PERFORMANCE ANALYSIS OF FIS AND ANFIS BASED MPPT FOR SOLAR PV SYSTEM WITH VARIOUS CONVERTERS TOPOLOGIES

DISSERTATION
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I, MOHAK JAIN, Roll No. 2K17/C&I/10 student of M.Tech (Control and Instrumentation), hereby declare that the thesis titled " PERFORMANCE ANALYSIS OF FIS AND ANFIS BASED MPPT WITH VARIOUS CONVERTERS TOPOLOGIES" which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associate ship, Fellowship or other similar title or recognition.

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CERTIFICATE

I, MOHAK JAIN, Roll No. 2K17/C&I/10 student of M. Tech. (CONTROL AND INSTRUMENTATION), hereby declare that the dissertation/project titled "PERFORMANCE ANALYSIS OF FIS AND ANFIS BASED MPPT WITH VARIOUS CONVERTERS TOPOLOGIES" under the supervision of PROF. BHARAT BHUSHAN of Electrical Engineering Department Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

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Date: MOHAK JAIN

ABSTRACT

As a result of increasing population and advancement in technologies the energy demand is also escalating rapidly, due to this exponential increase we cannot rely on non-renewable energy sources as one of our major energy source and some alternative is to be adopted to meet the energy demand of future generation, non- renewable energy sources and moreover solar energy is one of the reliable source of renewable energy and will be the major source of energy in coming years, but this option or source of energy is still not that much efficient and reliable and hence regular work and research is being performed to improve its performance. This project also works on then performance comparison and improvement of performance accordingly of the whole PV system, in this project two soft computing techniques has been implemented for tracking of maximum power point as it helps to extract the maximum power from panel and use it further.

Along with two MPPT techniques work in the field of converters is also accomplished as PV panel produce very less voltage hence a DC/DC converter is much needed to boost that voltage hence in this project four converters: boost, cuk, SEPIC, zeta has been implemented with the PV system and comparison has been made between then performance and characteristics of these four converters along with two MPPT techniques, beside this PV panel here used is also connected to grid to observe its performance with AC load.

All of the work in this project is completed through simulation work in software MATLAB/SIMULINK and results and waveforms have been recorded accordingly.

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LIST OF ABBREVIATIONS

ANFIS	Adaptive Neuro Fuzzy Inference System
FIS	Fuzzy Inference System
SEPIC	Single ended primary inductor converter
FLC	Fuzzy Logic Controller
MPPT	Maximum Power Point Tracking
MPP	Maximum Power Point
PV	Photovoltaic
BOS	Balance of System
ANN	Artificial Neural Networks
PWM	Pulse Width Modulation
STC	Standard Test Condition
NOCT	Normal Operating Cell Temperature

CHAPTER 1
INTRODUCTION

1.1 ENERGY

Before discussing about global energy production and consumption, it is necessary to have a look at the physics associated with energy. However most of the people are not new to the term energy, but only a small amount of this group praise the characteristics features or nature of energy. In everyday life words like work, power, fuel and energy are mostly used interchangeably and repeatedly. Basis of human life is formed with the help of energy only. There is hardly anything that is not associated with energy. In earlier times man used fire, muscle power and animal power. After that man came to know how energy can be generated or extracted from different sources and how to apply it in various applications. From the past few decade energy becomes the major part of technology and economics. After the men, money and machines the major factor of development is energy only. Energy is the main source to run machines; even electricity becomes the major part of our life and is our prime need. Hence, with the advancement in industrial revolution, requirement of energy also increases. This huge increase in use of energy has created a problem of supply and demand. If with this escalating demand of energy the use of fossil fuels is continued then in the coming years it will not be available for our future generation. That's why initiative should be taken by our current generation to conserve these resources or to switch to the use of renewable energy sources so that it will not create a problem for future generations. That's the reason a complete overview should be formulated that how to conserve the present natural resources and how to switch smartly to the use of renewable resource as the stock on non –renewable sources will end for future generation. In the process of survival and evolution of living beings energy plays an important role. It also helps in socio and economic development as well as welfare of human and country. For the countries the energy is termed as strategic commodity. The economy of country is deeply depends on the forms and nature of energy. Hence for the economic growth of the country and for the activities related to development of human energy security is the major concern energy. Some of the activities are providing employment, removal of poverty and completing the other goals of day to day life which can be completed by completing the energy demand which is increasing day by day with the development.

1.2 Classification of Energy Sources

In comparison to non-renewable energy sources like fossil fuels which are quickly being exhausted, renewable energy sources, that is sunlight and wind can be used again and again and can be recharged completely. Environmental change , and use of fossil fuels on large scale drive the world towards development and use of renewable energy sources. Sun is the major source of power in case of renewable energy sources for example if we consider wave energy then it is also indirectly dependent on sun only and in case of solar energy sun is the direct source of power. Once the earth absorbs the radiations emitted by the sun it spreads uniformly on the whole planet in the form of currents of oceans and wind. Also, solar energy leads to evaporation of water from the water bodies. This water at last falls as rain, which leads to creation of rivers which may be used to produce hydroelectric power. After all, solar energy helps in photosynthesis necessary for the plants that is used to produce biofuels. Currently, only about 18% of the total demand of energy is fulfilled by renewable energy sources. However, there is a great scope to uplift this share, it has been expected that potential of renewable energy resources is somewhat about more than 20 times the current energy demand around the globe. This survey is totally on the basis of usefulness and demands of the energy around the world and not taken into account the conditions or aspects of economics and budget. So a strong funding or financing is needed to develop and enhance the use of these renewable energy sources as they are actually the future of this globe. As we know to harness different forms of renewable energy sources we have to setup massive structures such as in case of hydroelectric power plants a dam is to be built similarly in case of solar energy a huge solar farm with large number of solar array is to be establish and same is the case for other forms so it is necessary that we should arrange a strong source of capital funding as these type of projects require huge investment when being setup on very large scale. As the non-renewable sources which are available are not that much efficient hence require a large scale setup to produce require amount of energy, so to meet this demand our setup should be large and to install such a big setup we need a huge amount of capital which can only be completed by a funding from any big firms or association which can fund these projects regularly so that In the upcoming times we should completely switch to use of renewable energy resources as it causes less pollution and help in substantial development of the environment, moreover it also help in the conservation of these resources.

Table 1.1 Renewable forms of energy resources

SOURCE	RENEWABLE RESOURCES	OUTPUT
Biological materials	Burns of animal waste and plant material	Heat energy and fuel
Hydro power	Water flowing through dams	Electric Energy
Wind energy	Collection of winds by turbines	Electric energy
Geothermal	Extracting steam, hot water from earth	Electricity and heat
Solar energy	Storing heat from sun	Electricity and heat
Hydrogen Fuels	Burning hydrogen gas	Motion power
Nanotechnology	Using unique property of material	Electric energy

1.3 Solar Radiation

Solar radiation is one of the vivid energy produced by the sun, majorly which is electromagnetic energy. If we look at the solar spectrum then most of the part lies in visible region, on the other hand the remaining half presents in infrared region and lastly very little or negligible part lies in ultraviolet area.. The suntan or sunburn occurred in living beings is due to the ultraviolet rays that are not absorbed or swallowed by the atmosphere. The period of time in which the ground surface is lightened by initial radiation due to sun that is the first ray of light that falls on the earth is termed as sunshine span. The period through which the registered sunlight based radiations exceeds a capacity quality of 122 W/m2 is represented as daylight span by the World Meteorological Organization. This much capacity is similar to the amount of radiations of sun that are present during initial daytime or for a little span of dusk when there are no clouds. Using a Campbell-Stokes daylight recorder we can record the real time sun irradiance just by looking at daylight span. Jordan daylight recorders and Campbell-Stokes daylight recorders are used to record the daylight span from a long time the advantage is that they have no any part in motion and does not require any electric force. The estimated precision of the photosensitized paper or recording paper used in these recorders is the major drawback in measuring daylight which is generally overlooked by the user, that’s why recording paper must be cleaned regularly after the time of dusk. A complete group of recorders use for recording photoelectric daylight has been generated for characterizing the daylight and is exploited as a part of spot of particular equipment. In addition a pyrheliometer is used to track daylight when the threshold limit of other instruments is reached during recording of characterized radiations of sun. It is very important to be knowledgeable about the amount of sunlight that falls on a particular area of the earth when we talk about the PV array system. Solar insolation and solar radiance are the two main systems which tell us about the radiations from then sun. The instantaneous power capacity whose unit is KW/m^2 is termed as solar radiance. The solar radiation keeps on changing, it varies from 0 KW/m^2 to peak value of 1 KW/m^2, this variation is generally seen from daytime to then evening. The climatic conditions as well as neighborhood area are one of the major factors on which solar radiation depends. The estimation of solar radiation is done through immediate data recording from round the world during daytime. Either a pyranometer is used for estimation if we are measuring worldwide radiation or one can use a pyrheliometer if we talk about measuring immediate radiation. This information has been gathered from overall built areas for more than 30 years by using these instruments. A daylight recorder is an alternative system for measuring sunlight radiation, the advantage of this recorder is that it is less faulty and requires less maintenance. The amount of hours is generally measured by this recorder for the daytime when daylight is above a particular level. By looking at the measured number of daylight hours which are dependent upon calculations and including some other compensation components the information is collected along these standards which can be used to effort the solar insolation. A major approach to detect solar insolation is using satellite pictures including information about shadiness. The figure 1.1 given below shows how the radiation has been absorbed by the earth surface

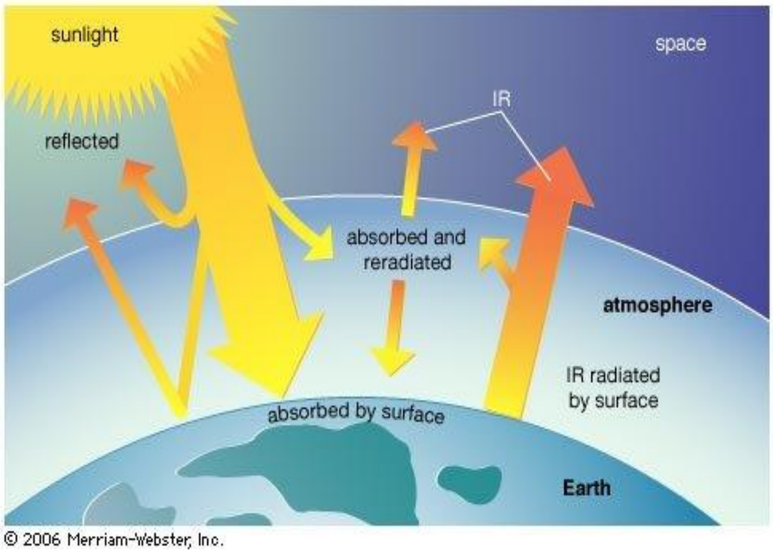

Figure-1.1 Concept of solar radiation

1.4 Solar Radiation Measurement

The electromagnetic energy is transmitted by everything present in this world, and the energy emitted by the sun are the sun based radiations. The energy which is radiated by this celestial body that is sun is spread over a wide range that is its extend from ultraviolet region to infrared region. In this spectrum, radiations from the sun that are present in the short wavelength (0.25–3.5 μm) region constitutes about 96 % of the total available energy. The mist concentration, atoms and water vapour which is present in atmosphere helps in reflection, scattering and retention of the sun's radiation as it passes through. The immediate sun powered radiation is termed as the first ray or immediate sun's radiation thet first arrive on planet.generally we measure sun's radiation in terms of irradiance but one more frequently used quantity is solar insolation. It is the total sum of sun energy at particular area throught a fix period of time or interval, it is measured in units of kwh/(m^2 day). While the units of solar insolation and sun powered irradiance are both a force thickness (for solar insolation the "hours" in the numerator are a period estimation as is the "day" in the denominator), solar insolation is truly unique in relation to the sun based irradiance as the solar insolation is the quick solar irradiance arrived at the midpoint of over a given time period. Solar insolation can also be expressed in units of MJ/m^2 for every year. For a given area the solar radiation can be represented in various ways:

1. Particular location's average data for the year.
2. Satellite data of solar insolation
3. data in hours of sunshine.

1.5 Motivation

Use of Renewable sources is increasing day by day, it is the source of energy of the future as the demand of energy is escalating rapidly fossil fuels and other non-renewable energy sources are not enough to meet the demands and needs of the world hence we have to start practicing and enhancing the use of non-conventional energy sources. Sun is one of the major source of energy and it is a important source of renewable energy but according to current technologies the energy produced by the sun which we termed as solar energy is not that efficient and reliable so we need to devise some technology which can help us to improve the prformance of the solar energy. A much amount of research has already been done in this field but thenalso there is vast area to research is still left. As PV system consists of many components such as converters, inverters, batteries, MPPT techniques and each system can be studied invidually hence there is much research content in this area and as practically it's actually will be the major energy source of future so to work on improving it's performance is essential.

1.6 Objective of Thesis

1. To provide a basic idea about solar PV array and associated components of the PV system such as converters and inverters or batteries.
2. To understand the equivalent circuit and mathematical equations of PV array and different converters used in PV system
3. To study about different types of algorithms use to track maximum power point and implementation of soft computing techniques that is Fuzzy Logic and Neuro-Fuzzy inference system (ANFIS) for MPP tracking.
4. Implementation of different converter configuration with grid connected PV array
5. Study of the voltage and current characterstics of different converters applied in PV system
6. Comparitive analysis of performance and relevant parameters of different converters with PV system and obtaining of conclusions accordingly.

1.7 Literature Review

Solar PV system is a very broad and very relevant topic. Many research papers have already been published in the field of MPPT algorithms such as comparison of classical MPPT approaches such as Perturb and Observe Technique and Increnmental conductance, or Fuzzy logic and neural network, some of the research has also be completed in suggesting the new algorithms for MPPT, also work has been done in the field of converters related to PV system and grid connected PV array. In paper[1] the study of battery charge controller used in standalone photovoltaic sytem has been done as it is a major component of standalone PV system. In [2] a soft computing technique that is adaptive neuro fuzzy inference system has been studied, in [3] also same soft computing technique ANFIS has been covered whereas [4] presents the application of ANFIS on the intelligent systems however [5] talks about the MPPT techniques when implemented on solar vehicle the complete simulation with analysis has been covered in this research work, now [6] covers the controlling of induction motor drives used in various types of applications, in [7] MPPT tracking using fuzzy logic controller when applied to a grid connected PV system has been discussed, however [8] works on the designing and proper selection of parameters of PV system dfor the production of electricity in malaysia, in [9] application of large number of PV modules for distribution of energy in urban areas has been covered whereas in [10] a complete case study on the renewable power of malyasia has been studied, in next [11] neural based MPPT for PV system connected with boost converter was studied, [12] covers the selection of proper sizing of PV system for electricity production, [13] presents the work or study of multilevel string inverters, whereas [14] talks about the life cycle of a solar thermal collector, [15] covers the complete study about then use of different inverters in grid connected PV system, [16] covers the study of grid connected PV system in spain. In [17] study of algorithms about current regulation has been accomplished, in [18] comparison between use of renewable sources in urrban and rural areas has been done, [19] dynamic performance of MPPT is analysed whereas [20] talks about the different MPPT algorithms for standalone PV system, study about genetic algorithm has been completed in [21] and [22] talks about the FLC modeled GUI for MPPT tracking, in [23] study is completed on photovoltaic simulator which is actually a programmable device, in [24] different MPPT techniques has been compared, besides this in [25] a photovoltaic model is simulated in MATLAB and has been analysed whereas in [26] study over multilevel inverter has been done using PWM, in [27] a new MPPT techniqe has been devised, [28] shows the analysis of inverter for solarpower generation for home, whereas [29] talks about FLC for MPPT optimized by genetic algorithm. In [30] complete modelling and simulation of photovoltaic system has been presented, in [31] study about different FACTS devices used in grid has been completed.[32] talks about the effect of applying of MPPT techniques on performance of PV array, in [33] charging of electric vehicles has been discussed, [34] presents the use of ANFIS in grid connected PV system, [35] also presents the work on different charge controller used in PV system. In [36] also research work related to ANFIS on fuzzy has been completed, [37] works on the concept of sun axis tracker used in PV system, a fuzzy logic approach has been used for this tracking control, now [38] shows the effect on performance of PV system when particle swarm optimization is used as one of the MPP tracking technique, in [39] presents the performance of PV module with incremental conductance as a MPPT technique, it is one of the classical technique used for MPP tracking, whereas [40] works on the effect of shading on PV system, it presents the performance analysis of system in partial shading conditions, [41] works on the battery charging methods used in standalone PV system, [42] present the use of ANFIS and PSO in photovoltaic system,[43] works on the use of neural network as one of the MPP tracking technique in PV, in [44] also ANFIS is used as MPP tracking technique for performance improvement of PV system, [45] works on the designing of boost converter used in solar PV system, on the other hand [46] sudy about photovoltaic emulator has been completed, even [47] agains presents the use of ANFIS as MPPT algorithm, [48] works on the MPPT techniques that are efficient with environmental changes also, whereas [49] talks about the challenges or barriers that we have to face during installation of solar PV plant, in [50] MPPT technique for hybrid system consisting of PV as well as wind mill has been discussed, [51] again talks about the incremental conductance as a MPPT technique, in [52] two MPPT techniques that is P&O an incremental conductance has been implemented along with the application of CUK converter, [53] again presents the use of neural network as a MPPT technique, in [54] economical consideration of power system when applied with a PV system is discussed, [55] comparitive study of different converters in PV with P&O as MPPT technique has been discussed, in [56] FLC based MPPT technique used in PV has been studied and lastly in [57] grey wolf optimization technique is proposed for MPP tracking in PV systems.

After reading this much literature it has been found that no comparitive study between FLC and ANFIS as the two MPPT techniques has been done till now moreover application of converters other than boost converter is not that much relevant in PV system however these other converters also can provide better results and performance when we talk about the case of PV system so in this project implementation of different converters in PV system with FLC and ANFIS as MPPT techniques has been completed.

CHAPTER 2

PHOTOVOLTAIC SYSTEM

2.1 BASICS OF PV SYSTEM

A photovoltaic system is generally made up of large number of photovoltaic solar cells. A single individual solar cell can generate power up to 1W or 2W which is roughly depends on the type of material used in manufacturing of solar cell. If the requirement of power is higher than large number of PV cells can be connected together to form a PV module. In the market the maximum power capacity of solar module which is available is about 1KW, although higher power models can be easily manufactured but it is generally not prefer as it is very bulky and this large amount of power is difficult to handle. Depending upon the power plant capacity or based on the power generation required several modules can be connected together to form a solar PV array. Solar PV systems are usually consists of large number of solar arrays, although the modules are from the same manufactures or from the same materials, the performance of module is totally characterized by the performance of the entire system that is efficiency and performance of individual components. Besides the solar PV module the system in additional consists of a battery charge controller, an inverter, MPPT controller and some other low voltage switchgear components. Presently in the market, power conditioning unit consists of charge controller, inverter and MPPT controller. A whole Balance-of-System (BoS) includes elements and components that convert the DC power generated by panel to AC power supplied to the grid. Generally BOS consists of all the components included in PV system except PV Module hence PV system is a PV module connected to the BOS. In addition to inverters, this includes the switches, enclosures, cables/wires, fuses, surge protectors, ground fault detectors etc. BOS can be applied to all types of solar applications (i.e., residential, commercial, public facilities, agricultural and solar parks). In most of the systems, the cost of BOS equipment may be equal to or even can exceed the cost of the PV modules. During evaluation of the costs of PV modules, these costs do not include the cost of BOS equipment. In a characteristic battery based solar PV system the actual cost of the modules is 20–30 % of the total while the remaining 70 % of the cost includes the balance of systems (BOS). Apart from the 50 % of the system BOS the cost or expense of the maintenance of the BOS is also very high. By maintenance and controlling of the BOS Component we can achieve higher efficiency and a good performance of a PV system. BOS components include the mainstream components, which make up approximately 10–50 % of solar expense and installation costs, and responsible for most of the maintenance requirements. That's why suitable incorporation of the BOS is important for the efficient functionality and the reliability of the solar PV system. However these things are rarely kept in mind and no focus is given on maintenance which is an important task. Costs are gradually decreasing with respect to solar panels and inverters. According to the statistics, the world market of Solar PV module is increasingly growing at the rate of 30 % per year. The reasons behind this rapid growth are that the reliable production of electricity without the consumption of fuels anywhere there is light and the flexibility of PV systems. Also the solar PV systems uses modular technology and the components of Solar PV can be synchronized for varying capacity, which ranges from watts to megawatts. In earlier times the large variation of solar PV applications found to be in industries but now it is being used for domestic needs as well as for commercial purposes. One of the major lagging factor is the efficiency of the solar PV cell, in the world market efficiency of a solar cell of about 18.3 % is currently obtained, which is totally depends on the current technology available. When we talk about the module efficiency, then it is slightly lower than the cell efficiency. This is majorly because of the blank spaces that are left between the arrays of solar cells during the manufacturing of the module. The overall efficiency of the system includes the efficiency and the performance of all the components in the system and also varies according to the solar installation. Here there is an another drop in figures in value when compared with the module efficiency, this is largely due to conductance losses, that occur in cables. When we talk about the case of inverter, it converts the DC output voltage from the Solar PV module to the AC grid voltage with some degree of efficiency. It actually depends on the conversion efficiency and the precision and readiness of the MPP tracking called tracking efficiency. MPP tracking having an efficiency of 98–99 % are available in today's market, each and every MPPT is based on a particular power tracking algorithm. Recent research states that all materials have physical limitations on the electricity which they can generate. For example, the maximum efficiency of crystalline silicon is only 28 %. But tandem cells provide a broader scope for development in coming years. Efficiency of cells that are used in laboratories in today scenario has already accomplished efficiency values of over 25 %.

PV Modules with BOS components known as an entire PV system. This system is usually appropriate to meet the desired energy requirements, such as powering a water pump, energy required by appliances and lights in a home, and electrical requirements of a society. In the cost of PV systems and in consumer acceptance, efficiency and reliability of PV arrays is always a critical factor. With the help of fault-protective circuit design, reliability can be improved using various laid off features in the circuit to control the effect of partial failure on overall module product and array power deficiency. Degradation of power can be controlled by separating the modules into a number of solar cells arranged in parallel configuration. This type of design can also improve the losses occurred in module due to breaking of cells. The hot-spots which formed in the Solar PV module can be controlled by connecting diodes across each cell and that is called a bypass diodes. Practically a solar PV module generally consists of one bypass diode for 18 cells to dismiss the effects of local hot-spots occur in cells.

2.2 Performance Measurements of PV module

The major performance measurement parameter of PV module is peak watt power (W_p). When power of PV module is measured in laboratory under Standard Test Condition (STC) then the maximum power which is obtained is the peak watt power (W_p).The power which is measured under STC is not practical that's why researchers used the other reference condition that is the normal operating cell temperature (NOCT). Both the methods are proposed to represents the solar PV module performance in realistic or practical operating conditions. The other way to measure the performance of PV module is to take in the account the whole day sun radiation and not just only the peak hour sunshine. It is basically based on factors like air mass, ambient temperature, and light level and also on the required application. Solar PV arrays can generate a fix amount of electricity under particular conditions. Following factors are considered to determine or evaluate the PV module performance: (i) identification and characterization of performance of solar PV module in terms of electricity (ii) factors that leads to degradation of PV array (iii) considerations of environmental condition such as ambient temperature or irradiance and (iv) Capability of PV panel to produce output. There are certain parameters on which performance of PV panel is determine, for the best use in any rooftop system or for generating electricity on very large scale. The output content of PV array is determined by following criteria.

1. Output Power: It is the power available at PV terminals or to the converter or charge controller. It is represented in watts and it is mainly the peak output power or average power.
2. Output Energy: amount of energy produced by PV panel in certain specific time is termed as output energy it is represented in Wh/m^2.
3. Efficiency: It is the ratio of output power that is power available at terminals to the power supplied by the sun or the input provided by the sun. It is also termed as power efficiency or conversion efficiency of PV array.

For best performance and consistency these parameters and quality of PV system should be checked and maintained properly and regularly

2.3 TYPES OF PV SYSTEM

Based on the requirement of electric energy, PV modules can be configured into arrays to increase electric power. Solar PV systems are generally classified based on their operational and functional characteristics and their component configurations. It can be classified into grid-connected and stand-alone systems.

2.3.1 Grid-Connected Solar PV System

For the generation of electricity on very large scale we have to connect the solar PV system directly to the grid. The major element of grid-connected PV systems is power conditioning unit (PCU). The PCU converts the DC voltage generated by the PV array into AC power as per the requirements of voltage and power of the utility grid. A bi-directional boundary is made between the PV system AC output circuits and the electric utility circuit, typically at a service entrance or on-site distribution panel. This make the AC power generated by the PV module to either supply on-site electrical equipment or feedback the grid when the PV system output is greater than the demand of the on-site load. This safety feature is required in all grid-connected PV systems, and ensures that the PV system will not able to operate and provide feed back into the utility grid when the grid is under maintenance or down during a failure. Figure 2.1 shows the schematic block diagram of the grid connected solar PV system. In grid-connected systems, switching of AC power from the reserve generator and the inverter to the service bus or the connected load is completed by external or internal automatic transfer switches. One of the major and mostly use components of a grid-connected PV system is net metering. Default service meters are odometer-type counting wheels that evaluate power consumption at a point of service with the help of a rotating disc, which is connected to the counting algorithm. The rotating discs of this meter functioned by an electro physical principle which is known as eddy current. However digital electric meters use the technology of digital electronics to record the power measurement along with solid-state current and voltage- sensing devices which converts values in analog form into binary form that are displayed on the meter using liquid crystal display (LCD). Inverters are the main different component between a grid-connected system and a stand- alone system. Inverters should have line frequency management capability to deliver the additional power to the connected grid. Net meters have a functionality to manipulate consumed or generated power in a varied summation format. The evaluated power registered is the net amount of power consumed minus the total power used minus the amount of power produced by the solar power cogeneration system. Net meters are transited and installed by companies that provide service for connection to the grid. Net metered solar PV power plants are governed by special contractual agreements and are funded by state and municipal governmental agencies.

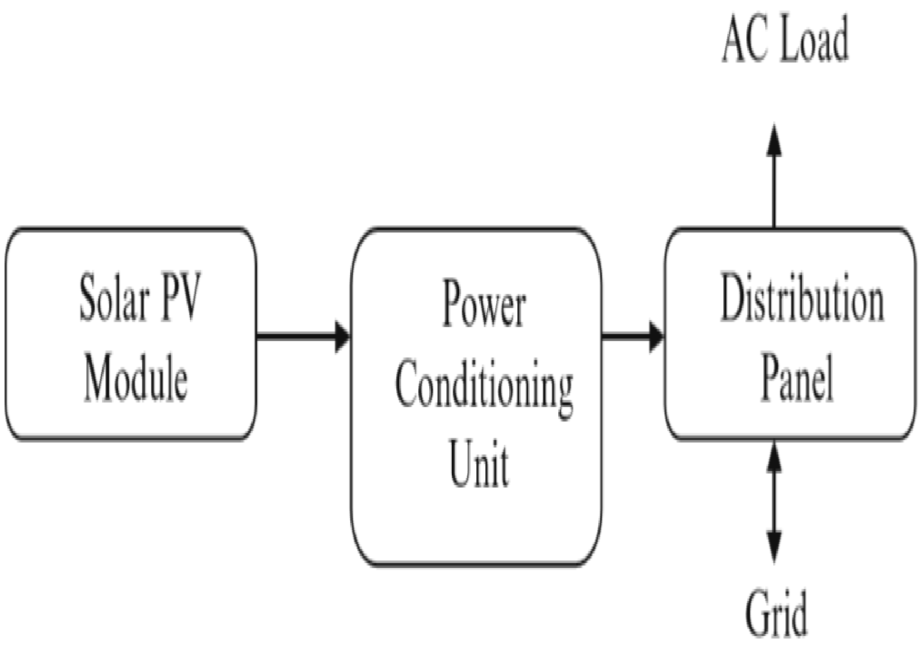

Figure 2.1-Grid connected solar PV system

2.3.2 Stand-Alone Solar PV System

Stand-alone PV systems or directly coupled PV module systems are designed and installed to supply power to DC and/or AC electrical equipment or loads. It is called direct coupled systems because; the DC generated output of a PV array is directly connected to a DC load. There is no provision of storage of electrical energy in case of direct-coupled systems and hence it supplies power to the load during sunlight hours only. The concept maximum power point tracker (MPPT) is used on the interface of array and load which helps in better utilization of the available array maximum power output and also helps in impedance matching of the electrical load to the maximum power output of the PV system. Figure 2.3 shows the schematic block diagram of the standalone solar PV system. For example direct coupled solar PV systems are widely used in agriculture applications, a solar PV array can be directly connected to run the pump. Configurations of module can be modulated according to the capacity of pump that is large number of modules can be connected in series or parallel. For such application to protect system from lightning surge a surge protector is provided between positive and negative terminals of the panel. Batteries are used for energy storage in many stand-alone PV systems. Figure 2.2 shows the block diagram of a complete stand-alone PV system providing power to both DC and AC loads with an option of power storage using battery. The solar PV array system with a DC load and with battery backup, is somewhat the same as the one without the option of battery storage except that some of the additional components required to provide charging and stability to the battery. A wide range of DC voltages can be obtained by connecting PV panel in series configuration, such as 12, 24, or 48 V. The function of charge controller is to regulate the current output and prevents the voltage level from to exceed from the mark of maximum value for charging the batteries. The output generated by the charge controller is connected to the battery bank with the help of a dual DC cutoff disconnect. Besides this in regards of safety measures a cutoff switch can be provided which can, disconnects the load and the PV arrays simultaneously. During the sunshine hours the battery connected to system gets charged as well as load is supplied with power. The controller will make sure that the DC power output from the PV arrays should be satisfactory to tolerate the connected load during the sizing of the batteries. Sizing of a battery depends on a number of factors, for instance the duration of an uninterrupted power supply to the load when there is almost no radiation from the sun. The battery bank when in operation produce power loss in the form of heat which is about 20–30 % of power, which also must be taken into consideration. During designing of a solar PV system with a battery backup, the designer must determine the proper location for the battery setup and keeps a check on ventilation of room.

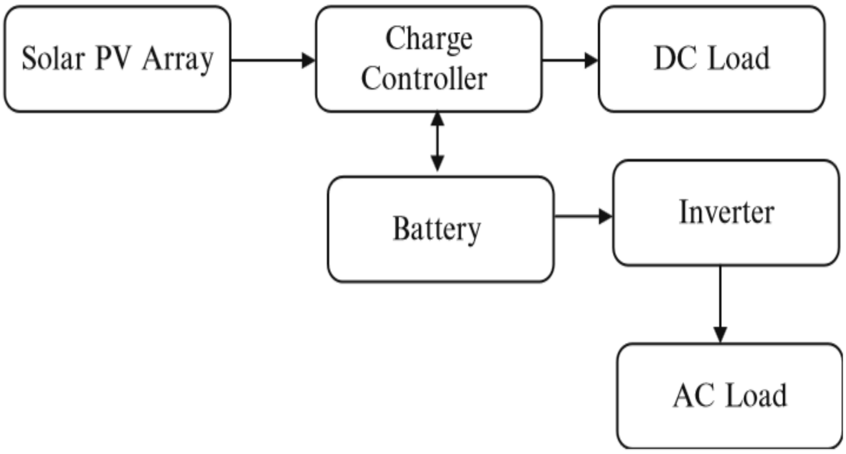

Figure 2.2-standalone PV system

2.3.3 Stand Alone Hybrid AC Solar System with Generator and Battery Backup

A stand-alone hybrid solar PV system is somewhat identical to the DC solar power system as shown in figure 2.3. In this inverters are used to convert the DC voltage supply to AC voltage supply. The output produce by this inverter is a square waves, which is then filtered and converted into sinusoidal AC waveforms. Any of the waveform, when analyzed, generally made up of the superimposition of large number of sinusoidal waveforms which is called as harmonics. The first harmonic indicates a pure sinusoidal waveform. Additional waveforms along with first harmonic with higher frequencies, when overlaid on the base waveform, add or subtract from the amplitude of the base sinusoidal waveform. The integration of fundamental waveform and waveforms of higher harmonics produce a distorted wave shape that look like a distorted sinusoidal wave. Converted DC output, generated from the PV array, is considered to be a large number superimposition of odd and even numbers of harmonics. To obtain a comparable clean sinusoidal output, most of the inverters are consist of electronic circuit which is capable of filtering out large harmonics. Filter circuits are specially designed with the help of inductor and capacitor circuits to block particular unwanted harmonics. In general, DC-to-AC inverters are complicated electronic power conversion equipment designed to convert direct current supply to a single or three-phase current supply that imitates the regular electrical services provided by utilities. Most of the inverters, in addition to PV module input power, accept auxiliary input power to form a standby generator, used to provide power when battery voltage is dropped to a minimum level. A special type of inverter, which is called as the grid-connected type, consists of synchronization circuitry that is capable of generating sinusoidal waveforms in harmony with the electrical service grid. When the inverter is connected to the electrical grid, it can efficiently act as an AC power generation source.

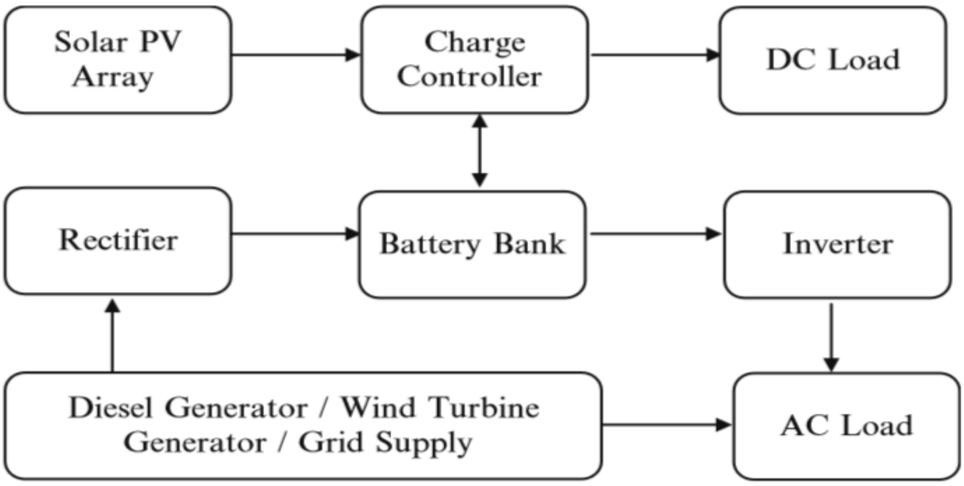

Figure 2.3-Photovoltaic Hybrid System

2.4 Model of Solar PV

Figure 2.4 shows the equivalent circuit of single solar cell consist of diode and resistances and a current source.

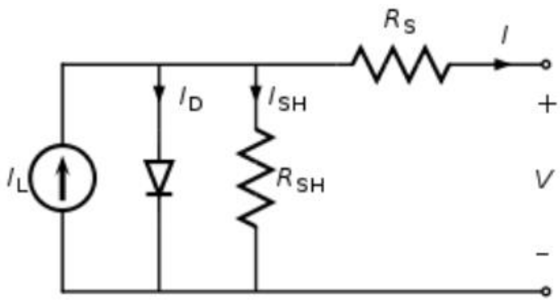

Figure 2.4 equivalent circuit of solar cell

The PV system configuration consists of a large number of solar photovoltaic cells, which are collectively known as PV modules, which can be connected in series or in parallel to achieve the required voltage output. The basic equation from the knowledge of semiconductors that mathematically describes the V-I characteristic of the ideal PV cell is

$$I = I_L - I_0 \left[exp\left(\frac{qv}{\alpha kT}\right) - 1 \right] \tag{2.1}$$

The basic equation (2.1) is for the ideal PV cell and does not valid for the representation of the I–V characteristic of a practical PV array. Cells when connected in parallel are capable of increasing the current and cells when connected in series can provide greater output voltages according to the requirements. Practical arrays are made up of large number of PV cells connected in series or parallel and the manipulation of the characteristics at the PV array terminal requires the integration of some additional parameters to the basic equation

$$I = I_L - I_0 \left[exp\left(\frac{V+R_S I}{V_t \alpha}\right) - 1\right] - \frac{V+R_S I}{R_p} \tag{2.2}$$

All PV array datasheets consists of the short-circuit current ($I_{sc,n}$), the voltage at the MPP (V_{mp}), nominal open-circuit voltage ($V_{oc,n}$), the nominal, the current at the MPP (I_{mp}), the short circuit current/temperature coefficient (K_I), the open-circuit voltage/temperature coefficient (K_v), , and the maximum experimental peak output power ($P_{max,e}$). This information of various parameters is always provided with reference to some standard value called as the nominal condition or standard test conditions (STC's) of temperature and solar irradiation. The practical PV module or an array has an additional series resistance R_s whose effect is major when the device operates in the voltage source region and also a parallel resistance R_{sh} with greater effect in the current source region of operation. The assumption $I_{sc} \approx I_{pv}$ is mostly used in the modeling of PV devices because in case of practical devices the resistance provided in series is low and there is a high value of parallel resistance. The saturation current of diode is given by

$$I_0 = \frac{I_{sc,n} + K_I \Delta_T}{exp\left(\frac{V_{oc,n} + K_V \Delta_T}{\alpha V_t}\right) - 1} \tag{2.3}$$

The saturation current I_0 is majorly dependent on the temperature so that the resultant effect of the temperature is that open-circuit voltage varies linearly according to the practical voltage or temperature coefficient. This equation simplifies the model and remove all types of error under the condition of open-circuit voltage, and subsequently, at other regions of the I–V curve.

$$I_L = \left(I_{L,n} + K_I \Delta_T\right) \frac{G}{G_n} \tag{2.4}$$

The relation between series resistance R_s and parallel resistance R_p, the two unknowns of (2.2) may be evaluated by making $P_{max,m}$=$P_{max,e}$ and solving the resulting equation for R_s, as show

$$P_{max,m} = V_{mp}\left\{I_{pv} - I_0\left[exp\left(\frac{q}{kT}\frac{V_{mp}+R_S I_{mp}}{\alpha N_s}\right) - 1\right] - \frac{V_{mp}+R_S I_{mp}}{R_P}\right\} = P_{max,e} \quad (2.5)$$

$$R_p = \frac{V_{mp}+I_{mp}R_S}{\left\{V_{mp}I_L - V_{mp}I_0 exp\left[\frac{(V_{mp}+I_{mp}R_S)}{N_S\alpha}\frac{q}{kT}\right] + V_{mp}I_0 - P_{max,e}\right\}} \quad (2.6)$$

Equation 2.6 shows that for any value of R_s there will be a value of R_p for sure that forces the numerical V-I curve to cross the practical (V_{mp},I_{mp}) point. The object is to find the value of R_s (and hence, R_p) which could makes the peak of the numerical P–V curve to coincide with the practical or we can say obtained experimentally peak power at the (V_{mp}, I_{mp}) point. This needed several iterations until $P_{max,m}$=$P_{max,e}$. Each iteration of the problem updates the value of R_s and R_p toward the best solution.

$$I_{pv,n} = \frac{R_p+R_s}{R_p} I_{sc,n} \quad (2.7)$$

The initial value of R_s can be zero. The initial value of R_p can be given as

$$R_{p,min} = \frac{V_{mp}}{I_{sc}-I_{mp}} - \frac{V_{oc,n}-V_{mp}}{I_{mp}} \quad (2.8)$$

Equation 2.8 evaluates the minimum value of R_p, which is actually the slope of the line segment between the short-circuit and the maximum-power significant points. Although R_p is still unknown, it is surely greater than $R_{p,min}$

2.4.1 Characteristics of solar cell

The I-V characteristics of solar cell are somewhat similar to diode characteristics, the difference is that normal diode dissipates energy and hence it's characteristics are plot in first quadrant whereas in case of solar cell diode act as a generating unit and hence it's characteristics are plotted in fourth quadrant. Photocurrent I_L is directly proportional to solar radiation intensity. Hence as the solar radiation intensity increases photocurrent increases and diode characteristics shift in fourth quadrant and we get somewhat this type of characteristics. Figure 2.5 shows the actual characteristics.

To obtain p-v characteristics curve simply take the product of current and voltage to obtain power and plot it against voltage.

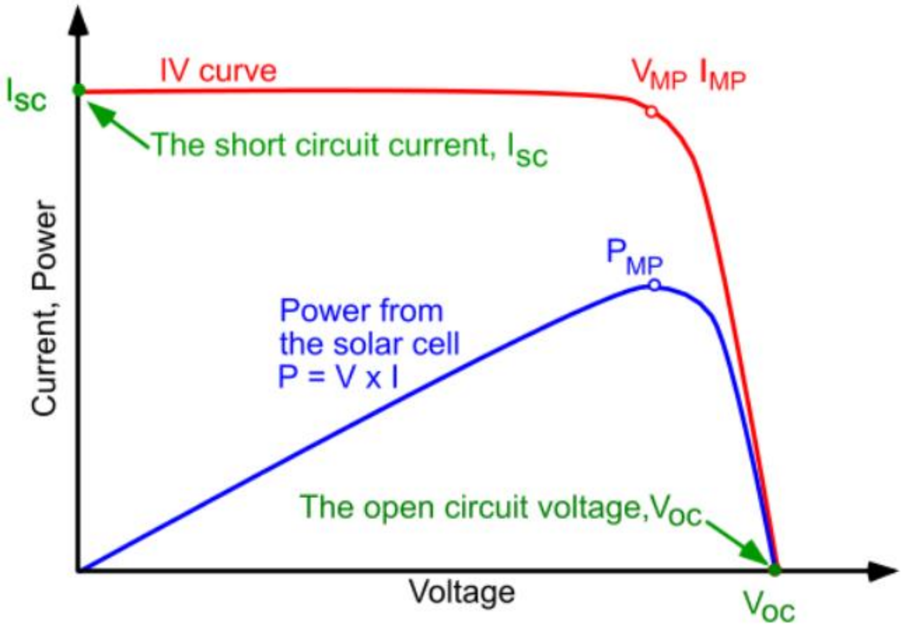

Figure 2.5 Characteristics of solar cell

Here I_{sc} is short circuit current, V_{oc} is open circuit voltage, $V_{mp,}$ I_{mp} are voltage and current at maximum power point respectively and P_{mp} is maximum power generated by solar cell

2.4.2 Maximum Power Point

Maximum Power Point Tracking, generally referred to as MPPT, drives solar PV array to operate in such a manner that maximum power which can be generated by PV module or array can be extracted fully to transfer it further. MPPT is not any mechanical device or mechanical technique to extract power but it works on control algorithm specially designed for a particular task. MPPT can be used along with with a mechanical tracking system, but both the systems act differently in case of power tracking. MPPT algorithms use the variation of irradiance and temperature to obtain or extract the maximum power from solar PV array. The voltage at which PV array can gives maximum power is called ‘maximum power point’ (or peak power voltage). Maximum power depends on solar radiation, ambient temperature and varies accordingly to the changes of these parameters. A characteristic PV module generates power having maximum power voltage of around 17 V measured when temperature of the cell is 25 degree Celsius, it can go down up to 15 V on a very hot day and it can also elevate to 18 V on a very cold day. The first and foremost principle of MPPT is to extract maximum power from the PV module by the application of suitable algorithm. MPPT Algorithm operates on the simple logic that, MPPT calculates the output of PV module, then compares it to voltage of battery then fix the optimum power which can be generated by PV module which helps in charging of battery and then converts it to the suitable voltage to obtain maximum current into battery. It can also use to supply power to a DC load, which is connected directly to the battery. MPPT is generally used to charge the deep discharged batteries mostly on cloudy days or time of faults

2.4.3 MPPT Techniques

From the day of discovery only many methods to find the MPP have been devised. These algorithms are different from each other in many aspects such as required sensors, range of effectiveness, complexity, convergence speed, cost, efficiency, reliable tracking when irradiation and/or temperature change, hardware required for the application or popularity, among others. Some of the MPPT techniques that are used frequently in these days are:

1. Fractional open circuit voltage
2. Perturb and Observe (hill climbing method)
3. Neural networks
4. Incremental Conductance method.
5. Fuzzy logic.
6. Fractional short circuit current
7. Ripple Correlation Control.
8. Current Sweep.
9. dP/dI or dP/dV Feedback control
10. Load current or load voltage maximization.
11. DC-link capacitor droop control.
12. Adaptive Neuro-Fuzzy Inference system based (ANFIS)

From all the above mentioned techniques, the first two techniques Perturb and Observe (P&O) method and the Incremental Conductance (Inc. Cond) algorithms are used frequently in PV array systems. Other techniques which are devised such as fractional open circuit voltage or short circuit current, neural network, fuzzy logic control, current sweep etc. Majority of these methods gives the local maximum power point and some, like short circuit current or the fractional open circuit voltage, give an approximated or adjusted MPP, rather than the actual value of output. In normal conditions the P-V curve consists of only one maximum. However, in the case of partial shading of PV array multiple maxima can occur on the P-V curve. Both P&O and Inc. Cond algorithms are work according to the "hill-climbing" approach, which involves the moving the operating point of the PV array in the direction in which the power increases. Hill-climbing algorithms are the mostly used MPPT methods due to their ease of implementation and efficient performance when the irradiation is constant. The advantages of both methods are its simple logic and can be computed easily as well as give correct results. Some of the drawbacks are: frequent oscillations which generally occur around the MPP and sometimes MPP is tracked in the wrong direction due to rapidly changing atmospheric conditions.

2.4.4 Applications of MPPT

Different MPPT algorithms discussed above will be applied for different applications. For example, in case of space satellites and space research centers or space stations that requires huge amount of money, the complexity and cost required for implementation of the MPP tracker is not that much important as its performance efficiency and reliability. The tracker should be designed in such a way so that it is able to continuously track the exact MPP in minimum time and should not require regular setting of data. In this case, hill climbing or Incremental Conductance, P&O and RCC are appropriate. Solar vehicles would mostly require fast convergence to the MPP. Neural Network, Fuzzy logic control, and RCC are some of the good techniques in this case. Since the load consist in solar vehicles includes batteries, voltage maximization, load current should also be considered. The object of PV array when implemented in residential areas is to minimize the feedback time and to implement it, it is important to constantly and quickly track the MPP. As effect of partial shading can be a problem in tracking of MPPT so it should be able to track multiple maximum power point Therefore, the current sweep and two-stage incremental conductance method should be uses in such cases. Since a residential system might also include an inverter, the OCC MPPT can also be used. Street lightning use PV array only need it for battery charging and hence no any other components included in that so it does not require very strict constraints or reliable performance and efficiency hence a simple and cost effective implementation can be used as MPPT algorithm such as fractional open circuit voltage and fractional short circuit current.

2.5 Inverter

Inverters are mainly used to convert DC supply into AC supply in field of electrical engineering in our case in PV systems. Various types of inverters generate a different nature of electricity. So, the consumer must compare the nature or quality of power required by certain loads with the characteristics of power generated by the inverter. Major differences comes into play when we talk about power generated by PV array and the power required by the utility grid. The main task of the inverter is to incorporate or integrate each component into a one system and to supply the maximum solar power to the utility grid with the efficiency as high as possible. The simple inverter circuit which can be incorporated in PV system is represented in figure 2.5.The power and voltage requirements helps to decide the nature or type of power electronic switch which is to be integrated in an inverter. The simplest control technique to obtain the inverter output is to obtain a square wave by operating the turn OFF and turn ON of the switches at desired frequency but square waves consists of too many harmonics. To reduce the amount of harmonics and to establish a load voltage control pulse width modulation technique of high frequency can be used. Harmonics are responsible for various types of losses such as copper loss due to overheating of motor present in loads, on the other hand overall operation of the PV system can be affected by the uneven magnetic fields generated due to presence of harmonics. Operation of display can also be disturbed by using sensitive electronic loads. These days, due to advancement in control strategies and due to application of different topologies the content of harmonic distortion is very less and we can achieve an AC supply with minimum disturbances by integrating more number of switches three phase inverter can also be devised. The efficiency of inverter is defined as the ratio of power that is supplied to utility grid to the power generated by PV array. Inverters that are used in PV system these days require some amount of power approximately 4% to 8% for conversion process and rest of the power is supplied to grid with this overall efficiency of the inverter is about 92-94%.The more innovative designs and research and inventions in this field can helps in increase in conversion efficiency of an inverter. As of now the inverters which are used in PV system are

1. Module integrated inverter
2. String inverters
3. Multi string inverter

4. Centralized inverters.

Inverters generally classified by the nature of waveforms they produce or the waveform that can be generated from it these are square wave inverter, modified square wave inverter, which is another name for quasi-square wave inverter, and a multilevel or sine wave inverter which can be obtained by the use of PWM of high frequency. The square wave inverters are generally not use due to poor quality of the wave they produce majorly in PV system we use multilevel inverter or a sine wave inverter. Circuit diagram of a simple single phase inverter is shown in Figure 2.6

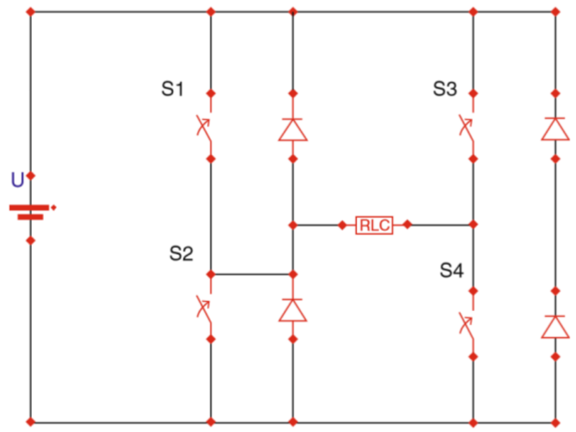

Figure 2.6 Single Phase inverter

A low frequency based inverter is termed as multilevel inverter and a high frequency inverter is called as sine wave. For high power applications multilevel inverter is the best option. Whereas sine wave inverter can be used for low and medium power loads according to the requirements. The advantages of high frequency inverters is its compact design and low cost, whereas in terms of efficiency and robustness low frequency inverters are the best. But more or less selection of inverter is done according to the application. In our case if we talk about stand-alone PV system then use of multilevel inverter is best option to have as it is reliable as well as efficient.

2.6 Batteries in PV System

In case of PV array system selection of suitable battery depends on numerous factors. The major factors of battery selection is totally depends on physical properties of the system while on the other hands some other factors that involves battery selection are linked with the characteristics properties of the system. Designers with their knowledge can easily differentiate between the types of batteries and with regular application they become familiar with the properties and gains of these. If we consider designing of battery then it includes proper arrangement of batteries in series or parallel, keeping the check on current value and also involves correct selection of types of wire use in the circuit. A single battery or a whole battery bank is generally used in PV system to store the energy according to the requirement. The main use of battery is in stand-alone type PV system as in this energy is first use to charge battery and then it is transferred to the load whereas battery is used as a backup device in case of grid connected PV system where power is directly fed to the grid. Some of the important functions of batteries in PV system are:

(a) It is basically used to store the generated electrical energy when it is obtained from the PV module which is used to supply energy to utility grids or other electrical loads as when needed or according to the requirements

(b) It helps in providing stability to the voltage and current during supplying of power to loads by removing or damping the transients in PV system or module

(c) It also leads to supply high peak or surge operating currents to the equipments used in electrical loads that are supplied by PV array

2.7 DC/DC Converters

A DC to DC converter takes the voltage from a DC source and converts the voltage of supply into another DC voltage level. They are used to increase or decrease the voltage level. The DC/DC converter is mostly used in portable DVD players, automobiles and portable chargers. As most of the equipments need certain range or level of voltage to operate as very high voltage can damage that device and very low voltage cannot make it to run so for such cases a converter is used as it can takes power from the PV panel and varied the voltage by stepping up or stepping down it to a certain level.

Different types of converter used with PV system in this project are

1. Boost Converter
2. SEPIC Converter
3. CUK converter
4. Zeta converter

The circuit diagram and calculations involved in the designing of each of the above converter is discussed in detail in the chapter 4 and their results are compared in the chapter 5 with detailed waveforms and parameters calculations.

CHAPTER 3
SOFT COMPUTING TECHNIQUES IN SOLAR PV

Traditional algorithms that are designed to solve various numerical problems gives good results with simple problems but in case of complicated situations such algorithms are not that much fruitful as well as reliable. Travelling salesman problem is one of the and hence some special algorithm or stochastic approach is needed to solve such type of uncertainty. The solution for this type of condition is application of soft computing techniques in such type of systems. Soft computing technique works by incorporating programming methodology that integrates the biological and physical nature of problem some of the soft computing algorithms are fuzzy logic, neural network etc.as there is nervous system in human body neural networks work on the framework of similar biological part. Likewise Darwinian evolution principles are used to obtain evolutionary computing. Genetic algorithm is one of the examples of this type of approach. Similarly, a fuzzy system involves use of human reasoning and fuzzy linguistic terms or imprecise data to solve such problems. These days in the field of modeling, designing, predicting, forecasting of sources and optimizing. Processes of renewable energy systems such as innovative and design models as well as environmentally directed processes are bit complex in structure as well as in computation on the other hand they are also non-linear in nature and involves various uncertainties so soft computing techniques plays a major role in solving such type of problems. When it comes about noise handling, data uncertainty or imprecision of data then soft computing techniques is the best solution as it can provide robust and cheap solution for such type of conditions. Due to this reason only the concepts and algorithms involved in this techniques are used frequently for the study of PV system or any renewable system. In this project we use two major soft computing techniques that are used to track MPP in the PV system and these techniques are Fuzzy logic and adaptive Neuro-fuzzy inference system (ANFIS).

3.1 MPPT using Fuzzy Logic

With the advancement in technology of microcontroller use of fuzzy logic controller as an algorithm for tracking MPP in PV system becomes popular The one of the major advantage of fuzzy system is, that it does not require exact mathematical model for handling non-linearities it can easily operate on general inputs. Fuzzy logic controller is generally composed of three independent processes which are: fuzzification, second is the rule base operation, and finally defuzzification as we have to convert fuzzy data again into crisp form. In whole fuzzification process, crisp or numerical data that is input variables are transformed into linguistic variables with the help of a membership function. Some of the linguistic variable used in this project are : NB (Negative Big), ZE (Zero) and PB (Positive Big). In Figures given below we can clearly observe the membership functions for two inputs and output. The inputs to a Fuzzy system used as MPPT are generally an error E and the second one is change in error CE. The value of error and change in error can be caluculated in many ways according to user. As dP/dV diminish at the maximum power point, the following approximation can be made.

$$E(n)=P(n)-P(n-1)/V(n)-V(n-1) \quad (3.1)$$

$$CE(n)=E(n)-E(n-1) \quad (3.2)$$

Once the value of E and CE are evaluated the rules can be applied to these linguistic variable according to the form stated in rule base the value of output which is usually a duty cycle that is provided to converter can be obtained. The inference system used in this case is mamdani. The selection of linguistic variables that are used to represent dD for the different combinations of E and CE is totally depends on the data collected or analysed by the user. In the final defuzzification process, the fuzzy controller output which is obtained from linguistic variable is converted again to numerical value or crisp data with the help of membership functions. The defuzzification process generates an analog function in the form of output which is given to the converter in the form of duty cycle to drive the system. MPPT implemented using fuzzy logic controller gives best results when operate under atmospheric conditions. But their overall efficiency depends majorly on the data of controller or engineer or the user by correct computation of error using the rule base.

3.2 Description and Design of FLC

Fuzzy framework helps in the development of base for the construction of fuzzy model. The block diagram shown in figure 3.1 shows the complete fuzzy logic controller. The fuzzy logic controller is broadly divided into four stages: the first and foremost is Fuzzification, then here comes the rule base, after that inference system is major part and finally the defuzzification. The inputs to the fuzzy logic controller are error (E) and change in error (CE) both obtained with the help of value of power and voltage as stated above

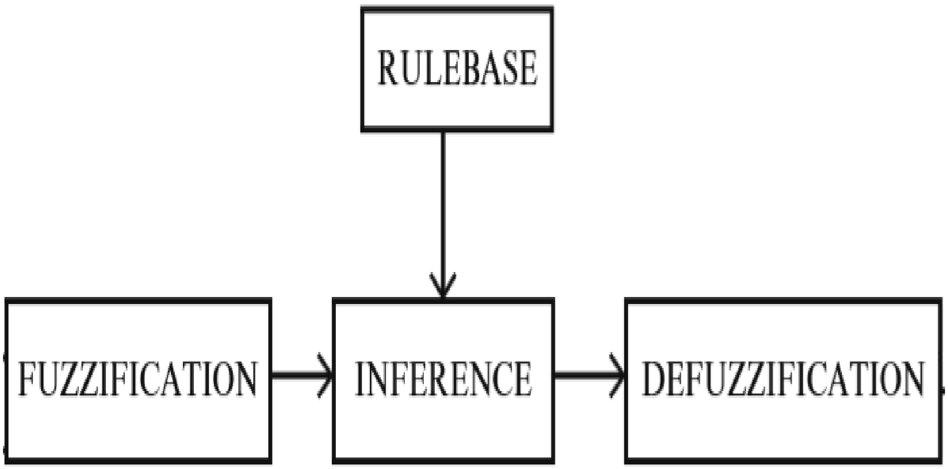

Figure 3.1 Block Diagram of FLC

The block shown in figure 3.2 is the fuzzy designer toolbox which helps in designing of membership functions and rule base for the fuzzy logic controller in MATLAB.

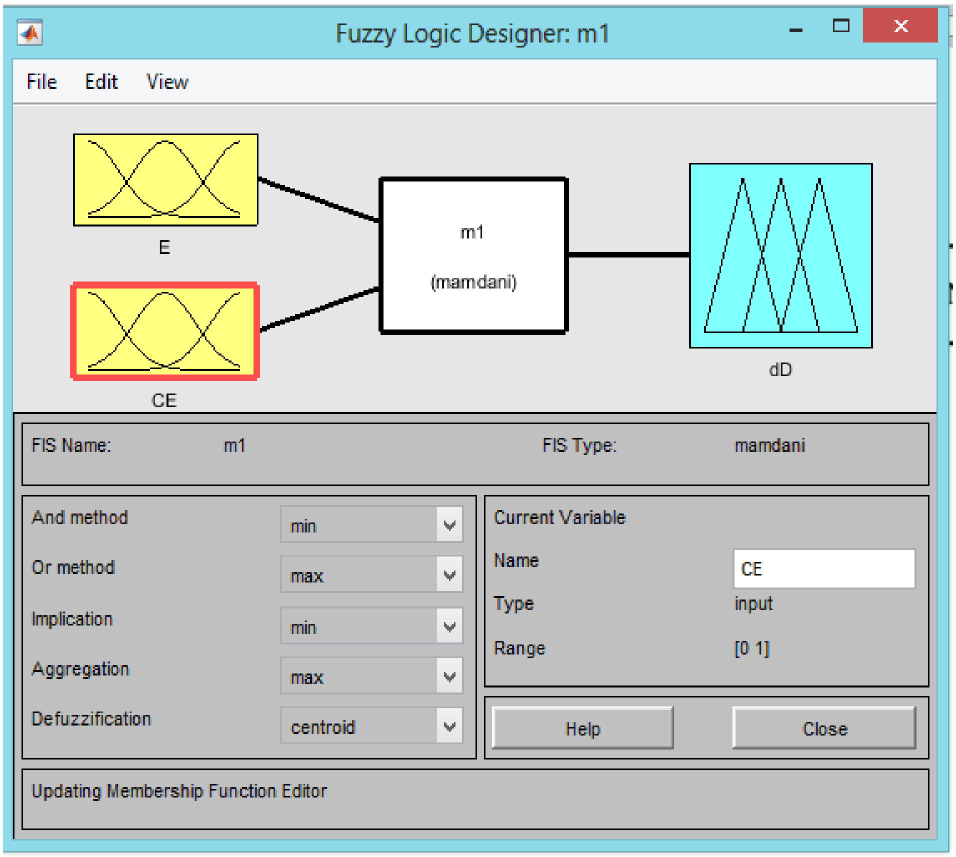

Figure 3.2 Fuzzy Logic ToolBox in MATLAB

3.2.1 Fuzzification

The fuzzy system is constructed on the basis of trial-and-error to meet the actual requirement. The universe of discourse for both inputs that is error (E) and change in error (CE) is divided into three triangular membership functions that is NB (negative big), ZE(zero) and PB (positive big). The two input membership functions are shown in figure 3.3 and figure 3.4 and output membership function is shown in figure 3.5. These are designed to model the unsymmetrical nature of the PV panel I-V curve. The membership functions are denser in center to provide greater sensitivity in their region near then MPP

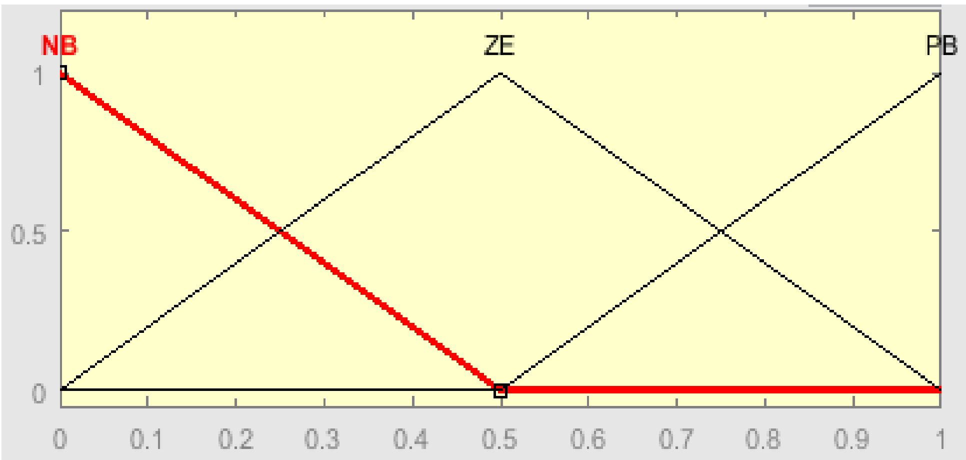

Figure 3.3 Membership functions for input variable (E)

The figure 3.3 and 3.4 shows the input membership function for the error and change in error, for this three linguistic variables are designed with the use of triangular membership functions and values are decided according to the trends in solar energy.

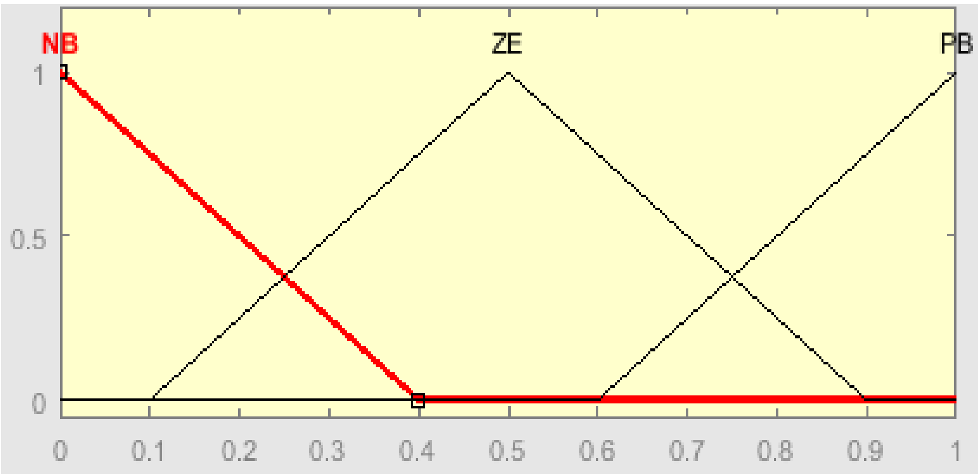

Figure 3.4 Membership function of input variable (CE)

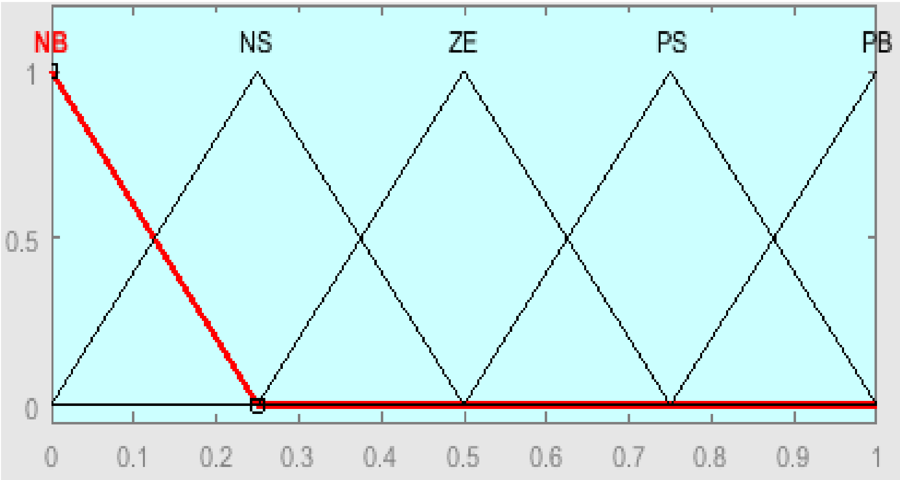

Figure 3.5 membership function of output variable (dD)

In the figure 3.5 membership functions of output variable are designed with the help of application of fuzzy rules on input membership functions.

3.2.2 Rule Base

On the basis of rule base only fuzzy algorithm tracks the maximum power. A rule base having 9 rules is shown below in figure 3.6

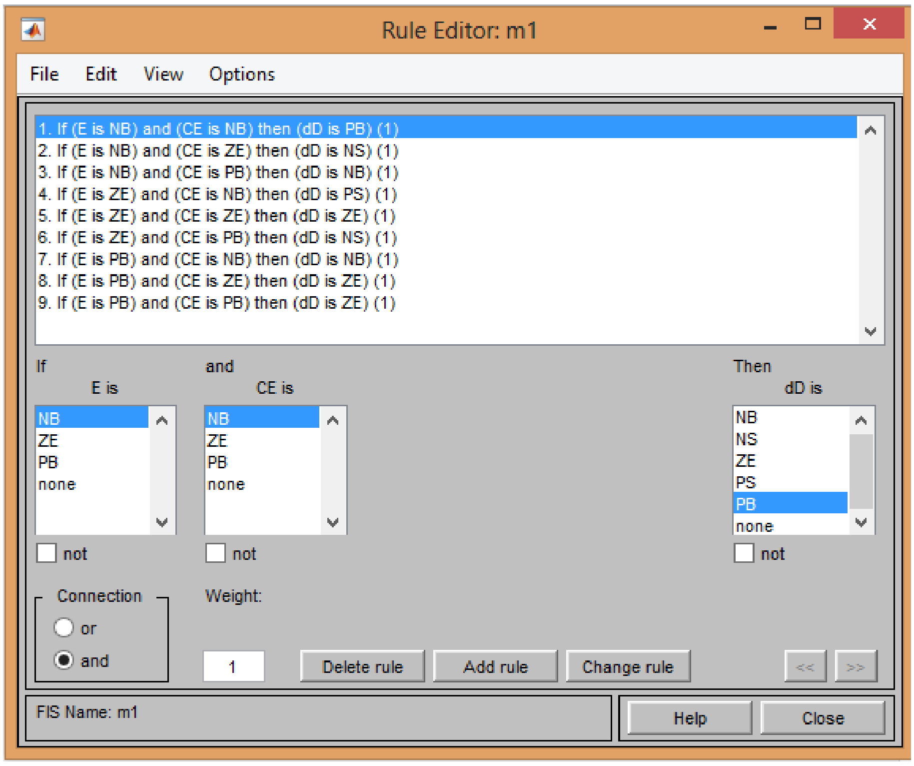

Figure 3.6 Rule base

This diagram shown in figure 3.7 is the surface view of fuzzy rules which are applied on input and output membership functions. It is a three dimensional plot in which two axis represents inputs and one axis represents the output of FLC.

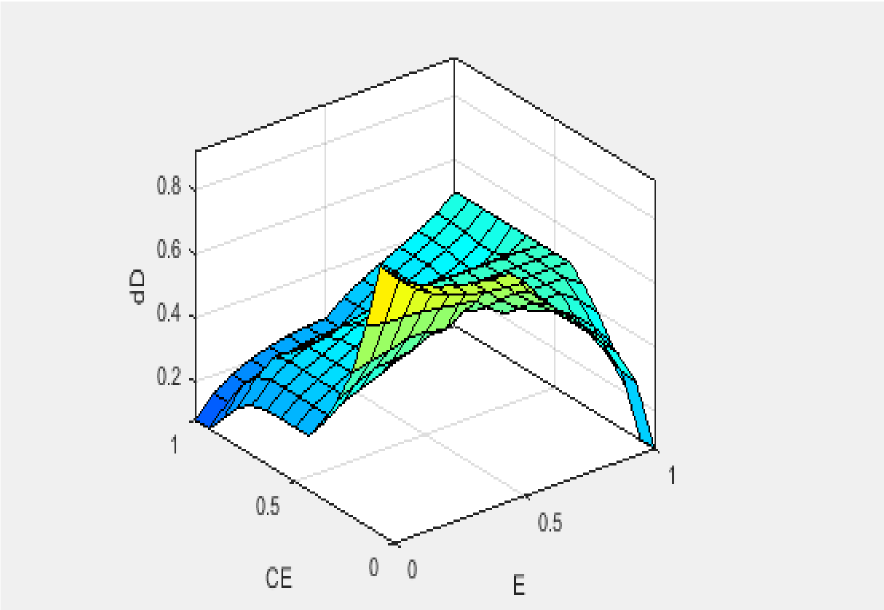

Figure 3.7 Surface viewer of rule base

The figure 3.8 is the representation of same rules in the rule view form which can be generated in MATLAB through fuzzy toolbox itself

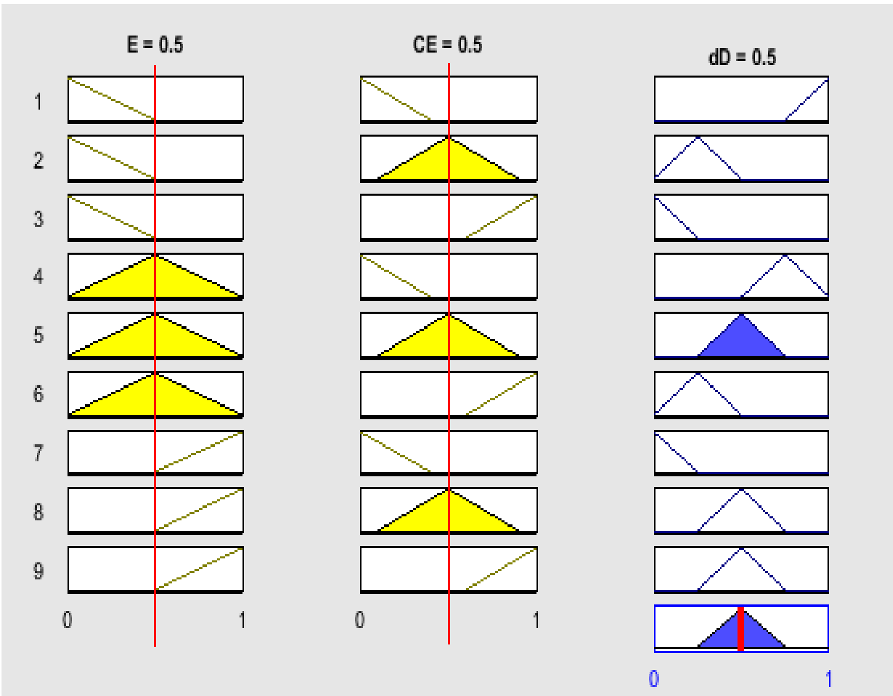

Figure 3.8 Rule viewer of rule base

3.2.3 Inference Method

The inference method decides the product of fuzzy logic. Mamdani's inference system is used within the framework with max-min creation strategy. This system is more efficient and proficient than other inference method and hence use for most of then control building provisions.

3.2.4 Defuzzification

The output of the fuzzy controller is a fuzzy variable itself hence to obtain a crisp quantity we need to defuzzify this variable. Generally centroid method of defuzzification is used for defuzzification

3.2.5 Simulation and Results

The simulation model shown in figure 3.9 is the controller model use to generate output duty cycle as shown in figure 3.10 which is furthur give to the converter as gate pulses.

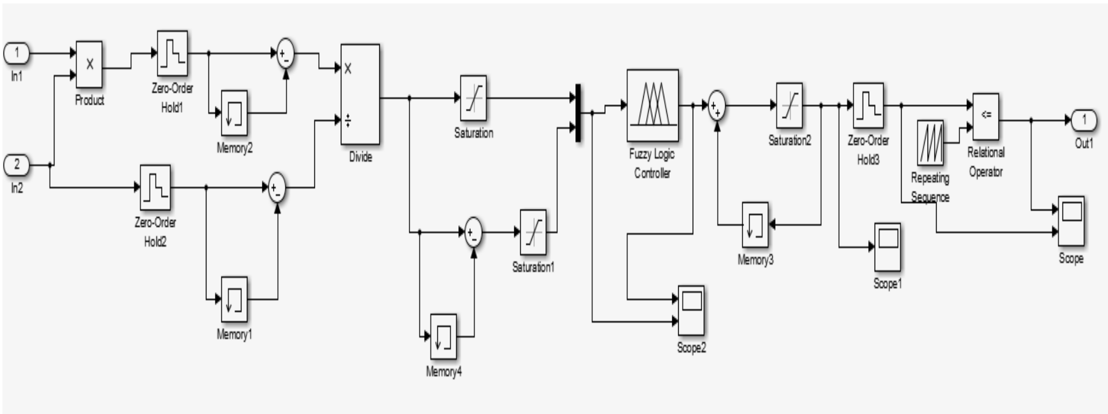

Figure 3.9 Simulation model of the controller used for MPP tracking

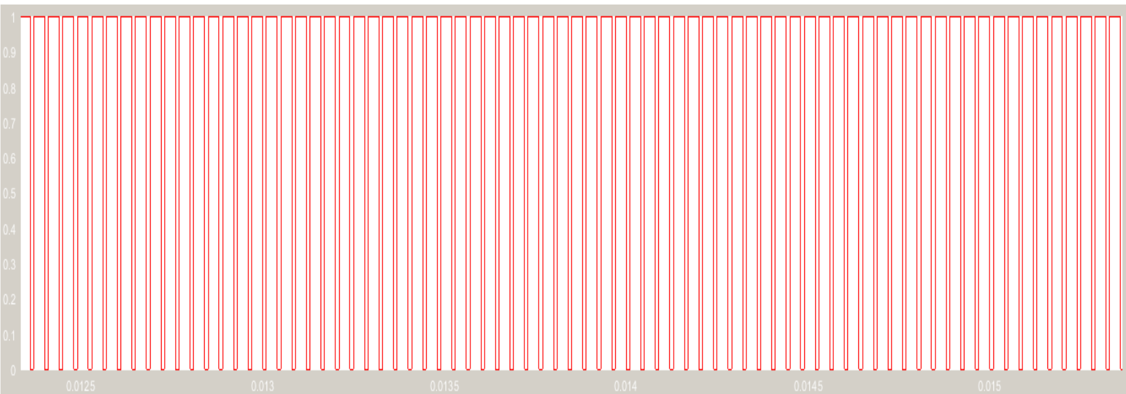

Figure 3.10 Duty cycle generated as output

3.3 MPPT using Adaptive Neuro Fuzzy system

Over the past few years there has been a great development in the field of information based on non-linear network. These complex and broad systems cannot be explained or made to work with only one of the controlling techniques hence we require some more efficient way to complete this. One of the algorithm to manage these complex issues is combination of two or more system to accomplish a pre define goal and to overcome the shortcomings of previous controlling methodology. Fuzzy logic is a good tool for displaying uncertainties and approximate reasoning, on the other hand neural network is the best machine in field of learning. Adaptive neuro fuzzy inference system combines the point of interests of fuzzy logic and neural network in one and produce enhanced fuzzy framework which is incorporated with learning mechanism of neural network and hence more efficient. For PV cells also we can create a cross breed system that joins fuzzy logic and neural network to detect the maximum power point.

The Fuzzy logic is basically used for its logicality and transparency whereas a Neuro-Fuzzy algorithm brings the concepts of ANN and FL together such that system has learning properties along with fuzzy based information. It joins transparency of fuzzy logic and provable learning and representation ability of the ANN weights. There are two methodologies to fuzzy neural structural planning which are alluded to as neuro-driven and fuzzy driven. The neuro-driven methodology offers power to the neural side of the depiction. Fuzzy math is utilized as a method for enhancing neuronal and/or whole system conduct. Then again, in the fuzzy driven methodology, neural systems are utilized as auxiliary apparatuses either to focus participation capacities, or to change the set of standards adaptively.

3.3.1 Algorithm for Neuro-Fuzzy based MPPT

Step1- Firstly we collect the data of error and change in error as calculated in the fuzzy logic controller and formulate in the form of table of three columns where first two columns represent the two inputs and third or last column represents the output.

Then this training data is loaded in MATLAB in Neuro-Fuzzy designer toolbox as shown in figure 3.11. Once the training data is loaded from workspace to Neuro-Fuzzy Designer Toolbox the plot between the training data entered by the user and respective output is generated on its own in the ANFIS toolbox.

This toolbox is present by default in MATLAB and used to implement ANFIS.

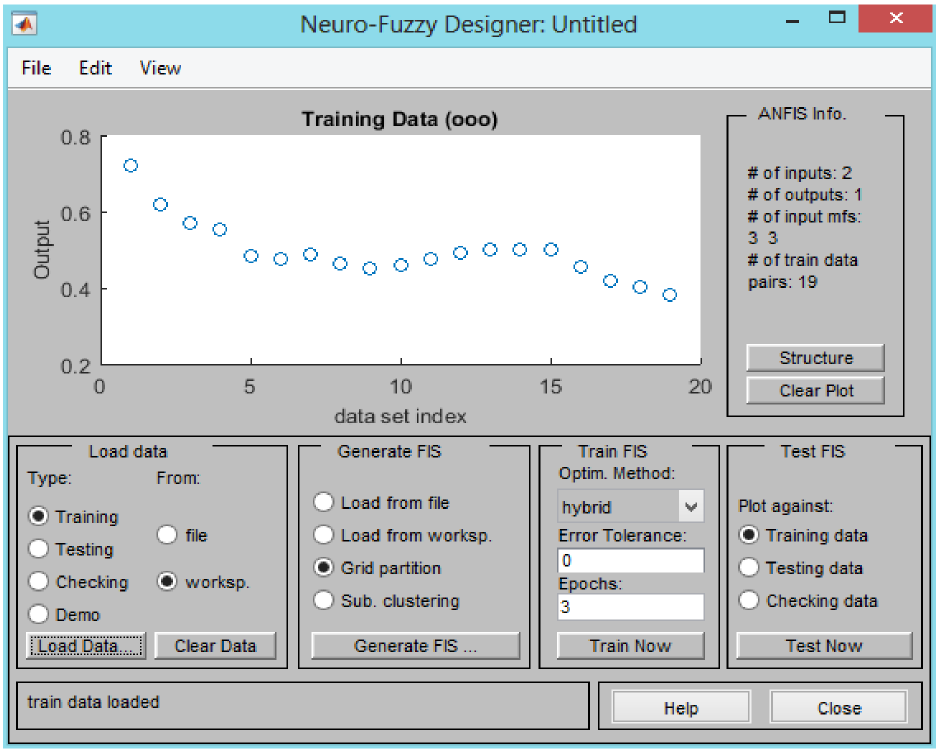

Figure 3.11 Neuro-Fuzzy designer toolbox

Step 2- This training data when loaded in toolbox generates a plot between loaded data and output as shown above now with help of this data we generate a sugeno fuzzy inference system with two inputs and one output having triangular membership functions whose surface view and rule view is shown in figure 3.12 and figure 3.13 respectively. An ANFIS generated fuzzy inference system is always a Sugeno type system with constant output

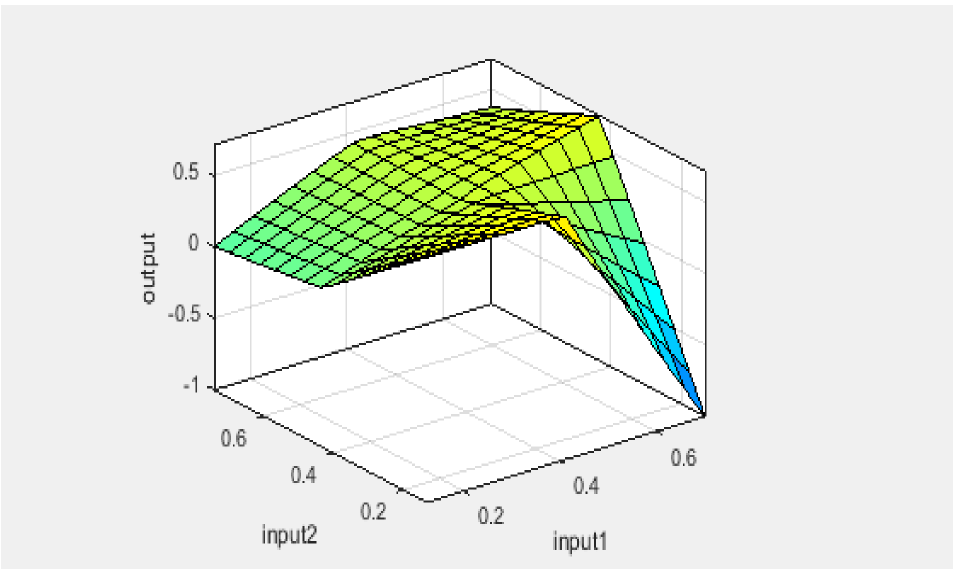

Figure 3.12 Surface Viewer

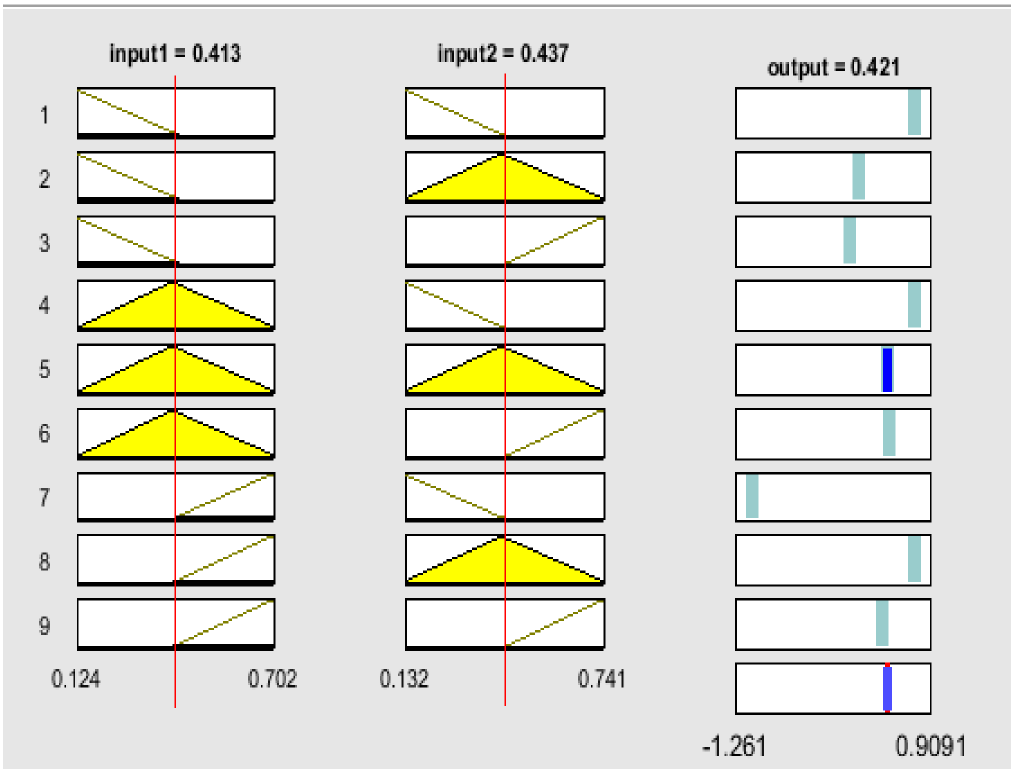

Figure 3.13 Rule Viewer

Step 3- Finally this generated FIS is trained with ANN learning algorithm to generate following five layer adaptive Neuro- fuzzy structure as shown in figure 3.14. It shows the complete neural network with trained data with incorporation of FLC

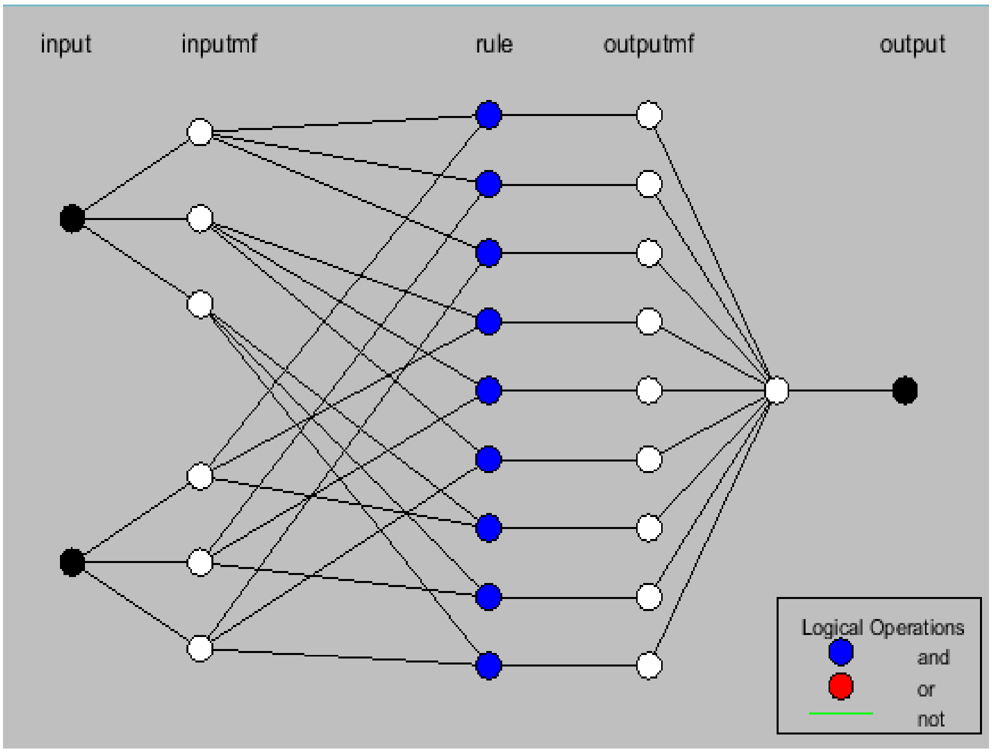

Figure 3.14-ANFIS model structure

Step 4- The final trained FIS system which is generated is tested and plot for error and output is derived accordingly. Figure 3.15 shows the training data and FIS output comparison.

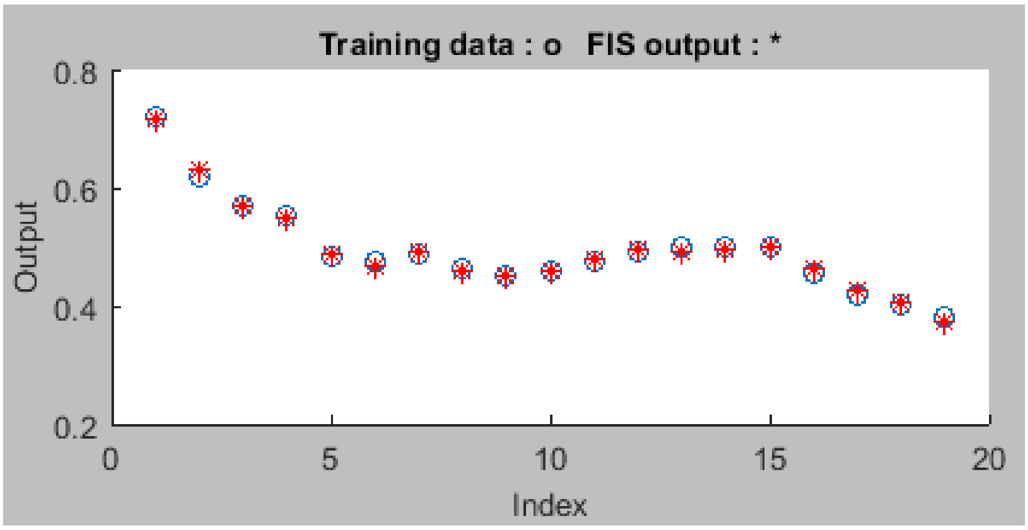

Figure 3.15 Final Tested ANFIS system

Step 5- The generated FIS system trained with neural network is incorporated in Simulink model of the controller as same as then one which is used in fuzzy controller and duty cycle is generated which is further given to converter.

CHAPTER 4

APPLICATION OF CONVERTERS WITH PV PANEL

4.1 PV Array with boost converter

A boost converter as shown in figure 4.1 is used to convert the unregulated direct current input voltage, generated by a PV module to a controlled DC voltage with value higher than the input as required by the load that is it boost the voltage value of input and hence named as boost converter. This conversion of voltage is generally perform by applying a DC voltage across an inductor, for a period of time (usually in range of 20kHz to 5MHz) that produces current which flow through it and stores energy magnetically, and then we switch OFF this voltage which results in the transfer of stored energy to the output voltage in controlled way. This voltage is regulated by adjusting the duty cycle. To achieve this fast switching power electronics component like IGBT or MOSFET is used as they dissipate least power. Pulse width modulation (PWM) technique is use to control and regulate total output voltage. The ideal boost converter possess 100% efficiency but in general 70% to 90% of efficiency is obtained.

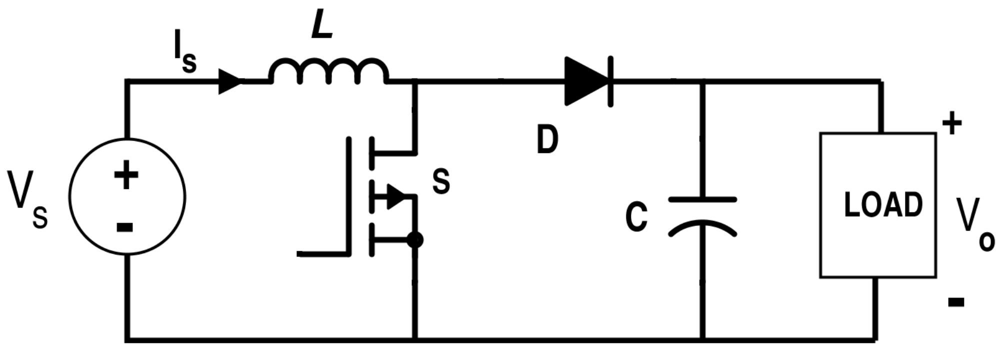

Figure 4.1 Boost converter

The boost converter as shown in the figure has a constant DC input voltage source Vs, boost inductor L, controlled switch S, diode D, filter capacitor C and a load.
DC voltage gain of converter is given as:

$$G = \frac{V_0}{V_S} = \frac{1}{1-\alpha} \quad (4.1)$$

Selection of inductor—Inductor with large value increases the startup time slightly whereas low inductance value allow the coil current to increase up to very high values before the switch turns OFF. It is selected on the basis of the maximum allowed ripple current at minimum duty cycle and maximum supply voltage. Boost converter works in continuous conduction mode for inductor value L>L_c where L_c is a critical inductance value and is given by

$$L_c = \frac{(1-\alpha^2)*\alpha*R}{2f_s} \quad (4.2)$$

where R is the load resistance and f_s is the switching frequency of converter.

Selection of capacitor—the current supplied to the RC circuit is discontinuous that's why a larger filter capacitor is required to decrease the ripples in output voltage. The primary way to select filter capacitor is its capacitance and it's series resistance as this series resistance affects efficiency, low ESR-capacitors is used for best performance. The filter capacitor is use to decrease the ripples in output voltage. Minimum value of filter capacitor that allow current to flow through load when diode is OFF is given by

$$C_{min} = \frac{V_o*\alpha}{f_s*\Delta V_o*R} \quad (4.3)$$

Where ΔV_o is the ripple in output voltage which is generally 5% of output voltage

4.2 PV Array with CUK Converter

A CUK converter as shown in figure 4.2 is an another type of DC/DC converter which produce output voltage either greater or lesser than the input voltage. It is actually a boost converter which is followed by a buck converter. The main difference is that it consists of an additional capacitor to store energy. As the buck-boost converter produces an inverted output similarly cuk converter also produces an inverted output which can be either higher or lower than the input. As most of the converters use inductor as their main energy storage element it uses an additional capacitor to store energy

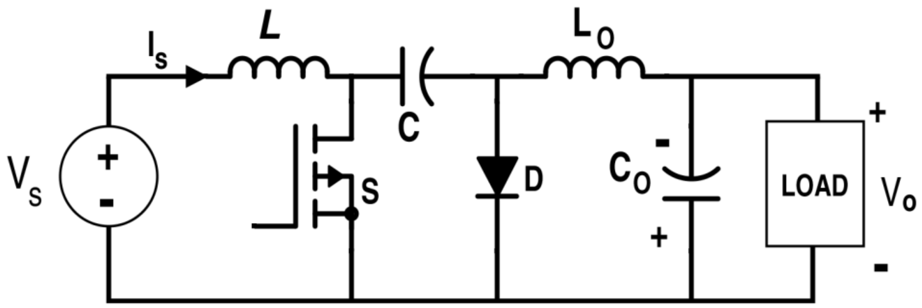

Figure-4.2 circuit diagram of Cuk converter

A cuk converter basically consist of two capacitor, two inductors, one swith and one diode. The transfer of energy is done with the help of capacitor C and two inductors L and L_0 are used to convert input voltage source and output voltage source respectively into current source. The conversion of voltage source into current source is necessary beacause if capacitor is directly connected to resistance then it will cause high energy loss in the system

Now if we apply voltage sec balance across L

$$V_s \alpha T + (V_s - V_c)(1-\alpha)T = 0 \tag{4.4}$$

$$\therefore \quad V_s(1-\alpha)V_c = 0 \tag{4.5}$$

$$\text{Or} \qquad V_c = \frac{V_s}{1-\alpha} \tag{4.6}$$

Applying voltage sec balance across L_0

$$(V_0 + V_c)\alpha T + V_0(1-\alpha)T = 0 \tag{4.7}$$

$$V_0 + \alpha V_c = 0 \tag{4.8}$$

$$V_0 = -\alpha V_c = -\frac{\alpha V_s}{1-\alpha} \tag{4.9}$$

Similarly current through two inductors L and L_0 are stated as follows

$$I = \frac{\alpha^2}{(1-\alpha)^2}\frac{V_s}{R} \quad , \quad I_0 = \frac{\alpha}{1-\alpha}\frac{V_s}{R} \tag{4.10}$$

So basically cuk converter combines the features of both boost and buck-boost converter hence it has following advantages

1. It provide continuous input current
2. It provide continuous output current
3. Output voltage obtained can be higher or lower than input voltage.

4.3 PV Array with SEPIC converter

A SEPIC converter or single-ended-primary-inductor-converter is also a DC/DC converter that gives output voltage either higher, lower or equal to the input voltage. It is actually a boost converter followed by a buck-boost converter. The major advantage of SEPIC converter over buck boost converter that unlikely buck boost converter it produces a non-inverting voltage output. It uses a series capacitor for energy coupling from input to output and hence can give better results when used in short circuit condition. Unlike cuk converter it has pulsating output which is one of the disadvantage of SEPIC converter, also its fourth order nature make it suitable for slow varying systems only. A detailed circuit diagram of SEPIC converter is shown in figure 4.3.

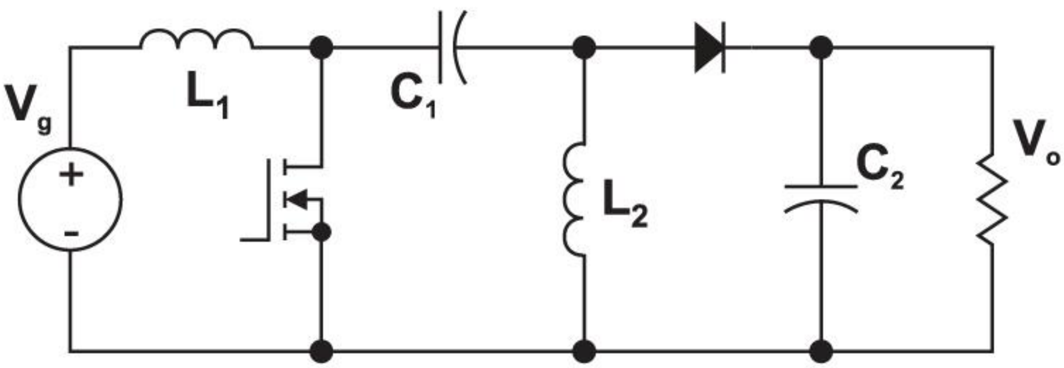

Figure 4.3 A SEPIC converter circuit diagram

During the turn ON time the diode gets reverse biased and coupling capacitor has negative polarity which helps in charging of inductor L_1 and L_2 via source and coupling capacitor gets discharge on the other hand in case of turn OFF time the diode gets forward biased and inductor L_1 helps in the charging of coupling capacitor whereas inductor L_2 transfer its stored energy to the output and this is how an SEPIC converter works.

Duty cycle selection-for continuous mode operation duty cycle is given by

Output of a SEPIC converter is given by

$$V_0 = \frac{\alpha * V_g}{1-\alpha} \tag{4.11}$$

If we consider losses due to voltage drop across diode then output can be stated as-

$$V_0 + V_D = V_0 = \frac{\alpha * V_g}{1-\alpha} \tag{4.12}$$

Due to this final expression of duty cycle becomes

$$\alpha = \frac{V_0 + V_D}{V_g + V_0 + V_D} \tag{4.13}$$

Inductor calculation- inductors are basically used in converters to produce a ripple free output.

The ripple current flowing through L_1 and L_2 is given by

$$\Delta I_L = I_{in} * 40\% = I_0 * \frac{V_0}{V_g} * 40\% \tag{4.14}$$

The value of two inductors can be calculated as-

$$L_1 = L_2 = L = \frac{V_{g,min}}{\Delta I_L * f_s} * \alpha_{max} \qquad (4.15)$$

Coupling capacitor calculation- The value of capacitor depends on RMS current whose expression is given as-

$$I_{c1,rms} = I_0 * \sqrt{\frac{V_0 + V_D}{V_{g,min}}} \qquad (4.16)$$

Peak to peak ripple voltage can be given as

$$\Delta V_{cs} = \frac{I_0 * \alpha_{max}}{C * f_s} \qquad (4.17)$$

4.4 PV array with Zeta Converter

A zeta converter is a fourth order converter. It is somewhat similar to cuk converter only, that is it is also a boost converter followed by a buck converter the only difference is that it inverts the polarity of output produce by the cuk converter that is as we know that cuk converter produces an inverted output that is of negative polarity but this is not the case in terms of zeta converter it inverts that voltage to produce a positive value. It is also consist of two inductors and one capacitor in series. This capacitor is generally termed as flying capacitor.

The advantages of zeta converter over other converters is that it produces an output which consist of very less ripples and compensation is easier.

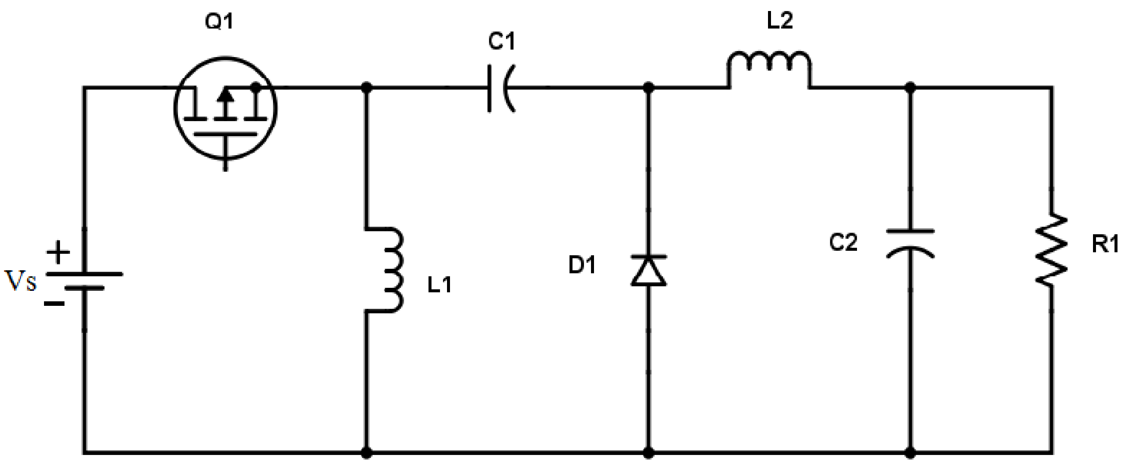

Figure 4.4 –Zeta converter circuit diagram

The detailed circuit of zeta converter is shown in figure 4.4 and the parameters of converter can be calculated as :

Duty cycle—if we consider 100% efficiency then for continuous conduction mode of zeta converter duty cycle α is given as:

$$\alpha = \frac{V_0}{V_s+V_0} \tag{4.18}$$

here V_s is the input voltage and V_0 is the output voltage

it can also be written as:

$$\frac{\alpha}{1-\alpha} = \frac{I_{in}}{I_{out}} = \frac{V_0}{V_{in}} \tag{4.19}$$

Passive components selection—during designing of any converter the first step is to set the value of inductor ripple current as very low ripple current can cause unstable operation of PWM. So the ripple current can be evaluated as

$$\Delta I_L = K * I_{in} \tag{4.20}$$

Or

$$\Delta I_L = K * I_{out} * \frac{\alpha}{1-\alpha} \tag{4.21}$$

Here value of K is kept between 0.2 to 0.4 of the average current

This ripple current is to be divided equally between two coupled inductors so the value of inductor can be given as:

$$L1 = L2 = \frac{1}{2} * \frac{V_S*\alpha}{\Delta I_L*f_s} \tag{4.22}$$

Similarly voltage ripple can be calculated as:

$$\Delta V_C = \frac{\Delta I_L}{8*C_2*f_s} \tag{4.23}$$

Similar to a buck converter a zeta converter also has very low ripple voltage.

CHAPTER 5

SIMULATION AND RESULTS

The basic Block Diagram of whole system on which analysis is done is shown in figure 5.1 below, it is divided into three parts the first one is PV array then the second art is DC/DC converter which is getting the gate pulse through the MPPT technique which has been applied to extract maximum power from the PV panel and the third segment is conversion of converter output into AC supply through which is supplied to the grid.

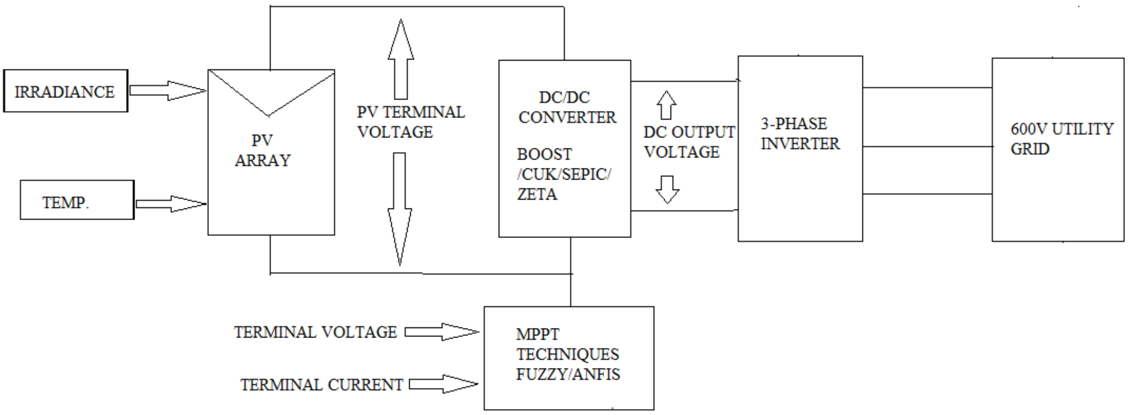

Figure 5.1 Schematic block diagram of system

5.1 PV panel specification

The Panel which is selected for analysis is one of the specified panels of MATLAB/SIMULINK library and that is Neo Solar Power D6P240B3A, in this project five parallel string with four panel in series connected in each string is taken into consideration for analysis. Hence we have an array of 20 such modules.

Technical specifications of this panel is shown below:

Table 5.1 Technical specifications of PV array

TECHNICAL SPECIFICATIONS	VALUE
Cells Per Module	60
Open circuit voltage (V_{oc})	36.96 V
Short circuit current (I_{sc})	8.49 A

Maximum power	240.694 W
Voltage at MPP (V_{mp})	30.2 V
Current at MPP(I_{mp})	7.97 A

The two major inputs to PV array are irradiance and temperature. In this project analysis is done for three different values of irradiance and temperature. For the daytime the value of irradiance is 600W/m^2 and temperature is 25˚C. For noontime the irradiance value is taken as 1000 W/m^2 and temperature is 45˚C and for evening time the value of irradiance is set at 400 W/m^2 and temperature is taken as 32˚C.

These values are plot using signal builder in MATLAB as shown in figure 5.2 and 5.3.

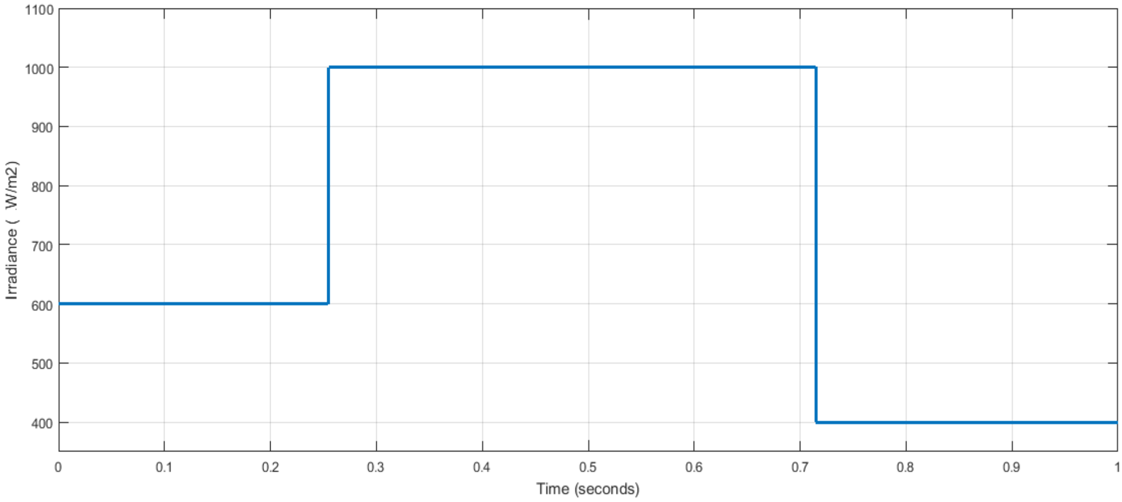

Figure 5.2 Irradiance plot for three different values

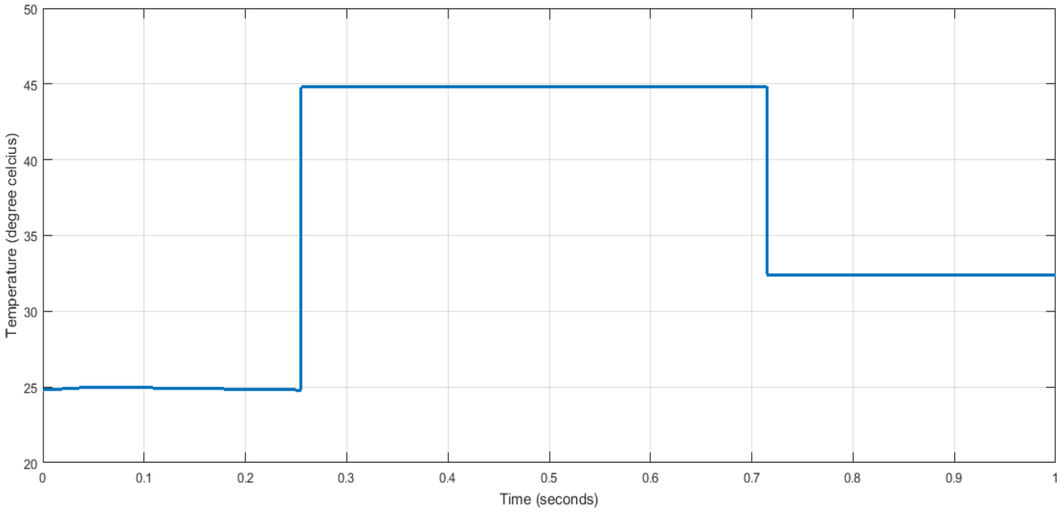

Figure 5.3 Temperature variation for three irradiance values

The P-V and I-V characteristics of PV array for these values of irradiance and temperature are as follows

1. Irradiance =1000W/m^2 at temperature = 45˚C

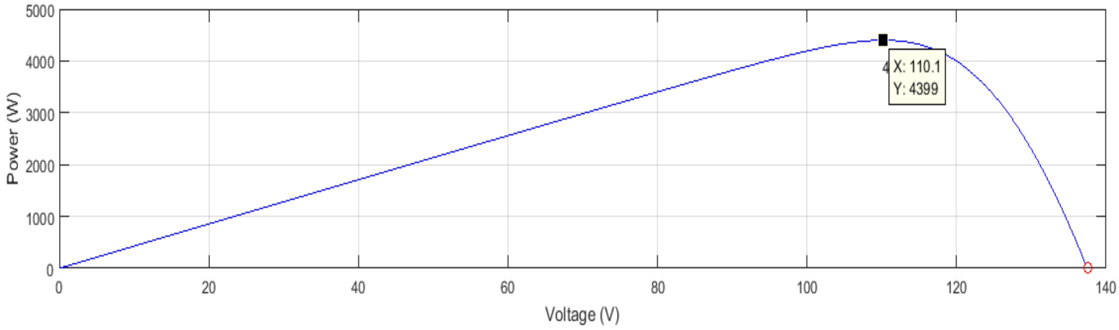

Figure 5.4 P-V characteristics for irradiance =1000 W/m^2

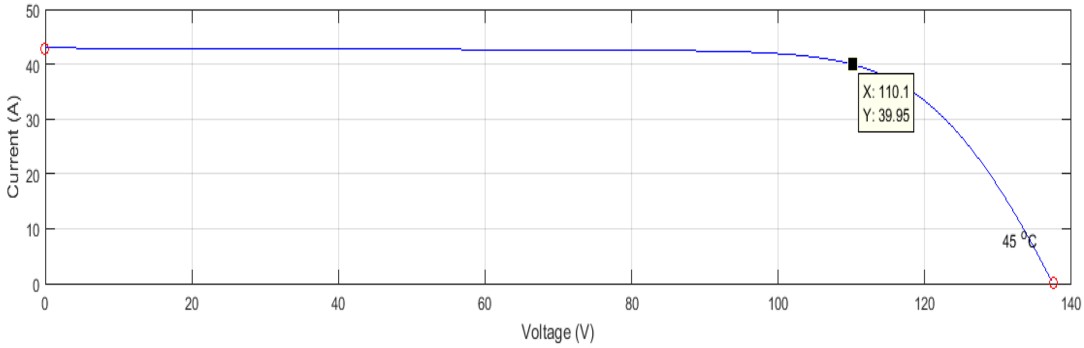

Figure 5.5 I-V Characteristics for irradiance=1000W/m^2

From the above two characteristics shown in figure 5.4 and 5.5 it is clear that maximum power point occurs at voltage value 110V and current value 39.95A also maximum power at this point is 4.39KW.

2. Irradiance=600W/m^2 at temperature=25˚C

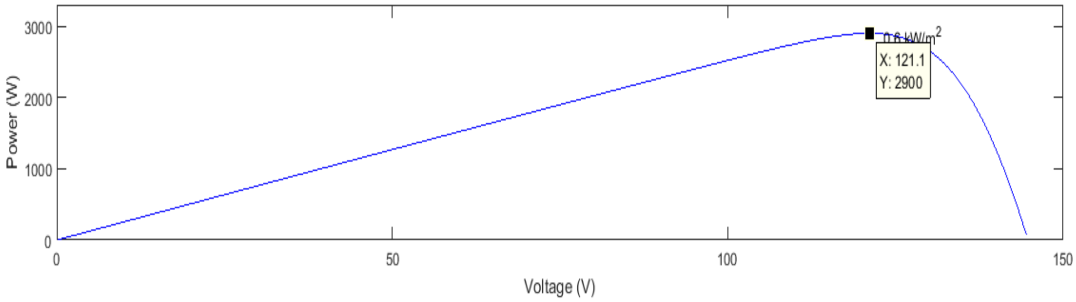

Figure 5.6 P-V characteristics for irradiance 600W/m^2

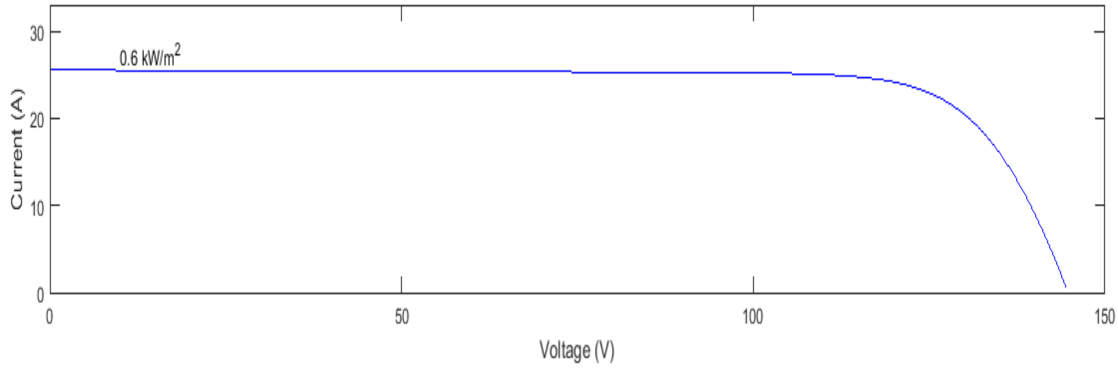

Figure 5.7 I-V characteristics for irradiance 600W/m^2

From the characteristics in the above figure 5.6 and 5.7 it can be noted that maximum power point is obtained at the voltage=121.1V and the power at this point is 2.9 KW

3. Irradiance=400W/m^2 at temperature 32˚C

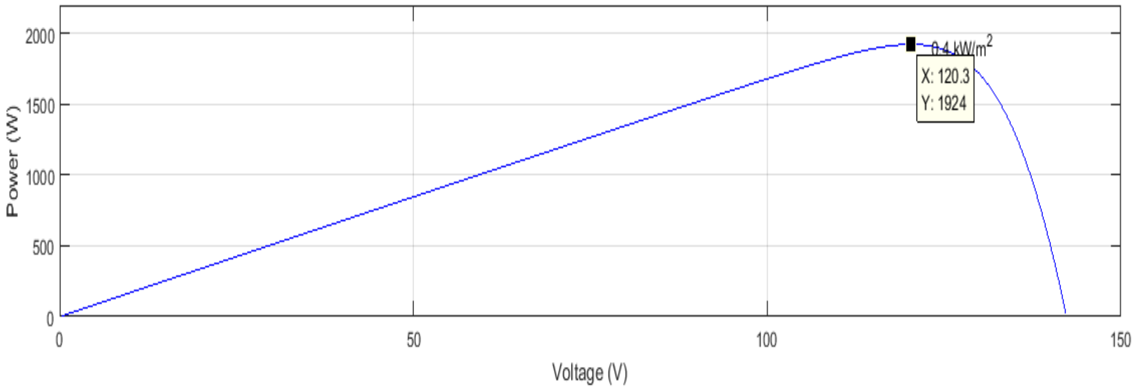

Figure 5.8 P-V characteristics at irradiance value 400W/m^2

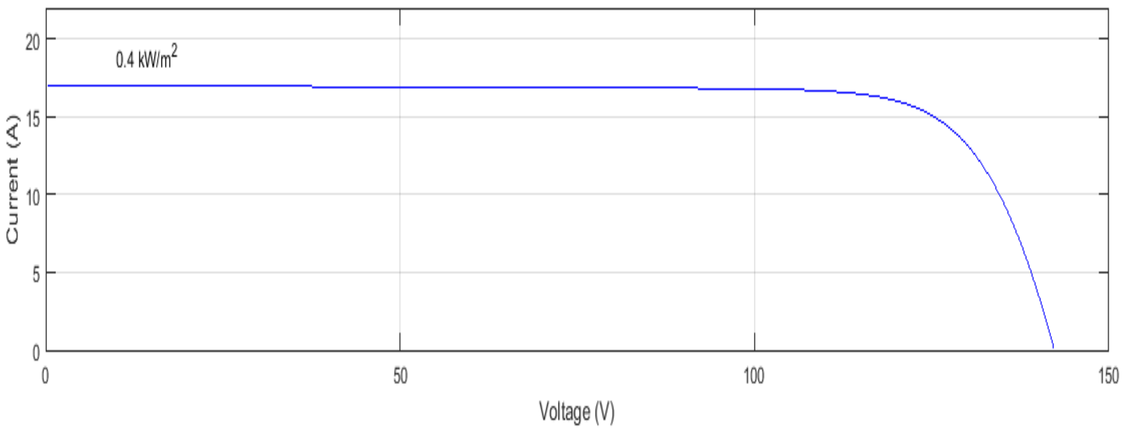

Figure 5.9 I-V characteristics for irradiance= 400W/m^2

As shown in the graphs in figure 5.8 and 5.9 the maximum power point occurs at voltage value of 120.3V with maximum power=1.924KW.

5.2 PV panel implemented with Boost converter

The first converter which is applied to this PV system in this project is the boost converter. Here the complete analysis is done with two MPPT techniques first is fuzzy logic and second is the ANFIS and results have been compared.

Boost Converter Calculations:

Duty Cycle--

$$\frac{106.7}{30.02} = \frac{1}{1-\alpha} \tag{5.1}$$

$$\alpha = 0.72 \tag{5.2}$$

Inductor—

$$L_C = \frac{(1-0.72^2)*0.72*100}{2*25000} = 0.693\, mH \tag{5.3}$$

Capacitor—

$$C = \frac{106.7*0.72}{25000*100*(0.05*106.7)} = 5.76\, \mu F \tag{5.4}$$

Fuzzy implemented MPPT:

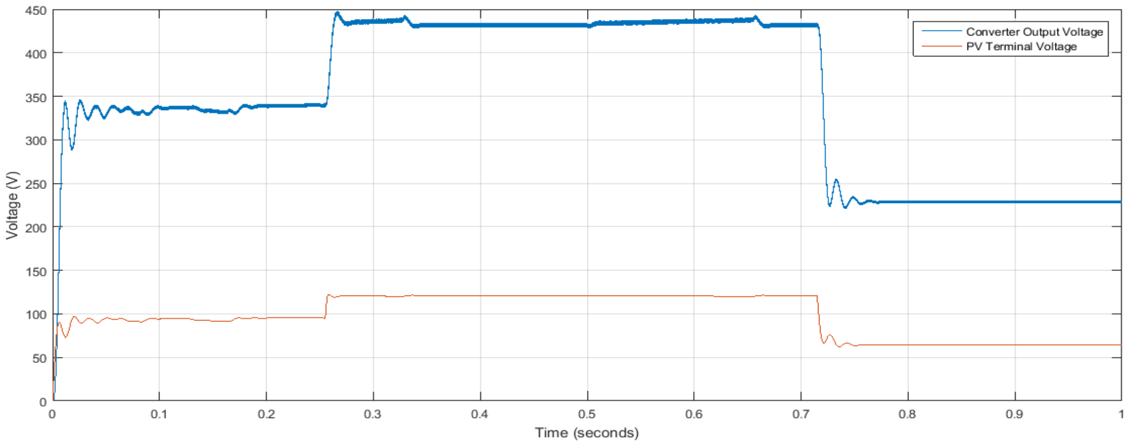

Figure 5.10 Voltage output of PV terminal and boost converter

From the waveforms in figure 5.10 we can clearly see that PV terminal voltage and accordingly boost converter voltage varies with the change of irradiance and temperature also the PV terminal voltage is close to the maximum power point voltage and boosted according to duty cycle.

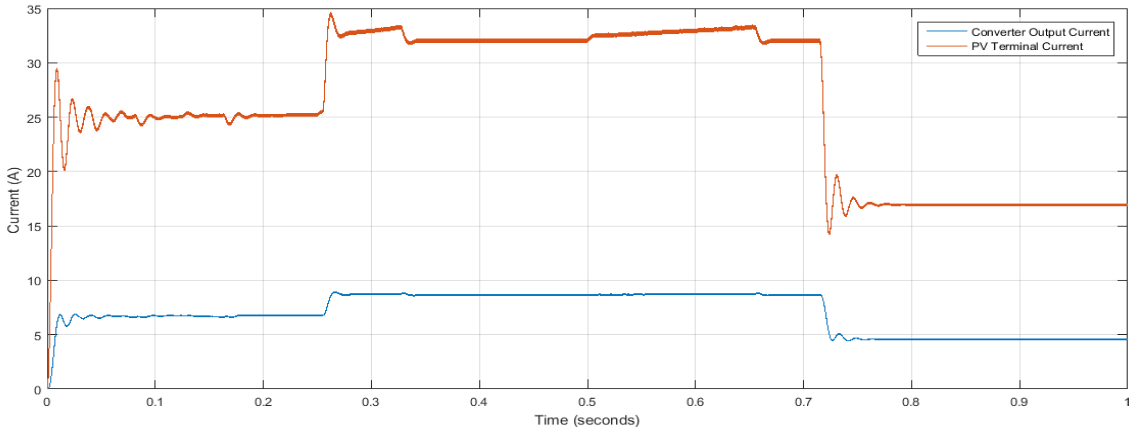

Figure 5.11 Current output of PV terminal and converter

Similar to the voltage waveforms current waveforms are shown in figure 5.11 here the current from the boost converter is lesser than the current at PV terminals and figure 5.12 shows the power variation accordingly.

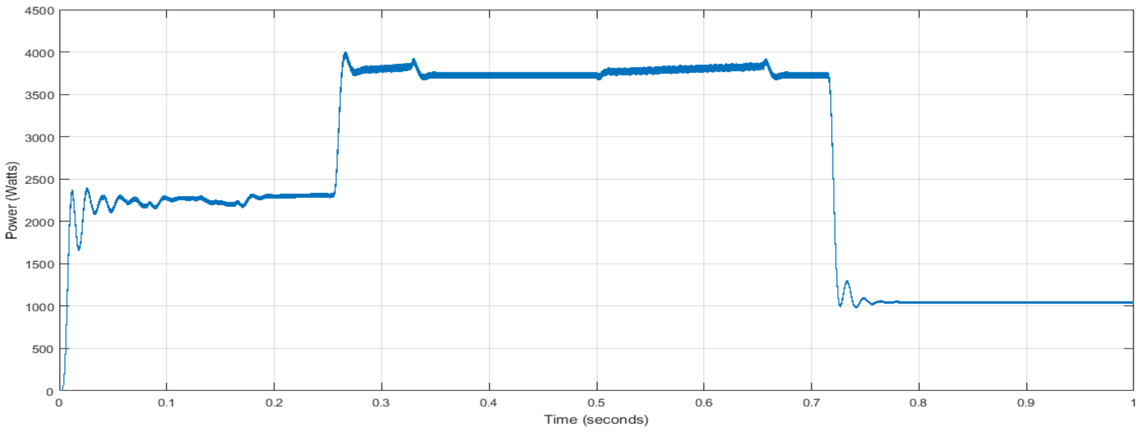

Figure 5.12 Output Power variation for different irradiance

ANFIS implemented MPPT:

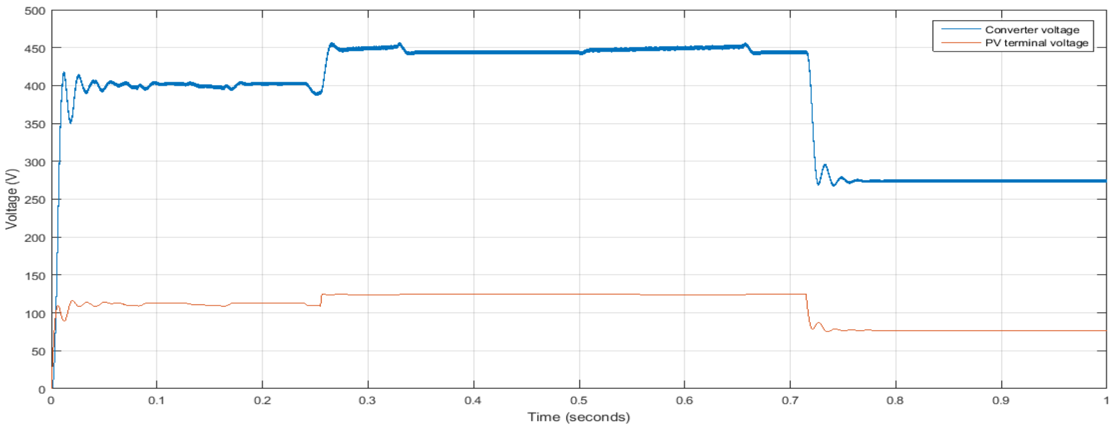

Figure 5.13 Voltage waveforms of converter and PV terminal

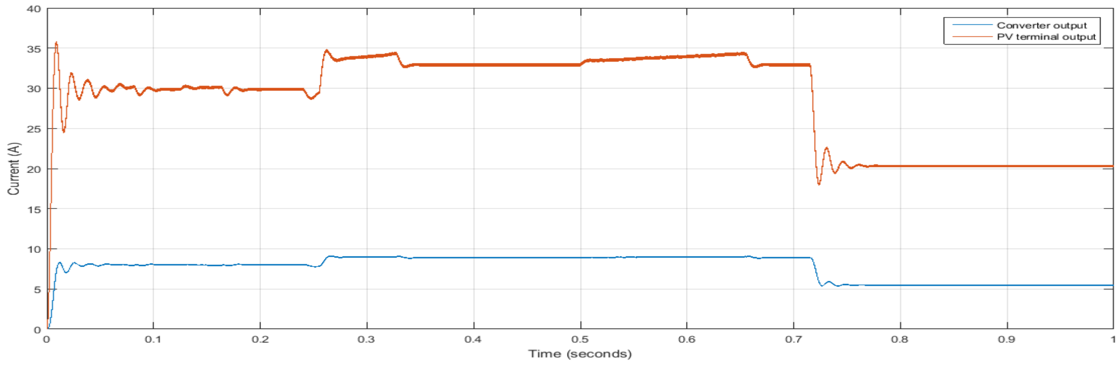

Figure 5.14 Output current of PV terminal and converter

Similar to fuzzy implemented MPPT the ANFIS implemented PV system has voltage, current and power variations as shown in figure 5.13, 5.14 and 5.15 which changes according to the change in irradiance and temperature but the performance is better than FLC

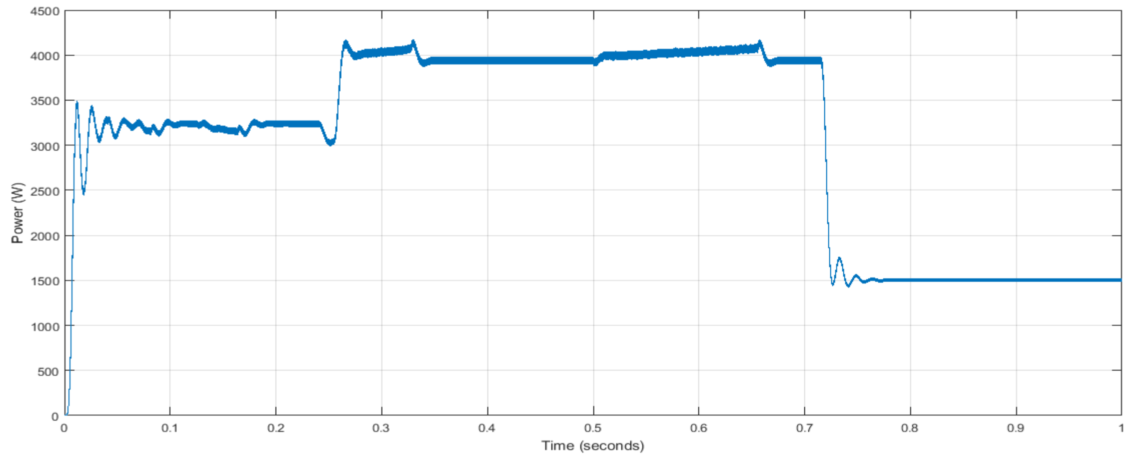

Figure 5.15 Power variation curve

Table 5.1 Boost converter performance comparison

MPPT TECHNIQUES	IRRADIANCE/TEMP.	PV TERMINAL VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE	POWER (KW)	EFFICIENCY
FUZZY LOGIC	600/25	99.8	356.42	2.4	82.7
	1000/45	109.9	392.5	3.6	81.8
	400/32	80.2	286.42	1.5	78.9
ANFIS	600/25	108.2	386.42	2.7	93.1
	1000/45	110	392.85	3.8	88.3
	400/32	98.6	352.14	1.7	89.4

5.3 PV panel implemented with CUK converter

Cuk converter inverts the output voltage as same as like buck-boost converter

Cuk converter Calculations:

Duty cycle

$$-\frac{\alpha}{1-\alpha} = \frac{87.36}{29.36} \quad (5.5)$$

$$\alpha = 0.74 \quad (5.6)$$

Current through Inductors

$$I_1 = \frac{0.74^2}{(1-0.74)^2} * \frac{29.36}{100} = 2.36 \text{ A} \quad (5.7)$$

$$I_2 = \frac{0.74}{1-0.74} * \frac{29.36}{100} = 0.80\ A \quad (5.8)$$

Fuzzy implemented MPPT:

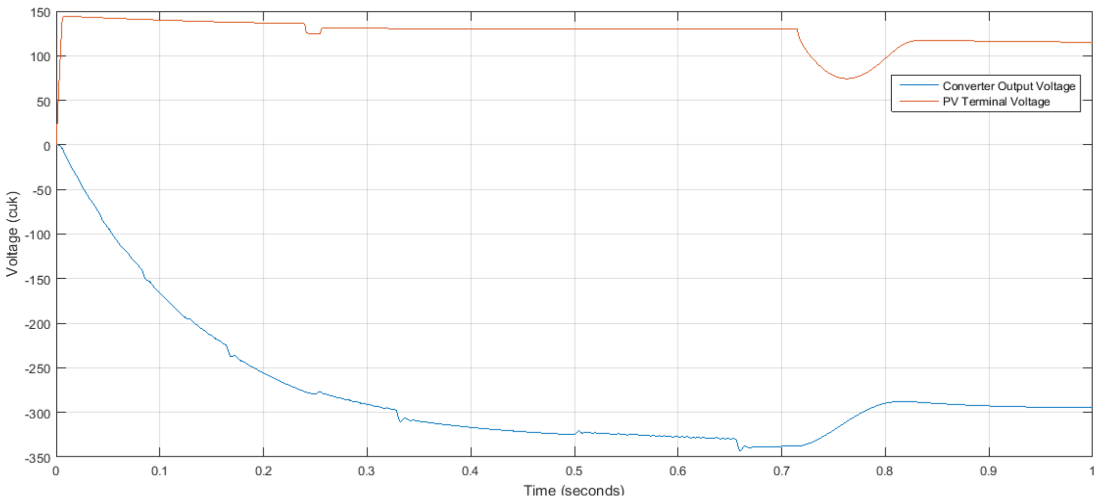

Figure 5.16 Output Voltage Waveforms

From the waveforms in figure 5.16 we can see that the voltage obtained at PV terminal is close to the voltage at maximum power point as stated above for particular irradiance also as the cuk converter produce inverted output we can clearly see from the waveform that output voltage through converter is going below zero and changes according to the value of irradiance and temperature and as we can see ripples are very less in this case, also if we look in to the waveforms of current and power shown in figure 5.17 and 5.18 similar trends can be seen, alike the voltage the current polarity also gets inverted.

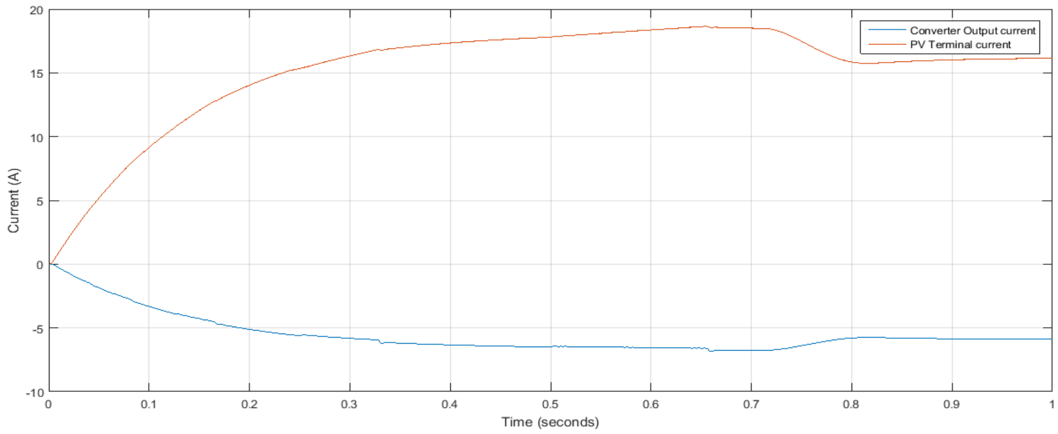

Figure 5.17 Cuk converter output current

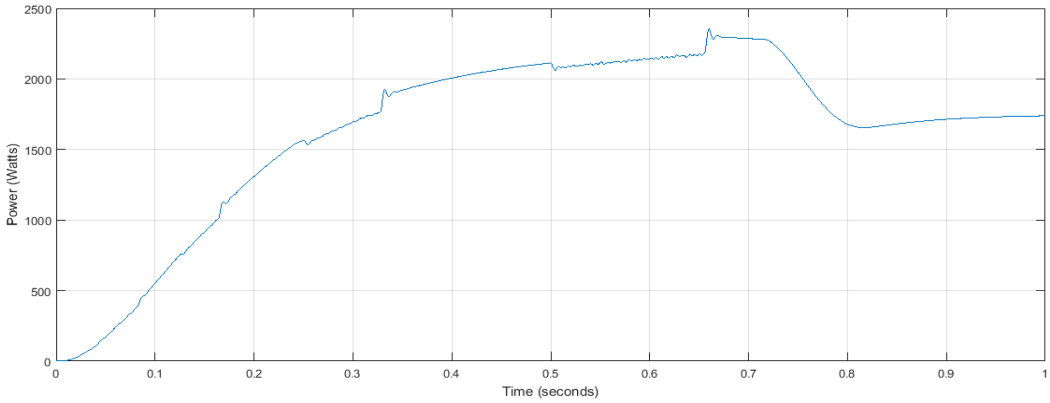

Figure 5.18 Power variation curve

Unlike boost converter the power does not changes rapidly on changing of irradiance and temperature but the nature of variation is gradual and has less ripples as shown in figure 5.18 which act as an advantage of CUK converter.

ANFIS implemented MPPT:

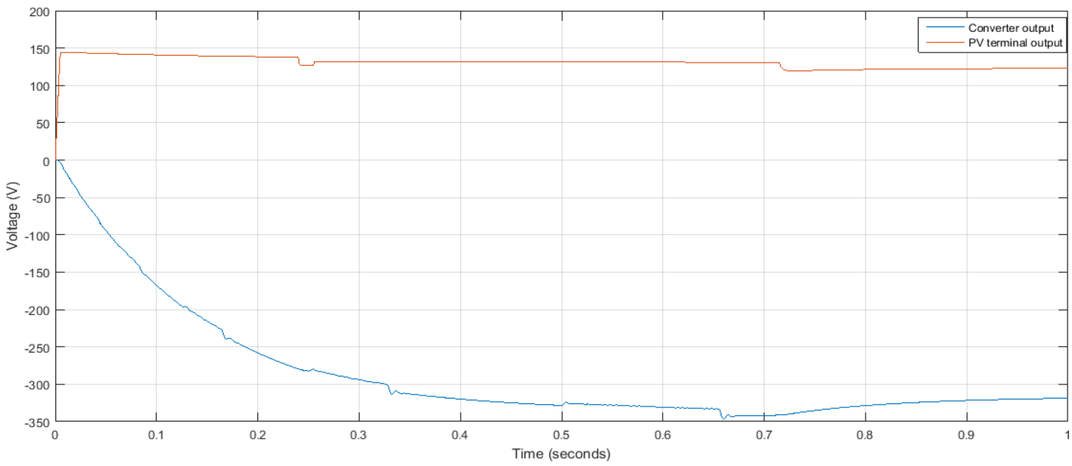

Figure 5.19 Voltage variation curve

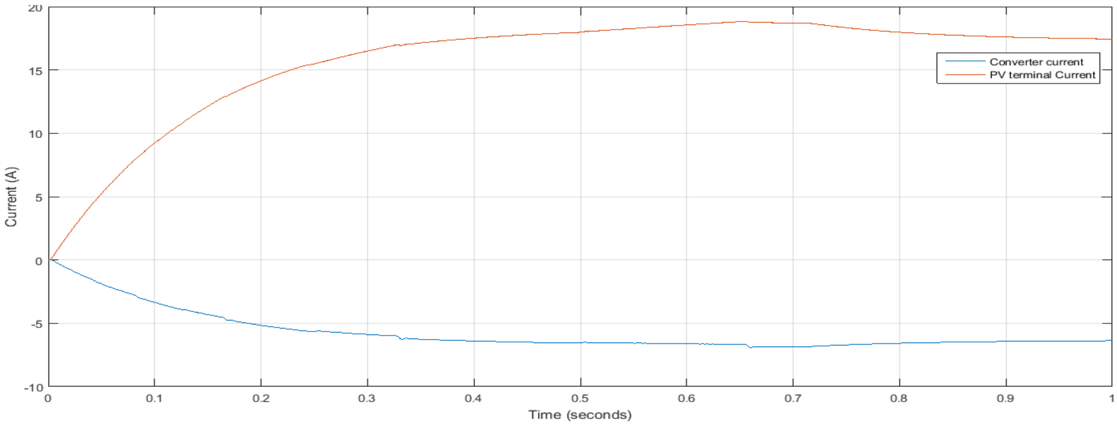

Figure 5.20 Current waveforms of CUK converter

The voltage, current and power variation curves are shown in figure 5.19, 5.20 and 5.21. These results are obtained by the application of ANFIS for tracking of MPP and hence has better performance

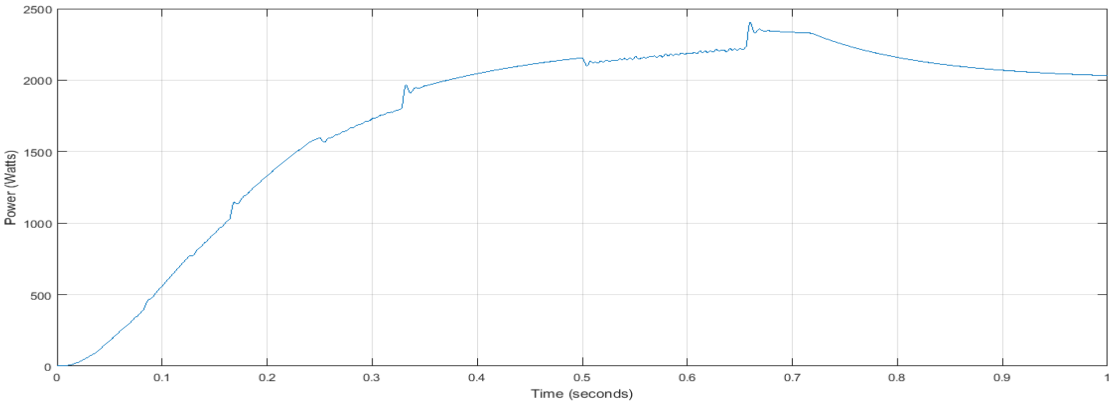

Figure 5.21 Output Power of Cuk converter

Table 5.2 CUK converter performance comparison

MPPT TECHNIQUES	IRRADIANCE /TEMP.	PV TERMINAL VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE	POWER (KW)	EFFICIENCY
FUZZY LOGIC	600/25	119.1	-338.24	1.8	62.0
	1000/45	108.2	-307.28	2.5	58.1
	400/32	105.6	-299.90	1.7	89.4
ANFIS	600/25	120	-340.8	2	68.9
	1000/45	109.4	310.69	2.5	58.1
	400/32	107.4	-305.01	1.8	90

5.4 PV panel implemented with SEPIC converter

Parameters calculations:

Duty cycle

$$\alpha = \frac{107.1+0.8}{30.2+107.1+0.8} = 0.78 \tag{5.9}$$

Ripple current:

$$\Delta I_L = 0.4 * I_{in} = 1.712A \tag{5.10}$$

Value of inductors:

$$L_1 = L_2 = \frac{30.2}{1.712*25000} * 0.78 \tag{5.11}$$

$$L = 0.5503\ mH$$

Fuzzy Implemented MPPT

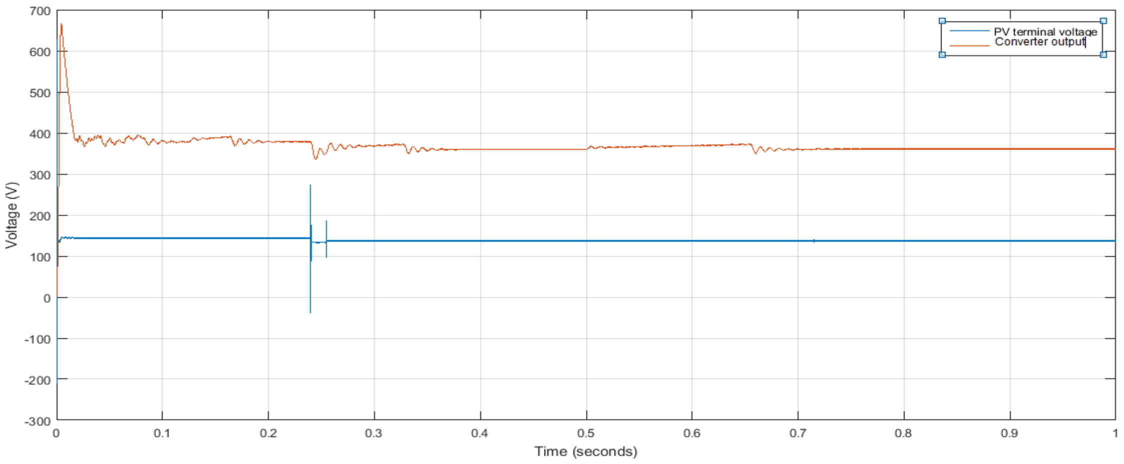

Figure 5.22 Voltage variation of SEPIC converter

As it is clear by just observing the curve of SEPIC converter output voltage shown in figure 5.22 that change in voltage with change in irradiance and temperature is not that much, that is it gives stable operation throughout the day the only disadvantage is that it consists of two much ripples due to which it is not that much efficient, for the current and power waveforms also shown in figure 5.23 and 5.24 the amount of ripples are high but the output is stable or we can say not vary much with then variation in irradiance and temperature throughout the day.

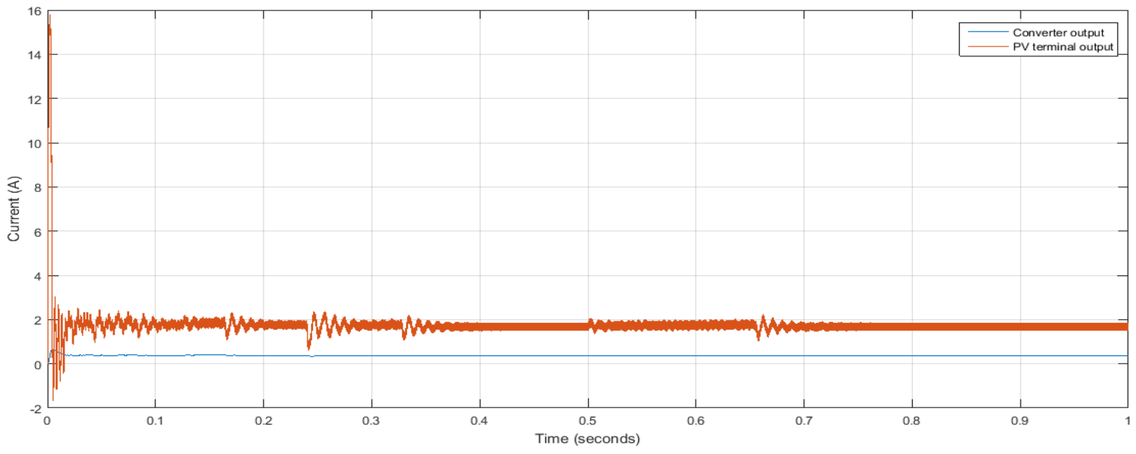

Figure 5.23 Current variations for SEPIC converter

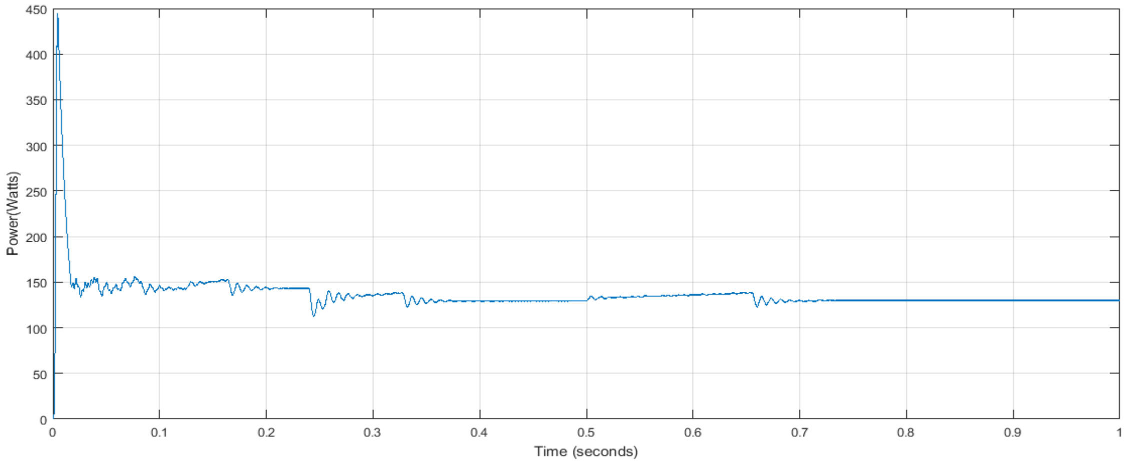

Figure 5.24 Output Power Curve

SEPIC converter gives stable output throughout the day but output is pulsating

ANFIS implemented MPPT

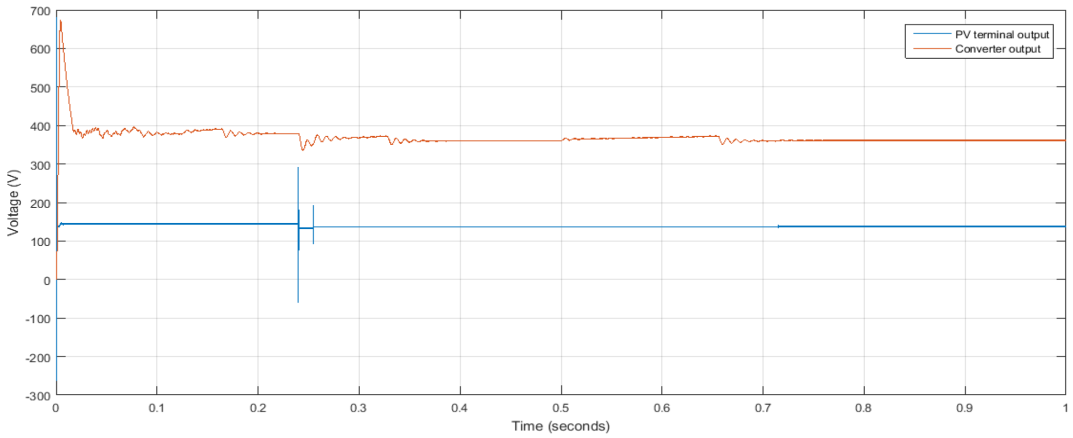

Figure 5.25 Voltage Curve

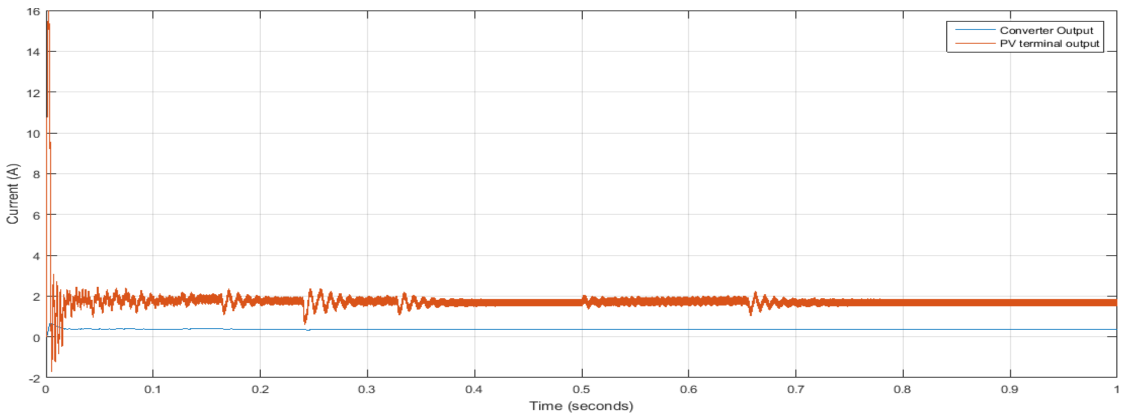

Figure 5.26 Current variations

Just like the waveforms obtained in the case of fuzzy implemented MPPT, voltage current and power waveforms are obtained in case of ANFIS with better performance as shown in figures 5.25, 5.26 and 5.27

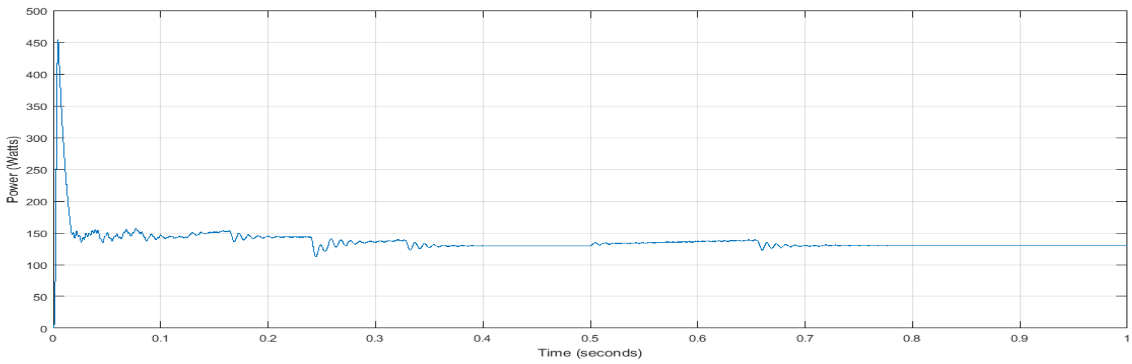

Figure 5.27 Output Power for SEPIC converter

Table 5.3 SEPIC converter performance comparison

MPPT TECHNIQUES	IRRADIANCE/TEMP.	PV TERMINAL VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE	POWER (KW)	EFFICIENCY
FUZZY LOGIC	600/25	109.6	356.3	1.3	44.8
	1000/45	109.7	358.2	2.7	62.7
	400/32	108.3	349.1	0.46	24.2
ANFIS	600/25	110	358.4	1.4	48.27
	1000/45	109.7	370.9	2.8	65.1
	400/32	109	352.5	0.50	26.3

5.5 PV implemented with Zeta Converter

Zeta converter provides similar output as cuk converter but unlike cuk converter it provides output of positive polarity that is output is not inverted

$$\alpha = 0.789 \tag{5.12}$$

$$\boldsymbol{L_1} = L_2 = \frac{1}{2} * \frac{28.9*0.789}{2.39*25000} = 0.19mH \tag{5.13}$$

Fuzzy implemented MPPT

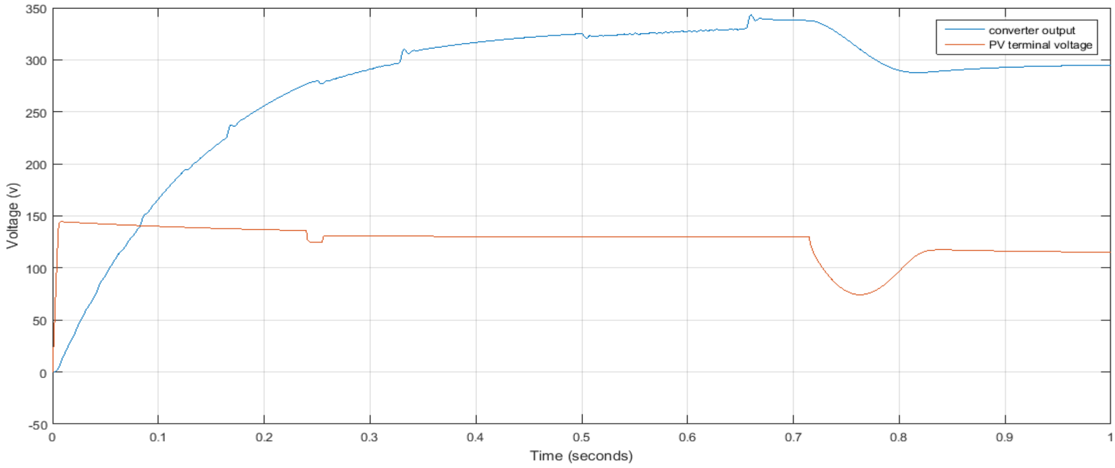

Figure 5.28 Voltage variation curve

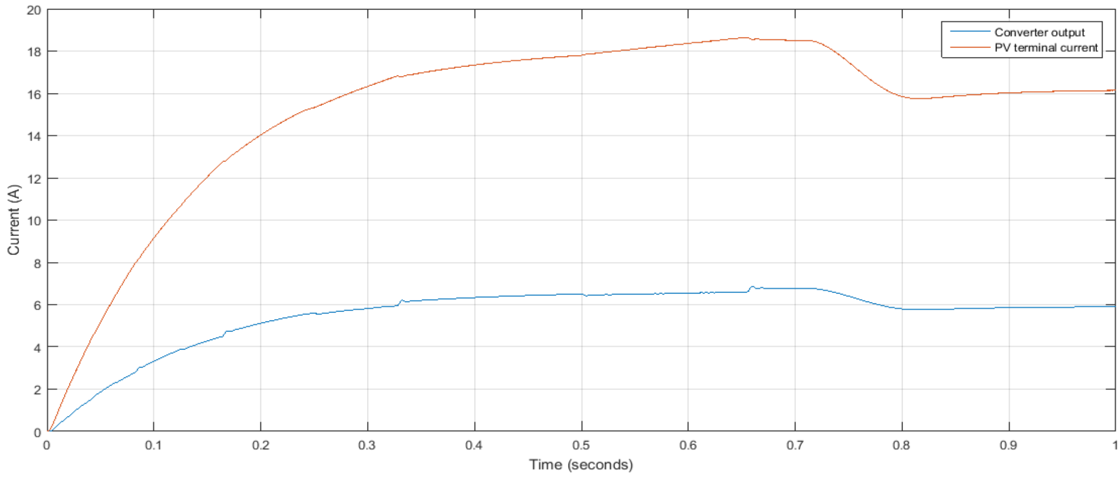

Figure 5.29 Current variation curve

As we have discussed earlier that zeta converter inverts the output produced by cuk converter, we can see the same in the waveforms of voltage, current and power in the figures 5.28, 5.29 and 5.30 the output is the inverted output of CUK converter only with better efficiency and reliability hence the performance of zeta converter is best.

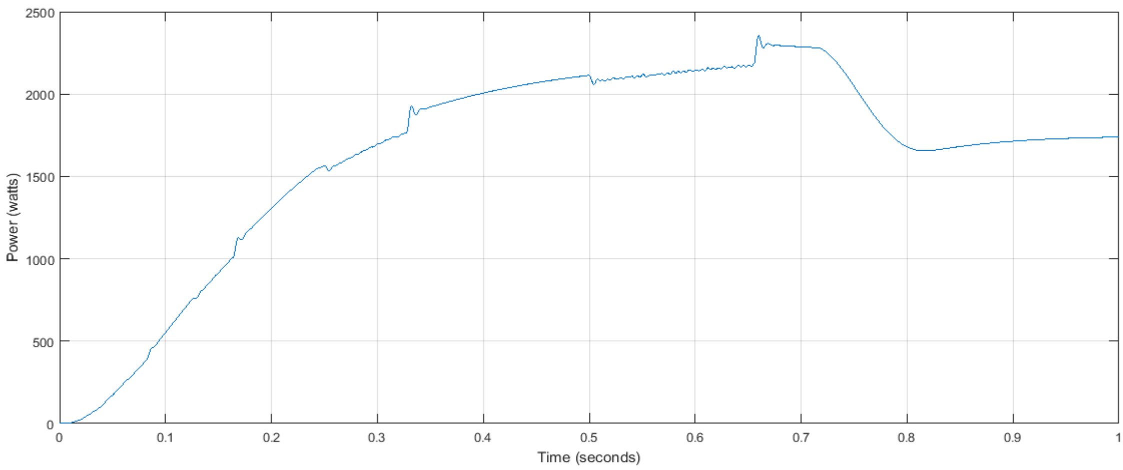

Figure 5.30 Power Variation

ANFIS implemented MPPT

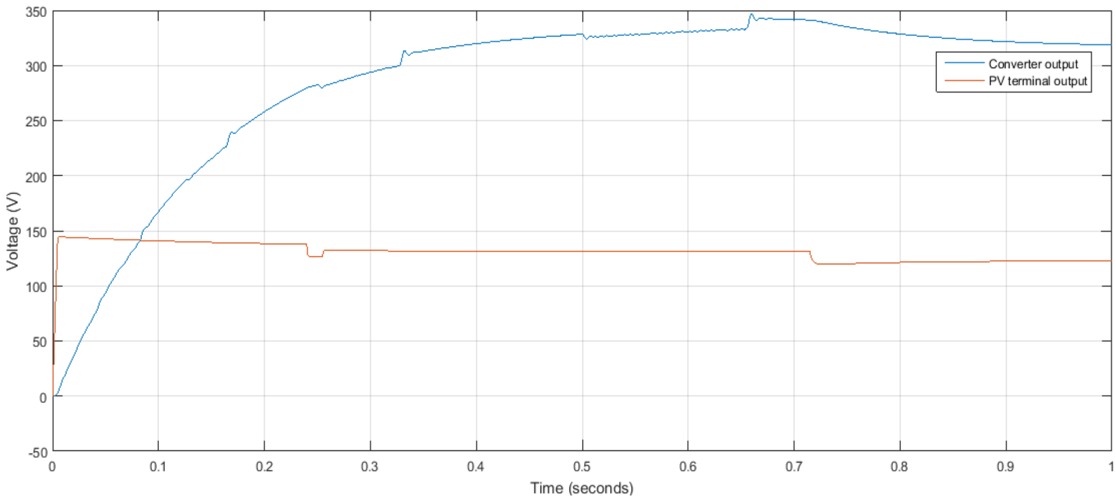

Figure 5.31 Voltage curve

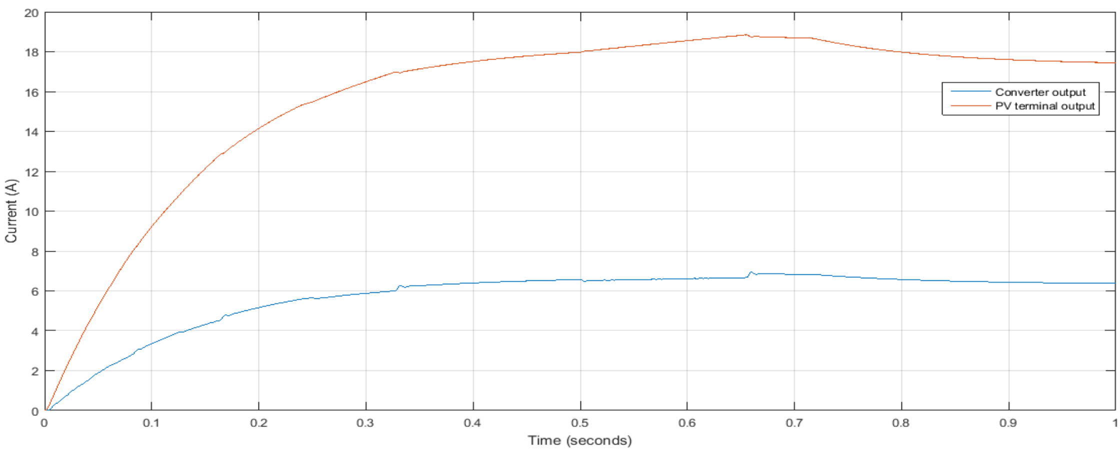

Figure 5.32 Current curve

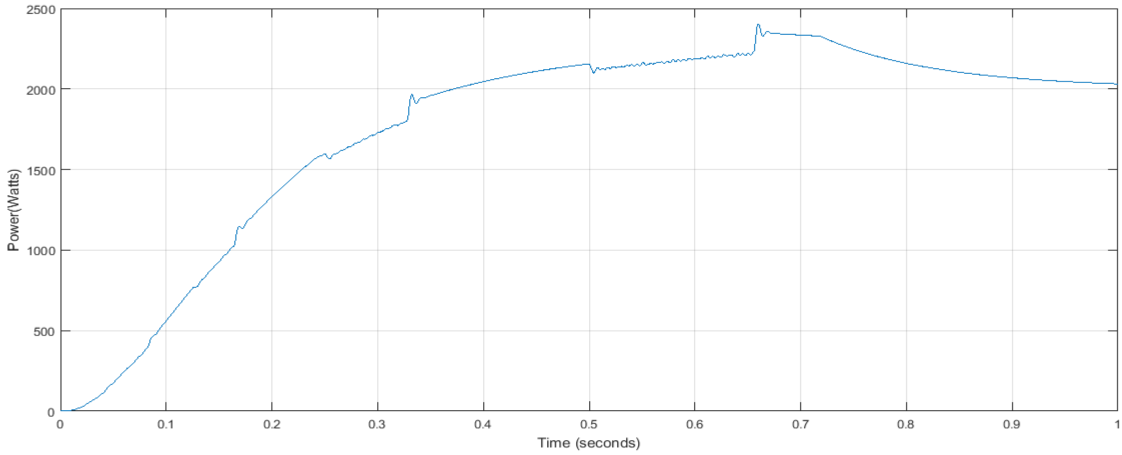

Figure 5.33 Power variations

From the voltage , current and power waveforms of figure 5.31, 5.32 and 5.33 we can clearly deduce that ANFIS implemented zeta converter gives more reliable and efficient result when compared to the outcomes of fuzzy implemented MPPT, as we can observe that fall in power when irradiance changes from 1000 to 400 is more in the case of FLC when compared to the case of ANFIS.

Table 5.4 Zeta converter performance comparison

MPPT TECHNIQUES	IRRADIANCE /TEMP.	PV TERMINAL VOLTAGE (V)	CONVERTER OUTPUT VOLTAGE	POWER (KW)	EFFICIENCY
FUZZY LOGIC	600/25	119.1	338.24	1.8	62.0
	1000/45	108.2	307.28	2.5	58.1
	400/32	105.6	299.90	1.7	89.4
ANFIS	600/25	120	340.8	2	68.9
	1000/45	109.4	310.69	2.5	58.1
	400/32	107.4	305.01	1.8	90

5.6 AC Output Voltage and Current waveforms

The DC output obtained from the different converters is given as input to the three phase inverter which furthur convert this DC voltage into AC supply and supplied to the grid. This AC supply can be use in household works or in big industries as per the requirements, then waveforms are generally sinusoidal in nature as shown in the figures

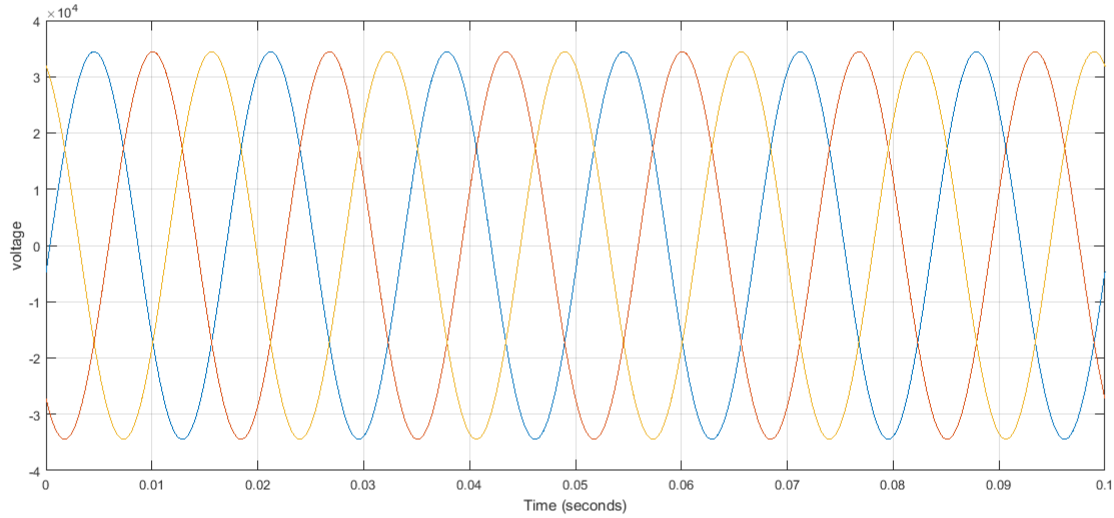

Figure5.34 AC Voltage output that is supplied to then grid

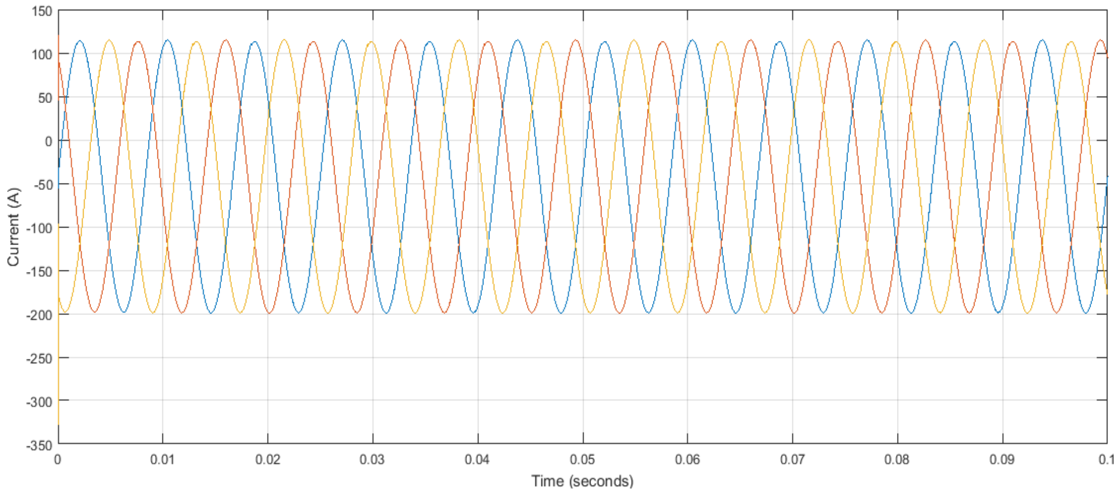

Figure5.35 AC Current output that is supplied to the grid

As we can see from the waveforms shown in figure 5.34 and 5.35 we get a three phase sinusoidal waveform when the DC output of the converter is passed through the inverter and this value of voltage is directly supplied to the grid for utilization.

CHAPTER 6

CONCLUSION AND FUTURE WORK

6.1 Conclusion

The complete analysis started with the discussion of energy and its type, the trends of energy, comparison between renewable and non-renewable sources of energy and how to enhance the reliablility and efficiency of renewable energy mainly the solar energy which is the major source of non-conventional energy sources. After this detailed analysis of photovoltaic system has been carried out which includes the modeling of solar PV module and other components of the whole PV system that is the inverter, batteries, converters and most important the MPPT techniques. Further to this design algorithm for two of the major soft computing techniques use in tracking of MPP the fuzzy logic and adaptive neuro-fuzzy inference system is proposed, which includes the proper designing of membership functions rule base, training of data and finally implementing it to the controller to obtain the duty cycle required by the particular converter as a gate pulse to make PV system works. After the complete designing of two algorithms for tracking MPP detailed analysis of four different DC/DC converters that is Boost, Cuk, SEPIC and finally zeta has been completed which includes the designing of circuit diagram calculation of values of passive components that is inductor and capacitor used in these converters and finally after all this discussion the complete PV system with converter, inverter and grid is simulated in MATLAB/Simulink environment individually with each converter and for both fuzzy based MPPT and ANFIS based MPPT and results of current, voltage and power has been obtained accordingly, the whole analysis is completed for three values of irradiance and temperature considering three different time or we can say position of sun throughout the day and variation due to these changes in the value of voltage and power are recorded accordingly.

After obtaining all the results, these values are summarized in tabular form and efficiency for each converter is evaluated separately which made us to conclude that performance of zeta converter is the best, which is followed by cuk and boost and finally the SEPIC converter when implemented in PV system, conventionally boost converter is used for boosting up the DC voltage in the PV system but by this project this can concluded that application of other converter can enhance the performance and efficiency of the PV system, at last the obtained DC output of each converter has been passed through a three phase inverter which converts this DC output into AC and fed this output to the utility grid.

6.2 Future Work

In this project MPP tracking is achieved by two soft computing techniques that is fuzzy logic and ANFIS, in addition to that performance of grid connected PV system is compared on the implementation of four different types of converter, further research in this field can be achieved by using other soft computing techniques such as artificial neural network or by using some new algorithm for tracking of MPP such as PSO or genetic algorithm, moreover research can also be performed with other different types of existing converters or a converter with totally new configuration that can improve the efficiency and performance of PV panel can be implemented, secondly no research work is done with respect to inverters or grid in this project, however it is also a very vast topic on its own so a much wider research can also be done in field of inverter or grid connected PV system such as fault analysis or efficiency improvement because low efficiency is one of the major problem with solar energy as a renewable source of energy.

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