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

DISSERTATION

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Submitted by:

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CANDIDATE'S DECLARATION

I, SERVAVIDYA KUMAR MANAS, Roll No. 2K17/C&I/501 student of M. Tech (Control and Instrumentation), hereby declare that the thesis titled "PERFORMANCE ANALYSIS OF FUZZY LOGIC 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 fulfilment 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

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Place: Delhi
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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 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 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, beside using cascaded converters for voltage improvement, it is desired that photovoltaic (PV) power system extracts 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 Fuzzy Logic based MPPT controller in solar PV system for conventional, quadratic and double cascade boost converters connected to a resistive load and investigates their performance at varying solar radiation and ambient temperature.

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 Source
PVSC	Photovoltaic Side Converter
CBC	Conventional Boost Converter
QBC	Quadratic Boost Converter
DCBC	Double cascaded boost converter
FLC	Fuzzy Logic Controller
MPPT	Maximum Power Point Tracking
MPP	Maximum Power Point
PV	Photovoltaic
SPV	Solar Photovoltaic
PVES	Photovoltaic Energy System
PWM	Pulse Width Modulation
STC	Standard Test Condition
FIS	Fuzzy Inference System

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 use can be divided based on end products as Electrical Energy, Thermal energy, and Transportation energy. We need these forms of energy for heating and cooling our homes, lighting office buildings, driving vehicles, moving freight, and manufacturing. Thus, major economic sectors for energy use are: residential, commercial, transportation, and industrial and agricultural. Energy use acts as an indicator to recognize or point out the difference between developed and developing nation. The energy use of a nation distinguishes its measure of progress and development compared to others. A citizen in a less-developed country depends on mostly on human and animal power while, a developed country consumes large quantities of energy for transportation, industrial and agricultural purposes as well as heating and cooling of homes.

In recent centuries amount of the energy demands have increased in a remarkable manner and in last few decades researchers seeks for various types of energy sources. International Energy Agency (IEA) released a data based on study between 1990 to 2008, from which the facts came that the average energy consumption/person increased by 10 %. Also, worldwide renewable energy consumption will increase at the rate of 3.1%

per annuum 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

Demand for electrical energy has risen in recent years. In addition, the constraints, like environmental pollution and global warming has also stiffened. Conventional energy sources trio of coal, oil and natural gas have remained dominant players in electric power generation. However, because of the adverse effect on environment such as air pollution and policy constraints on the conventional power generation, a need to explore options into the development of sustainable energy sources has also sharply risen. The rising concern about sustainability has kicked in an interest in researchers to exploit renewable energy sources in recent years.

A sustainable energy source is explained as one, that are almost inexhaustible, have much lower emission of greenhouse gases and does not entails environmental pollutants. Renewable energy sources are carbon-free and appears 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 system, 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 source would establish its sovereignty over world's energy supply system having percentage share of different forms as shown in Fig. 1.1.

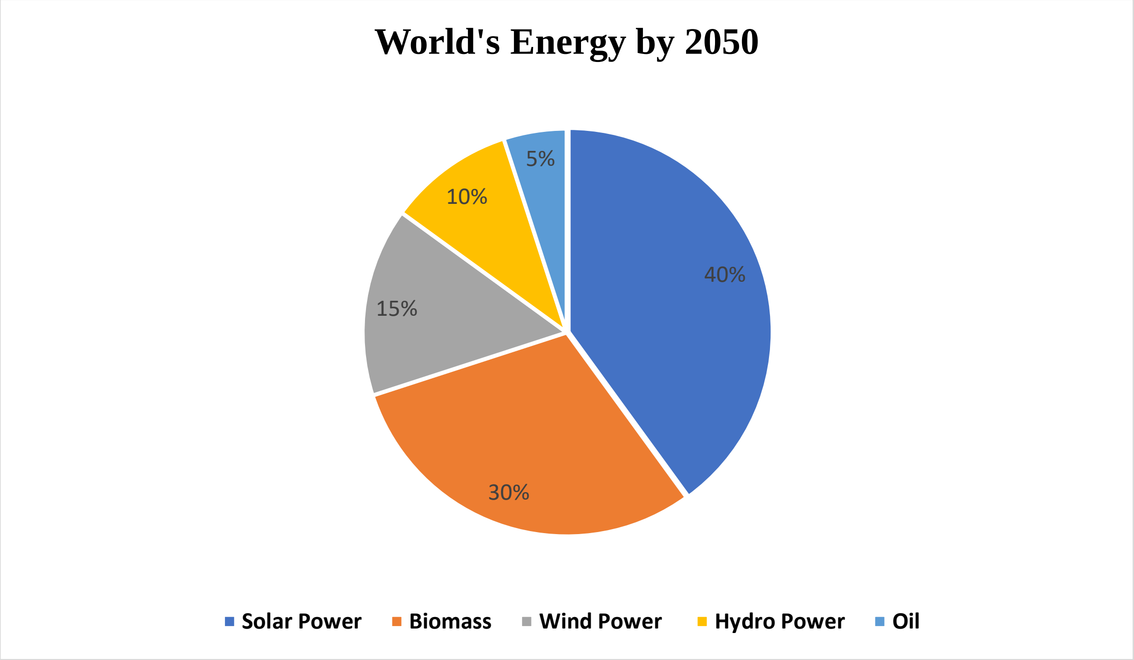


Fig 1.1 World Energy Consumption by Year 2050

Renewable energy can be divided into two groups:

1. Solar renewables
2. Non-Solar renewables

1.2.1 Solar renewables

Solar renewables are those sources of renewable energy which directly or indirectly depends on solar radiation. Solar radiation can be directly converted into useful energy using technology that are solar thermal energy conversion technology and the Solar Photovoltaic (PV) technology. Solar radiation can be indirectly converted into useful energy are hydro energy, wind energy, wave energy and bioenergy.

1.2.2 Non-solar renewables

The sources of renewable energy that does not depend on solar irradiation are termed as non-solar renewables. These are tidal and geothermal energy.

Several studies and research are going and numerous expert studies suggest about the bright future for renewable energy system [61].

1.3 Solar Energy

Solar renewables or say solar renewable energy or sun energy are the ultimate source of most of our renewable energy supplies. The 21st century is being called as the Solar Age. The sun is a gigantic natural nuclear fusion reactor as it converts hydrogen into helium at the rate of 40 lacs tonnes per seconds. World's annual energy consumption appears to be a drop in the bucket of Solar radiation which is ten thousand times voluminous. On average, seventeen hundred kWh/m^2 /year is solarized.

The energy given off by the sun at any given point in space, outside the earth's atmosphere, is nearly constant. However, this insolation when reaches the earth 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 sun, the sun appears at different place in the sky and thus affects the amount of insolation at any given point on earth. Thus, there will be continuous need to move our solar devices and also to focus it at different angles at different point 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 gases 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 absorbs around thirty percent of solar radiation passing through it and thus reveals that effect by casting shadow while moving place to place. Also, air-pollutants, blocks 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. Solar energy direct uses are – 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 [64].

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 solar heating systems uses active mechanical or electrical devices like photovoltaic panels, solar heat collectors, charge controllers, pumps etc. to process the heat energy of sun. An active solar energy system may also have batteries that store the collected energy for later use. Application areas are 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 solar energy system uses sunlight to heat air, water, and thermal material and cause, air movement for heating, cooling, and ventilation of living spaces and to absorb and 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 withhold heat energy, buildings are designed for natural circulation of air and energy capture .

1.4.3 Components of a Solar Energy System

A general solar energy system is depicted in Fig 1Solar PV array captures the sun's energy from sunlight falling on it. The solar tracking system comprise light sensors like photodiode or phototransistors to give command to servo-motor position control system. The output of the PV panel is conductively connected to a DC/DC converter which is designed to deliver desired current or voltage at load ends to harvest the maximum available power from the PV module. The DC/DC converter whose switching action is controlled by MPPT controllers is followed by a DC/AC converter (i.e. an inverter) which supply 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 that might not be available from the PV module during night and cloudy weather.

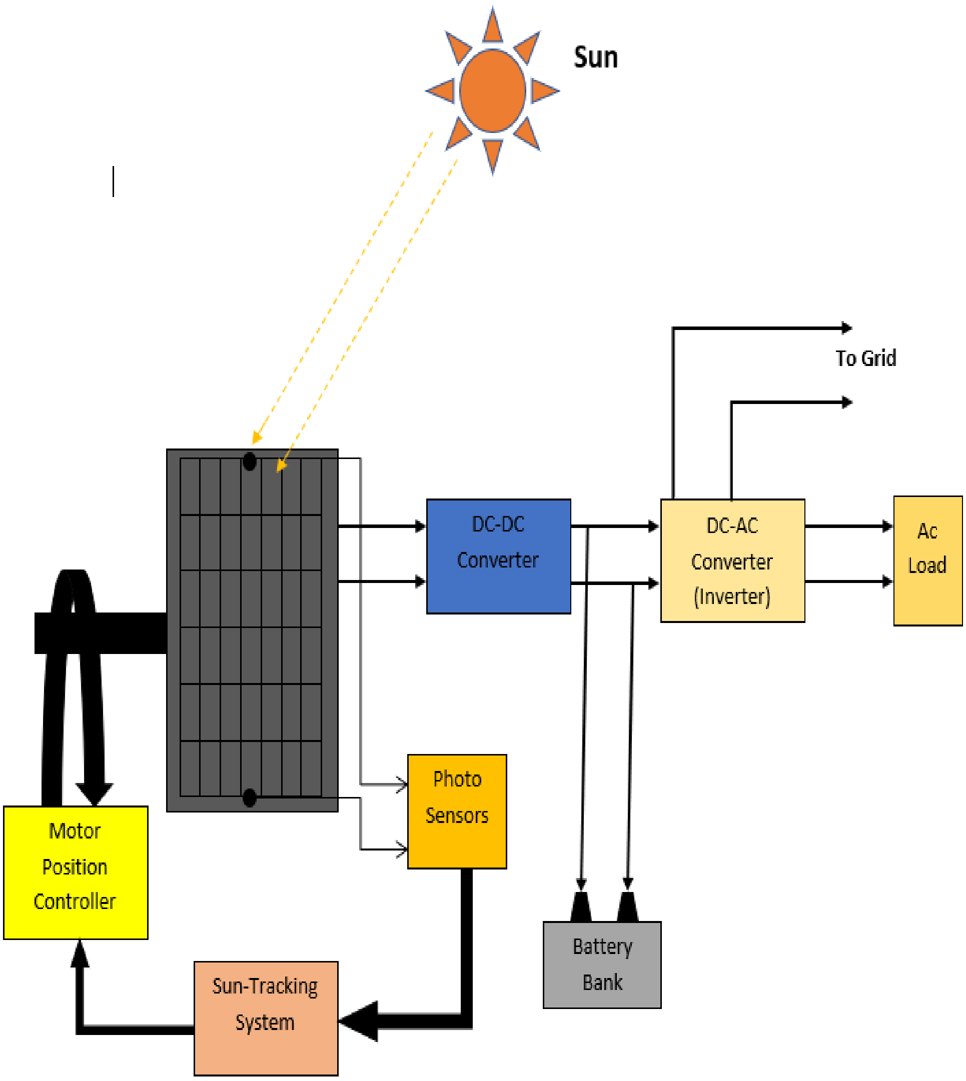


Fig 1.2 A General Solar Energy System

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

1. PV modules are connected in various configuration depending on load requirement and rating. It could be a series connection to increase voltage, a parallel connection to fulfil 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 send the control signal to servomotor coupled with solar panel for the best possible illumination. This is also termed as 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 PV panel by switching on and off a DC/DC converter.

4. The battery bank also has another role store surplus energy from 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 unit of energy or not.

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 do 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 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 decide 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 power & electronics control circuit. The electronic control circuit comprises a DC-DC converter 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 dc-dc 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 operates 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 show 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 understand the modelling techniques of different boost converters i.e. a conventional boost converter, a quadratic boost converter and a double cascaded boost converter used in PV system.
3. To compare performance of a conventional boost converter, a basic quadratic boost converter and a basic double cascaded boost converter supplied by Battery.

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 Fuzzy Logic MPPT Algorithm for implementation in 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 Fuzzy Logic 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 the 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 tap 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 system.

2.2 LITERATURE REVIEW

2.2.1 Solar Photovoltaic (PV) energy System

In paper [1], a design based of solar photovoltaic system design based on annual mean Global Solar Radiation (GSR) involving sizing of the array and the battery is proposed.

In [2] simulation and development of Solar PV system with components like PV solar panel, dc-dc boost converter and two-level is presented. Also, a PI controller controls inverter output and keep it constant.

The paper [3] describes in detail the background and need to develop a photovoltaic system. Four maximum power point tracking algorithms are introduced, and their advantages and disadvantages are discussed. Also, the major technologies of inverter are analysed.

In [4] the authors presented the overview of the research areas of single-phase solar PV energy system and discussed the characteristic of solar PV module. Advantages and complexities of various MPPT schemes are discussed. The effect of partial shading is discussed, and solution is proposed. The various types of Power electronics converters and their role are explained.

The paper [5] presents a case study with modeling and stability analysis of 95 kWp power on-grid solar photovoltaic system. The researchers presented design considerations for various components of grid connected PV system. The on-grid PV system is realised by connecting 312 PV modules as solar generator and 4 numbers inverters of 25-kVA rating .

The paper [6] discusses the design of a 2-kilowatt standalone SPV system. The paper reveals that shading had limited effects on the system performance, however high ambient temperatures severely affects the system.

Analysis of different photovoltaic technologies like crystalline silicon and thin film technologies for a Grid Connected Solar Photovoltaic System is presented in [7].

In [8] grid-connected Photovoltaic system is designed. The solar PV system consists of the boost converter, a controller, and an inverter. The boost converter and inverter comprise two-stages conversion blocks. The system is tested at various irradiances conditions for constant voltage at output terminals for all these conditions. PIC16F877A microcontroller is used.

In [9] authors presented a paper regarding energy management in grid connected rooftop solar photovoltaic system with Battery Storage. Modelling for better energy management is done by the dynamic switching process in the system. The paper also discusses selection of number of solar panels and battery.

In [10] study of design and implementation 3.12 kWp on-grid rooftop solar PV system is conducted.

In [11] a standalone PV system in conjugation with battery management is designed for ac loads and dc loads. This paper proposes, control logic for standalone photovoltaic system and provides regulated and continuous power supply.

This paper [12] presents guidelines and technical considerations for systematically designing standalone PV system. These includes site selection, estimation of available solar energy at the selected site, daily load energy demand and designing of the various components of solar system like PV panels, charge and MPPT controller, batteries, inverter etc.

In [13], authors propose in the research paper control of standalone solar PV system in changing operating conditions when surplus solar energy is available, and the battery is on float charge. In such condition a dump load is required to sink the extra energy, but that is not a fruitful way for efficient working of the system. The problem is rectified by deriving only the required amount of power from PV source.

In [14] The researchers proposed a Single Stage Standalone Solar PV system integrated with Inverter and thus obtain the output from the PV panel directly as alternating current, for constant voltage. Inverters efficiency as switching loss is minimized by operating power switch at high frequency. The voltage drop is minimized by selecting suitable inductance value.

The paper [15] presents stand-alone centralized PV system for residential purposes to feed lighting loads, television and computer, refrigerator and washing machine of overall wattage of 2 kilowatt. The PV system comprise PV array, batteries and battery charger, inverter for feeding ac loads and maximum power point trackers. The paper presents an in-depth analysis for PV modeling, develops software programmes for monitoring battery status, develops maximum power point tracking controller, designs inverter with filter.

In [16] the authors discuss numerous drawbacks and issues related to a standalone three-phase PV system like low-voltage issues, effects of partial shading, parasitic capacitance effects on the PV panel, overcharging and discharging issues related to battery and proposes a new configuration as a solution. A PV system configuration with bidirectional dc-dc converters power with battery interface is presented. The high voltage gain dc-dc converters solve the issue related to low voltage PV source. The series configuartion of battery modules is suggested to overcome the issue of overcharging and discharging issues. The voltage coming out of inverter is regulated by sinusoidal PWM. The active power requirement of ac load is controlled by the dc link voltage.

In [17], the researchers propose design and simulation of standalone solar PV system is developed incorporating both electrical and mechanical maximum power point tracker.

The [18] proposes hybrid thermal photovoltaic system and describe method of designing hybrid of the thermal system with solar PV to increase the efficiency of overall system.

The [19] proposed system presents hybrid photovoltaic system. The modelling and optimization of photovoltaics (PV) system having battery energy as a storage element is connected to diesel generator and wind power plant to create a grid system. The maximum power point tracker is realized using like Perturb and Observation (P&O) the algorithm. A voltage source inverter (VSI) is designed analytically, to provide alternating current as output.

In [20], a hybrid power system comprised a PV array together with a diesel generator is proposed. A dc-ac converter, and a battery bank are implemented to feed the ac load. The comparative study show the result that the hybrid solar PV-Diesel generator power system with battery and inverter exhibits superior performance compared to solar PV-Diesel generator with inverter but no battery or Diesel generator with battery and inverter or Diesel generator alone.

2.2.2 DC-DC Converters

B. M. Hasaneen and A. A. Elbaset Mohammed in [21] present design and simulation of DC-DC boost converter for a PV system and tracking the point of maximum power. A solar PV system operates under varying conditions of irradiance and ambient temperatures throughout the day, weeks, and months in a year. These variations digress and thus divert the operating points from nominal conditions. Also, variations in load demand at the output or in line voltage at the input affects operating point. PV array provides the input; thus, the simulation is performed over wide variations of radiations and temperature. In this paper the authors analyse the boost converter.

S. Masri and P. W. Chan, in [22] proposes design and develop a DC-DC boost converter for constant output voltage for a fluctuating or varying input voltage. A microcontroller is both a low power consumption and a low-cost device and thus PIC16F877 microcontroller is used as controller and voltage feedback control technique is applied. Pulse width modulation (PWM) technique is applied to control the active switch.

Conventional boost converter is an important component and is employed with fuel cell, in electric vehicle, in SMPS, and with renewable energy conversion system like solar PV systems. Ripples in the input current of conventional boost converters affects its performance and thus to reduce this ripple large value of L-C filter is used, which degrade dynamic response and increase the overall weight. S. Antony and S. P. Sathiyan in [23] proposes boost DC-DC converter with reduced input current ripple, with a closed loop control for better voltage regulation. Ripple cancellation network (RCN) is implemented using small value of inductor and capacitor. Comparative analysis between conventional boost converter (CBC) and proposed boost converter with RCN is done.

In [24] D. J. Grinkevich and A. V. Troitskiy, propose a transformer-less dc-dc boost converter that allows a high voltage gain on loading. Robust Control methods are implemented for output voltage in case of disturbance.

It is a general trend in power electronics that to minimize harmonics and to reduce sizes of passive component power semiconductors devices are switched at very high frequencies. Due to increase in switching frequency the switching losses increases which affects the performance of power circuits at high power levels. Methods like constructing resonant inverters and a 4-level multilevel inverters (MLI) have been proposed for decreasing switching losses. In this paper [25], to interface a low-voltage dc source to a high-voltage inverter, K. A. Corzine and S. K. Majeethia propose a new two-quadrant buck-boost and one-quadrant boost four-level dc-dc converters.

Boost converter are extensively used in regulated power supplies. They work in different conduction modes depending on the behaviour of inductance current. There are four conduction modes named as continuous current mode (CCM), critical current mode (CRM), discontinuous current mode (DCM) and forced continuous conduction mode (FCCM). In CCM the inductor current is always positive, and ripples are small. In DCM the current will not be negative after it reaches zero. In CRM the converter operates at the border of CCM and DCM. In FCCM the inductor current can be negative. L. Yi, L. Wang, X. Wang and S. Yang [26] in their paper operate the dc-dc Boost converter in different working modes using silicon carbide diodes as a freewheel. Efficiency comparison is performed in different modes and found to better in CRM mode.

In [27] F. S. F. Silva propose design, mathematical modeling, simulation and hardware realization of a high gain dc-dc boost converter coupled with inductor and a battery bank for off-grid PV system. The authors plead that the cost of the electricity produced from PV conversion is still not very attractive or say in comfortable zone of general public and hence, it is mandatory to go for efficient converters. As the non-isolated can be more efficient than the isolated several non-isolated dc-dc converters are taken into consideration for comparative evaluation. These are classical boost converter, modified boost converter, high gain boost converter, cascade boost converter, interleaved boost converter, high gain interleaved boost converter. Finally, high gain boost converter, with coupled inductor topology is analysed as most suitable.

P. F. Liya and K. V. Aathira, in [28] presents analysis and design of inductor coupled buck-boost dc-dc converter with wide range voltage variation. Authors proposes Wide-input-wide-output (WIWO) dc-dc converter as an integration of buck and boost converter by replacing the inductors by coupled inductor and thus extend the conversion range besides retaining the buck and boost characteristics.

A basic QBC already has a high boost ratio and a excellent efficiency in continuous conduction mode (CCM). A new dc-dc boost converter is presented in [29]. Y. Li and S. Sathiakumar proposes an improved voltage lift technique based quadratic boost converter for solar energy system to increase voltage conversion ratio.

D. Sivaraj and M. Arounassalame in [30] proposes a novel multilevel high gain quadratic boost switched capacitor converter (QBCSS) for photovoltaic system and compares its performance with quadratic boost converter (QBC) and obtains much higher voltage step-up ratio for the same duty cycle.

Ping Yang, Jianping Xu, Guohua Zhou and Shiyu Zhang, in [31] modify a basic quadratic boost converter having high voltage conversion ratio and reduced voltage stress by using an additional capacitor-inductor-diode (CLD) cell consisting of two capacitors, an inductor and two diodes. The modified converter shows improvement of the voltage conversion ratio in comparison to conventional boost converter and quadratic boost converter. Also, voltage stresses of switch and diodes is greatly reduced.

V. J. Samuel, G. Keerthi and M. Prabhakar propose a novel high gain interleaved quadratic boost dc-dc converter (IQBC), as in in recent years trend for distribution generation is rising. Solar PV and wind power are two of the most exploited distribution energy generation sources. Solar PV generation system has the limitations of low-voltage in the range of 12 volt to 60 volts. The authors suggest in [32] synthesis of interleaved quadratic boost converter (IQBC) by interleaving two quadratic boost converter and obtain a two phase QBC. The novel dc-dc converter is ripple free as the proposed converter is operated with a phase shift of 180-degree.

A traditional boost converter is not able to step-up a low-voltage PV source to a higher load voltage at low duty ratios and thus several literatures are about developing boosting topologies in which modifications are done. M. Veerachary and N. Kumar in [33] finds that most of them use either switched-inductor or switched-capacitor configurations to gain higher voltage step-up ratio and propose a fifth-order quadratic following boost converter (QFBC) for realizing high voltage-gain at low duty ratios.

The problem of low-voltage generation in Renewable Energy Sources (RES) is also investigated by authors T. R. Choudhury and B. Nayak in [34] and thus as for alternative to traditional boost converter compares and analyse cascaded and Quadratic Boost Converter. It is concluded in this research paper that both quadratic boost converter and cascaded boost converter can give high voltage gain, however more stress is observed in QBC. However, less the switching losses is recorded while operating QBC as smaller number of switches are used for this case.

M. Delshad, S. Mohammadi and S. Moosavi, in their research paper propose a new cascaded high step-up dc-dc converter [35] in which quadratic boost configuration is combined with a flyback configuration to decrease the conduction losses through as well as stress voltage across the switches.

Jian Fu, Bo Zhang, Dongyuan Qiu and Wenxun Xiao in [36] proposed novel cascaded converter which is basically a single-switch cascaded Boost and Buck-boost converters. The voltage gain is increased in comparison with classical dc-dc converters. The number of magnetic components implemented is small, similar to a Cuk or a Sepic converter. The circuit configuration is greatly simplified because of the use of single switch.

A high voltage step-up ratio, two-stage cascade boost converter topology is proposed for PV system by Y. Lee, W. Lin and L. Yu in [37]. The converter operates in different conduction modes. The average efficiency of the boost converter is over 90%. The proposed converters can be used in the PV battery charger based or PV inverter-based systems.

M. Sulthon, O. A. Damanik, Efraim, A. Rizqiawan and P. A. Dahono in their work [38] address the current ripple issue on solar photovoltaic (PV) generation. A photovoltaic system is expected to operate at maximum power point and should not get biased either towards constant current region or constant voltage region. Current ripple pushes the operating point on the I-V characteristics of photovoltaic module towards the constant voltage region, resulting in a sharp decline in the average power.

In [39] J. F. J. van Rensburg, M. J. Case and D. V. Nicolae presents a new variation of boost topology, configured as two parallel connected dc-dc boost converters, and shows in simulation results a net improvement in voltage step-up ratio. In this topology there are two inductors that are charged in parallel but release energy in series.

For a PV hybrid power system, J. Vincent, K. V. Aathira and K. S. K. Das, implemented an improved version of non-isolated bidirectional dc-dc converter having high voltage gain [40]. The improved converter consists of two traditional boost converters. In this circuit there are switches, in which two switches act as power switches and other two as synchronous rectifiers. The configuration being simple offers larger voltage boost ratio.

2.2.3 Maximum Power Point Tracking

In paper [41], V. Salas, E. Olı´as, A. Barrado, A. La´ zaro, present a comprehensive review of different ways of tracking the maximum power point for a photovoltaic (PV) energy source. These methods are categorised as direct and indirect methods. Direct methods are straightforward methods to obtain the actual maximum power by directly measuring the PV panels output voltage and current and are suitable for all variations of irradiance and temperature. The indirect methods on the other hand estimates the maximum power point by indirectly measuring the PV panels output voltage and current, using the solar irradiance or ambient temperature, or using empirical data.

In paper [42], Trishan Esram and Patrick L. Chapman presents a comprehensive research on comparison of MPPT methods for solar PV energy system. It is a compilation over 90 papers belonging to numerous maximum power point tracking methods.

A comprehensive review was published on maximum power point tracking (MPPT) techniques for solar photovoltaic (PV) power system by researchers Bidyadhar Subudhi and Raseswari Pradhan in paper [43].

Rajiv Roshan, Yatendra Yadav, Umashankar S, Vijayakumar D, Kothari D P in paper [44], proposed Incremental Conductance method for maximum power harvesting from the PV panel. The proposed Incremental Conductance controller requires more computation in comparison to perturb and observe (P&O) based MPPT technique and exhibits fast dynamics.

A quadratic boost converter with incremental conductance (InCond) based maximum power point tracking algorithm is proposed by N. Altin and E. Ozturk in [45]. The proposed quadratic boost converter with InCond based MPPT algorithm exhibit high tracking speed with less oscillations at maximum power point and fits more suitably than a conventional converter under rapidly changing atmospheric conditions.

In another study [46], efficiency analysis of the quadratic boost converter (QBC) operating controlled by a sliding-mode control (SMC) based MPPT controller is presented. The quadratic boost converter comes out to be the best converter among the cascaded converters and is suitable for solar PV system constructed to feed a.c. load without using transformer.

Incremental Conductance based controller and Fuzzy Logic Controller for maximum power point tracking for a solar Photovoltaic Systems is presented in [47]. Fuzzy Logic Controller with reduced dynamic response time and a decrease in steady state error shows better performance.

In Chapter 3 of [48] fundamentals of soft computing techniques such as fuzzy logic (FL) and artificial neural network (ANN) based MPPT is described in detail.

A comprehensive review of widely-used MPPT Techniques for solar PV energy system is presented by A. K. Gupta and R. Saxena, in which analysis of three most popular maximum power point tracking on-line techniques - perturb-and observe (P&O),

incremental conductance (InCond), and fractional open circuit voltage (FVOC) with respect to various advantages and disadvantages are discussed [49].

Ismail H. ALTAS1 and Adel M. SHARAF proposes an intensive and direct method for designing fuzzy logic controllers (FLC) in [50]. The fuzzy rule base construction is done by analysing time response curve of control error and change in error, which is then mapped on e-Δe space like phase-plane analysis.

In [51] design of conventional boost Converter (CBC) and quadratic boost converter (QBC) is presented and a comparative analysis is done based on converter efficiency.

In [52], Chapter No. 4, efficiency is compared between a conventional boost converter (CBC), a basic quadratic boost converter (QBC) and a basic double cascaded boost converters (DCBC) has been studied for constant voltage source, in which it is concluded that the double cascade boost converter exhibits best response.

In [53] Quadratic Boost Converter & Boost converter were compared and it is analysed that the quadratic boost converter resulted in high voltage gain, but ripples were present in the output voltage for a fuzzy logic based MPPT controller based PV system.

In [54], the book comprehensively treats the subject of control circuits, PV systems, and MPPT techniques dedicated to the maximization of the electrical power produced by a PV source. This book discusses the two important parameters and how to determine them, while designing an MPPT controller and which is rarely found in literatures that are: (a) Tp, the time interval between two perturbations (perturbation period), & Δx, the amplitude of the perturbation imposed to x, (perturbation amplitude).

Next in [55], concepts sampling frequency and perturbation size are given a place in the book. This books also discusses in sequence the concepts dynamic modelling by state-space averaging and linearization techniques to design power conditioners like PV-side Converters (PVSC) and Grid-side converters (GSC).

In [56], the book presents modern methods of performing maximum power tracking in a photovoltaic energy system (PVES). A general overview of the modelling of PVES is presented. It also deals with various novel methods for operating system at maximum power point under partial shading conditions. A chronological sequence of evolution and modification of the old and new MPPT technique is treated. These articles have been a motivation to enquire, the relative efficiency of these converters when energized by a PV Module, both without and with an effective MPPT controller.

In fuzzy logic based MPPT controller, the controlling action is determined from a set of simple linguistic rules known as fuzzy rules. The development of fuzzy rules depends solely on the knowledge and expertise of the operator and doesn’t require any mathematical model. The rule decision table may be determined in different ways like (i) By trial and error method (ii) By using artificial neural network (ANN) or (iii) By using genetic algorithms (GA) based control techniques [57].

L. Reznik, in [58] presents analysis and classification of different methods of Fuzzy Logic Controller (FLC) design.

The paper [59] analyses and classifies different methods for designing fuzzy logic controller (FLC).

The basics of fuzzy logic and its application to the design of fuzzy controllers is comprehensively treated in [60]. The authors Leonid Reznik teaches the design process to be considered in two stages: an initial choice of a controller structure and parameters at first stage and their further tuning at second stage. At the initial level choice of the fuzzy structure i.e. Mamdani versus Sugeno model, scaling factors, rules and membership functions is taken into account and at advanced stage methodologies such as artificial neural networks, genetic algorithm and other nature inspired and evolutionary algorithms are considered.

2.3 CONCLUSION

It is revealed hm the review of literature that there is tremendous research going on in the area of solar photovoltaic (PV) energy system. The fundamental limitation of any solar PV system is in value of output voltage that can be obtained from a solar PV module or array. To overcome this problem dc-dc boost converters are implemented in conjunction with PV module, however a conventional boost converter has limitation in producing very high voltage value and thus several researches to improve the basic converter or to propose new topologies are going on. The literature survey identifies several possible solutions offered by researchers in terms of modified or novel topologies, selection criterion, components design and parameter selection based on application areas. Maximum power point tracking is a crucial concept for optimum functioning of any given solar photovoltaic (PV) energy system. Several conventional and modern methods are being implemented and new algorithms are evolving. Fuzzy logic is an optimum choice among various soft computing-based techniques and exhibit excellent performance in the field of control. Considering all the above literature, this work is an attempt to design, simulate and compare the performance of fuzzy logic controller for solar PV energy system using conventional, quadratic, and cascaded boost converter.

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 the 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 produces very high temperature heat and convert it into produces 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 (RES), solar photovoltaic (PV) has been proven to be very reliable energy source.

3.2 Solar Photovoltaic (PV) Energy system

Solar photovoltaic (PV) technology directly converts sunlight into electricity and do not require any other additional energy conversion stage. 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 dispensable or indispensable components in PV systems [65].

3.3 Grid-Connected Solar PV Energy Systems

A network of the transmission lines which transfer electrical energy from various power plants to our houses and industries is called Grid. The network of transmission lines can be hundreds of kilometers long. Fig. 3.1 shows a general electrical power grid.

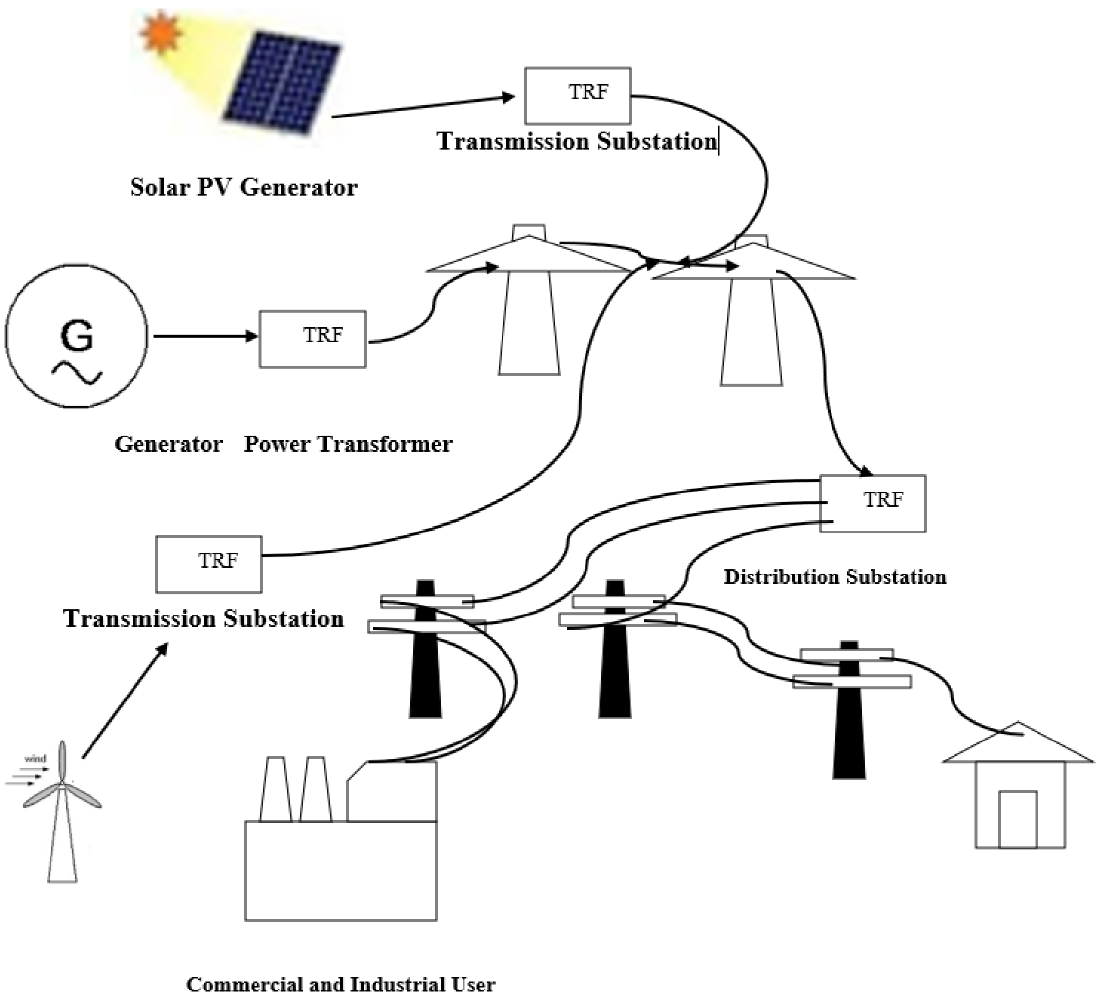


Fig. 3.1 General Electrical Power Grid

Electric power generated by the solar power plant is feed into the electricity grid. These solar PV can be of more than one-megawatt (1 MW) capacity. Generally, in a grid connected solar PV plant, battery backup is not required. However, residential solar PV system use battery for storing energy.

Based on whether battery bank is required or not required grid-connected solar PV system, can be categorized as:

1. Grid-Connected Solar PV Energy System without battery storage as shown in Fig. 3.2
2. Grid-Connected Solar PV Energy System with battery storage as shown in Fig. 3.3.

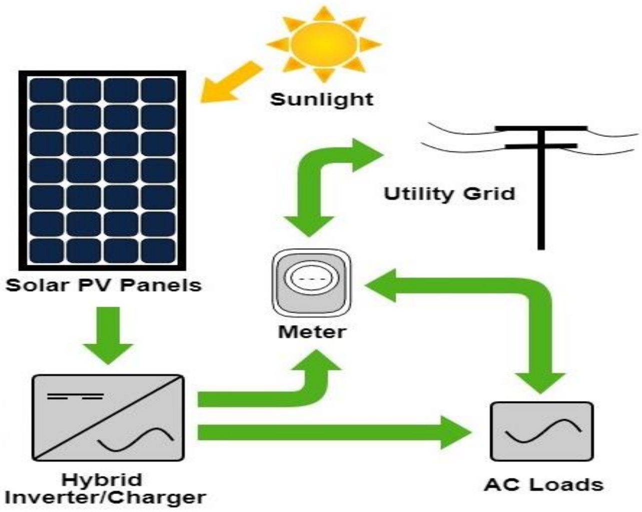


Fig. 3.2 On-Grid Solar PV System (Without battery Backup)

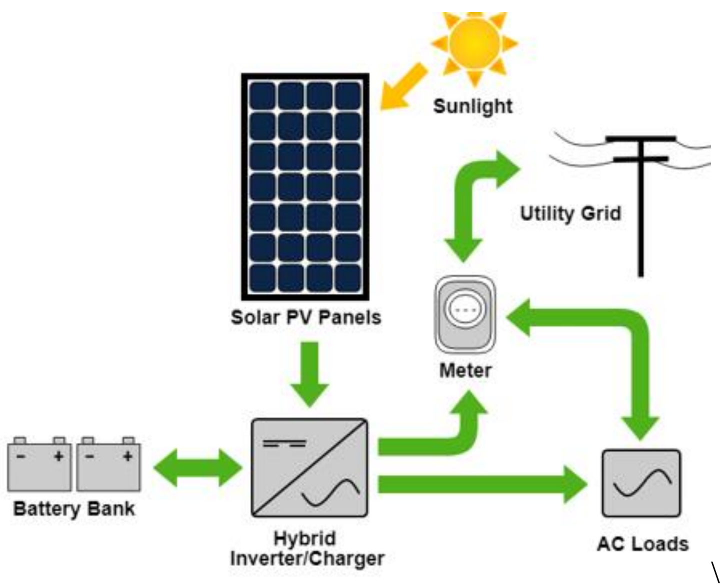


Fig. 3.3 On-Grid Solar PV System (With battery Backup)

3.4 Standalone solar PV Energy Systems

Standalone solar PV systems are suitable at the remote places like in rural areas, where grid supply is not present or where it would be inconvenient or expensive to use conventional grid supplies. They are independent of conventional grid and therefore are also named as off-grid PV systems. Standalone solar PV systems are suitable for solar PV parking meter, navigation buoy, telemetry, solar home lighting systems, solar water pumping systems, PV refrigerators, PV powered street-lighting system. As they are appropriate for loads running at low electrical energy level and are installed at remote places with no grid supply, therefore standalone PV systems are also described in literature as 'PV systems for remote power'. One of the crucial and most beneficial advancement in the space industry is perhaps the photovoltaic (PV) cell technology. It is used to convert solar radiation into electrical energy for satellite power system and spacecraft power system. Today, the photovoltaic (PV) cell is the most widely used technology for direct electricity production from sun in space industry and has boosted the information technology (IT) revolution using solar-powered satellites for communication. A satellite has a useful lifetime of between 5 and 20 years. Power requirements from tens of watts to several kilowatts can be met with an array of photovoltaic cells over a life span of satellite from a few months to 15 to 20 years. In satellite power systems rechargeable battery in conjunction with the PV array is a very crucial component and is comes into picture whenever there is an eclipse, then the satellite requires continuous power.

There are different ways to configure the Standalone Solar PV Energy systems depending on whether load is ac or dc, grid-connected or far from grid etc. and whether power & electronics control circuit is required or not.

1. Standalone Solar PV Energy system direct coupled with DC load.
2. Standalone Solar PV Energy system with DC load and power & electronics control circuit.
3. Standalone Solar PV Energy system with DC load, power and electronics control circuit and Battery storage.
4. Standalone Solar PV Energy system with AC/DC load, power and electronics control circuit and Battery storage.

3.4.1 Standalone Solar PVES direct coupled with DC load

In this system, as shown in Fig. 3.4 there are only two blocks; the first one is SPV panel and the second is the D.C. load. A DC load directly coupled to solar PV modules is the simplest of all standalone SPV system. As in this system configuration, there is no control circuitry thus, this system is an unregulated SPV system. Such type of system is designed for operation during daylight only. As it is an unregulated system the load should be such that it does not require precise operation. For example, solar water pumping system for drinking or irrigation do not require fixed amount of water on hourly basis.

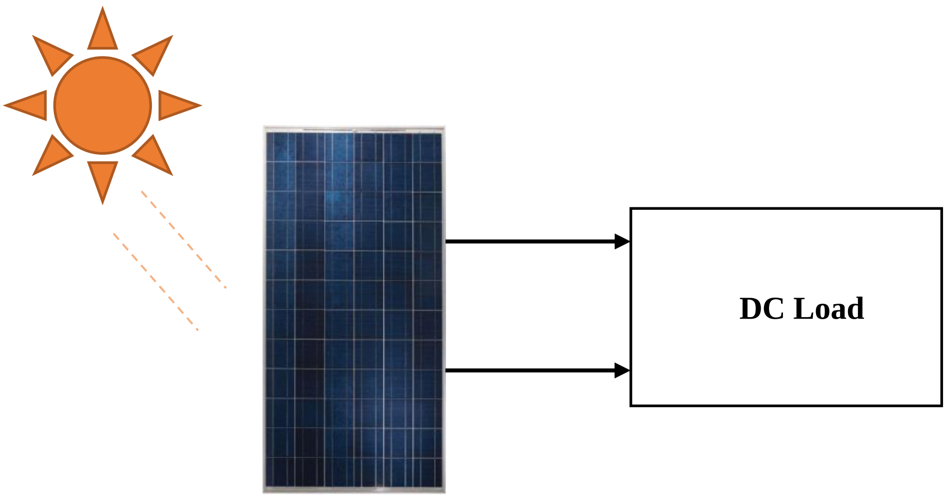


Fig. 3.4 Standalone Solar PVES direct coupled with DC load

3.4.2 Standalone Solar PVES with DC load and Power & Electronics Control Circuit

In the system shown in Fig 3.5, there are more than two elements; the first one is SPV panel or module, the second element is the D.C. load and the third one is a power and electronics control circuit (PECC) as DC-DC converter and MPPT controller respectively, implemented with the PV modules and the DC load. As in this system configuration, there is a control circuitry thus, this system is a regulated SPV system. Since there is no battery, thus such type of system is designed for operation during daylight only. This type of arrangement/assembly is found suitable for operating loads like DC fan or DC pump, DC water heater element etc.

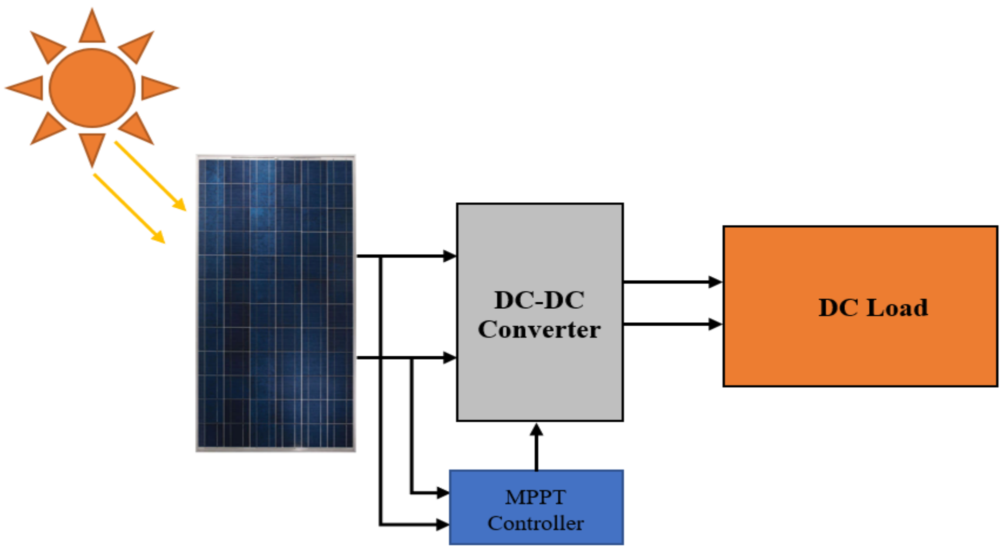


Fig. 3.5 Standalone Solar PVES with DC load and control circuitry

3.4.3 Standalone Solar PVES with DC load, Power & Electronics Control Circuit and Battery

In this type of PV system, batteries keep on charging and stores energy during the solar time i.e. whole day. Electrical energy stored in the batteries as chemical energy may be used to supply the

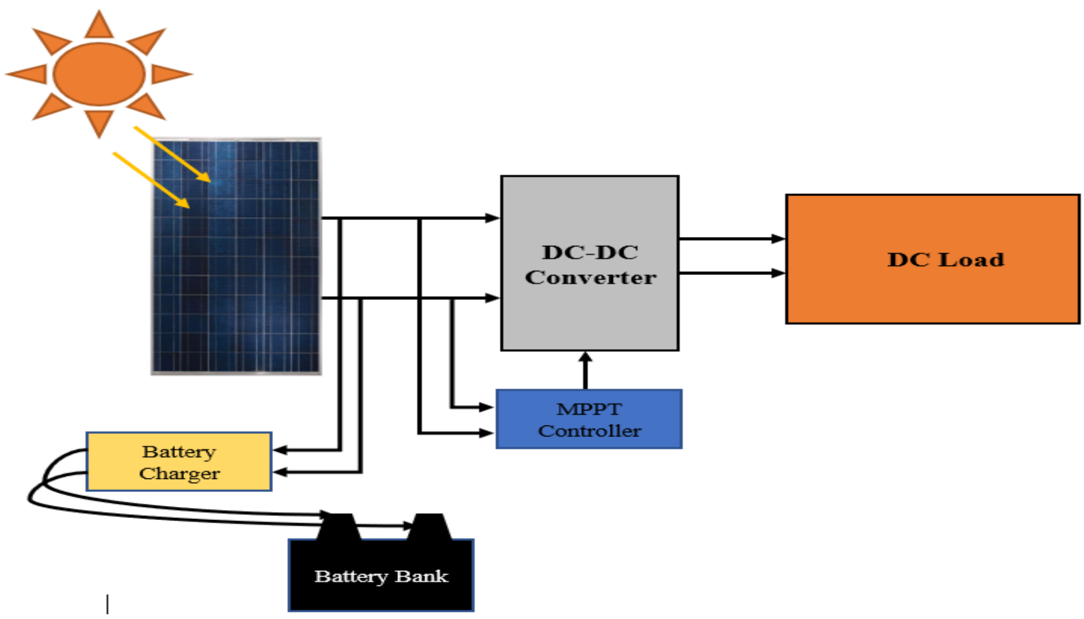


Fig. 3.6 Standalone Solar PVES with DC load, control circuitry and Battery

load both during the daytime and in the night. DC loads like home lighting and street lighting etc. are common applications. The system is as shown in Fig. 3.6.

3.4.4 Standalone Solar PVES with AC/DC load, Power & Electronics Control Circuit and Battery

This arrangement is the most general standalone solar PV system which encompasses all type of AC or DC load. Fig. 3.7 depicts the system.

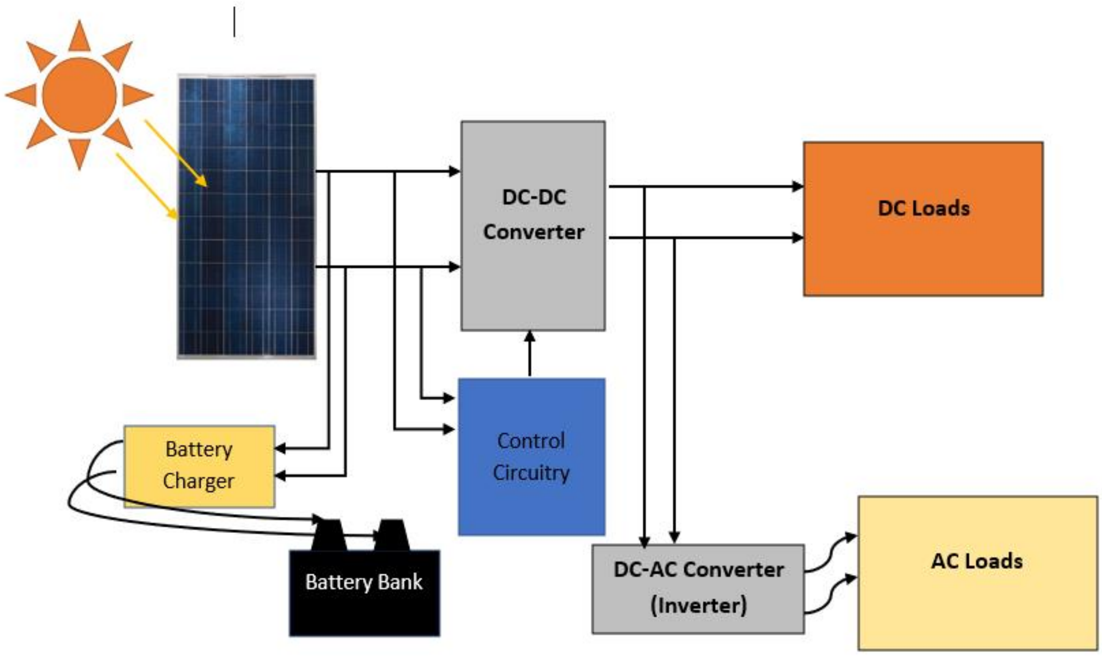


Fig. 3.7 Standalone Solar PVES with AC/DC load, control circuitry and Battery

3.5 Hybrid solar PV Energy Systems

Hybrid solar PV energy system works in conjugation with other renewable and non-renewable energy sources, like diesel power station, wind power system etc. to ensure continuous supply of electricity to the loads. The solar PV system has the limitation to generate electricity only during the daylight. A Solar PV system is unable to generate electricity as there is no irradiation during night. Thus, energy stored in battery during daytime may be utilized. For an increase in load demand that if may not be able to fulfill by this capacity diesel power plant comes in action. Similarly, wind power plant can provide any surplus demand of electrical energy. However, a diesel connected hybrid solar PV system is able to cope up a sudden surge in demand of electricity at any time [64].

3.6 Solar Photovoltaic (PV) Energy System Research Model

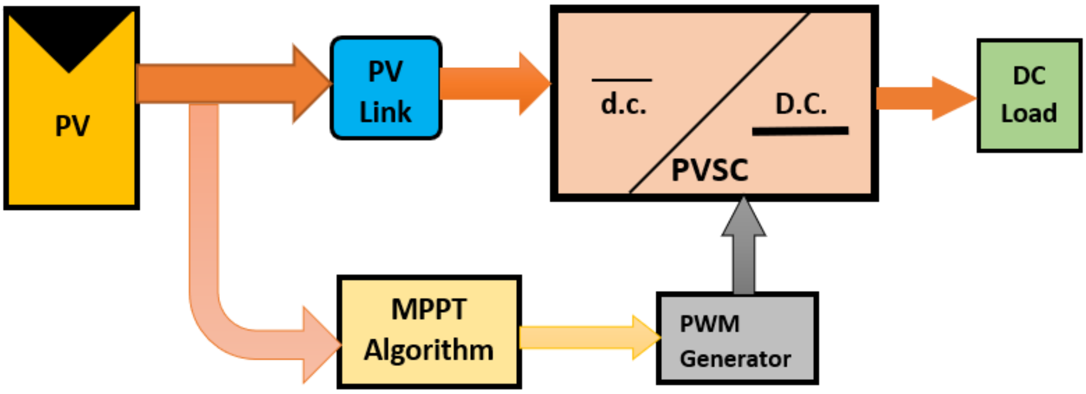


Fig. 3.8 Solar Photovoltaic Energy System (SPVES)

The configuration selected for the research purpose for this project is standalone Solar photovoltaic system with DC load and Power & Electronic Control Circuit. The various components are:

1. Solar PV Panel
2. The Power & Electronic Control Circuit
3. Constant DC load (Resistive)

The electronic control circuitry is comprised of a dc-dc boost converter and a maximum power point tracking (MPPT) control algorithm. The application areas comprise solar water heater element as a low profile, in high profile load areas like spacecraft power system and satellite power 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 than photovoltaic side voltage. Conventional boost converter is the widely used boost converter because of its simple circuit configuration and efficient voltage step-up behaviour. However, it is pertinent to mention that a conventional boost converter may not meet always fulfil 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 [52].

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 Solar PV Module. The photovoltaic Side Converter (PVSC) is usually controlled by the maximum power point tracking.

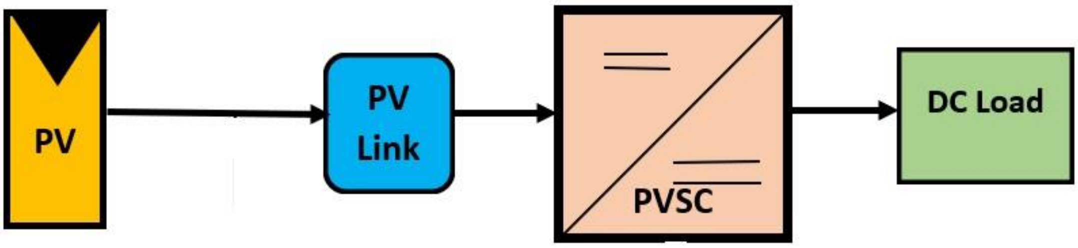


Fig. 4.1 Block Diagram of a Solar PV system with PVSC

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 quadratic boost converter is shown in Fig 4.2.

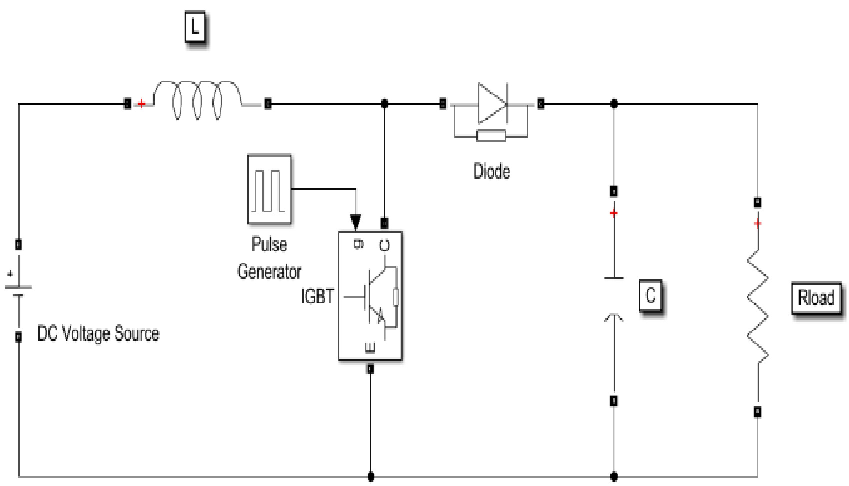


Fig 4.2: A Conventional boost converter

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.

Mode 1: On-State

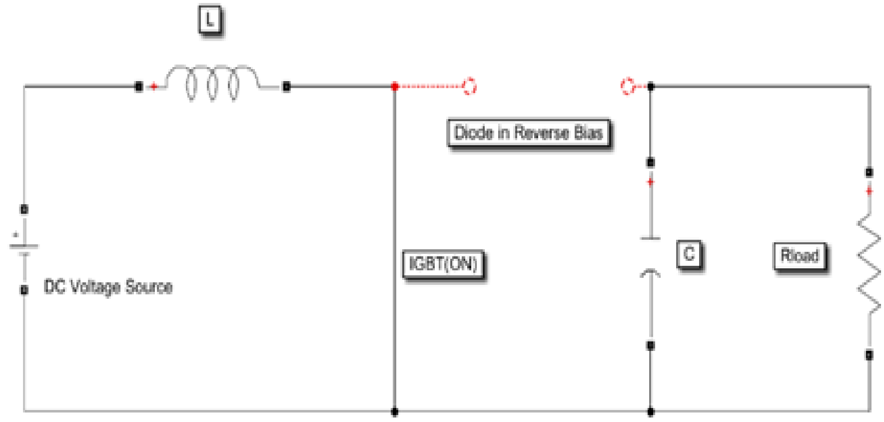


Fig 4.3: A conventional boost converter (On-State)

The mode 1 circuit of conventional boost converter is given in Fig 4.3. In on-state, active switch (IGBT) is turned on, whereas the diode, D is reverse biased. The inductor, L is energised by the supply voltage from the capacitor, C and magnetic energy gets stored in it. During this state, the inductor current, i_L gradually increases.

Mode 2: Off-State

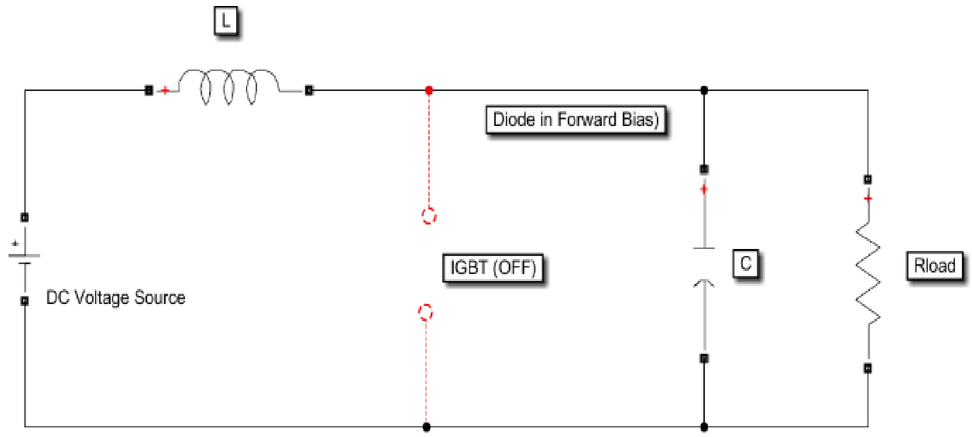


Fig 4.4: A conventional boost converter (Off-State)

The mode 2 circuit of conventional boost converter is given in Fig 4.4. In off-state, 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, act 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,

The duty cycle is calculated as

$$D = 1 - \frac{v_{in}}{v_{out}} \quad (4.1)$$

The output and the input currents are calculated as

$$I_{out} = \frac{V_{out}}{R} \quad (4.2)$$

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

The inductor value is calculated as

$$L = \frac{DV_{in}}{f\Delta i_L} \quad (4.4)$$

The capacitor value is calculated as:

$$C = \frac{DV_{out}}{fR\Delta v_c} \quad (4.5)$$

4.3 The Quadratic Boost Converter

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

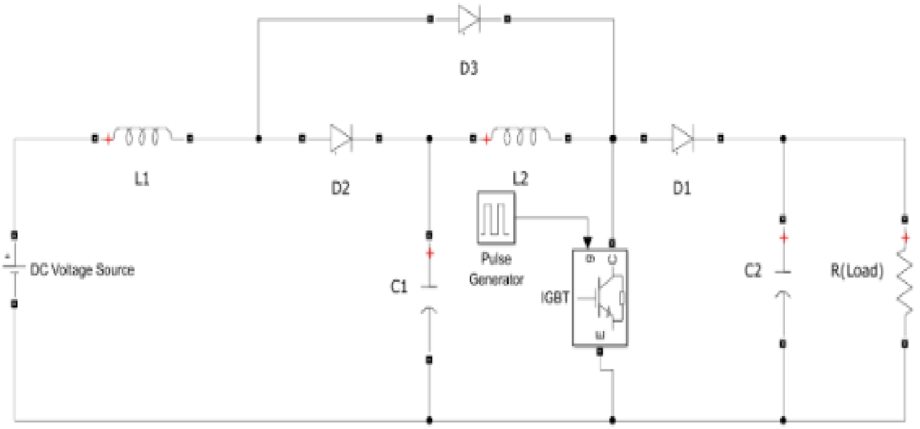


Fig 4.5: A quadratic boost converter

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

Mode 1: On-State

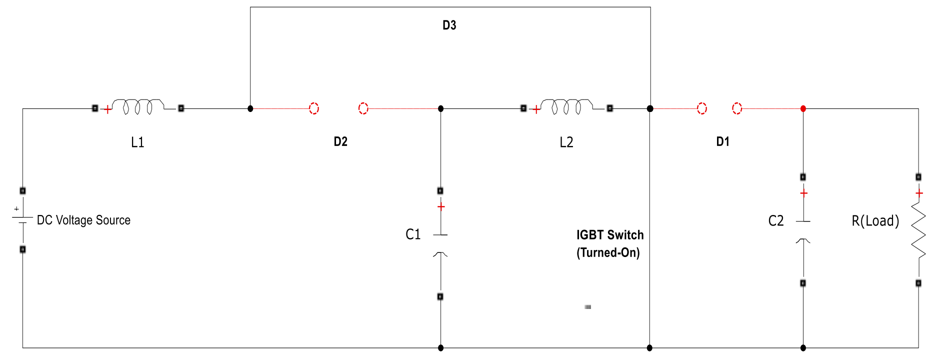


Fig 4.6: A quadratic boost converter (On-State)

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 D1 and D2 are reverse biased. Currents passes through L1 and L2 because of Vin and C1 respectively. During this mode of conduction, the inductor current, i_{L1} gradually increases.

Mode 2: Off-State

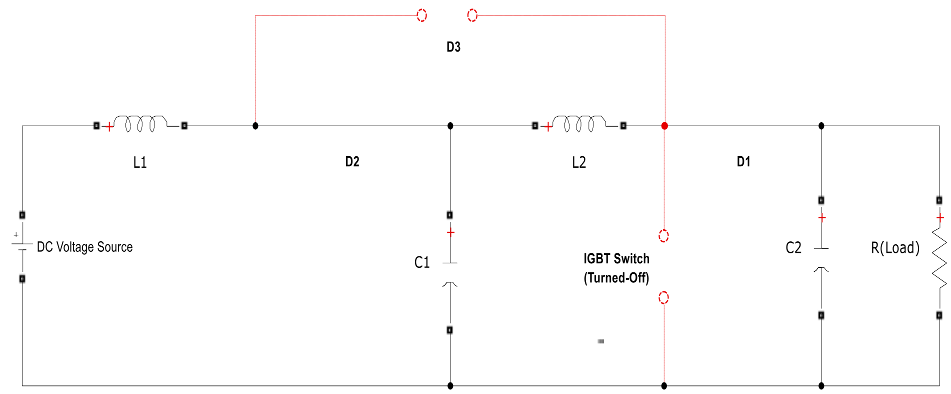


Fig 4.7: A quadratic boost converter (Off-State)

The mode 2 circuit of quadratic boost converter is given in Fig 4.7. In off-state, switch (IGBT) is turned off, D3 is reverse biased, whereas D1 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.

A high value capacitor Cin, act as DC-Link. The L1 cannot be connected in series to the PV module, modelled 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,

The duty cycle is calculated as

$$D = 1 - \frac{\sqrt{V_{in}}}{\sqrt{V_{out}}} \tag{4.6}$$

The output and inductor currents are calculated as follows:

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

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

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

The inductors values are calculated as:

$$L_1 = \frac{DV_{in}}{f\Delta iL_1} \tag{4.10}$$

$$L_2 = \frac{DV_{in}}{f\Delta iL_2} \tag{4.11}$$

The capacitors values are calculated as:

$$C_{1,2} = \frac{DV_{in}}{(1-D)\Delta v_c Rf} \tag{4.12}$$

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.

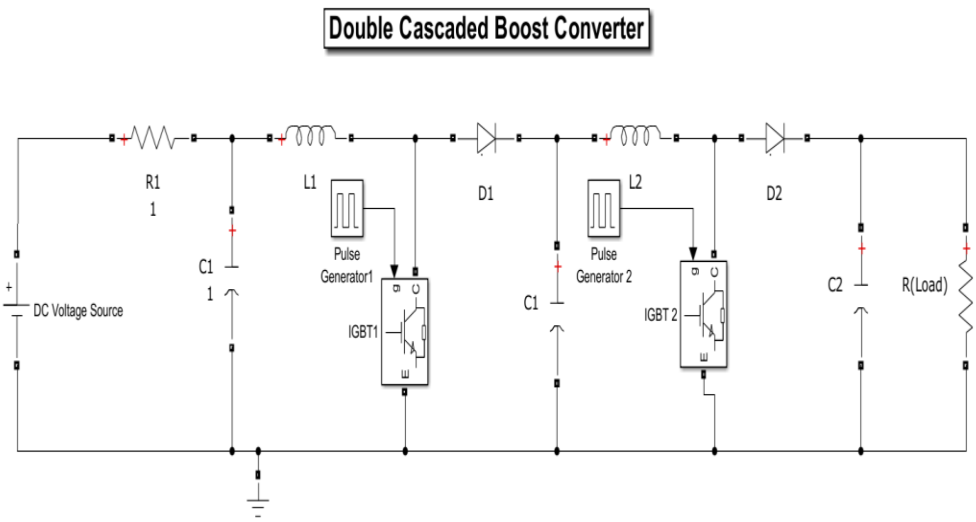


Fig 4.8: A double cascaded boost converter

It consists of one input voltage source Vin, two numbers of independently controlled active switches IGBT1 and IGBT2, two numbers of freewheeling diodes D1 and D2, two numbers of capacitors C1 and C2 and two numbers of inductors L1 and L2. The double cascaded boost converter operates in two possible modes of operation in continuous mode.

Mode 1: On-State

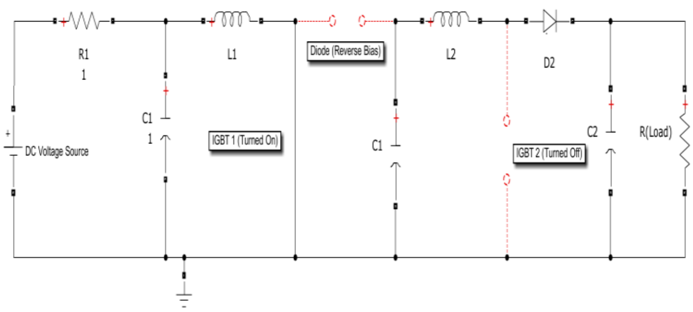


Fig 4.9: A double cascaded boost converter (On-State)

The mode 1 circuit of double cascaded boost converter is given in Fig 4.9. In on-state, the switch IGBT1 is turned on, IGBT2 will remain off, D1 is reverse biased and D2 is forward biased. The inductor L1 stores the energy.

Mode 2: Off-State

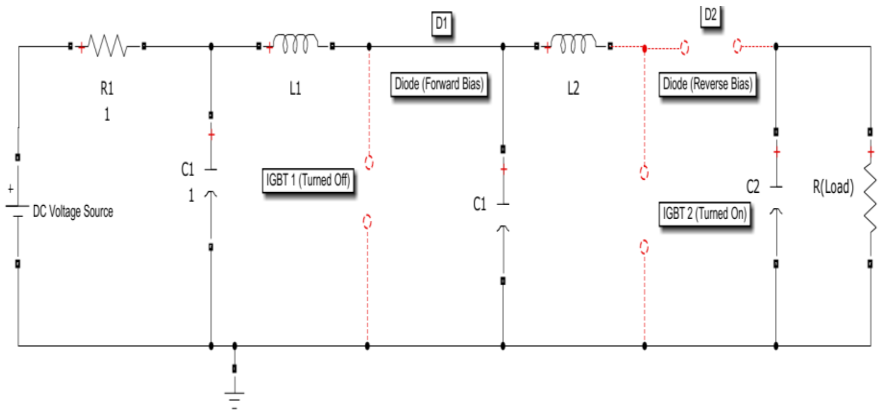


Fig 4.10: A double cascaded boost converter (Off-State)

The mode 2 circuit of double cascaded boost converter is given in Fig 4.10. In Off-state, the switch IGBT1 is turned off, IGBT2 will gets turned on, D1 becomes forward biased and D2 is reverse biased.

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

The voltage ratio is calculated as:

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

The output and inductor currents are calculated as follows:

$$I_{out} = \frac{V_{out}}{R} \qquad (4.14)$$

$$I_{L2} = \frac{I_{out}}{(1-D_2)} \qquad (4.15)$$

$$I_{L1} = \frac{I_{L2}}{(1-D_1)} \qquad (4.16)$$

Where, I_{L2} is the output current of the first boost stage.

The inductors values are calculated as:

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

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

The capacitors values are calculated as:

$$C_1 = \frac{D_1 V_1}{\Delta v_{c1} R f} \tag{4.19}$$

$$C_2 = \frac{D_2 V_{out}}{\Delta v_{c2} R f} \tag{4.20}$$

Where, where V_1 is the output voltage for the first boost stage.

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

CHAPTER 5

MAXIMUM POWER POINT (MPP) SEARCH

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 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. Thus, most of the time the operating point of the solar panel neither coincide nor stay 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. 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.

The electrical MPPT control techniques are categorised into following types:

(i) Off-line control techniques
   - (a) Fractional open-circuit voltage (FOCV)
   - (b) Fractional short-circuit current (FSCC) techniques.

(ii) On-line control techniques
   - (a) Perturb and Observe (P&O)
   - (b) Incremental conductance (InCond) techniques.

(iii) Artificial intelligence (AI) based control techniques

(a) fuzzy logic control (FLC) technique
(b) artificial neural network (ANN) technique
(c) genetic algorithm (GA) etc.

Several researches 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 [56].

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.

Fuzzy logic controllers (FLCs) are based on fuzzy set theory which uses experience and knowledge of a human operator in terms of linguistic variables called fuzzy rules. An expert human operator is the experienced one who controls the system inputs to get a desired output by just looking at the system output without any knowledge of the system’s dynamics and interior parameter variations, like a black box.

5.2 MPPT Using Fuzzy Logic

In fuzzy logic based MPPT controller the controlling is determined from a set of simple linguistic rules known as fuzzy rules. The development of fuzzy rules depends solely on the knowledge and experience of a human operator in understanding of the process to be controlled and doesn’t require any mathematical model. The rule decision table may be determined in following different ways:

(i) By Hit and Trial method –some previous knowledge system behaviour is used to create an elementary rule table which is further evolved by trial and error until a complete working table with desired control features is obtained.

(ii) By using artificial neural network (ANN) – in which the algorithm is learned by applying a given set of data from pre-knowledge of expert and experiments to an artificial neural network. The network is thus trained using based on 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.

(iii) Genetic algorithms (GA) based algorithms - GA methods similar as ANN method in which a set of rules is learned and evolved till perfection from a set of data.

All these methods exhibits excellent performance ; however, it would be pertinent to note that they are not simple fuzzy systems, rather they are hybrid fuzzy systems, means a Fuzzy-ANN or a GA-Fuzzy etc, which combine different intelligent methods such as neural networks and GAs with the Fuzzy Logic. Hybrid Fuzzy systems needs high-level computation algorithms. Neural networks, genetic algorithms and many other evolutionary algorithms needs relatively more computation time than that for a simple fuzzy logic-based controller. Such type of time-consuming computation algorithm is usually not desired in control system applications. Most of the time simple Fuzzy Logic Controllers (FLCs) are modelled for specific applications and not for a general case. In our case study Hit and Trial method of designing FLC is applied. [57].

5.3 Fuzzy Logic Controller

Fuzzy Logic Controller design is very subjective process, and there no such as a general method of designing, determining and optimisation of parameters for a fuzzy controller. It all and always depends on the control objectives and on the specific process, plant or system under control and. Also, there is no analytical equation i.e. a mathematical control function that can be written for a fuzzy controller and it is also not essential rather the mathematical model of a controller should describe mapping of an input to an output which is control signal.

There are two most discussed and widely used approach while designing a fuzzy controller, the first is Mamdani fuzzy controller and other is Sugeno fuzzy controller. In a Mamdani fuzzy controller each and every input and output are described by a membership function and thus it is good for apprehending the expertise of a human experience. But human operator is also a limitation of this controller because even though we have a plant model this approach will not work, as controller cannot be designed in his/her absence. In a Sugeno fuzzy controller each rule's output is a linear equation and thus it is good for implanting a linear controller and continuous switching occurs between these output equations. The Sugeno model is very effective due to its an adaptive capability and mathematical tractability when the plant model is known. Therefore, the Sugeno fuzzy controller becomes a dominant choice for nonlinear and/or adaptive control design [60]. The design scheme normally contains the following steps:

1. To decide the input and control variables.

2. To determine fuzzy sets.
3. To Design the rule base and representing it as rule table.
4. To compute fuzzy outputs.
5. Defuzzification

A Fuzzy Logic Controller (FLC) is evolved in three stages: fuzzification, rule inference, and defuzzification as shown in Fig. 5.1

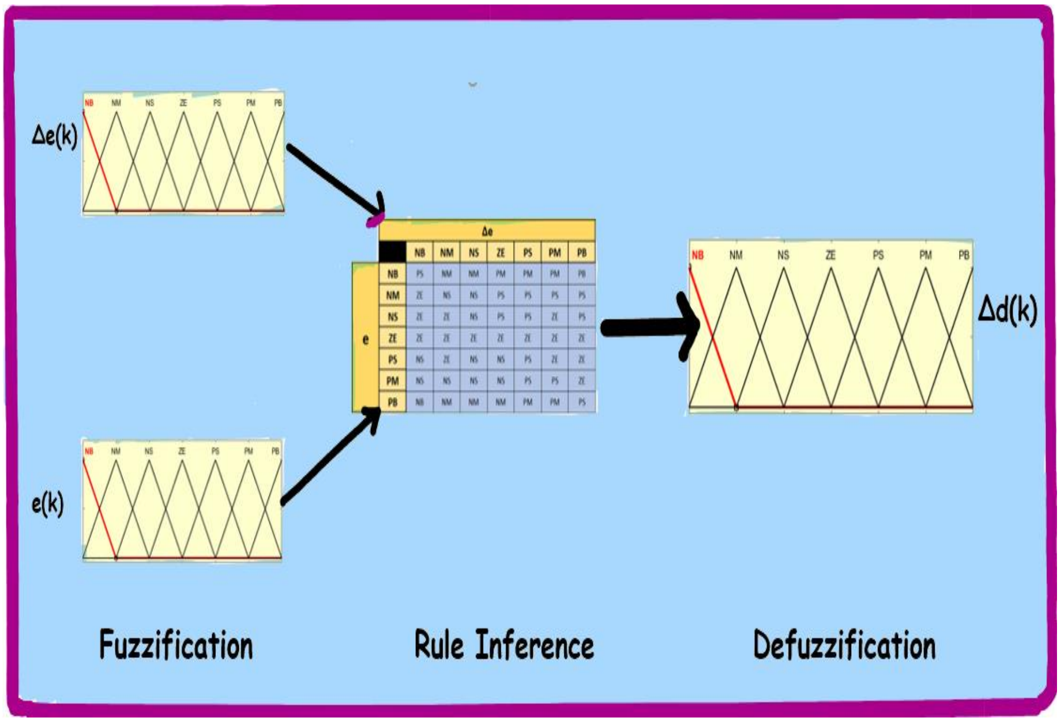


Fig. 5.1 FLC Block Diagram

Fuzzification.

The operation in which numerical values of input variables are mapped into a membership function is known as fuzzification. These values of Ipv and Vpv are used to compute the power, Ppv from a PV array. The error signal e(k) and change in error Δe(k) are the input variables and are calculated from Equation (5.1) and Equation (5.2), respectively.

$$e(k) = \frac{P_{pv}(k) - P_{pv}(k-1)}{V_{pv}(k) - V_{pv}(k-1)} \qquad (5.1)$$

$$\Delta e(k) = e(k) - e(k-1) \tag{5 .2}$$

The crisp numerical values of e(k) and Δe(k) are expressed in fuzzy linguistic variables such as NB (Negative Big), NM (Negative Medium), NS (Negative Small), ZE (Zero), PS (Positive Small), PM (Positive Medium) and PB (Positive Big) using basic fuzzy subset.

Rule Inference.

The rule inference is designed and evolved by trial and error method. These rules are developed on the "if-then" concept to determine the output variables as fuzzy variables based on membership function (MF) between e(k) and Δe(k). The Mamdani's inference method is used here as it is normally prominent in most control application.

Defuzzification.

It is the inverse operation of the fuzzification and computes a crisp numerical value of the fuzzified output variable and thus made it explicit to the external environment i.e. boost converter. The duty cycle step, Δd(k) for the boost converter, is the FLC output.

5.4 Fuzzy Controller Design Using Fuzzy Logic Toolbox

Fuzzy logic toolbox helps MATLAB users to create and edit fuzzy inference system (FIS). The inference system can be integrated in Simulink environment. The fuzzy toolbox has three categories of tools:

1. Graphic interactive tools (GUI)
2. Command line functions
3. Simulink blocks

In this project Graphic User Interface (GUI) tool is used in building fuzzy inference system (FIS) for developing fuzzy controller. There are five basic tools in the toolbox for building, editing and observing fuzzy inference system.

1. Fuzzy Inference System (FIS) Editor
2. Membership Function (MF) Editor

3. Rule Editor
4. Rule Viewer
5. Surface Viewer

Fuzzy Inference System (FIS) Editor

The block shown in Fig. 5.2 is the fuzzy designer toolbox which is used to define the input and output variables of the fuzzy system. The following information can be observed:

(a) Input variables are e(k) and Δe(k)
(b) Output variable is Δd(k)
(c) Name of FIS is Fuzzy MPPT Controller for Solar PV System
(d) FIS type is Mamdani

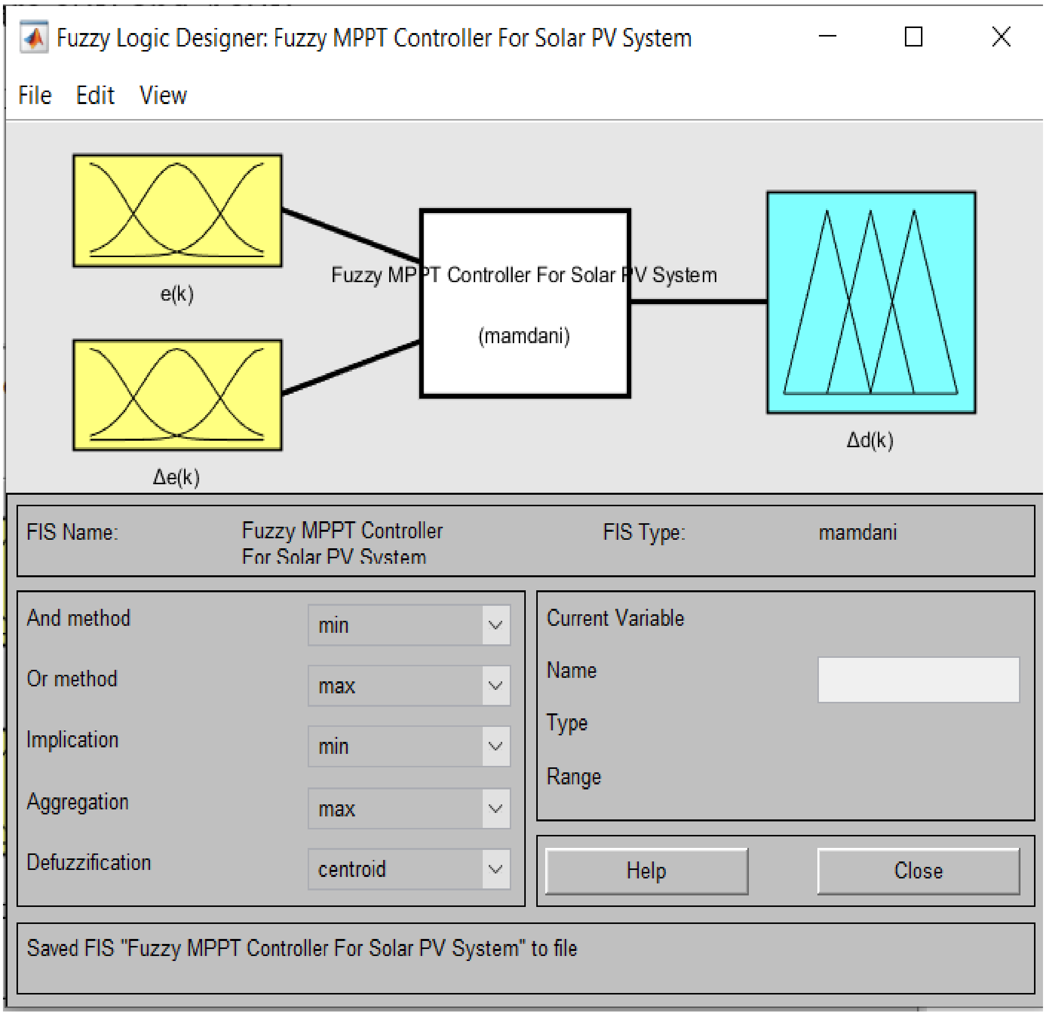


Fig. 5.2 FIS Editor for Fuzzy MPPT Controller for Solar PV system

Membership Function (MF) Editor

The membership function editor is shown in Fig. 5.3. Using this we assign and edit linguistic variables and universe of discourse.

(a) Membership functions for input and output variables in linguistic terms. These are seven in numbers as:

a. Negative Big (NB)
b. Negative Medium (NM)
c. Negative Small (NS)
d. Zero (ZE)
e. Positive Small (PS)
f. Positive Medium (PM)
g. Positive Big (PB)

(b) Type of membership function are all trimf (triangular membership function).

(c) Universe of discourse for input variable is (-30, 30) and for output variable is (-1,1).

Membership functions for input and out variables are shown in Fig. 5.4, Fig. 5.5, and Fig. 5.6 respectively.

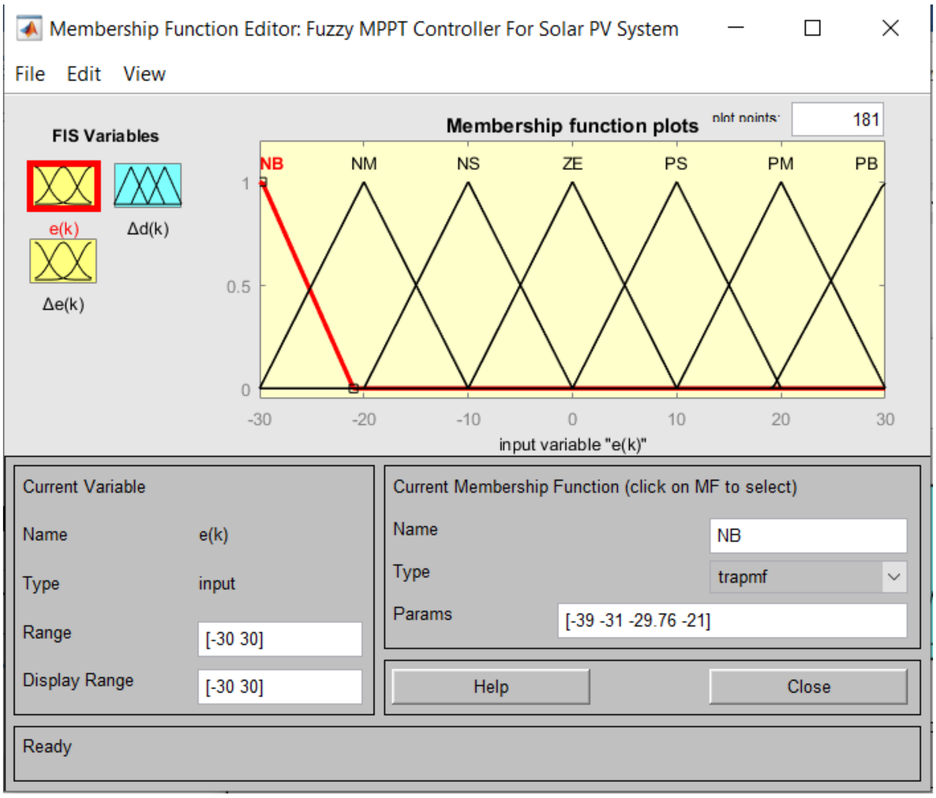


Fig. 5.3 Membership functions (MF) editor

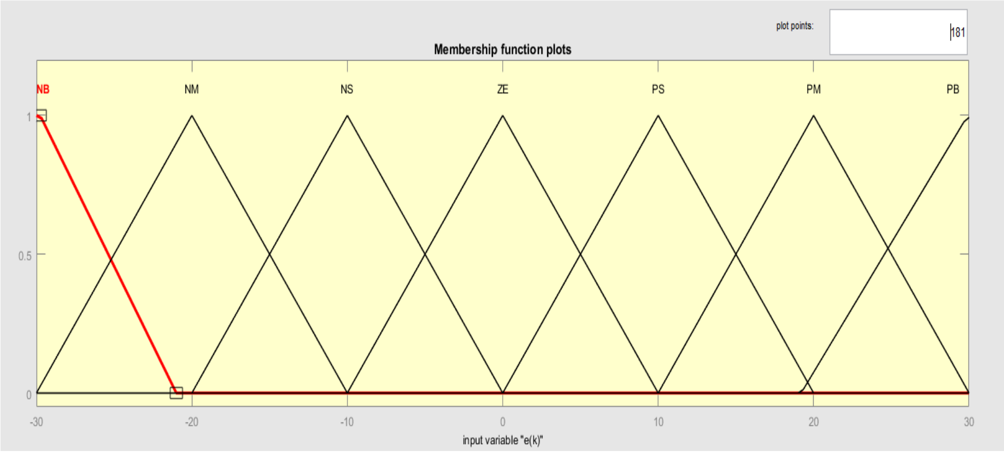


Fig. 5.4 Membership functions for input variable e(k)

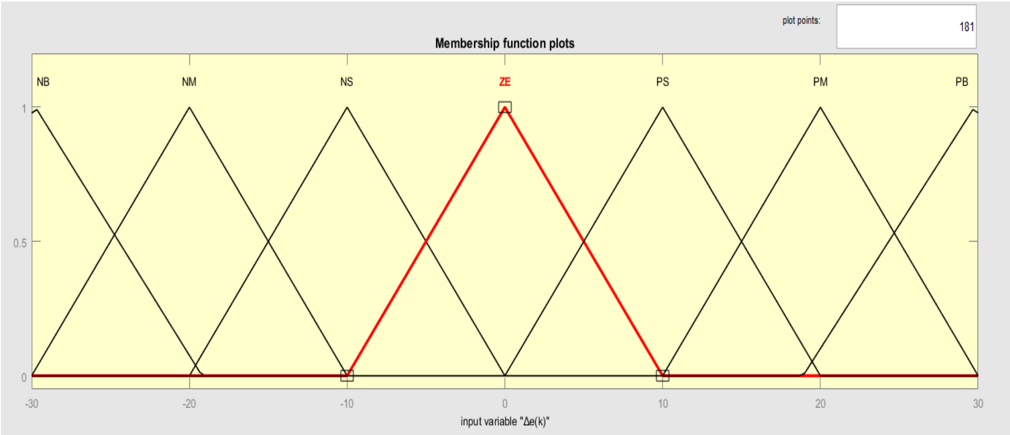


Fig. 5.5 Membership functions for input variable Δe(k)

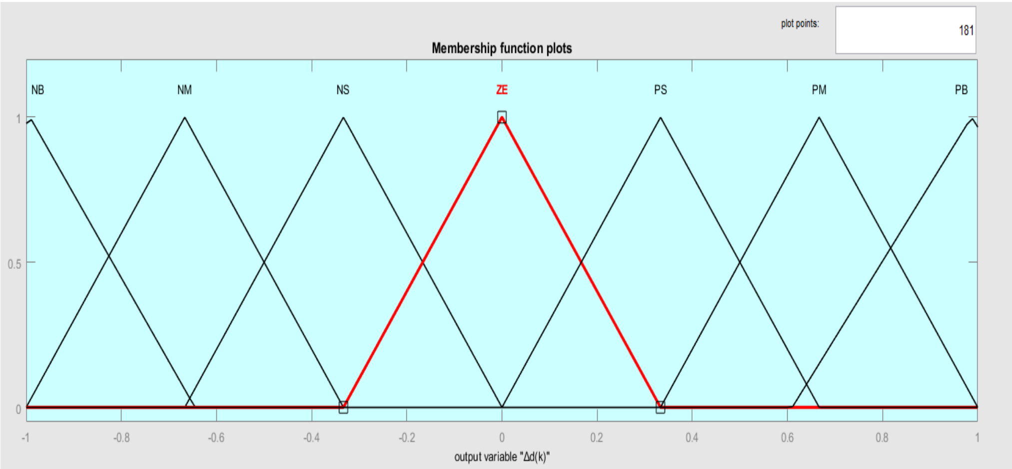


Fig. 5.6 Membership functions for input variable Δd(k)

Rule Editor

Rule editor facilitates to frame the rules for producing the crisp as output duty cycle step, Δd(k) for boost converter. A rule table developed by using a generalised table approach initiated with a three-by-three rule table, which is then evolved to a larger dimension of seven-by-seven table is shown in Fig. 5.7.

		Δe						
		NB	NM	NS	ZE	PS	PM	PB
e	NB	PS	NM	NM	PM	PM	PM	PB
	NM	ZE	NS	NS	PS	PS	PS	PS
	NS	ZE	ZE	NS	PS	PS	ZE	PS
	ZE	ZE	ZE	ZE	ZE	ZE	ZE	ZE
	PS	NS	ZE	NS	NS	PS	ZE	ZE
	PM	NS	NS	NS	NS	PS	PS	ZE
	PB	NB	NM	NM	NM	PM	PM	PS

Fig. 5.7. Rules Table for building rule base of FLC

A rule base of 49 rules is shown in Fig. 5.8

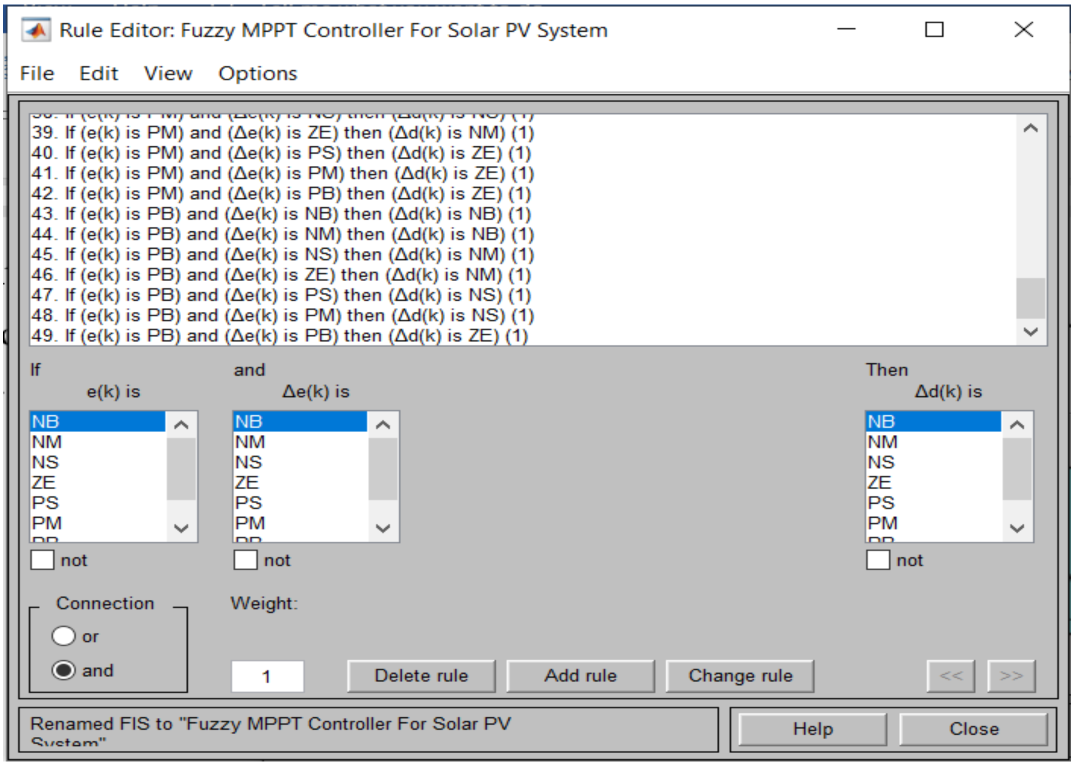


Fig. 5.8 Rule editor window with 49 rules in text field

Rule Viewer

The Fig. 5.9 is the representation of same rules in the rule view form.

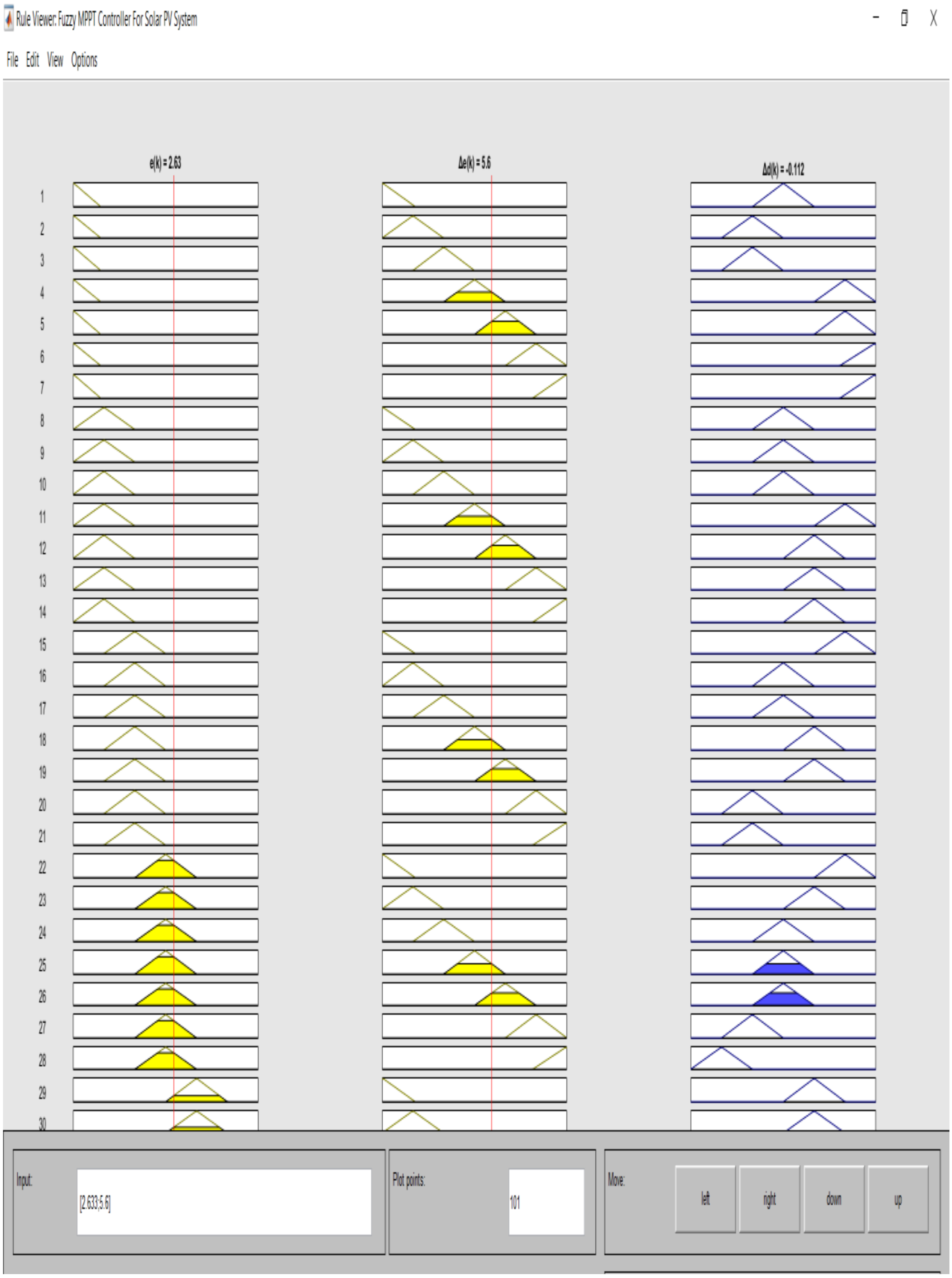


Fig. 5.9 Rule viewer window

Surface Viewer

The Fig. 5.10 shows the surface view of fuzzy rules. It is a surface map generated between the two input variables i.e. e(k), Δe(k) and one output variable Δd(k).

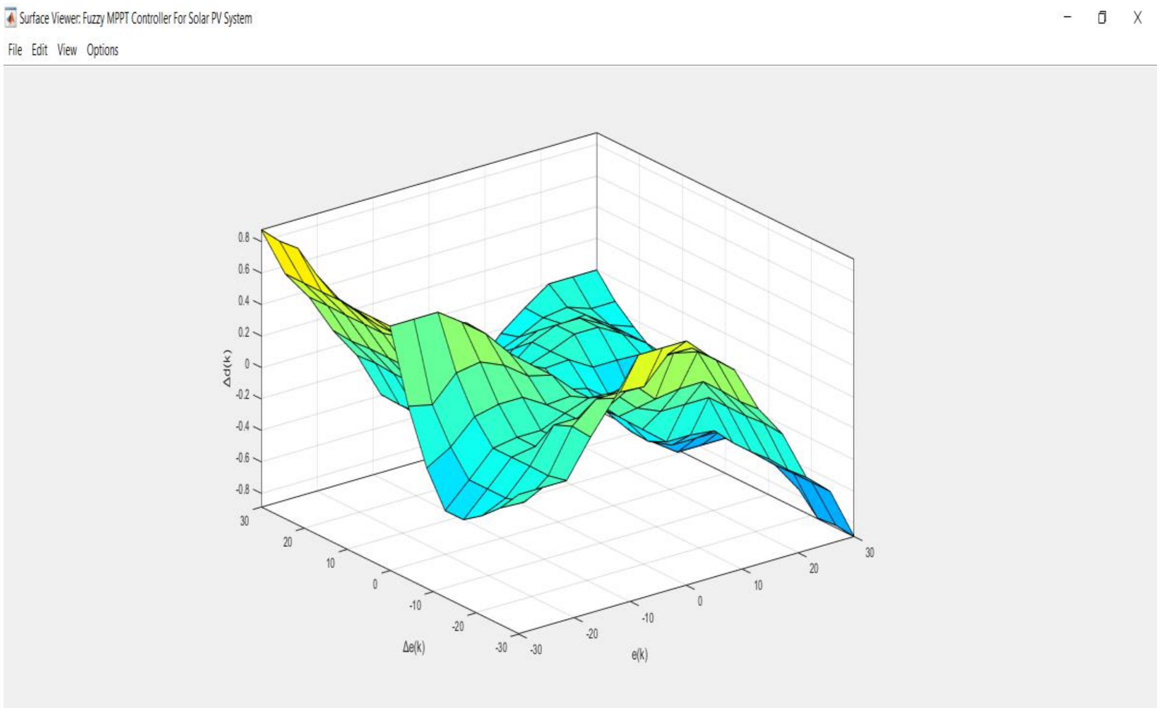


Fig. 5.10 Surface viewer window

CHAPTER 6

SIMULATIONS AND RESULTS

The Simulink model of whole system on which analysis is done is shown below in Fig. 6.1. It is divided into three parts the first one is PV array then the second is DC/DC converter which is drive through the MPPT technique which has been applied to derive maximum power from the PV module and the third part is constant load.

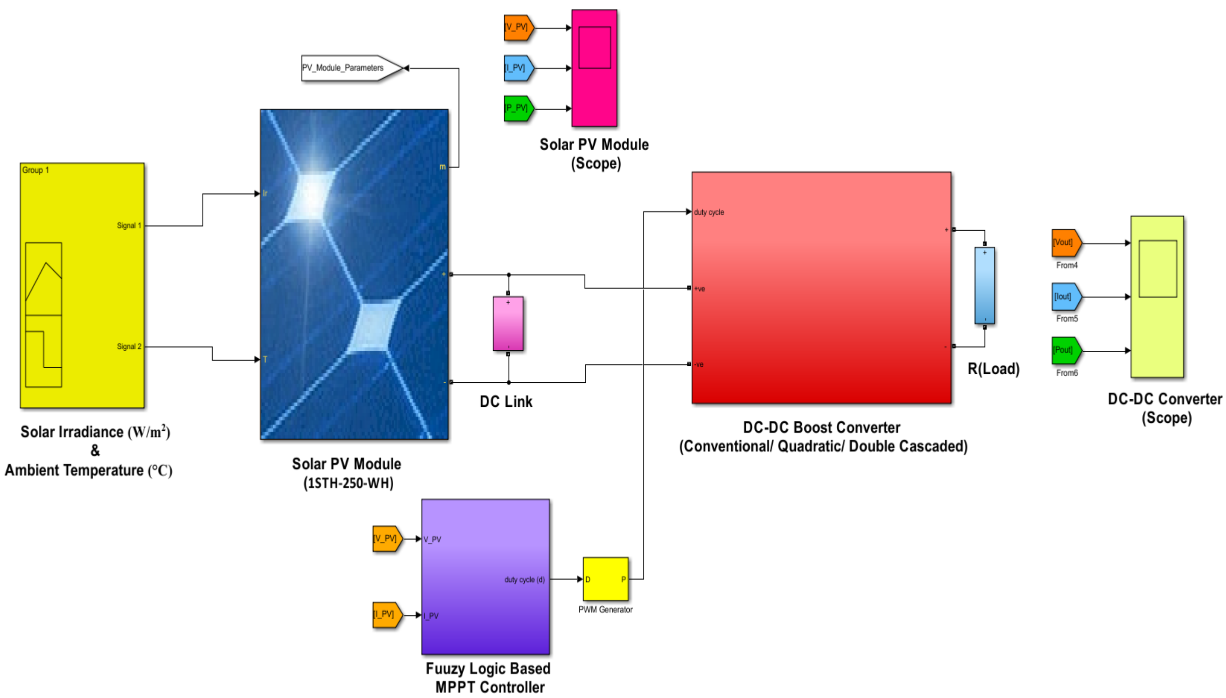


Fig. 6.1 Simulink Model of Solar PV Module Connected Boost Converters with Fuzzy MPPT controller

It is divided into following parts:

1. The PV Array
2. The DC/DC Converter
3. Fuzzy MPPT Controller + PWM Generator
4. The Load (Resistive, in nature)

6.1 Simulation of Battery Connected Boost Converters

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

Conventional Boost Converter (CBC)

The simulation circuit diagram for the boost converter is shown in Fig. 6.1

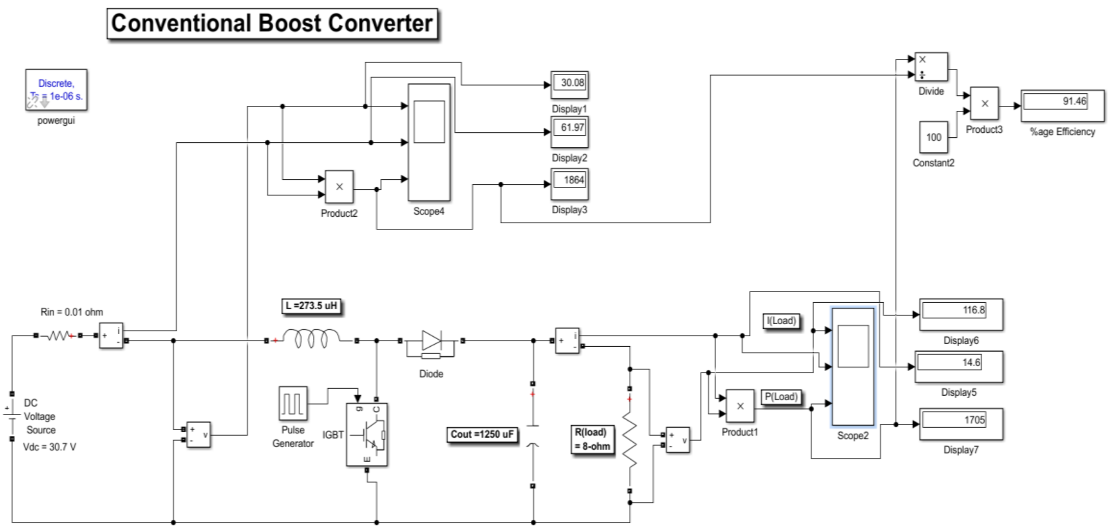


Fig. 6.1 Simulink Model of PV Array Connected Boost Converter

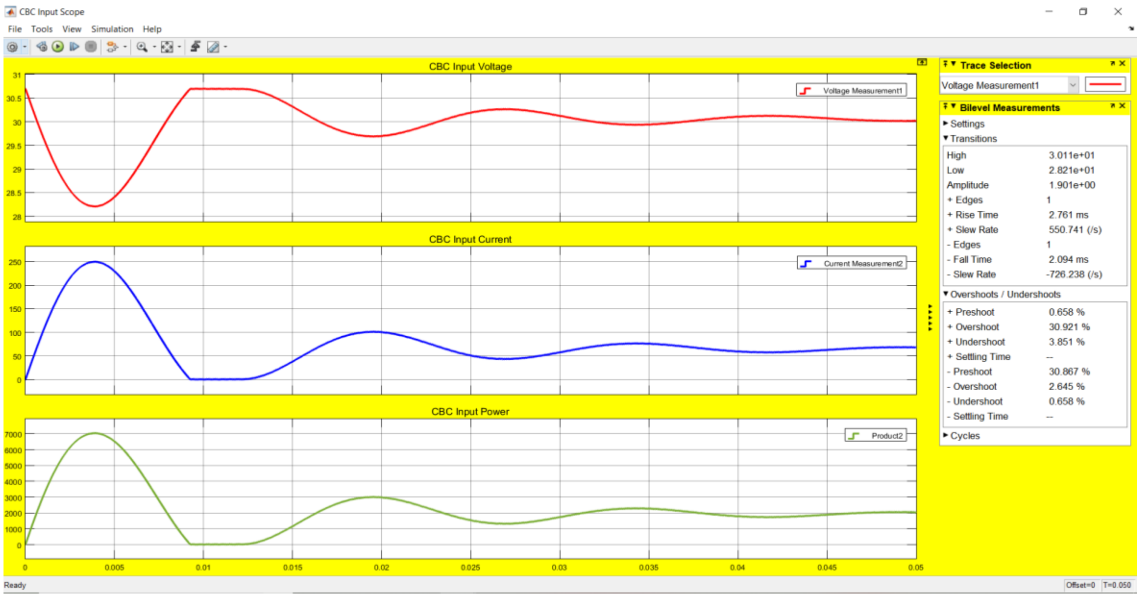


Fig 6.2 Waveforms of Input electrical signals of Conventional boost converter

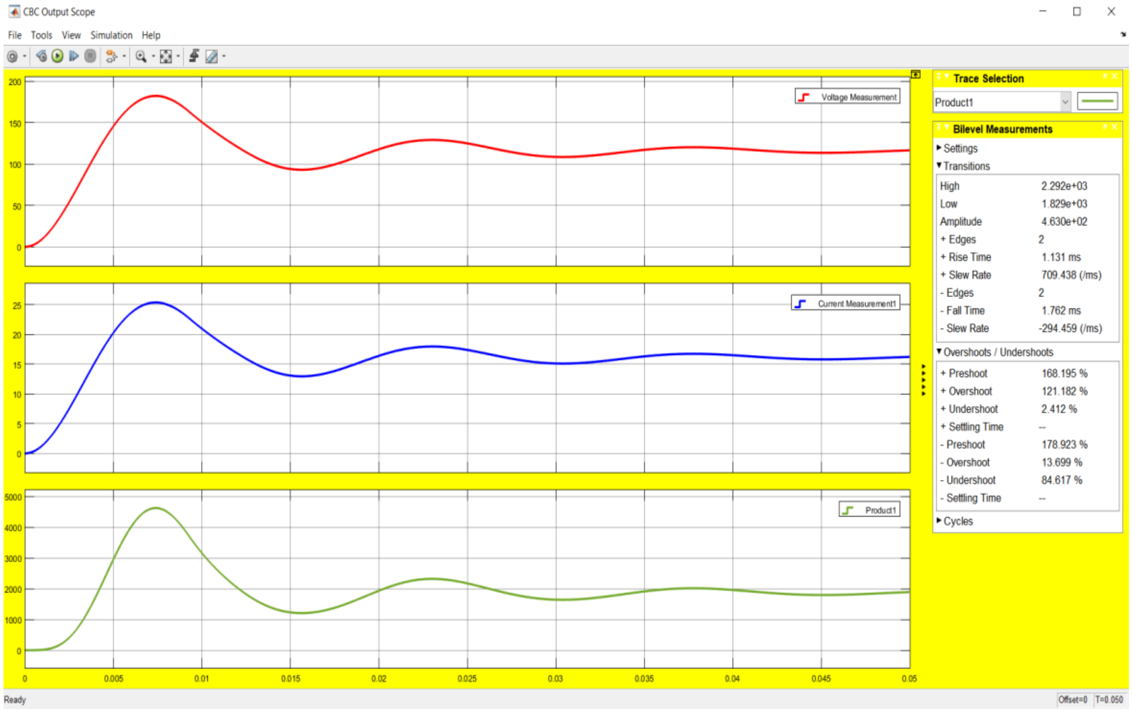


Fig 6.3 Waveforms of Output electrical signals of Conventional boost converter

Quadratic Boost Converter (QBC)

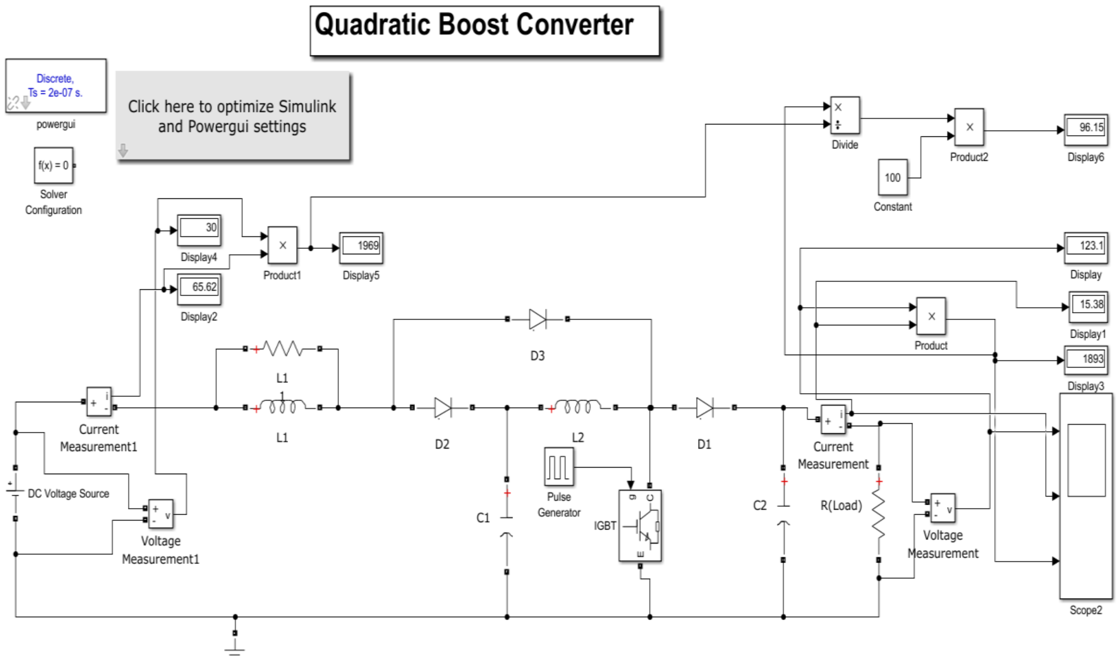


Fig. 6.4 Simulink Model of PV Array Connected Quadratic Boost Converter

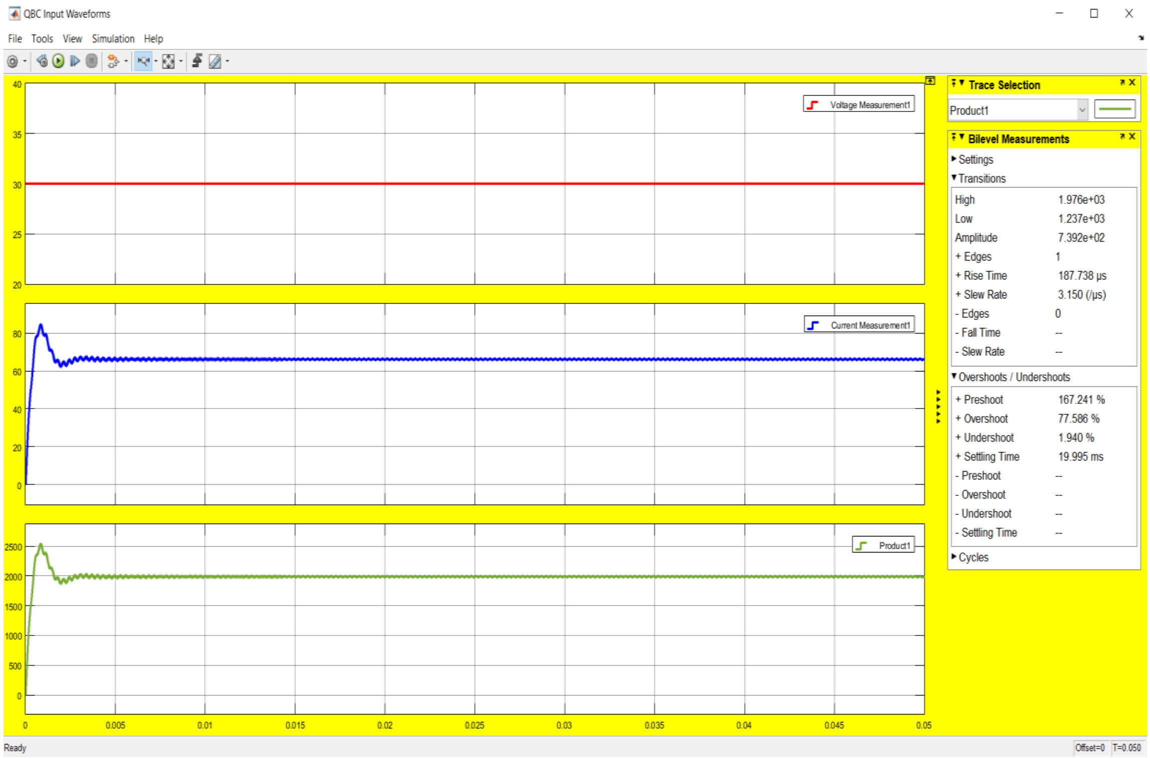


Fig 6.5 Waveforms of Input electrical signals of quadratic boost converter

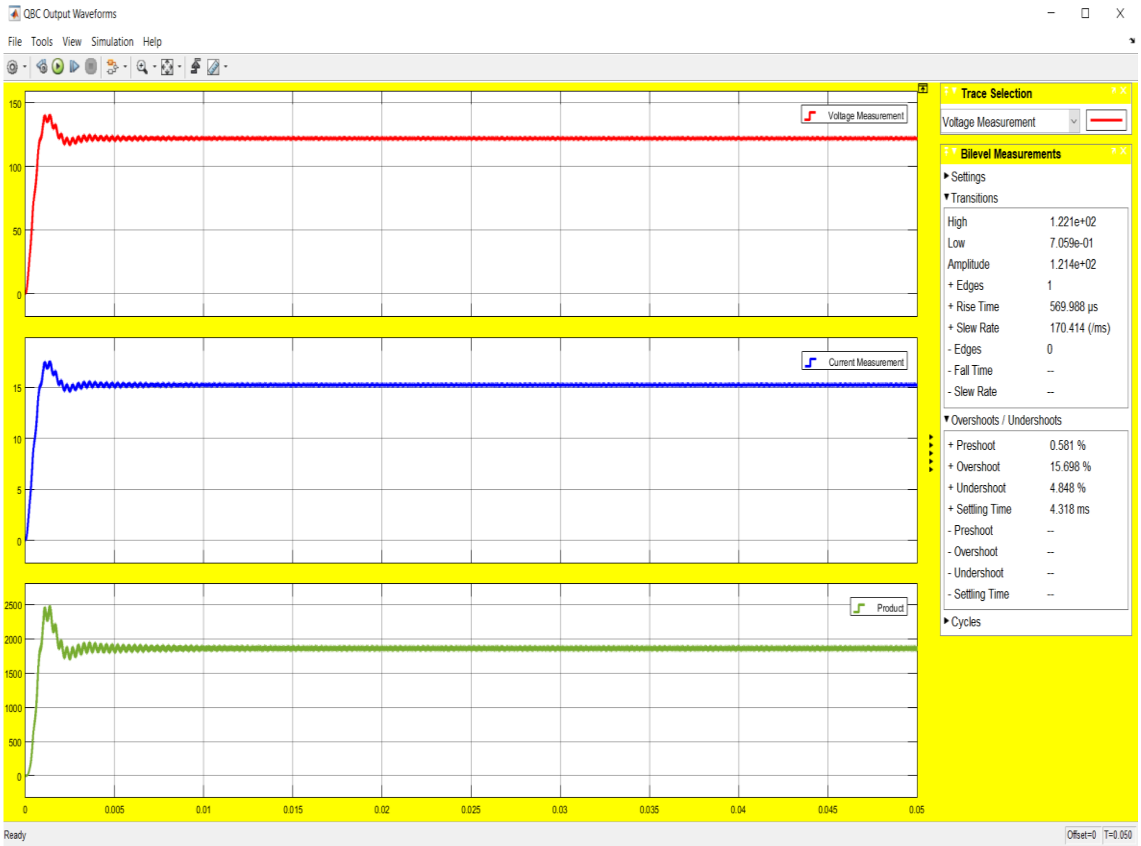


Fig 6.6 Waveforms of Output electrical signals of Quadratic boost converter

Double cascaded Boost Converter (DCBC)

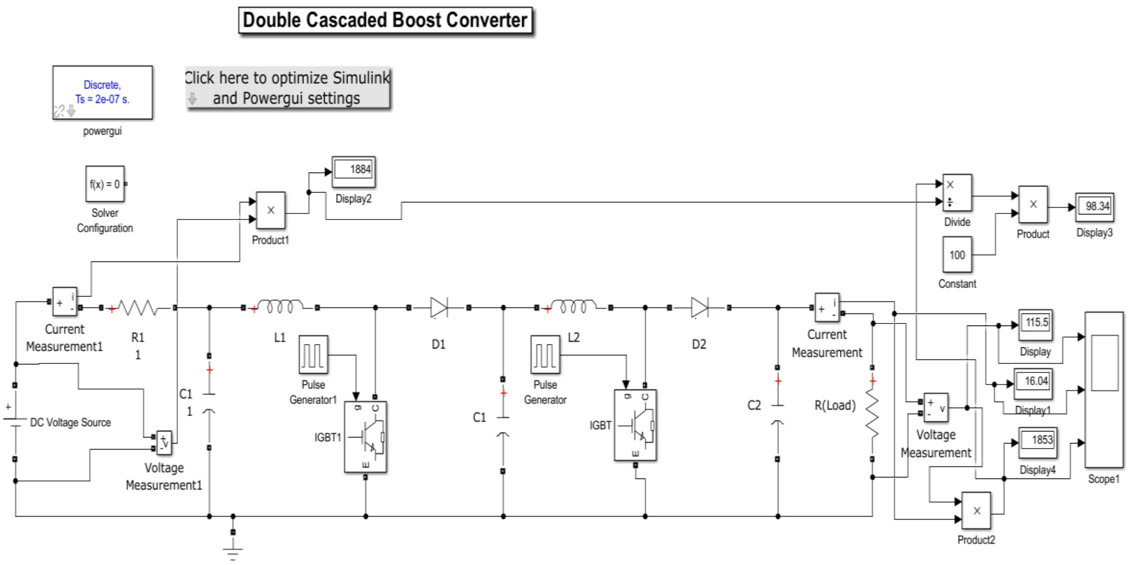


Fig. 6.7 Simulink Model of PV Array Connected Double Cascaded Boost Converter

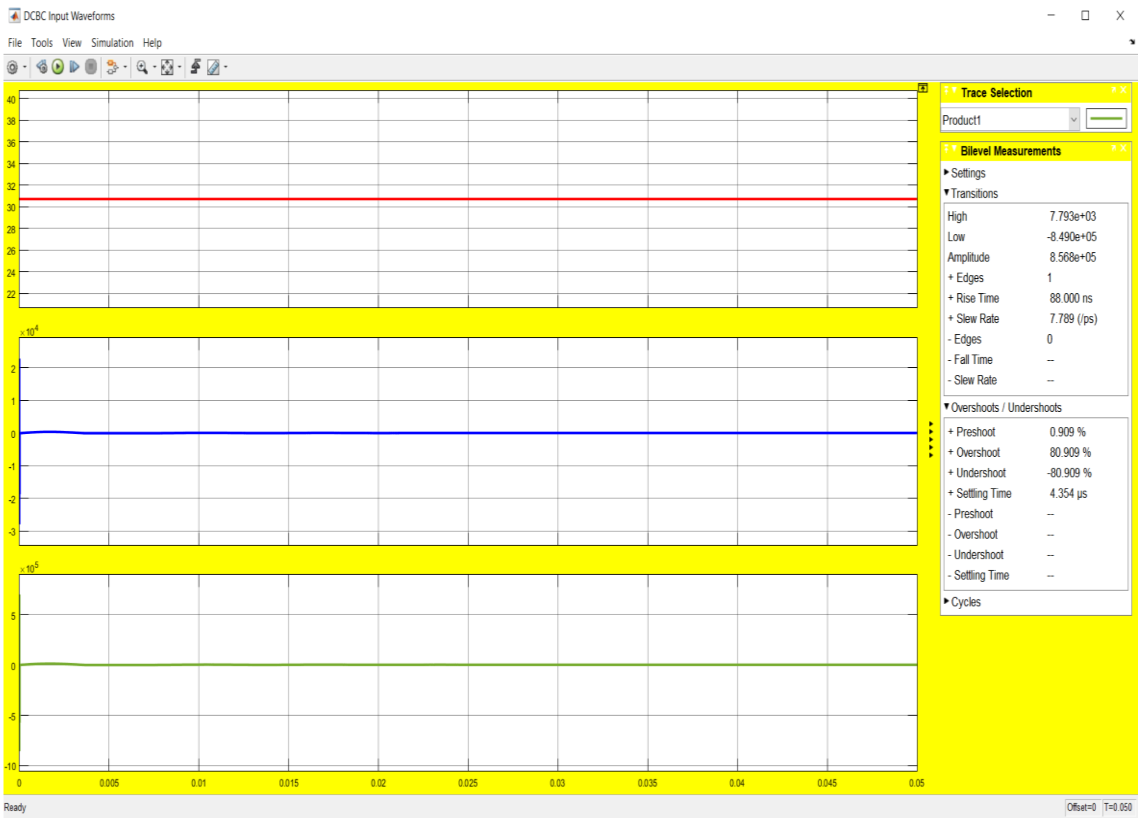


Fig 6.8 Waveforms of Input electrical signals of double cascaded boost converter

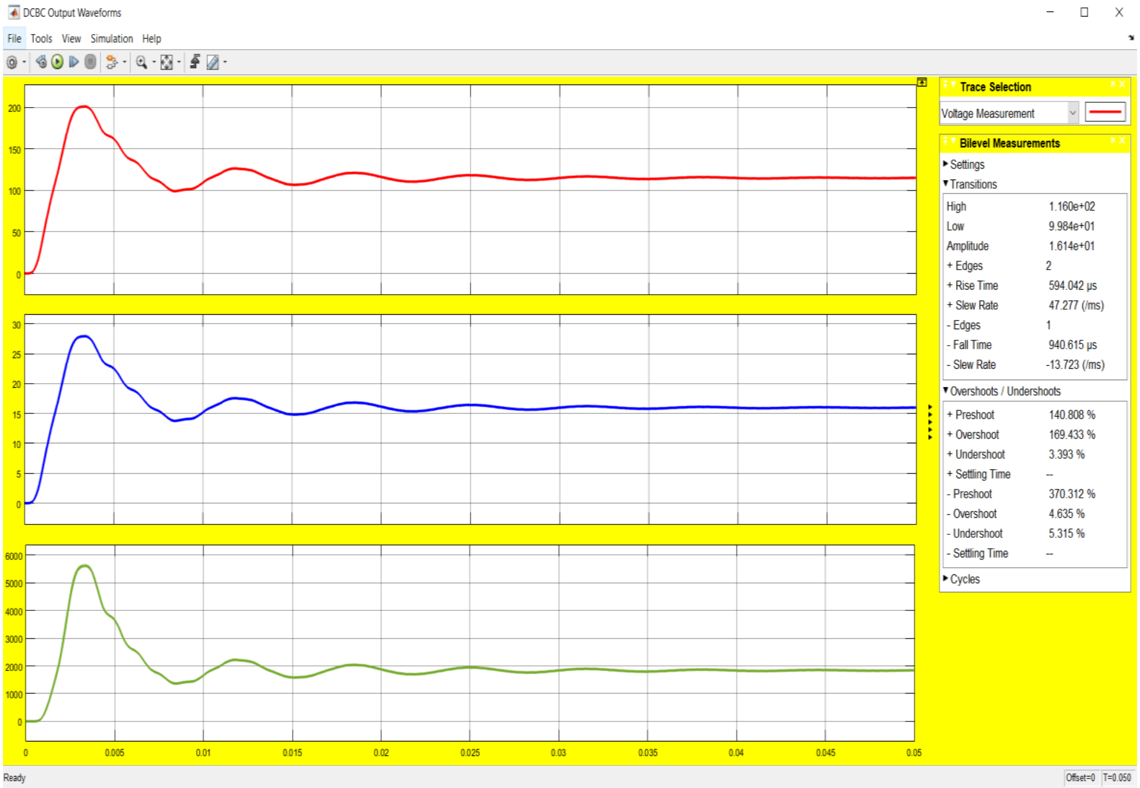


Fig 6.9 Waveforms of Output electrical signals of double cascaded boost converter

Table 6.1: Efficiency Comparison between boost converters

Types of Converter	Conventional Boost	Quadratic Boost	Double cascaded Boost
Duty Cycle	D_O = 74.4 %	D_O = 52 %	D_1 = 62 % & D_2 = 33 %
Efficiency %	93.29 %	96.15 %	98.34 %

Thus, the efficiency analysis shows that the best topology in our case is the Double cascaded boost converter (DCBC), for Battery Connected Boost Converters at STC i.e. Standard Testing Conditions (1000 W/m^2, 25^{0}C).

6.2 Solar PV Module – 1STH-250-WH

The simulation model consists of PV array with a peak power of 2000 Watt. The PV Array block is a five-parameter model using a current source IL (light-generated current), diode (I0 and nI parameters), series resistance Rs, and shunt resistance R_{sh} to represent the irradiance- and temperature-dependent I-V characteristics of the modules. The PV array consists of strings of PV modules connected in parallel, NP. Each string consists of modules connected in series, NS. The PV array consists of 08 parallel strings and 01 series-connected modules per string. The inputs to the PV array are sun irradiance (W/m2) and cell temperature (°C). Here, 1Soltech 1STH-250-WH PV Array Model is selected. The main characteristic of the present PV module used (1Soltech 1STH-250-WH) is given in Table 6.2 and the P–V characteristics of the PV array are shown in Fig. 6.10.

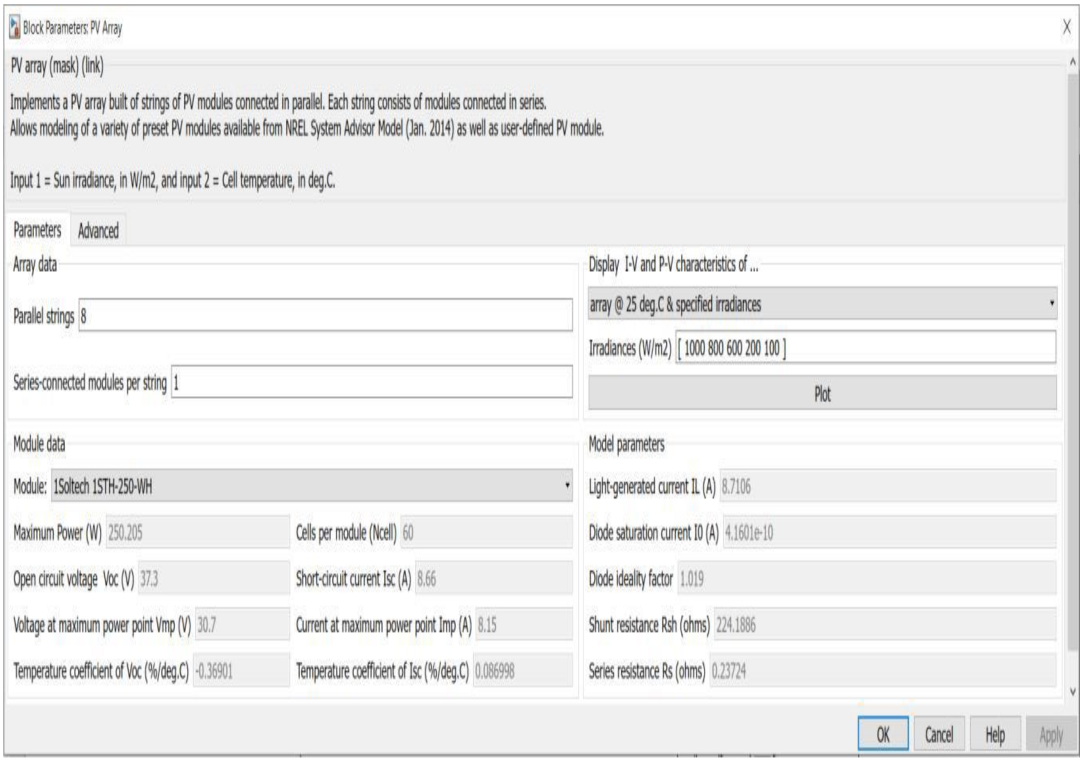


Fig. 6.10 Block Parameters Of 1Soltech 1STH-250-WH PV Array Model

Table 6.2: Technical Specifications of 1Soltech 1STH-250-WH

Specifications	**Values**
Maximum power (Pmax)	2000-Watt
Cells per module	60
Open-circuit voltage (V_{OC})	37.3 Volt
Short-circuit current (Isc) 5	8.66 Amp
Voltage at maximum power point (V_{MPP})	30.7 Volt
Current at maximum power point (I_{MPP})	8.15 Amp

6.3 Simulation of Solar PV Module Connected Boost Converters

To compare performance of a Conventional boost converter, a basic quadratic boost converter and a basic double cascaded boost converter supplied by solar PV module 1STH-250-WH.

Conventional Boost Converter (CBC)

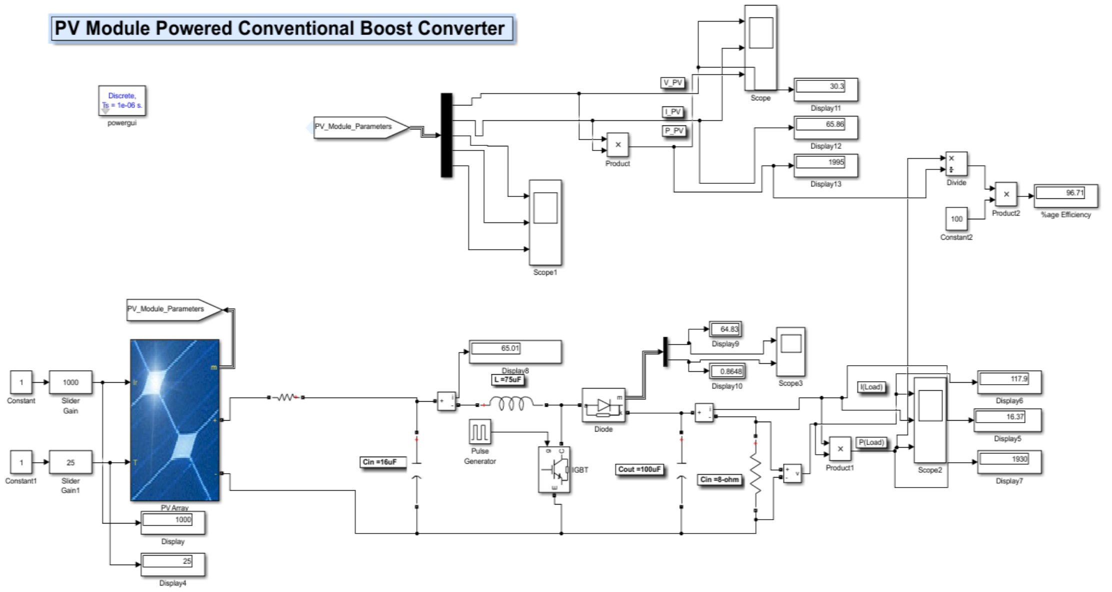


Figure 6.11 Simulink Model of PV Array Connected Boost Converter

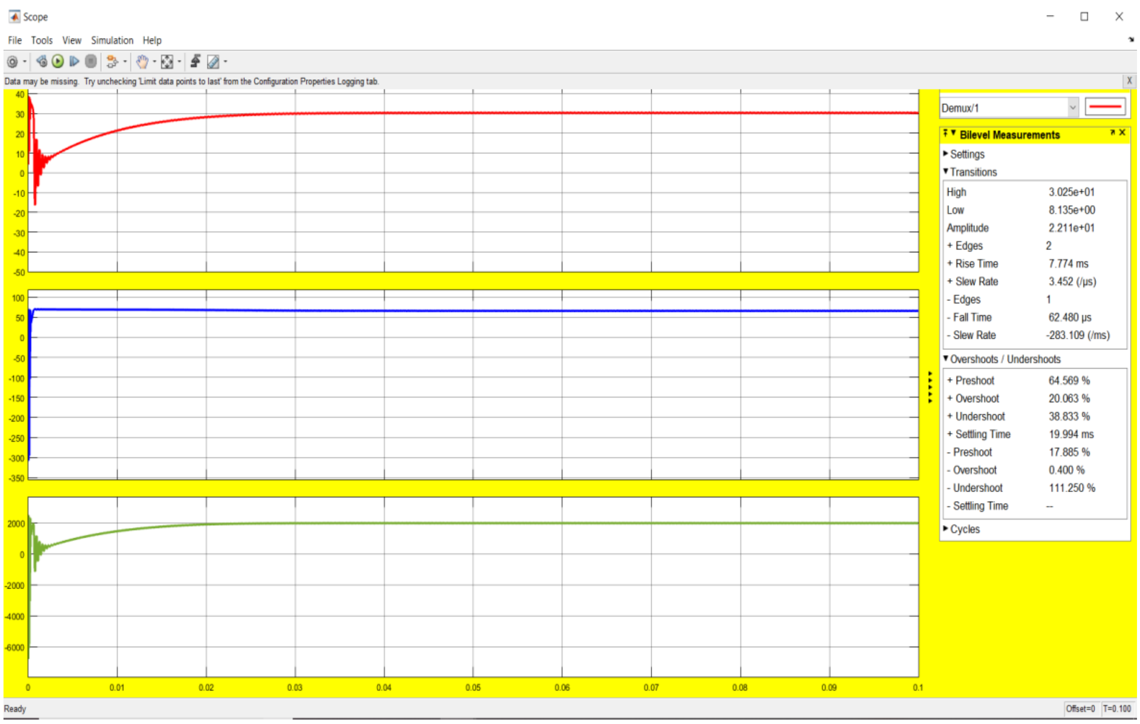


Fig 6.12 Waveforms of Input electrical signals of conventional boost converter

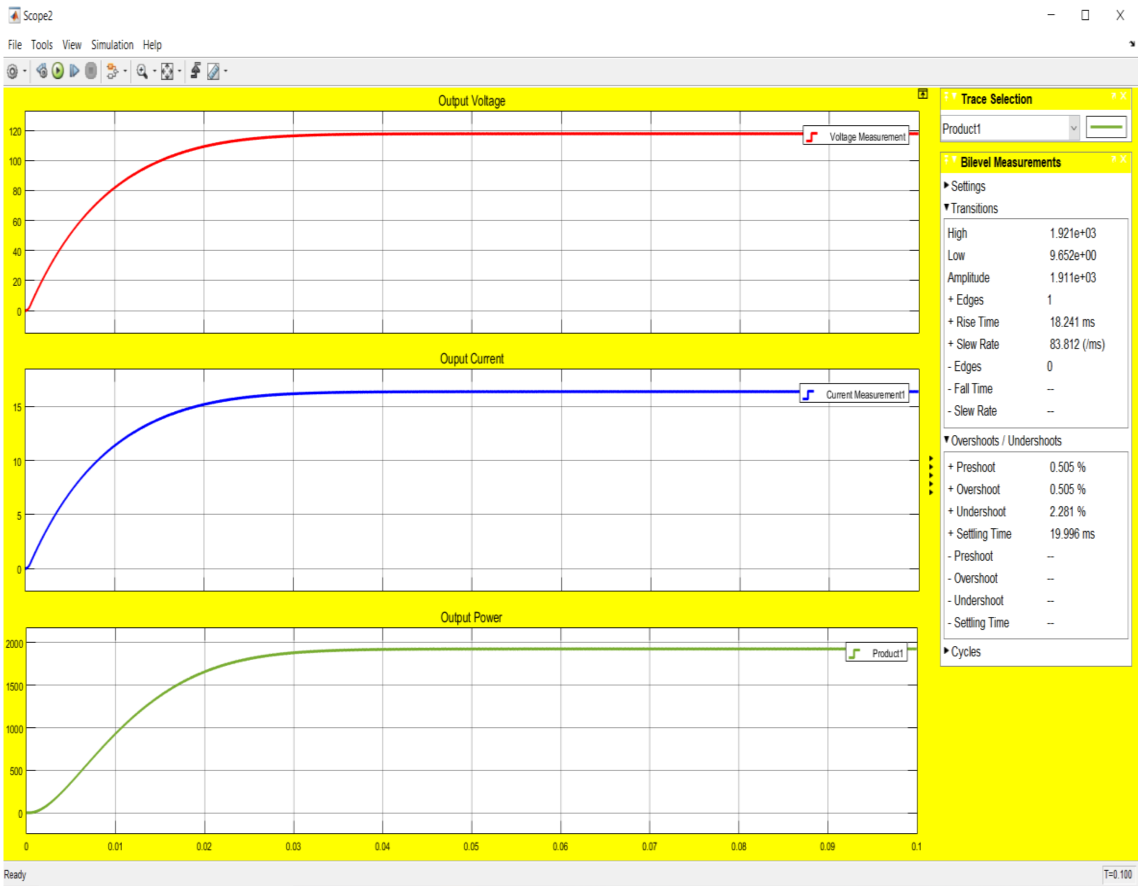


Fig 6.13 Waveforms of Output electrical signals of conventional boost converter

Quadratic Boost Converter

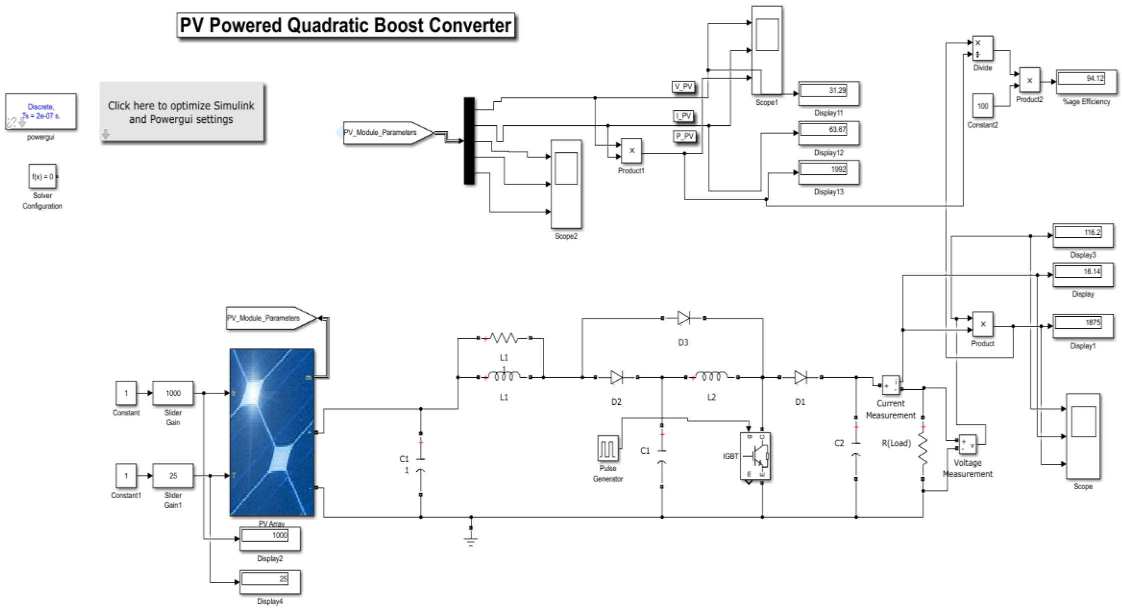


Figure 6.14 Simulink Model of PV Array Connected Quadratic Boost Converter

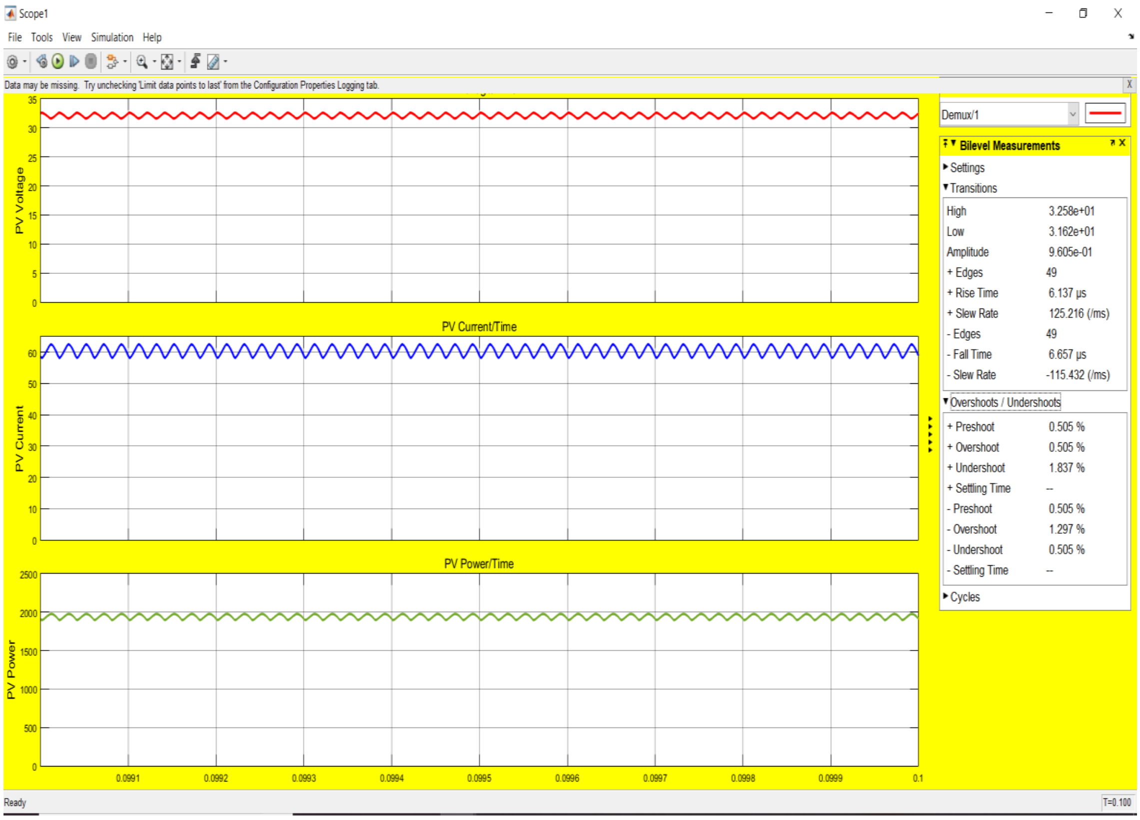


Fig 6.15 Waveforms of Input electrical signals of Quadratic boost converter

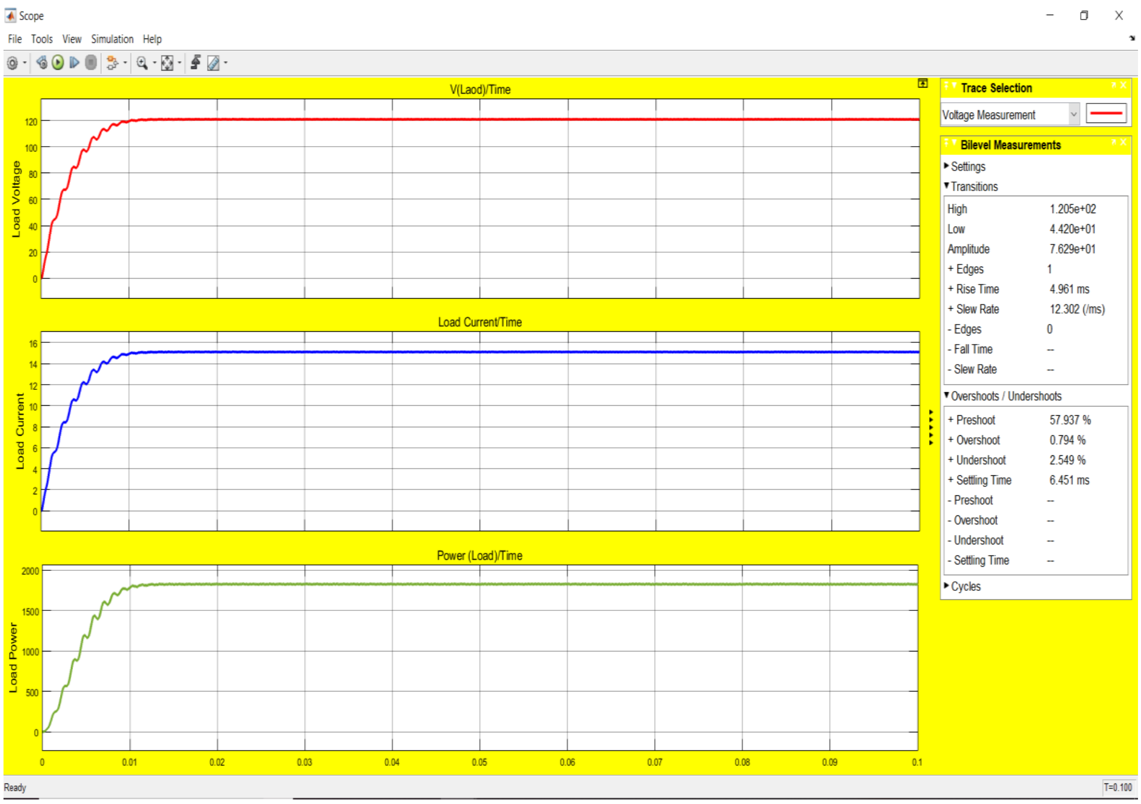


Fig 6.16 Waveforms of Output electrical signals of Quadratic boost converter

Double Cascaded Boost Converter

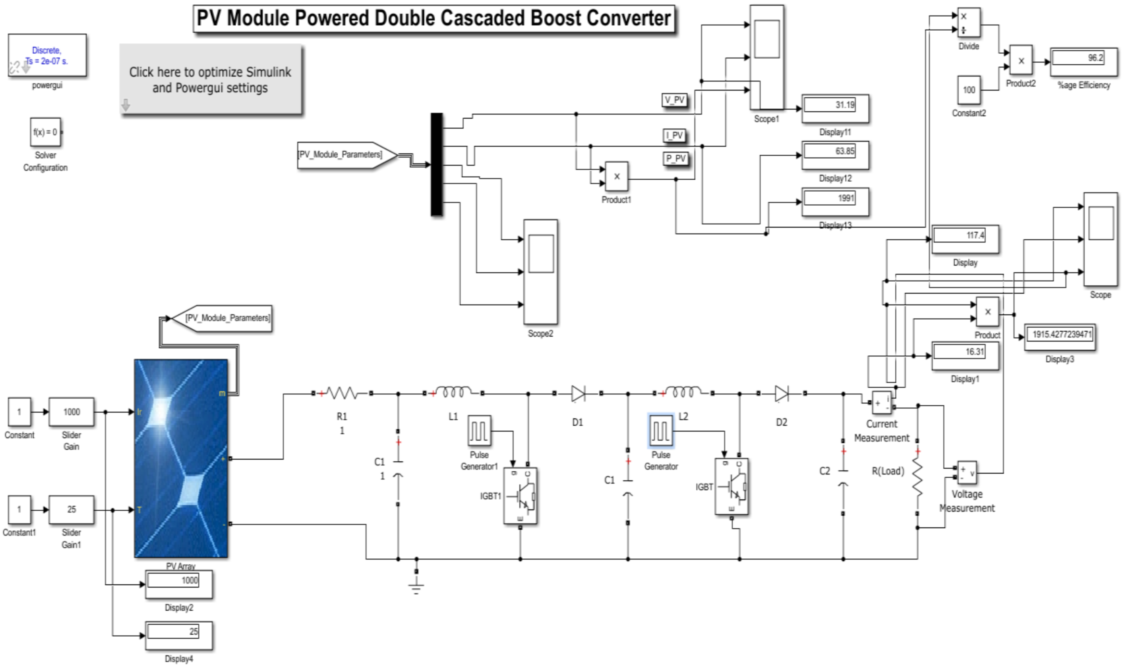


Figure 6.17 Simulink Model of PV Array Connected Double Cascaded Boost Converter

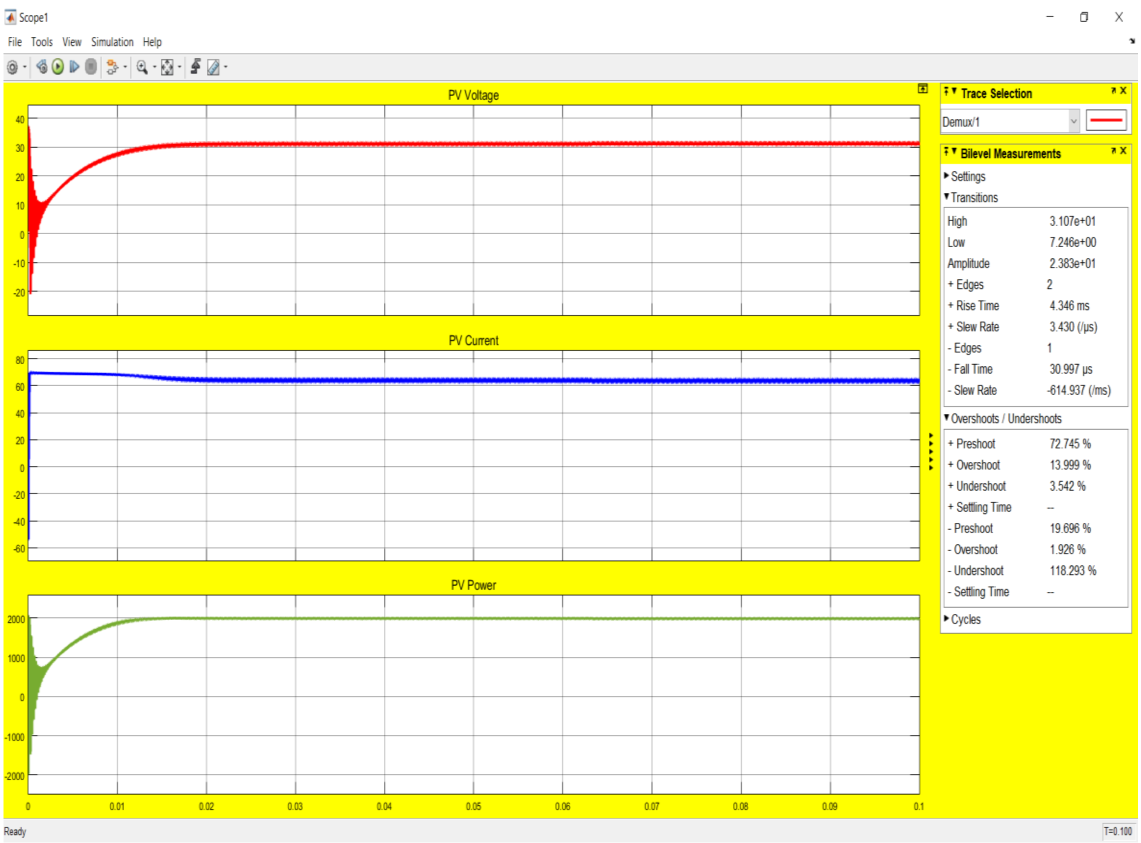


Fig 6.18 Waveforms of Input electrical signals of Double Cascaded boost converter

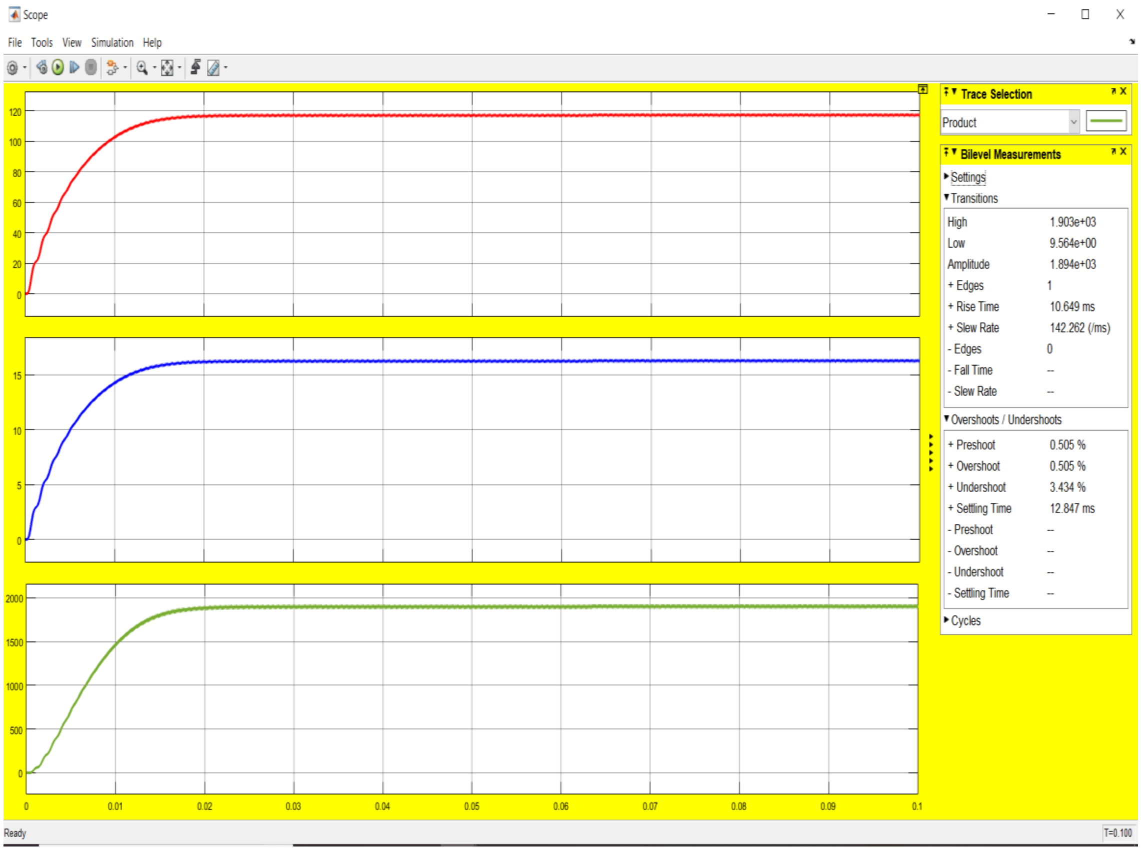


Fig 6.19 Waveforms of Output electrical signals of Double Cascaded boost converter

Table 6.3 Efficiency Comparison between boost converters

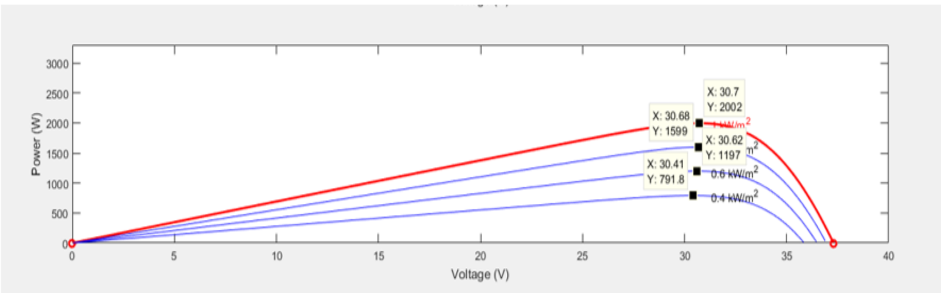
Types of Converter	Conventional Boost	Quadratic Boost	Double cascaded Boost
Duty Cycle	D_O = 74.4 %	D_O = 52 %	D_1 = 62 % & D_2 = 33 %
Efficiency %	96.29 %	94.04 %	95.4 %

Thus, the performance analysis reveals that the quadratic boost converter with a mean efficiency of 94.04%, fastest rise time 4.961 milliseconds and earliest settling time of 6.451 milliseconds exhibits optimum dynamic performance, for PV module Connected Boost Converters at STC i.e. Standard Testing Conditions (1000 W/m^2, 25^{0}C).

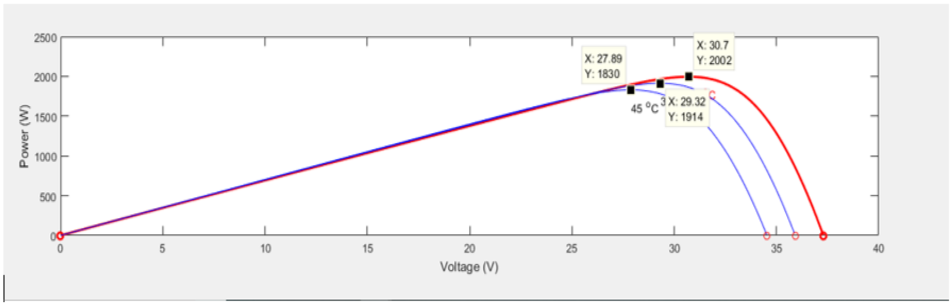
6.4 Simulation of Solar PV Module Connected Boost Converters with FLC

To compare performance of Conventional boost converter, quadratic boost converter and double cascaded boost converter supplied by solar PV module 1STH-250-WH and controlled by fuzzy logic based MPPT controller.

The I-V and P–V characteristics of the PV array are shown in Fig. 6.20.



P-V Characteristics of a Solar PV Module 1STH-250-WH for 400 w/m², 600 w/m², 800 w/m² and 1000 w/m² @ 25°C



P-V Characteristics of a Solar PV Module 1STH-250-WH for 25°C, 35°C and 45°C @ 1000 w/m²

Fig. 6.20: PV characteristics of array for different values of radiance and temperature.

Simulation and analysis are done for different combinations values of solar irradiance and temperature. Signal Builder Input for Solar Irradiance values: 400 W/m², 600 W/m², 800 W/m² and 1000 W/m² at ambient temperature 25°C and for Solar irradiance 1000 W/m² at ambient temperature of 25°C, 35°C and 45°C. The plot is shown in Fig. 6.21 and Fig. 6.22, respectively.

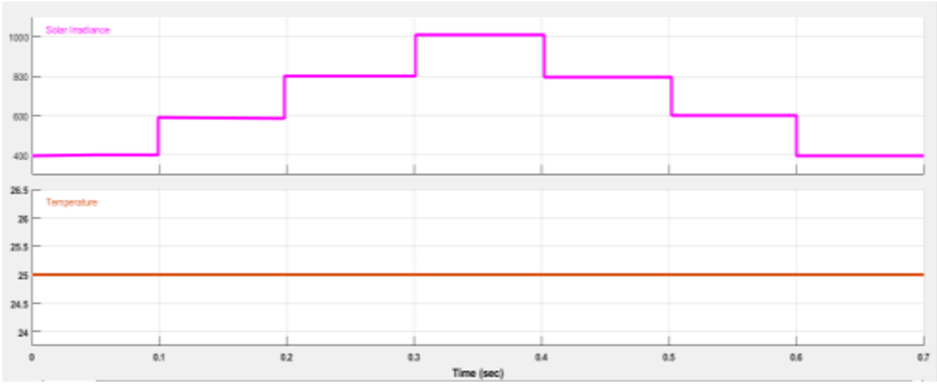


Fig. 6.21: Signal Builder Input for Solar Irradiance: 400 W/ m^2, 600 W/m^2, 800 W/m^2 and 1000 W/m^2 @ ambient temperature 25°C.

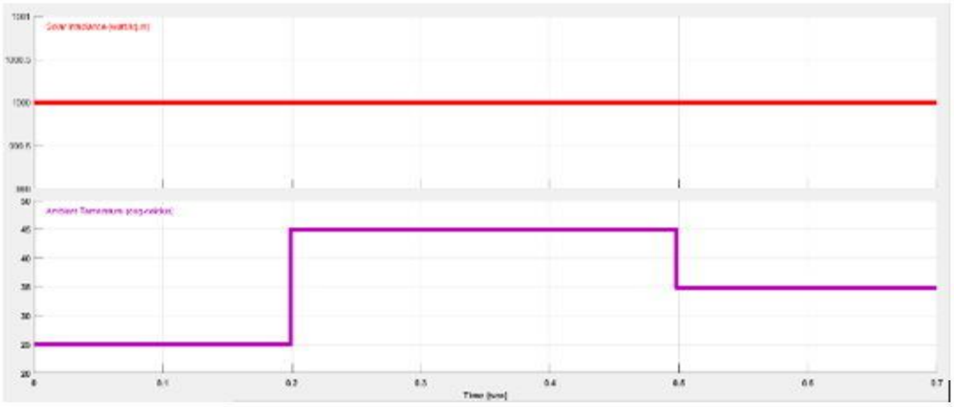


Fig. 6.22: Signal Builder Input for Solar Irradiance 1000 W/m^2 at ambient temperature of 25°C, 35°C and 45°C

Conventional Boost Converter

The simulation model of Solar PV powered Conventional Boost Converter using fuzzy based MPPT controller on which analysis is done is shown in Fig .

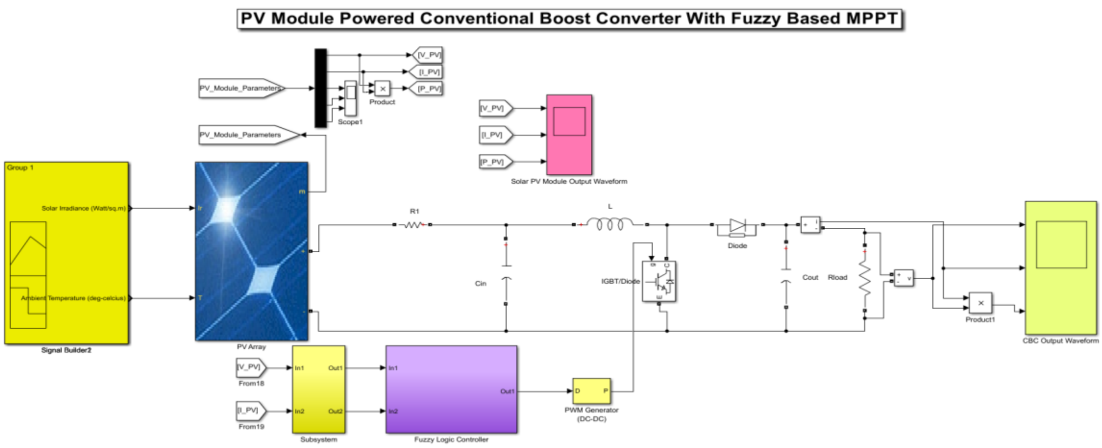


Figure 6.23 Simulink Model of PV Array Connected Boost Converter with fuzzy MPPT controller

The waveforms of output voltage, current and power of PV module and boost converter at standard ambient condition 1000 W/m^2, 25^{0}C is shown in Fig. 6.24 and Fig. 6.25 respectively and similarly for different combinations of solar irradiance and temperature it is shown in Fig. 6.26, Fig 6.27, Fig 6.28 and Fig. 6.29.

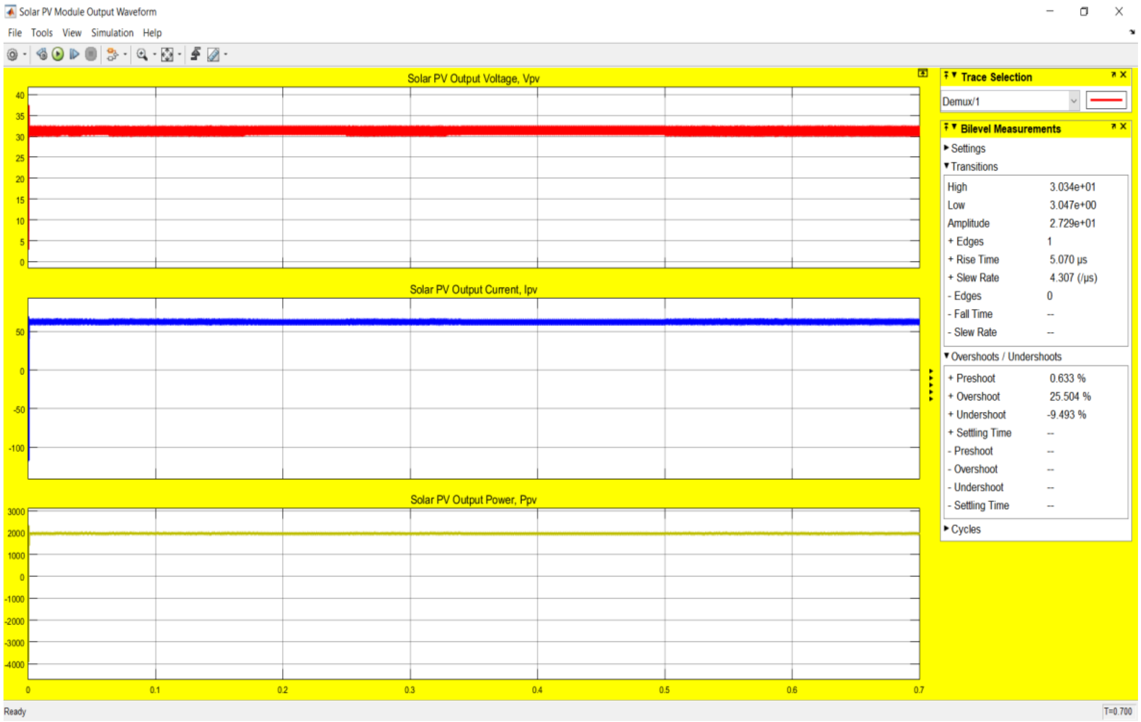


Fig. 6.24 Output waveforms of CBC connected PV Module at standard ambient conditions

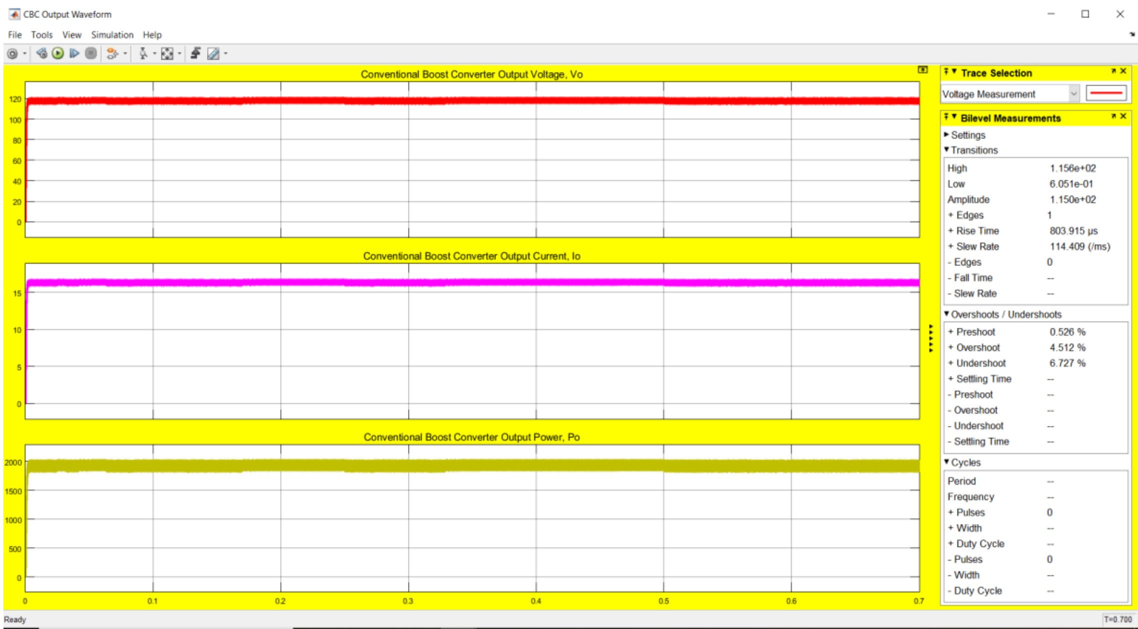


Fig. 6.25 Output Waveforms of CBC corresponding to waveforms of Fig 6.24.

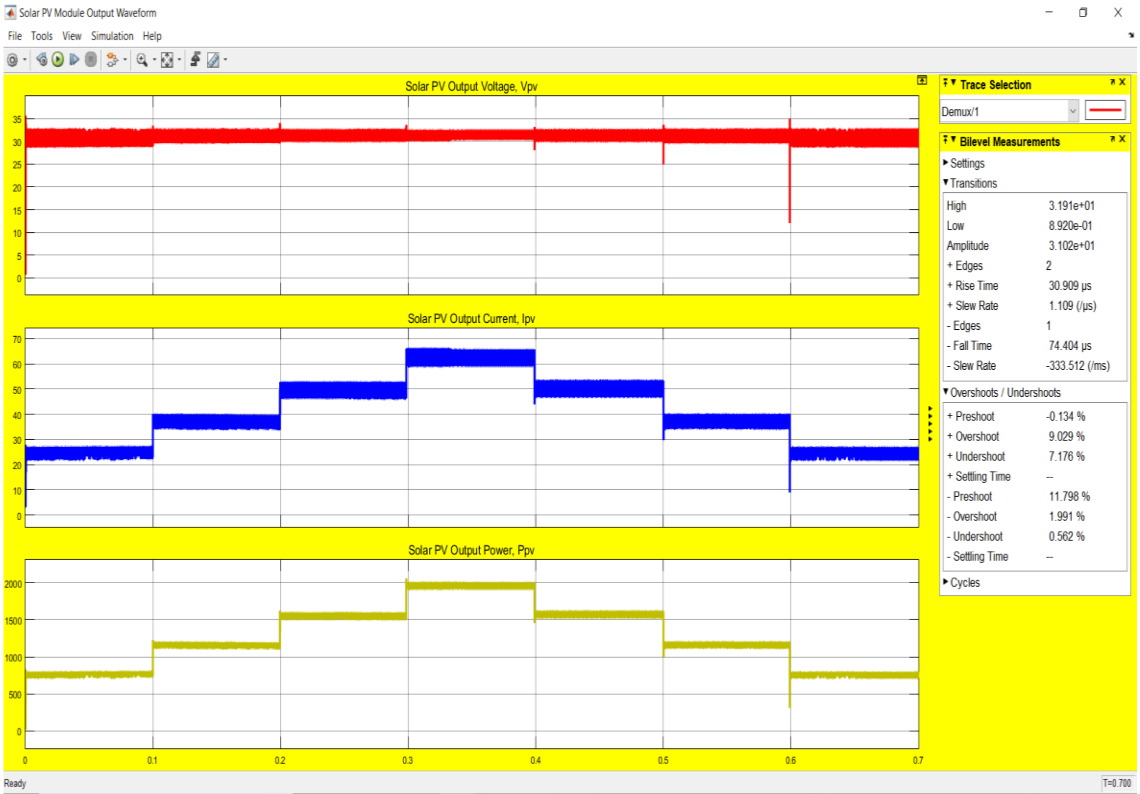


Fig. 6.26 Solar PV Module Output waveforms at Temperature = 25°C and different Values of Irradiation.

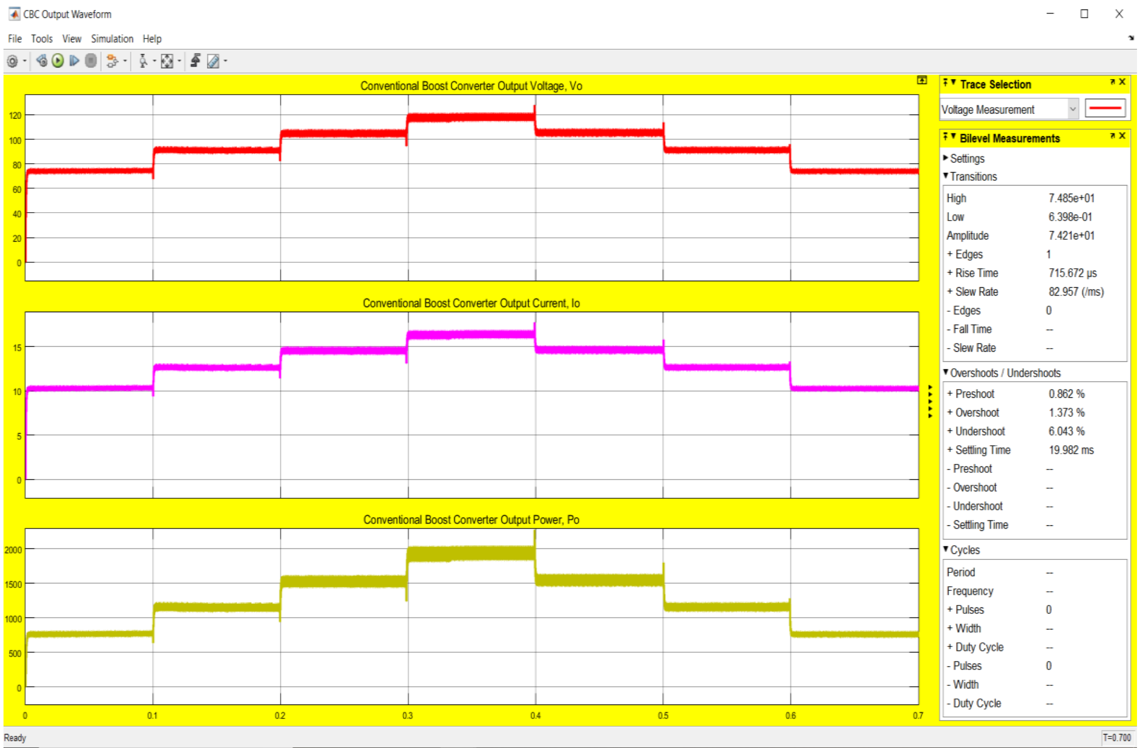


Fig. 6.27 Output Waveforms of CBC corresponding to waveforms of Fig 6.27

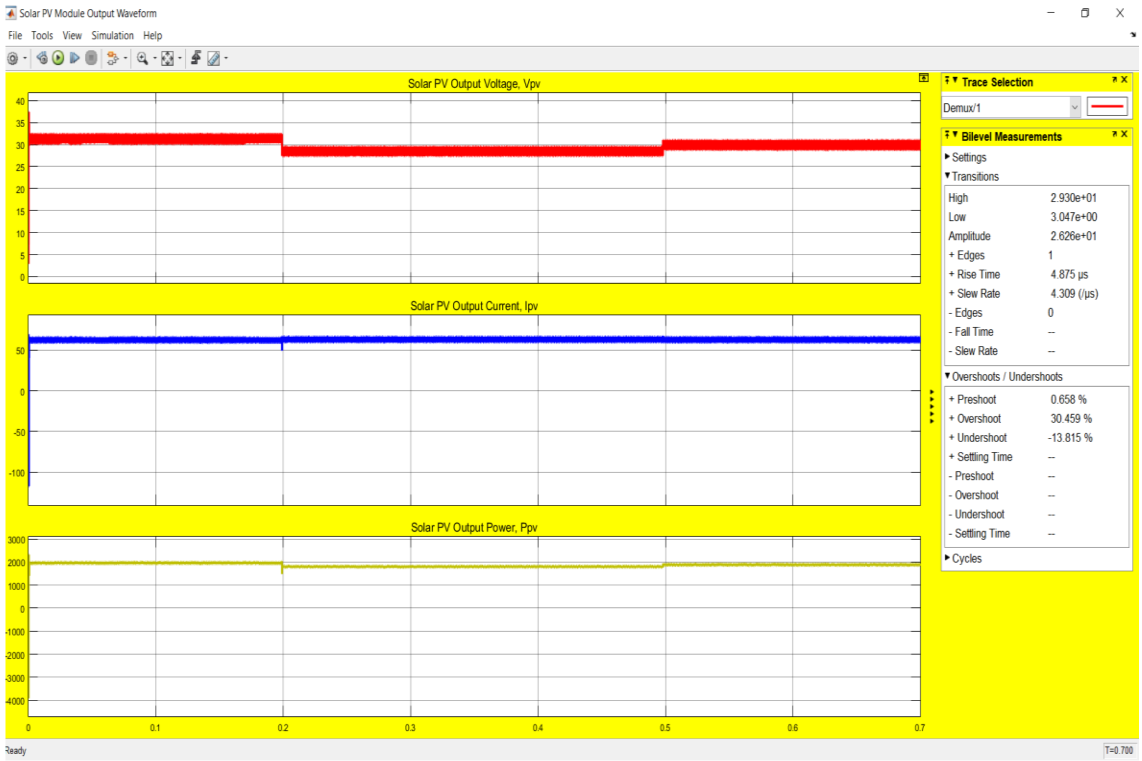


Fig. 6.28 Solar PV Module Output waveforms at Irradiation = 1000 W/m2 and different values of temperature.

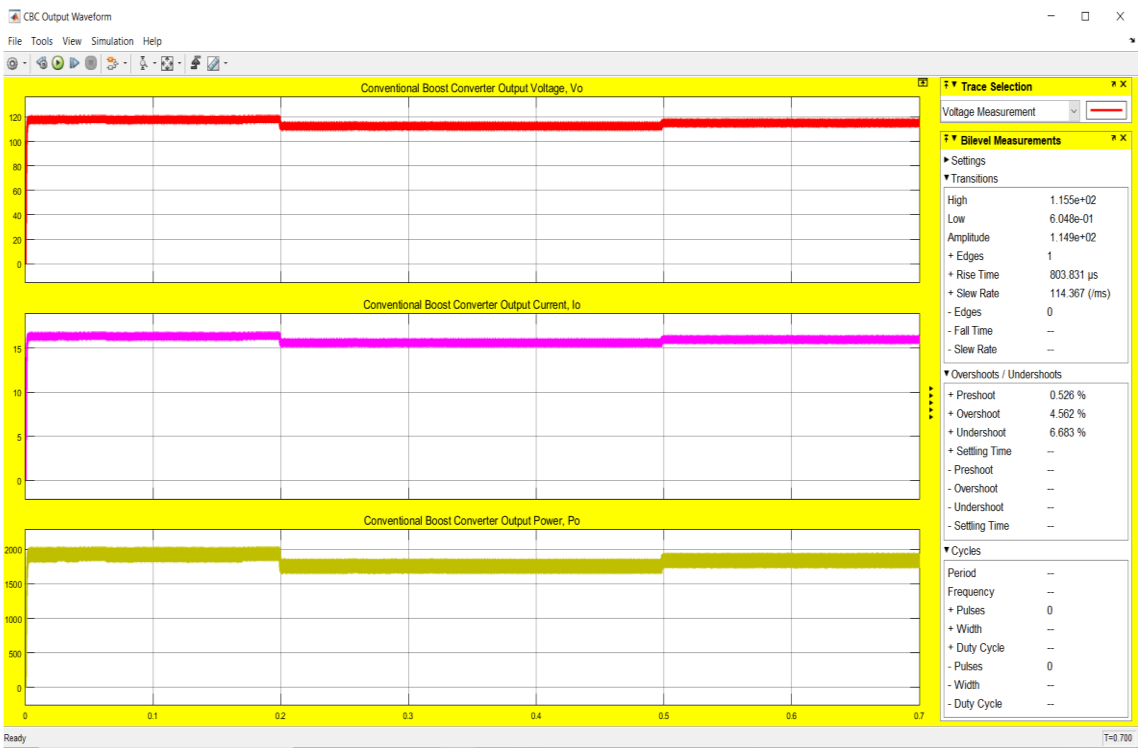


Fig. 6.29 Output Waveforms of CBC corresponding to waveforms of Fig 6.29

The simulation results are summarised in the Table 6.4, given below.

Table 6.4 Performance analysis of PV Connected CBC with Fuzzy MPPT Controller

Irradiance/Temp. (watt/m²/°C)	**Maximum Power (PV Module), P_{MPP}**	**PV Module Output Power, P_{PV}**	**MPPT Efficiency, η_{MPPT}**	**CBC Output Power, P_{QBC}**	**CBC Efficiency, η_{CBC}**
400/25	792	739	93.31 %	720.8	97.54 %
600/25	1197	1124	93.93 %	1094	97.31 %
800/25	1599	1503	94.00 %	1458	97.00 %
1000/25	2000	1976	98.77 %	1912	96.76 %
1000/35	1914	Unstable	Unstable	----------	----------
1000/45	1830	Unstable	Unstable	----------	----------

The MPPT efficiency so obtained is in the range of 93.31% to 98.77 %, under given variations of Irradiance and Temperature and is about 98.77 % under standard conditions. The Quadratic Boost Converter efficiency is nearabout 96.76 %.

6.4.2 Quadratic Boost Converter

The simulation model of Solar PV powered Quadratic Boost Converter using fuzzy based MPPT controller on which analysis is done is shown in Fig. 6.30

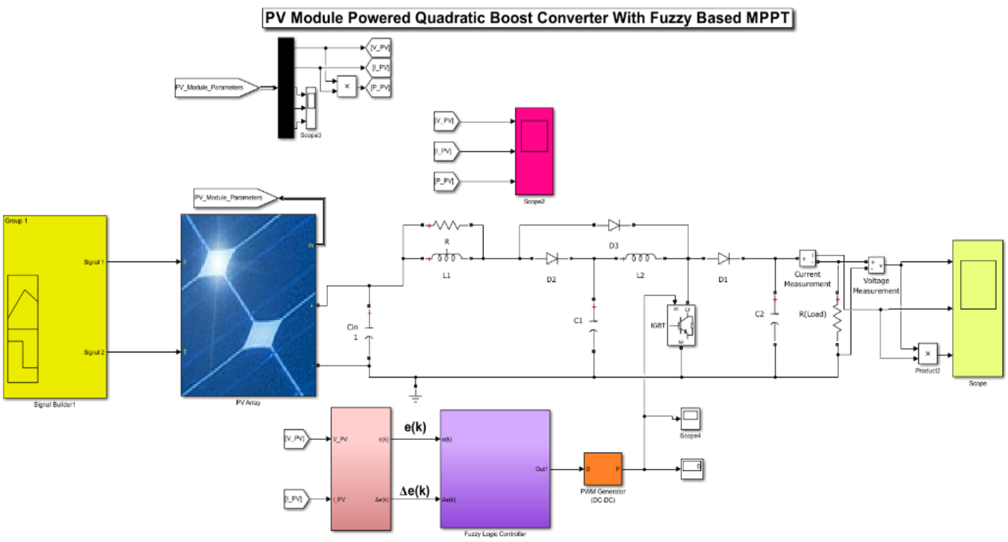


Figure 6.30 Simulink Model of PV Array Connected quadratic Boost Converter with fuzzy

The waveforms of output voltage, current and power of PV module and quadratic boost converter at standard ambient condition 1000 W/m^2, 25^{0}C is shown in Fig. 6.31 and Fig. 6.32 respectively and similarly for different combinations of solar irradiance and temperature it is shown in Fig. 6.33, Fig 6.34, Fig 6.35 and Fig. 6.36.

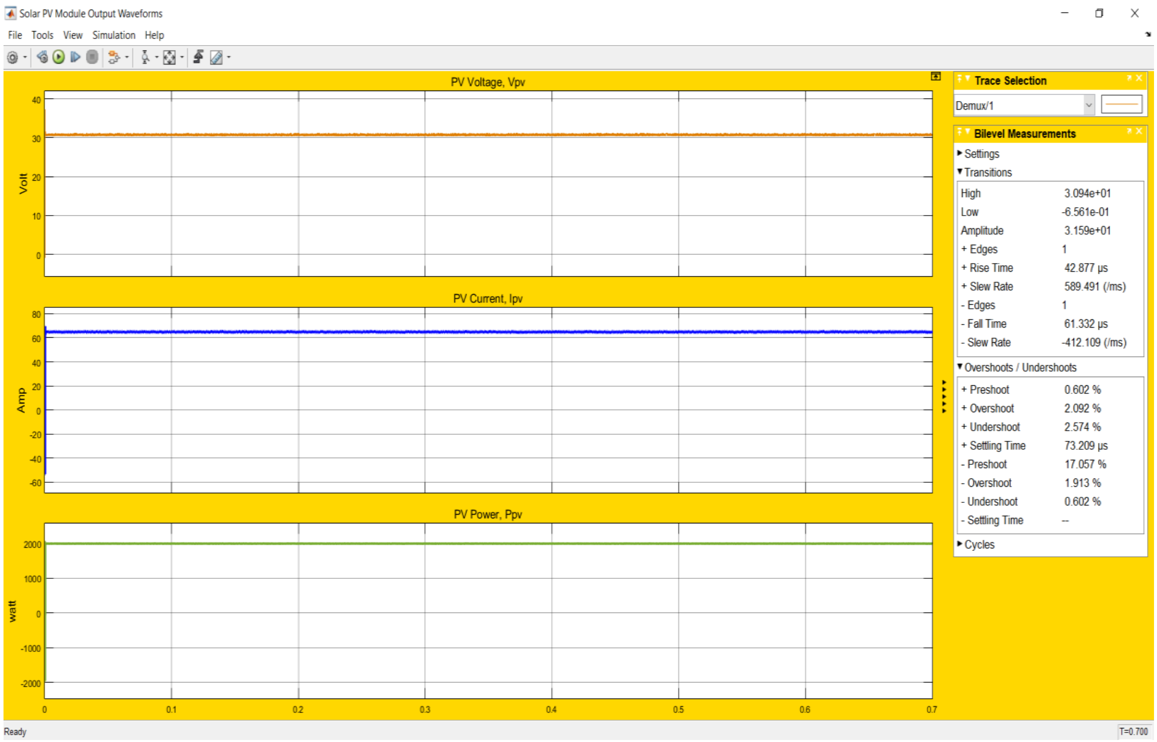


Fig. 6.31 Output waveforms of QBC connected PV Module at standard ambient conditions

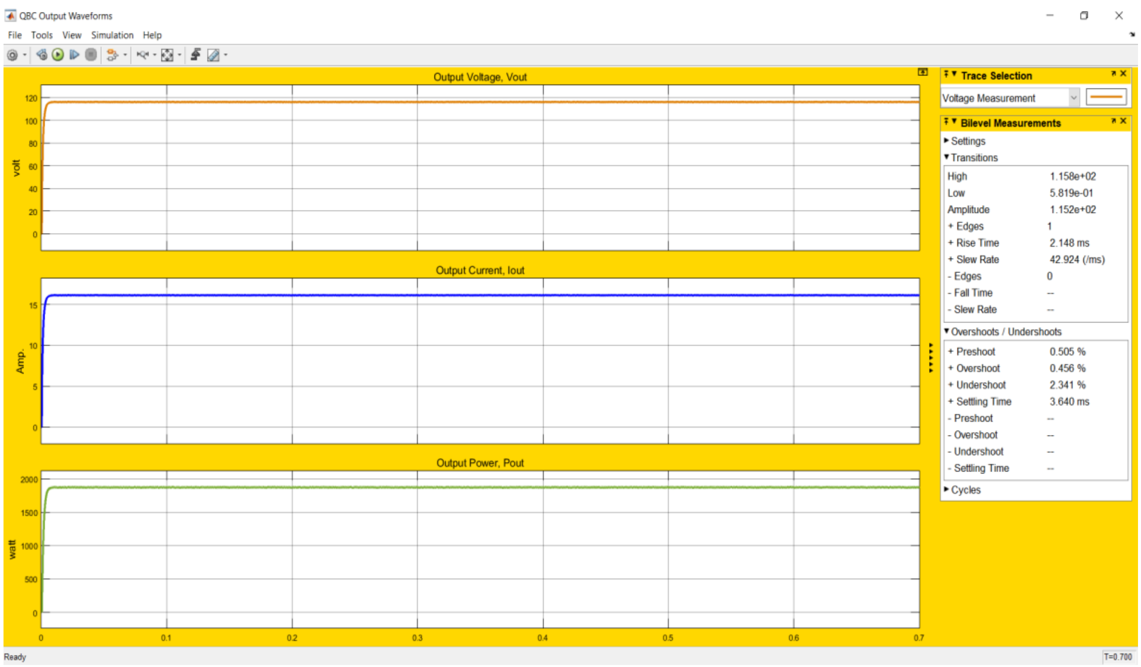


Fig. 6.32 Output Waveforms of QBC corresponding to waveforms of Fig 6.31.

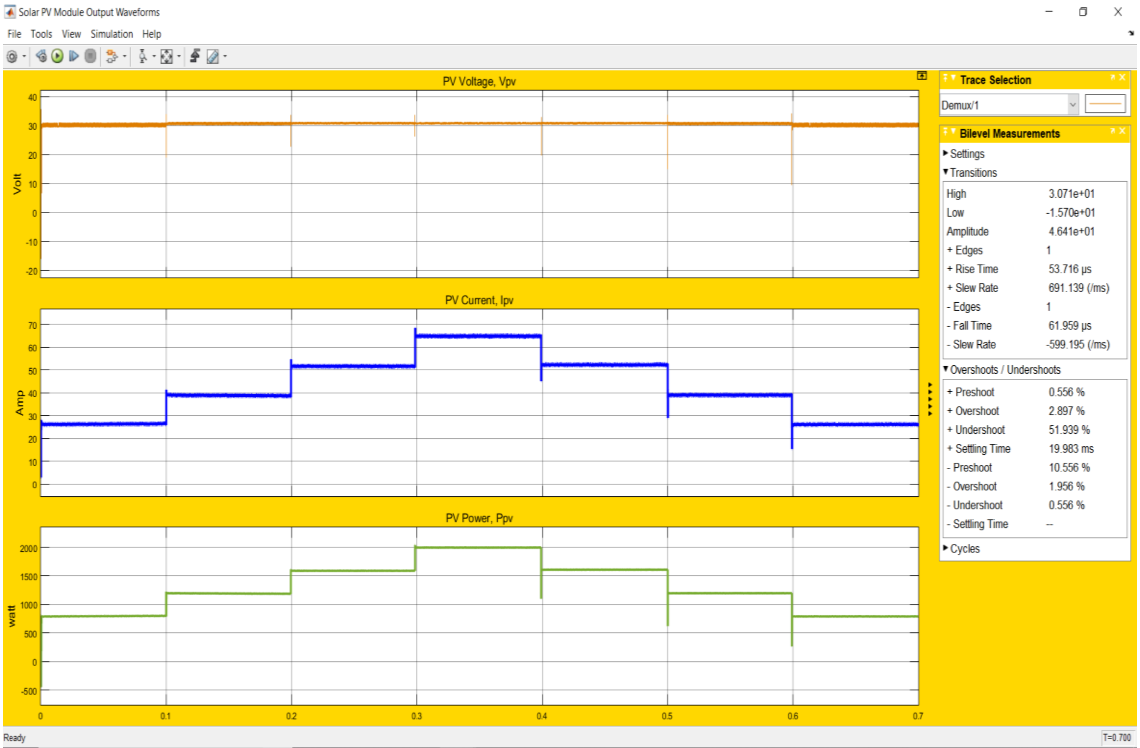


Fig. 6.33 Solar PV Module Output waveforms at Temperature = 25°C and different Values of Irradiation.

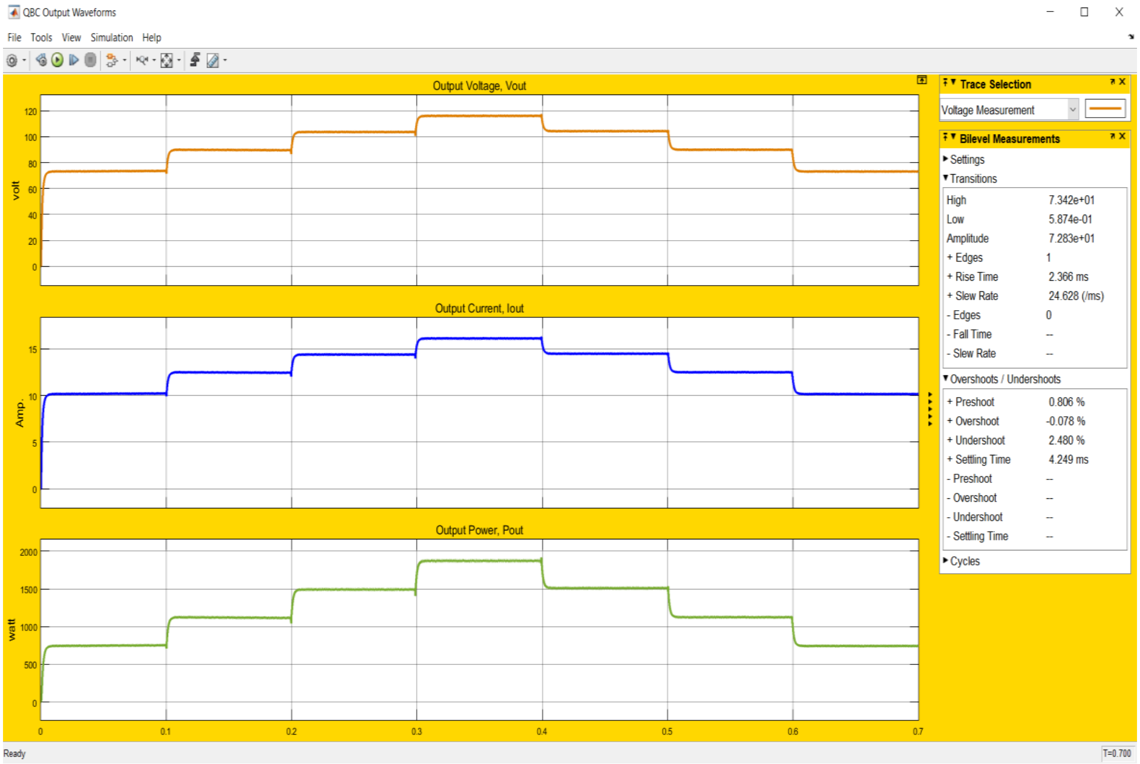


Fig. 6.34 Output Waveforms of QBC corresponding to waveforms of Fig 6.33

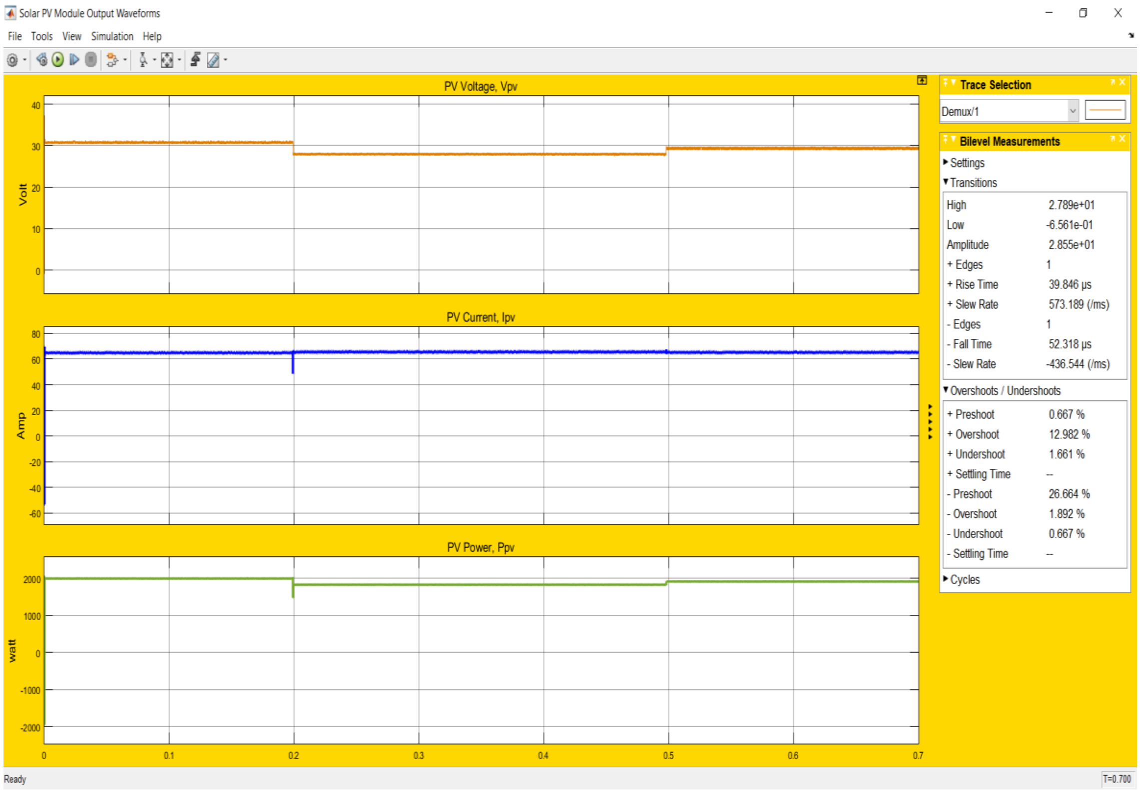


Fig. 6.35 Solar PV Module Output waveforms at Irradiation = 1000 W/m2 and different values of temperature.

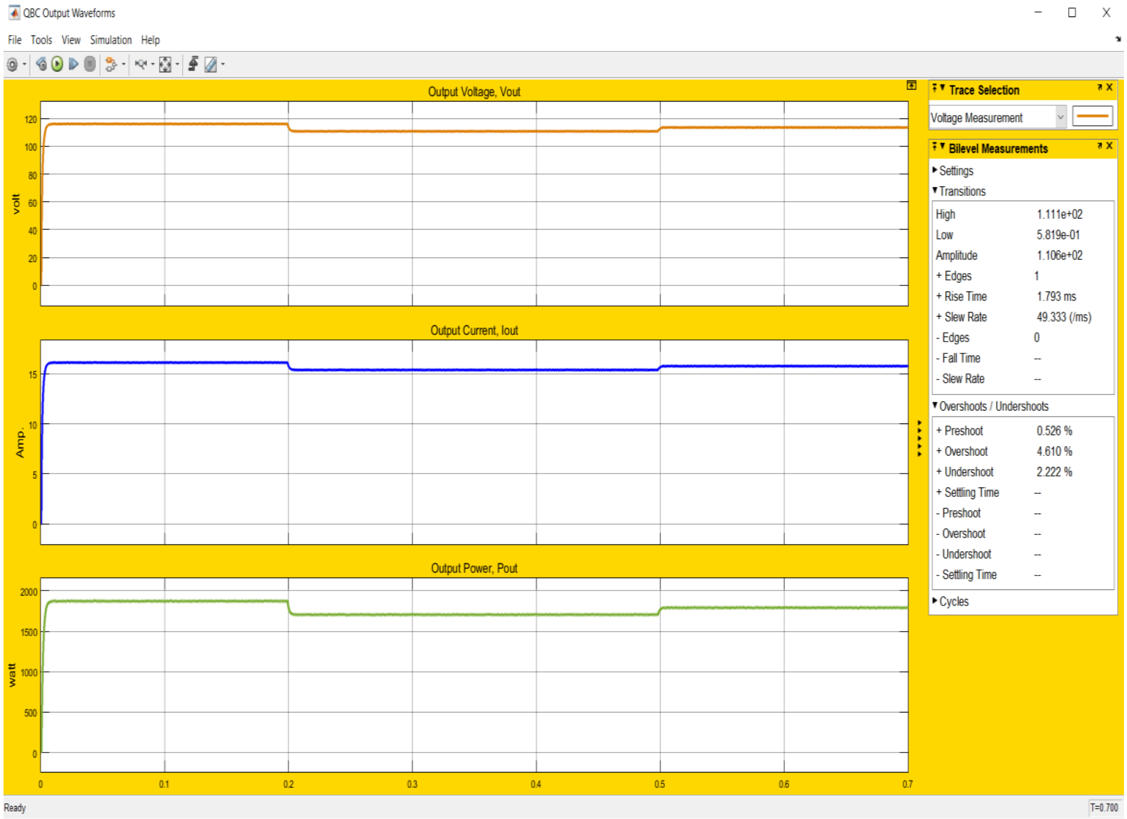


Fig. 6.36 Output Waveforms of QBC corresponding to waveforms of Fig 6.35

The simulation results are summarised in the Table 6.5, given below.

Table 6.5 Performance analysis of PV Connected QBC with Fuzzy MPPT Controller

Irradiance/Temp. (watt/m^2/^{o}C)	**Maximum Power (PV Module), P_{MPP}**	**PV Module Output Power, P_{PV}**	**MPPT Efficiency, η_{MPPT}**	**QBC Output Power, P_{QBC}**	**QBC Efficiency, η_{QBC}**
400/25	792	755.6	95.41 %	707.2	93.59 %
600/25	1197	1168	97.58 %	1095	93.74 %
800/25	1599	1580	98.84 %	1482	93.64 %
1000/25	2000	1995	99.75 %	1868	93.96 %
1000/35	1914	1900	99.29 %	1773	93.31 %
1000/45	1830	1819	99.39 %	1691	92.98 %

The MPPT efficiency so obtained is in the range of 95.41% to 99.39%, under given variations of Irradiance and Temperature and is about 99.75 % under standard conditions. The Converter efficiency is nearabout 93%.

6.4.3 Double Cascaded Boost Converter

The simulation model of Solar PV powered Double cascaded Boost Converter using fuzzy based MPPT controller on which analysis is done is shown in Fig 6.37

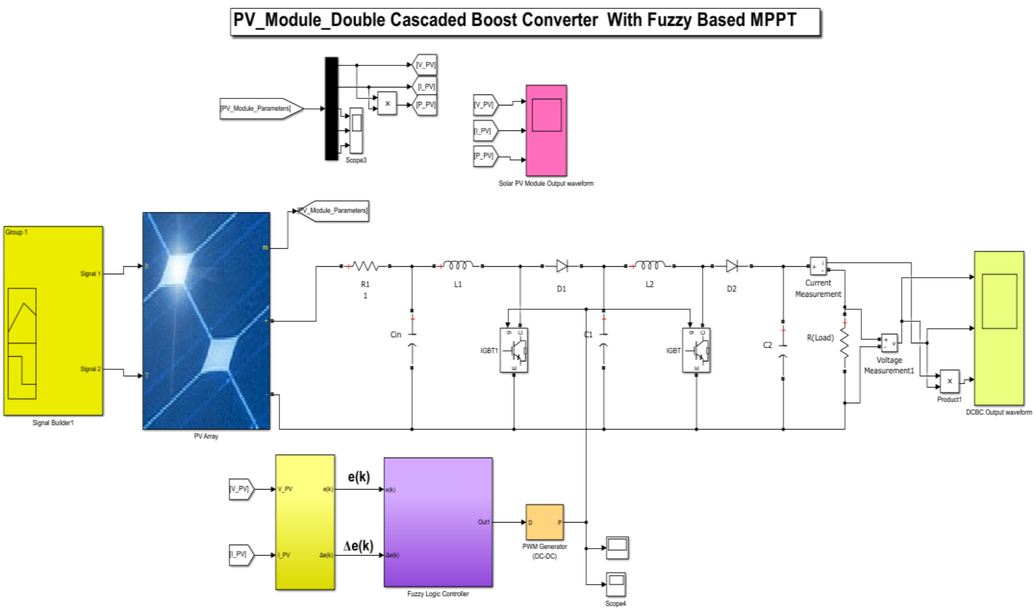


Figure 6.37 Simulink Model of PV Array Connected DCBC with fuzzy MPPT Controller

The waveforms of output voltage, current and power of PV module and double cascaded boost converter at standard ambient condition 1000 W/m^2, 25^{0}C is shown in Fig. 6.38 and Fig. 6.39 respectively and similarly for different combinations of solar irradiance and temperature it is shown in Fig. 6.40, Fig 6.41, Fig 6.42 and Fig. 6.43.

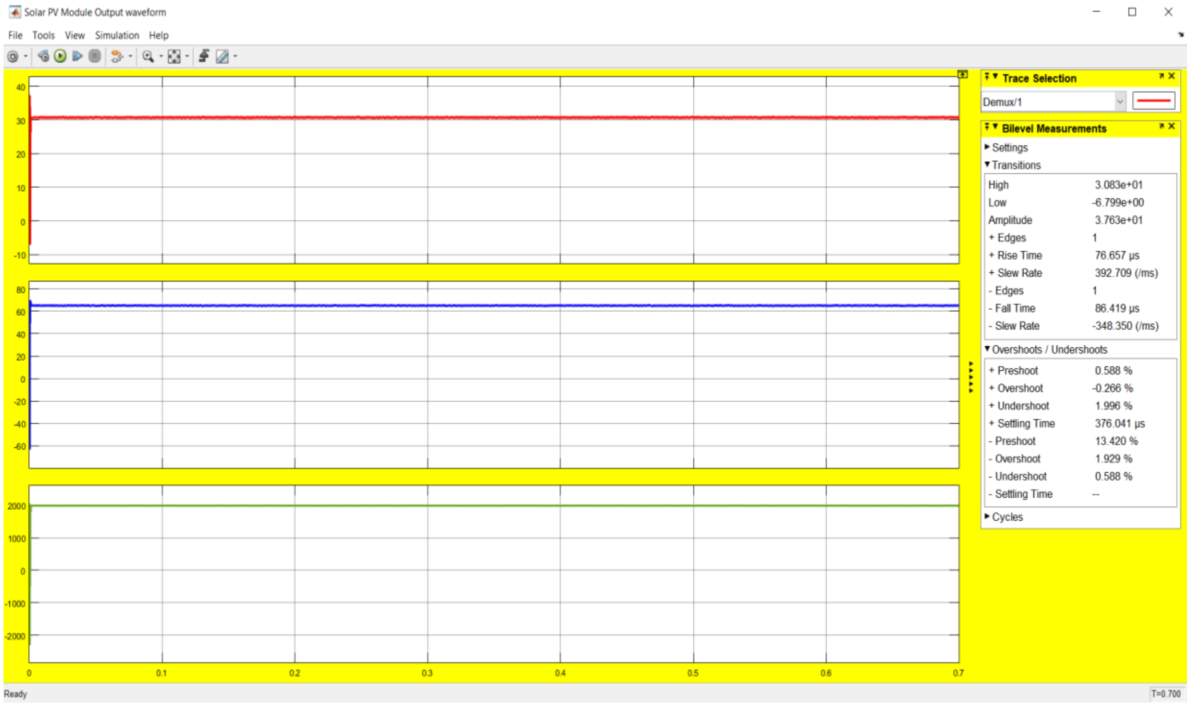


Fig. 6.38 Output waveforms of DCBC connected PV Module at STC

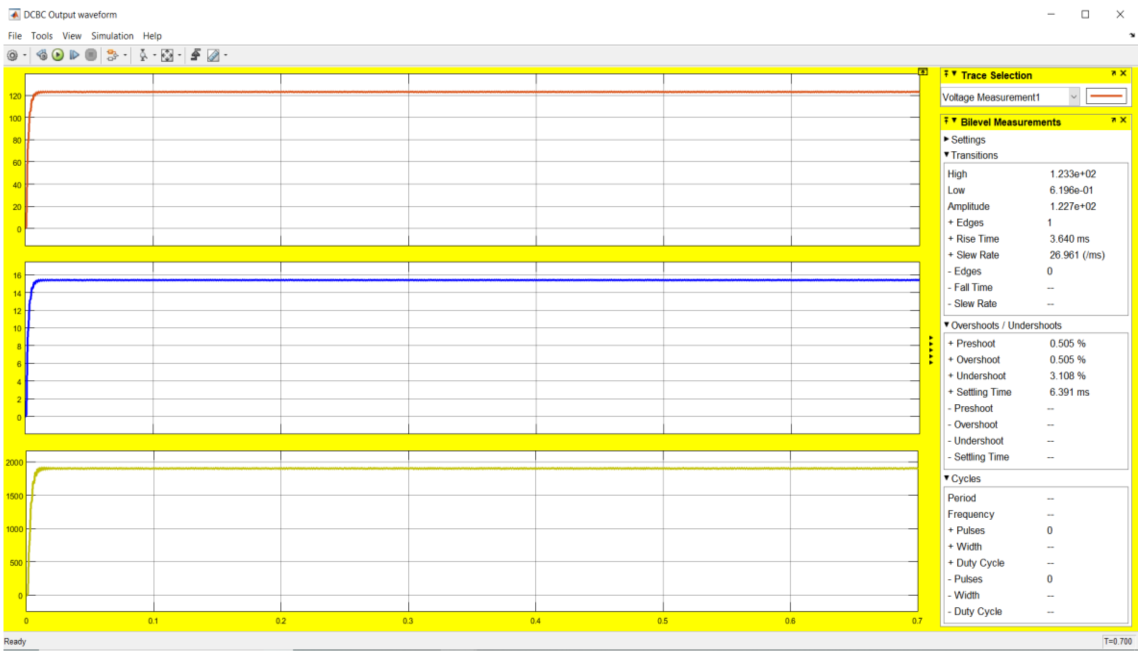


Fig. 6.39 Output Waveforms of DCBC corresponding to waveforms of Fig 6.38.

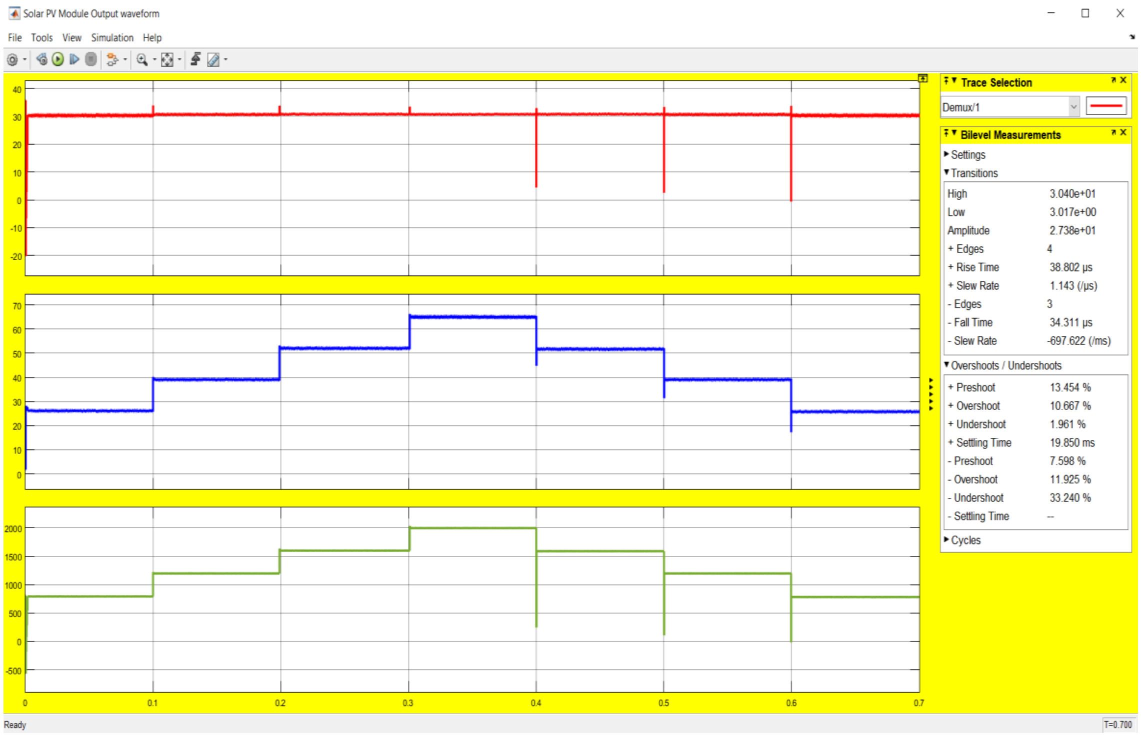


Fig. 6.40 Solar PV Module Output waveforms at Temperature = 25^{o}C and different Values of Irradiation.

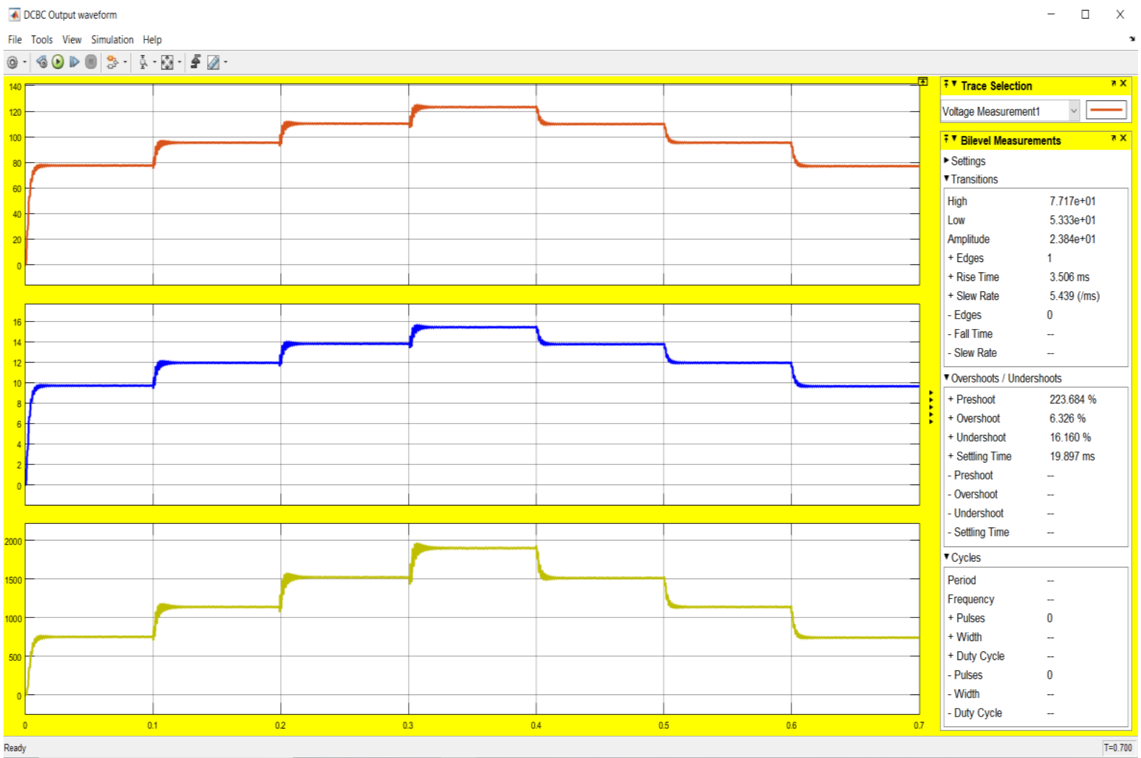


Fig. 6.41 Output Waveforms of DCBC corresponding to waveforms of Fig 6.40

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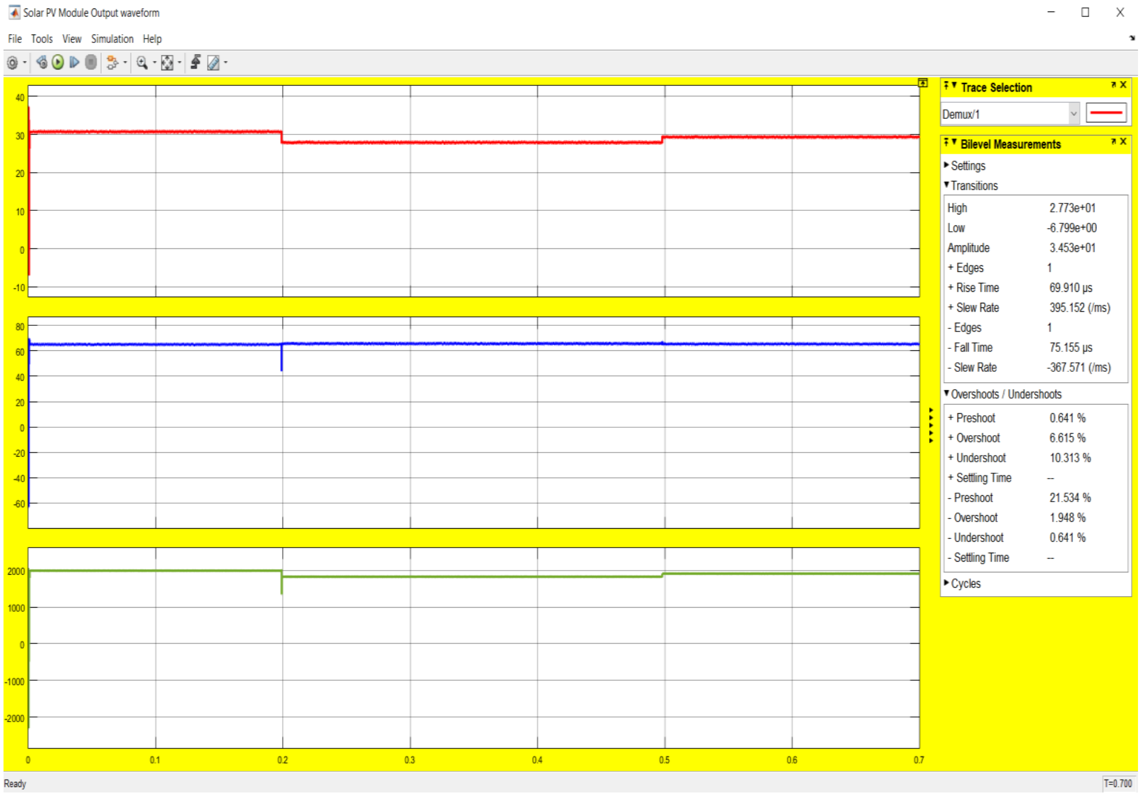

Fig. 6.42 Solar PV Module Output waveforms at Irradiation = 1000 W/m2 and different values of temperature.

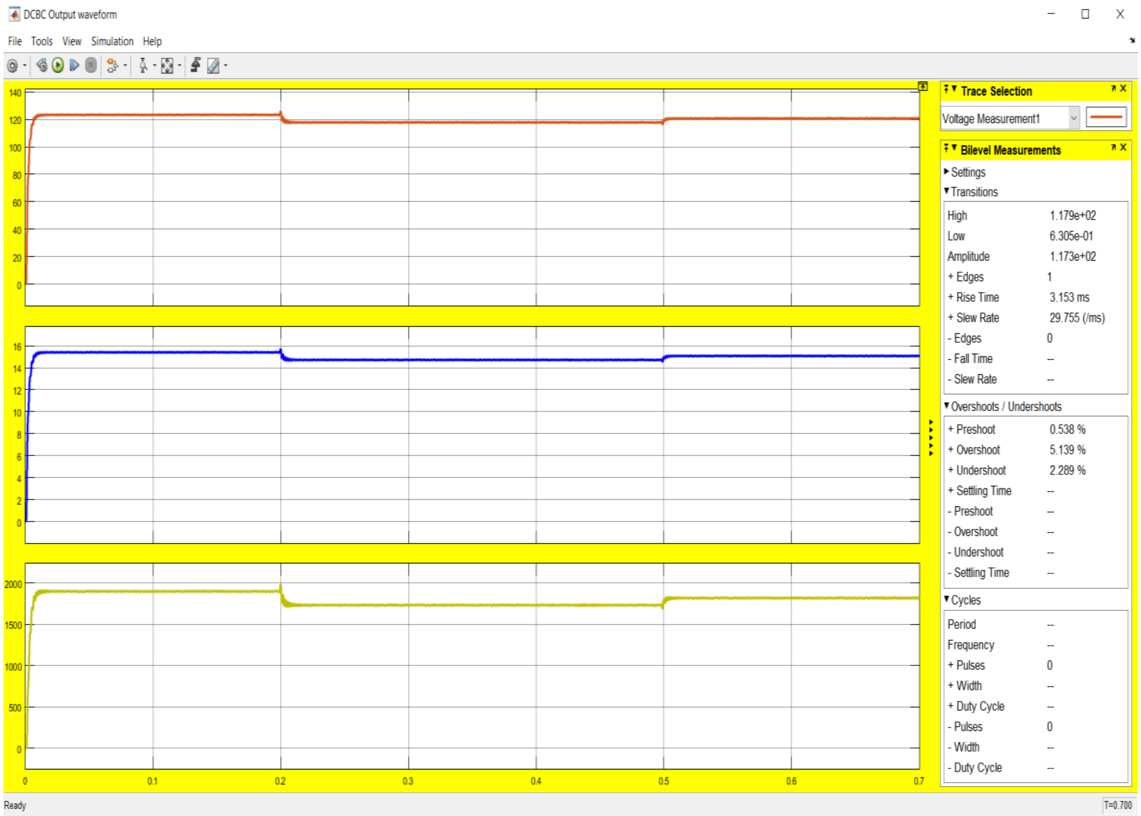

Fig. 6.43 Output Waveforms of DCBC corresponding to waveforms of Fig 6.42

The simulation results are summarised in the Table 6.6, given below.

Table 6.6 Performance analysis of PV Connected DCBC with Fuzzy MPPT Controller

Irradiance/Temp. (watt/m^2/^{o}C)	**Maximum Power (PV Module), P_{MPP}**	**PV Module Output Power, P_{PV}**	**MPPT Efficiency, η_{MPPT}**	**DCBC Output Power, P_{DCBC}**	**DCBC Efficiency, η_{DCBC}**
400/25	792	776	98.01 %	734.3	94.60 %
600/25	1197	1188	99.28 %	1126	94.76 %
800/25	1599	1591	99.50 %	1507	94.70 %
1000/25	2000	1988	99.74 %	1881	94.57 %
1000/35	1914	1906	99.60 %	1794	94.13 %
1000/45	1830	1824	99.69 %	1717	94.15 %

The MPPT efficiency so obtained is in the range of 98.01 % to 99.74 %, under given variations of Irradiance and temperature and is about 99.74 % under standard conditions. The Converter efficiency is nearabout 94.57 %.

CHAPTER 7

CONCLUSIONS AND FUTURE SCOPE

7.1 Conclusion

Solar energy is going to be the most promising renewable energy source for a sustainable future and the solar photovoltaics to be the most ideal energy conversion system. On the other hand, the Quadratic Boost Converter is simple, highly efficient and having high conversion ratio than other cascaded boost converters as it is realized by assembling the circuit elements of two boost converters but using single switch instead of two switches for example as in case of a double cascaded boost converter. In this study complete modeling of boost converter is done, parameters of each converter topology has been evaluated, performance analysis of three topologies of boost converter a conventional, a basic quadratic boost converter and a basic double cascade for gaining high voltage conversion ratio is investigated and a fuzzy logic based maximum power point tracking controller is proposed. The proposed fuzzy logic controller has two inputs and one output, where the kth sample of error signal e(k) and change in error Δe(k) are the input variables and the change in duty cycle Δd(k) is derived as output variable of the FLC. The duty cycle d(k) for the Boost Converters is build up by repetitively summing the Δd(k) value to the d(k-1) i.e. the (k-1)th sample of the duty cycle. The results were obtained from MATLAB/SIMULINK simulations. The MPPT efficiency so obtained is in the range of 93.31% to 98.77 %, under given variations of Irradiance and Temperature and is about 98.77 % under standard conditions. The Quadratic Boost Converter efficiency is nearabout 96.76 %. The system fails to operate at MPPT at 35^0C and 45^0C. The MPPT efficiency for Quadratic Boost Converter is about 99.75 % under standard conditions of solar irradiance and temperature i.e. (1000 w/m^2, 25^0C) and is in the range of 94.55% to 99.04%, under given variations of Irradiance and Temperature. The Converter efficiency is nearabout 93%.

The MPPT efficiency obtained for Double Cascaded Boost Converter is in the range of 98.01 % to 99.74 %, under given variations of Irradiance and Temperature and is about 99.74 % under standard conditions. The Converter efficiency is nearabout 94.57 %. The performance analysis reveals that a double cascade boost converter having an imperceptible difference with that of quadratic boost converter. The dynamic behaviour shows that the quadratic boost converter has the best performance in terms of settling time, overshoot and undershoot and is simple and cost effective, however the double cascaded converter beats the quadratic converter-based PV system in overall efficiency.

7.2 Future Scope

The solar PV system is designed as a standalone without a battery management system block. Further study may include this aspect to make the system more versatile and greatly flexibility regarding maintaining continuous feed of electricity to load. Also, the system can be investigated further for generalised configuration in which inverter is a very important component and so are the AC loads. The classical MPPT techniques especially perturb and observe (P&O) and incremental conductance (IncCond), hill climbing (HC) and constant voltage (CV) are being efficiently applied and are simple, accurate and reliable in tracking the peak under uniform and constant irradiance conditions however the algorithm most of the time change its course and digress from global maximum power point and gets trapped at some local peak under Partial Shading Conditions (PSCs). Thus, the research area for PSCs is both very interesting and challenging. Modern methods maximum power point tracking such as bio-inspired algorithm, ant bee colony optimisation , firefly , ant colony optimisation, cuckoo Search (CS) , Bat algorithm, particle swarm optimization (PSO), grey wolf optimizer (GWO) algorithms and hybrid combination of these can be investigated to design controller to track global maximum power point (GMPP) instead of local maximum power point (LMPP) under PSCs. Future work can be done in this direction.

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RESUMÉ

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