T.R.
YUZUNCU YIL UNIVERSITY
INSTITUTE OF NATURAL AND APPLIED SCIENCES
ELECTRICAL ELECTRONICS ENGINEERING DEPARTMENT

DESIGN OF NEURAL FUZZY MPPT CONTROLLER FOR PV BASED BOOST CONVERTER

MASTER'S THESIS

PREPARED by Dilovan Muhsin HAJI
SUPERVISOR: Assoc. Prof. Dr. Naci GENÇ

VAN - 2016

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ACCEPTANCE AND APPROVAL PAGE

This thesis entitled "DESIGN OF NEURAL FUZZY MPPT CONTROLLER FOR PV BASED BOOST CONVERTER" presented by Dilovan Muhsin HAJI under supervision of Assoc. Prof. Dr. Naci GENÇ in the Department of Electrical Electronics Engineering has been accepted as a M. Sc. thesis according to Guidelines of Graduate Higher Education on 29/12/2016 with unanimity of vote's members of jury.

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This thesis has been approved by the committee of The Institute of Natural and Applied Science on …. /.... /…...... with decision number.................

Signature
……………..…….

Director of Institute

THESIS STATEMENT

All information presented in the thesis obtained in the frame of ethical behavior and academic rules. In addition, all kinds of information that does not belong to me have been cited appropriately in the thesis prepared by the thesis writing rules.

Dilovan Muhsin HAJI

ABSTRACT

DESIGN OF NEURAL FUZZY MPPT CONTROLLER FOR PV BASED BOOST CONVERTER

HAJI, Dilovan Muhsin
M. Sc. Thesis, Department of Electrical Electronics Engineering
Supervisor: Assoc. Prof. Dr. Naci GENÇ
December 2016, 69 pages

Fossil fuel consuming and the environmental problems caused by the traditional power stations became one of people's recent consideration. Renewable energy sources such as photovoltaic panels and wind energy are widely used in present time. Photovoltaic systems have the advantage of being pollution and maintenance free but their high fabrication cost and low energy conversion efficiency are the main drawbacks.

To overcome mentioned disadvantages, a maximum power point tracking (MPPT) controller is needed to raise the efficiency and extract the maximum produced power from the photovoltaic systems.

Several MPPT algorithms have been proposed in literature. Regardless of some drawbacks, incremental Conductance (IncCond) and perturbation and observation (P&O) MPPT algorithms are usually used in PV systems duo to the ease of design and ability to compensate the weather different circumstances such as the variation in solar irradiation level and temperature.

This thesis proposes the PV module of YGE Solar YL250P-29b and the implementation of Maximum Power Point Tracking (MPPT) controller based on Adaptive Neuro Fuzzy Inference System (ANFIS) using MATLAB/Simulink framework. The proposed controller has two input and one output, the inputs are error "e" and variation in error "Δe". While the output is the reference voltage to the pulse width modulator which in his place connected to a power stage boost converter.

Depending on the simulation results, the proposed system is able to track the maximum power point successfully under deferent weather circumstances such as different level of irradiance and temperature.

Keywords: ANFIS, MPPT, Neuro Fuzzy, Photovoltaic, Renewable Energy.

ÖZET

PV BESLEMELİ BOOST DÖNÜŞTÜRÜCÜ İÇİN NEURAL-FUZZY MPPT KONTROLCÜ TASARIMI

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Tez Danışmanı: Doç. Dr. Naci GENÇ
Aralık 2016, 69 sayfa

Geleneksel enerji santrallerinin neden olduğu fosil yakıt tüketimi ve çevre sorunları insanların son zamanlarda önemli bir sorunu haline geldi. Bu sorunun çözümü için günümüzde fotovoltaik paneller ve rüzgar enerjisi gibi yenilenebilir enerji kaynaklarının kullanımı yaygınlaşmıştır. Mekanik akasmalarının olmayışı fotovoltaik sistemlerin avantajı iken, yüksek imalat maliyeti ve düşük enerji dönüşüm verimliliği en büyük dezavantajlardır.

Sözü edilen dezavantajların üstesinden gelmek için, verimliliği artırmak ve maksimum üretilen gücü fotovoltaik sistemlerden çıkarmak için bir maksimum güç izleme noktası (MPPT) denetleyicisine ihtiyaç duyulmaktadır. Literatürde birkaç MPPT algoritması önerilmiştir. Bazı dezavantajlara bakılmaksızın, artan İletkenlik (IncCond) ve pertürb ve gözlem (P & O) MPPT algoritmaları, tasarım kolaylığı ve güneş ışınlama seviyesi ve sıcaklıktaki değişme gibi farklı koşullara göre MPPT özelliği sağlamaktadırlar.

Bu tez, YGE Solar YL250P-29b'nin PV modülünü ve MATLAB / Simulink simülasyon programını kullanarak Uyarlamalı Sinirsel Bulanık Çıkarım Sistemine (ANFIS) dayanan Maksimum Güç Noktası İzleme (MPPT) denetleyicisinin uygulanmasını önermektedir. Önerilen kontrol yöntemi iki giriş ve bir çıkışa sahiptir, girişler "e" hatası ve "Δe" hatasındaki değişimdir. Çıktı, darbe genişliği modülatörüne giren referans gerilimi (PWM) olup bir güç kademesi olan yğkselten (Boost) dönüştürücüye bağlanır.

Simülasyon sonuçlarına bağlı olarak, önerilen sistem, farklı ışıma sıcaklığı ve sıcaklık seviyesi gibi farklı hava şartları altında maksimum güç noktasını başarıyla izleyebilmektedir.

Anahtar Kelimeler: ANFIS, Fotovoltaik, MPPT, Neuro Fuzzy, Yenilenebilir.

ACKNOWLEDGMENTS

I would like to express my highest gratitude to my project supervisor, Assoc. Prof. Dr. Naci GENÇ for the right guidance and courage given from the start of my MSc. Project work to the last. My great appreciation goes to my family who have supported me all these year. Their love and motivation provides me the spirit to finish this thesis successfully.

I also would like to express my gratitude to all academic staff of Electrical and Electronic Engineering department in the University of Yüzüncü Yıl and my special thanks to my friends that were always beside me and never stopped giving the motivation specially my dear friend Shimal TAHER.

December-2016

Dilovan Muhsin HAJI

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ABBREVIATIONS

Along with a description of some abbreviations used in this study are presented below:

Abbreviation	**Explanation**
AC	Alternative Current
ANFIS	Adaptive Neuro Fuzzy Inference System
ANN	Artificial Neural Network
D	Duty Cycle
DC	Direct Current
FL	Fuzzy Logic
FLC	Fuzzy Logic Control
FNN	Fuzzy Neural Network
G	Irradiance
GA-ANFIS	Genetic Algorithm of Adaptive Neuro Fuzzy Inference System
HC	Hill Climbing
I	Current
I/O	Input / Output
IC	Incremental Conductance
IEEE	Institute of Electrical and Electronics Engineers
$\mathbf{I_{mpp}}$	Current at Maximum Power Point
$\mathbf{I_{sc}}$	Short Circuit Current
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
NN	Neural Network
NF	Neuro Fuzzy
P	Power
P&O	Perturb and Observe
PI	proportional integral
$\mathbf{P_{max}}$	Maximum Power

PV	Photovoltaic
PWM	Pulse-Width modulation
SI	Silicon
SPWM	Sinusoidal Pulse Width Modulation
STC	Standard Test Condition
T	Temperature
T_c	Operating Cell Temperature
V	Voltage
V_{mpp}	Voltage at Maximum Power Point
V_{oc}	Open Circuit Voltage
K	Boltzmann Constant 1.38×10^{-23}J/K
q	Electron Charge 1.602×10^{-19}C

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1. INTRODUCTION

Photovoltaic (PV) system is one of power sources that rapidly evolving and vastly used in modern electric technologies, brought more safe power provenance and contamination free. The generated power in photovoltaic applications are produced by solar panel. Solar arrays consist of multiple solar cells that transform solar rays into electrical power. As it is pure and contamination free power resources, the submitted project is associated with the 2009 National Green Technology Policy (Rekioua and Matagne, 2012), which is to make the expansion of green technology industry easy and to raise national capability for development in green technology

Although, usually the structure of solar panels has high manufacturing cost and weak efficiency in energy transformation (Kumaresh and Prabu, 2014). By applying the maximum power point tracking system, it can conquer the cons of solar panel (Sharma and Jain, 2014). The MPPT, which impose the Photovoltaic (PV) modules because it is essentially an electronic system, allowing the modules to be sufficient to make the utmost power. MPPT is not a mechanical device that point and move straight to certain high intensity solar array but a system dominating the electrical operating point (Rekioua and Matagne, 2012). The module is able to disseminate maximum power.

The DC-DC converter is connected to MPPT controls to allow a photovoltaic generator produce the maximum persistent power, at any value of the metrological terms (irradiance, temperature). The premier system with MPPT had been implemented in the year of 1968 for a NASA's space system. After time passing, several MPPT algorithms were progressed and widely favored to determine the MPP (Yazdani, 2009). The MPPT control technique that widely used perform automatically on the duty ratio of a converter to place the PV module at the best and optimal output value regardless of the differences of the changes in the value of loads that may happen in any moment or the weather conditions (Paul and Mathew, 2014). The major components of the Maximum Power Point Tracking circuit consist of are the converters which in this project is boost converter and the controller.

By examining the MPPT tracking algorithm point of view, a lot of techniques of MPPT can be applied. These methods are hill climbing, voltage feedback, perturb and observation (P&O), incremental conductance, current feedback, FL and neural network

(Karthika et al., 2013). Among these methods, hill climbing and voltage feedback are easy to stratify but inefficient in the maximum power point tracking with differences of environment conditions. In addition, perturb and observation technique has hitched as it processes an extra P-I control loops which result slow tracking process. And also, the neural network based algorithm is difficult to implement.

One of the most efficient techniques in MPP is the ANFIS (Adaptive Neuro Fuzzy Inference System) based algorithm (Savaliya and Ray, 2015). The blend of developed fuzzy logic and neural network algorithm is able of tracing the maximum power point by a suitable speed. Furthermore, the fuzzy logic algorithm offers a very dynamic response with any kind of environment conditions. As well as, the enforcement of this algorithm is possible with obtainable components at a medium cost (Sharma and Jain, 2014).

There are three fundamental operator that affect power conversion efficiency; cell temperature, solar irradiation and series array of solar panel. The cell temperature and solar irradiation is an unsettled variable because it changeable by the weather. This leads to a non-sureness of the maximum power generated.

Therefore, this project proposes to develop a controller of the Adaptive Neuro Fuzzy Inference System (ANFIS) to control and maximizes the output maximum power.

This project’s main objective is to develop the boost converter based MPPT controller of PV system. Also, to design an ANFIS algorithm simulation for the MPPT by using MATLAB/Simulink.

This thesis's work is goes through five chapters, in the first chapter it gives the introduction to MPPT system using Neuro Fuzzy control algorithm, and describe the objective and organization of the thesis. Chapter tow covers the literature review MPPT of photovoltaic system, in this chapter a number of researches will be discussed with taking in mind the author’s conclusions about the algorithm used in the MPPT control system. The material and method are discussed in chapter three, which gives information about the constituent and architecture of MPPT system in general and the Adaptive Neuro Fuzzy Inference System (ANFIS) control, explaining the algorithm that is hired in this thesis, component description, and the structure of the system with circuit diagrams. The fourth chapter gives the implementation result with discussion. And the last chapter gives the conclusion and suggestion for future work.

2. LITERATURE SURVEY

Several authors discussed many methods to trace MPP (Maximum Power Point) for PV arrays, discussion is included in this chapter of the relevant studies to implement MPPT controller for PV system using neuro fuzzy as summarized information. The main sources of this information are from journals, conferences and books.

Karthika et al. (2013) offered for the PV system an intelligent MPPT control strategy by using fuzzy logic controller. MATLAB/Simulink was used to simulate the maximum power point tracking technique. The P&O (Perturb and Observe) based MPPT technique can track the maximum power point slower compare to the suggested fuzzy logic based MPPT technique. It has the ability of dropping the voltage variation after MPP (maximum power point) has been recognized. The outcome of the simulation show the competence of the fuzzy logic controller in preserving the stable maximum power point (Karthika et al., 2013).

Allataifeh et al. (2015) developed a fuzzy logic controller for the PV system to track the maximum power point . MATLAB/Simulink has been used simulate PV panel, boost converter with Fuzzy Logic Controller (FLC) connected to a resistive load. Simulation outcome have been compared to ordinary power values. The suggested system showed that it is able to reach MPP in uniform irradiation, partial shading, and unexpected changes of irradiation. They found that by using FLC have great advantages over conventional methods. Fuzzy logic systems are easily implemented with minimal oscillations with fast convergence around the desired MPP .And It discovered Fuzzy controller always finds the global MPP (Allataifeh et al., 2015).

Kumar et al. (2015) has proposed a comparative study between Fuzzy Logic MPPT controller methods and Incremental Conductance in MATLAB/Simulink. The high cost and low efficiency are solar PV system main problems, and result is change in cloudy weather conductions. Therefore the system needs an efficient MPPT controller. Finally performance of comparative study, they found that the Fuzzy Logic controller is effectiveness compare to IC controller. The Fuzzy Logic controller Increase output power, less variation and fast Response, against change in weather conductions. The Fuzzy controller is better compared to Incremental conductance (Kumar et al., 2015).

Salah and Ouali (2011) introduced two new MPPT methods the first is based on the FL and the second on the NN were investigated and proposed. NN and FL can model dynamical complex systems that change with non-linear laws of time following. These suggested algorithms in NN and FL made of in commanding a boost dc–dc inverter to gain the MPPT straight from the PV cell temperature and climate data solar radiation. Additionally these two MPPT give a low cost to do it and simplified system. The outcomes of the experiment have demonstrated that the MPPT controller by using NN has provided less power than the FL one (Salah and Ouali, 2011).

Sedaghati et al. (2012) Discussed neural network-based MPPT. Under any variation in atmospheric conditions, by using neural network, point of maximum power is specified precisely and fast. They discovered one more advantage of the neural network in PV maximum power-point tracking (MPPT) that its superior dynamic execution by comparing it with the other methods for example Hill Climbing (HC), Perturb and Observe (P&O) and Incremental Conductance (IC). And also the maximum power point is tracked by dc-dc boost chopper. So the maximum power solar energy and the best efficiency were obtained (Sedaghati et al., 2012).

Putri and Rifa'i (2012) presented neural fuzzy for dominating PV system produced voltage to operate at maximum power point in various irradiation changes and temperature. A good performance has been shown from applications of neural fuzzy controller on MPPT of PV. The system was analyzed and designed, and then the performance was studied by simulation with MATLAB/Simulink. PV system can operate at maximum power point although sun irradiation and occur temperature change that can shift maximum power point (Putri and Rifa'i, 2012).

Lu and Shih (2010) proposed FNN (fuzzy neural network) control system with DC/DC boost converter for the solar cells Maximum Power Point Tracking controller. The FNN system with integrated Fuzzy theory and Neural Network, advantages include uncertainty data processing and neural network learning. First, applicable structure was designed. The second, adjustment of the parameters for learning and weight of links in the neuron network to be efficiently and rapidly tracking the maximum power point of solar cell power output increases the performance of solar systems. Finally, the tracking speed of the proposed MPPT method was the quickest compared with other qualitative controller.

The energy collected from the solar panels will be maximized by the duty cycle, and the converter will standby for the following signal. Therefore , the simulation results verified the efficiency of the controller (Lu and Shih, 2010).

Mohammad et al. (2011) suggested an intelligent way for controlling a photovoltaic system's MPPT. Both the neuro fuzzy controller and the conventional fuzzy-based MPPT controller were simulated and carried out using a single-chip microcontroller with buck-boost converter. The results of the simulation demonstrate that the neuro-fuzzy controller is able to deal with system parameters and disturbances for fast and good transient performance under all conditions. They discovered that the link between the two approaches gives so many advantages, essentially they are:

- Lack of learning in fuzzy systems and the lack of comprehensive knowledge extraction in ANNs can be avoided in neuro-fuzzy system.
- Fuzzy clustering methods based on fuzzy number play an important role in the hybrid neuro-fuzzy approach.
- Generalization feature of ANNs adds a very effective characteristic to FLC system.
- The dramatically decrease of the size of the controller architecture offers less computations time, less fuzziness and less storage memory.

So more efficient controller is obtainable and a cheaper hardware controller, if required, can be easily achieved (Mohammad et al., 2011).

Della and Midoun (2005) investigated a high performance maximum power point tracker based on neural fuzzy identification and fuzzy control. Optimal efficiency operation under changing in temperature and irradiation demonstrated through the simulation and experimental results (Della and Midoun, 2005).

Awadallah and Salem (2014) presented an Adaptive Neuro Fuzzy Inference System (ANFIS) based methodology to MPPT in PV arrays. Their system was consists of a PV array comprising 576 solar cells connected in series. A buck chopper follows the PV array in order to convert its varying MPP voltage into a fixed voltage feeding a three-phase inverter. The inverter was controlled in open-loop by SPWM (Sinusoidal Pulse Width Modulation) switching logic to feed a three-phase induction motor driving a water pump. A battery was connected across the DC link to fix the chopper produce voltage and compensate for the energy difference among the PV panel and load. Firstly, they use ANFIS to estimate the chopper duty ratio for MPP operation from cell temperature and solar irradiation. Then, a pilot module of the PV array is used to periodically check its open circuit voltage and short circuit current. ANFIS is applied to model the PV behavior and understand the solar irradiation and cell temperature from the pilot module testing. Lastly, one ANFIS is developed to deduce the chopper duty ratio for MPPT directly from pilot module testing.

They found excellent ANFIS performance whether in PV array modeling or in MPPT; operation of the induction motor drive is also investigated and found acceptable under different environmental conditions. The contribution of the present work stems from the elimination of the need to measure irradiation and temperature which are costly and technically troublesome when directly measured. In addition, the pilot module could be arbitrarily frequently tested to cope with rapidly changing environmental conditions (Awadallah and Salem, 2014).

Mohan and Mohanapriyaa (2012) produced a hybrid generation system that work with solar and diesel–wind. The suggested stand-alone hybrid generation system is able to extract the maximum power effectively from the solar and wind energy sources. From the case studies, it demonstrates that power and voltage may be quite controlled in the hybrid system in a changing environment. An efficient power sharing technique among energy sources are successfully demonstrated with more efficiency, a better transient and more stability, even under disturbance.

For better performance they proposed a hybrid neuro-fuzzy network instead of neural network. MATLAB/Simulink was used to develop The simulation model of the hybrid system (Mohan and Mohanapriyaa, 2012).

Maissa and Lassâad (2015) studied the PV pumping system components in their work. They suggested improving PV system performance; they investigated and studied different maximum power point controller. The system behavior including the neuro fuzzy, ANN, Fuzzy and P&O were compared and investigated based on an extended simulation work. By using an ANFIS controller finally the Maximum Power Point tracking of PV pumping system is ensured. The simulation tests that were performed for the entire system led to two major conclusions. the pumping flow rate benefit is going up to three times more and the suggested PV system performances were highly boosted (Maissa and Lassâad, 2015).

Rezvani et al. (2015) to track MPP of PV system they applied GA-ANFIS method. By the help of this technique, the PV module was capable of increasing the production of the outcome power under different circumstances at an optimal solution. To provide the optimal voltage the GA was implemented to correspond to the MPP for each environmental condition. After that; for training the ANFIS the optimized values were used.

The suggested method, for different conditions, was verified and discovered that the percentage error of V_{mpp} was in between 0.05% to 1.46%. and diminished Error of ANFIS is possible by increasing the number of the training data (Rezvani et al., 2015).

Bendary et al. (2015) for the maximum power point tracking under different temperature conditions and irradiance they studied an adaptive neuro-fuzzy inference system. The results were gained from ANFIS based MPPT method demonstrates better robustness and performances in comparing to ANN and FL under varying irradiance circumstances. Therefore, the ANFIS combined with PID controller improves the tracking almost to ideality 100% (Bendary et al., 2015).

Reddy and Venkatrao (2015) presented the simulation and design for MPPT (maximum power point tracking) to the PV system, that involves a high-efficiency boost converter with fuzzy logic algorithm. By adjusting the duty cycle of the converter, the converter is able to draw maximum power from the PV panel for a given solar insulation ad temperature. Thus improves the efficiency of the PV system and decrease system cost and low power loss (Reddy and Venkatrao, 2015).

Shanthi and Vanmukhil (2013) submitted by using ANFIS MPPT controller a Photovoltaic generation system to interface the solar power to the three phase ac load. By using MATLAB/Simulink software the ANFIS controller has been executed. A boost converter and a voltage source inverter were used to accomplish the interface stage between the load and the generation source. The boost converter boosts the output voltage from the PV array of 22 V to about 415V. The inverter and then the three phase load are then given the boosted voltage. The maximum power point tracking, by using the proposed system ,voltage boost and inversion are achieved (Shanthi and Vanmukhil, 2013).

Kharb et al. (2014) designed and implemented an ANFIS based MPPT control scheme with open loop boost converter. MATLAB/Simulink software package was used to do the simulation of suggested control scheme and the operation is investigated in different weather conditions. The simulation outcomes reveals that ANFIS based MPPT control scheme is efficient and effective to track maximum available power from PV module in different weather circumstances. Specially at low irradiance amount, without making oscillations the maximum output power can be tracked (Kharb et al., 2014).

Karthika et al (2014), by using fuzzy logic controller they presented an intelligent MPPT control strategy for the PV system. MATLAB/Simulink was used to simulate the maximum power point tracking technique. They found fuzzy logic based MPPT technique with triangular membership functions is able to track the maximum power point faster if compared to the Gaussian membership functions. And the system have the ability of decreasing the voltage fluctuation after maximum power point has been recognized. The outcome of the simulation shows the efficiency of the fuzzy logic controller in preserving the stable MPP (Karthika et al., 2014).

Bin-Halabi et al. (2014) designed for PV system a microcontroller based MPPT algorithm, the design has been simulated and experimentally carried out. Simulink environment have been used to run the simulations. The reaction of the suggested algorithm has been analyzed under varies irradiance levels. Raising the accuracy of ANFIS estimations of the MPP when the solar irradiance is not contained was the prime contribution of their work. Furthermore, the hardware application of the suggested system was achieved. To avoid estimation errors that might happen in the case of temperature changes the cell temperature sensor has been used with current and voltage sensors. To validate the functionality of the suggested method experimental results and Simulation have been presented. Experimental results have presented good agreement with simulation outcomes. The efficiency of the proposed system has been evaluated, and was found that the suggested system is highly efficient with more than 98 % average efficiency.

The proposed algorithm has made the transient response and the steady state response of the PV power system better when it was compared with the P&O algorithm, where it enhanced the tracking speed at quickly changing weather conditions and has cancelled the power oscillations at the steady state (Bin-Halabi et al., 2014).

Singh and Shahid (2016) introduced artificial neural network and fuzzy logic controller algorithms of single-ended primary inductor converter. Huge scope of irradiation degree, slow, fast and constant changing has been discussed which adds to the uniqueness of their work. to obtain an accurate results the performance analysis of MPPT algorithms on the basis of time taken to track maximum power point and many different significant element such as stability, efficiency, oscillations, overshoot in power, settling time and voltages before reaching MPP are done. This analysis demonstrate that the response of the system while using ANN is more efficient than FLC as it is precise and fast in tracking MPP but with more overshooting in voltage and duty cycle during changing irradiation level. FLC has 94.47 kW power delivered to the grid and efficiency of 95.48% while ANN controller have 98.93 kW power delivered to the grid and the efficiency of 99.86% (Singh and Shahid, 2016).

Kharb et al. (2013) used MATLAB/Simulink environment to design simulated model of solar PV module and ANFIS based MPPT control scheme. After a decent training of suggested ANFIS reference model, the ANFIS based MPPT control scheme has tracked the maximum available power successfully at various weather circumstances. Under different operating temperature and irradiance level the operation of ANFIS based MPPT scheme is investigated. With the presented ANFIS based MPPT control scheme the outcome power of solar PV module stays almost fixed under different operating temperature. In the resulting waveforms of outcome power reached the maximum value in short time with high gain, which shows that the response of given ANFIS based MPPT controller, with good dynamics, is extremely fast and the gain in the outcome power is significantly higher at all solar irradiance conditions. Unlike traditional perturb & observation (P&O) technique at the ANFIS based control even at low value of irradiance level there is no oscillations near the maximum power point in the outcome power. So, the ANFIS based control is an effective tool to track and extract maximum power from solar PV module (Kharb et al., 2013).

MPPT techniques have been classified into two categories by Savaliya and Ray (2015) online and hybrid methods. This classification depends upon the PV system behavior around the steady state conditions. The result shows that the efficiency of Hybrid technique is 98% which is better than all other techniques available, although ANN method has the same efficiency as Hybrid method but its complexity is very high so they do not consider it. So finally P&O and Incremental conductance has very good characteristics than others in terms of cost, complexity and implementation (Savaliya and Ray, 2015).

3. MATERIAL AND METHOD

3.1. Photovoltaic System

Photovoltaic is a technique in converting abundance solar rays into electrical energy. The generation of power from PV module is clean and sustainable energy. The abundance solar rays is drawn from the sun to make a renewable energy sources. Photovoltaic system is a system designed in converting solar rays into electrical energy efficiently. The system consists of certain part of components. The components are arranged in order, to generate the maximum power (Rekioua and Matagne, 2012). There are several components in photovoltaic system which are solar panels, battery, inverter and charge controller as depicted in Figure 3.1.

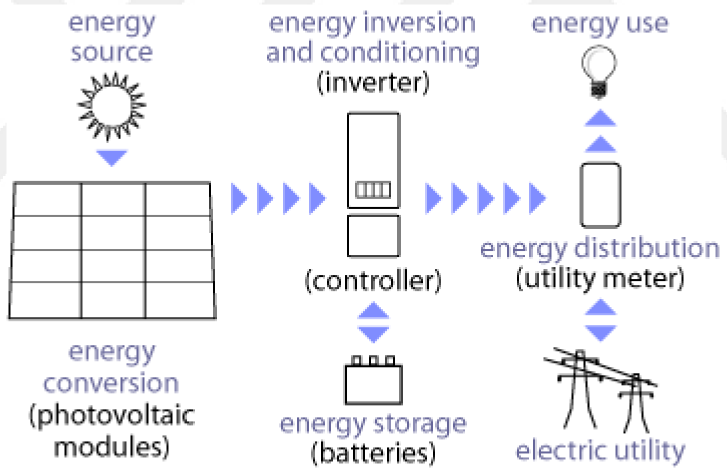


Figure 3.1. The components arrangement of photovoltaic system (Rekioua and Matagne, 2012).

The first component of photovoltaic system is solar panel which is responsible in converting solar ray into electricity. The second component is solar inverter which convert the electrical current from DC to AC. The output power will be stored in batteries. The charge controller is responsible in driving the output power to the maximum. Lastly, the power generated will be transferred to load for industrial or daily uses.

3.1.1. Solar panel

In designing PV system, the first part of PV system is solar panel. Solar panel is the most important part of solar system as it captures the sun energy and converts it to electrical energy. There are mainly three types of solar panels; monocrystalline, polycrystalline and thin film (Rekioua and Matagne, 2012).

The monocrystalline solar cell is made of monocrystalline silicon (mono-Si), also known as single-crystalline silicon (single-crystal-Si), are quite easily recognizable by an external even coloring and uniform look, indicating high purify silicon.

Monocrystalline solar cells are made of silicon ingots, which are cylindrical in shape. To optimize performance and lower costs of a single monocrystalline solar cell, four sides are cut out of the cylindrical ingots to make silicon wafers.

The polycrystalline silicon, also called polysilicon (p-Si) and multi-crystalline silicon (mc-Si). Despite from monocrystalline-based solar panels. Raw silicon is melted and poured into a square mold, cooled and cut into perfectly square wafers.

The thin-film solar panel is made of one or several thin layers of photovoltaic material onto a substrate.

Table 3.1. Characteristics of solar panel types.

Solar Panel Type	Characteristics
Monocrystalline	Made out of the highest-grade silicon Highest efficiency Space efficient Better performance even at low-high conditions
Polycrystalline	Simpler making process and low cost Less silicon waste Lower heat tolerance
Thin-film	Simple mass production Flexible High temperature and shading

In this thesis, multicrystalline silicon (polycrystalline-based) solar panel is used because it is low cost and simple.

3.1.2. Photovoltaic panel model

In solar panel model, single diode model is proposed. Plus, there are plenty of researches about the model regarding in extracting parameters of single diode photovoltaic modeling. Figure 3.2 shows the circuit of single-diode model.

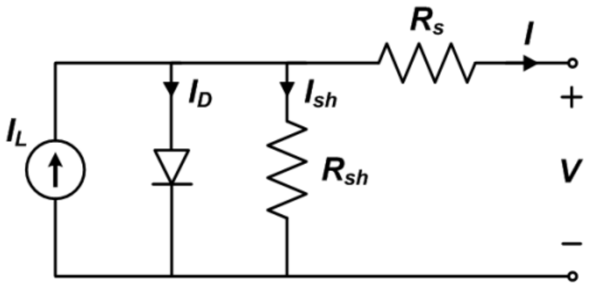


Figure 3.2. Single diode model of PV solar panel.

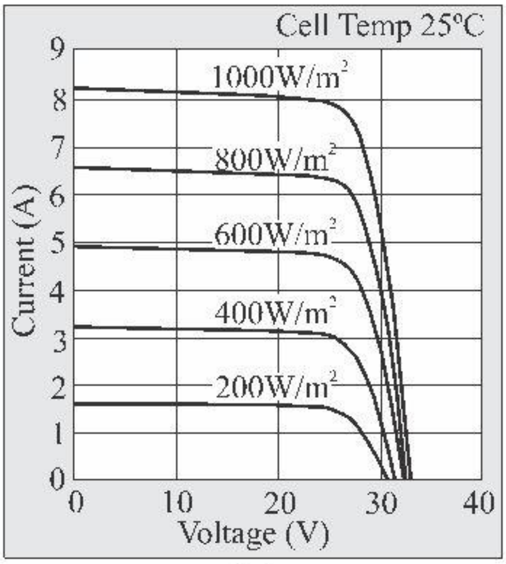
Table 3.2. Electrical characteristics of YL250P-29b module.

Electrical Characteristics	Symbol	YL250P-29b
Power output	P_{max}	250 W
Power output tolerances	ΔP_{max}	-5 / + 5 W
Module efficiency	η_m	15.3 %
Voltage at P_{max}	V_{mpp}	29.8 V
Current at P_{max}	I_{mpp}	8.39 A
Open-circuit voltage	V_{oc}	37.6 V
Short-circuit current	I_{sc}	8.92 A
Temperature coefficient of P_{max}	Γ	-0.42 %/°C
Temperature coefficient of V_{oc}	β_{Voc}	-0.32 %/°C
Temperature coefficient of I_{sc}	α_{Isc}	0.05 %/°C
Temperature coefficient of V_{mpp}	β_{Vmpp}	-0.42 %/°C
Max. system voltage		1000 V_{DC}

In this thesis, PV module, YL250P-29b solar panel is used. YL250P-29b is produced by YGE Solar is multicrystalline solar panel. In the next chapter, the mathematical modelling will be deriving according to single-diode model and parameter from YL250P-29b module. The electrical characteristic of YL250P-29b is described in Table 3.2.

3.1.3. Photovoltaic generation

Photovoltaic (PV) modules output power relies on cell temperature and solar irradiation. The temperature influences the photovoltaic (PV) module output voltage, while the solar radiation mainly effects the photovoltaic (PV) module output current. Since P = IV where P is power in Watt (W), I is current in Ampere (A) and V is Voltage in Volt (V), the power increases as I and V increases. In real life, weather differs from time to time, therefore it will cause fluctuations in temperature and solar radiation, resulting in a non-linear and time variant power source. The I-V curve presented at Figure 3.3 is obtained from Kyocera KC200GT PV module datasheet (Rekioua and Matagne, 2012).



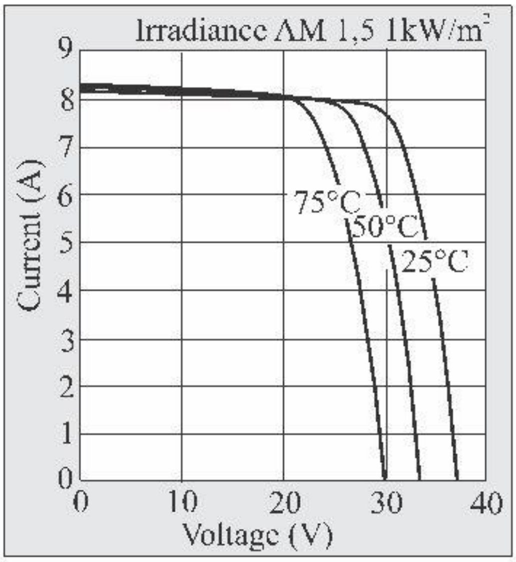


Figure 3.3. I-V curve from Kyocera KC200GT PV module (Rekioua and Matagne, 2012). (a) Constant temperature, T = 25◦C, (b) Constant irradiation, G = 1000 W/m2.

In PV system, the operation point is obtained on the knee of I-V curve. For a given solar radiation and temperature, the product of PV output voltage and current at maximum available power is usually known as Maximum Power Point (MPP) (Sharma and Jain, 2014). For determining the maximum power point, an alternative P-V (power versus voltage) curve may be plotted, in accordance with Figure 3.4.

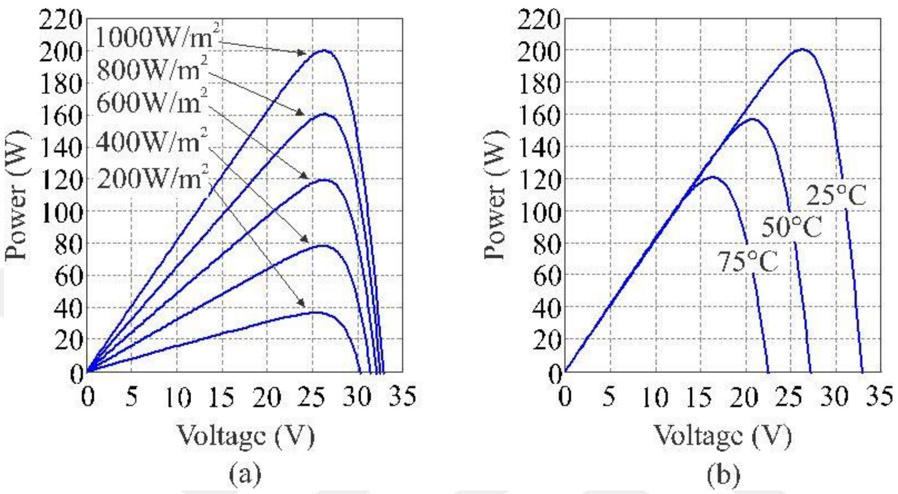


Figure 3.4. P-V curve from Kyocera KC200GT PV module (Rekioua and Matagne, 2012). (a) Constant temperature, T = 25◦C (b) Constant irradiation, G = 1000 W/m2.

In MPP point of view, there are several parameters for completing the PV module characterization. The parameters are short circuit current (I_{sc}), open circuit voltage (V_{oc}), current at maximum point (I_{mpp}), and power at maximum point (P_{mpp}). These parameters represent the points where the PV generated power is zero, but the current and voltage reach the maximum as shown in Figure 3.5.

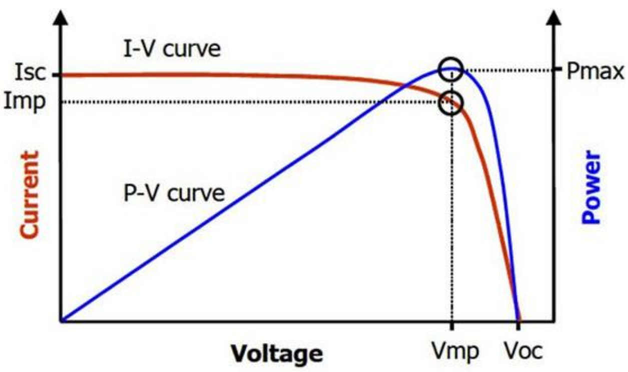


Figure 3.5: Maximum power point identification of I_{sc}, V_{oc}, I_{mpp} and P_{mpp} on the I-V and P-V curves (Sharma and Jain, 2014).

3.2. Maximum Power Point Tracking (MPPT)

The sun energy is converted to electrical energy. It is converted based on the conversion efficiency. High conversion efficiency is accomplished when the photovoltaic module operates on the maximum power point (Huang et al., 2011). However, due to uncertainty of solar radiation and temperature, it affects the power point. This leads to vary I-V curve, as illustrates on Figure 3.6.

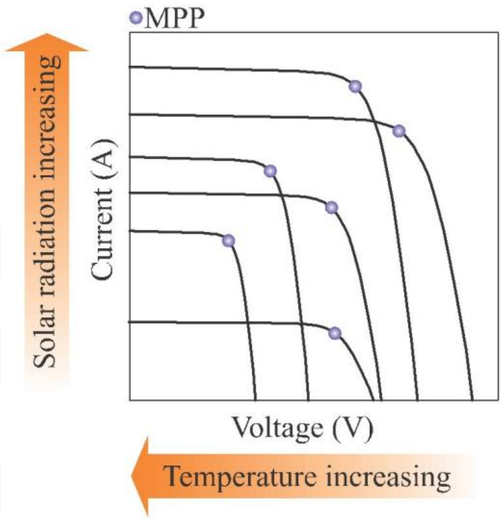


Figure 3.6. MPP across the I-V curves under varies solar radiation and temperature (Huang et al., 2011).

Dealing with varies solar radiation and temperature, the MPP is also varies. Therefore, in order to dynamically set the MPP as operating point for wide range of inputs (solar radiation and temperature), Maximum Power Point Tracking (MPPT) technique is required (Kumaresh and Prabu, 2014).

MPPT application is basically a DC-DC converter placed between the photovoltaic modules and the load controlled by tracking algorithm, as shown in Figure 3.7.

The study of MPPT has two major approaches: dc-dc converter topology optimization; and maximum power point tracking algorithm. The dc-dc converter topology is a technique to resolve an applicable dc-dc converter for operating as MPPT. On the other hand, the maximum power point tracking algorithm is applied to regulate the dc-dc converter (Zaki et al., 2012). The regulation made by the maximum power point tacking algorithm is to generate the top Maximum Power Point (MPP).

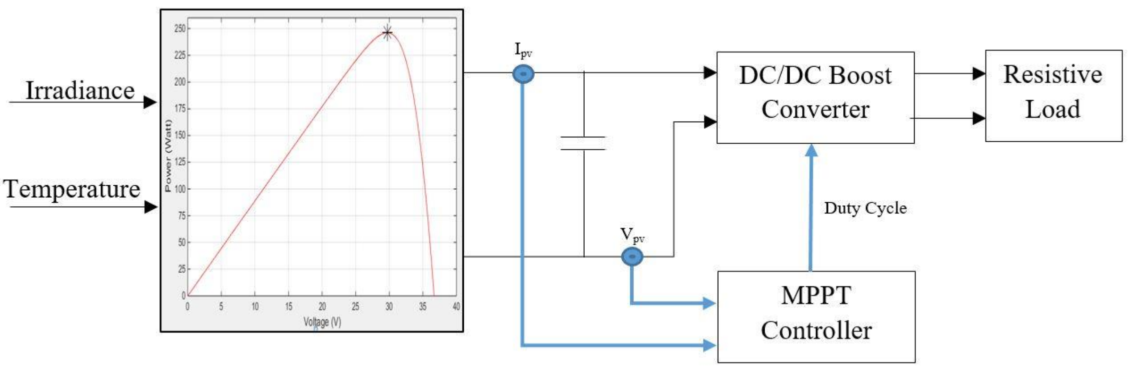


Figure 3.7. MPPT system consists of DC-DC converter and tracking controller.

In conclusion, a dynamic MPPT system is designed by combining the integration of suitable dc-dc converter and suitable tracking algorithm (Paul and Mathew, 2014).

3.2.1. Tracking algorithm

For controlling the dc-dc converter, a suitable tracking algorithm is required. The tracking algorithm performance is fundamental for an efficient tracking response. Basically the tracking algorithm will receive the inputs which are PV module voltage and current and cooperates with dc-dc converter duty cycles that establishes the system operating point of MPP (Rekioua and Matagne, 2012).

As the temperature and solar radiation are dynamic variables, the tracking algorithm must practically work in real time updating the duty cycle for a fast and accurate tracking. There are several algorithms for improving the tracking speed and accuracy (Dolara et al. 2009).

Many of tracking algorithms has been mentioned in literature review, in this study we will use neuro fuzzy algorithm to control the duty cycle of the boost converter. MATLAB/Simulink software will be used to model the MPPT system.

3.2.1. Adaptive neuro fuzzy inference system (ANFIS) method

Neuro-fuzzy technique is combining the ANN learning methods and the fuzzy inference system (FIS). In general the FIS structure consists of three important components:

The rule base one, for rule fuzzy selection; a database, which defines the fuzzy rules MF and a decision generator, which bring up the inference procedure to finally generate an output as shown in Figure 3.8. Moreover, neuro-fuzzy approach seems covenant and suitable if both advantages of the tow method are combined. The neuro-fuzzy controller is the called, in this work adaptive network (ANFIS). The structure of the system is an adaptive network running as a first-order Sugeno fuzzy inference system. The hybrid ANFIS learning rule, combine the back-propagation gradient-descent first and second a least-squares algorithm for identification and optimization of the the Sugeno first order system (Maissa and Lassâad, 2015).

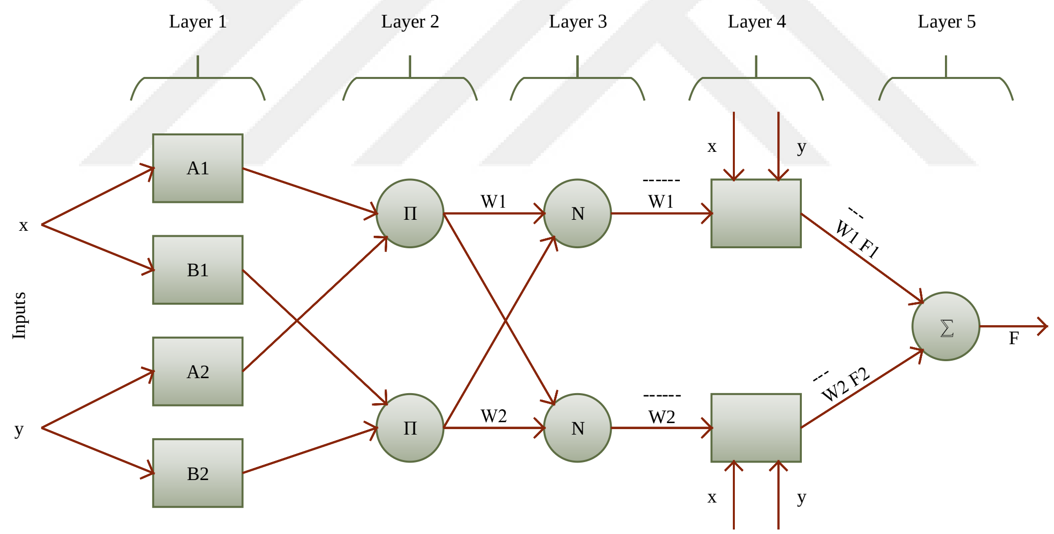


Figure 3.8. Architecture of ANFIS model Sugeno's fuzzy inference method.

The given architecture has five layers and every node in a layer has a similar function. The two fuzzy rules, in which outputs are dressed as linear combinations of their inputs, are (Maissa and Lassâad, 2015):

$$Rule1: if\ x\ is\ A_1\ and\ y\ is\ B_1\ then\ f_1 = p_1x + q_1x + r_1$$

$$Rule2: if\ x\ is\ A_2\ and\ y\ is\ B_2\ then\ f_2 = p_2x + q_2x + r_1$$

Layer 1: consists of adaptive nodes that generate membership grades of linguistic labels based upon premise signals, using any appropriate parameterized membership function such as the generalized bell function given by:

$$O_{1i} = \mu_{A_i}(x) = \frac{1}{1+\left|\frac{x-c_i}{a_i}\right|^{2b_i}} \tag{3.1}$$

Where output $O_{1,i}$ is the output of the i^th node in the first layer, x is the input to node i, A_i is a linguistic label ("small," "large," etc.) from fuzzy set A = (A_1, A_2, B_1, B_2) associated with the node, and (A_i, B_i) is the premise parameter set used to adjust the shape of the membership function.

Layer 2: are fixed nodes designated Π, which represent the firing strength of each rule. The output of each node is the fuzzy AND (product or MIN) of all the input signals.

$$o_{2,i} = w_i = \mu_{A_i}(x)\mu_{B_i}(y) \quad i = 1,2 \tag{3.2}$$

Layer 3: The outputs are the normalized firing strengths. Each node is a fixed rule labeled N. The output of the i^{th} node is the ratio of the i^{th} rule's firing strength to the sum of all the rules firing strengths (Konsoulas, 2014).

$$O_{3,i} = \overline{w_i} = \frac{w_i}{w_1+w_2} \tag{3.3}$$

Layer 4: the equation gives the rule outputs is:

$$o_{4,i} = \overline{w_i}f_i = \overline{w_i}(p_i x + q_i y + r_i) \tag{3.4}$$

Layer 5: the ANFIS output is given by:

$$o_{5,i} = \sum_i \overline{w_i}f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \tag{3.5}$$

The ANFIS controller developed in this project includes ' e ' and ' Δe' as inputs and 'D’ as output which represent respectively, the error, the error variation and the converter duty cycle. The input variables allow the ANFIS to generate the converter command. This last is applied to the boost converter, in order to ensure the adaptation of the power provided by PV. This controller yields to an automatic fuzzy rules generation based on the Sugeno inference model.

3.3. Boost Converter

A boost converter it also called “step-up converter” is a DC-to-DC power stage that steps up voltage (while stepping down current) from its source to the load. It is a class of switched-mode power supply containing at least two semiconductors (a diode and a transistor) and at least one energy storage element, a capacitor, inductor, or the two in combination. To reduce voltage ripple, filters made of capacitors in combination with inductors are normally added to such a converter's output (load-side filter) and source filter. Figure 3.9 shows the schematic diagram of Boost converter. (Lu and Shih, 2010).

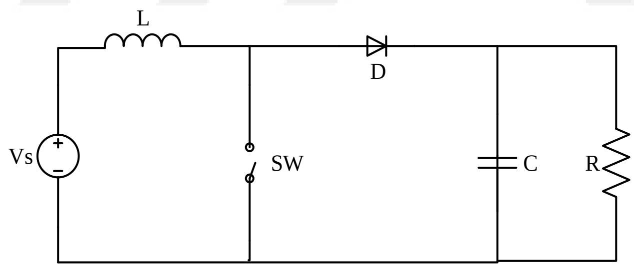


Figure 3.9. Schematic diagram of boost converter.

A boost regulator can step up the voltage without a transformer. Due to a single switch, it has a high efficiency. The input current is continuous. The output voltage is very sensitive to changes in duty cycle D in equation 3.6. The average output current is less than the average inductor current by a factor of (1-D), and a much higher rms current would flow through the filter capacitor (Kumar et al., 2015).

$$DC\ voltage\ gain = \frac{V_o}{V_s} = \frac{1}{1-D} \tag{3.6}$$

Where, V_s is input voltage, V_o is output voltage, and D is the duty cycle of the pulse width modulation (PWM). The design and implementation of boost converter is discussed in next chapter.

4. IMPLEMENTATION AND RESULTS

4.1. Introduction

The simulation development and implementation will be discussed in this chapter, also the technique used in developing the scheme including tool, equipment procedure and process involved in proposed project will be explored. The methodology procedure utilizes on software using MATLAB/Simulink. Firstly designing of PV panel will be discussed then the implementation of neuro fuzzy controller and boost converter.

4.2. Structure of the System

As mentioned in chapter 3, for extracting the MPP from the PV module a MPPT controller is needed. In this project it apply the extracted power to resistive load. The interface among the load and PV module is a DC-DC Boost converter. In this thesis by using MPPT controller, new adapted maximum power point can be tracked to match the P-V curve at any changes in irradiance and temperature. The MPPT controller is used to adjust the duty cycle of boost converter and control the index of PWM to keep the power extracted from the PV panel at its maximum point. Figure 4.1 is showing the complete structure of the proposed system.

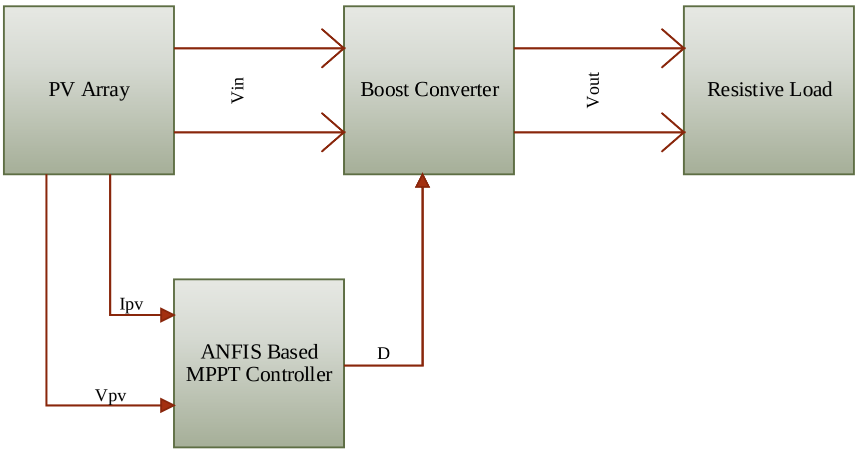


Figure 4.1. Overall structure of the system.

4.3. Flowchart of Implementation

MATLAB/Simulink framework is the main tool used for implementation in this project. The design of neuro fuzzy controller and simulation of PV panel are developed. The system outputs are analyzed in MPPT output power, voltage, and current. The flowchart shown on Figure 4.2 shows the flow of the software implementation.

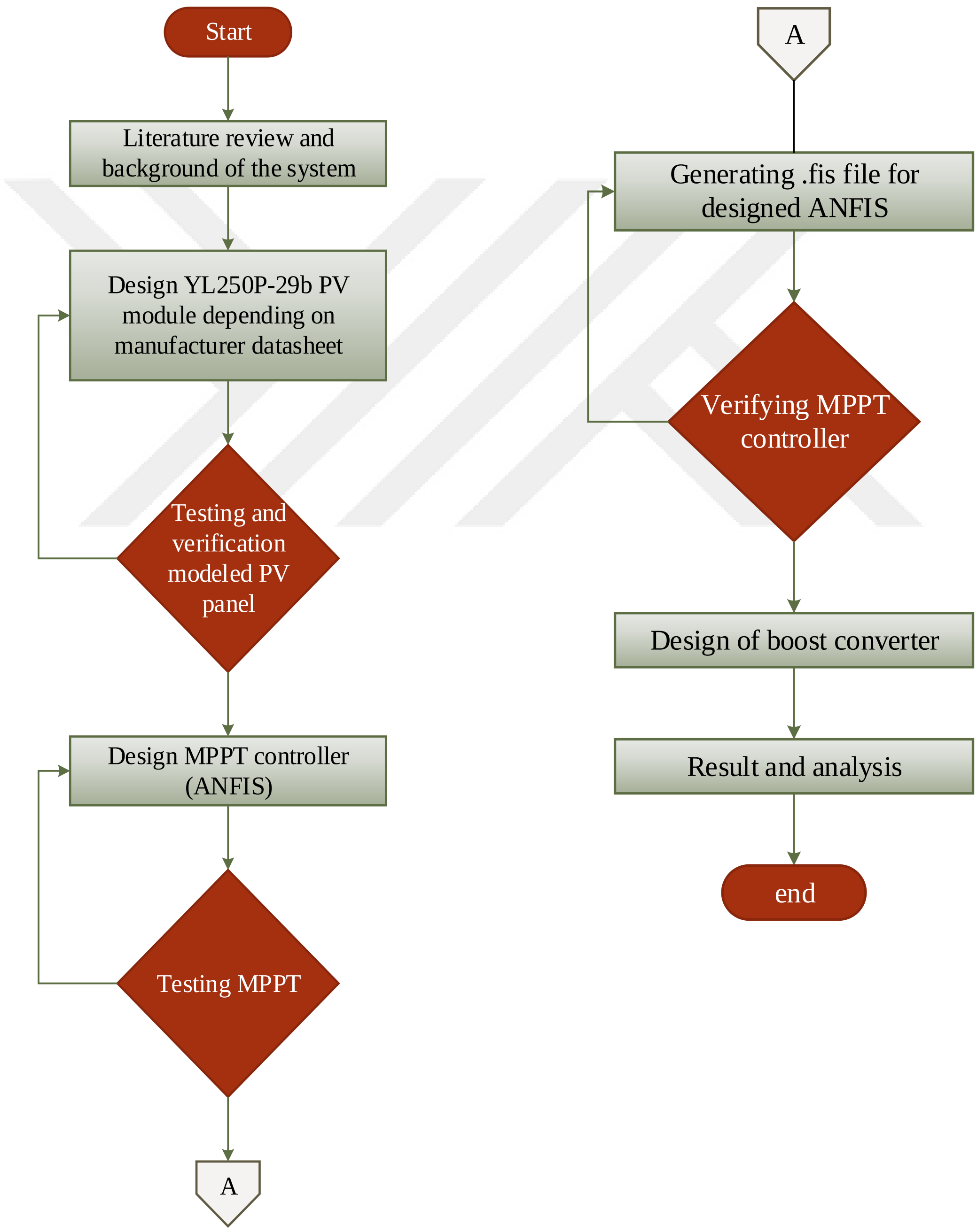


Figure 4.2. Flowchart of the software implementation.

4.4. Implementation of Project Using MATLAB/Simulink

The implementation of MPPT system which is based on the tracking controller and PV module is explained in this section. For first phase, by using MATLAB/Simulink the modeling, designing and verification of PV module is described.

Then the designation of tracking controller and its verification are described. In the third phase the design of boost converter will be discussed.

4.4.1 Simulink modeling of photovoltaic module

To assemble the PV module, the fundamental mathematical equations have been used. The PV module parameter depends on the electrical characteristics datasheet of YGE Solar YL250P-29b PV module.

Also, the electrical characteristics and equivalences are applied into MATLAB/Simulink. The generated outputs will be verified based on the electrical characteristics provided by YGE Solar.

4.4.1.1. Simulink implementation of PV array

Basically, there are two type of PV panel modeling. The first one is single-diode and the second is two-diode model. for this project, the proposed model applied single-diode since it is accurate and simple (Kulaksiz, 2013). The equivalent circuit of a single diode solar cell is depicted in Figure 4.3.

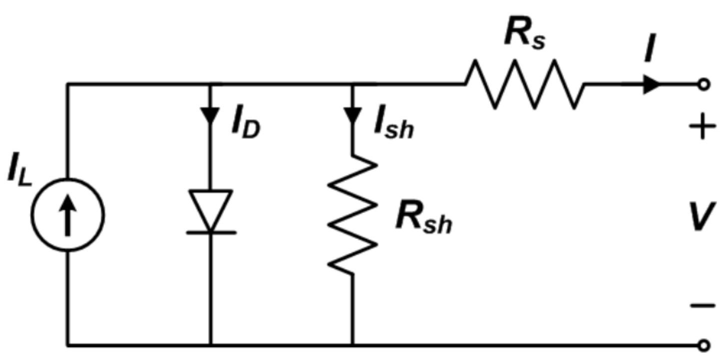


Figure 4.3. Single-diode cell.

The symbols in pervious figure are defined as below:

$I_L = I_{ph}$: Photocurrent

I_D: Parallel diode current

I_{sh}: Shunt current

I: Output current

V: Output voltage

R_{sh}: Shunt (parallel) resistance

R_s: Series resistance

The fundamental single-model solar cell is equation derived using Kirchhoff's current law as showed in equation 4.1 and figure 4.4 describe the Simulink model of the output current I.:

$$I = I_{ph} - I_D - I_{sh} \tag{4.1}$$

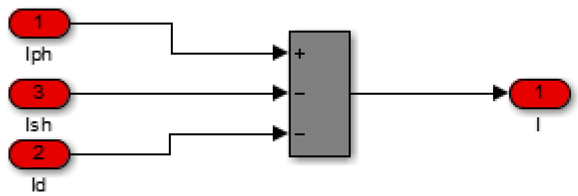


Figure 4.4. Simulink model of PV output current I.

As shown in above figure, to calculate PV output current first we should determine (I_{ph}, I_D, I_{sh}).

4.4.1.2. Simulink implementation of photovoltaic current I_{ph}

To determine I_{ph}, its equation is derived from the output current at the standard test conditions (STC) at it shown in equation 4.2.

$$I = I_{ph} - I_D \tag{4.2}$$

Where I_D is the diode current and equals to:

$$I_D = I_s\left[e^{\left(\frac{V+I.R_S}{A.N_S.V_T}\right)} - 1\right] \Rightarrow \; I = I_{ph} - I_s\left[e^{\left(\frac{V}{A.N_S.V_T}\right)} - 1\right] \tag{4.3}$$

Using the following equation $I_{ph,ref}$ can be calculated, which is the only way for determining it. When the PV cell is short-circuited:

$$I_{sc,ref} = I_{ph,ref} - I_{s,ref}\left[e^{\left(\frac{0}{A.N_S.V_T}\right)} - 1\right] \tag{4.5}$$

But the above equation is valid in ideal case only and the equality is not correct (Bellia, Youcef et al. 2014). And then

$$I_{sc,ref} = I_{ph,ref} \tag{4.6}$$

The photocurrent (I_{ph}) depends on both irradiance and temperature, The Simulink model of Iph is displayed in figure 4.5:

$$I_{ph} = G\left(I_{sc} + \alpha_{I_{sc}} \cdot \Delta T\right) \tag{4.7}$$

Where:

G: Irradiance per unit (p.u) which is equal to $\left(\frac{G}{G_{ref}}\right)$ and Gref = 1000(W/m2)

ΔT = Tc-Tc,ref (Kelvin)

Tc,ref : Cell temperature at STC = 25 + 273 = 298 K

I_{sc}: Short circuit current (A) at STC

$\alpha_{I_{sc}}$: I_{sc} temperature coefficient and for implemented PV panel is (0.05% A/K).

4.4.1.3. Simulink implementation of shunt resistor current I_{sh}

I_{sh}, is the current leak in shunt resistor, which is by using Kirchhoff's low:

$$I_{sh} = \frac{V+IR_S}{R_{sh}} \tag{4.8}$$

The value of R_s and R_{sh} should be known to evaluate the shunt resistor current, which they will be discussed later. Figure 4.6 showing the equivalent Simulink model of above equation.

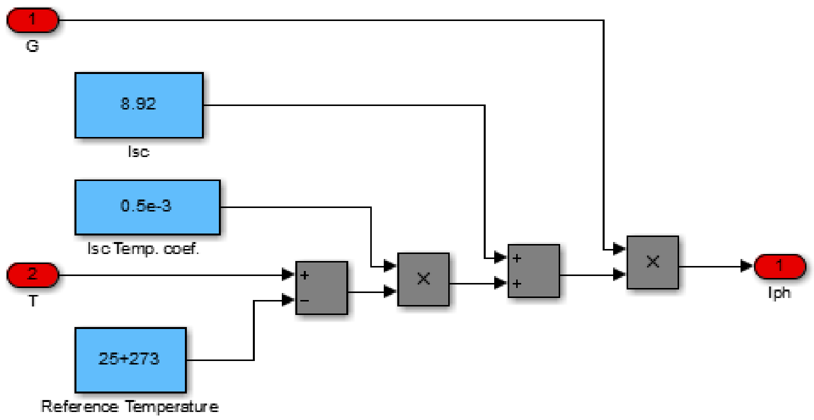


Figure 4.5. Simulink model of I_{ph}.

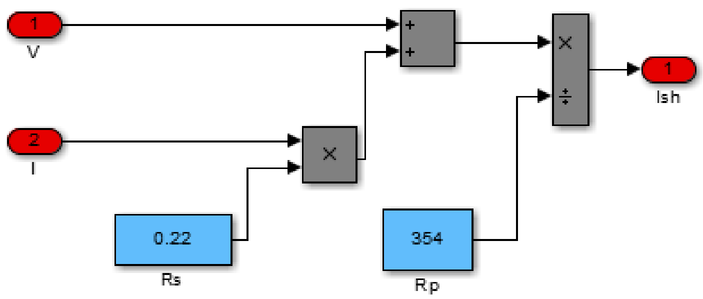


Figure 4.6. Simulink model of I_{sh}.

4.4.1.4. Simulink implementation of diode current I_D

As mentioned before, I_D is the diode current which is relative to I_s and is given by equation 4.9:

$$I_D = I_s \left[e^{\left(\frac{V+I.R_S}{A.N_S.V_T}\right)} - 1 \right] \quad (4.9)$$

Where V is the voltage imposed on the diode. V_T is thermal voltage which is can be calculated using equation 4.10, the Simulink implementation of I_D and V_T are shown in figure 4.7 and 4.8 respectively.

$$V_T = \frac{k.T_C}{q} \qquad (4.10)$$

Where:

I_s : Diode's reverse saturation current and it measured in Ampere

Ns: number of PV cells connected in series and for proposed panel it is 60 cells

T_c: Operating cell temperature (K)

k: Boltzmann constant 1.38×10^{-23}J/K

q: electron charge 1.602×10^{-19}C

A: Ideality factor, which is 1.2 for si-mono.

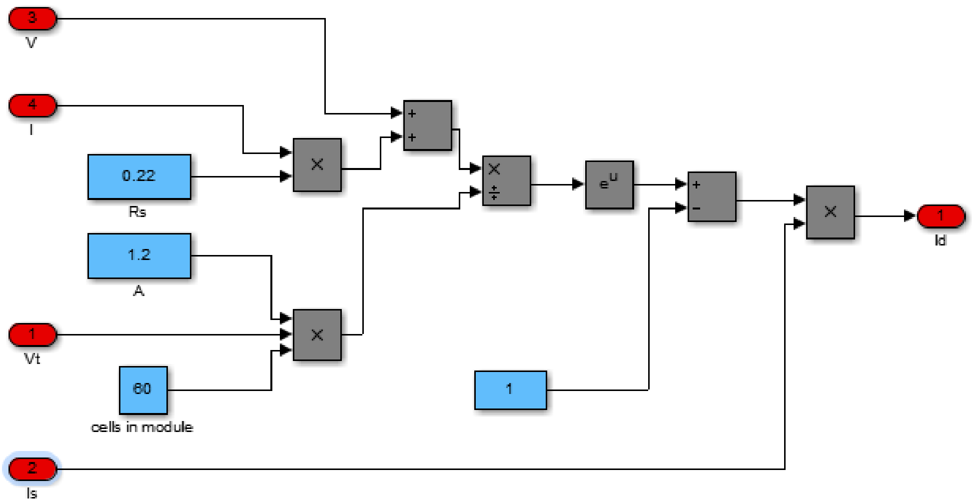


Figure 4.7. Simulink implementation of diode current I_D.

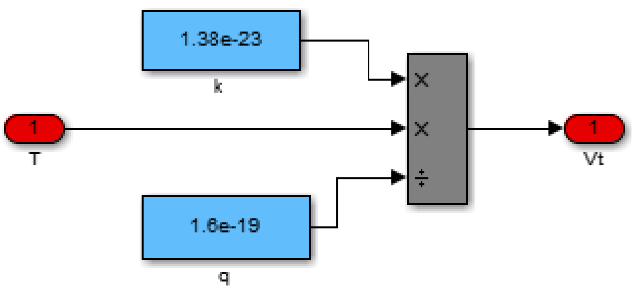


Figure 4.8. Simulink implementation of thermal voltage V_T.

To implement I_D, first we need to determine the reversed current I_s, the series resistor R_s, and the shunt resistor R_{sh}.

4.4.1.5. Simulink implementation of saturation current I_s

The output current can be written as equation 4.11:

$$I = I_{ph} - I_s \left[e^{\left(\frac{V + I.R_S}{A.N_S.V_T} \right)} - 1 \right] - \frac{V + IR_S}{R_{sh}} \tag{4.11}$$

Referring to previous above equation, and because the parallel resistance R_{sh} is usually considered as great, the last term of the equation can be canceled for calculating I_s. the pervious equation has been applied in STC's remarkable points which they are:

1- The voltage at open circuit (I = 0, V = $V_{oc,ref}$).

2- The Voltage and current at MPP ($V_{mp,ref}$) ($I_{mp,ref}$).

3- The current at short circuit (V = 0, I = $I_{sc,ref}$).

The following equations (4.12 – 4.14) can be concluded:

$$I_{sc,ref} = I_{ph,ref} - I_{s,ref} \left[e^{\left(\frac{I_{SC}.R_S}{A.N_S.V_T} \right)} - 1 \right] - 1 \tag{4.12}$$

$$0 = I_{ph,ref} - I_{s,ref} \left[e^{\left(\frac{V_{OC}}{A.N_S.V_T} \right)} - 1 \right] \tag{4.13}$$

$$I_{mp,ref} = I_{ph,ref} - I_{s,ref} \left[e^{\left(\frac{V_{mp} + I_{mp}.R_S}{A.N_S.V_T} \right)} - 1 \right] \tag{4.14}$$

According to equation 4.12, and by substituting ($I_{ph,ref}$) in equation 4.14. The following equation can be driven:

$$0 \cong I_{sc} - I_{rs,ref} \left[e^{\left(\frac{V_{OC}}{A.N_S.V_T} \right)} - 1 \right] \Rightarrow I_{rs,ref} = \frac{I_{SC}}{\left[e^{\left(\frac{V_{OC}}{A.N_S.V_T} \right)} - 1 \right]} \tag{4.15}$$

The equivalent Simulink implimentation of reversed refernce saturation current at operational temperature ($I_{rs,ref}$) is shown in figure 4.9.

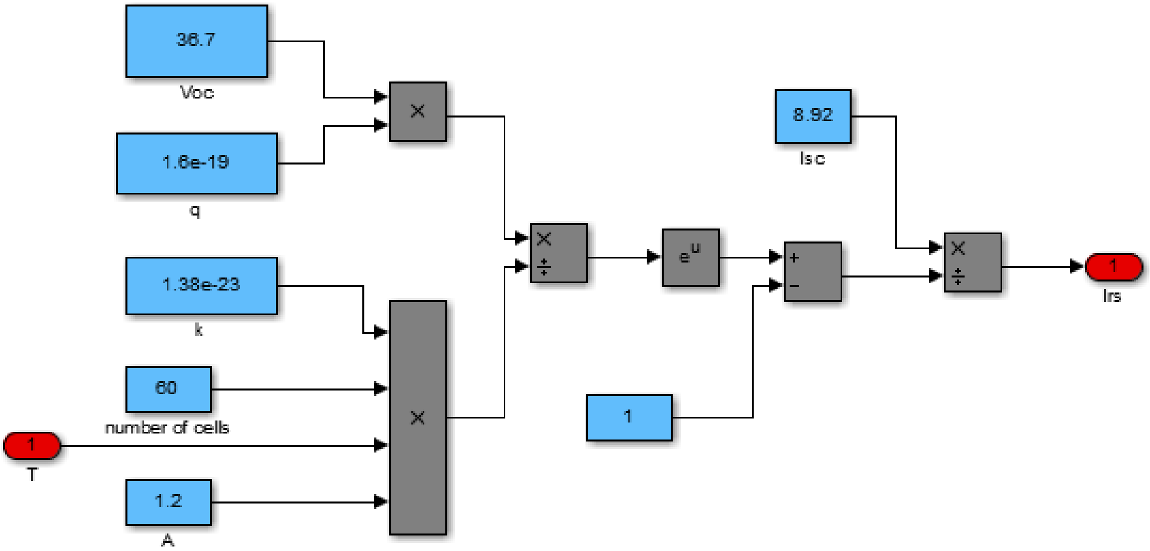


Figure 4.9. Reversed reference saturation current at operational temperature.

The reverse saturation current is defined by equation 4.16:

$$I_s = D\, T_C^3 \left[e^{\left(\frac{-q\varepsilon_G}{A.k}\right)} \right] \quad (4.16)$$

Where

ε_G: Physical band gap energy (eV) and its 1.12eV for Si

D: diode diffusion factor

The last equation calculated twice; first at operational temperature (T_c) and then at reference temperature ($T_{c,ref}$). So, by taking the ratio of obtained equations under both conditions, saturation current equation can be written as in equation 4.17. And the execution of I_s shown in the following figure:

$$I_s = I_{rs} \left(\frac{T_{op}}{T_{ref}}\right)^3 \left[e^{\left(\frac{-q\varepsilon_G}{A.k}\left(\frac{1}{T_{op}} - \frac{1}{T_{ref}}\right)\right)} \right] \quad (4.17)$$

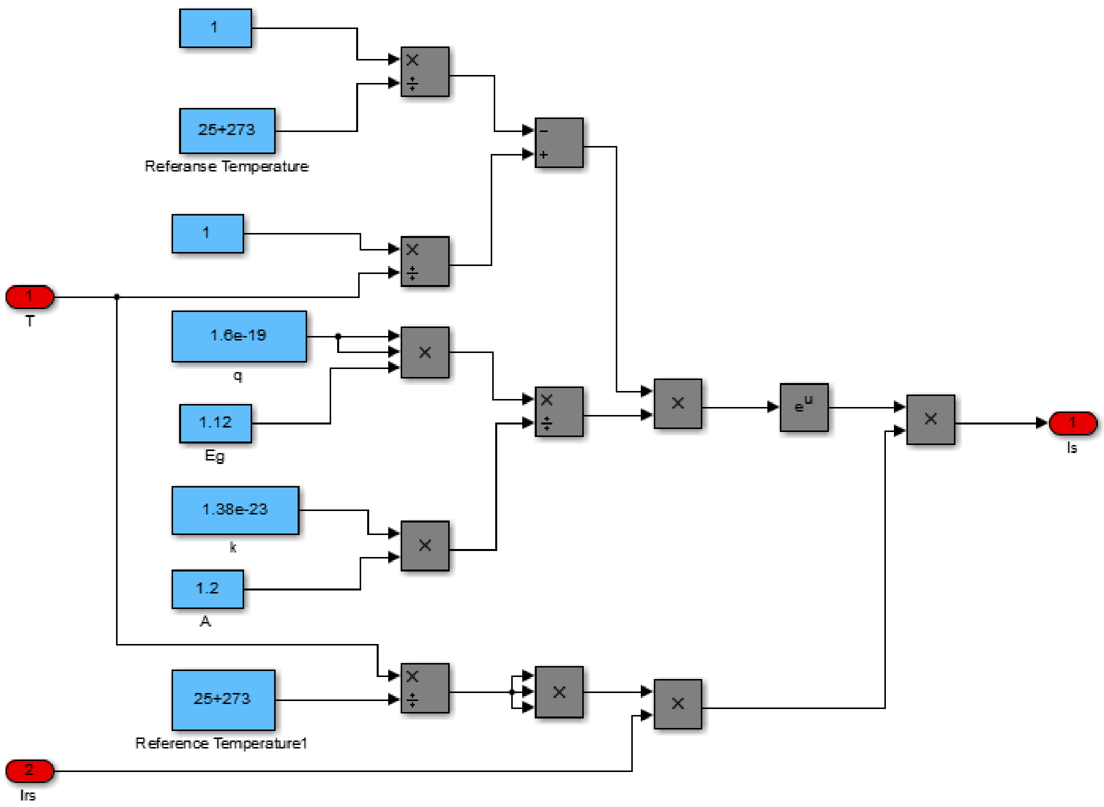


Figure 4.10. Simulink equivalent of I_S.

4.4.1.6. Calculation of resistors

In order to make the implemented PV module more reliable, we should evaluate R_{sh} and R_S, they are chosen so that the computed maximum power P_{mp} is equal to the experimental maximum power $P_{mp,ex}$ at STC. According to the following equation (Kulaksiz, 2013):

$$I_{mp,ref} = \frac{P_{mp,ref}}{V_{mp,ref}} = \frac{P_{mp,ex}}{V_{mp,ref}}$$

$$= I_{ph,ref} - I_{s,ref}\left[e^{\left(\frac{V_{mp,ref}+I_{mp,ref}.R_S}{A.N_S.V_T}\right)} - 1\right] - \frac{V_{mp,ref} + I_{mp,ref}R_s}{R_{sh}}$$

And in STC the $I_{ph,ref} \approx I_{sc,ref}$ then the equivalent R_{sh} is equal to:

$$R_{sh} = \frac{V_{mp,ref} + I_{mp,ref}R_s}{I_{sc,ref} - I_{sc,ref}\left\{e^{\left(\frac{V_{mp,ref}+I_{mp,ref}.R_S-V_{oc,ref}}{A.N_S.V_T}\right)}\right\} + I_{sc,ref}\left\{e^{\left(\frac{-V_{oc,ref}}{A.N_S.V_T}\right)}\right\} - \left(\frac{P_{max,ex}}{V_{mp,ref}}\right)}$$

By taking iteration of the series resistance from $R_S = 0$ and increasing it to modify calculated MPP until it be equal to the experimental MPP. Then the corresponding R_P calculated.

According to manufacturer, the provided MPP under STC is 250W for implemented PV panel. Using Newton Raphson method, the values of (R_s=0.22Ω and R_p=354Ω) were evaluated.

All implemented parameters have been combined into subsystems, figure 4.11 shows the overall PV panel module. Figure 4.12 shows PV solar panel subsystem.

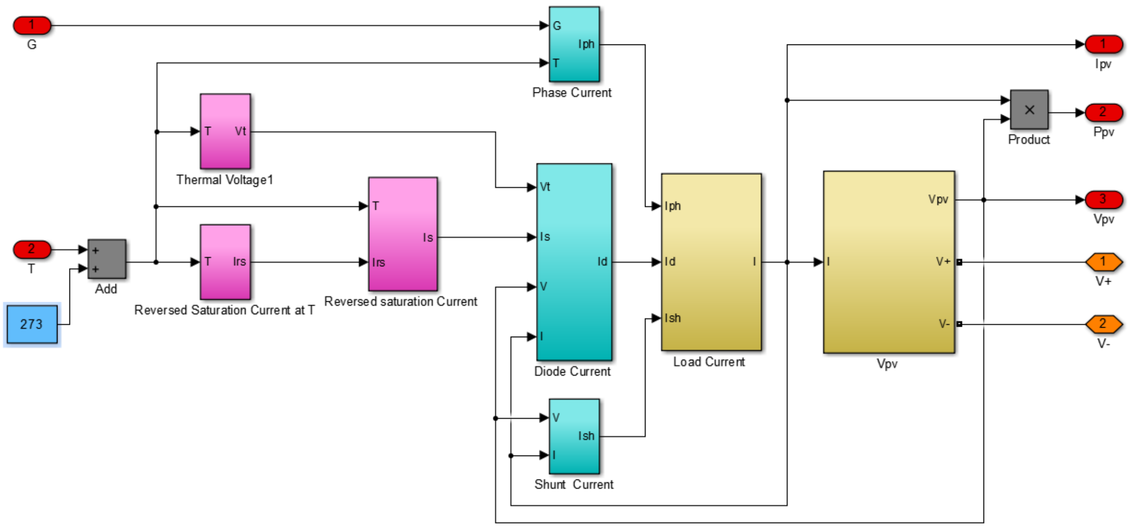


Figure 4.11. Simulink model of PV panel.

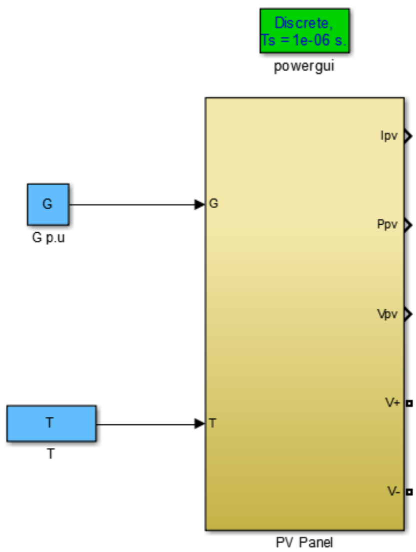


Figure 4.12. PV Panel Simulink Subsystem.

4.4.1.7. Verifying PV module modelling

In this section, the verification of the designed panel will be done. The PV module of YL250P-29b I-V curve obtained from the MATLAB/Simulink simulation will be compare with the electrical characteristics provided by manufacturer.

In verification of implemented PV panel, the P-V and I-V curve is simulated. The curve is observed through outputs under varies inputs. Testing conditions are shown in table 4.1, it clearly show constant temperature at 25C with changing in irradiation from 400w/m^2 to 1000w/m^2 in step of 200w/m^2 to relate the results of simulation with manufacturer datasheet. Figure 4.13 and 4.14 shows the I-V and P-V curve under constant temperature respectively.

Table 4.1. Varies input of PV panel model

Irradiance (p.u)	Temperature (C^o)
0.4	25
0.6	25
0.8	25
1	25

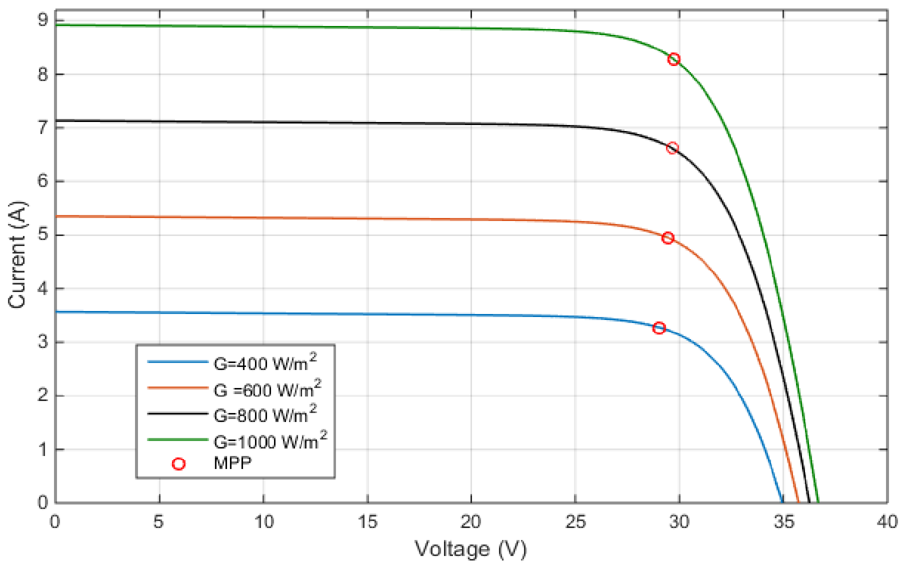


Figure 4.13. I-V characteristics of modeled YL250P-29b PV panel under constant temperature.

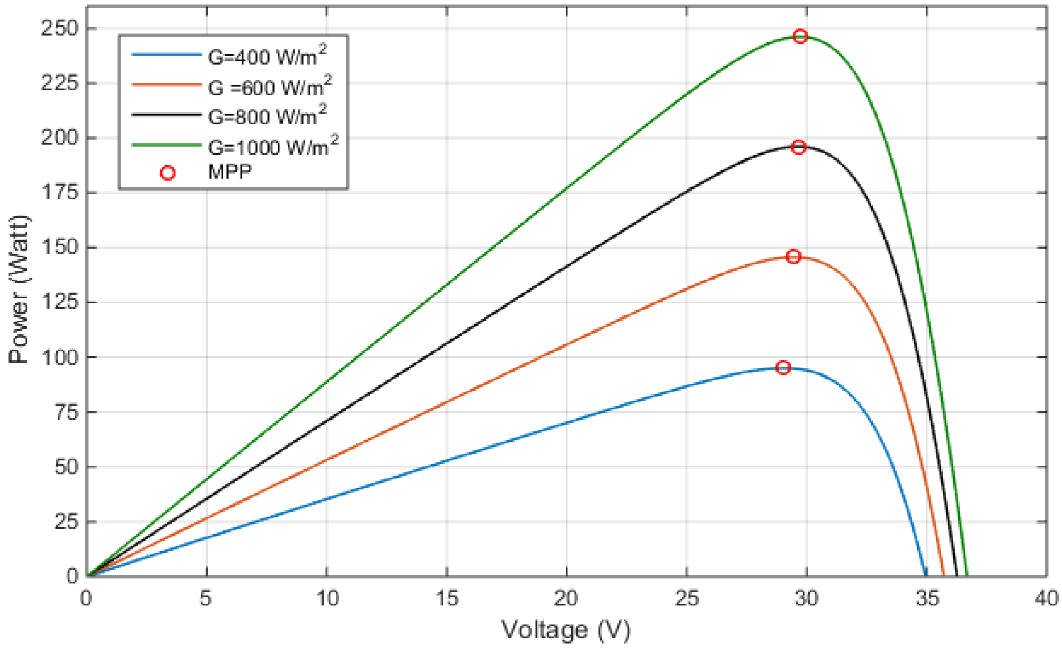


Figure 4.14. P-V characteristics of modeled YL250P-29b PV panel under constant temperature.

4.4.2. Implementing MPPT algorithm

MPPT systems are designed to track the MPP from the PV panel. The most frequently used algorithms according to several publications are Incremental Conduction (InCond) and Perturb and Observe (P&O) methods.

Beside of mentioned methods, there are several other algorithms in MPPT such as Artificial Neuarl Network (ANN), Fuzzy Logic Controller (FLC), and Adaptive Neuro Fuzzy Inference System (ANFIS) method. For Fuzzy Logic Controller, the membership functions are manually set by the designer, and Artificial Neural Network are complex in design. While in ANFIS, the training of the input data set is automatically managed to produce the output. The input are trained as to get similar output.

However, there are many other methods in implementing the MPPT, some advantages and disadvantages can be concluded. We select ANFIS algorithm because it is fast algorithm and best learning method. The structure of a PV system with a MPPT control network-based Neuro fuzzy is represented in figure 4.15.

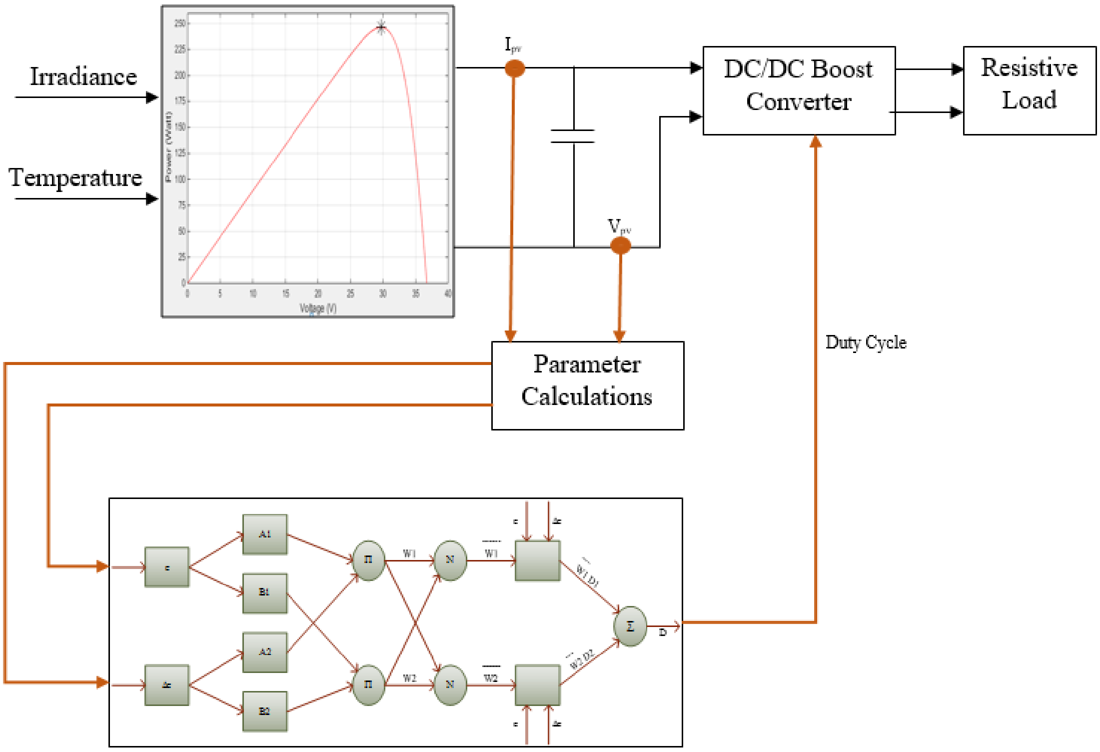


Figure 4.15. PV system with MPPT using neuro-fuzzy.

4.4.2.1. Simulink implementation of ANFIS controller

In pervious section we explained that tracking the MPP using ANFIS needs a sets of input and output data. These data sets are obtained from the system operating results and they called training data. To collect those data there are two possible ways. The first one is collecting data sets from the real-time system, and the second one is from simulation using accurate model for photovoltaic panel module.

Collecting data using first method is very hard due to the asymmetrical weather conditions and the capability to control the weather is impossible. Therefore, in this work the training data were collected from simulation after implementing and verifying the PV module.

The proposed ANFIS have two inputs and one output, the inputs are 'e' and 'Δe', while the output is the V_{ref} for boost converter PWM which is also called duty cycle and we will use symbol 'D' for it.

The inputs of ANFIS controller were calculated from MPP as follows:

$$e(t) = \frac{\Delta P(t)}{\Delta V(t)} = \frac{P(t)-P(t-1)}{V(t)-V(t-1)} \quad (4.18)$$

$$\Delta e(t) = e(t) - e(t-1) \quad (4.19)$$

Where:

P: output power from PV array

V: output Voltage from PV array

While the output is the duty cycle ‘D’ to operate the boost converter so it can operate the PV array at MPP. The duty cycle of boost converter can be calculated as follows:

$$\frac{V_O}{V_{PV}} = \frac{1}{(1-D)} \Rightarrow D = \frac{V_O - V_{PV}}{V_O} \quad (4.20)$$

Where V_o is the output voltage to the load and V_{PV} is the input voltage of boost converter. To calculate the duty cycle, the V_o is the desired output voltage which in our case is V_{mpp} (29.8V) and it called $V_{optimal}$ and V_{PV} is the actual output voltage of the PV panel.

Figure 4.16 describe the flowchart of designing ANFIS controller. The first step was collecting data for training and testing the control system. The designed PV panel have been used under STC condition which its constant temperature and irradiation (25C^o, 1000w/m^2) to calculate ‘e’ and ‘Δe’ and the output ‘D’, figure 4.17 showing Simulink subsystem used to calculate desired inputs.

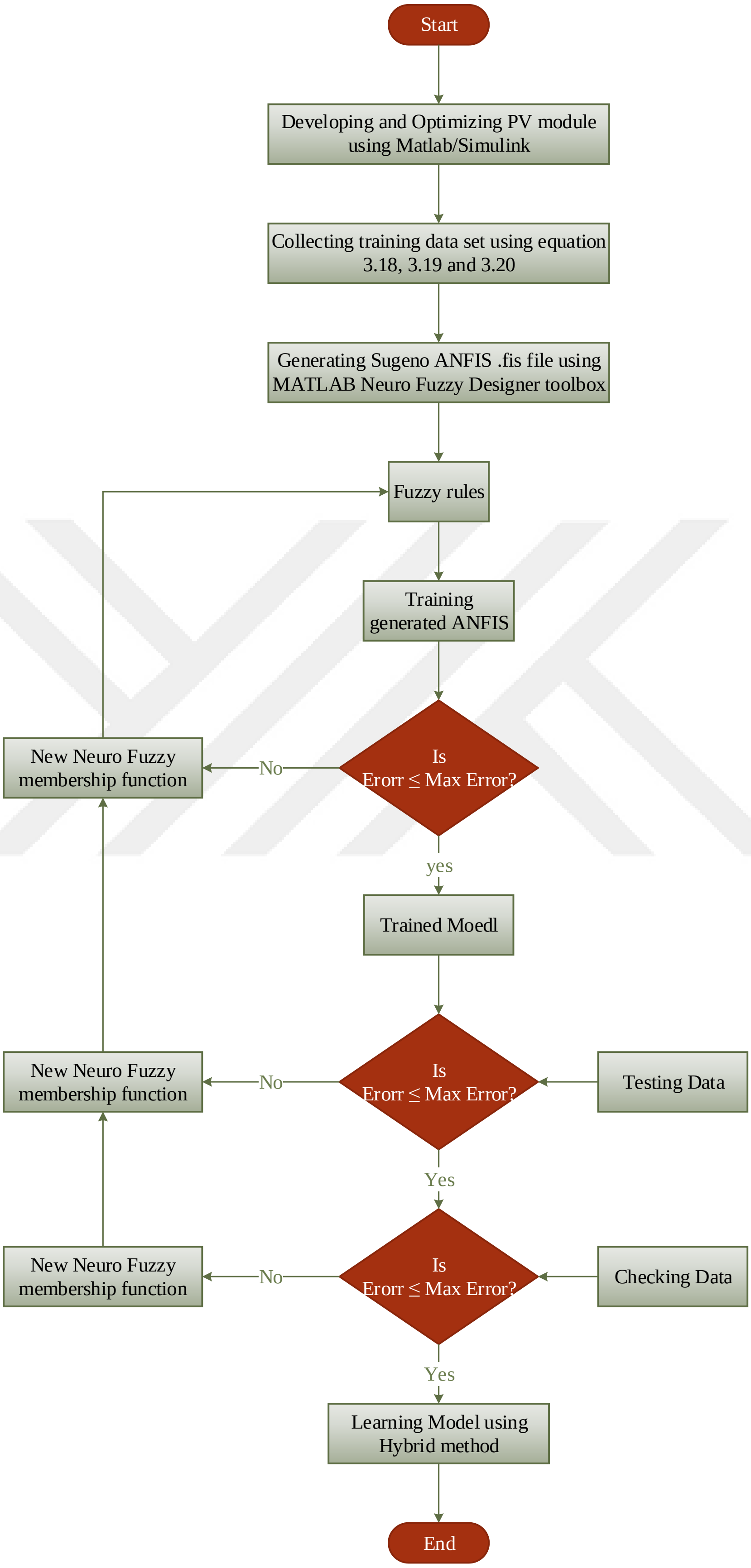


Figure 4.16. Designing MPPT controller flow chart.

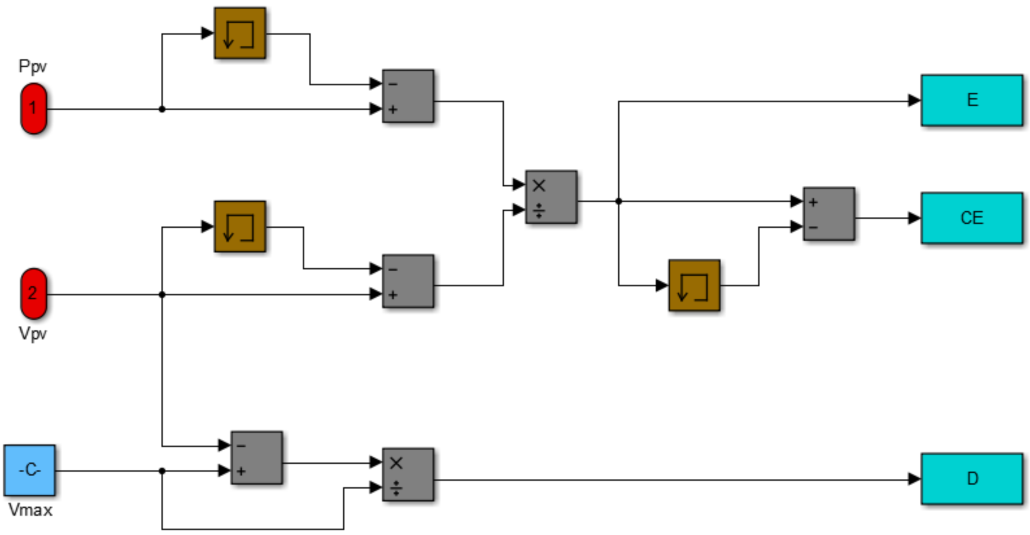


Figure 4.17. Simulink subsystem to calculate input and output dataset.

The collected input and output data (‘e’ ‘Δe’ and ‘D’) saved as an array and by using neuro fuzzy toolbox a Fis file have been generated. The equivalent neural diagram of the suggested ANFIS is shown in figure 4.18, MPPT-ANFIS validation and errors curves are shown in figure 4.19.

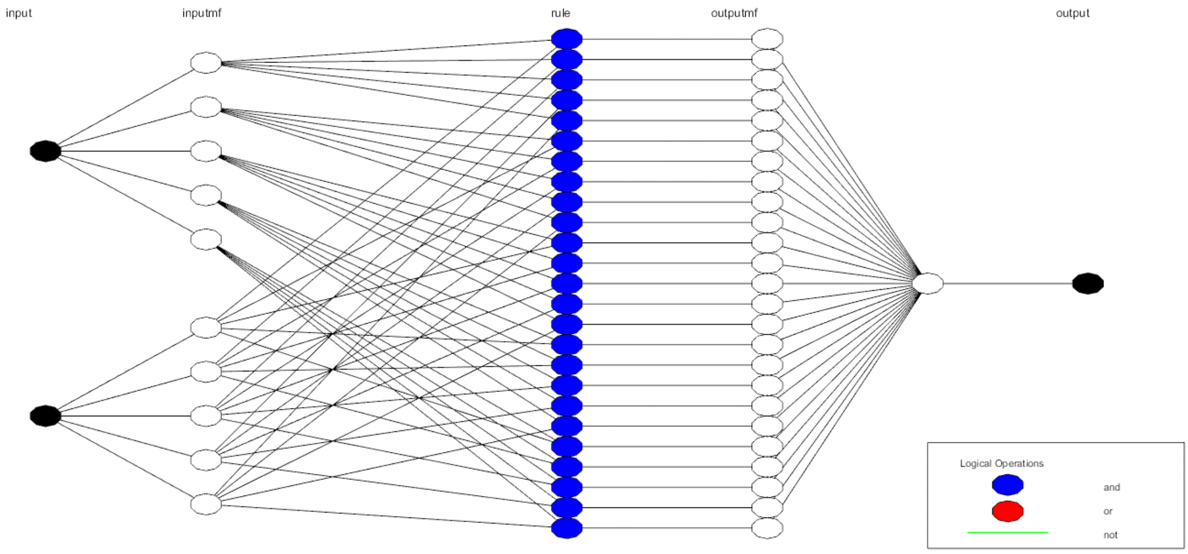


Figure 4.18. Neural diagram of the suggested ANFIS.

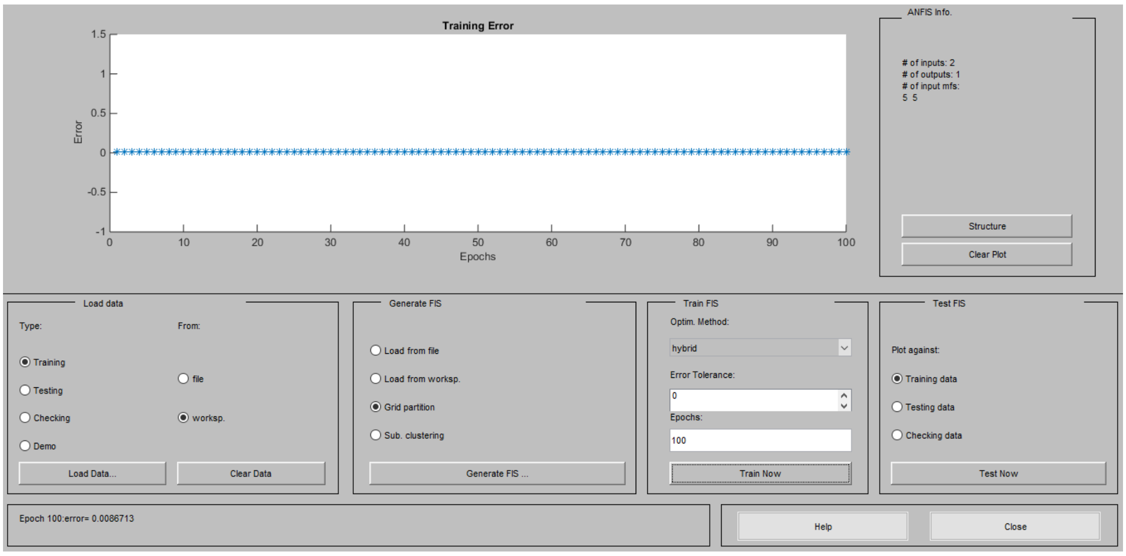


Figure 4.19. ANFIS curves of validation and error.

The two inputs represent error and variation of error (‘e’, ‘Δe’); we choose 5 Gaussian membership functions for each input. In Figure 4.20, the structure of the error (‘e’) is shown and also, the structure of the second input which is variation of error is demonstrated in Figure 4.21.

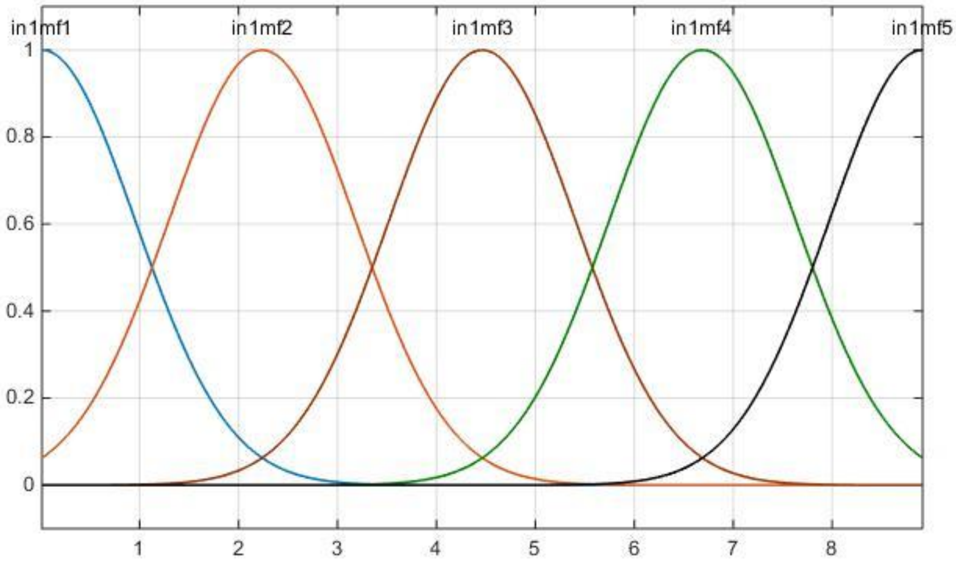


Figure 4.20. Error (‘e’) membership function.

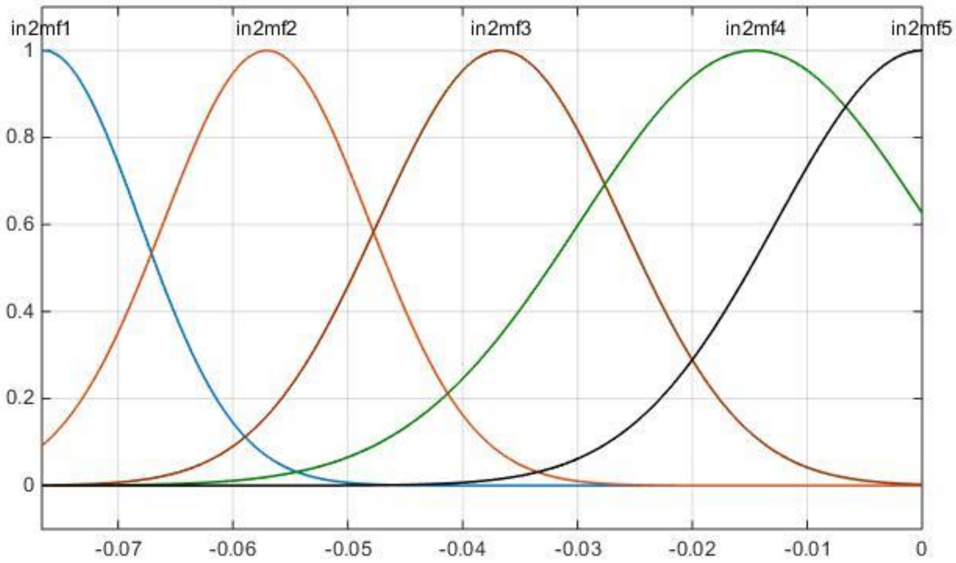


Figure 4.21. Variation of error (‘Δe’) membership function.

The neuro fuzzy inference system have 25 fuzzy rules, each one have a unique output for every input, the fuzzy rules are shwon in figure 4.22. By using fuzzy rule viewer the output and input values are presented in figure 4.23. The network has trained for 100 epochs to minimize the error to 0.0066%.

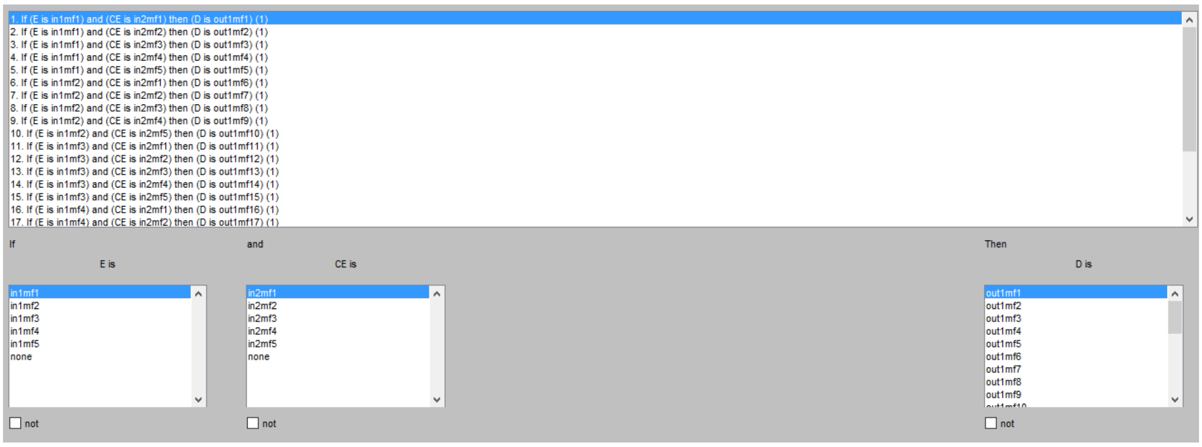


Figure 4.22. Fuzzy rules.

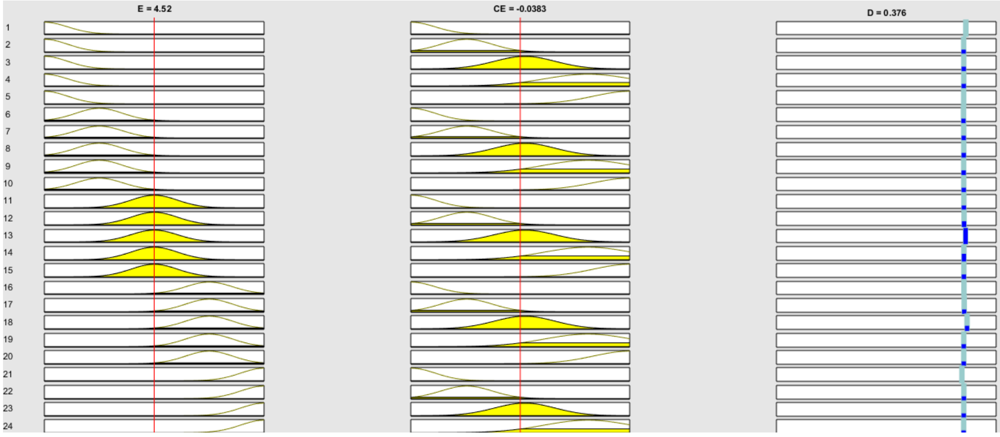


Figure 4.23. Input and output value using fuzzy rule viewer.

Figure 4.24 describe the surface of input and output data sets. After applying the hybrid training process, output data become very close to the target data as shown in Figure 4.25.

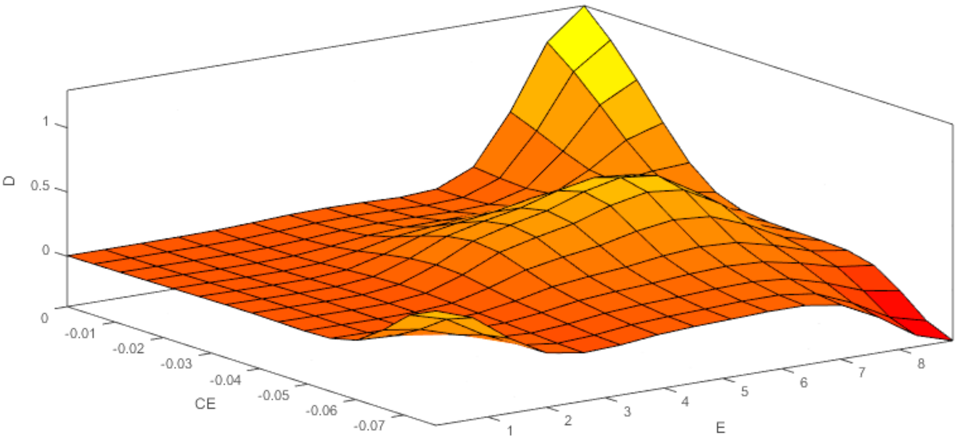


Figure 4.24. Surface of input and output data sets.

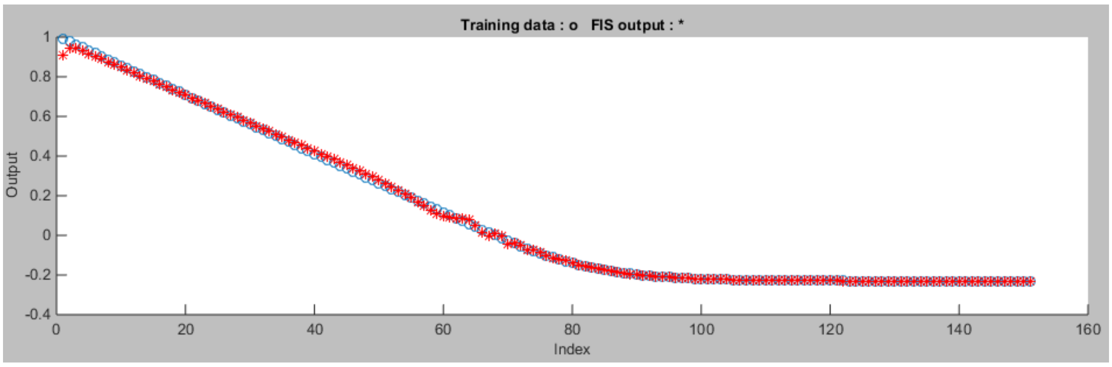


Figure 4.25. Output data vs. target data.

4.4.3. Implementation of perturb and observation based MPPT

Perturb and Observation method is the widespread MPPT techniques and can be considered as the easiest to use (Savaliya and Ray, 2015). Figure 4.26 shows flowchart of Perturb and Observe technique, the major idea of P&O method is to lead the PV system to run at the direction of which the power gained from the PV system increases. The change of power is represented in equation (4.21) and it defines the technique of the P&O algorithm.

$$\Delta P = P(t) - P(t-1) \tag{4.21}$$

Depending on above equation and by using the flowchart of the method, in case the alteration of power is positive, the incremental of duty cycle (D) will remain the same to decrease or increase the PV voltage, while if the alteration is negative, the direction of incremental duty cycle command will reverse.

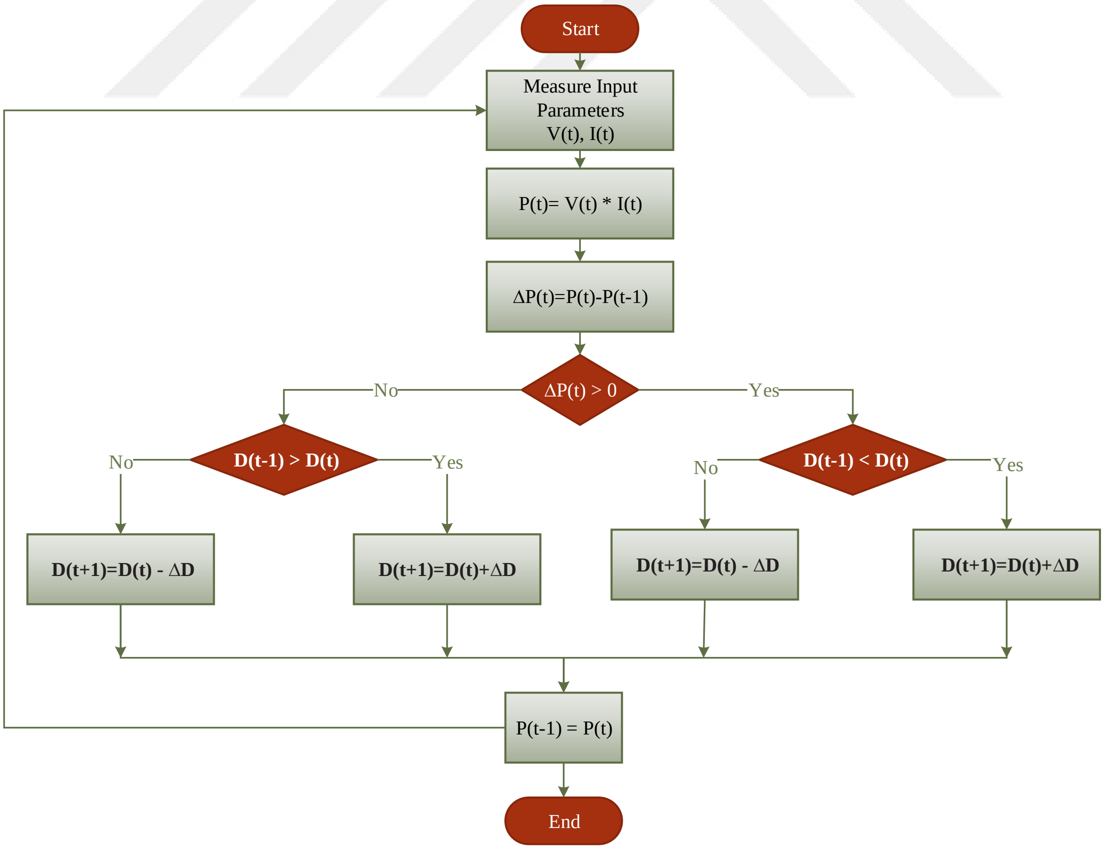


Figure 4.26. P&O method flowchart.

4.4.3. Boost converter designation

The boost is known as a step-up power stage. The boost converter has been chosen because it invert the output voltage from the input voltage, and it maximize the input voltage which in our case is the PV voltage and reaches it to the desired V_{mpp}. Figure 4.27 shows a simplified schematic of the boost converter.

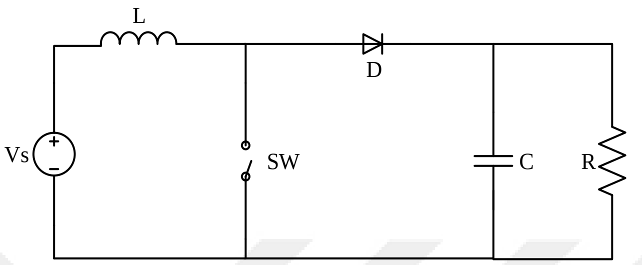


Figure 4.27. Boost converter diagram.

Where V_s is input DC voltage (V), L is the inductor (H), C is capacitor (F), R is resistor (Ω), SW is switch. Voltage gain of boost converter is given in equation 4.22:

$$DC\ voltage\ gain = \frac{V_o}{V_s} = \frac{1}{1-D} \tag{4.22}$$

Where, V_s is input voltage and in our case is V_{pv}, V_o is output voltage, and D is the duty ration which control the index of (PWM). To design a boost converter should be chosen carefully, the selection converter components were done as the following:

4.4.3.1. Selection of the inductor (L)

The selection of inductance is depends on the maximum allowed ripple current at maximum input voltage V_{pv} and minimum duty cycle. Using equation 4.23, the minimum required value of inductor can be calculated.

$$L_{min} = \frac{(1-D)^2 D R_{load}}{2 f_s} \tag{4.23}$$

4.4.3.2. Selection of the capacitance required

The output capacitor is selected to meet voltage ripple qualifications. The minimum value of capacitor can delivers the output current to the load when the diode is calculated using equation 4.24:

$$C_{min} = \frac{D}{2f_s R_{Load}} \tag{4.24}$$

Minimum values of inductor and capacitor were estimated using equation 4.23 and 4.24. But the real values of used capacitance and inductance in the simulation are larger than calculated values. Figure 4.27 showing Simulink model of designed boost converter using the selected parameters.

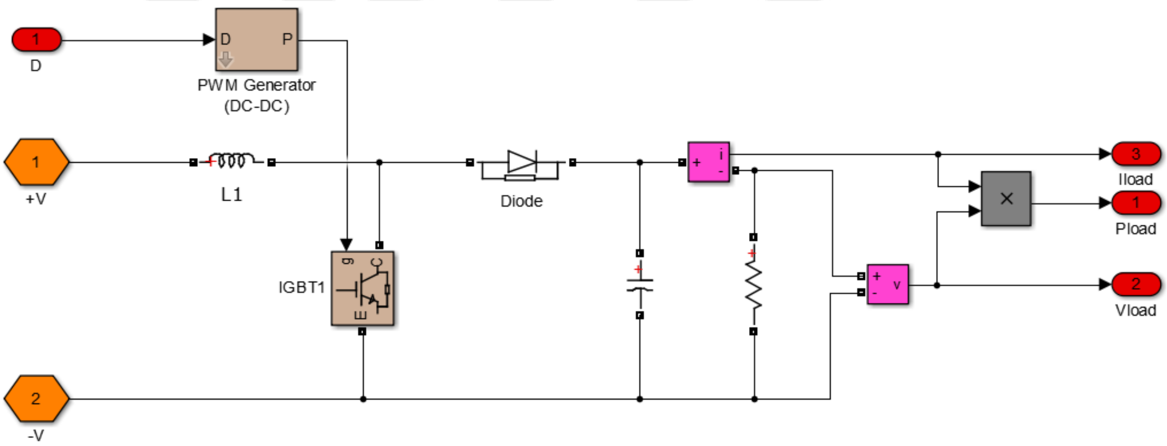


Figure 4.28. Simulink model of boost converter.

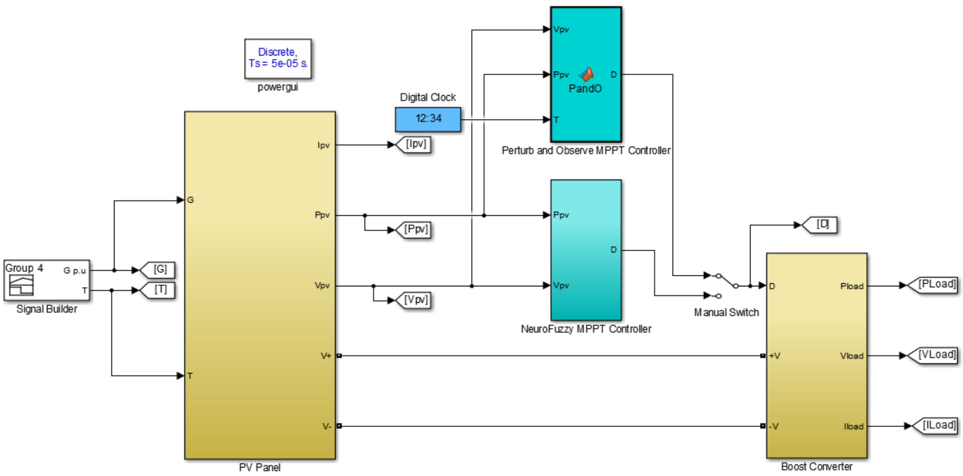
4.5. Results and Verification

The evaluation and analysis of obtained results from the project will be discussed in this chapter. In first phase, the verification of MPPT controller is explained. Verification of the system is important to produce an effective knowledge of proposed MPPT system in application projects.

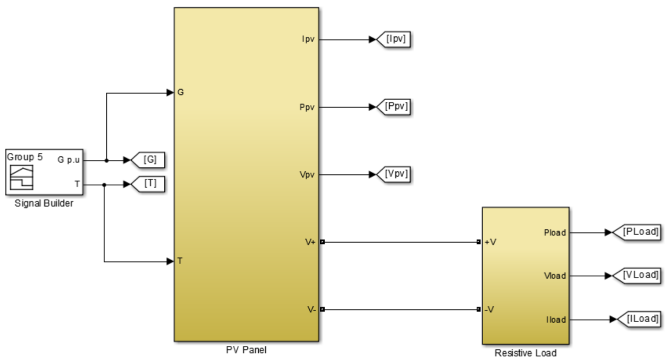
In the second section the variation in irradiance and temperature effects will be discussed. Firstly the system will simulated under constant irradiance and temperature, then the mentioned inputs will be varies according to weather. System response of selected inputs of irradiance and temperature and the PV outputs and corresponding boost converter outputs will be discussed.

4.5.1. Verification result of MPPT model

To verify the ANFIS model, a uniform radiance and temperature are chosen to verify whether it is producing the optimal duty cycle to the boost converter or not. To analyses the outputs, a pure resistive load of (60 Ω) has been connected to the PV panel in tow phase. The first one implemented using ANFIS controller producing duty cycle to PWM which in his place connected to boost converter. And direct coupling of same load without using MPPT controller. Figure 4.29 showing both mentioned models.



(a)



(b)

Figure 4.29. PV panel with resistive load (a) using MPPT (b) direct coupling.

In first case, the irradiance and temperature are constant at 1000W/m^2 and 25C^o. Using Neuro Fuzzy controller, the generated Power, Current and Voltage of PV panel is showing in figure 4.30, it clearly shows that the PV is running in the maximum power point voltage and current (29.8 V, 8.1 A) respectively which they present the power of the maximum power point (about 250 W). And these results matches the electrical performance of manufacturer datasheet.

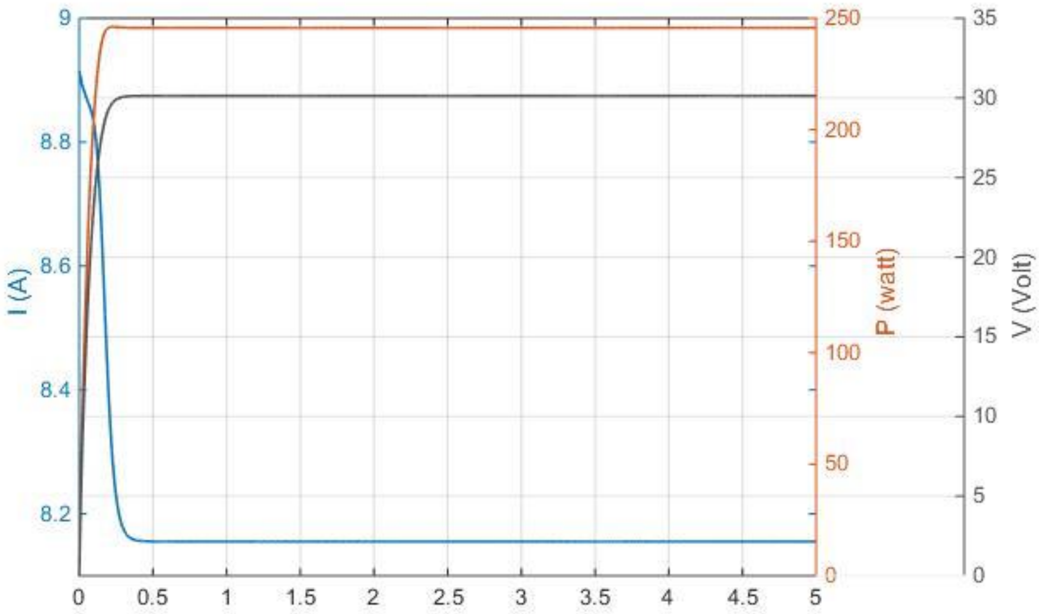


Figure 4.30. Outputs of PV panel using neuro fuzzy controller under constant irradiation and temperature.

While figure 4.31 shows simulated result of outputs generated from PV panel under constant resistive load of (60Ω) and with constant irradiance and temperature (1000W/m^2, 25C^o) using both MPPT controllers and by direct coupling the load without MPPT.

In figure 4.31(a and b) the results shows that the PV panel is running at maximum power point power and V_{mpp}, and boost converter raise the produced PV voltage to (121 V) using MPPT controllers, but it’s clear that Neuro Fuzzy controller has faster response time and lower rippling voltage, while in direct connected load the PV is running in its open circuit voltage and current.

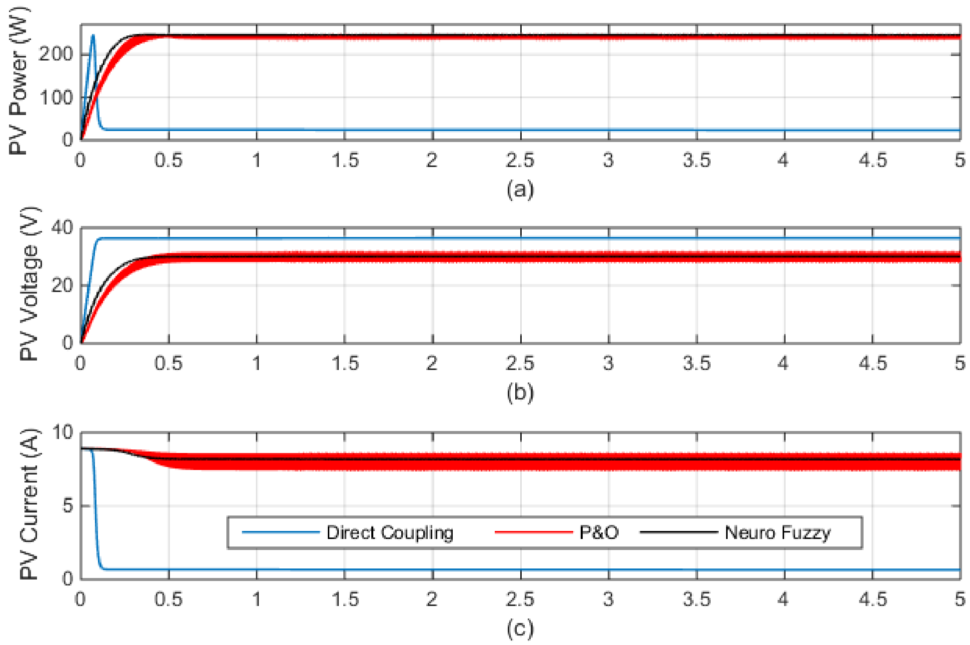


Figure 4.31. Simulation result power with and without MPPT under constant irradiance and temperature.

Similarly, as shown in figure 4.31(c) and by comparing the current of the load in both cases, MPPT controller forcing PV panel to run in maximum power point current and Perturb & Observation MPPT showing large rippling current comparing with another controller.

4.5.2. Simulation of MPPT system under changing parameters

4.5.2.1 Constant temperature and irradiance with variable resistive load

In the proposed MPPT system, the main inputs of the system are irradiance and temperature. In this section, as described in figure 4.32 constant irradiation and temperature with variable resistor are applied to the system.

Figure 4.33 shows the produced PV power and load voltage. It can be concluded that proposed controller can track the MPP in case fast change in the load happens. The PV current and voltage changes to track the maximum power point and produce the desired power.

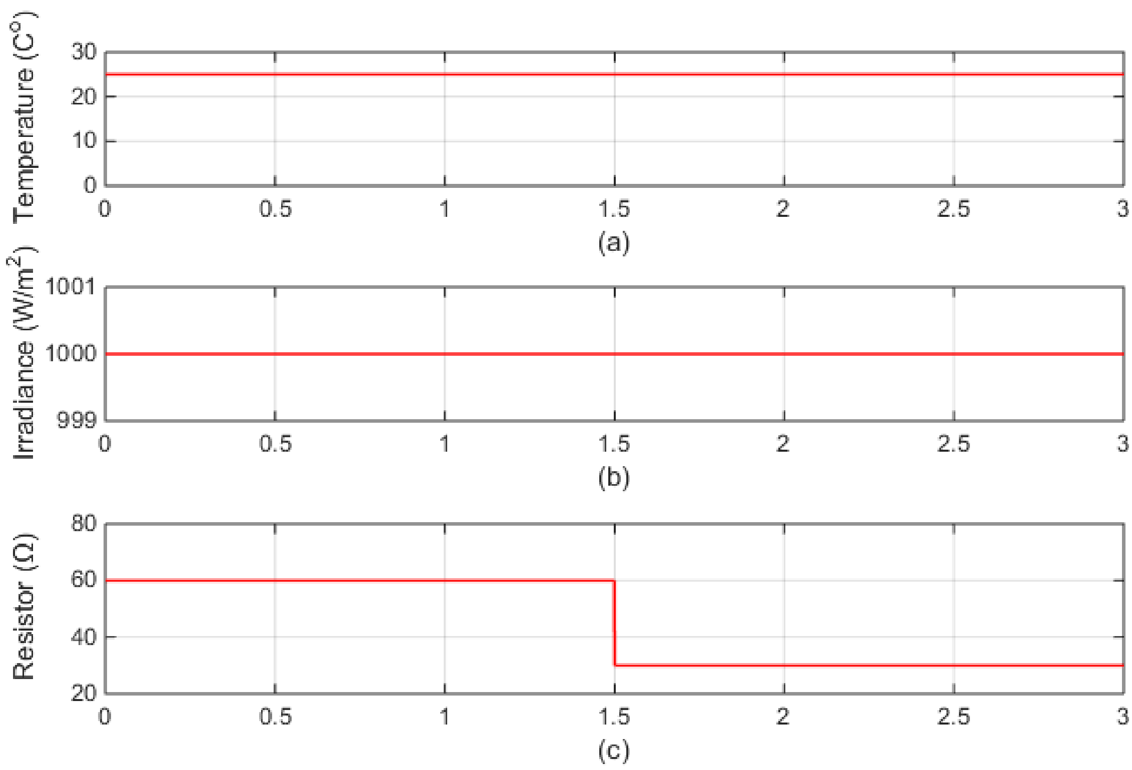


Figure 4.32. PV parameters (a) temperature, (b) irradiance, (c) load resistor.

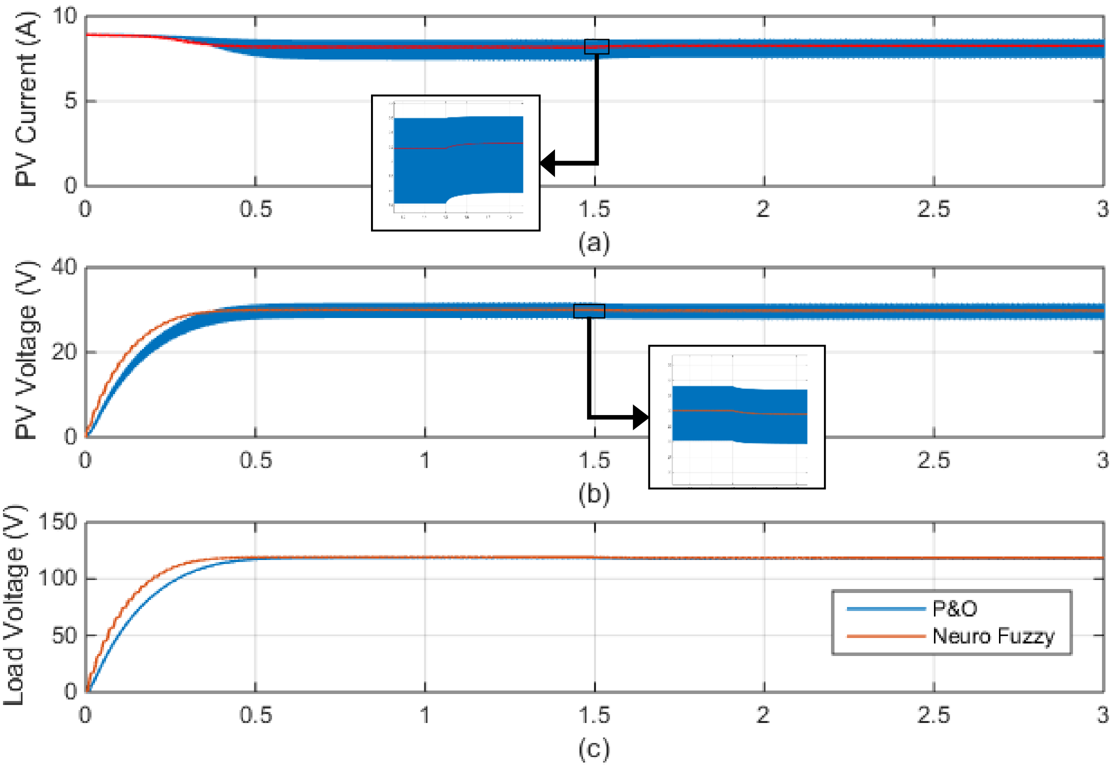


Figure 4.33. Simulation result and constant irradiation and temperature with fast change in load (a) PV power, (b) load voltage.

4.5.2.2. Constant temperature and resistor with variance irradiance

In this case, as shown in figure 4.34 various level of irradiation with constant temperature and resistive load has been applied to the system for further analysis.

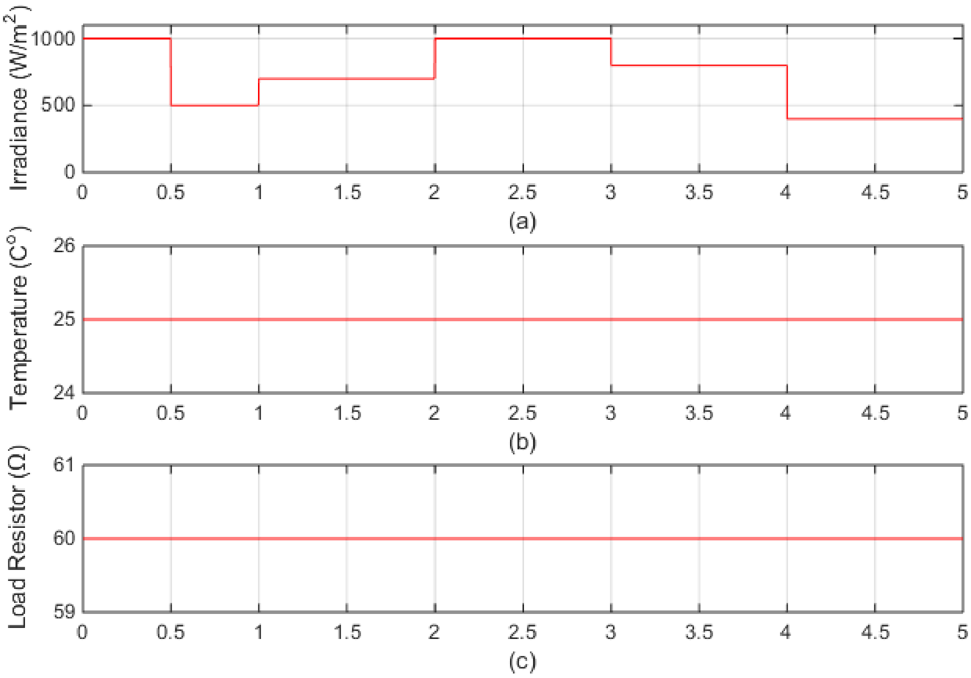


Figure 4.34. PV parameters (a) irradiance, (b) temperature, (c) load resistor.

The load voltage and corresponding PV current and voltage are explained in figure 4.35. By using the proposed system the extracted power is the maximum power of PV panel. P&O shows rippling voltage and current special in high irradiance levels.

From Figure 4.35 (b and c), the voltage varied over certain time because of the irradiance intensity changes. Based on the result from proposed two cases, it shows that the proposed model is able to maximize the load voltage under varies irradiance and constant temperature.

In this case, the currents are described in figure 4.36 (a). It clearly showed that PV panel running in maximum power point current continuously.

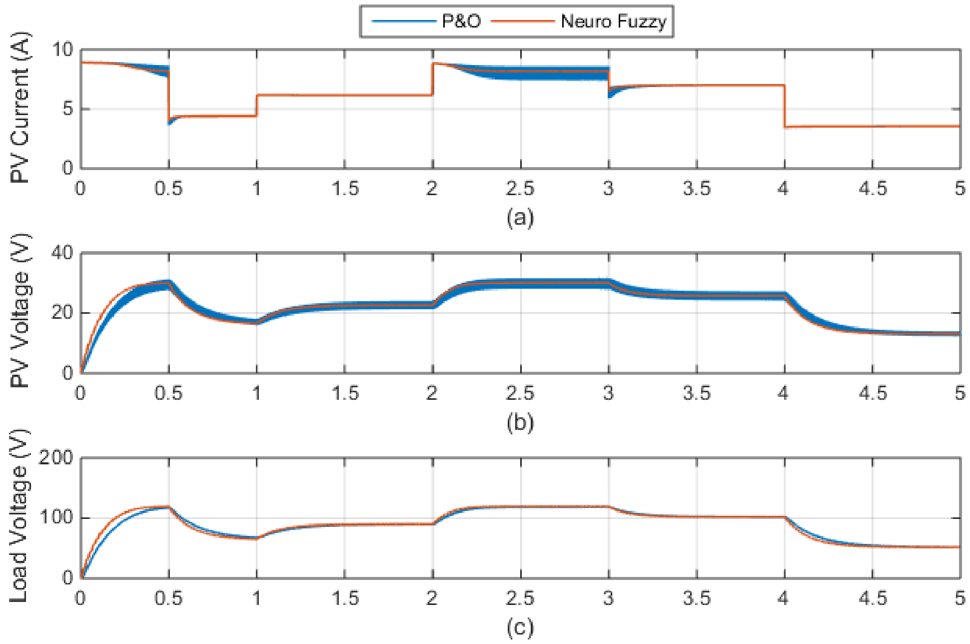


Figure 4.35. Simulation power results using MPPT under varies irradiance with constant temperature and resistive load (a) PV current (b) PV voltage (c) load voltage.

4.5.2.3. Variance irradiance and temperature with constant load

The simulation have been applied in extensive cases, the produced YL250P-29b PV panel model connected to resistive load directly and using proposed neuro fuzzy and P&O MPPT controllers for comparison. In this case the simulation implemented under varies irradiance and temperature with constant resistive as load. Figure 4.36 shows decreasing and increasing in irradiance and temperature in many case, the irradiance starting from 100 W/m^2 and increasing to 1400 W/m^2 in its maximum value, while the temperature is starting from 0 C^o and reaches over 100 C^o. this case represent many weather condition to analysis the MPPT controller response.

Figure 4.37 shows PV outputs under changing in temperature and irradiance with constant resistive load, it can be noticed that using proposed algorithm succeed to track maximum power point. Also it’s clear that the observed power under high irradiance and by using neuro fuzzy is up to five times higher from direct connecting the load.

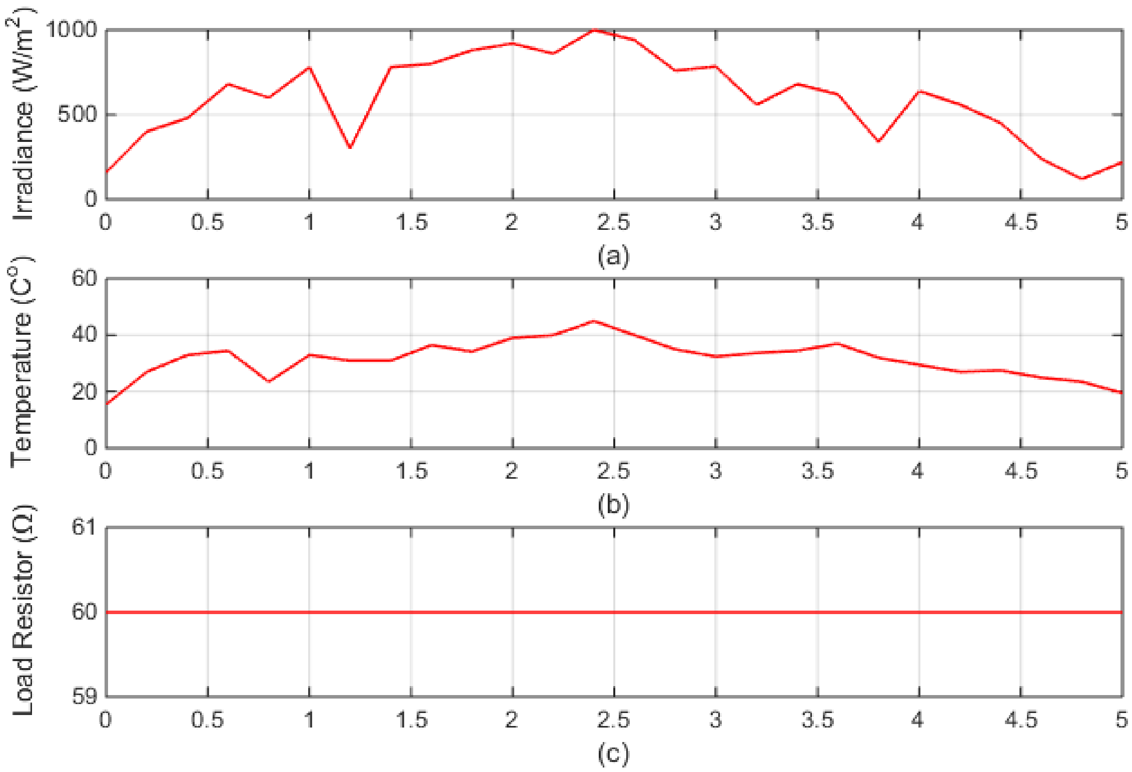


Figure 4.36. PV parameters (a) irradiance (b) temperature (c) load resistor.

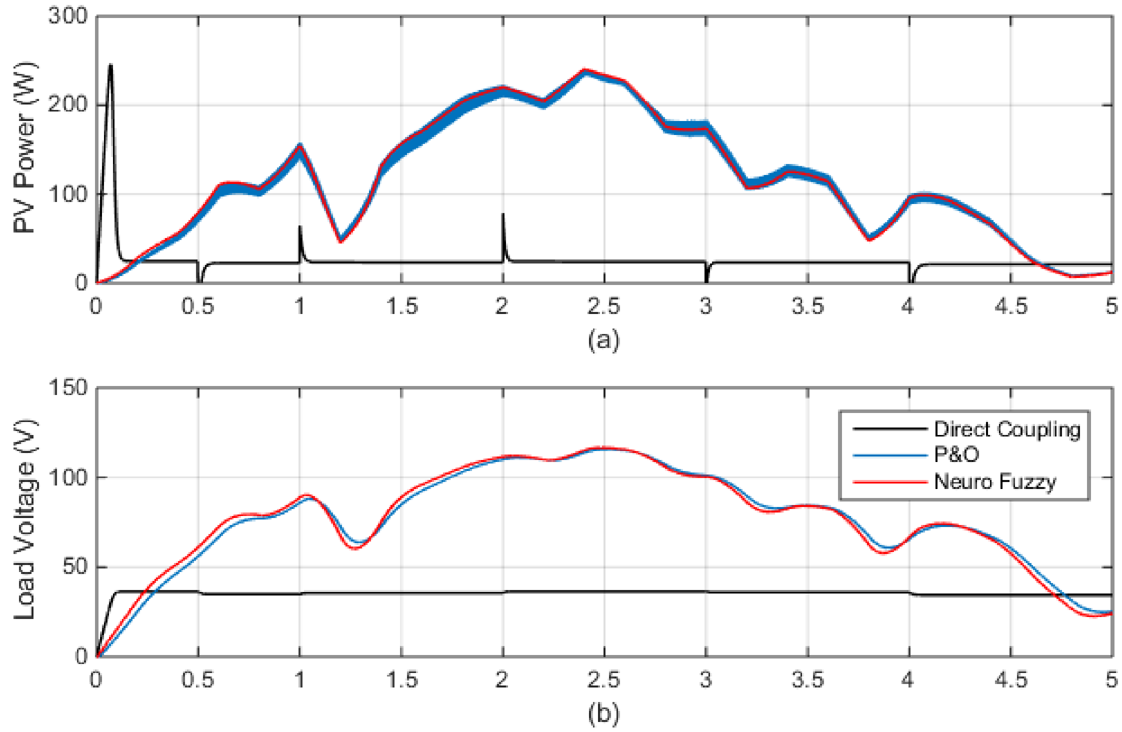


Figure 4.37. Outputs under various irradiance and temperature (a) PV power (b) load Voltage.

Figure 4.37 (b) shows the resistive load voltage, it can be observed that by using neuro fuzzy MPPT controller can track the desired power faster than P&O and it have difference in values depending on connecting method.

4.5.3. Neuro fuzzy controller parameters analysis

The MPPT controller parameters are studied during simulation under changing in irradiation and variation in temperature which represent various weather condition. By referring to the electrical characteristic of YGE Solar YL250P-29b, the maximum power produced is 250W under STC condition. The generated power have been discussed before, and it proved that the proposed controller delivered maximum power in several weather conditions.

In this section the inputs and output of MPPT controller are discussed, inputs of ANFIS are error ('e') and variation in error ('Δe'), figure 4.38 and 4.39 showing that mentioned inputs (time domain is simulation based) are isolating in required place to track the maximum power by producing desired duty cycle which is shown in figure 4.40.

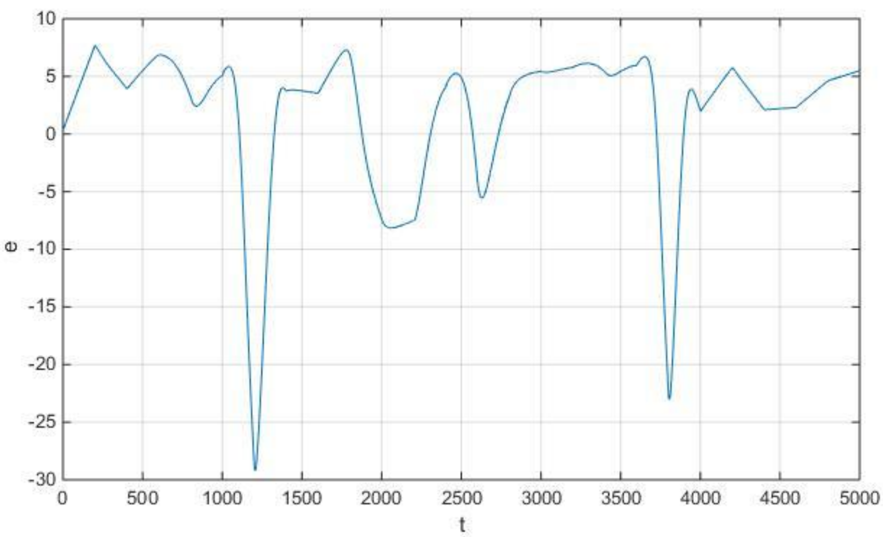


Figure 4.38. Input of MPPT controller 'e'.

The main function of duty cycle is to generate pulse width modulation (PWM) signal. Figure 4.41 showing part of PWM which will be fed to boost converter as a driving signal of MPPT system.

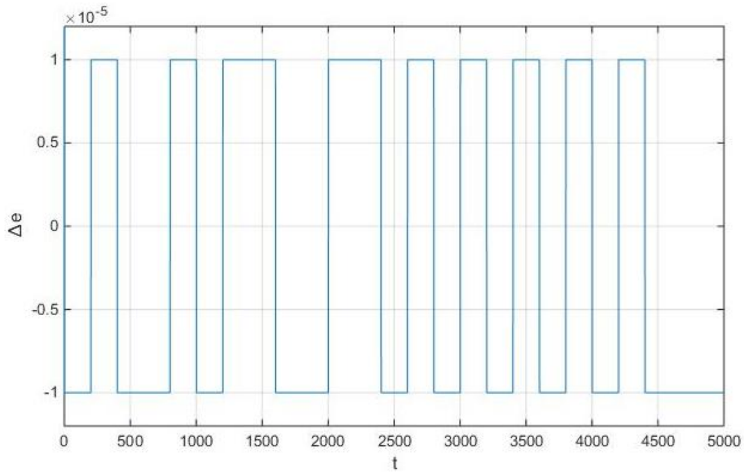


Figure 4.39. Input of MPPT controller ‘Δe’.

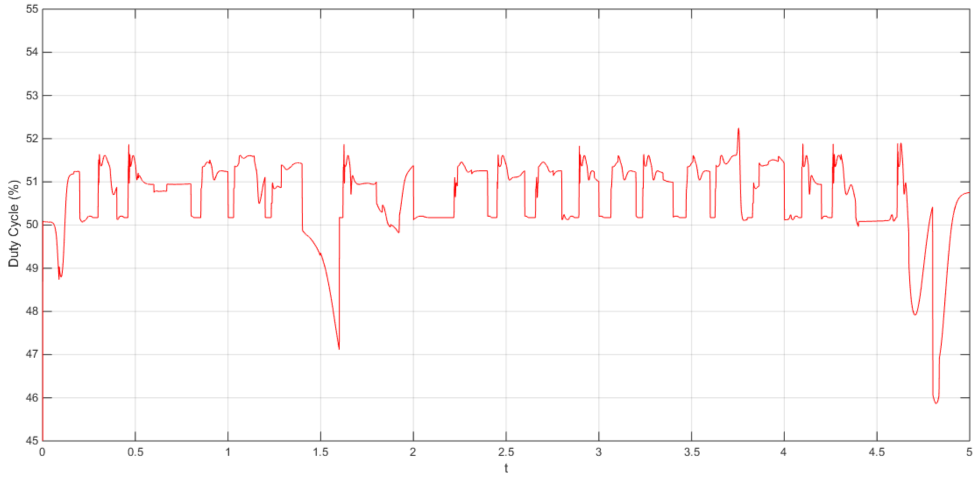


Figure 4.40. MPPT duty cycle output.

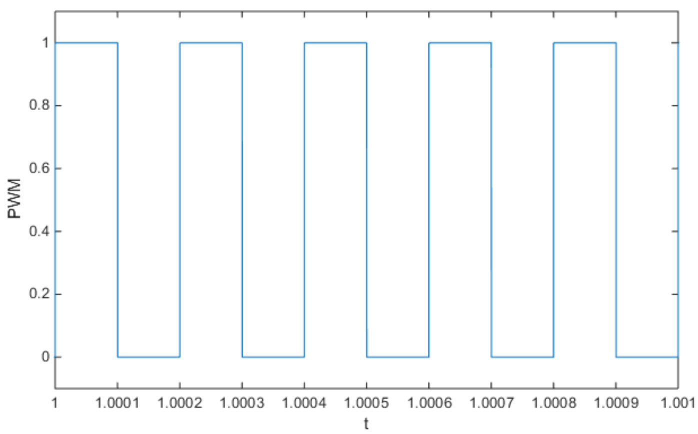


Figure 4.41. Boost PWM.

5. CONCLUSIONS

This thesis has given the PV module of YGE Solar YL250P-29b and the growth and evolution of MPPT controller of PV systems. MATLAB simulation framework has been used to measure and implement the performances of the controller. Depending on the MATLAB/Simulink simulation results, this work has successfully covered the scope and achieved the objectives.

The suggested algorithm for adapting FLC using NN has been implemented. The simulation outcomes demonstrate that the advantages of proposed system is that fuzzy parameter can adapt for fast reaction, and has fast transit response, not easily affected by the diversity in outside conflicts. Farther more the outputs of simulation demonstrate that MPPT controller by using ANFIS has produced a good power.

The simulation framework produced in this thesis gives the opportunity of investigation and assessment of a solar power MPPT system without needing any gadgets and hardware devices. It is particularly helpful in the early stage of enhancing a solar power controlling system such as the proposed algorithm. However, it can also be used for evaluating the act of other power converters and MPPT algorithms.

By operating the simulation several times and changing the inputs of the system to minimum required values, the outcomes demonstrate that the proposed model is able to maximize the output power under different temperature and irradiance.

For development of MPPT controller in future works there are much to be considered. In this work the Adaptive Neuro Fuzzy Inference system (ANFIS) is using Gaussian membership function, this membership functions can be changed to triangular and the number of them can be reduced from 5 to 3 with considering the acceptable value of error. In this thesis the suggested system have been implemented using MATLAB/Simulink, it can be model using hardware such as FPGA or DSP using mathematical equation of inference system.

In this thesis, Boost converter have been used as an interface to allow the controlling of tracking maximum power point. Future research may investigate another converter such as buck-boost, buck and cuk converter besides the suggested MPPT strategies to enhance elasticity in the selection and configuration of PV module.

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CURRICULUM VITAE

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APPENDICES

APPENDIX 1. Genişletilmiş Türkçe Özet (Extended Turkish Summary)

ÖZET

PV BESLEMELİ BOOST DÖNÜŞTÜRÜCÜ İÇİN NEURAL-FUZZY MPPT KONTROLCÜ TASARIMI

Hazırlayan :HAJI, Dilovan Muhsen
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Tez Danışmanı: Doç. Dr. Naci GENÇ
Aralık 2016, 69 sayfa

Geleneksel enerji santrallerinin neden olduğu fosil yakıt tüketimi ve çevre sorunları insanların son zamanlarda önemli bir sorunu haline geldi. Bu sorunun çözümü için günümüzde fotovoltaik paneller ve rüzgar enerjisi gibi yenilenebilir enerji kaynaklarının kullanımı yaygınlaşmıştır. Mekanik akasmalarının olmayışı fotovoltaik sistemlerin avantajı iken, yüksek imalat maliyeti ve düşük enerji dönüşüm verimliliği en büyük dezavantajlardır.

Sözü edilen dezavantajların üstesinden gelmek için, verimliliği artırmak ve maksimum üretilen gücü fotovoltaik sistemlerden çıkarmak için bir maksimum güç izleme noktası (MPPT) denetleyicisine ihtiyaç duyulmaktadır. Literatürde birkaç MPPT algoritması önerilmiştir. Bazı dezavantajlara bakılmaksızın, artan İletkenlik (IncCond) ve pertürb ve gözlem (P & O) MPPT algoritmaları, tasarım kolaylığı ve güneş ışınlama seviyesi ve sıcaklıktaki değişme gibi farklı koşullara göre MPPT özelliği sağlamaktadırlar.

Bu tez, YGE Solar YL250P-29b'nin PV modülünü ve MATLAB / Simulink simülasyon programını kullanarak Uyarlamalı Sinirsel Bulanık Çıkarım Sistemine (ANFIS) dayanan Maksimum Güç Noktası İzleme (MPPT) denetleyicisinin uygulanmasını önermektedir. Önerilen kontrol yöntemi iki giriş ve bir çıkışa sahiptir, girişler "e" hatası ve "Δe" hatasındaki değişimdir. Çıktı, darbe genişliği modülatörüne giren referans gerilimi (PWM) olup bir güç kademesi olan yğkselten (Boost) dönüştürücüye bağlanır. Simülasyon sonuçlarına bağlı olarak, önerilen sistemin, farklı çevresel koşullar altında maksimum güç noktasını başarıyla izleyebildiği gözlenmiştir.

Anahtar Kelimeler: ANFIS, Fotovoltaik, MPPT, Neuro Fuzzy, Yenilenebilir.

1. GİRİŞ

Fotovoltaik (PV) sistemler birçok alanda yaygın olarak kullanılmaktadır. Bununla birlikte, güneş enerjisinin öngörülemezliği, fotovoltaik (PV) sistemlerin daha az güvenilir olmasını sağlar.

Güç dönüştürme verimliliğini etkileyen üç temel operatör vardır; Hücre sıcaklığı, güneş radyasyonu ve güneş paneli. Hücrenin sıcaklığı ve güneş ışınlaması, ayarlanamayan bir değişkendir çünkü hava tarafından değiştirilebilir. Bu, maksimum gücün üretilmediğini gösterir.

Bu nedenle, bu çalışma, çıkış maksimum gücünü kontrol etmek ve maksimuma çıkarmak için bir Uyarlamalı Neuro Fuzzy Çıkarsama Sistemi (ANFIS) denetleyicisi geliştirmeyi öneriyor.

Bu tezin temel amacı, fotovoltaik sistemin MPPT denetleyicisini dayandıran Boost dönüştürücü geliştirmektir. Buna ek olarak, MATLAB / Simulink kullanılarak maksimum güç noktası izlemesi için bir Uyarlamalı Neuro Fuzzy Çıkarım Sistemi (ANFIS) algoritması simülasyonu tasarlamak.

2. MATERYAL VE YÖNTEM

Fotovoltaik sistem, güneş ışınlarını elektrik enerjisine verimli bir şekilde dönüştürmek için tasarlanmış bir sistemdir. Sistem PV panel gibi temel bileşenler ve maksimum güç üretmek için kullanılan diğer bileşenlerden oluşur. Bu tezde, PV modülü olan YL250P-29b güneş paneli kullanılmıştır. YL250P-29b, YGE Solar tarafından üretilir ve çok kutuplu güneş paneldir.

Fotovoltaik (PV) modüllerin çıkış gücü, hücre sıcaklığına ve güneş ışınlarına bağlıdır. Sıcaklık fotovoltaik (PV) modül çıkış voltajını etkilerken, güneş radyasyonu esas olarak fotovoltaik (PV) modül çıkış akımı etkiliyor. PV sisteminde, çalışma noktası I-V eğrisinin dizinde elde edilir. Verilen bir güneş radyasyonu ve sıcaklığı için, mevcut maksimum güçte PV çıkış gerilimi ve akımının ürünü genellikle Maksimum Güç Noktası (MPP) olarak bilinir.

Güneş enerjisi elektrik enerjisine dönüştürülürken yüksek dönüştürme verimliliği, fotovoltaik modül maksimum güç noktasında çalıştığı zaman elde edilir. Bununla birlikte, güneş radyasyonunun ve sıcaklığının belirsizliği nedeniyle, güç noktasını etkiler. Bu I-V eğrisine yol açar.

Çeşitli güneş radyasyonu ve sıcaklıklarla uğraşmak, MPP de değişir. Bu nedenle, geniş giriş aralığı (güneş radyasyonu ve sıcaklık) için MPP'yi çalışma noktası olarak dinamik olarak ayarlamak için Maksimum Güç Noktası İzleme (MPPT) tekniği gereklidir.

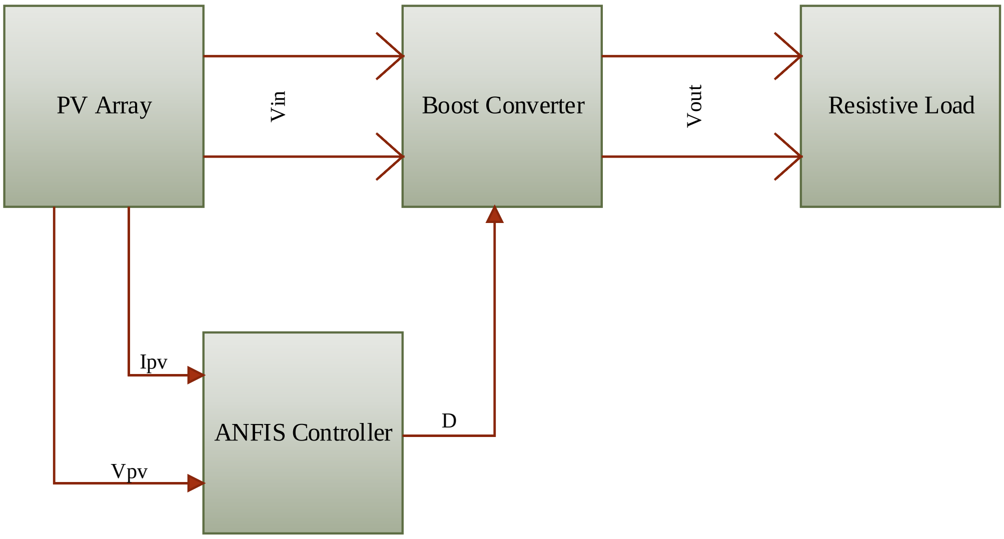
DC-DC dönüştürücüyü kontrol etmek için uygun bir izleme algoritması gereklidir. İzleme algoritması performansı, etkili bir izleme tepkisi için esastır. Temel olarak izleme algoritması, PV modülü voltajı ve akımı olan girdileri alır ve MPP'nin sistem çalışma noktasını oluşturan DC-DC dönüştürücü görev döngüleri ile birlikte çalışır.

Sıcaklık ve güneş radyasyonu dinamik değişkenler olduğu için, izleme algoritması hızlı ve doğru bir izleme için görev döngüsünü güncelleyerek gerçek zamanlı olarak çalışmalıdır. İzleme hızını ve doğruluğunu iyileştirmek için çeşitli algoritmalar vardır.

Bu çalışmada Boost dönüştürücü çalışma döngüsünü (D) kontrol etmek için Neuro fuzzy algoritma kullanılmıştır. MPPT sistemini modellemek için MATLAB / Simulink yazılımı kullanılacaktır.

3. UYGULAMA SONUÇLARI VE TARTIŞMA

MPPT, güneş enerjisi PV modülünden maksimum gücü çıkarmak için kullanılır. Bu projede, elde edilen ve elektriksel forma dönüştürülen güç dirençli yüke uyguluyor. Kullanılan yükseltici DC-DC dönüştürücü, yük ve PV modülü arasındaki bir arabirimdir. Bu tezde kullanılan maksimum güç noktası (MPPT) denetleyicisi, sıcaklık ve radyasyon değişiklikleri oluştuğunda eşleme eğrisinde yeni uyarlanmış maksimum güç noktasını izler. MPPT denetleyicisi, PWM modülasyon indeksini ayarlamak ve PV panelinden çıkarılan gücü maksimum noktasında tutmak için Boost dönüştürücü çalışma döngüsünü ayarlamak için kullanılır. Şekil 3.1 önerilen sistemin tüm yapısını göstermektedir.



Şekil 3.1. Sistemin genel yapısı.

Bu bölümde, MPPT sisteminin uygulanması izleme denetleyicisi ve uygulanan PV modülü aktarılmıştır. İlk aşamada, MATLAB / Simulink'te tasarlanan PV modülünün tasarımı, modellenmesi ve doğrulanması verilmektedir. Ardından izleme denetleyicisinin belirlenmesi ve doğrulaması açıklanmaktadır. Üçüncü aşamada, Boost dönüştürücütasarımı tartışılacaktır.

PV modülünün tek diyotlu modelinin temel matematiksel modellemesini kullanarak elde edilir. PV modülünün parametresi, YGE Solar YL250P-29b PV modülünün elektriksel özellik veri sayfasına bağlıdır. Bu elektriksel özellikler ve eşdeğerlikler MATLAB / Simulink'e uygulanır. Üretilen çıkışlar, YGE Solar tarafından sağlanan elektrik özelliklere göre doğrulanır.

Bu tezde, ANFIS kullanan MPPT, bir dizi girdi ve çıktı verisine ihtiyaç duymaktadır. Bu veri setleri sistem işletim sonuçlarından elde edilmiş ve eğitim verileri olarak adlandırılmıştır. Bu verileri toplamak için iki olası yol vardır. Birincisi, gerçek zamanlı sistemden veri setleri topluyor ve ikincisi, PV panel modülü için doğru bir model kullanarak simülasyondan ikinci yöntem seçildi.

Önerilen ANFIS'nin iki girişi ve bir çıkışı vardır, girişlar 'e' ve 'Δe', çıkşı ise görev çevrimi olarak da bilinen Boost dönüştürücü PWM'inin V_{ref}'idir ve bunun için 'D' sembolünü kullanacağız.

Boost, ortak bir güç katmanı topolojisidir, aynı zamanda bir yükseltme güç kademesi olarak da bilinir. Boost dönüştürücü, çıkış gerilimi giriş voltajından tersine çevrildiğinden ve bizim durumumuzda PV voltajı olan ve istenen V_{mpp}'ye ulaşan giriş voltajını maksimuma çıkarmak için seçildi.

Sonuçların değerlendirilmesi ve analizi projeden tartışılmaktadır. Birinci aşamada, MPPT denetleyicisinin doğrulanması açıklanmaktadır.

İkinci aşamada ışınım ve sıcaklık etkilerindeki değişim tartışılmaktadır. Öncelikle sistem, sabit ışıma ve sıcaklık altında simüle edildi, daha sonra ışınım ve sıcaklık hava durumuna göre değişir. Işınım şiddetinin ve sıcaklığın seçilen girişlerinin sistem tepkisi ve PV çıkışları ve buna karşılık gelen Boost dönüştürücü çıktıları iyi sonuçlar vermiştir.

4. SONUÇ

Bu tez, Solar YL250P-29b'nin PV modülünü ve fotovoltaik sistemin Maksimum Güç Noktası İzleme (MPPT) kontrolörünün büyümesini ve gelişimini vermiştir. Kontrolörün performanslarını ölçmek ve uygulamak için MATLAB simülasyon programı kullanılmıştır. MATLAB / Simulink simülasyon sonucuna bağlı olarak tez kapsamında geliştirilen MPPT algoritması ile başarılı sonuçlar elde edildiği gözlenmiştir.

Fuzzy logic kontrolü denetimini neural network kullanarak uyarlamada önerilen algoritma uygulanmıştır. Simülasyon sonuçları, bu sistemin avantajlarının, hızlı tepki için fuzzy parametrenin uyarlanması olduğunu ve dış etkileşimlerin çeşitliliğinden kolayca etkilenmeyen hızlı geçiş yanıtına sahip olduğunu göstermektedir. Ayrıca, simülasyonun sonucu, uyarlanabilir Neuro fuzzy çıkarım sistemini kullanarak bir MPPT denetleyicisinin iyi bir güç ürettiğini göstermektedir.

Simülasyonun birkaç kez çalıştırılması ve sistemin girişlerinin minimum gerekli değerlere getirilmesi sonucunda, önerilen model, farklı sıcaklık ve ışınım altında çıkış gücünü maksimuma çıkarmak edebildiğini göstermektedir.

APPENDIX 2. Originality Report

UNIVERSITY OF YUZUNCU YIL
THE ISTITUTE OF NATURAL AND APPLIED SCIENCES
THESIS ORIGINALITY REPORT

Date: 5/12/2016

Thesis Title: **Design of Neural Fuzzy MPPT Controller For PV Based Boost Converter**

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Science: Electric and Electronic Department

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Statute: M. Sc. ☐ Ph.D. ☐

APPROVAL OF SUPERVISOR	**APPROVAL OF THE INSTITUTE**
SUITABLE	SUITABLE
Assoc. Prof. Naci GENÇ	
(Title, Name-Surname, Signature)	(Title, Name-Surname, Signature)