PERFORMANCE ANALYSIS OF NEURAL NETWORK BASED MPPT CONTROLLER FOR SOLAR PV SYSTEM WITH CONVENTIONAL AND CASCADED BOOST CONVERTERS

DISSERTATION

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Submitted by:

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I, Harsh Kaushik, Roll No(s). 2K20/C&I/02 student of MTech (Control & Instrumentation), hereby declare that the thesis titled "PERFORMANCE ANALYSIS OF NEURAL NETWORK BASED MPPT CONTROLLER FOR SOLAR PV SYSTEM WITH CONVENTIONAL AND CASCADED BOOST CONVERTERS" 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 Associateship, Fellowship or other similar title or recognition.

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CERTIFICATE

I hereby certify that the thesis titled "PERFORMANCE ANALYSIS OF NEURAL NETWORK BASED MPPT CONTROLLER FOR SOLAR PV SYSTEM WITH CONVENTIONAL AND CASCADED BOOST CONVERTERS" which is submitted by Harsh Kaushik, 2K20/C&I/02 [Electrical Engineering Department], Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Among all renewable energy sources, solar photovoltaic (PV) represents a very important and reliable energy source. However, the output of the PV module is limited. The system performance in renewable energy sources is improved using DC - DC converters. Boost converters are used if output voltage higher than the PV module is desired. If further higher voltage step-up ratio is required by the solar PV system for which the performance of traditional boost converter declines, then cascaded boost converter configurations are employed. Also, besides using cascaded converters for voltage improvement, it is desired that photovoltaic (PV) power systems extract maximum power from the solar module for efficient operation. The issue of operating the Solar PV Module at the maximum power point at all operating conditions is resolved by applying maximum power point tracking techniques.

This project is focused on the implementation of P&O based MPPT controllers in solar PV systems for conventional, quadratic and double cascade boost converters connected to a resistive load and investigates their performance at varying solar radiation and ambient temperature.

Then the project is carried forward using Artificial Neural Network as a controlling technique for the MPPT algorithm in order to provide a fast and efficient response from the controller. Furthermore, an impedance load of resistive-inductive type is used to record the performance of the system.

All the work in this project is accomplished through simulation of the power and control circuits using MATLAB/Simulink software and results and waveforms have been recorded accordingly.

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LIST OF ABBREVIATIONS

RES	Renewable Energy Sources
PVSC	Photovoltaic Side Converter
CBC	Conventional Boost Converter
QBC	Quadratic Boost Converter
DCBC	Double Cascaded Boost Converter
MPPT	Maximum Power Point Tracking
MPP	Maximum Power Point
PV	Photovoltaic
SPV	Solar Photovoltaic
PVES	Photovoltaic Energy System
HEMS	Home Energy Management System
ANN	Artificial Neural Network
PWM	Pulse Width Modulation
IGBT	Insulated Gate Bipolar Transistor

CHAPTER 1

INTRODUCTION

1.1 Energy

Evolution of human civilization is based on obtaining and effectively using energy. The fundamentals of every human activity are to secure a fair, sensible and sustainable quality of life. Energy is indispensable for economic and social growth of our world. Energy is vital and an essential factor for all human activity and without these human activities of all kinds and different aspects of growth cannot be imagined.

Energy utilization can be classified on the basis of end products as Electrical, Thermal, and Transportation energy. These energy forms are required for our homes, office buildings, vehicles, and manufacturing. Thus, majority of economic sectors that require energy are: residential, commercial, transportation, and industrial and agricultural.

The amount of Energy consumption works as a differentiator between developed and developing nations. The energy used by a nation indicates its measure of progress and development compared to others. A citizen in a developing country depends mostly on human and animal power while a developed country consumes large quantities of energy for transportation, industrial and agricultural purposes.

Energy demands have increased in a remarkable manner in recent centuries and in the last few decades researchers have sought for various types of energy sources. According to the data based on a study between 1990 to 2008 by The International Energy Agency (IEA), the average energy consumption/person increased by 10%. Also, worldwide renewable energy consumption will increase at the rate of 3.1% per annum between 2018 and 2050 compared with 1.1% growth in natural gas consumption per year, 0.6% annual growth in petroleum and other liquids consumption per year and 0.4% growth in coal consumption per year.

1.2 RENEWABLE ENERGY SOURCES

A sustainable energy source is explained as one that is almost inexhaustible, has much lower emission of greenhouse gasses and does not entail environmental pollutants. Renewable energy sources are carbon-free and appear to be very close to this ideal, as they are restored after they are used or reappears naturally as they get replenished over a period of time.

Renewable energy based electrical power systems in the form of biomass energy systems, hydroelectric systems, photovoltaic systems, wind power systems etc. are successively acquiring a significant part of the electric power network worldwide. In recent decades the use of renewable energy sources has substantially increased. This has allowed both developed and developing countries to reduce their dependence on energy from fossil, nuclear fuels and natural gas.

In addition, it has also contributed in the elimination of the adverse environmental effects of conventional energy systems. According to a study done by the European Commission, by the year 2050 renewable energy sources will establish their sovereignty over the world's energy supply system having Percentage share of different forms.

Renewable energy can be divided into two groups:

1. Solar renewables
2. Non-Solar renewables

1.2.1 Solar renewables

Solar renewables directly or indirectly depend on solar radiation. Solar radiation is directly converted into useful energy with the use of solar thermal energy conversion technology, Solar Photovoltaic (PV) technology. Solar radiation can be indirectly converted into useful energy forms such as hydro, wind, wave and bioenergy.

1.2.2 Non-solar renewables

These types do not depend on solar irradiation and are termed as non-solar renewables. For example, tidal and geothermal energy. Several studies and research are going on and numerous expert studies suggest a bright future for renewable energy systems.

1.3 Solar Energy

Solar renewable energy is the majorly contributing source of renewable energy supplies. With 21st century being called the Solar Age. The sun acts as a gigantic natural fusion reactor which converts hydrogen into helium at the rate of 40 lacs tonnes/seconds. World's annual energy consumption is very trivial compared to the Solar radiation (ten thousand times voluminous). On average, seventeen hundred kWh / (m^2) / year is solarized.

The insolation by the sun at a random point in space, outside the earth's atmosphere, is nearly constant. However, when it reaches the earth, it is affected as a result of three aspects:

1. Relative position of earth with respect to sun
2. Earth's rotation and its axis of rotation
3. Earth's atmosphere

As a result of changes in the relative position of earth with respect to the sun, the sun appears at different places in the sky and thus affects the amount of insolation at any given point on earth. Thus, there will be a continuous need to move our solar devices and also to focus it at different angles at different points of time to capture solar energy in a year.

The earth rotates at constant speed upon its axis, and the axis of rotation is slightly inclined. Due to this, there will be particular positions in the earth's orbit when the sun radiates energy for much time on a particular part of the earth - and thus, that part of earth will be nearer to the sun for that duration of time in a day.

The gasses in the atmosphere remain relatively stable. Out of the insolation, hitting our earth, around nineteen percent of sun energy is absorbed by the atmosphere. Clouds absorb around thirty percent of solar radiation passing through it and thus reveals that effect by casting shadow while moving from place to place.

Also, air-pollutants block some fraction of the solar energy from hitting the earth and the phenomenon is popularly known as global dimming. The solar radiation finally reaching our earth's surface, and the energy out of this actually that can be used, depends solely on the conversion efficiency of present technology.

Now, the question is, how can we harness solar energy? As mentioned, there are several manifestations of solar energy either directly or indirectly, so we have several options to choose from. Solar energy directly uses arc- solar thermal energy conversion into heat and electricity and solar photovoltaic (PV). Solar energy indirect uses are - wind energy, biomass energy, wave energy and hydro energy.

1.4 Solar Energy System

Solar energy systems are designed in a way to accumulate maximum solar energy when it is available and deliver it when needed by the load.

1.4.1 Active Solar Energy System

Active mechanical, electrical devices like photovoltaic panels, solar heat collectors, charge controllers, pumps etc are used in this system to process the heat energy of the sun. An active solar energy system may also have batteries to collect the energy for later use. There are variety of applications such as pumped solar water heater, solar cooking, solar thermal engines for electricity generation, solar photovoltaic (PV) energy system etc.

1.4.2 Passive Solar Energy System

Passive systems use sunlight for air, water, and thermal material for heating, cooling, and ventilation purpose and to store heat energy without active mechanical or electrical devices. They take advantage of natural convection of heat. Thus, materials having thermal properties are selected to store heat energy.

1.4.3 Components of a Solar Energy System

A general PV system is depicted in Figure 1.1. Solar PV array captures the sun's energy from sunlight falling on it. The solar tracking system consists of light sensors such as photodiodes or phototransistors that commands the servo-motor for position control. The output of the PV panel is coupled to a DC / DC converter designed to deliver required current or voltage at load ends to harness maximum power from the PV module.

The switching action of the DC/DC converter is controlled by MPPT controllers which is followed by an inverter which supplies electrical energy both to AC load and the grid connected to it. A battery backup may or may not be connected to provide any shortfall in power which might be unavailable from the PV module during night and cloudy weather.

The components of a general solar energy system are as discussed below:

1. PV modules are connected in various configurations depending on load requirement and rating. It could be a series connection to increase voltage, a parallel connection to fulfill power demand or a suitable combination of both. The direction of the PV module toward the sun might be controlled by the position control servo-motors allowing the motion either single axis or dual axis.

2. The Solar tracker receives data from light sensors and processes it and sends the control signal to a servo motor coupled with a solar panel for the best possible illumination. This is also termed as a mechanical power point tracking technique.

3. The I-V and P-V characteristics of the PV array shows that the electrical maximum power point (MPP) may vary based on load demand or change in ambient conditions. An electrical MPPT controller operates the PV array at the MPP. An electrical MPPT controller controls the power to be derived from the PV panel by switching on and off a DC / DC converter.

4. The battery bank also has another role to store surplus energy from the PV module when the PV module generates more power than the demand.

5. A grid connection may or may not be required depending upon whether the power for domestic AC loads is required or not and more importantly whether standalone generates sufficient units of energy or not.

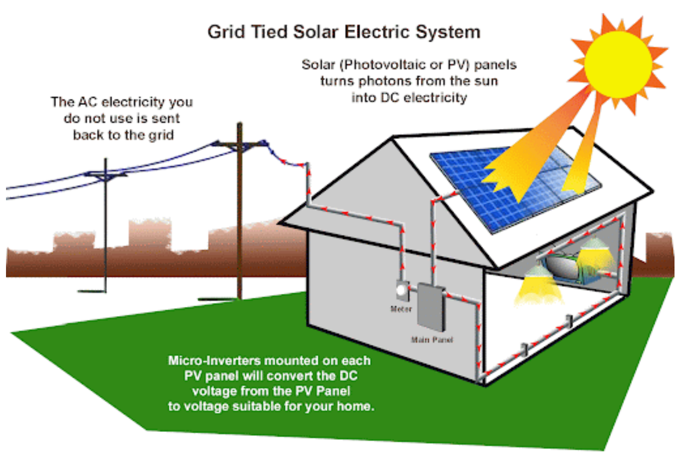

Fig 1.1 Solar PV Model for Home Energy System

1.5 Motivation

The solar photovoltaic electricity generator is a superior renewable energy source (RES). The energy produced is non-polluting, static, noise-free, requires little maintenance, is most promising and above all inexhaustible. Solar photovoltaic (PV) technology directly converts light energy into electrical energy and does not require any other additional energy conversion stage.

The solar PV systems in general can be classified as, Standalone Solar Photovoltaic (PV) system or off-grid system, Grid connected Solar Photovoltaic (PV) system and standalone hybrid solar Photovoltaic (PV) system.

In a pure Standalone solar PV system, solar PV modules are the only source of power whereas in a hybrid standalone solar Photovoltaic (PV) system, a solar PV module works in combination with other energy sources. standalone systems can be configured in different ways by the type of load whether ac, dc or both, converter circuit like boost, buck or buck-boost, requirement of battery backup and need of inverter circuit.

One of the configurations could be a solar PV energy system with DC load and electronics control circuit. The electronic control circuit comprises a DC-DC converter power & and a maximum power point tracker (MPPT). A DC-DC converter regulates the voltage level and thus the current level fed from the PV panel to the DC load and transforms one dc level to another, and hence acts like a de-de transformer. The MPP tracker is a control algorithm and is used to harvest maximum power from the PV modules for all conditions and time.

Boost converter is an important component in a given solar photovoltaic system. Also, it is pertinent to mention that a conventional boost converter may not meet the demand of high boost ratio requirement of the system and shows poor performance as it has to operate at higher duty cycle, resulting in more conduction losses and hence decline in efficiency.

The quadratic and cascaded boost converter comparatively gives a higher voltage boost ratio and shows good converter efficiency. The output power that can be derived from a PV module is limited.

The solar PV module is said to be operating in a steady state, corresponding to a single operating point on the I-V and P-V curve for a given solar irradiance and cell temperature.

The output voltage and current for which the solar module results in the maximum power output, the corresponding operating point is termed as the maximum power point (MPP).

In most PV power systems, a control algorithm called maximum power point tracking (MPPT) is used to harvest maximum available solar energy.

1.6 Objectives

1. To study the basic characteristics of a PV Module Array block from MATLAB Simulink Library, in different solar irradiance and ambient temperature conditions.

2. To compare performance of a conventional boost converter, a basic quadratic boost converter and a basic double cascaded boost converter supplied by Battery.

3. To understand the modeling techniques of different boost converters i.e., a conventional boost converter, a quadratic boost converter and a double cascaded boost converter used in PV systems.

4. To compare performance of a conventional boost converter, a quadratic boost converter and a double cascaded boost converter supplied by PV Module Array without MPPT controller.

5. To study the concepts and design Artificial Neural Network MPPT Algorithm for implementation in the solar PV system.

6. To compare performance of a conventional boost converter, a quadratic boost converter and a double cascaded boost converter supplied by PV Module with a Neural Network based MPPT controller.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

Solar energy is evolving as the most promising renewable energy source for a sustainable future and solar photovoltaics to be the most ideal energy conversion system. The dc-dc boost converter has become an indispensable component in any given solar photovoltaic system due to its low-voltage output limitations. The output power that can be derived from a solar photovoltaic module is limited. Thus, a control algorithm called maximum power point tracking (MPPT) is indispensable to take full advantage of the available solar energy. This chapter deals with the literature review of the research work and developments in the field of solar photovoltaic (PV) energy systems.

2.2 LITERATURE REVIEW

The design of solar PV systems is presented in [1], and a complete overview of PV systems for a constant voltage operation is discussed in [2]. In paper [3] discusses the design and implementation of solar systems on the grid.

An independent MPPT control system is proposed in [4]. A high-density dc-dc converter with integrated inductor and a non-slip snubber is recommended in [5]. A new DC-DC converter with a new step-up is proposed [6], and in novel [7] the DC / DC high step-up converter contains an inductor connected with two duplicate cell voltages to obtain maximum rise. voltage gain.

In [8] a new high step-up dc-dc converter is proposed with two switches running on two operating modes. In [9] researchers experienced ripple cancellation in the dc-dc converter. Of the [10] authors they designed and compared a standard converter with a quadratic boost.

In [11] the quadratic boost converter is taken from the generalized cascaded boost topology with a single switch and a double cascade boost from a combination of two identical boosters connected in tandem. In [12], [13] a comparative analysis of the various MPPT methods was presented.

In [14] the review introduces MPPT control methods that are widely used in solar PV systems. In [15] an in-depth study to address high energy photovoltaic Energy System (PVES) tracking using both the old and modern MPPT techniques. In [16] and [18] strategies for developing DC / DC converter, topology and applications are discussed in combination with inductor and power supply.

For the [17] authors built a bidirectional DC-DC converter for electric vehicles. In [18] the MPPT modified P&O method is used to reduce Steady-State movement and improve tracking performance.

A neural network model MPPT controller is created for PV system in [19] and in [20] various MPPT algorithms are used for photovoltaic system based on PV neural network. [21] Application of artificial neural networks in optimizing MPPT control for standalone solar PV system [22] Estimating the photovoltaic MPPT by artificial neural network

[23] An artificial neural network based MPPT algorithm for solar PV system is stating the neural network model for searching the maximum power point to attain the maximum voltage for the system to perform with high efficiency. [24] Comparison of MPPT using GA optimized ANN employing PI controller for solar PV system with MPPT using incremental conductance is differentiating between the 2 techniques to find the best performing algorithm between them. [25] Solar array modeling and simulation of MPPT using neural network is showing the working of layers of then neural network.

[26] Behavior of neural network MPPT technique on a PV system operating under variable load and irradiation is depicting the various conditions of temperature and irradiance to mimic the day cycle working of the solar panel. [27] neural network-based hybrid MPPT for photovoltaic modules is showing the working of NN module to form a MPPT controller that regulates the maximum voltage of the system.

[28] Efficient MPPT scheme for a photovoltaic generator using neural network finds an efficient way of forming the MPPT module by making it to respond faster and more accurate to have a better controlling action. [29] Networks Technique for Maximum Power Point Tracking of Photovoltaic Array is stating the neural network model for searching the maximum power point to attain the maximum voltage for the system to perform with high efficiency.

[30] An extension neural network based incremental MPPT method for a PV system is stating the neural network model for searching the maximum power point to attain the maximum voltage for the system to perform with high efficiency. [31] Artificial neural network-based fault detection and classification for photovoltaic system is detecting the faults in the solar PV system and showing the results with switching and timing of the system.

[32] Improved design of artificial neural network for MPPT of grid-connected PV systems is stating the neural network model for searching the maximum power point to attain the maximum voltage for the system to perform with high efficiency. [33] Neural Network Based Maximum Power Point Tracking of a Photovoltaic System is stating the neural network model for searching the maximum power point to attain the maximum voltage for the system to perform with high efficiency.

[34] Comparison of several neural network perturb and observe MPPT methods for photovoltaic applications is comparing the different MPPT methods like perturb and observe along with incremental conductance to compare between the two.

[35] An ANN-INC MPPT Strategy for Photovoltaic System is working on the incremental conductance method for the MPPT module. [36] Comparison of ANN and P&O MPPT methods

for PV applications under changing solar irradiation is stating the neural network model for searching the maximum power point to attain the maximum voltage for the system to perform with high efficiency.

[37] Efficiency Enhancement of a Solar Photovoltaic Panel by Maximum Power Point Tracking Using Artificial Neural Network Methodology is stating the neural network model for searching the maximum power point to attain the maximum voltage for the system to perform with high efficiency and [38] An Efficient Neural Network-based MPPT technique for PV Array Under Partial Shading Conditions.

CHAPTER 3

Solar PV Energy System

Solar energy is going to be the most promising renewable energy source (RES) for a sustainable future and probably solar photovoltaics to be the most ideal energy conversion system.

3.1 Solar Photovoltaic (PV) Energy

Electricity can be generated from solar energy by two methods either by using solar thermal engines which produce very high temperature heat and converting it into mechanical energy to drive an electrical generator. A more direct method of generating electricity without any intermediate energy conversion is photovoltaic. Among all solar and non-solar renewable energy sources (RFS) solar photovoltaic (PV) has been proven to be a very reliable energy source.

3.2 Solar Photovoltaic (PV) Energy system

Solar photovoltaic (PV) technology directly converts sunlight into electricity and does not require any other additional energy conversion stage [1]. The solar PV systems in general can be classified in three categories, as

1. Standalone Solar PV energy system,
2. Grid-connected Solar PV energy system
3. Hybrid Solar PV energy system

There are several configurations in which solar photovoltaic (PV) modules and loads can be connected in conjunction with other disposable or indispensable components in PV systems [2].

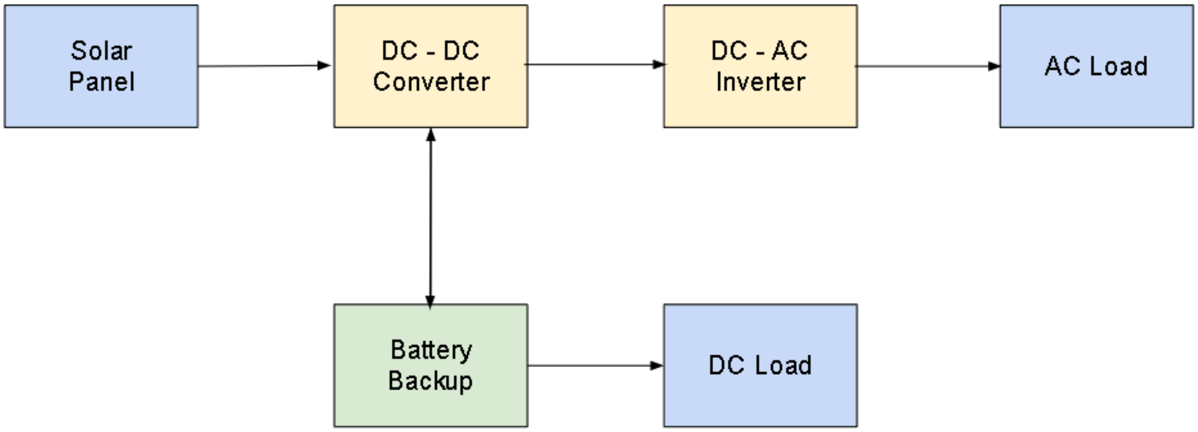

Fig 3.1 Solar PV System Block Diagram

DC power is generated from a Solar PV array but the generated DC voltage amplitude is very low so, a DC-DC converter is added to boost up the voltage and power is sent to two paths. First the power is sent to a Battery Backup to store the electrical power in order to give power to the system at night.

The second path is where the DC power is converted to AC power using an inverter and boosting the voltage using a transformer. Then this AC voltage is sent to power the AC load.

The overall system is controlled by a MPPT module to control the output voltage when the values of Irradiation and Temperature are not according to the set amplitudes to generate maximum power from the PV array system.

CHAPTER 4

DC-DC CONVERTERS

4.1 PVSC (Photovoltaic Side Converter)

Power electronic systems are essential for harnessing renewable energy like wind energy, solar energy using photovoltaics etc. Converter design is a major research area in the field of power electronics. Harnessing of solar energy using photovoltaics, requires dc-dc converters to convert voltages and currents from one dc level to another, and to operate these systems optimally. Besides this, dc-dc converters function also as the fundamental block of conversion between ac and dc voltages, required in applications such as harnessing of wind energy etc.

There are various topologies that are regularly used to implement DC - DC converters, like Buck, Boost and Buck-Boost converters. Each converter's topology has its own advantages and limitations, which makes it best suited for a certain application. A boost topology is selected when output voltage needs to be stepped up more than photovoltaic side voltage.

Conventional boost converter is the widely used boost converter because of its simple circuit configuration and efficient voltage step up behavior. However, it is pertinent to mention that a conventional boost converter may not always fulfill the high voltage step-up transformation ratio requirement of the system.

A possible solution to the problem of obtaining higher voltage step-up ratio is to use other boost converter topologies like cascaded boost converter configurations. Several research works are done on various converters for obtaining high step-up voltage

Thus, the need to have converters having higher voltage conversion ratio with no compromise in performance, brings DC - DC cascaded converters as an optimal solution. Comparison of efficiency is computed by simulation between a conventional boost converter (CBC) a basic quadratic boost converter (QBC) and a basic double cascaded boost converters (DCBC) for constant voltage source, in which it is concluded that the double cascade boost converter exhibits best response.

The DC / DC converter is also known as photovoltaic Side Converter (PVSC) as its input is coupled to the PV link as shown in Fig 4.1. The PV link is realized by capacitor and acts as a filter to maintain a steady voltage at the output of the Solar PV Module. The photovoltaic Side Converter (PVSC) [15] is usually controlled by the maximum power point tracking.

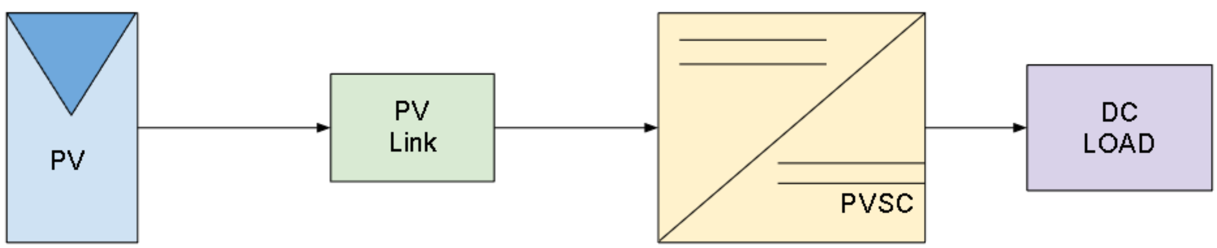

Fig 4.1 Block Diagram of Solar PV System with PVSC

A possible solution to the problem of obtaining higher voltage step-up ratio is to use other boost converter topologies like cascaded boost converter configurations.

4.2 The Conventional Boost Converter

A conventional boost converter basically consists of one capacitor, one inductor, one passive switch (i.e., diode) and one active switch (IGBT). The boost converter operates in two modes.

A conventional boost converter is shown in Fig 4.2.

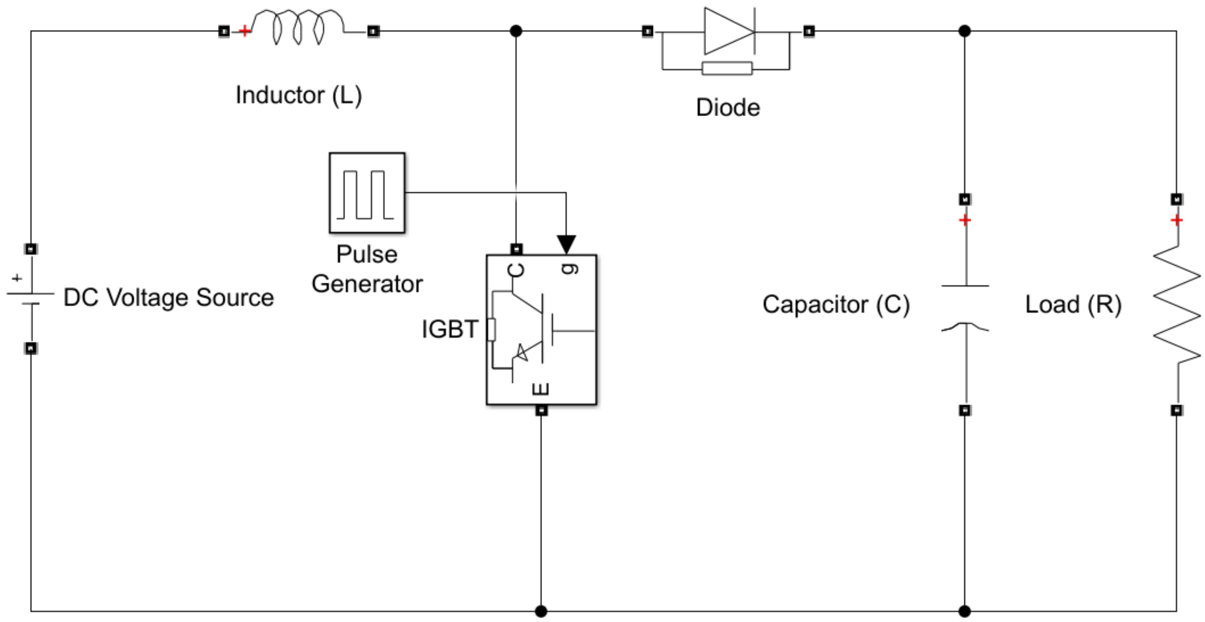

Fig 4.2 Conventional Boost Converter

The mode I circuit of conventional boost converter is given in Fig 4.3. In ON state, the active switch (IGBT) is turned on, whereas the diode, D, is reverse biased.

The inductor, L is energized by the supply voltage from the capacitor, C and magnetic energy gets stored in it. During this state, the inductor current gradually increases [8].

The mode 2 circuit of conventional boost converter is given in Fig 4.4. In off-state, the switch (IGBT) is turned off. The magnetic energy stored in the inductor, L, is discharged via diode D and the capacitor C gets charged.

A high value capacitor Cin, acts as DC-Link. Let Vin is the input voltage, Vout is the output voltage, Δi_L the ripple current, Δv_C the ripple voltage and f be the switching frequency. Then,

Mode 1: On-State

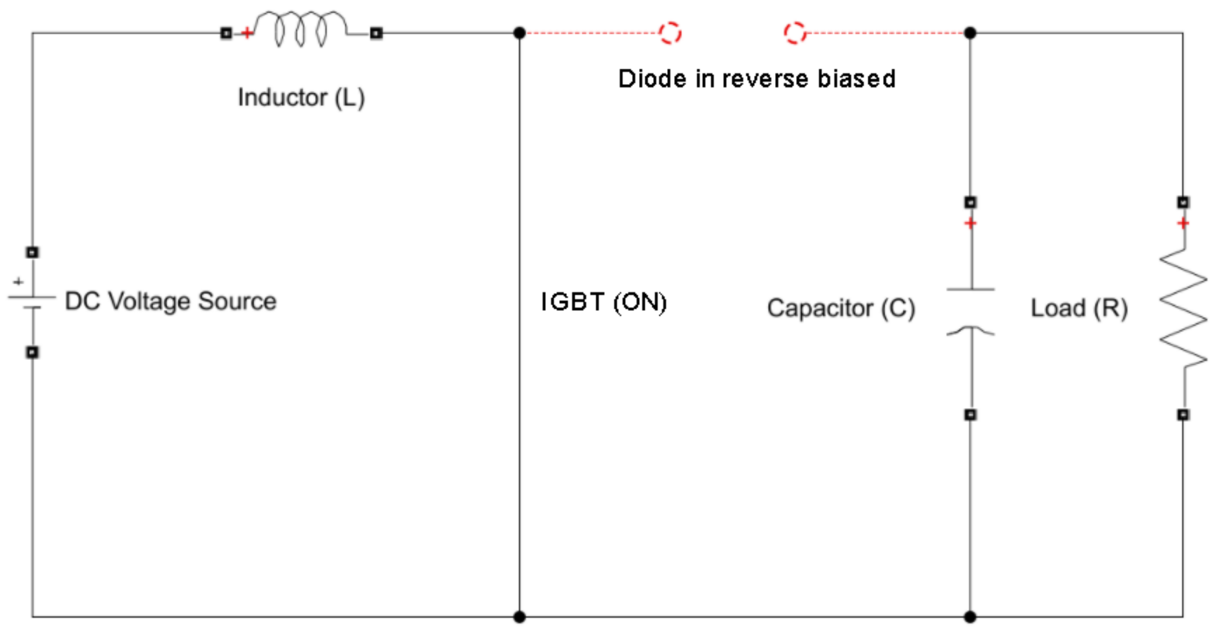

Fig 4.3 Conventional Boost Converter ON State

Mode 2: Off-State

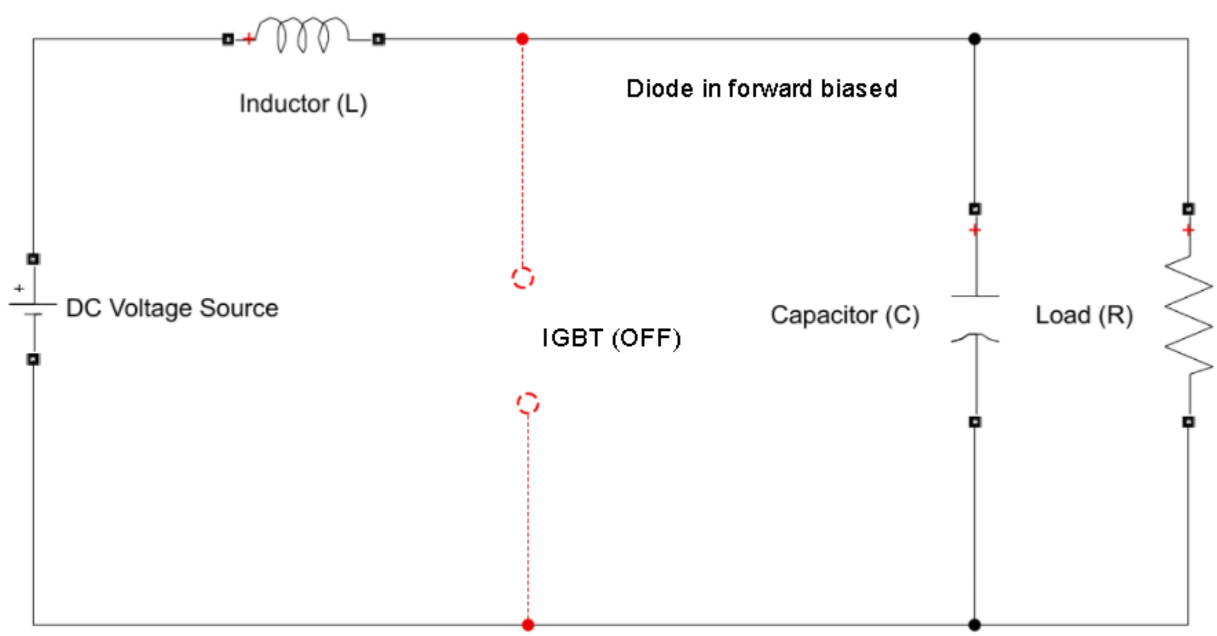

Fig 4.4 Conventional Boost Converter OFF State

The duty cycle is calculated as

$$D = 1 - \frac{v_{in}}{v_{out}} \qquad 4.1$$

The input and output currents are calculated as

$$I_{out} = \frac{V_{out}}{R} \qquad 4.2$$

$$I_{in} = \frac{V_{out}}{(1 - D)} \qquad 4.3$$

The Inductor value is calculated as

$$L = \frac{DV_{in}}{f\Delta i_L} \qquad 4.4$$

The capacitor value is calculated as

$$C = \frac{DV_{out}}{fR\Delta v_C} \qquad 4.5$$

4.3 The Quadratic Boost Converter

A quadratic boost converter is configured by the circuit elements of two boost converters by using a single switch as shown in Fig 4.5.

A quadratic boost converter basically consists of two capacitors, two inductors, three diodes and one switch. The boost converter operates in two possible modes [11].

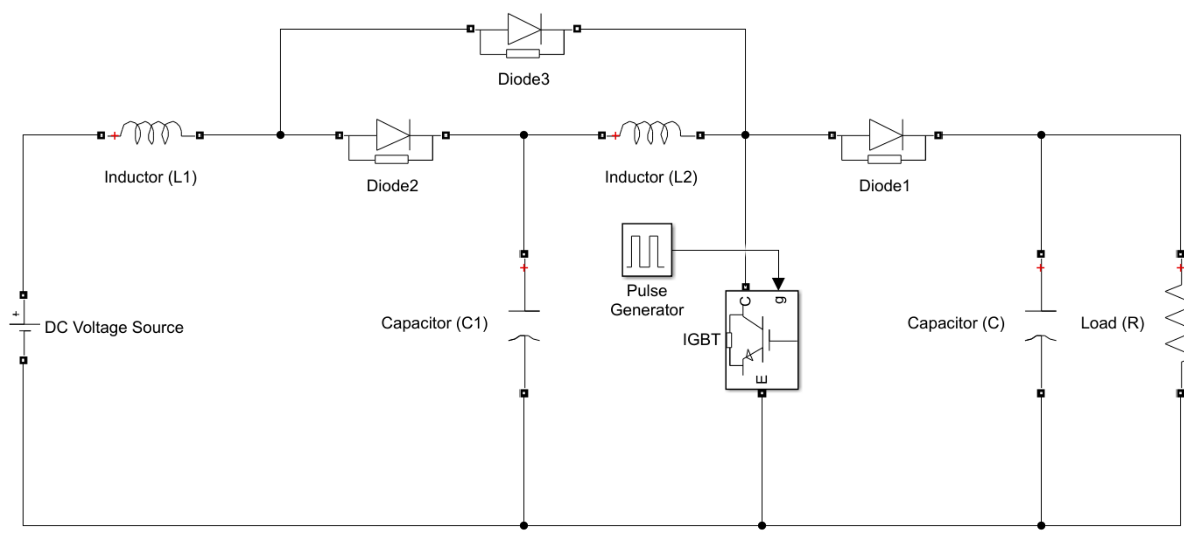

Fig 4.5 Quadratic Boost Converter

The mode 1 circuit of quadratic boost converter is given in Fig 4.6. In ON state, the switch (IGBT) is turned on, D3 is forward biased, whereas DI and D2 are reverse biased. Currents pass through LI and L2 because of Vin and C1 respectively. During this mode of conduction, the inductor current gradually increases.

The mode 2 circuit of quadratic boost converter is given in Fig 4.7. In the off state, switch (IGBT) is turned off, D3 is reverse biased, whereas DI and D2 are forward biased.

The energy stored in the inductors L1 and L2 changes its polarity to charge the capacitor C1 and C2 through the diode D1 and D2 respectively. During this state, the inductor current decreases gradually [10].

A high value capacitor Cin, acts as DC-Link. The LI cannot be connected in series to the PV module, modeled as a current source, thus this problem is rectified by adding a high-value resistance in parallel with inductor L1. Let f be the switching frequency. Then,

Mode 2: ON-State

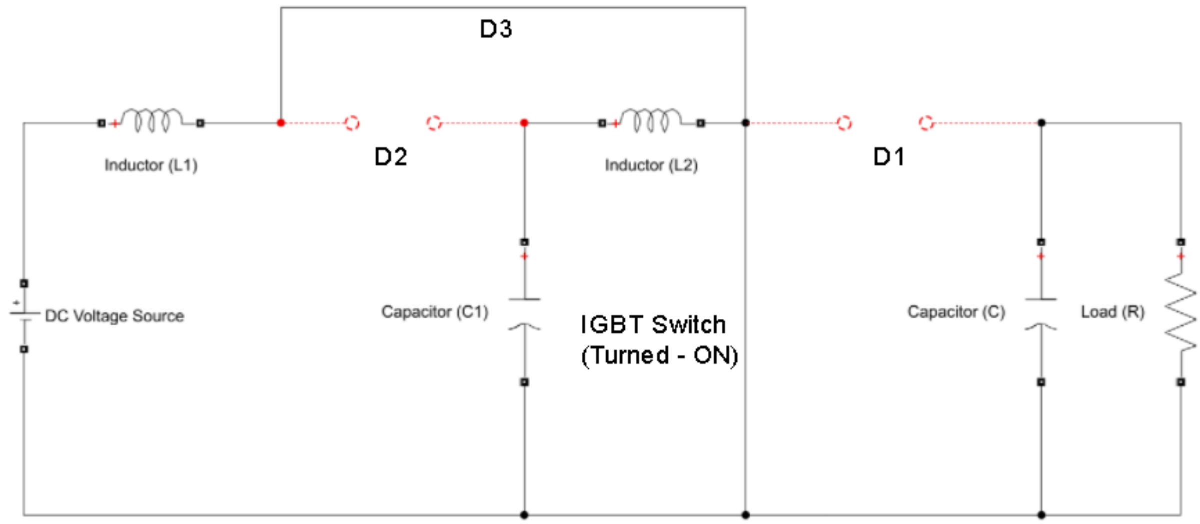

Fig 4.6 Quadratic Boost Converter ON State

Mode 2: Off-State

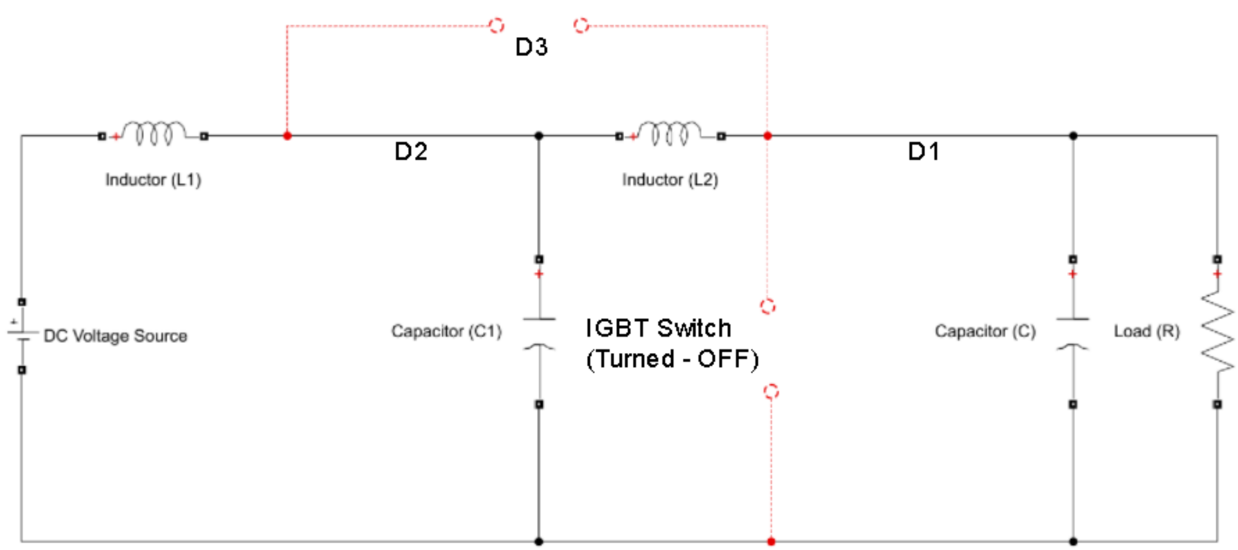

Fig 4.7 Quadratic Boost Converter OFF State

The duty cycle is calculated as

$$D = 1 - \frac{\sqrt{V}_{in}}{\sqrt{V}_{out}} \quad 4.6$$

The input and output currents are calculated

$$I_{out} = \frac{V_{out}}{R} \quad 4.7$$

$$I_{L1} = \frac{I_{out}}{(1 - D^2)} \quad 4.8$$

$$I_{L2} = \frac{I_{out}}{(1 - D)} \quad 4.9$$

The Inductor values are calculated as

$$L_1 = \frac{DV_{in}}{f\Delta i_{L1}} \quad 4.10$$

$$L_2 = \frac{DV_{in}}{f\Delta i_{L2}} \quad 4.11$$

The Capacitor values are calculated as

$$C_{1,2} = \frac{DV_{in}}{fR\Delta v_C(1 - D)} \quad 4.12$$

4.4 The Double Cascaded Boost Converter

A double cascade boost converter is basically evolved by associating two identical elementary boosts connected in tandem, as shown in Fig 4.8.

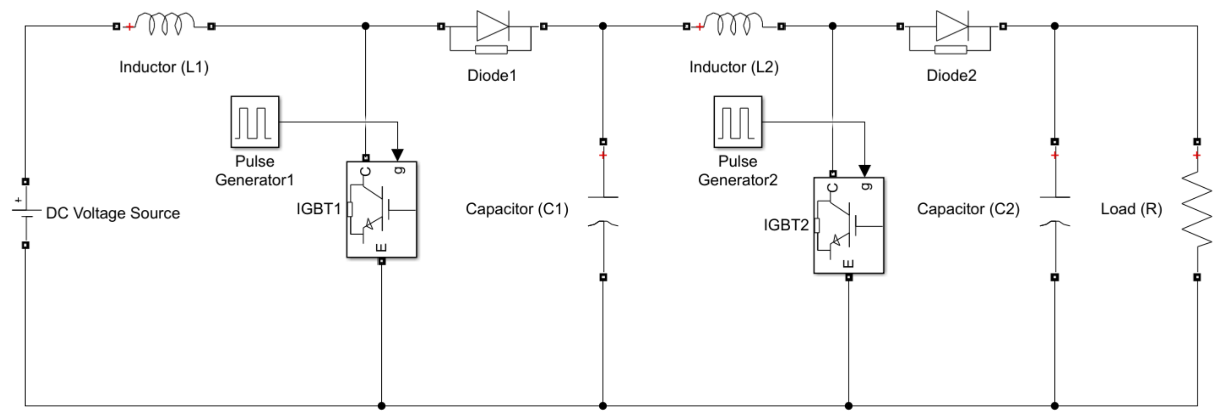

Fig 4.8 Double Cascaded Boost Converter

It consists of one input voltage source Vin, two numbers of independently controlled active switches IGBT 1 and IGBT 2, two numbers of freewheeling diodes DI and D2, two numbers of capacitors Cl and C2 and two numbers of inductors L1 and L.2. The double cascaded boost converter operates in two possible modes of operation in continuous mode.

Mode 1: On-State

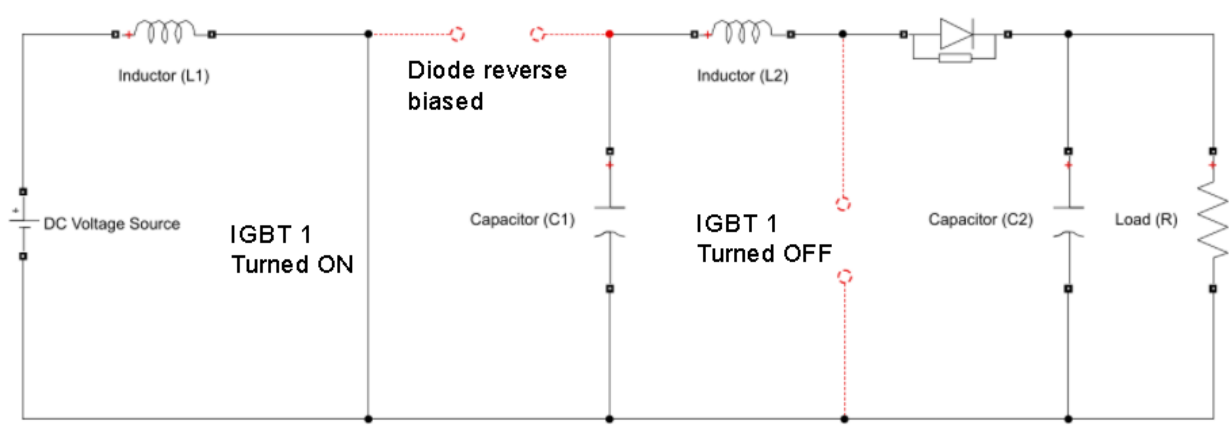

Fig 4.9 Double Cascaded Boost Converter ON State

The mode 1 circuit of double cascaded boost converter is given in Fig 4.9. In on-state, the switch IGBT 1 is turned on, IGBT2 will remain off, D1 is reverse biased and D2 is forward biased. The inductor L1 stores the energy [7].

Mode 2: Off-State

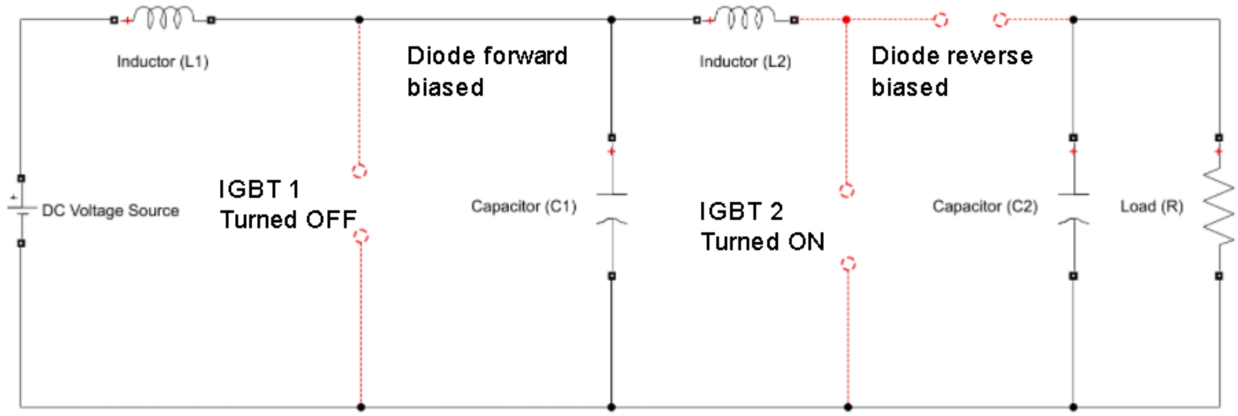

Fig 4.10 Double Cascaded Boost Converter OFF State

The mode 2 circuit of double cascaded boost converter is given in Fig 4.10. In Off-state, the switch IGBT 1 is turned off, IGBT2 will get turned on, D1 becomes forward biased and D2 is reverse biased.

A high value capacitor Cin, acts as DC-Link. Let f be the switching frequency and D1 and D2. Then,

The voltage ratio is calculated as:

$$\frac{V_{in}}{V_{out}} = \frac{1}{(1 - D_1)(1 - D_2)} \quad 4.13$$

The output and inductor currents are calculated as

$$I_{out} = \frac{V_{out}}{R} \quad 4.14$$

$$I_{L1} = \frac{I_{out}}{(1 - D_1)} \tag{4.15}$$

$$I_{L2} = \frac{I_{out}}{(1 - D_2)} \tag{4.16}$$

The Inductor values are calculated as

$$L_1 = \frac{D_1 V_{in}}{f \Delta i_{L1}} \tag{4.17}$$

$$L_2 = \frac{D_2 V_{in}}{f \Delta i_{L2}} \tag{4.18}$$

The Capacitor values are calculated as

$$C_1 = \frac{D_1 V_{in}}{f R \Delta v_{C1}} \tag{4.19}$$

$$C_2 = \frac{D_2 V_{out}}{f R \Delta v_{C2}} \tag{4.20}$$

Where, V1 is the output voltage for the first boost stage.

For all the above converters, the switching frequency is taken as 50khz, the peak-to-peak ripple voltage of the PV module is specified as 0.2V, and peak to peak ripple of the inductor current is specified as 1A.

CHAPTER 5

NEURAL NETWORK BASED MAXIMUM POWER POINT TRACKING

5.1 Maximum Power Point Tracking

PV systems are desired to operate at their maximum output power levels in all operating conditions i.e., for all possible combinations of ambient temperature and solar irradiation level [17] at all the time. The output voltage, current and power of a solar photovoltaic system vary as functions of solar irradiation level, temperature for a given load [13].

Thus, most of the time the operating point of the solar panel neither coincides nor stays stable at the maximum power point. To overcome the adverse effects of the variable temperature and solar irradiation on the output power of PV systems, two different control strategies have usually been applied: (a) controlling the solar power input to the PV array (b) controlling the electrical power output from the PV array.

The solar-tracking method is used to maximize the solar power input and is a mechanical tracking - where the solar panels are on a mount that follows the sun [14]. A maximum power point tracking (MPPT) is a control algorithm used to extract maximum electrical power output possible from the PV module and is an electrical tracking [4].

The electrical MPPT control techniques are categorized into following types:

(1) On-line control techniques

(a) Perturb and Observe (P&O)

(b) Incremental conductance (InCond) techniques.

(2) Artificial intelligence (Al) based control techniques

(a) fuzzy logic control (FLC) technique

(b) artificial neural network (ANN) technique

(c) genetic algorithm (GA) etc.

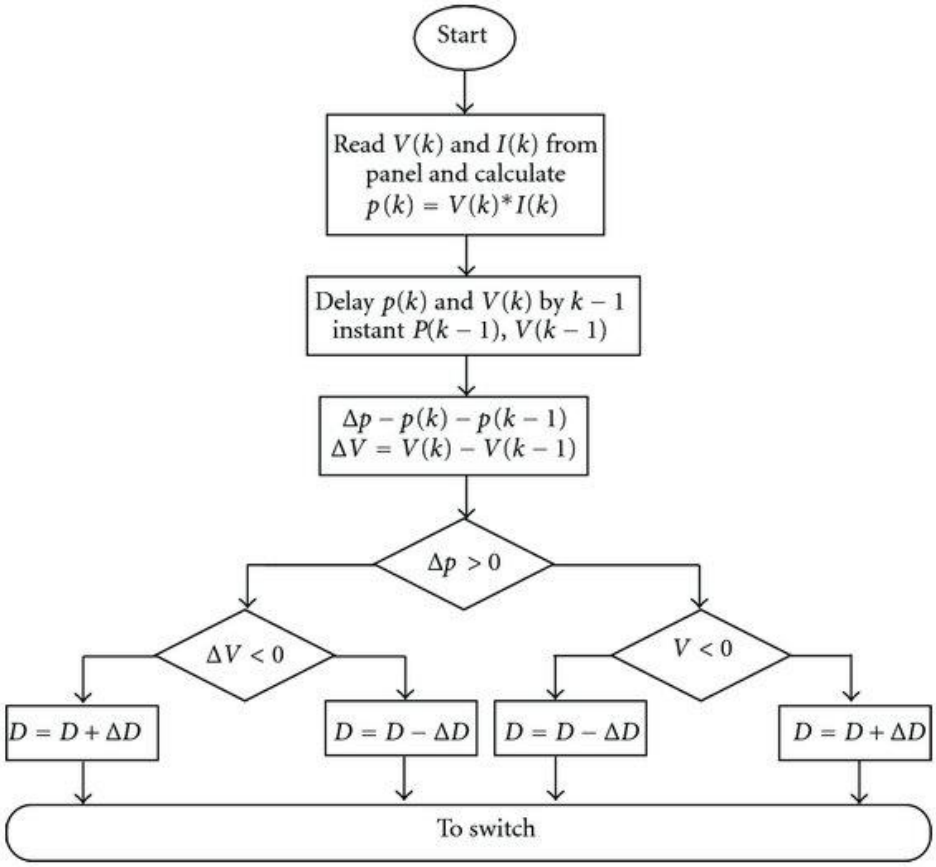

Fig 5.1 P&O based MPPT Algorithm

Several research work and experiments are going on to develop and evolve old control algorithms and to introduce novel control techniques for harvesting the maximum energy from the solar panel.

The issue of operating the Solar PV Module at the maximum power point at various operating conditions is resolved by applying maximum power point tracking techniques.

By using artificial neural network (ANN) - in which the algorithm is learned by applying a given set of data from pre-knowledge of experts and experiments to an artificial neural network.

The network is thus trained using this data and in a similar way the fuzzy rule table is completed by using previously trained data to estimate the rest of the data.

5.2 Neural Network Logic

The ANN logic consists of input layer, hidden layer and output layer consisting of some biasing with some weights between input layer, hidden layer and output layer. Each node or neuron connects to another and has an associated weight or threshold [27].

If the output of any individual node is above the specific threshold value, that node is activated sending data to the next layer of the network [29]. Otherwise, no data is passed along to the next layer of the network.

The input from the solar PV array as Irradiance and Temperature and output voltage at maximum power point of the system, present in the logic are known. The model trains itself for different values of Irradiation and Temperature to create a Simulink block [30] to be used as MPPT controller.

The output of this controller is a duty cycle which is converted to a pulse using a PWM converter, which is fed to the gate of the IGBT part of the system in order to extract maximum power [28] from the PV module.

The Neural Network model is shown in Fig 5.2.

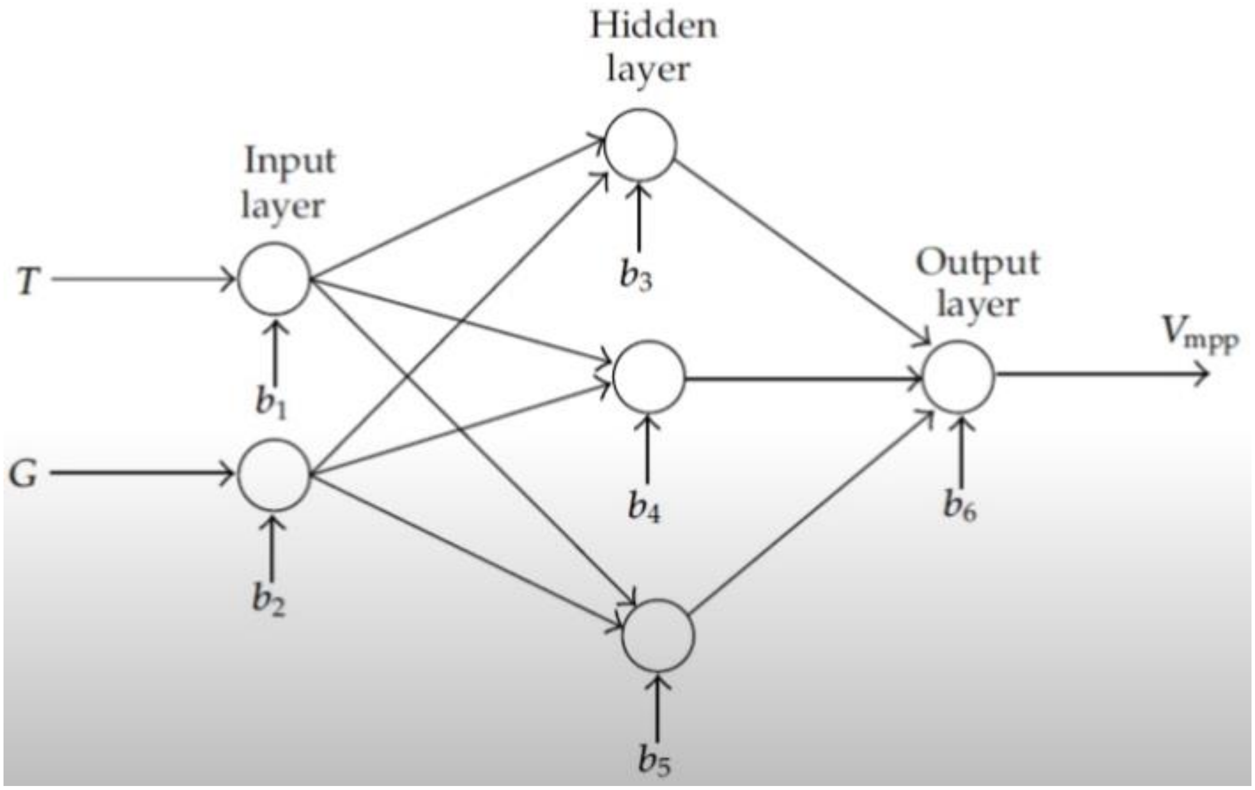

Fig 5.2 Neural Network

5.3 Neural Network Dataset

The dataset for the model is calculated using the input and output range of values [19]. The range of the values are taken as below:

Temperature: -

1. Minimum Temperature: - 15^{o}C
2. Maximum Temperature: - 45^{o}C
3. Standard Temperature: - 25^{o}C

Irradiance Range is from 0 to 1000 watts per meter square

The input dataset is showing the blue waveform which is Irradiation from the solar PV array with it range from 0 to 1000 and the red colored waveform is the second input which is Temperature in degree Celsius ranging from 15 to 45 shown in Fig 5.3.

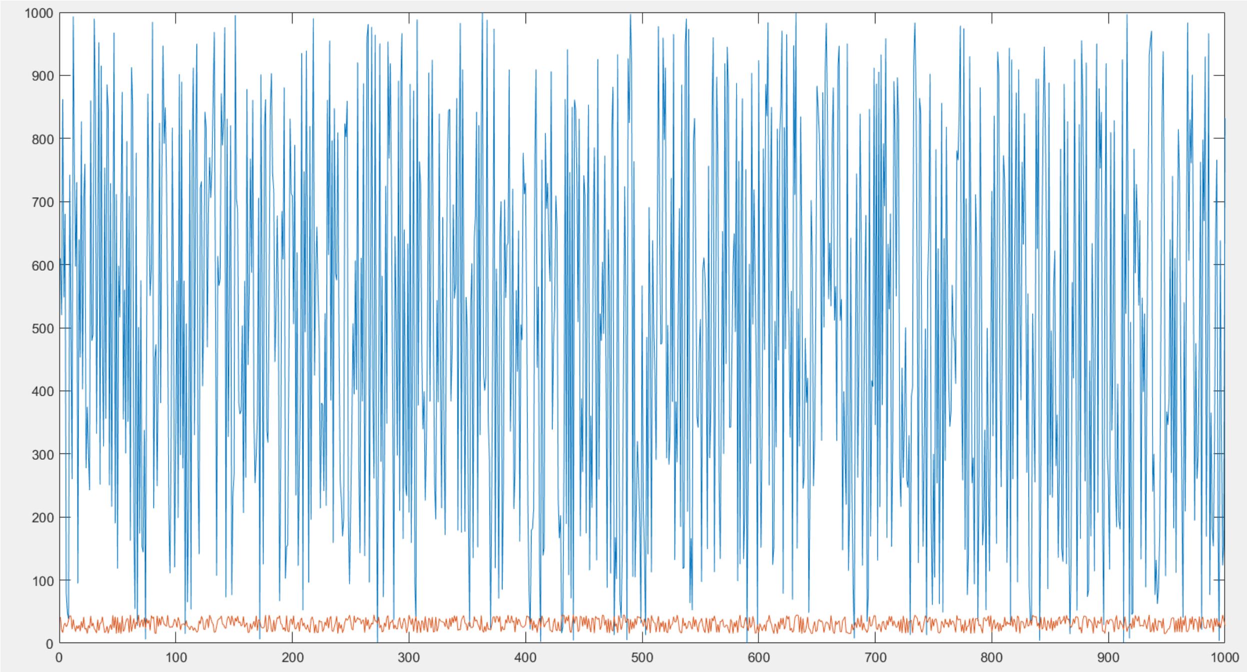

Fig 5.3 Neural Network Input Dataset

Using the formulas and calculations in the MATLAB software the output waveform is generated which is the output voltage [20] from the solar PV system shown in Fig 5.4.

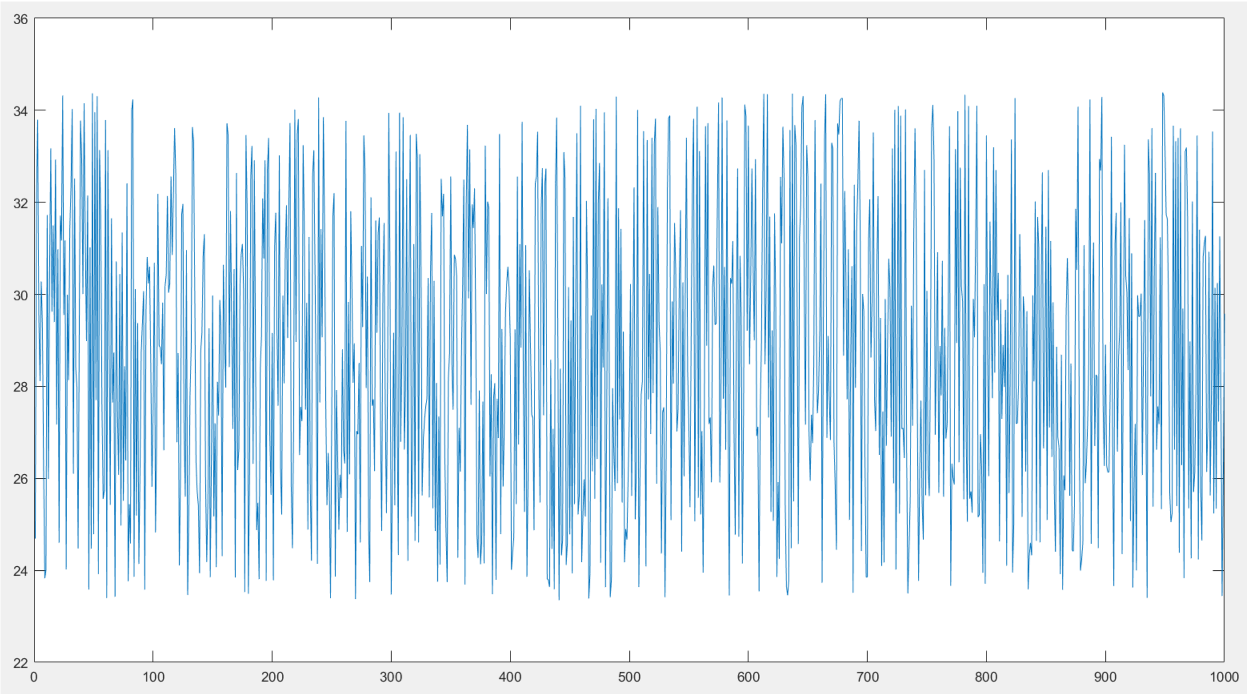

Fig 5.4 Neural Network Output Dataset

5.4 Controller Design Using ANN Toolbox

After getting the input and output values we need a Simulink block to be used in the MPPT controller, for this enter the Neural Network toolbox using the command nnstart and begin with input-output curve fitting app. Use the input dataset as input for the model and output as target for training the ANN model.

Using the default value of 10 neurons in the hidden layer and Levenberg-Marquardt [33] as the training algorithm to complete the training and find the epoch values. Total number of iterations used are 1000 for different combinations of input and output as shown in Fig 5.5. In the output plot shown in Fig 5.6 all the plots have R=1 showing that trained data and the trained data has matched with the given data meaning the model is well trained [34]. If the trained and given data was not matched then the value of R would be less than 1.

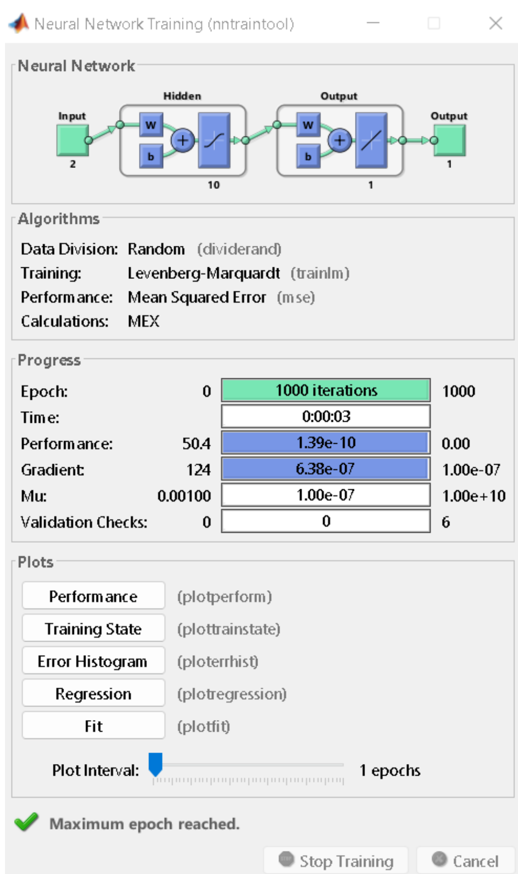

Fig 5.5 ANN Toolbox Training

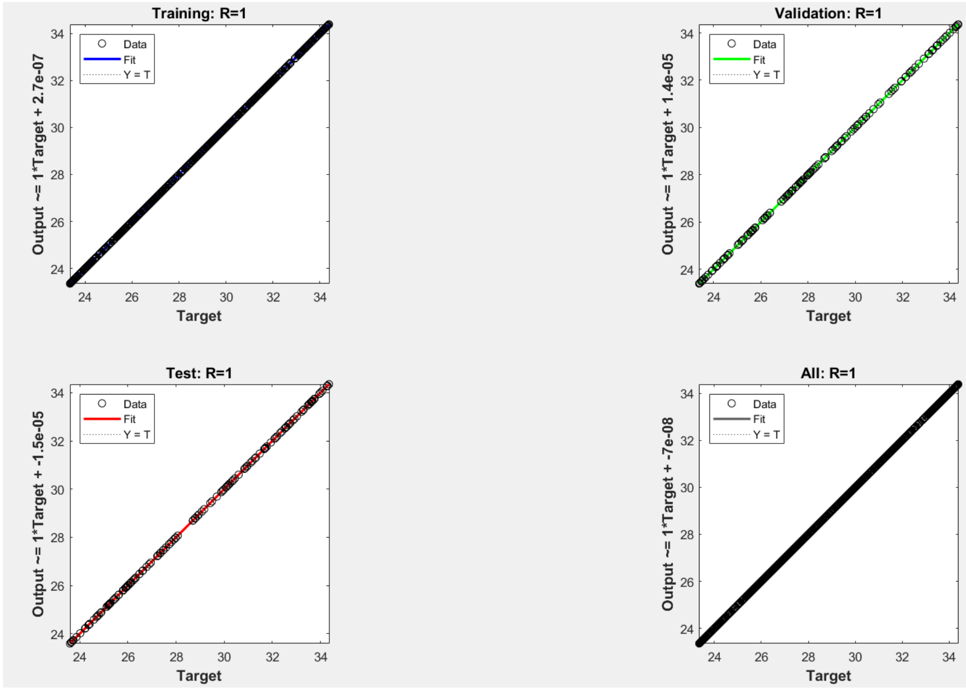

Fig 5.6 Input to Output Targets Plot

5.5 Neural Network Simulink Block

When the training is completed, the trained model is converted to a Simulink model as shown in Fig 5.7.

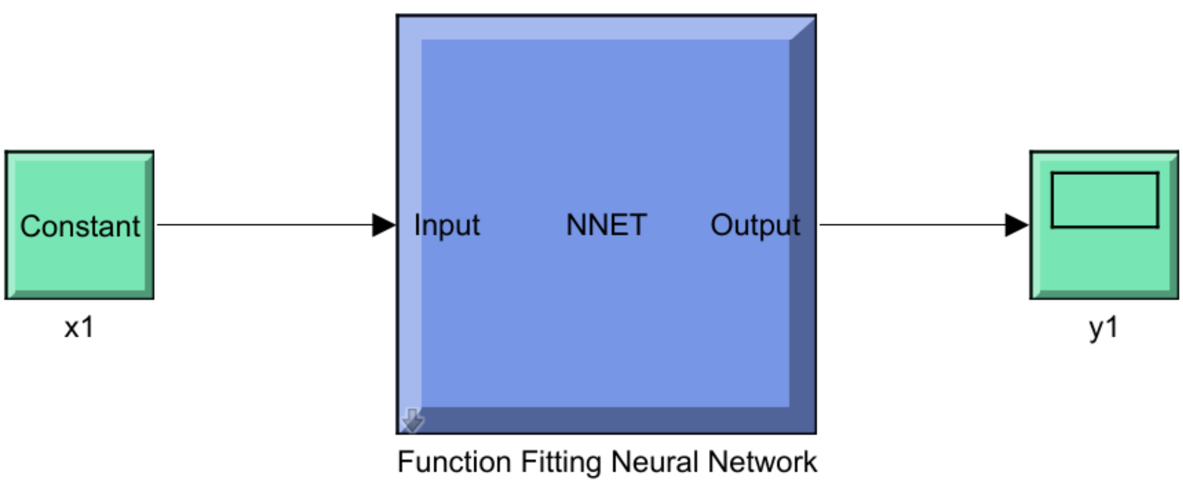

Fig 5.7 ANN Simulink Model

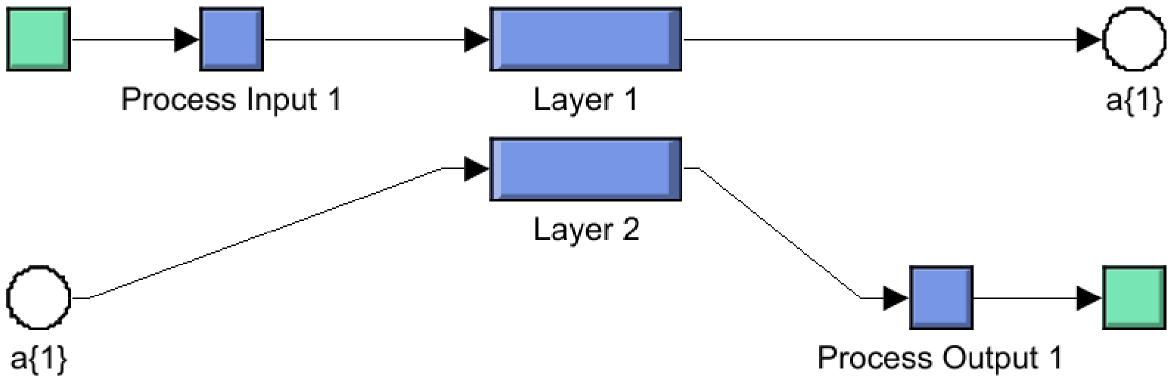

Fig 5.8 Internal model of Function Fitting Neural Network Block

In this model there are two layers shown in Fig 5.8 as required by the training model [36]. Within each layer there are weights, biasing, delay blocks and timing processes [37] shown in Fig 5.9 and 5.11.

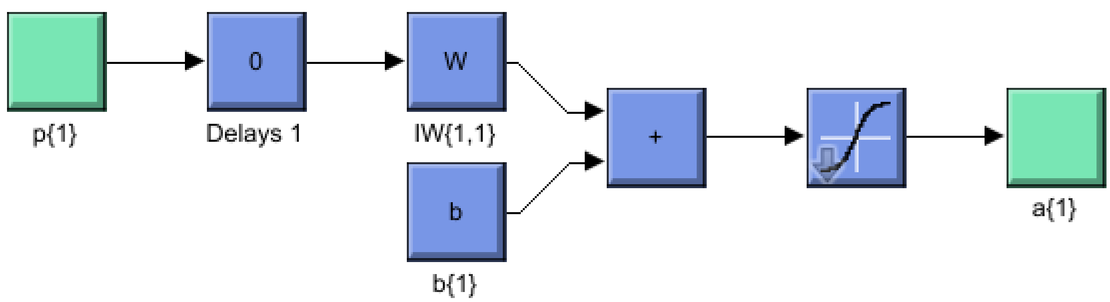

Fig 5.9 Layer 1 Simulink Diagram

In order to create a MPPT controller taking Irradiance and Temperature as input and voltage as output. The weight model is shown in Fig 5.10 which is present in both the layers.

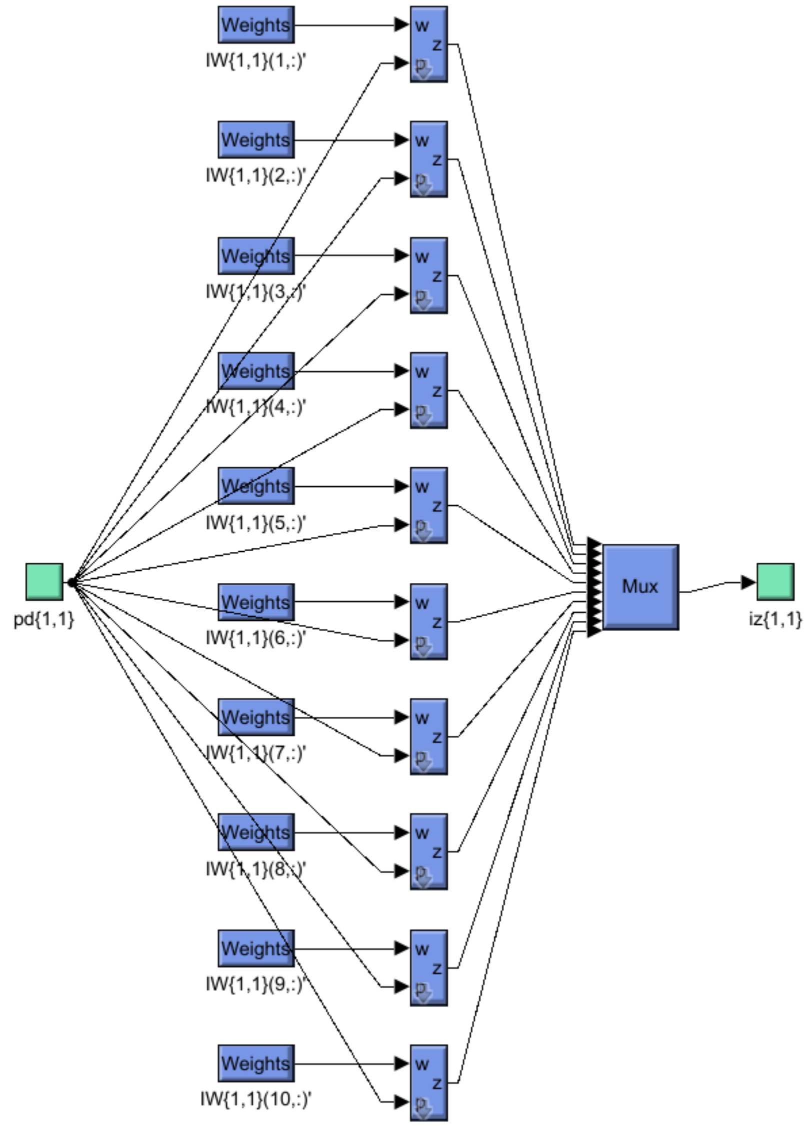

Fig 5.10 Weighted Block of Layer 1

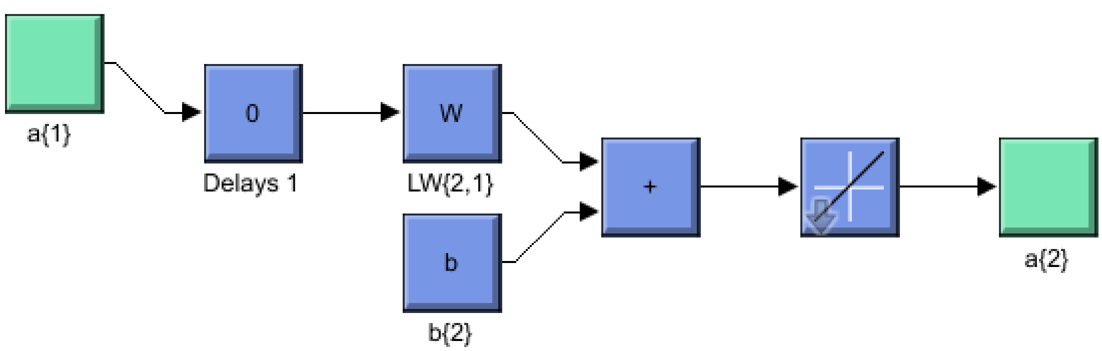

Fig 5.11 Layer 2 Simulink Diagram

CHAPTER 6

SIMULATIONS AND RESULTS

The Simulink model for the whole analysis system is shown below in Figure 6.1. It is divided into three parts: the first PV array and the second DC/DC converter operated with the MPPT technology used to deliver high power to the PV panel and the third part is a continuous load.

The Model consists of the following parts:

1. PV Array
2. DC/DC Converter
3. MPPT Controller
4. Load

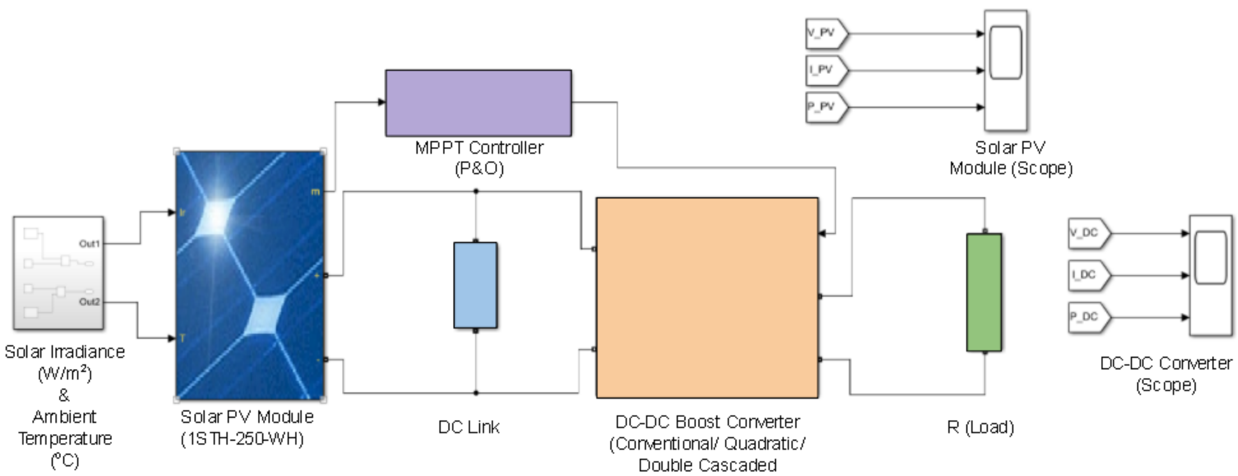

Fig 6.1 Solar PV System with MPPT Controller

The PV array consists of 47 parallel strings and 10 series connected modules. The main features of the preset PV module are given in Table 6.1. The voltage from the PV array is around 300V and after boosting up the voltage using boost converters the voltage is 480V keeping the power as constant. Using a manual switch to move from constant to variable values of Irradiance and Temperature, in order to vary the input signal builder block is used with sample time of each pulse paired with amplitudes. The I-V and P-V features of the PV system are shown in Figure 6.2.

Table 6.1: Characteristics of 1SOLTECH 1STH-250-WH

Specifications	**Values**
Maximum Power (Pmax)	250 Watt
Open-circuit voltage (V_{OC})	37.3 Volt
Short-circuit current (I_{SC})	8.66 Amp
Voltage at maximum power point (V_{MPP})	30.7 Volt
Current at maximum power point (I_{MPP})	8.15 Amp

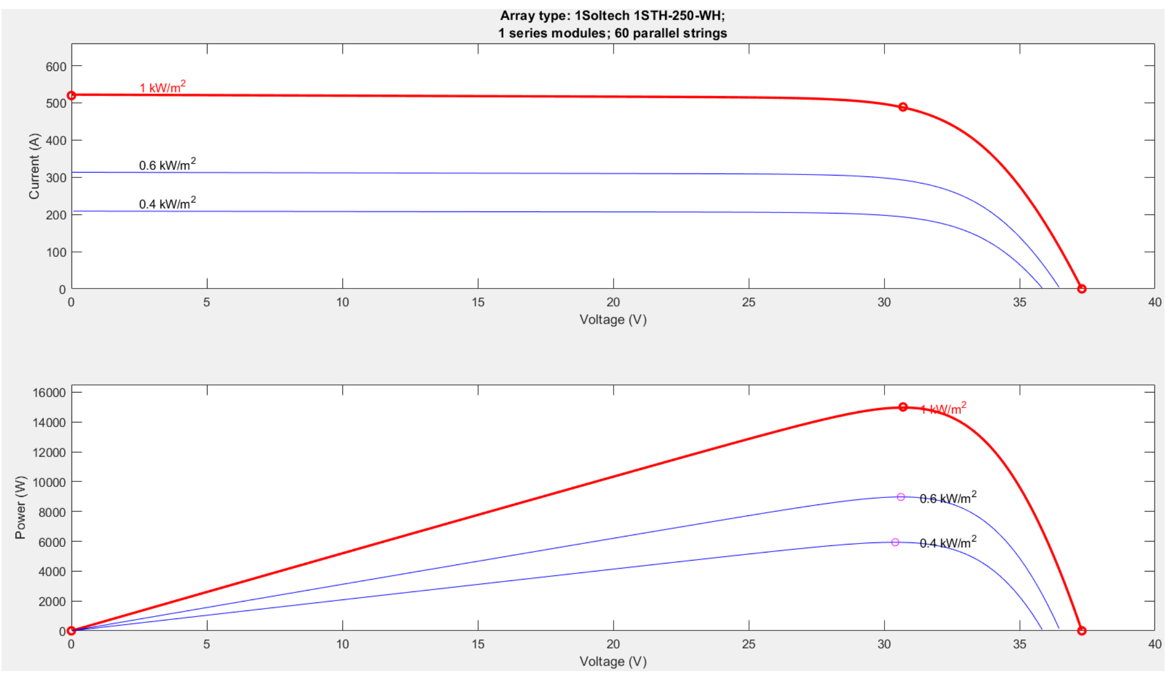

Fig 6.2 PV characteristics of array for different combinations of solar irradiance and temperature

Signal Builder Input plots for Solar Irradiance values: 400 W/m^2, 600 W/m^2 and 1000 W/m^2 at ambient temperature 25°C is shown in Figure 6.3 and for Solar irradiance 1000 W/m^2 at ambient temperature of 25^{o}C, 35^{o}C and 45^{o}C is shown in Figure 6.4.

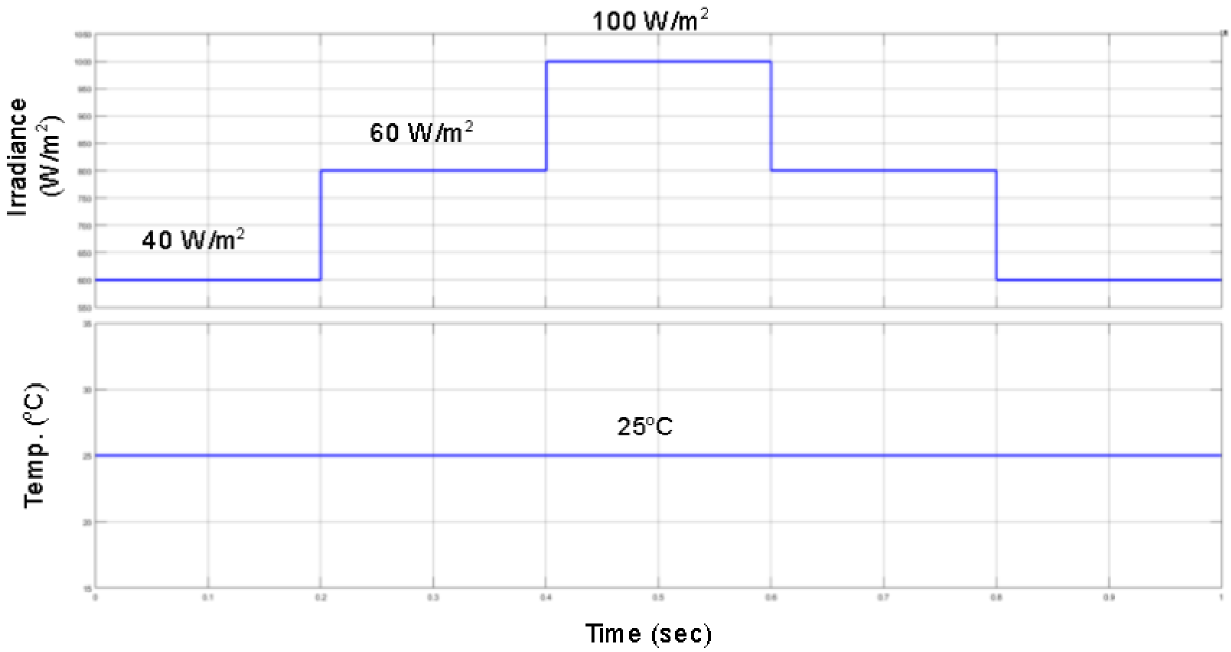

Fig 6.3 Signal Builder Input for Solar Irradiance values:
400 W/m^2 , 600 W/m^2 and 1000 W/m^2 at ambient temperature 25°C

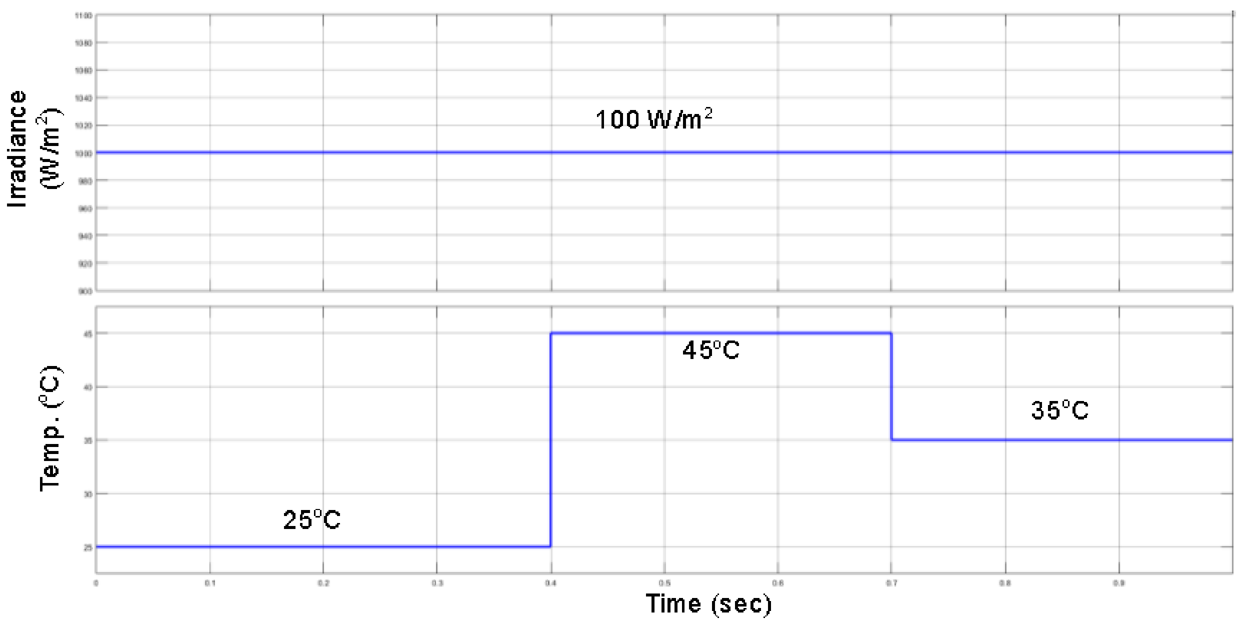

Fig 6.4 Signal Builder Input for Solar Irradiance values:
1000 W/m^2 at ambient temperatures of 25°C, 35°C, 45°C

6.1 Solar PV System with Conventional Boost Converter

The output waveforms of voltage, current and power of the system in standard ambient mode 1000 W/m^2, 25^{o}C is shown in Figure 6.5 and combinations of different solar irradiance and temperature are shown in Figures 6.6 and 6.7.

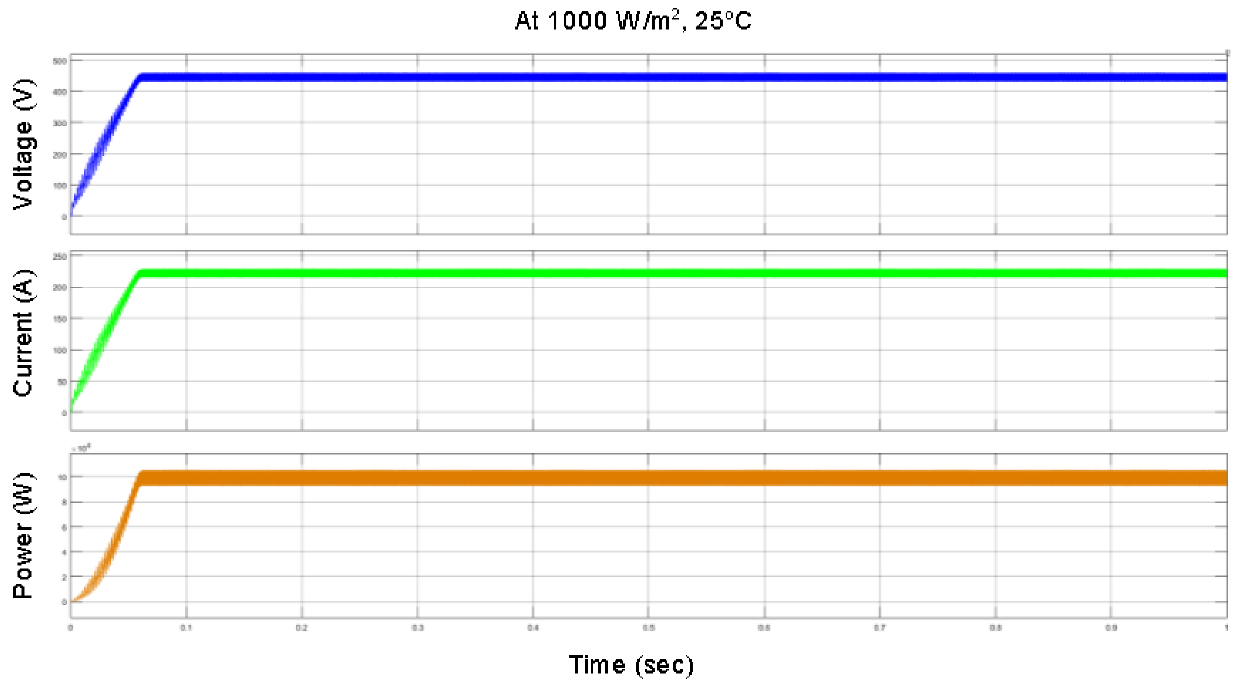

Fig 6.5 CBC Output Waveforms at standard conditions

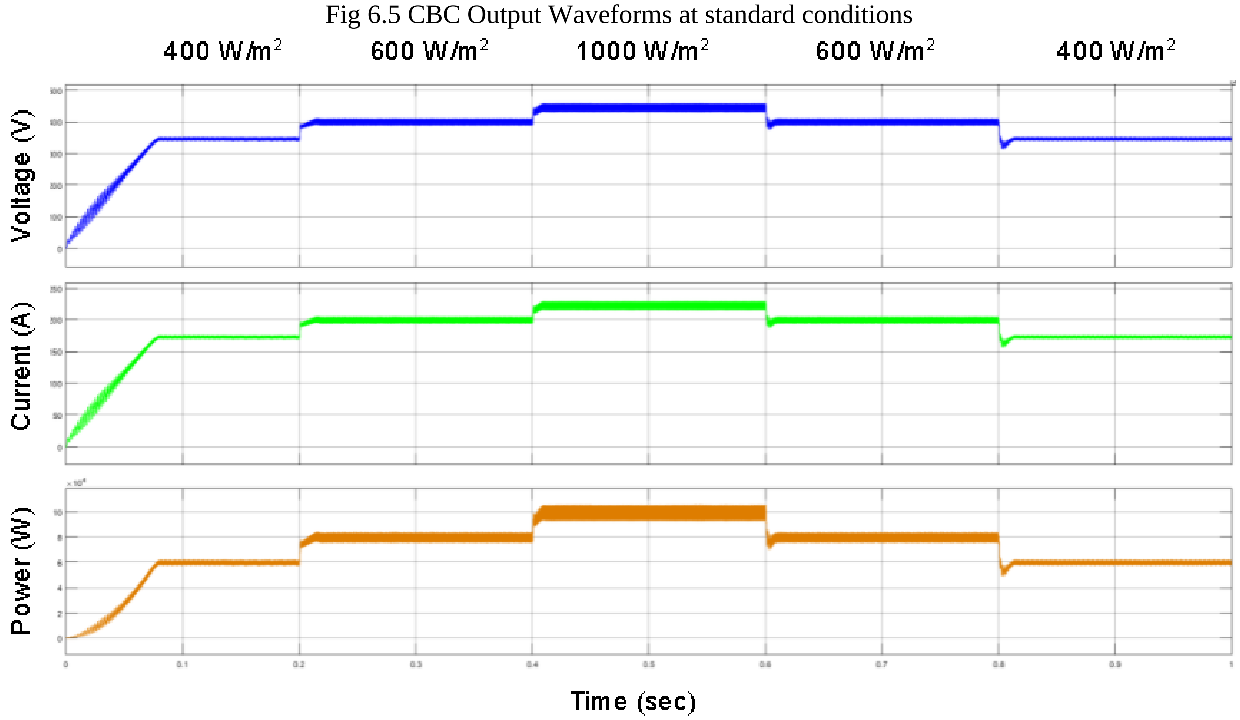

Fig 6.6 CBC Output waveforms at 25^{O}C temperature with different irradiation

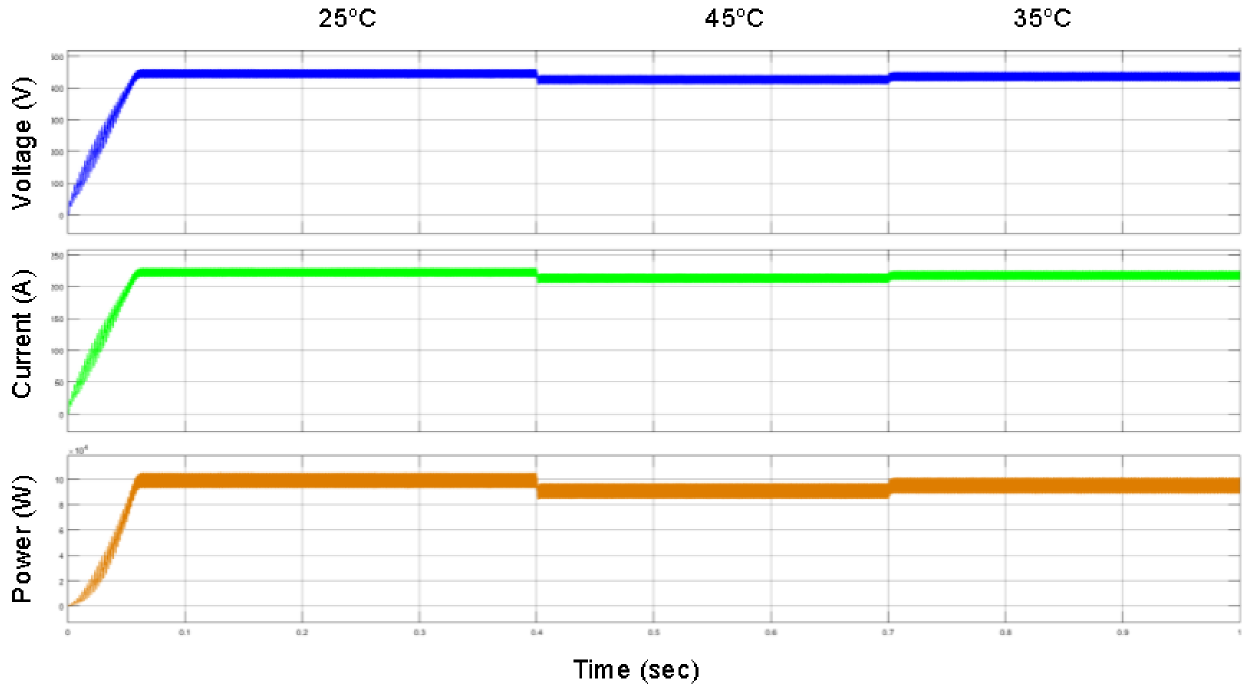

Fig 6.7 CBC Output Waveforms at irradiation = 1000 W/m^2 at different temperatures

The results have been summarized in Table 6.2, the columns are specified as Irradiance/Temperature, Maximum Power point of PV Module, Power of Solar PV Module and MPPT Efficiency.

Table 6.2: Performance analysis of solar PV system connected to CBC with P&O based MPPT Controller

Irradiance (W/m^2)/ Temperature (℃)	**Maximum Power point of PV Module P_{MPP} (W)**	**Power of Solar PV Module P_{PV} (W)**	**MPPT Efficiency η (%)**
400 / 25	60	54	90%
600 / 25	80	74	93%
1000 / 25	100	95	95%
1000 / 35	90	76	85%
1000 / 45	85	70	83%

6.2 Solar PV System with Quadratic Boost Converter

The output waveforms of voltage, current and power of the system in standard ambient mode 1000 W/m^2, 25^{o}C is shown in Figure 6.8 and with different combinations of solar irradiance and temperature, shown in Figures 6.9 and 6.10.

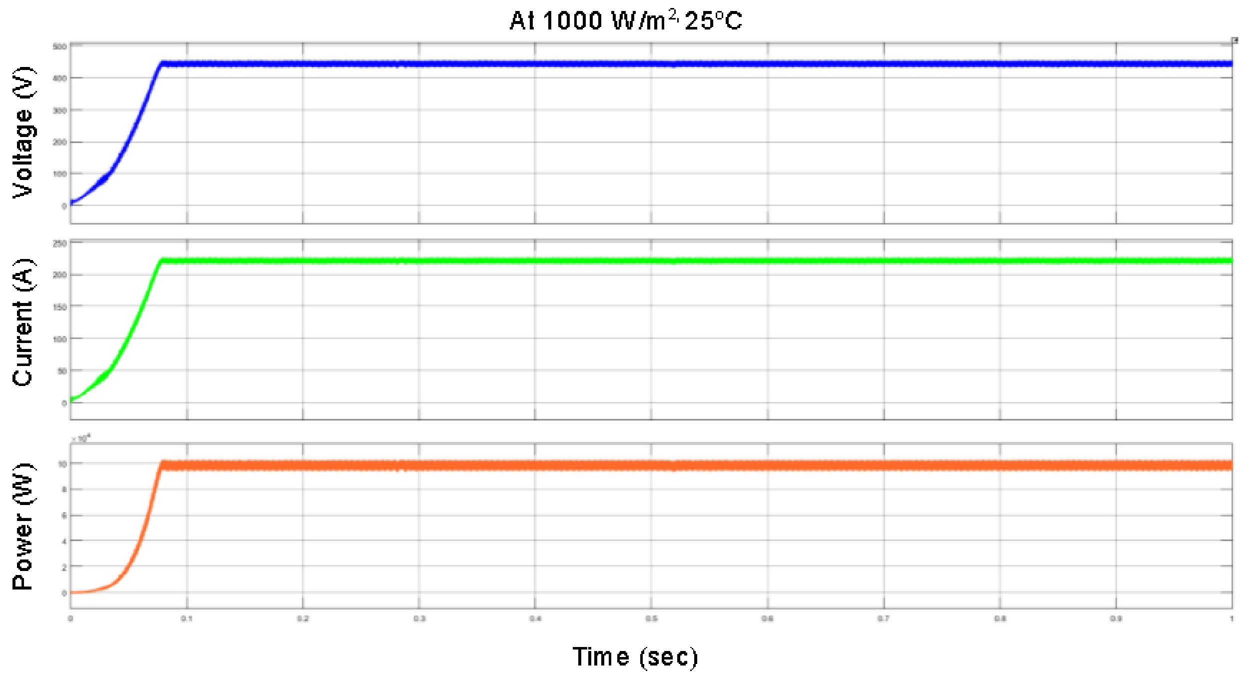

Fig 6.8 QBC Output Waveforms at standard conditions

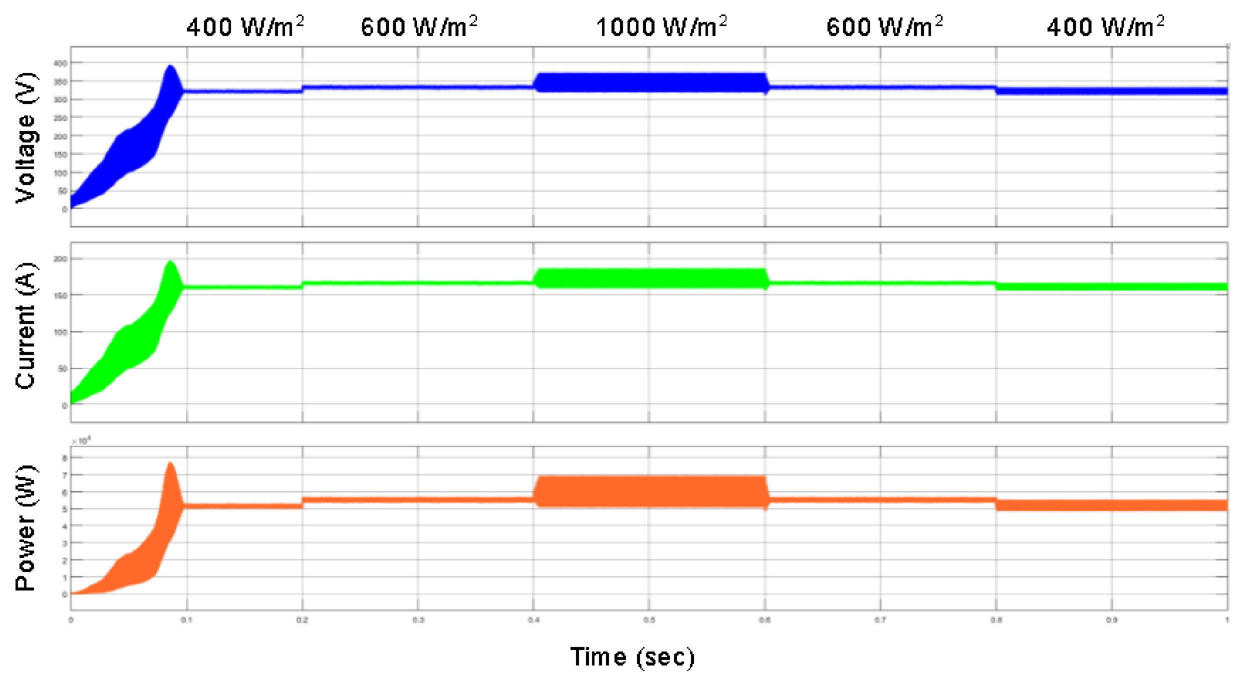

Fig 6.9 QBC Output Waveforms at 25^{O}C temperature with different irradiation

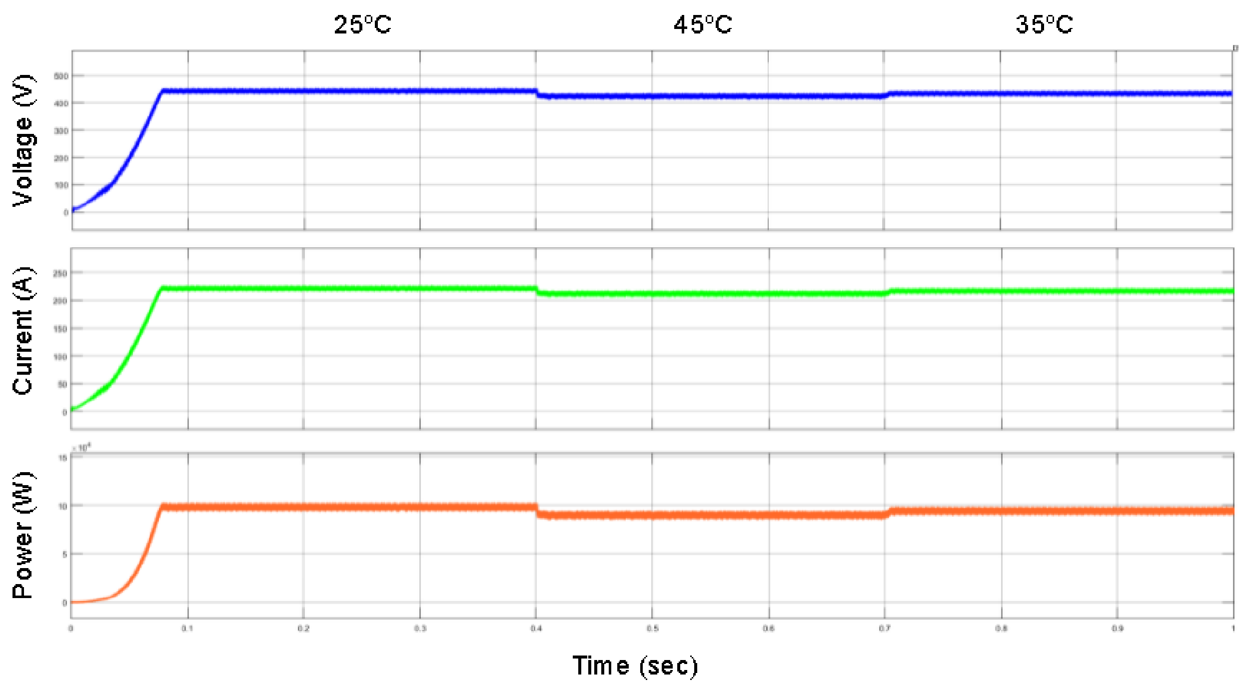

Fig 6.10 QBC Output Waveforms at Irradiation = 1000 W/m^2 at different temperatures

The results have been summarized in Table 6.3.

Table 6.3: Performance analysis of solar PV System connected to QBC with P&O based MPPT controller

Irradiance (W/m^2)/ Temperature (℃)	**Maximum Power point of PV Module P_{MPP} (W)**	**Power of Solar PV Module P_{PV} (W)**	**MPPT Efficiency ŋ (%)**
400 / 25	60	55	93%
600 / 25	80	76	95%
1000 / 25	100	98	98%
1000 / 35	90	82	91%
1000 / 45	85	74	88%

6.3 Solar PV System with Double Cascaded Boost Converter

Output waveforms of voltage, current and power of the system in standard ambient mode 1000 W/m^2, 25^{o}C is displayed in the Figure 6.11 and the various combinations of solar irradiance and temperature, shown in Figures 6.12 and 6.13.

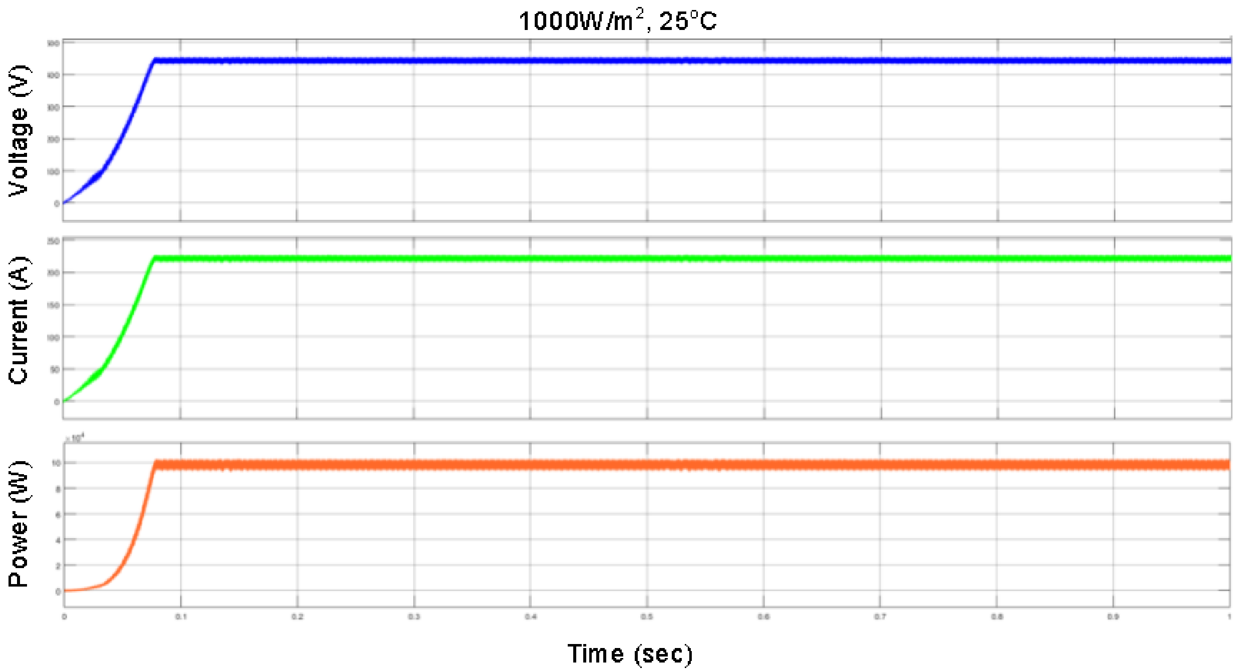

Fig 6.11 DCBC Output Waveforms at standard conditions

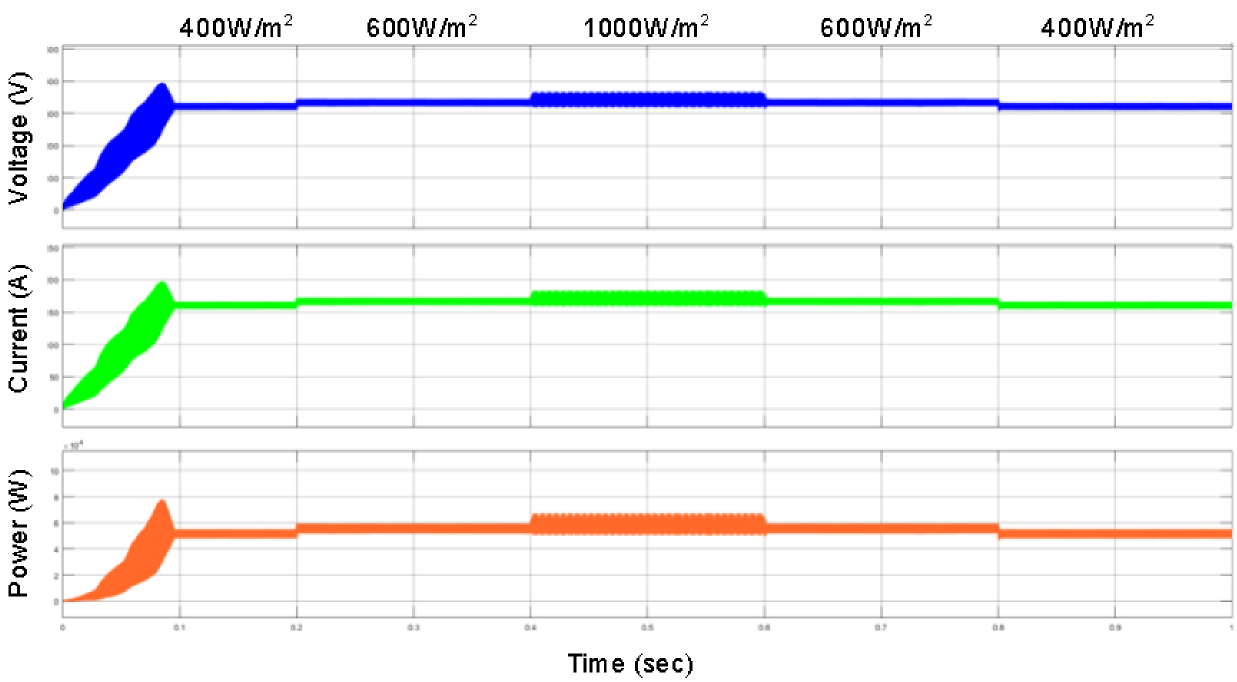

Fig 6.12 DCBC Output Waveforms at 25^{O}C temperature with different Irradiation

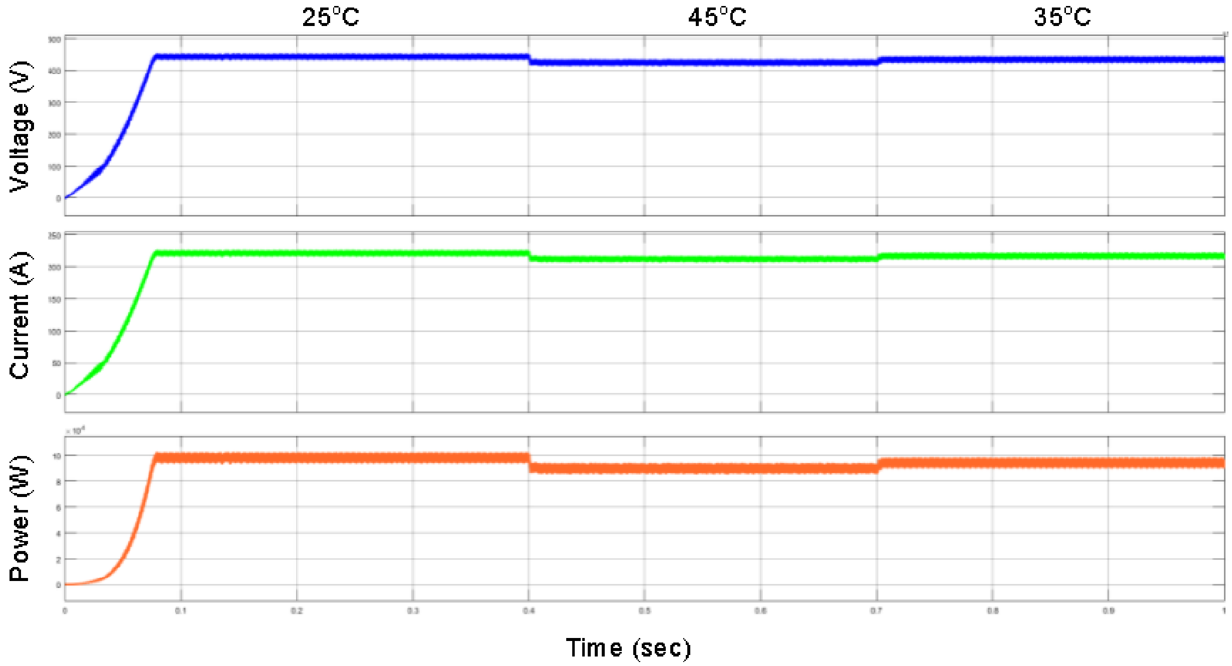

Fig 6.13 DCBC Output Waveforms at irradiation = 1000 W/m^2 at different temperatures

Results are visualized in below Table 6.4.

Table 6.4: Performance analysis of Solar PV system connected to DCBC with P&O based MPPT controller

Irradiance (W/m^2)/ Temperature (℃)	**Maximum Power point of PV Module P_{MPP} (W)**	**Power of Solar PV Module P_{PV} (W)**	**MPPT Efficiency η (%)**
400 / 25	60	55	92%
600 / 25	80	76	95%
1000 / 25	100	97	97%
1000 / 35	90	81	90%
1000 / 45	85	73	86%

6.4 Neural Network based MPPT for Solar PV System using CBC

The Simulink model of Neural Network based MPPT using CBC is shown in fig 6.14. In this model three variations are used that are Irradiance, Temperature and load. Fixed Irradiance and Temperature with Variable Load is shown in fig 6.15. Variable irradiance and fixed temperature with fixed load are shown in fig 6.16. Fixed irradiance and variable temperature with fixed load are shown in fig 6.17.

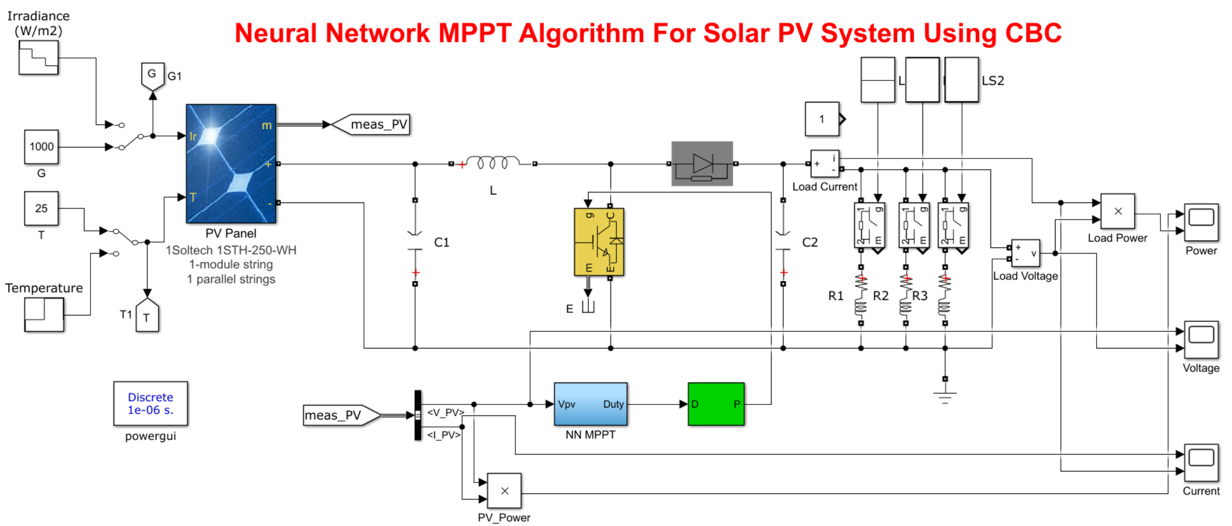

Fig 6.14 Simulink Model of ANN based MPPT using CBC

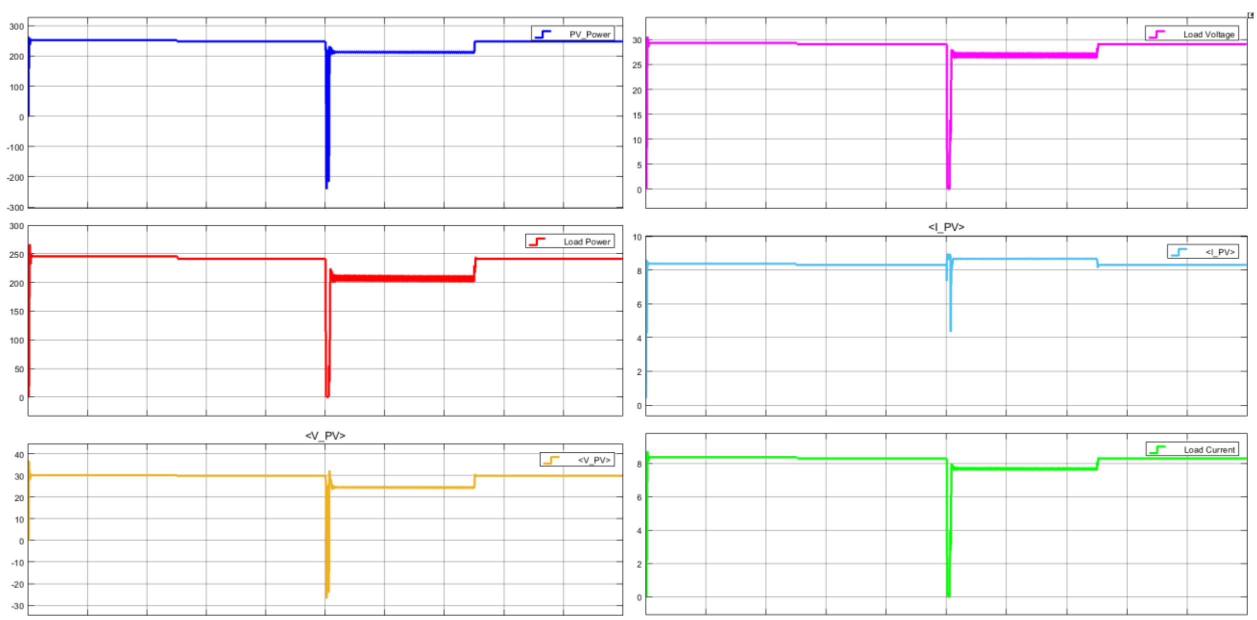

Fig 6.15 Fixed Irradiance and Temperature with Variable Load

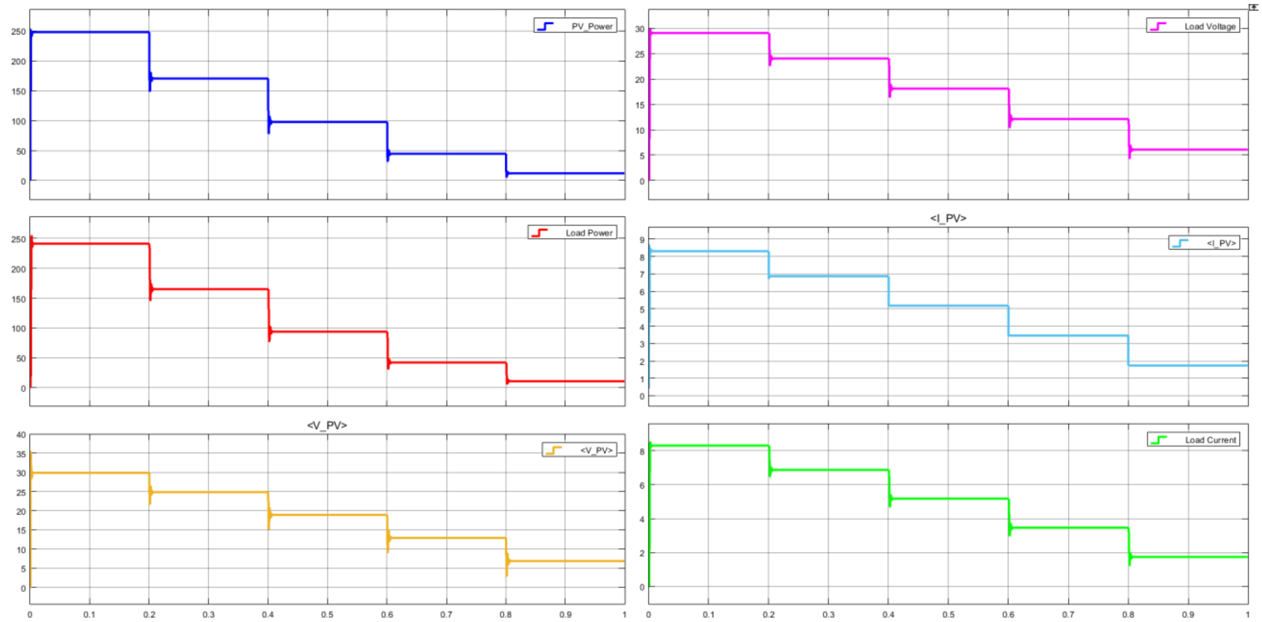

Fig 6.16 Variable Irradiance and Fixed Temperature with Fixed Load

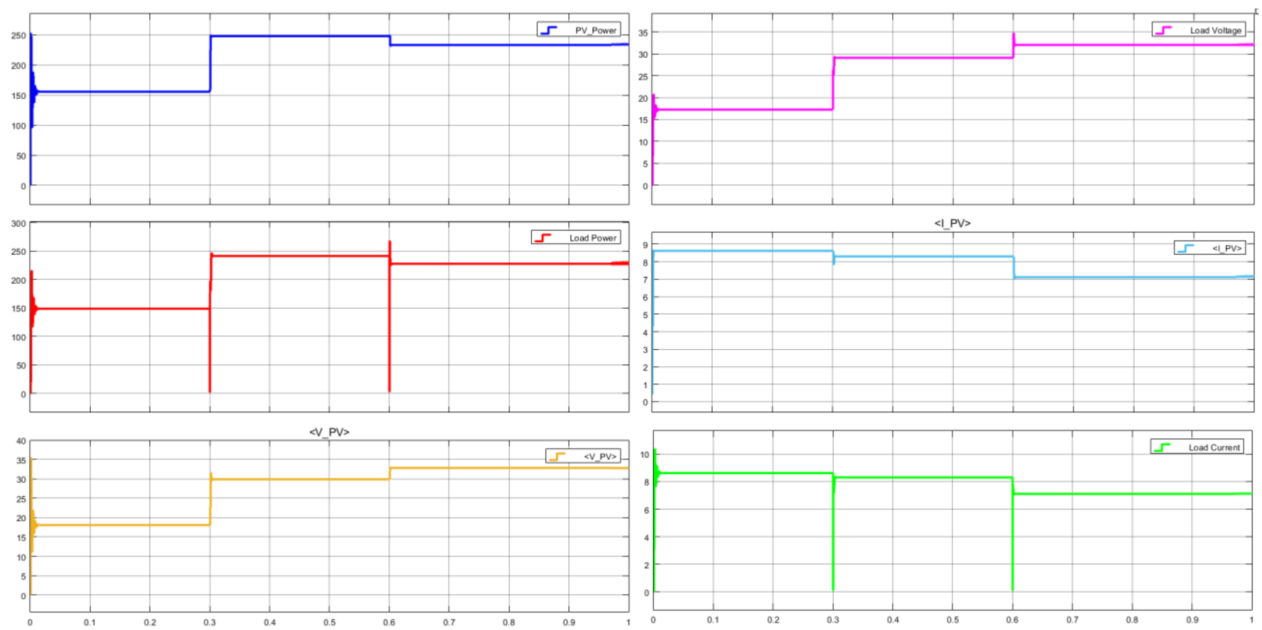

Fig 6.17 Fixed Irradiance and Variable Temperature with Fixed Load

6.5 Neural Network based MPPT for Solar PV System using QBC

The Simulink model of Neural Network based MPPT using QBC is shown in fig 6.18. In this model three variations are used that are Irradiance, Temperature and load. Fixed Irradiance and Temperature with Variable Load is shown in fig 6.19. Variable irradiance and fixed temperature with fixed load are shown are fig 6.20. Fixed irradiance and variable temperature with fixed load are shown in fig 6.21.

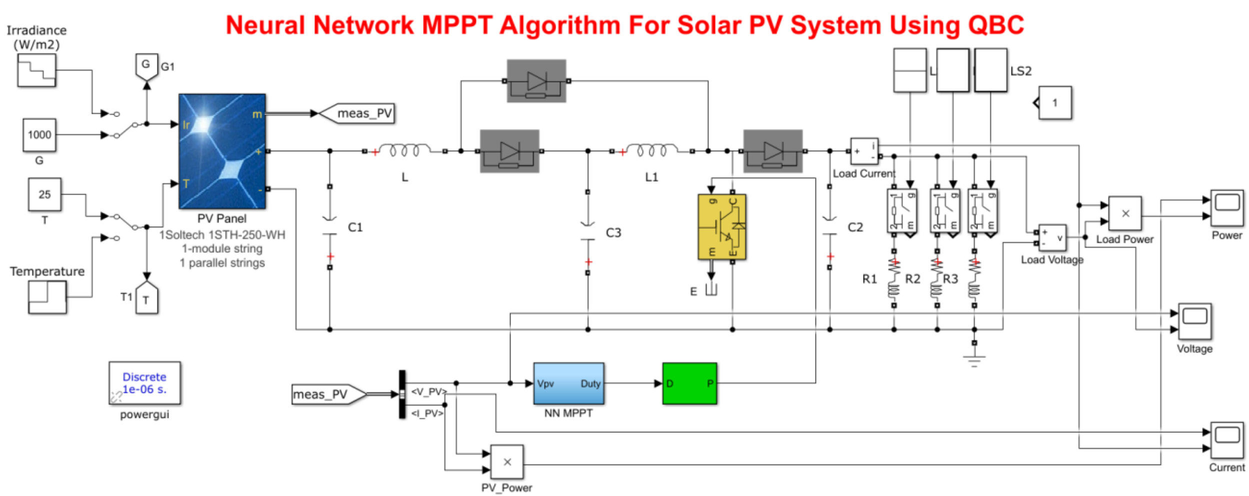

Fig 6.18 Simulink Model of ANN based MPPT using QBC

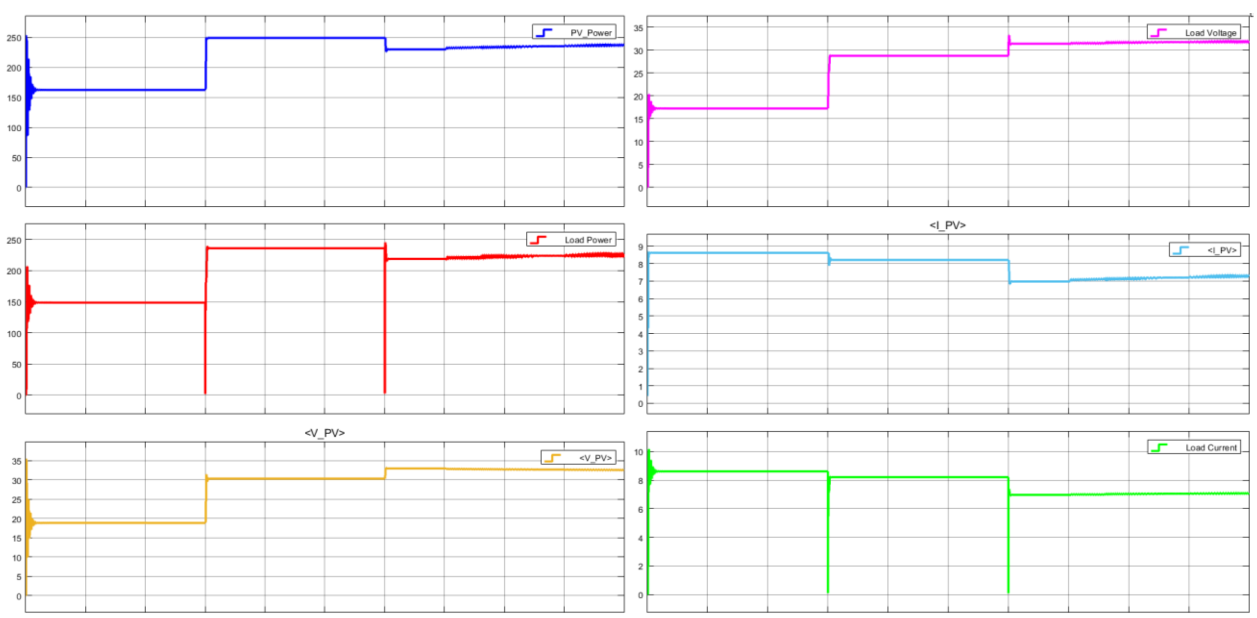

Fig 6.19 Fixed Irradiance and Temperature with Variable Load

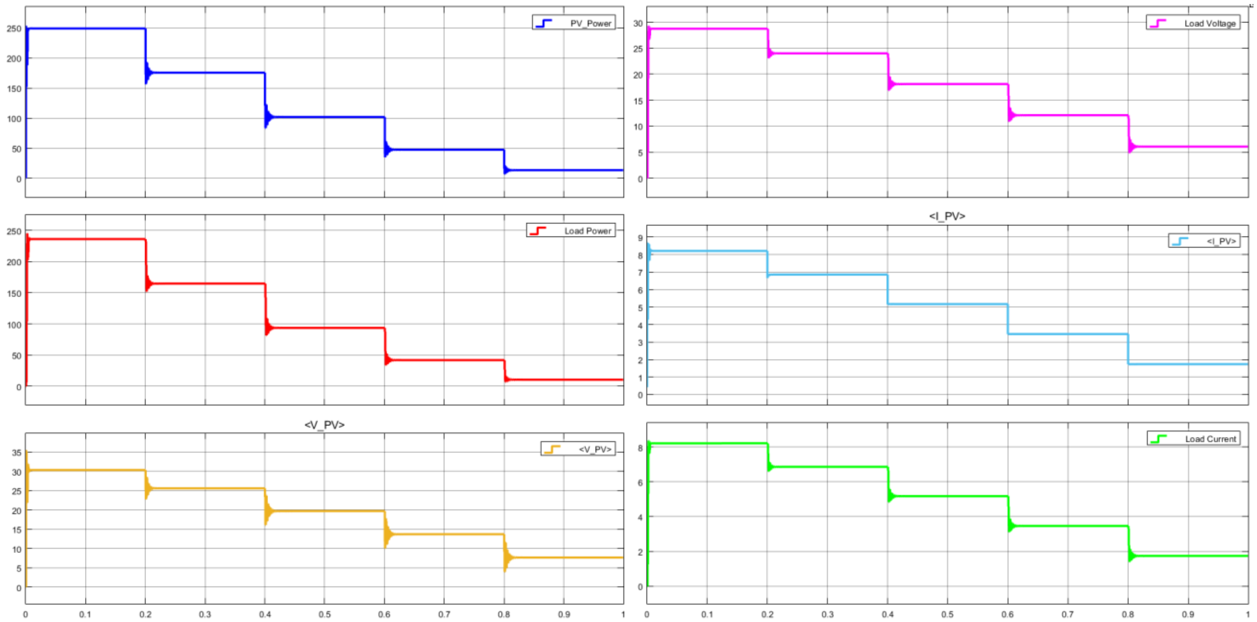

Fig 6.20 Variable Irradiance and Fixed Temperature with Fixed Load

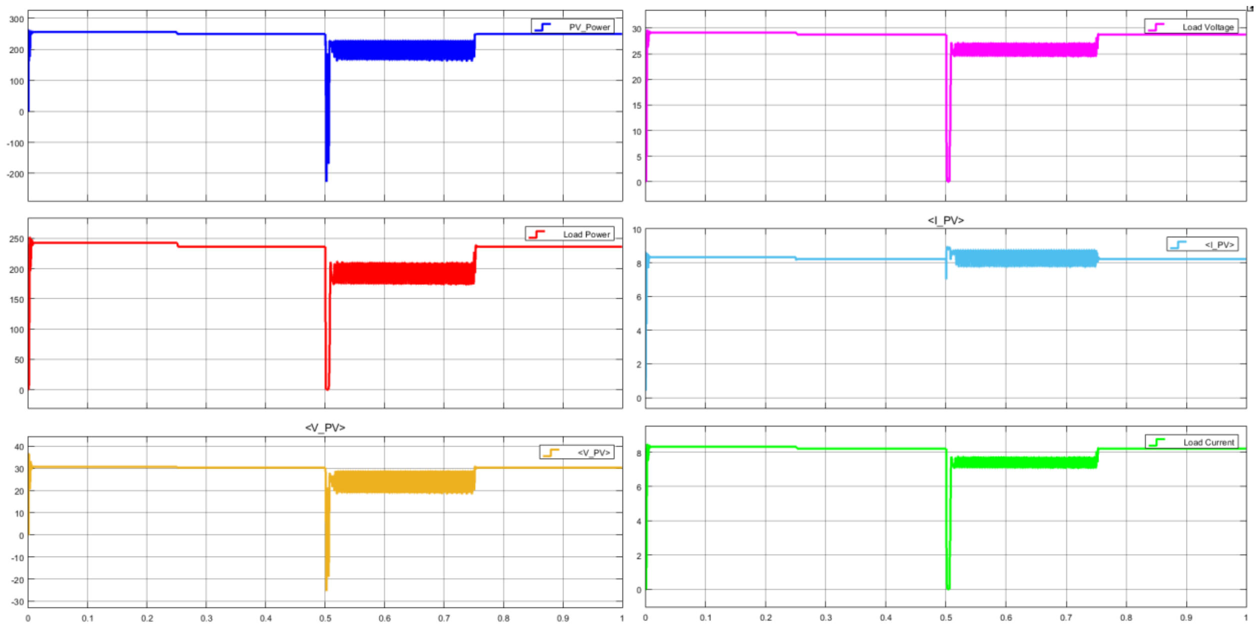

Fig 6.21 Fixed Irradiance and Variable Temperature with Fixed Load

6.6 Neural Network based MPPT for Solar PV System using DCBC

The Simulink model of Neural Network based MPPT using DCBC is shown in fig 6.22. In this model three variations are used that are Irradiance, Temperature and load. Fixed Irradiance and Temperature with Variable Load is shown in fig 6.23. Variable irradiance and fixed temperature with fixed load are shown in fig 6.24. Fixed irradiance and variable temperature with fixed load are shown in fig 6.25.

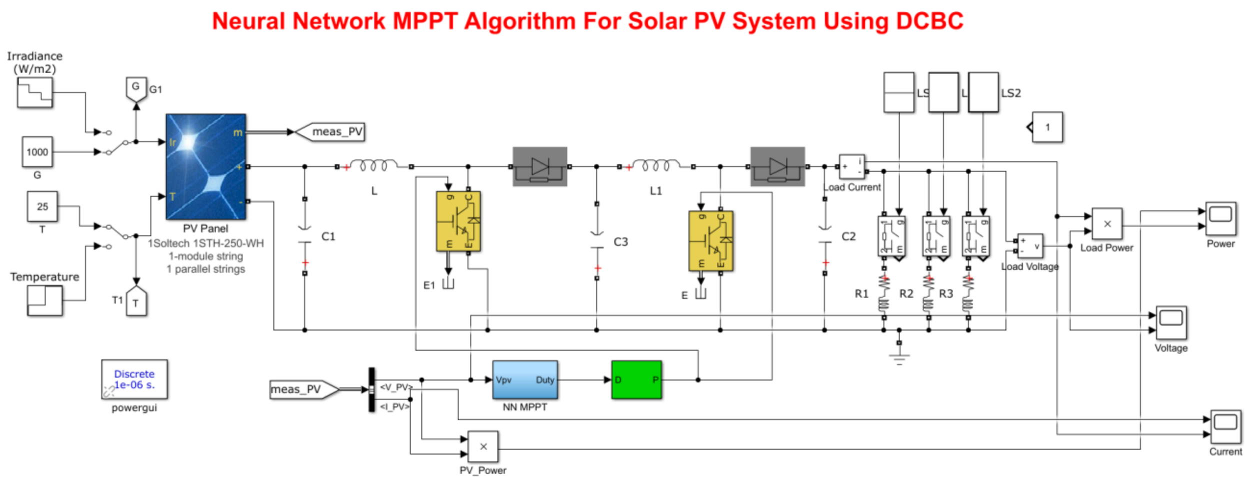

Fig 6.22 Simulink Model of ANN based MPPT using DCBC

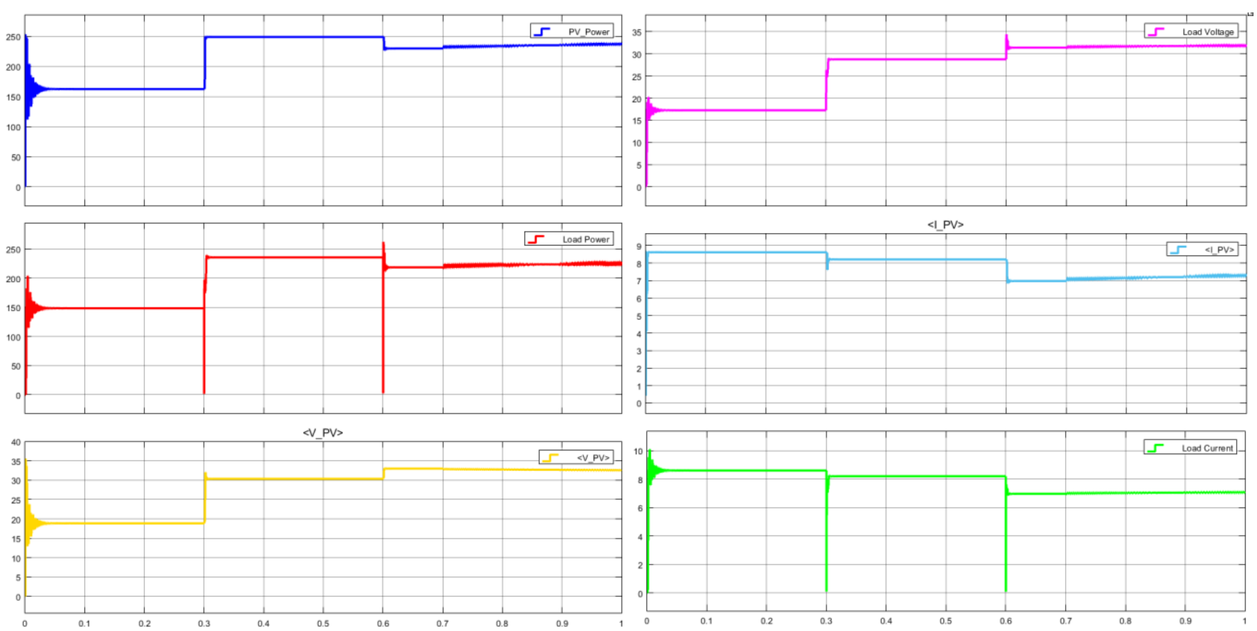

Fig 6.23 Fixed Irradiance and Temperature with Variable Load

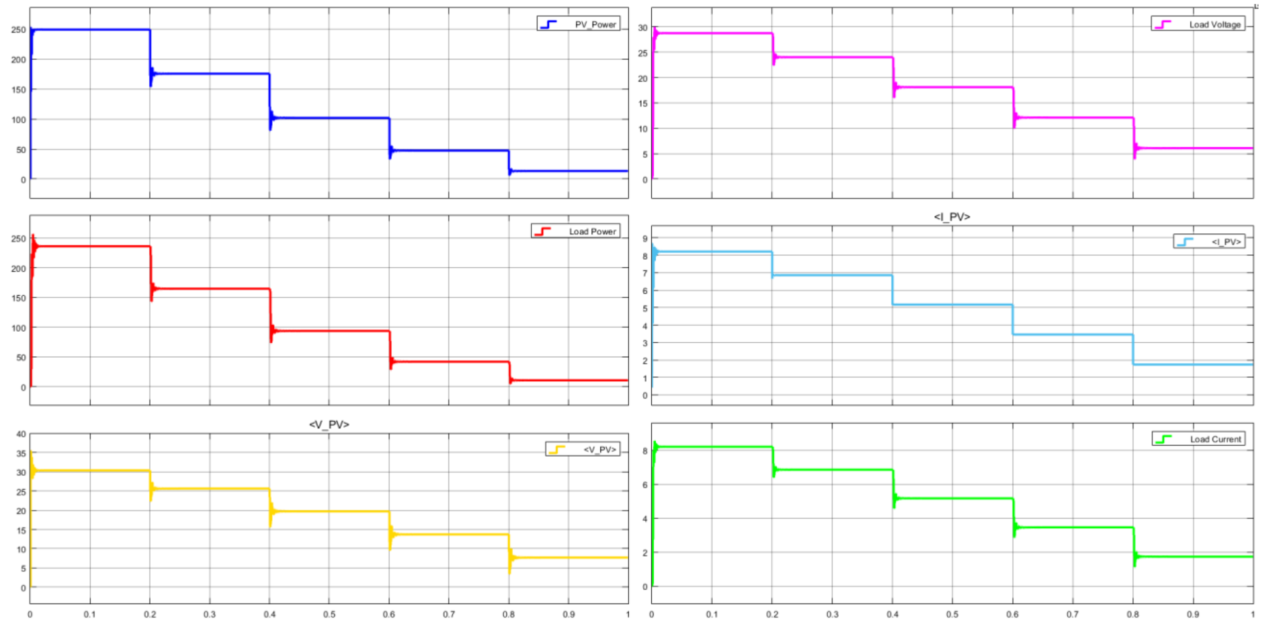

Fig 6.24 Variable Irradiance and Fixed Temperature with Fixed Load

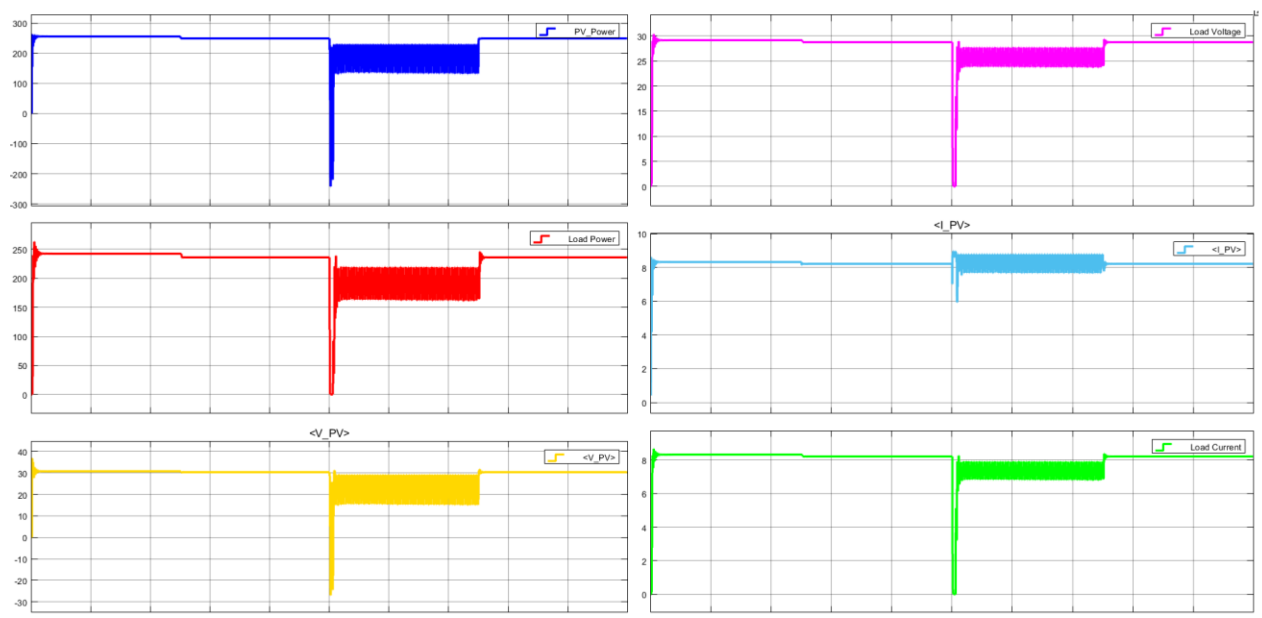

Fig 6.25 Fixed Irradiance and Variable Temperature with Fixed Load

6.7 Home Energy Management System using Solar PV System with Battery Backup Connected to a Grid

The PV solar system, grid power connection, and battery backup are connected to the home power management system (HEMS) shown in Figure 6.26. They use 6 kW of power combined when both are connected and their switching cycle is shown in Figure 6.27.

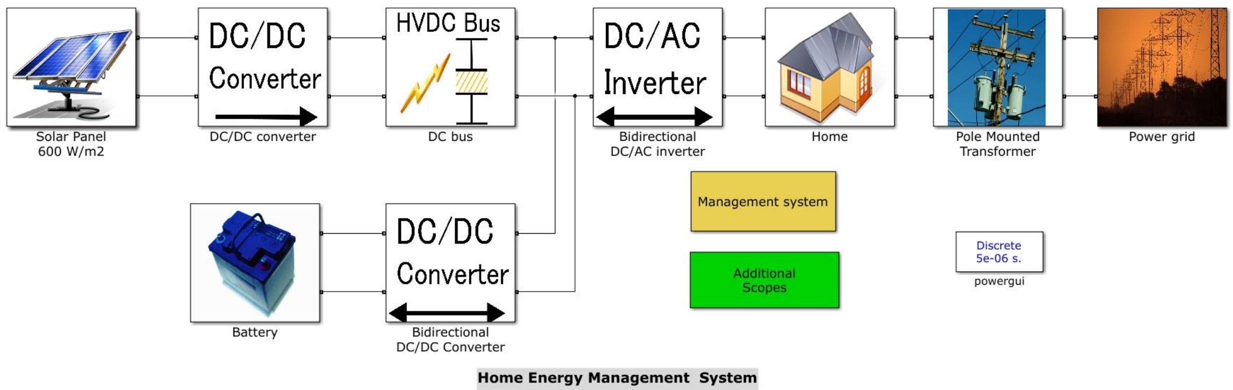

Fig 6.26 Home Energy Management System

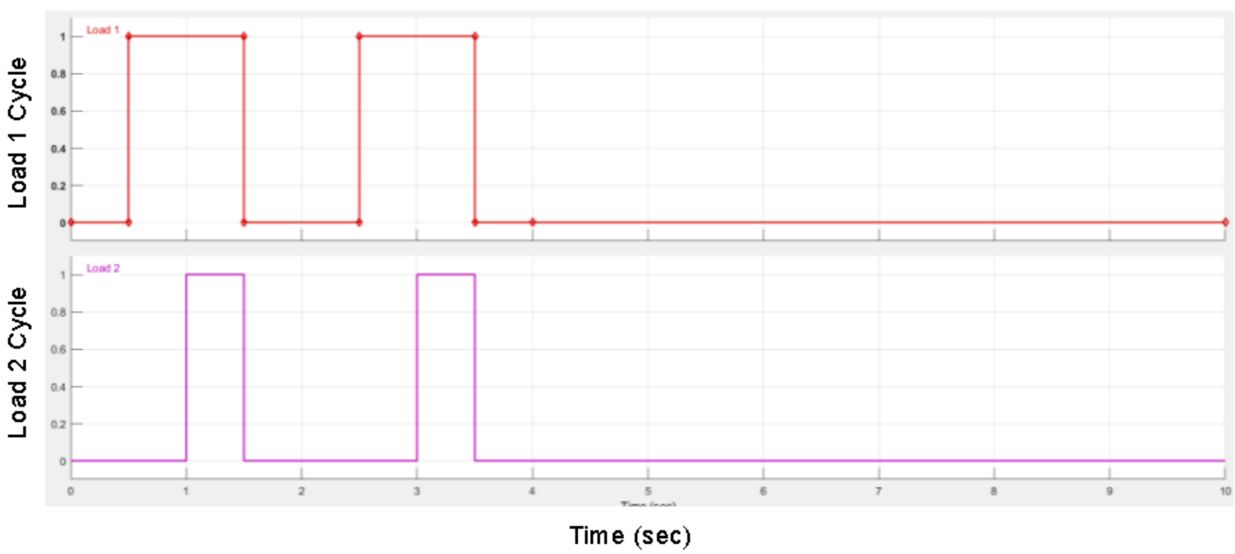

Fig 6.27 Load Switching Cycle

The photovoltaics system is directly connected to HEMS. The Maximum Power Point Tracking (MPPT) controller absorbs most of the energy from the solar panel using a unidirectional DC / DC converter. The power grid of the system is connected to the house from a distribution transformer mounted on poles. It can absorb additional power into HEMS or demand power to supply HEMS.

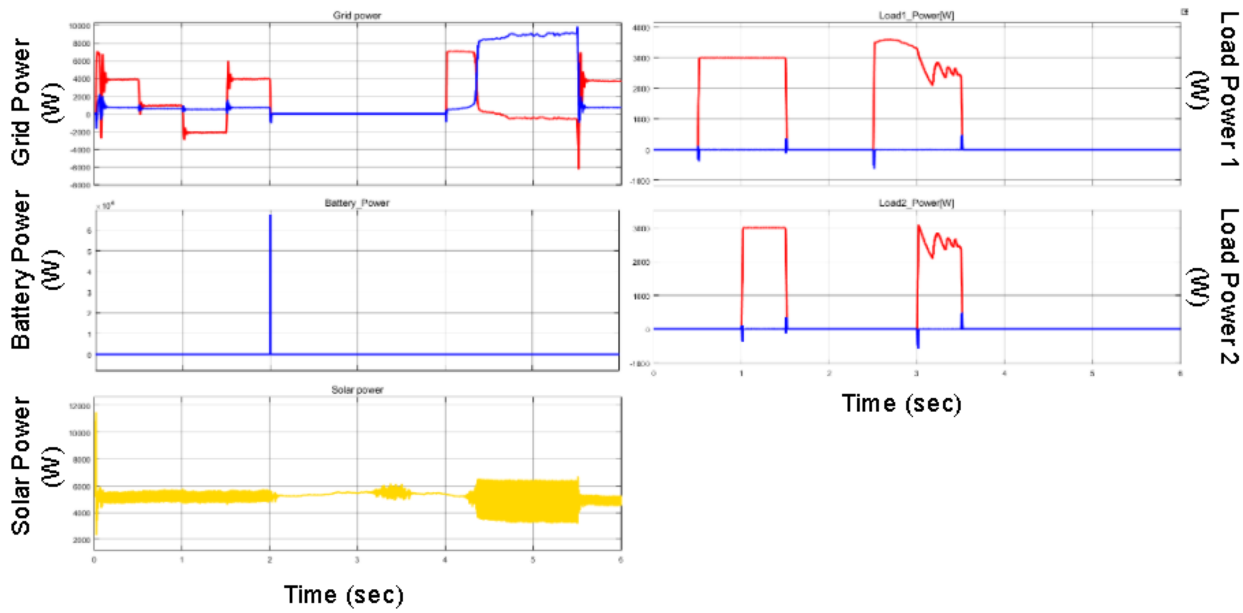

Fig 6.28 Grid Power, Battery Power, Solar Power and Load Power of the system

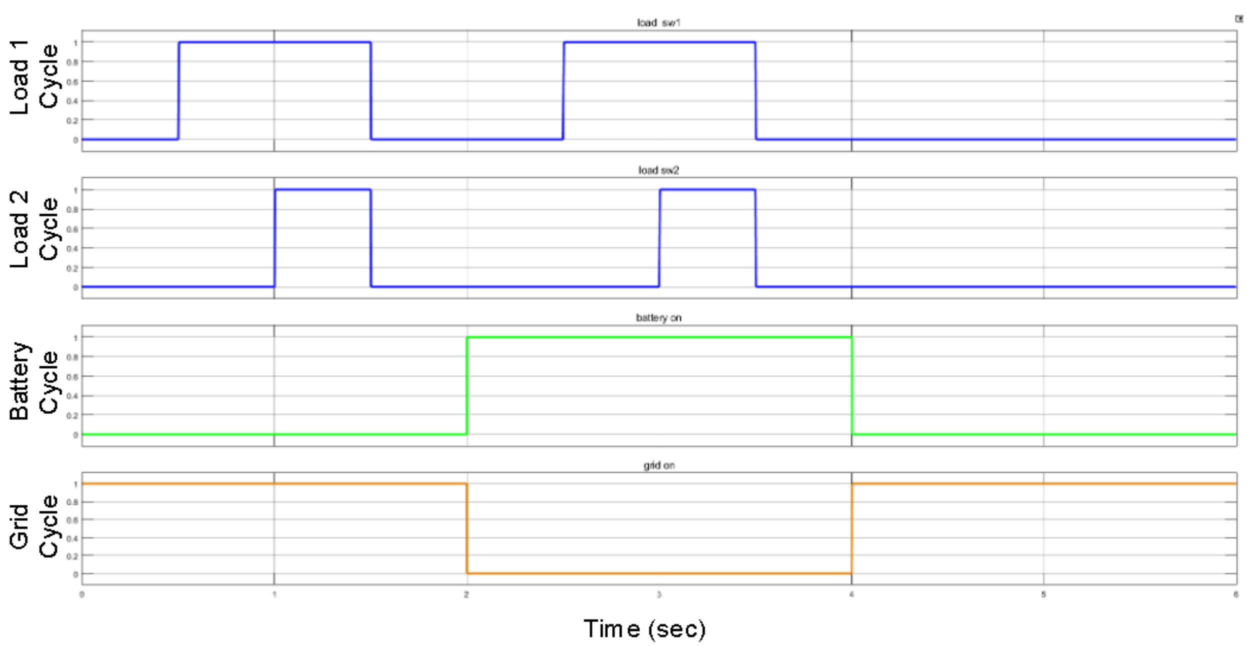

Fig 6.29 Battery and Grid working with respect to Load Switching

The connection between the power grid and house energy system is regulated by a bidirectional DC to AC inverter. Solar power, grid power, battery power, load capacity 1 & 2 are shown in Figures 6.28 and 6.29.

CONCLUSION

In this study of the PV solar power system, it is noted that, under normal ambient conditions (i.e., 1000 W/m^2, 25^{O}C), the MPPT efficiency obtained from normal, quadratic and double the cascaded boost converters are 95% 98% and 97% respectively. Therefore, it is concluded that with the same rate of power conversion, cascade converters show better performance compared to CBC. Performance analysis reveals that DCBC has a significant difference from that of QBC. In the case of DCBC when the system approaches MPP, the disruptive nature of the P&O MPPT algorithms involves oscillations throughout the MPP, while being significantly reduced to conventional converters. Overall, QBC exhibits faster tracking speed and less stability time and is easier to configure. Therefore, of all quadratic boost converters it is the best topology of a given solar PV system. Using this QBC the home power management system is designed which is connected to a battery backup and the grid.

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