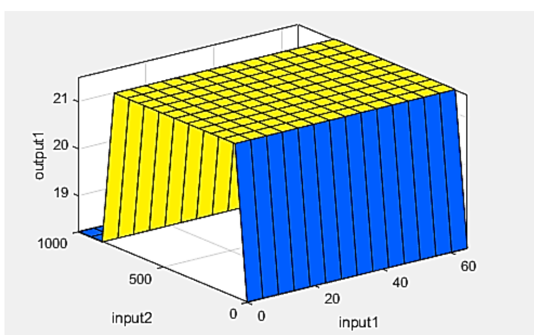


Figure 3. 11.3D surface view of the control rules

3.5.1. Adaptive Neural Network based Fuzzy Controller Design

Combining the training capability of Artificial Neural Networks (ANNs) with the fuzzy logic controller results in a technique called Adaptive Neuro-Fuzzy Inference System (ANFIS). ANFIS is employed to learn from a given training data set and adaptively model the system based on fuzzy logic rules and membership functions. The process involves the following steps:

- Designing the membership functions and rule base for the fuzzy logic controller.
- Providing a training data set that corresponds to the maximum power (Pmax) at different cell temperatures and solar radiation levels to the ANFIS.
- Generating a Sugeno fuzzy inference system (FIS) using grid partitioning.
- Training the selected FIS file using a hybrid learning rule optimization method, with 0 error tolerance and 20000 Epochs. The hybrid learning rule combines the least squares estimation (LSE) and gradient method.
- Providing multiple data sets to the ANFIS from the workspace to form the membership functions for the fuzzy logic controller based on the input-output relationship of the ANFIS.
- ANFIS automatically generates its own rule base based on the training data set, which in turn generates the fuzzy logic rule base during execution. Approximately 200 sets of training data are recorded from the simulation. The Sugeno inference mechanism, known for its ability to model nonlinear systems, is used in this thesis. The structure of ANFIS includes inputs, input membership functions (Inputmf), rules, output membership functions (outputmf), and outputs, as illustrated in Figure 4.5.

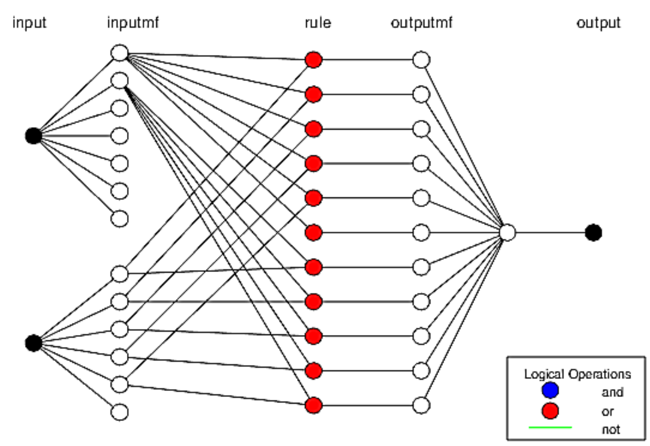


Figure 3. 12.Structure of ANN

Upon completion of the training process, the ANFIS editor displays the training error plot, as shown in Figure 4.6. This plot illustrates the training error during the training phase of the ANFIS. The selected approach in this thesis is the grid partitioning fuzzy inference mechanism, as indicated by the plot. Each input variable is assigned three membership functions, and the training process utilizes approximately 2000 iterations with the hybrid learning rule. The overall training error achieved for 2000 epochs is 0.045436.

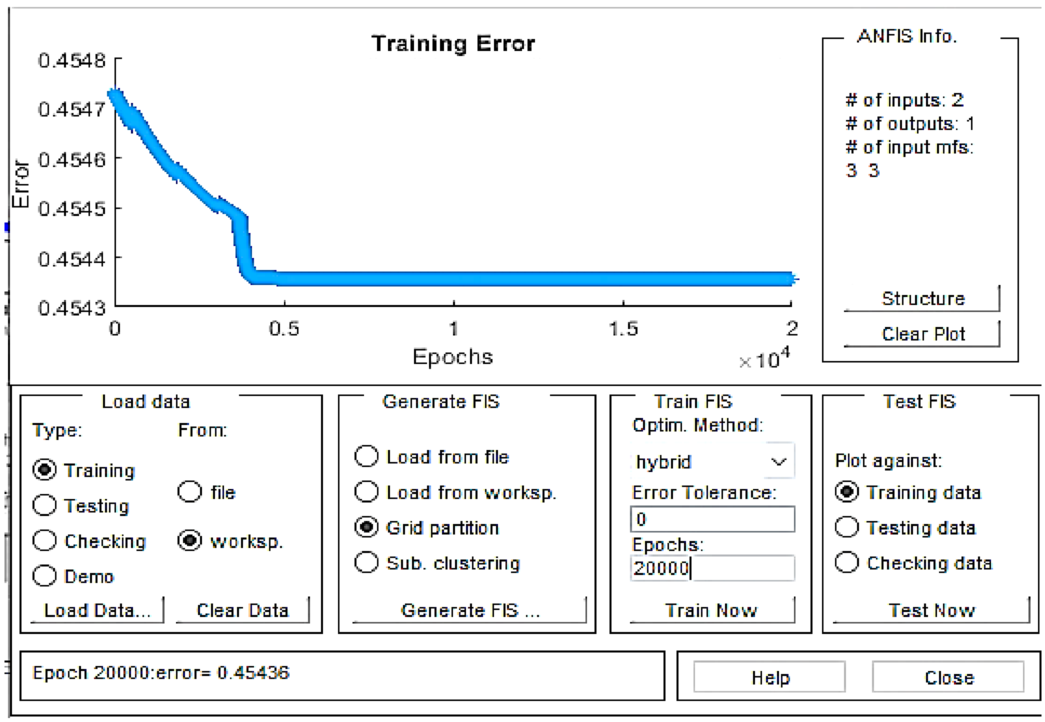


Figure 3. 13.ANFIS Editor for the PV model

3.6. General Sizing of solar PV system

The initial stage in designing a solar photovoltaic (PV) system involves calculating the combined power and energy requirements of all the loads that the system will support. This is achieved by summing up the watt-hours needed for each appliance to determine the total watt-hours per day that must be supplied. The sizing of the PV system is then determined based on this information. To determine the necessary array output per day, the total energy demand per day is divided by the battery round trip efficiency.

$$Required\ array\ output\ per\ day = \frac{Total\ energy\ demand\ per\ day}{Battery\ effciency} \tag{3.20}$$

Energy output of the selected module obtained by multiplying the peak power of the selected by peak sunshine hour (A. A. Kebede, n.d.).

$$E_{pv} = P_{pv} p_{SH} \tag{3.21}$$

Where,

E_{pv} is energy output of module per day

$P_{pv}$is selected PV module generated power and module and

p_{SH} is peak sunshine hour

3.7. DC-DC Boost Converter Modelling

A DC-DC boost converter is an electronic device that increases the input voltage to a higher output voltage. It is composed of several components, including an inductor, a switch, a diode, a capacitor, and a load resistor. During operation, the inductor and capacitor store and release energy in each switching cycle, while the switch and diode control the flow of current through these components.

The mathematical model of a DC-DC boost converter can be obtained by applying Kirchhoff's laws and using the fundamental equations of circuit analysis. The output voltage of the boost converter can be determined using the following equation.(G. V. Athira B, n.d.):

$$Vout = Duty\ Cycle\ x\ Vin\ /\ (1 - Duty\ Cycle) \tag{3.22}$$

In the boost converter, the output voltage (Vout) can be calculated based on the input voltage (Vin) and the duty cycle, which represents the ratio of the switch's on-time to the total period of the switch.

During operation, the inductor and capacitor in the boost converter store and release energy in each switching cycle. Their behavior can be described using specific equations.

$$Vl = L(di/dt) \tag{3.23}$$

$$Ic = C(dv/dt) \tag{3.24}$$

where Vl is the voltage across the inductor, L is the inductance, Ic is the current through the capacitor, C is the capacitance, and dv/dt and di/dt are the rates of change of voltage and current, respectively.

The switching behavior of the boost converter can be modeled using the following equations:

$$Vout = Vin\ x\ Duty\ Cycle\ /\ (1 - Duty\ Cycle) \tag{3.25}$$

$$Iout = Iin\ /\ (1 - Duty\ Cycle) \tag{3.26}$$

where I_{out} is the output current, I_{in} is the input current, and the switch is assumed to have zero resistance.

To regulate the output voltage of a boost converter, a feedback loop is employed, which can be represented by a transfer function. This transfer function establishes a relationship between the output voltage, input voltage, and reference voltage. By utilizing this feedback loop, a controller can be designed to adjust the duty cycle of the switch in order to maintain the desired output voltage.

In general, the modeling of a DC-DC boost converter involves creating a set of equations that describe the behavior of its components. These equations are then analyzed to predict how the converter will perform under various operating conditions. The resulting mathematical model can be utilized to design a suitable controller for the feedback loop and optimize the converter's performance according to the specific requirements of the application.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Introduction

In this chapter the result and analysis of the proposed PV configuration MPPT control using Fuzzy-PI optimized by adaptive neural network. The system design includes a PV configuration with a boost DC to DC converter, fuzzy-PI MPPT controller and optimization of adaptive neural network. All this process id done and clarified starting from the introduction part.

A comparison analysis of the proposed system in the open and controlled system with the different PV configuration system is done for checking the performance of different configuration in energy generation.

4.2. Open Loop Simulation Result

4.2.1. Simulation Result of Series PV Configuration without Controller

In this study the different configuration of photovoltaic cell is considered and analyzed through simulation. For this thesis the series configuration, series-parallel configuration and Total Cross Tied PV configuration are considered.

Figure 4.1 and 4.2 is the representation of voltage current and power output from series connected PV configuration. Figure 4.1 is the voltage, current and power of series configuration in open loop system.as shown in this figure the voltage is around 45V with 0.0085sec settling time and 0.252 sec rise time.

Figure 4.2 specifies the output voltage from series PV configuration before and after boost converter. The blue line is the voltage without boost converter having unstable region and higher settling time than that of the voltage after the boost converter. The pink line is voltage output from series PV configuration after boost having less settling and rise time than that of the original voltage.

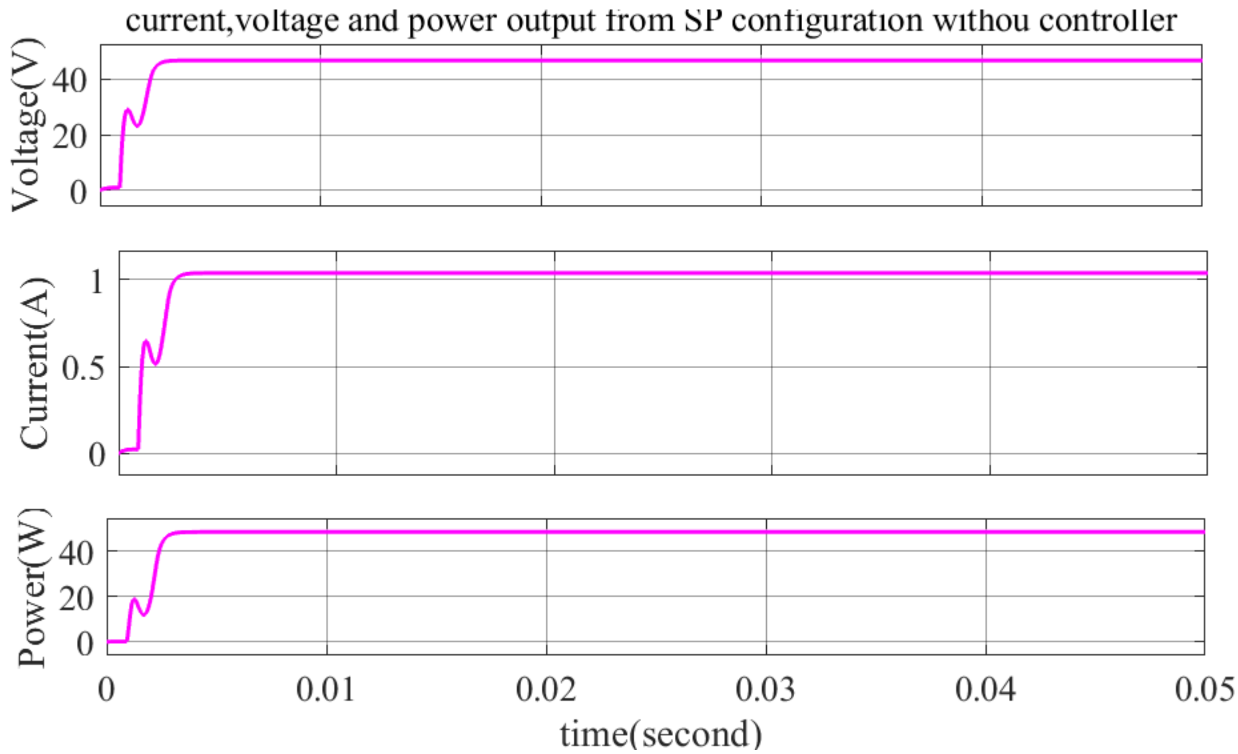


Figure 4.1.

Figure 4. 1.voltage, current and power output from Series connected PV configuration

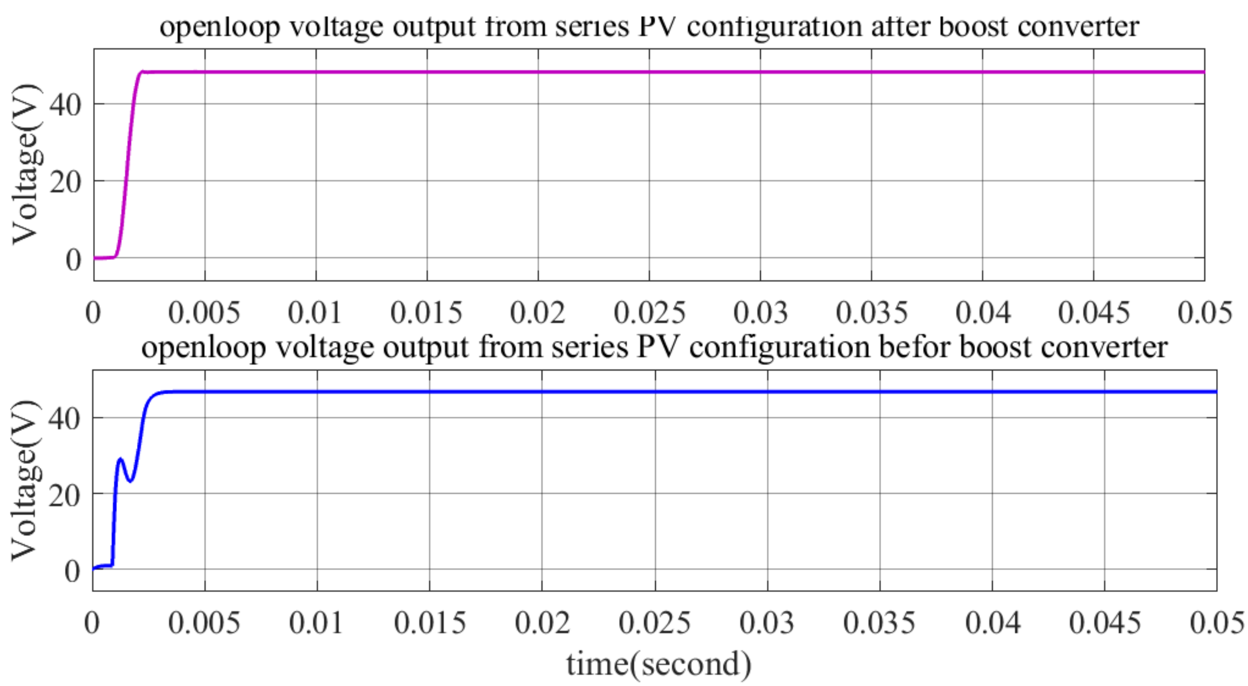


Figure 4. 2.voltage output before and after boost converter from Series connected PV configuration

4.2.2. Simulation Result of Series Parallel (SP) PV Configuration without Controller

Figure 4.3 and 4.4 described below indicates the current, voltage and power output of series parallel PV configuration. The first figure 4.3 is the voltage, current and power output of SP configuration. The three parameters in this configuration have the same rise time and settling time.

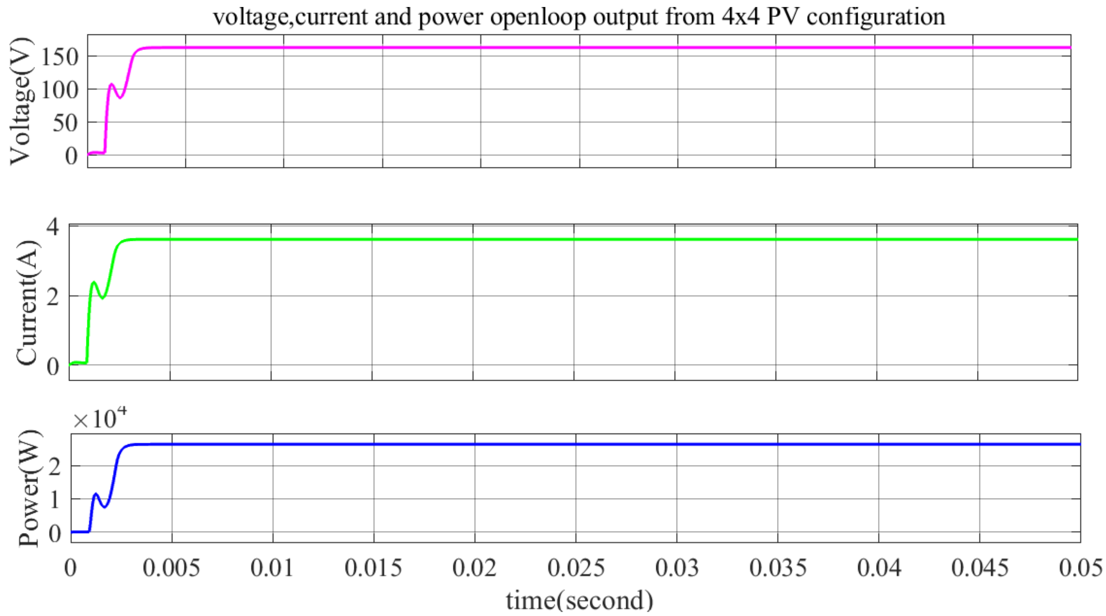


Figure 4. 3.voltage, current and power output from SP connected PV configuration

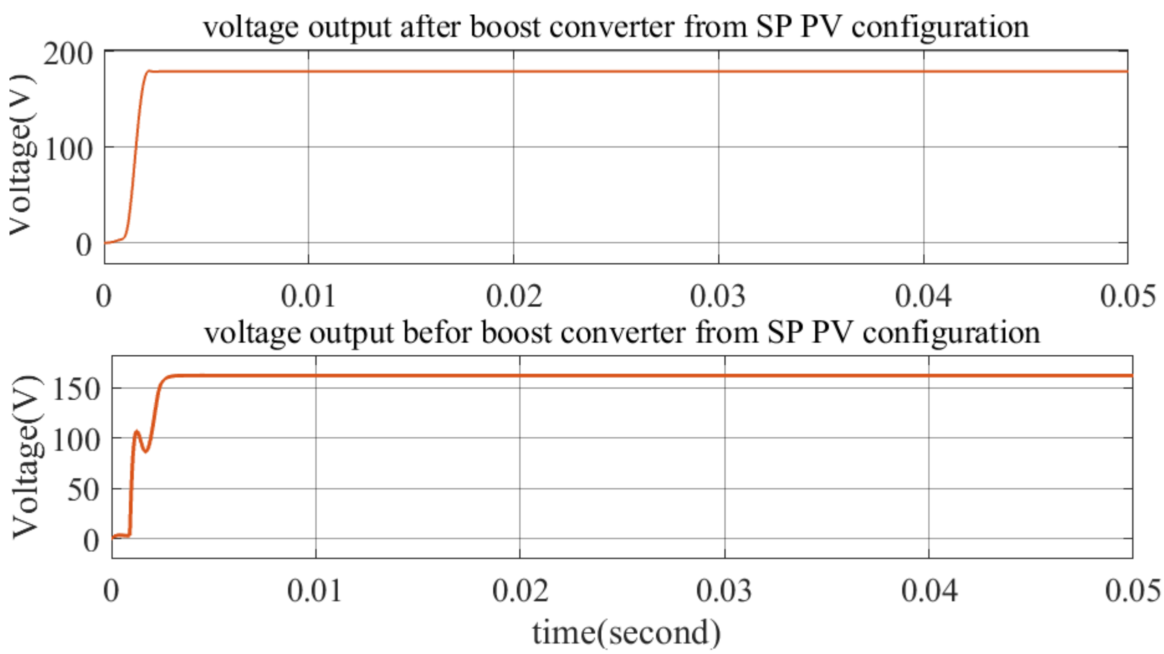


Figure 4. 4.voltage output before and after the boost converter from SP PV configuration

Figure 4.4 if the voltage output of SP PV configuration before and after the boost converter in open loop simulation.as seen from this output the voltage after the boost converter have better stable signal and also the voltage magnitude is greater than that of the voltage generated before the boost converter in SP configuration.

4.2.2. Simulation Result of Total Cross Tied (TCT) PV Configuration without Controller

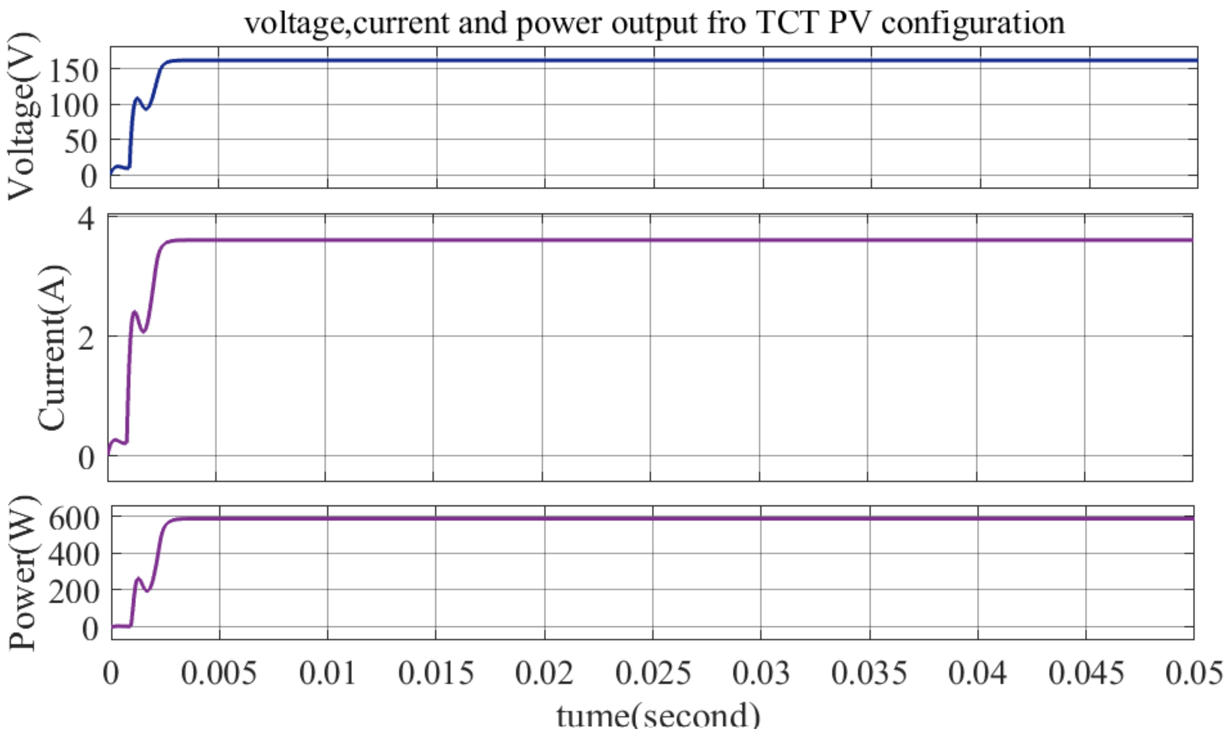


Figure 4.5.

Figure 4. 5.voltage, current and power output from TCT connected PV configuration

4.3. Simulation Result with ANN optimized Fuzzy-PI

4.3.1. Simulation Result of Series PV Configuration

All the figures mentioned after 4.6 are simulated with all the PV configurations using adaptive neural network optimized fuzzy-PI controller to check the stability of PV parameters and to understand which PV configuration have better controllable property.

Figure 4.6 is the voltage output of series connected PV configuration before and after MPPT which is controlled with ANN optimized fizzy-PI controller. From this the red signal is the voltage before MPPT and the blue one is the voltage after MPPT. But the two signals have no the same settling and rise time with varying in value of voltage. And also at the start of the simulation there is less stability of voltage signal. Compared to the open loop the value of voltage is increased and the settling time is also increased.at the start there is maximum power generated and the controller works after 0.038sec.

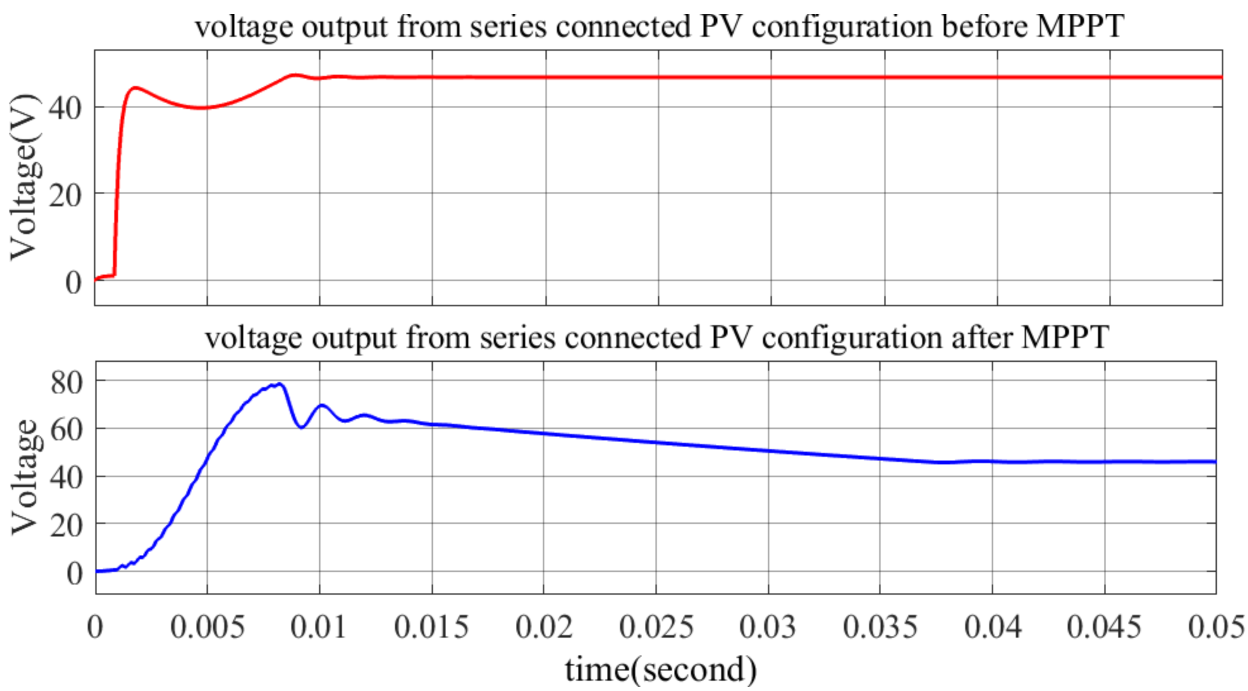


Figure 4. 6.voltage output from series connected PV configuration before and after MPPT

The result described in figure4.7 is the voltage, current and power output of series parallel connected PV configuration with controller. The figure shows the output current is controlled to a stable zero after 0.001sec.from this it is clear that the controller is effective on SP PV configuration. And the stability of power is depending on the voltage after the controller since the main controlled parameter is voltage.

Figure 4.8 shows the result of voltage output of series connected PV configuration before and after boost converter. The first stable signal is the voltage after boost the voltage coming from the controller. The voltage after boost have less settling time than that of the voltage after before boost converter. This shows the effectiveness of boost converter design.

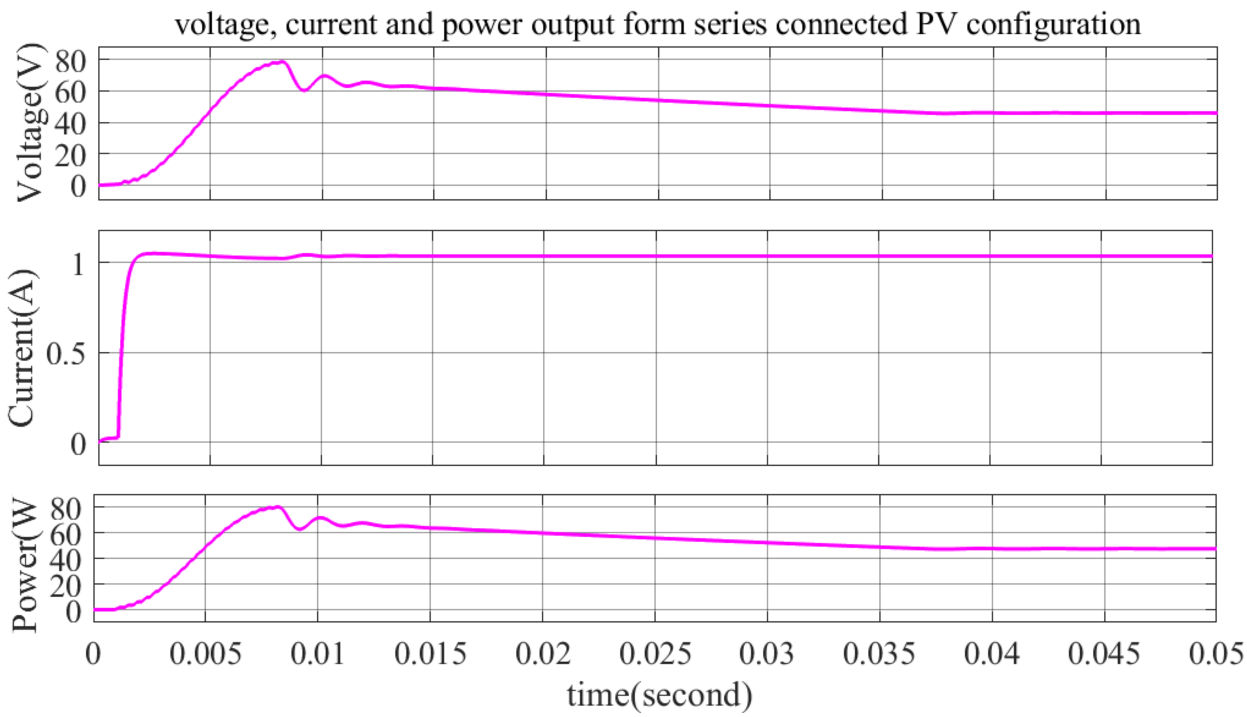


Figure 4. 7.voltage, current and power output form series connected PV configuration

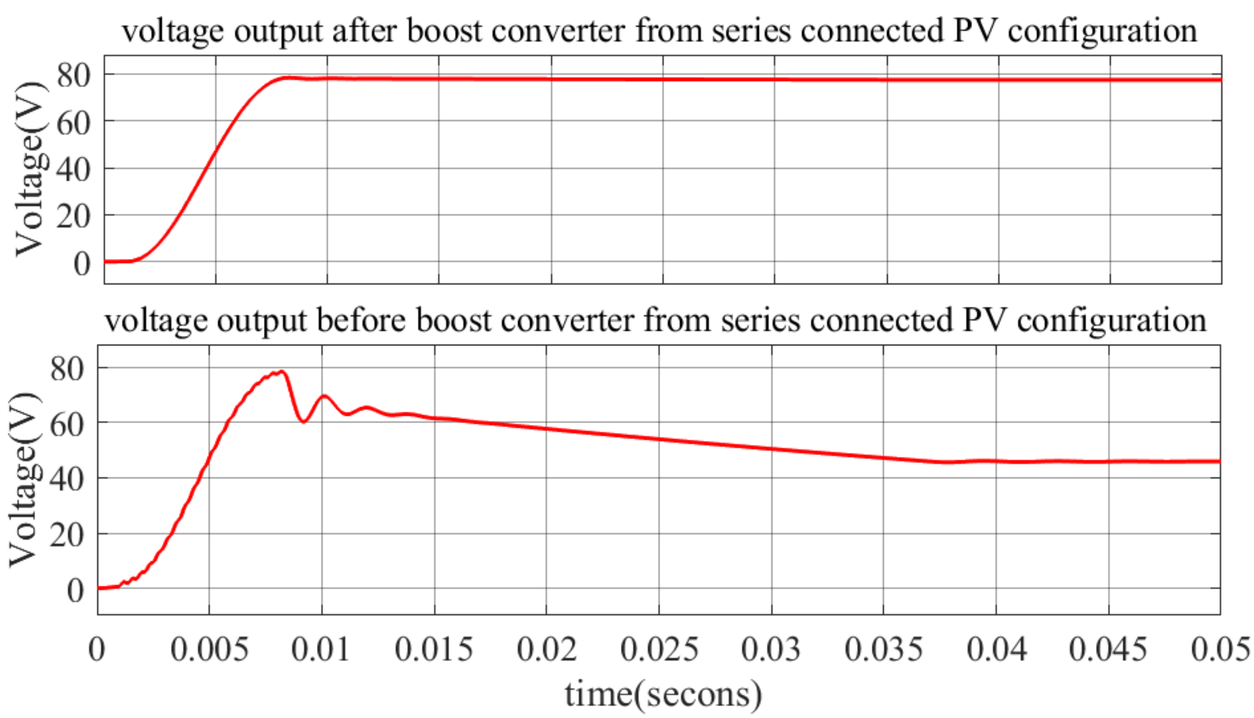


Figure 4. 8.voltage output before and after boost converter from series connected PV configuration

4.3.2. Simulation Result of Series Parallel (SP) PV Configuration

The output from figure 4.9 to 4.11 is parameter result from SP PV configuration. The first figure 4.9 is the voltage output from SP configuration before and after MPPT. the first line signal is the voltage before maximum power point tracking have a magnitude of around 160V.the second line is the voltage output after maximum power point tracking having the magnitude of around 270V.from the two result it is clear that MPPT algorithm generates higher voltage with this configuration also. The voltage before MPPT have less settling time than that of after MPPT.the voltage after MPPT settle after around 0.04sec

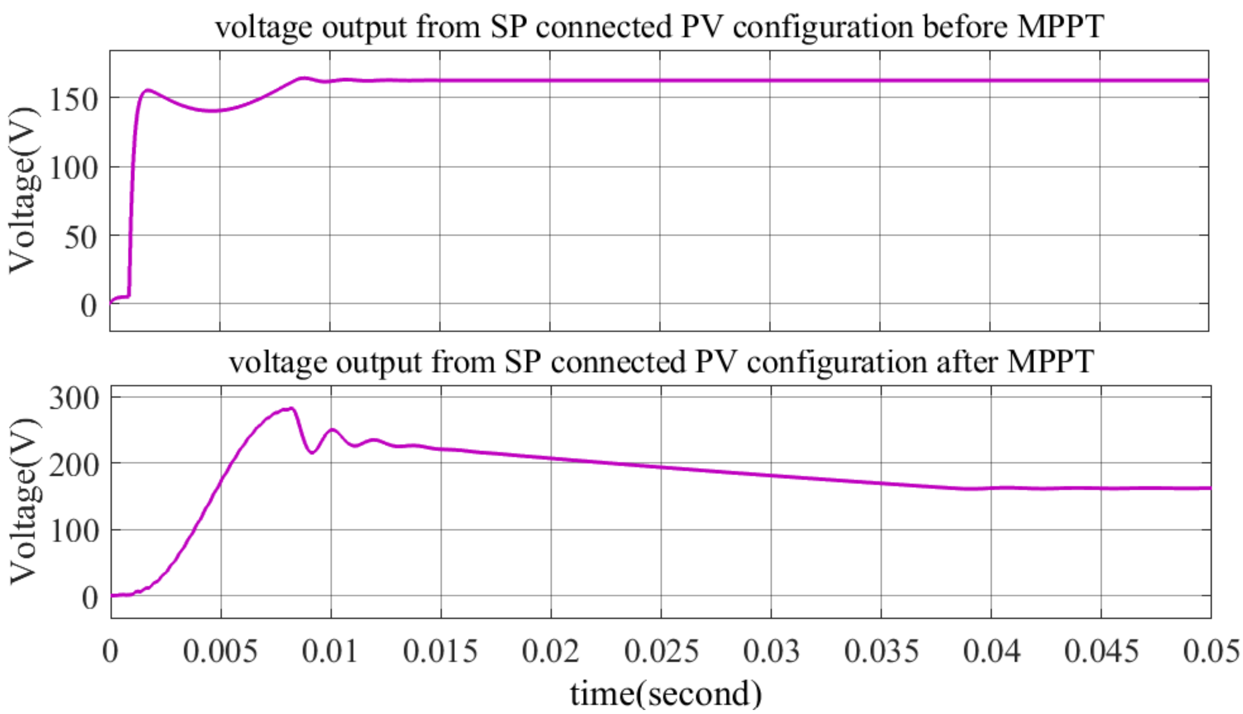


Figure 4. 9.voltage output from SP connected PV configuration before and after MPPT

Figure 4.10 is the output of voltage, current and power of SP PV configuration after MPPT with controller signal. With the similar MPPT voltage of figure 4.9 the current in SP configuration is around 4A and the power output is around 600W.the current parameter has better performance in this SP configuration by having good stable signal. And also the value of voltage and current is greater than that of the current and voltage generated from series configured PV.

The figure described in 4.11 is the voltage output of SP configuration before and after boost converter. Like that of series configuration the boost converter have similar application in SP configuration that makes the signal smooth.

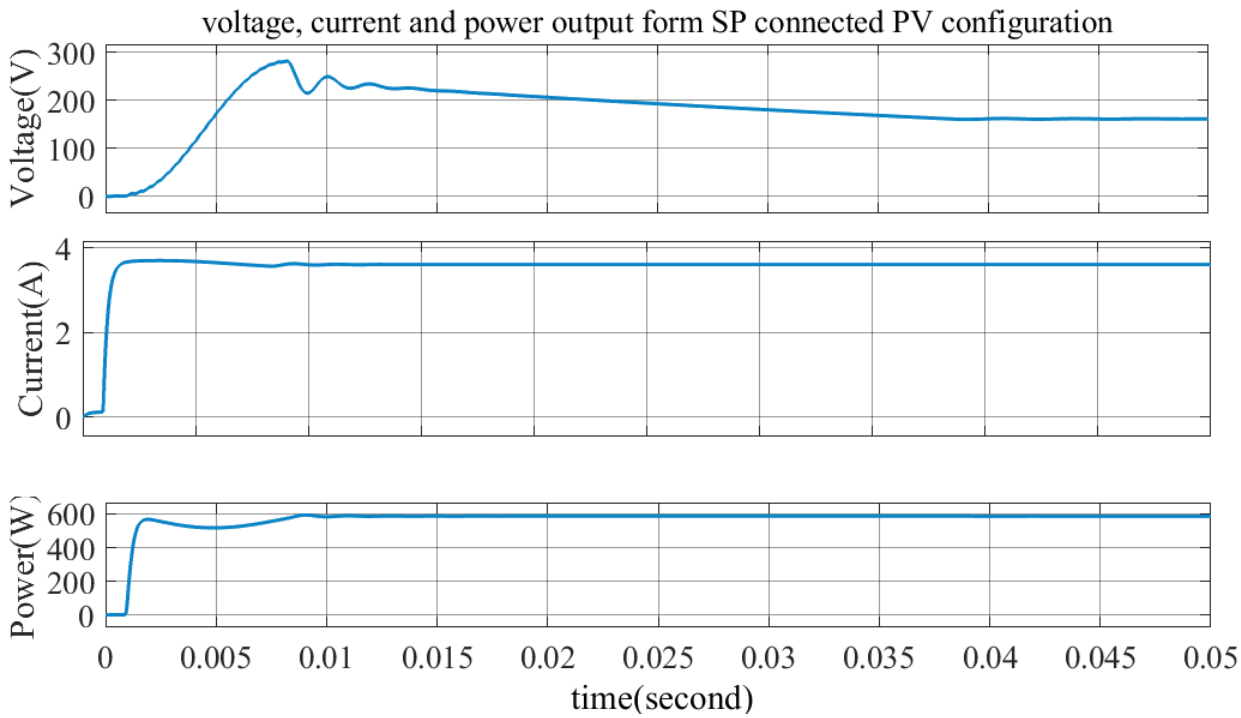


Figure 4. 10.voltage, current and power output form SP connected PV configuration

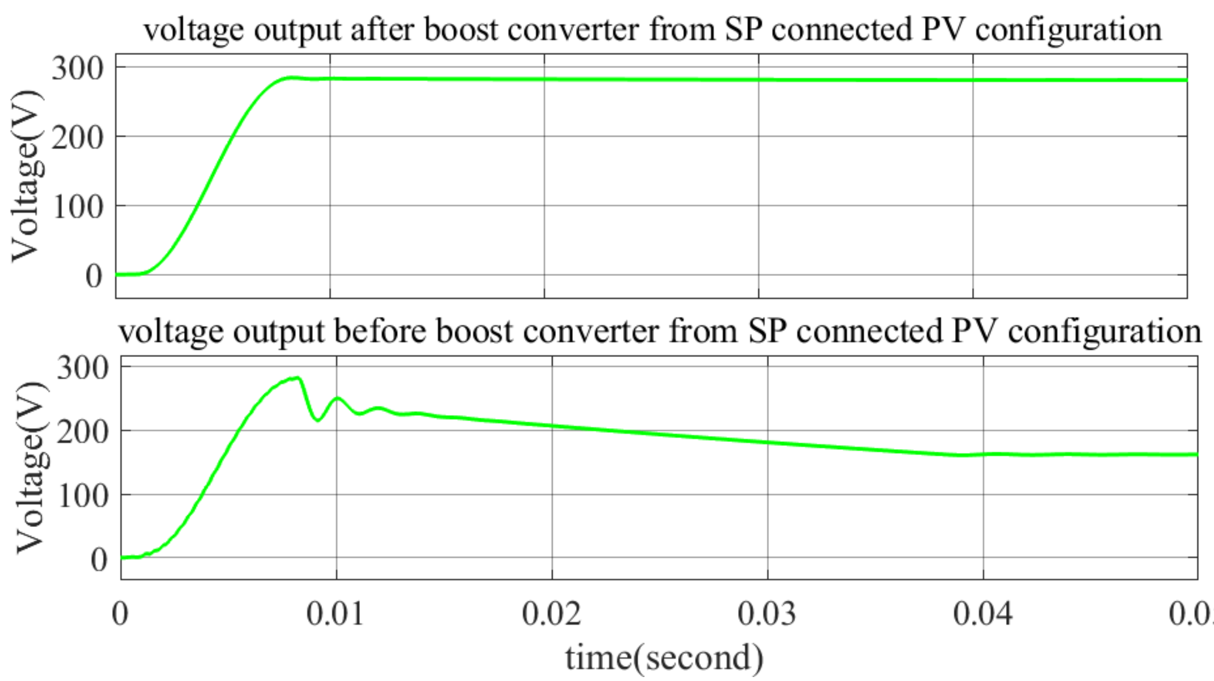


Figure 4. 11.voltage output before and after boost converter from SP connected PV configuration

4.3.3. Simulation Result of Total Cross Tied (TCT) PV Configuration

The figure described from 4.12 to 4.15 is the parameter output of total cross tied PV configuration. The fist figure is the voltage output from TCT configuration before and after MPPT.as seen from this figure then voltage output in both the voltage before and after the applied maximum power point tracking are the same value. This is happen only in TCT configuration which makes total cross tied configuration is better since it reduce the applied MPPT cost.

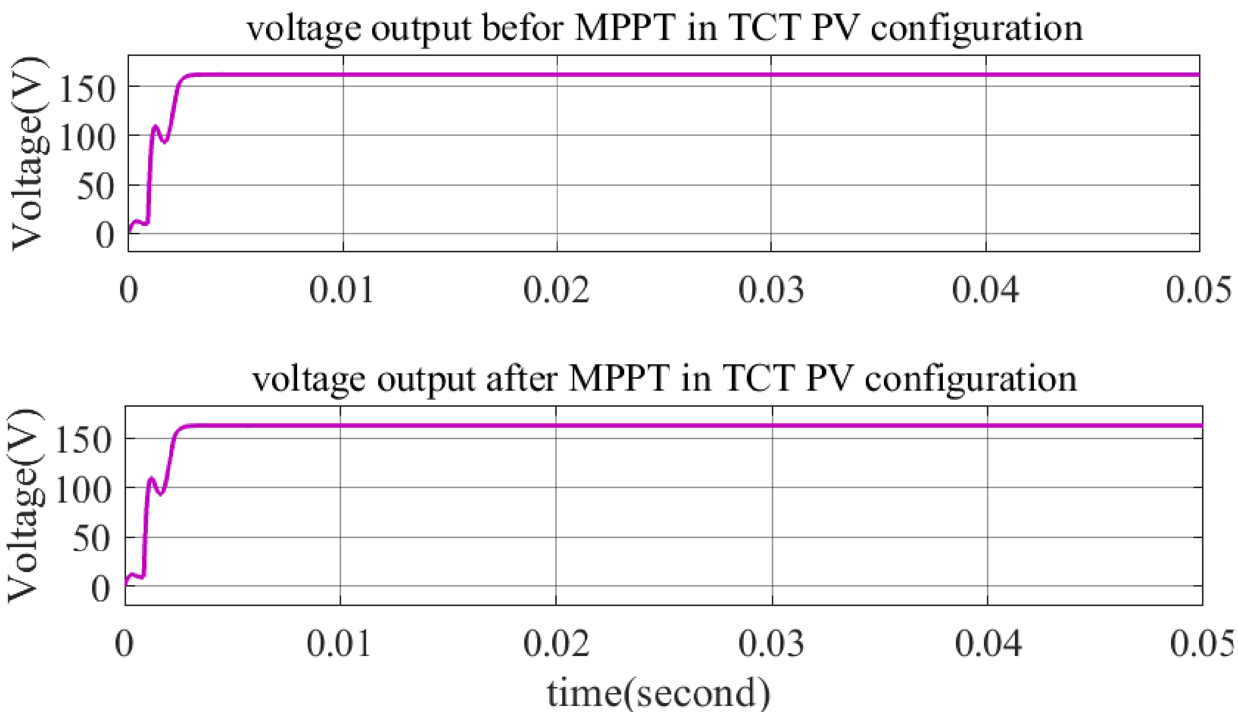


Figure 4. 12.voltage output from TCT connected PV configuration before and after MPPT

Figure 4.13 shows the voltage, current and power output of TCT connected PV configuration. From this figure the three parameters have the same stable region signal. The three PV parameters in TCT configuration have very small settling and rise time dynamic performance.

The last output of PV parameters in TCT configuration is the voltage before and after boost converter described in Figure 4.14.in this figure the first line is the voltage output of TCT configured PV after boost converter. The result shows a very stable signal compared to the voltage signal after the boost converter with the same PV configuration.

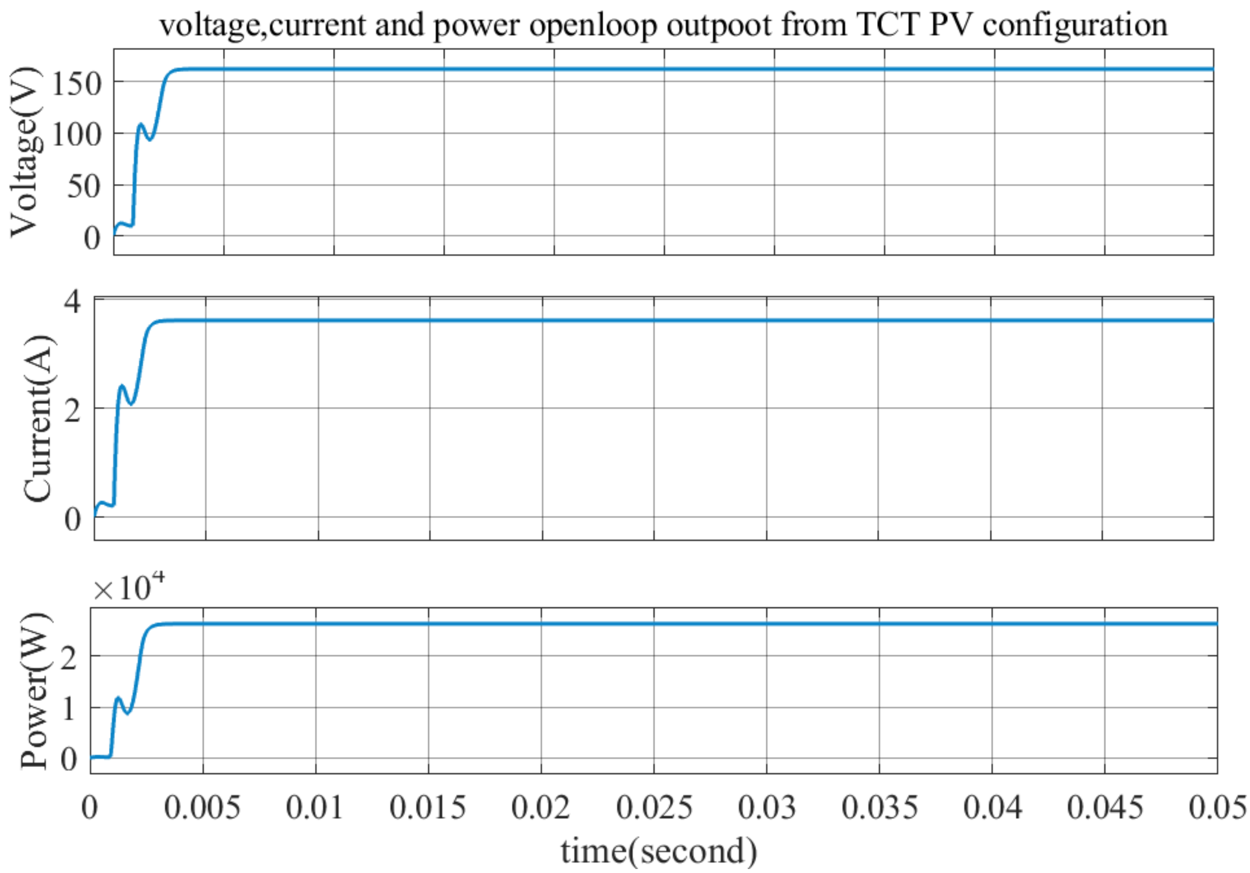


Figure 4. 13.voltage, current and power output form TCT connected PV configuration

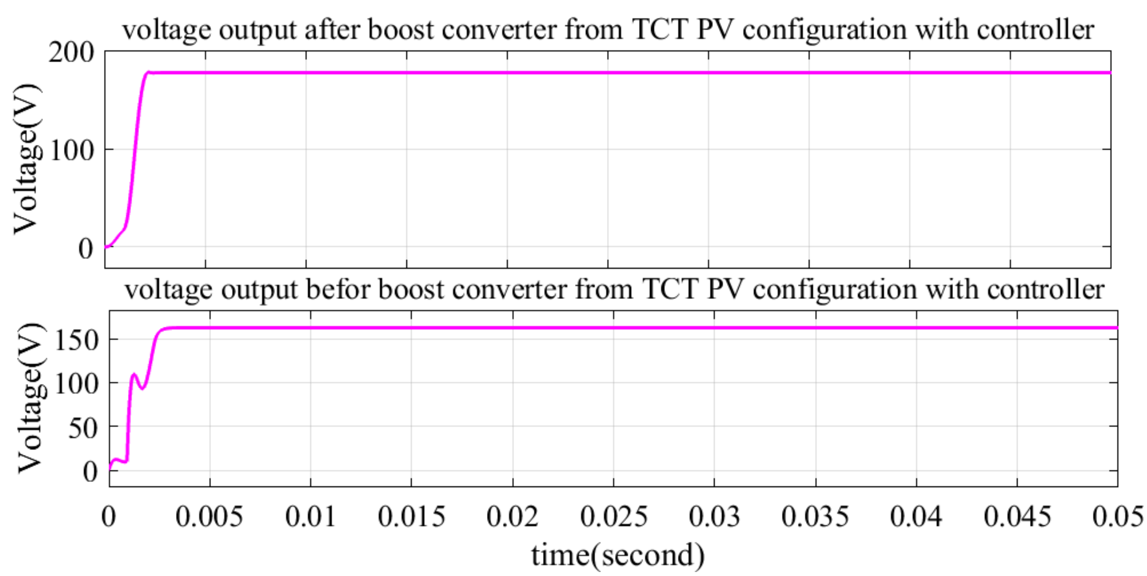


Figure 4. 14.voltage output before and after boost converter from SP connected PV configuration

4.4. Comparison of three PV configuration with controller

Figure 4.15 to Figure 4.17 described the comparative analysis of all the photovoltaic configuration of series, series parallel and total cross tied. Figure 4.15 is the voltage output before and after MPPT in the three PV configuration.in the series and series parallel configuration the voltage is increased after the applied maximum power point tracking algorithm with a controller signal as shown in blue and pink signal line. But the red line that represent the total cross tied connection have the same magnitude of voltage before and after applied MPPT algorithm with a controller signal.

Figure 4.16 is the output of voltage, current and power after the controller signal in the three PV configuration system. The magnitude of current generation in series parallel and total cross tied configuration are the same. From this it is clear that the current has good stable signal in series parallel configuration. But in the series configuration is less than the other two configuration.

From this figure the power outpour of SP and TCT configuration have the same magnitude but at the start of the simulation the power in SP configuration has furcation after the stable point in TCT configuration. This is due to current fluctuation in SP configuration. The power of series configured PV is very low compared to the two configurations.

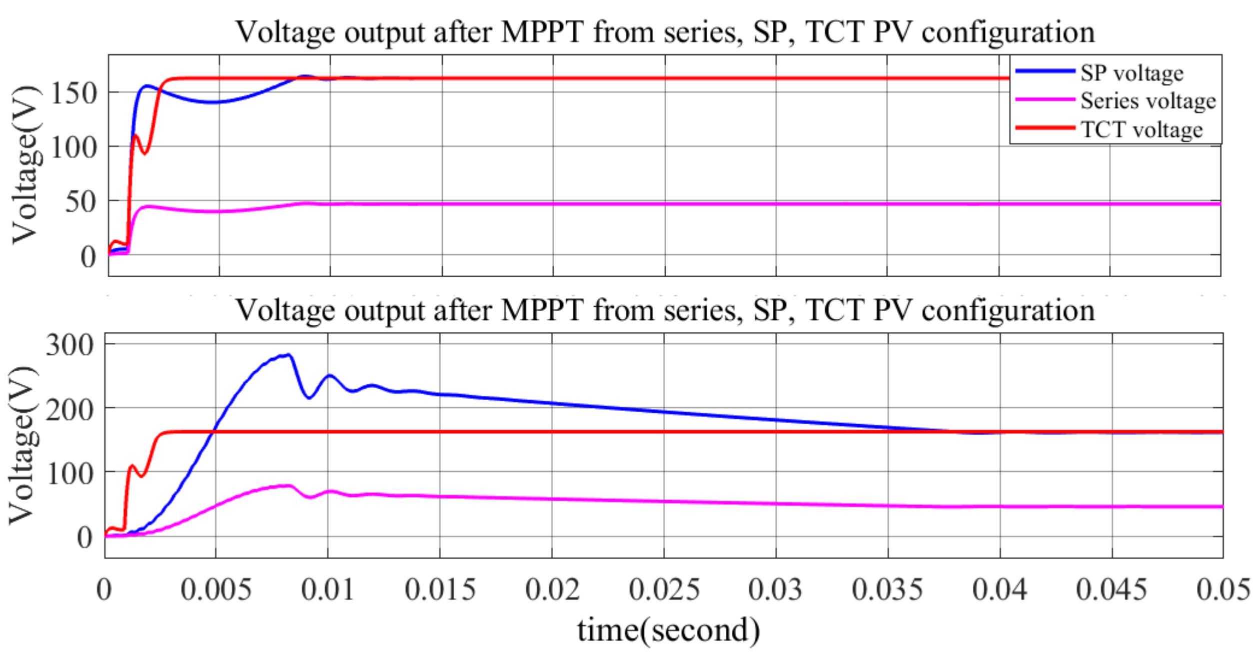


Figure 4. 15.Voltage output before MPPT from series, SP, TCT PV configuration

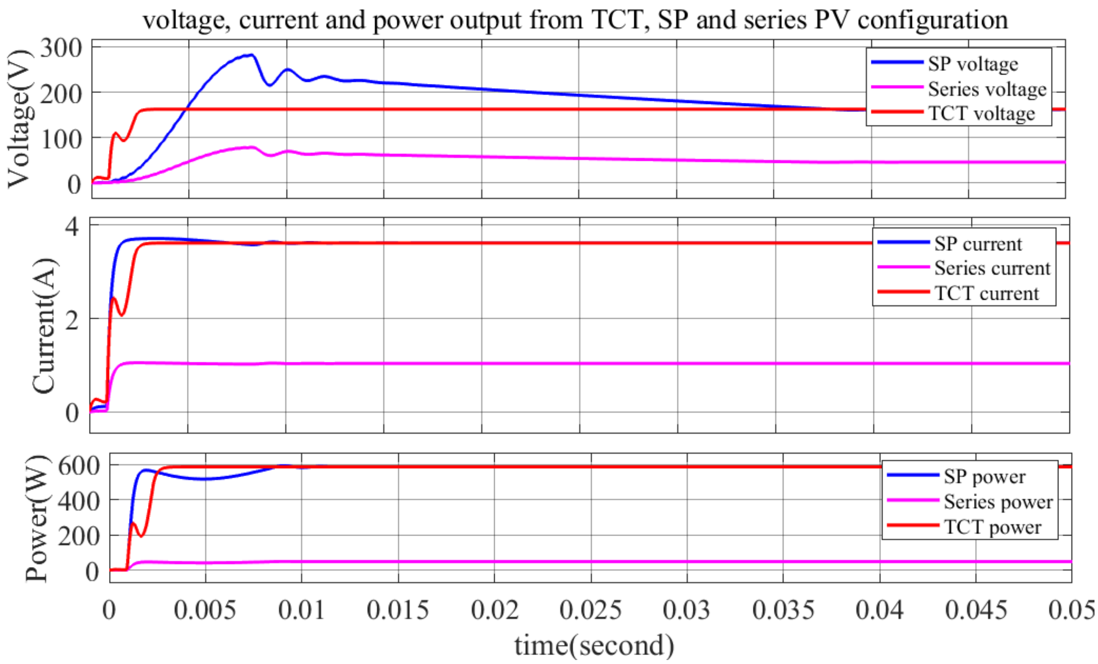


Figure 4. 16.voltage, current and power output from TCT, SP and series PV configuration

Figure 4.17 described below is the output of the series, series parallel and total cross tied PV configuration before and after boost converter.in all the three the converter have better performance in equal manner with the corresponding settling time.

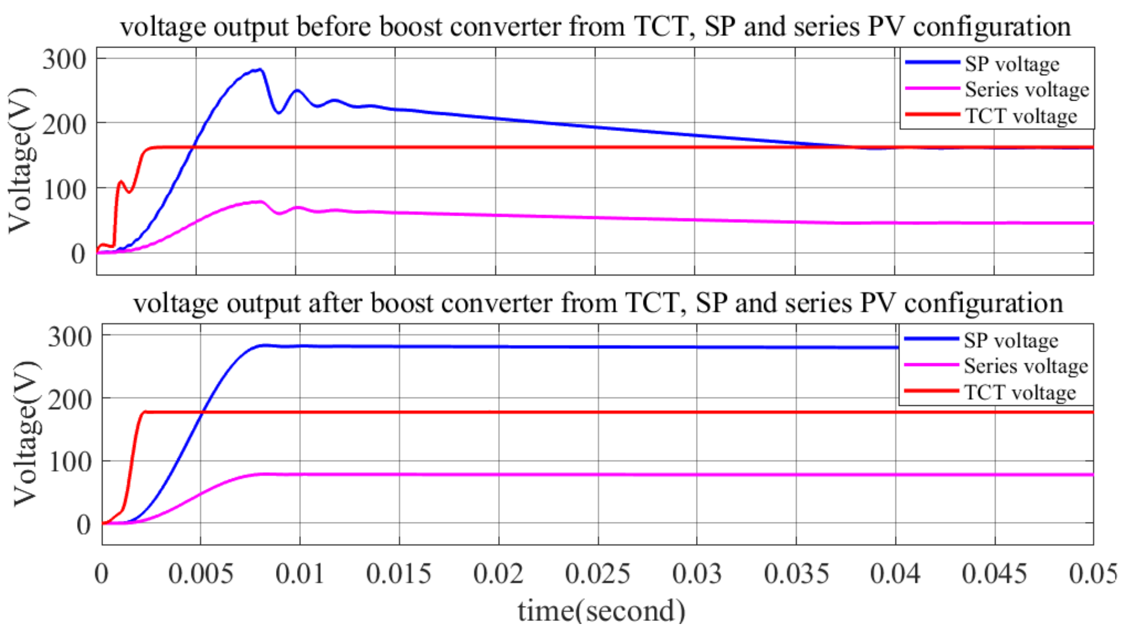


Figure 4. 17.voltage output before and after boost converter from TCT, SP and series PV configuration

Table 4.1 comparison of PV configurations with controller

No	PV configuration type	Voltage output at maximum	Voltage output after stable limit	Current output	Power output	controllability
1	Series	80	65	1.5	120	good
2	SP	270	160	3.8	600	Get difficulty
3	TCT	160	160	3.8	600	Very good

From the table it is clear that at the start of the simulation the voltage in SP configuration is higher compared with TCT configuration. But as looked from figure 4.16 value of TCT and SP are equal after 0.035sec.but the signal of SP configuration is uncontrolled.so from this the TCT configuration have better controlling behavior.

In general from the three series, series parallel and total cross tied photovoltaic configuration the output of voltage is effective in TCT configuration since the voltage in this configuration is the same before and after maximum power point tracking. The current also stable and effective in TCT PV configuration.

5.CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The use of Artificial Neural Network (ANN) optimized Fuzzy-PID controllers for Maximum Power Point Tracking (MPPT) algorithms in solar photovoltaic (PV) configurations has shown promising results. The combination of ANN and Fuzzy-PID techniques offers an efficient and accurate approach to achieving optimal power extraction from solar PV systems.

The primary objective of MPPT algorithms is to track the maximum power point (MPP) of a PV system, which corresponds to the voltage and current values at which the system operates most efficiently. Traditional MPPT techniques, such as Perturb and Observe (P&O) and Incremental Conductance (INC), have limitations in terms of accuracy, robustness, and adaptability to varying environmental conditions.

The integration of ANN and Fuzzy-PID controllers overcomes these limitations by leveraging the learning capabilities of ANN and the control capabilities of Fuzzy-PID. The ANN is trained to accurately predict the optimal operating conditions based on historical data and real-time inputs from the PV system. The Fuzzy-PID controller then adjusts the system parameters, such as duty cycle or voltage reference, to maintain the system at the MPPT.

The benefits of using ANN optimized Fuzzy-PID controllers for MPPT include improved tracking accuracy, faster convergence to the MPP, enhanced robustness against environmental changes (e.g., irradiance variations, temperature fluctuations), and reduced power losses. The adaptability of ANN allows for efficient operation under different weather conditions, shading effects, and partial shading scenarios, which are challenging for traditional MPPT methods.

However, it is essential to note that the performance of ANN optimized Fuzzy-PID controllers for MPPT relies heavily on the quality and representativeness of the training data, as well as the design of the Fuzzy-PID controller. Insufficient or inaccurate training data may lead to suboptimal performance, while poorly designed Fuzzy-PID controllers may introduce additional complexities and tuning challenges. And also this paper is considering only three configuration technique with ANN optimized fuzzy-PI controller.

The effectiveness of all the three PV configuration is analyzed by an optimal power point tracking using an adaptive neural network based fizzy-PI controller. With this controller the TCT PV configuration is more effective than the other two PV configuration.

In general, Optimal Maximum Power Point Tracking Algorithms for Solar Photovoltaic Configurations using ANN optimized Fuzzy-PID controllers offer a promising approach to maximize the energy extraction from solar PV systems. The combination of ANN's learning capabilities and Fuzzy-PID's control capabilities provides an efficient and robust solution for MPPT, leading to improved performance and increased energy efficiency in solar PV applications.

5.2. Recommendation

There are many factors affecting the generation of energy from photovoltaic cell in different conditions. And also, it possible to consider many configurations of photovoltaic cell in generating electric energy.

But in this thesis there are only three configuration of photovoltaic cell for testing an adaptive neural network to optimize fuzzy-PI controller. For these three configurations the controller shows its performance but it is possible to use many kinds of configuration in PV cell for the generation of different voltage label.

The other thing is this thesis work is only implemented in software for the testing the performance of the controller and the generation label of the three basic PV configurations due to economic problem and nonexistence of materials. But it is possible to implement in Hardwar to check the exact generation value and stability of the output.

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APPENDIX

MATLAB Model

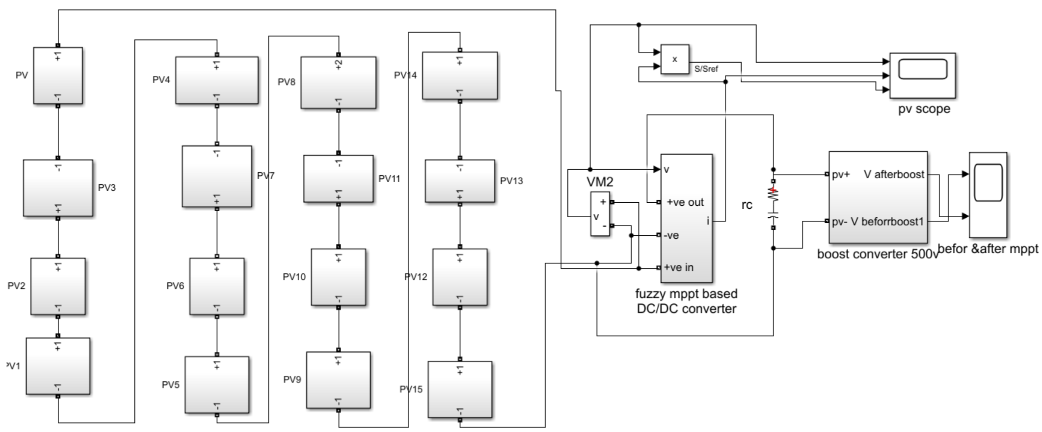

Figure A. 1.overall series PV configuration system

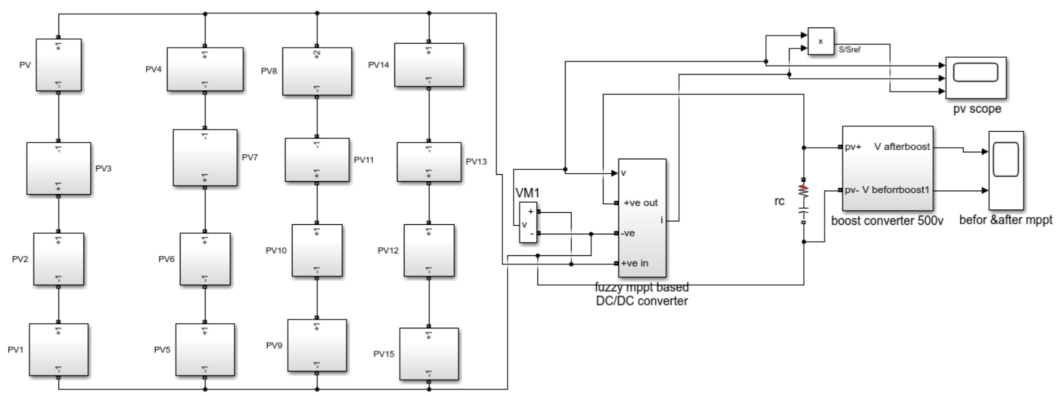

Figure A.2 Figure A. 2.overall SP PV configuration system

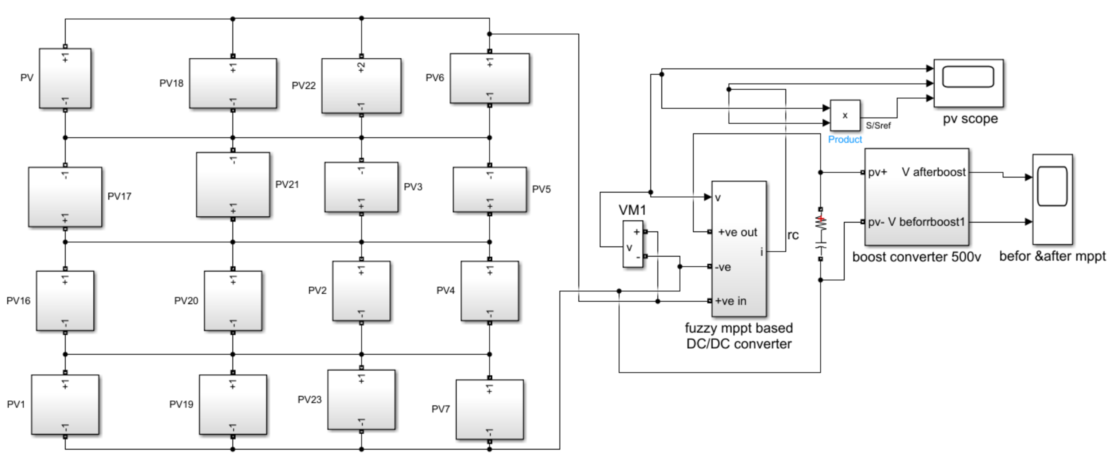

Figure A. 3.overall TCT PV configuration system

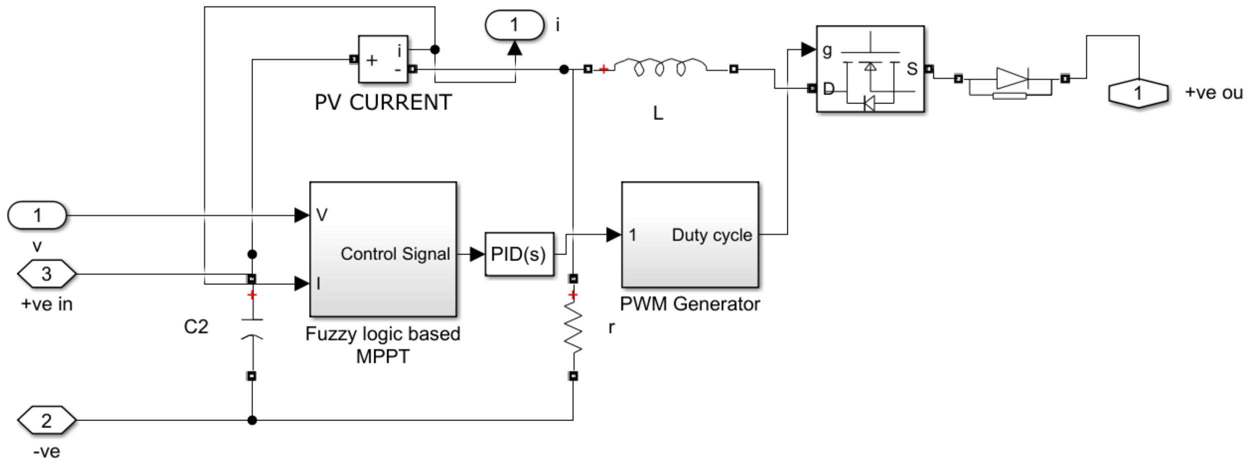

Figure A. 4.Overall ANN optimized fuzzy-PI control system