Chapter-1
INTRODUCTION

1.1 GENERAL INTRODUCTION: -

Electric power system is one of the most vital key in improving the social and economic conditions of human race, and continued urge of improvement in lifestyle has made a huge demand of electric power. More and more manufacturing processes and service industries have become dependent on electric power, and, automation has driven the machines for yielding higher profits. World electricity generation is going to touch 39 trillion kWh by the year 2040 which is almost a 100 percent jump from total generation of 20.2 trillion kWh in year 2010. Despite India being world fifth largest electrical power generator with installation capacity of 243028.95 MW as on March 2014, there is still huge power deficit. The growing demand of energy, depleting stock of fossil fuels, environment concerns have called upon all stake holders to deviate from convention way of energy generation and start looking for renewable resources. The new energy paradigm must have attributes of decentralization, diversification on fuels, environment friendliness and integration of distributed energy resources (DERs) at its core for its sustainability in future. Solar power is poised to occupy centre stage as the chief contributor for energy security being available everywhere and being closer to the loads, thus circumventing the necessity of creating infrastructure for transmission and distribution.

In Indian context the conditions are favorable for large scale exploitation of solar power due to its vicinity to the tropic of cancer. Taking the advantage of geographical location, India receive solar energy equivalent of more than 5000 trillion kWh/year with an average intensity of solar radiation around 200 MW/km^2. With 58% of land area receiving annual average insolation of above 5 $kWh/m^2/day$, and having number of sunny days ranging from 250 to 325 days, over a year, India is waiting for a dawn of solar revolution. Thus using solar power with zero fuel cost and no emanation of greenhouse gases, great advantages queuing for the country.

Currently two approaches are being employed to generate electricity from solar energy, namely the solar thermal and photovoltaic (PV). PV system directly converts solar power into electricity utilizing the photoelectric effect. It is preferred for local small scale and distributed power generating units. Moreover, PV systems have suitability both for off and on grid operation depending upon the location of load and grid availability.

Solar energy sources are suffering from high capital cost and less efficiency as compared to wind. But the technology is still more suitable and useful due to its vicinity with loads, higher life cycle, lower intermittency and easy conversion to useful electricity. Polycrystalline PV cells are more popular but monocrystalline PV cells have higher efficiency (16-20%).

However, it still draw certain drawbacks like:- higher capital cost, lifecycle of Inverter and energy storage system, availability during day only, environmental and seasonal weather conditions, partial shading effects, mismatching PV array behaviour etc.

In order to tackle the issues of PV system an efficient means and ways with which power has to be extracted from the incoming solar radiation has to be devised. The power conversion system has been greatly reduced in size over the past few years. The development in power electronics and material science has helped the engineers to come up with smaller but powerful systems to harvest energy from sun. To avert the ill effect of partial shading trends have been set for the use of multi-input converter units that can effectively handle the partial shading and intermittency in solar irradiation. But due to higher production cost and the low efficiency of such PV systems, these are hardly able to compete in the competitive markets as a fore running power generation units.

The use the Maximum Power Point Tracking (MPPT) algorithms has enabled the increase in the efficiency of operation of the PV generation units and thus is effectively employed in the field to harness renewable sources of energy [1-2].

For implementing the MPPT, power converters are employed in the generating system.

1.2 MAXIMUM POWER POINT TRACKING (MPPT): -

Maximum power point tracking (MPPT) acts automatically to adjust the operation point and achieve the greatest possible energy harvest, during moment to moment variations of insolation levels, shading, temperature, and the PV module characteristics. Main control objective of MPPT is to maximize power output and efficient solar energy harvesting.

A typical operation of MPPT is demonstrated as block diagram in Fig.1.1.

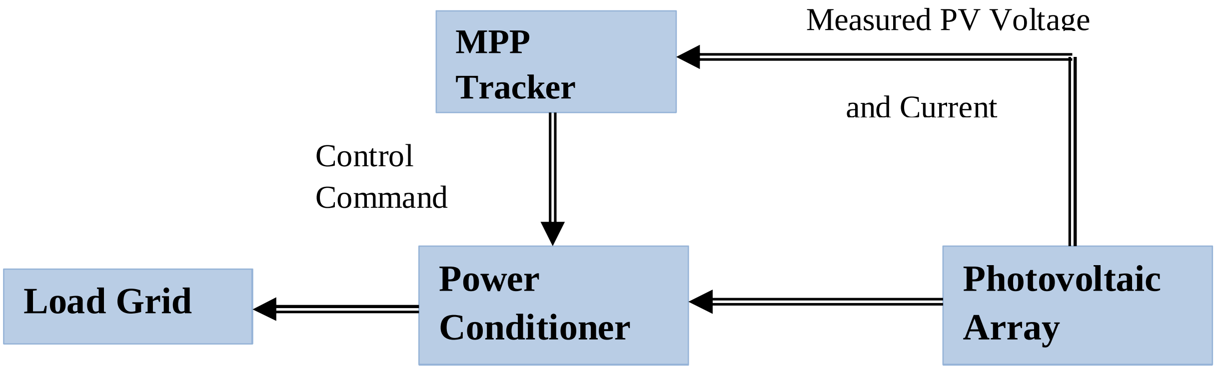

Fig.1.1 Block Diagram of Maximum Power Point Tracking

MPPT controller senses and assesses the output power of the photovoltaic array and adjusts the operating point to follow the optimal operating conditions. Power conditioner utilized as MPPT Controller can either be a DC/DC Converter or a DC/AC inverter and adapts the load to the PV array such that the load characteristics are transformed along locus of MPP to evacuate maximum power from the PV array. The load can be typically DC and/or AC. The controller senses and computes the output parameters, instead of the input power, and control to achieve MPPT.

Choice of MPPT Techniques depends upon the complexity, requirement of sensors, convergence speed, cost, range of effectiveness, implementation hardware etc. [3]. Numerous methods have been reported in the literature and often it becomes difficult to adequately determine which method, newly proposed or existing, is most appropriate for a given PV system.

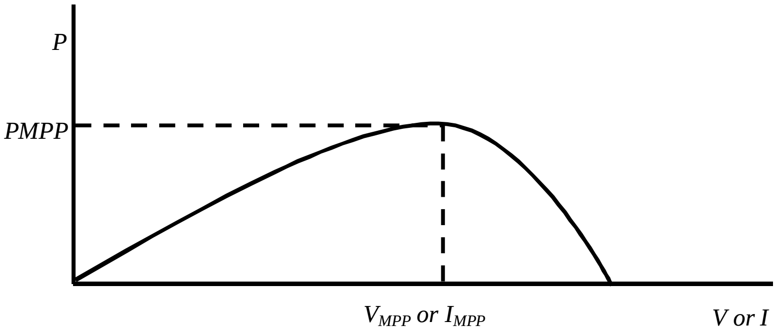

Fig. 1.2: Characteristic PV Array Power Curve

Fig.1.2 shows the characteristic power versus voltage curve for a PV array. The task assigned to MPPT algorithms focus on automatically finding the voltage *VMPP* or current *CMPP* at which a PV array should be operated to obtain the maximum power output *PMPP* under a given temperature and irradiance.

1.3 DC-DC CONVERTER: -

Power Electronic Converters modulates electrical energy from one level of voltage, current or frequency to another as a function of switching states. Thus process of switching the power devices from one state to another is called modulation. For various applications, various converters with optimum modulation technique should be used to deliver desired energy with maximum efficiency. For Renewable Energy Systems, three families of power converters are:

1. AC-DC converters
2. DC-DC converters
3. DC-AC converters

As per the load requirement, the power may be transformed to DC or AC. Therefore, based on the requirement, proper combination and control of above types of power converters are used to supply the load.

DC-DC converters are high frequency converters, which convert unregulated DC power to regulated DC power. Since the output voltage/current of renewable energy systems is basically unregulated, on employment of a DC-DC converter the power output could be regulated either in terms of voltage or current to cater different applications

DC-DC Converters are either isolated or non-isolated based on the isolation provided between the input and output terminals.

1.3.1 Isolated DC-DC Converter: -

Isolated DC-DC Converters are the converters which have isolation between the input and the output terminals of the system and thus can be called as galvanic isolated or isolated ground type. Galvanic isolation can be done either by using a low frequency transformer or high frequency transformer. Low frequency transformer usage results in high cost and low power efficiency thus mostly high frequency transformers are used for isolation.

Various topologies that are using high frequency transformer as isolation are flyback, forward or push-pull, half bridge or full bridge and its variant which is reported in literature. Advantage of using these types of converters is cleaner DC output for sensitive loads as it has high noise and interference blocking capability.

1.3.2 Non-Isolated DC-DC Converter: -

Non-isolated type of DC-DC Converters is the transformer-less and economic solution for various renewable energy applications and for negative ground application like DC powered appliances and equipment. In Literature various topologies like Boost, Buck-Boost, Coupled Inductor Topology, etc. that come under this category are reported. Boost, Buck-Boost, Coupled Inductor Topology etc. Advantage of using these converters is its lower cost and modular structure.

One major disadvantage in this converter topology is lack of isolation between input and output terminals of the system thus requires noise filtering.

1.4 PROBLEM DEFINITION: -

For small power generation, PV generation system should be small and compact in size so that it can easily be ported from one place to another and were equally well amidst insolation change and variable input voltage. Thus power conditioning equipment or dc-dc converter integrated with PV cell should have a high input range and also have compact size, with robust control for MPPT and control of the switching converter, in accordance with fast detection of insolation change so that evacuation of maximum power from PV Panel can be realized.

Converter used as module integrated converter should operate with less number of switching and magnetic devices, thus reducing the cost of the system and also it should offer a high voltage gain at small duty ratio to operate with lesser stress on active power devices.

1.5 OBJECTIVE AND APPROACH: -

Power Electronic Application in Solar Power generation system is making a major impact on its cost, size and efficiency. Accordingly the main objectives of this thesis can be summarized below:

For small power generation to develop a converter system which has the following characteristics:-

1. Have a high range of voltage gain
2. Less stress on the active devices
3. Cost-effective and easy maintenance
4. Less output current and voltage ripples
5. Easy control

The approach to develop such a device consists of the following steps:

- Review the fundamentals of Photovoltaic generating system and maximum power point tracking with respect to operating principles, advantages and limitations.

- Find the different configuration that can be used as module integrated converter

- Use a converter system that can be cost-effective and compact in size so that can easily be integrated with PV Panel. A new concept of "Cascaded High Gain Boost Converter (CHGBC) is presented in this thesis. CHGBC is a multi-input and a single-output configuration which works on the concept of Transformerless conversion and the switching duty controlled by using the MPPT Technique. This concept offers a cost-effective solution and also provides an advantage of portability in case of small power generation. Once in the following chapters analysis of CHGBC is presented. Research follows the following steps :-

    1. Finding the mathematical equation for the gain of the converter system.

    2. According to mathematical equation analysis is done for a constant gain.

    3. Integrating PV Panel with converter system.

4. Applying control scheme so that PV Panel can operate at maximum power point even in insolation variation.
5. Verifying the system with simulated results.

1.6 THESIS LAYOUT: -

The thesis work is presented in the different chapters. A brief overview of the chapters is as follows:

Chapter II: It gives an overview of literature survey. This chapter begins with research and development in Photovoltaic system followed by MPPT Techniques and DC-DC converter systems. Various DC-DC converter systems are categorized and discussed depending upon their characteristics and application. Due to variation in insolation in PV generation system, voltage fluctuates at output side. Thus for controlling this multi-input converters are discussed. These are also classified into isolated and non-isolated topologies.

Chapter III: This chapter deals with the Modeling and simulation of solar PV panel and various MPPT methods like, Incremental Conductance, etc. so that PV Panel may be interfaced with power electronic converter to operate the PV at maximum efficiency.

Chapter IV: The analysis of conventional boost converter and High Gain Boost converter (HGBC) is discussed. Proposed Cascaded High Gain Boost Converter (CHGBC) employs two HGBCs connected in cascade form for two isolated inputs for a single output, making it a multi-input single output system, favorable for PV applications.

Chapter V: This chapter covers the comparison of Boost Converter and HGBC. Also analysis of Dual stage cascaded converter for PV application is done under MATLAB/Simulink environment. Performance evaluation of the system for two isolated PV systems and its controlling is done by using MPPT Method under the MATLAB Simulink environment under two cases of constant insolation and varying insolation. Application of system in grid-connected system is evaluated under the Simulink environment.

Chapter VI: This chapter presents the main conclusions based on the proposed work and also enlists the suggestions for the further work based on the present investigation.

CHAPTER-2
LITERATURE REVIEW

2.1 GENERAL INTRODUCTION: -

Solar power is going to be major contributor for future energy security and sustainability. Several researches have highlighted India’s Solar Power potential and stressed the need to harness this everlasting natural resource of power [4]. India ranks ninth overall on Ernst & Young LLP’s most recent renewables attractiveness index and is on third place on Solar Index [5]. Government of India has taken various initiatives for solar revolution. According to MNRE report, under Jawaharlal Nehru National Solar Mission (JNNSM), which is launched on 11 January, 2010,sets an ambitious target of installation of 20,000 MW Solar by 2022[6]. However inspite of several efforts solar power still contributes to only 6% in renewable energy sector as on March 2013[5]. The major reason behind is the low efficiency of PV system and high capital cost involved in it.

Research is being carried out worldwide to improve the efficiency of PV system. Several factors affect the performance of PV system namely solar insolation, temperature and materials used for making of PV Panel. These all parameters affect the interfacing of PV Panel with power conditioning equipment. Researchers are trying to increase the efficiency of PV system by investigating the various materials that can be used for making of PV Panel. A comprehensive treatment on photovoltaic materials in solar cells and potential of thin film silicon solar cell and its cost effectiveness is investigated [7-8]. Various techniques employed in third generation of solar cells viz. multi-junction cells; intermediate-band cells, hot carrier cells and spectrum conversion have been analysed [9]. A new control scheme is introduced by researchers which can easily track the maximum power point (MPP) of PV Panel Output characteristics thus increasing the output efficiency of PV system. Various techniques are discussed by the researchers depending upon the complexity, sensors used, convergence speed etc. a wide literature is shown in the chapter discussing about various aspects.

As PV Panel have low output voltage and high input current thus for interfacing panel with any application, power conditioning equipments are needed. These equipments are in majority can be dc-dc converter or dc-ac converter. For various dc application voltage outputted from PV Panel should be boosted depending upon the load requirements and for it a dc-dc step-up converter can be used effectively. Research includes various high gain high efficiency dc-dc converters.

Main drawback while using PV as a source is the intermittent supply due to insolation variation or partial shading thus causing voltage or power fluctuation. Solar power generation with multiple converter units effectively handle the voltage fluctuation during partial shading condition. In some cases the PV system can be connected in hybrid mode or two or more isolated PV system can be used as inputs for the converters so that during intermittent supply condition so that voltage fluctuation may be controlled effectively. Research included in this work around various multi-input converters and finally selecting low cost maintenance free converter which can deliver power to both off-grid and grid connected systems. In this chapter survey of literature is presented covering the topics from PV Array, MPPT techniques, isolated/non-isolated converters and multi-input converters.

2.2 MODELLING AND SIMULATION OF PV ARRAY: -

A circuit model of PV system is necessary to get the detailed knowledge about the output characteristics of a PV Panel. Various researchers discussed about various equivalent model and system behaviour at varying insolation and temperature for easy interfacing of power conditioning equipment. A single solar cell is not enough to be used for power generation as it have a very low output voltage thus a PV array or PV module is formed by series and parallel connection of solar cells. It has been observed that both fill factor and open circuit voltage of PV cell decrease with temperature while short circuit current increases [10]. PV array output power as a function of temperature is shown by exhaustive list of correlation equations by E. Skoplaki et al [11].

Samer Said et. al [12] considers PV cell as the main block of simulation for monitoring the performance of PV Array under Simulink environment to obtain I-V and P-V characteristics. Authors divided the study in two sections. In one, varying insolation is studied and another is under partial shading.

The generalised equation used for modelling of equivalent circuit of a PV Panel is described as

$$I = N_P I_{PH} - N_P I_s \left[exp\left\{ \frac{qV}{N_S AkT} \right\} - 1 \right] \tag{2.1}$$

By-pass diode affects the output characteristics in case of shading of PV array. Presented analysis shows that presence of multiple peaks (local peaks) reduces MPPT efficiency as unable to track global peak.

Kashif Ishaque et.al [13] proposed a MATLAB Simulink simulator for PV system, utilizing a two diode model which represents a PV cell which has good accuracy at low irradiance levels thus giving a more accurate idea about PV system performance. Values of R_P and R_S by iteration method thus reducing computation time.

Output current for two-diode model is:

$$I = I_{PV} - I_{01}\left[exp\left(\frac{V+IR_S}{a_1V_{T1}}\right) - 1\right] - I_{02}\left[exp\left(\frac{V+IR_S}{a_2V_{T2}}\right) - 1\right] - \left(\frac{V+IR_S}{R_P}\right) \qquad (2.2)$$

where I_{01} and I_{02} are reverse saturation currents of diode 1 and diode 2, V_{T1} and V_{T2} are thermal voltages of their respective diodes, and a_1 and a_2 represents diode ideal constants.

The simulator inputs are available on a standard PV module datasheet. Accuracy of the system is verified by applying model to five PV modules having different materials and different manufacturer.

M.G. Villalva et. al [14] discusses about an easy and accurate method for modelling of PV array. In this a method is developed for mathematical modelling of PV array which obtain parameters of I-V equation by using nominal information from datasheet: open-circuit voltage, short-circuit current, maximum output power, voltage and current at the maximum power point, current/temperature and voltage/temperature coefficients. This analysis provided a closed solution of finding the parameters of the single diode model equation of a practical photovoltaic array. Author proposed an effective and straightforward method to fit the mathematical I-V curve to the three (V, I) remarkable points (short circuit, maximum power, and open circuit) from the datasheet without the need to guess or to estimate any other parameters except the diode constant a. The developed model is suitable and easy to interface with power electronics equipment.

2.3 MAXIMUM POWER POINT TRACKING: -

In the future solar energy will be very important energy source. More than 45% of the necessary energy in the world will be generated by the photovoltaic plants. Therefore it is necessary to concentrate our efforts in order to reduce the application costs and to enhance their performances. In order to reach this last aspect, it is important to note that the output characteristic of a photovoltaic array is nonlinear and changes with solar irradiation and the cell's temperature. Therefore a Maximum Power Point Tracking (MPPT) technique is needed to draw peak power from the solar array in order to maximize the produced energy.

M. Berrera has compared seven different algorithms experimentally for maximum power point tracking using two different solar irradiation functions to depict the variation of the output power in both cases using the MPPT algorithms and optimized MPPT algorithms [2]. In this paper low and medium irradiation levels are considered and energy supplied by the PV system is evaluated. The results show that the best MPPT technique is the modified P&O (P&O b) and always provide highest efficiency. But its limitation is in the response to the irradiance variation at low irradiance level. The Incremental Conductance (InC) technique has efficiency lower than the P&O techniques, but its response time is quite independent to the irradiation values and its efficiency increase with the irradiance level. This technique can be a good alternative to the P&O techniques in applications characterized by high, fast and continuous radiance variations, e.g. the PV applications in transportation.

Ali Nasar Allah Ali et. al [15] discussed the 30 MPPT techniques. This work gives the complete understanding of maximum power point tracking algorithms available in literature. In this research work all the old and new MPPT methods observed and investigated thoroughly and some useful methods also introduced by the authors. New developed methods are; β method, system oscillation method, constant voltage tracker method, online MPP searches algorithm, variable inductor MPPT, POS control etc.

R. Faranda et al [16] discussed about comparison among ten different Maximum Power Point Tracking techniques in relation to their performance and implementation costs. For comparison of energy supplied from PV Panel twelve different values of solar insolation were considered. The implementation of MPPT and a cost comparison in terms of hardware is shown taking into consideration the costs of sensors, microcontroller and additional power components. According to author P&O and InC get the best ranking.

Many methods to track Maximum Power Point (MPP) for PV arrays have been discussed by Trishan Esram et al [3]. It comprises of all the techniques implied in this field. It was shown that at least 19 distinct methods have been already introduced. Author has done the comparison of all the 19 MPPT Techniques and among all, InC MPPT Technique is considered to be the best suited under the insolation variation condition as it has a fast convergence speed thus instantly track the MPP point.

2.4 POWER CONVERTER INTERFACING: -

Power electronic converter is used to interface the PV array to dc bus to perform three major functions including step up or step down the generated PV voltage, regulate the varying dc output voltage of PV array and implement the MPPT of solar array to ensure operation at maximum efficiency. However, there are various topologies of DC-DC converter including buck, boost, push pull, half bridge, full bridge, flyback, buck-boost etc [17-18]. The choice of topology depends on system requirements and its applications. For practical domestic or industrial application high step-up DC-DC converters are essential to obtain high voltage from photovoltaic energy [19-20].

A. Tomaszuk et al [21] discussed about different step-up isolated and non-isolated topologies for grid integration of PV module. Author discussed about advantages and drawbacks of each converter system in brief.

2.4.1 Isolated Topologies: -

Isolated topologies are those topologies which have isolation between the input and output of the system. Isolation used in these topologies is called as galvanic isolation which can be a low frequency or a high frequency transformer. Due to high cost and low efficiency of low frequency transformer, it is not used with renewable energy application, saving the way for high frequency transformer for isolation.

Luciano Andres Garcia Rodriguez and Juan Carlos Balda has done a comparison of isolated DC-DC Converters for Micro inverter application depending on the rating of the active device, which affects the system cost [22]. Two basic topologies discussed here are: Flyback and Push-Pull Converters. Different Flyback technologies are discussed in [23-26], including interleaved Flyback Converter, which uses two flyback transformers instead of one, soft switching technique and ZVS switching. Benefit of using two transformers in interleaved Flyback is reduction of the input and output ripple currents, which reduce the requirements on the input and output capacitances, and also increase the lifetime of the capacitors. Another benefit is the possibility of providing more power to the grid.

Chuan Yao et. al [27] discussed about family of isolated Buck-Boost converter in which full bridge boost converter is analysed as a typical topology. To improve efficiency and reliability of the topology, author introduces a three mode control scheme which according to different regions of input voltages works in boost, full bridge boost and full bridge modes.

In [28] an active clamp step-up DC-DC converter is introduced which has the advantages of both flyback and forward converters. It regulates the DC link voltage besides providing high voltage conversion ratio. This topology uses the active-clamp circuit both in ON-state and OFF state so the input power is delivered to the output in both these states. As seen in [19-20, 29] isolated topologies can be used to achieve high voltage gain, but they suffer from circuit complexity, bulky size and switching losses. Consequently, research drifted towards non isolated topologies.

2.4.2 Non-Isolated Topologies: -

In order to satisfy the requirements with performance in renewable energy applications, many researchers concentrate on how to realize high voltage gain step-up, low cost and high efficiency single-stage converters [30]. Modular power conversion without galvanic isolation is a promising solution because it is less perturbed and it would allow an effective use of the energy available in the PV arrays. But it has a major drawback of not having isolation, thus suffer from low leakage current problem. Therefore, in this context, it is necessary to utilize a step-up DC-DC converter as an intermediate stage, between the PV array and the inverter.

Various non-isolated topologies have been put forward by research community to obtain high step operation and with superior circuit performance.

Wuhua Li et al [30] gave comprehensive review of various schemes and discussed about their advantages and disadvantages, summarizing major challenges of high step-up converter in renewable energy application. Conventional boost converter is generally used for such application. But, its voltage gain is limited due to the losses associated with inductor, filter capacitor, rectifier grade diodes and the main power switch when operating with extreme duty cycle [18, 32]. In [33] interleaved boost structures are advocated for low input current ripple for enhanced PV module life. These converters demonstrated low current ripple, reduced component size and better transient response. However they suffered from large switching losses. Further to improve voltage gain, interleaved structures with coupled inductors are suggested[30].

Q. Zhao et al. [34] investigated a high step up converter with coupled inductor. They proposed that Coupled inductor can be used as transformer to scale up the voltage gain in non-isolated DC-DC converters. Coupled inductor has two windings, primary winding serves as similar function of filter inductor and secondary wing as a voltage source in series to power branch. This topology offers high static gain by properly choosing the winding ratio [30]. Also, the switch voltage stress of switches is suppressed and reverse recovery of the output diode is alleviated. But the voltage across the output diode remains high and the resonance between the leakage inductance and parasitic capacitor of the output diode causes electromagnetic interference and increases losses. Furthermore, the input current ripple is high due to the discontinuity of the current.

H. S. Chung et al [35] presented High step-up converters with switched capacitors. Authors employed capacitors as voltage source to obtain high voltage gain. Each switched capacitor cell consists of a capacitor, a diode and two switches in which capacitor acts as a voltage source. In this topology high voltage gain can be achieved but a large number of MOSFETs are required to realize it thereby increasing the cost of gate driver circuits, thus increasing the cost of the system.

R. D. Middlebrook [36] proposed High step-up converters with inductor and switched capacitors. In this N-staged Capacitor cells are inserted into Cuk Converter to achieve a high voltage gain. Steeples voltage gain can be realized with low input and output current ripples. The diodes in such configuration have to sustain high voltage stress and output diode suffer from reverse recovery problem. R. J. Wai, et al [37] studied High step-up converters with coupled inductor and switched capacitors. In their proposed voltage gain was enhanced with both the storage elements inductors and capacitors, with low switch voltage stress.

Lung-sheng Yang et.al [38] presented a family of transformerless high gain DC-DC converter utilizing the switching inductor technique. These systems have advantages of modular configuration, easy control, a high voltage gain , less stress on the active power devices and easy to interface for renewable energy application.

2.4.3 Multi-Input Converters: -

As input power, output demand or both are changing instantaneously and not same at any time instant, thus a need of additional source is there to fulfil the load demand. The conventional approach is to connect the sources either in parallel or series with each other. If sources are placed in series then they have to conduct same current which is not always desirable. Also different sources having different voltage levels cannot be connected in parallel directly. Thus multiple input converters are required to connect multiple sources in a single system to supply to load. Advantages of using multi-input converters are: less no. of components, simple control, more stability, lower losses.

These topologies are nowadays widely used in various applications like photovoltaic systems, hybrid energy systems, hybrid electric vehicles, aerospace, satellite applications and portable electronics devices. Zubair Rehman et. al gives a detailed overview of multi-input isolated and non-isolated topologies for renewable energy application. Comparison of the topologies is done on the basis of cost, reliability, efficiency and flexibility [39].

2.4.3.1 Multi-Input Isolated Topologies: -

Multi-input converters can be derived by using the principle of flux additivity [40-45]. In this, sources are interconnected using multi-winding transformer thus different sources with different voltage levels can be used as inputs and they are combined magnetically by adding produced magnetic flux in core of coupled transformer. Sources are galvanically isolated for safety purpose.

Basic topologies of isolated converters are Flyback, Forward, Push-Pull, Full Bridge and Half Bridge Converters. Flyback or simple isolated Buck-Boost converter as shown in fig. 2.1 is the simple type of multi-input converter which uses principle of magnetic coupling to combine two input sources. but they lack in bidirectional power transfer. They are not suitable for high power and high output voltage applications [46].

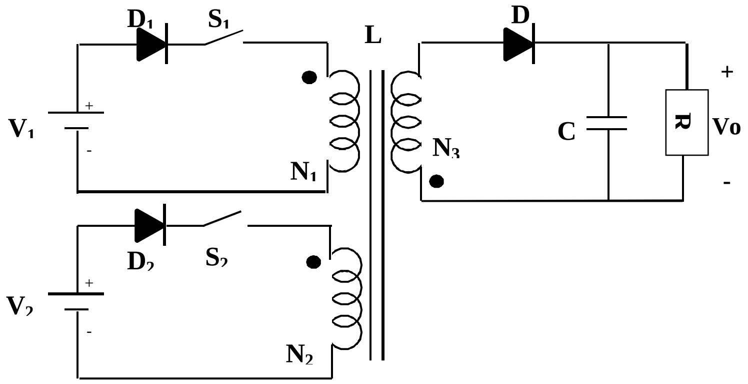

Fig. 2.1 Simple Isolated Buck-Boost Multi-Input Converter

H. Tao et.al [47] discussed about a family of multiport bidirectional DC-DC Converters which are a combination of coupling of DC link and magnetic coupling. Such topologies provides a solution to integrate diverse sources owing to flexibility in structure with a minimal number of power conversion steps, low cost, easy control and power management.

A Zero Voltage Switching (ZVS) based full bridge multi-input DC-DC Converter is discussed in [48-50]. For this system additional switches to interrupt circulating currents are required. Also this system is able to achieve higher gain and good power regulation.

A multi-input transformer coupled DC-DC converter for PV-Wind Hybrid system is proposed by B. Mangu and B.G. Fernandes, for remote location where there is no grid availability [51]. The transformer based half bridge boost converter is used to harness the wind energy and the bi-directional converter utilizes bidirectional power transfer from PV with battery for charging and discharging control. The system has less number of power conversion stages and thus incur less component cost and losses resulting in high efficiency and reliability.

The advantages of using all these structures for medium and high power application are low voltage stress on active devices and less switching losses. But these systems are complex both on design and their control strategy. Thus for low power applications non-isolated system are advocated as they are modular, more robust and have easy control scheme.

2.4.3.2 Multi-Input Non-Isolated Topologies: -

In [52] various feasible topologies of multi-port DC-DC Converters are identified based on some assumptions, conditions and restrictions. These topologies are derived from single-input converter by using time multiplexing control schemes on the basis of four basic rules explained by author. A multi-input converter is proposed which is an integration of Cuk and SEPIC Converters [53]. Advantages of this system is that, there is no need of separate input filters, these can support step-up or step-down operations for each renewable source, and it can ensure MPPT for each source and supports individual and simultaneous operations.

A dual input single output converter, which is a combination of the buck-boost and the buck converter, for low or high voltage sources has been analysed by Y. M. Chen et. al [54]. The converter can individually or simultaneously deliver the power to the load and there is no need of multi-winding transformer. In addition to this soft switching control can easily be implemented, and extra bypass short circuit is also not needed. In [55], a multi-input non-isolated DC-DC converter having high voltage gain for photovoltaic power generation system is reported. This system have advantages, viz., reduced current stress and wide control range of different input powers.

B. G. Dobbs et. al [56] discussed about a topology which has n number of inputs and is based on buck-boost converter shown in fig.2.2. It operates in three modes: buck, boost, buck-boost mode. This system has fewer components and delivers positive output voltage but has a drawback of negative reference output which can be reversed by using a transformer thus adding on to cost and size. The rider of only one source can deliver power at a time, further adds to the misery.

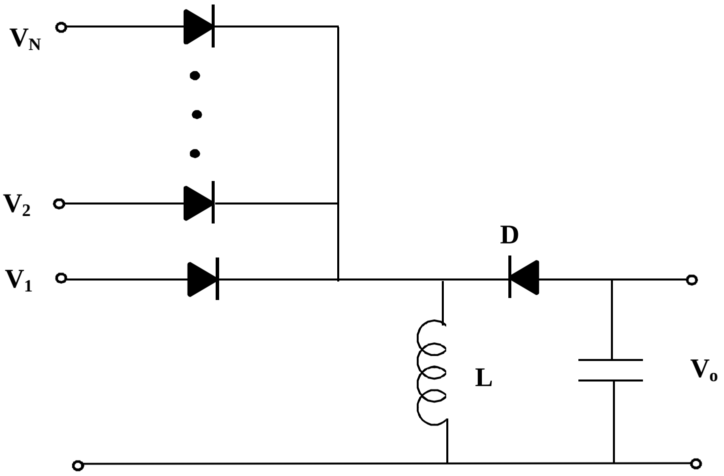

Fig. 2.2 Multiple-Input Buck-Boost Converter

G.R. Walker and P.C. Sernia [57] discussed about “converter per module” approach. In it simple non-isolated per module DC-DC Converters are connected in series to make a high voltage string. Each DC-DC converter switching can individually be controlled by MPPT Technique. Authors analysed that boost, buck, buck-boost and Cuk converters are the possible cascadable converters. Boost as per voltage gain, Buck as per cost, Cuk and Buck-Boost (When large flexibility of voltage range is solicited) as per both cost and efficiency. As small PV panel have the limitation to produce a low voltage and a high current output, there is need to boost the output voltage from PV panel to cater with different loads for different applications.

2.5 RESEARCH GAP: -

As solar insolation is varying throughout a day, the manner in which PV generating system supply to load becomes important. For residential rooftop PV applications, PV source are installed in vicinity of load so the maximum power evacuated from PV source is transferred from panel to load take place. During partial shading conditions or insolation variation, MPPT techniques are employed to track the maximum power and accordingly control the power electronic interfacing converter to harness maximum efficiency from PV module. To control the fluctuation in voltage at the output due to partial shading or insolation variation and to make the system more reliable, hybrid system having battery or grid as storage elements are cited in literature. Storage elements can supply the power to the load during the intermittent period or shading conditions and absorb the excessive power from the PV system if the load demand is lesser.

For small power generation, small PV array is used which have output lower voltage and a high output current. For off-grid systems often a higher voltage is needed at a usable level to meet the requirements of load, whereas, for on-grid systems, requirement of higher voltage demand at dc link is also requisite. Thus in either cases, a high step-up and highly reliable interfacing converter is needed. The other requirement for PV rooftop application demands the PV generating system to be compact and easily portable, leading to the topologies of micro-inverter or converter.

Focus of research for high step-up DC-DC converters are therefore requisites and focuses on the following:

1. Extending the voltage gain and avoiding the extreme duty cycle thus obtaining lowered current ripple and the conduction losses;
2. Lowering the value of switch voltage to make low voltage MOSFETs available;
3. Realizing efficient switching techniques for enhanced performance by minimizing the switching losses;
4. Finding solution of output diode reverse-recovery problem;
5. Obtaining higher voltage level with reduction in size of the passive component.
6. Easy and simple control scheme

Research focused on the above issues are represented in [22-57].

Thus a converter system which has wider characteristics: - high voltage gain, high input voltage range(to cater with intermittent period/partial shading), reduced stress on active power devices, economic, modular, robust, and easy control so that can easily be interface with PV Panel is represented for research.

2.6 CONCLUSION: -

From the above literature it is concluded that transformerless high gain boost converter will be investigated to supply the roof top microinverter applications. The Cascaded High Gain Boost Converter topology is selected for further investigates were of has a high voltage gain as compared to conventional topologies used for module-integrated converters. Also it is compact in size and fewer components usage makes it a more reliable, easily controllable and an economic solution. Topology can easily be controlled using popular MPPT technique, thus works as an easy interface between PV Panel and the load.

CHAPTER 3
PV MODULE MODELLING AND INC MPPT CONTROLLER

3.1 GENERAL INTRODUCTION: -

To study the integration of PV Panel with converter system, a detailed study and analysis of the system behaviour is essential. A mathematical model of PV system is considered emulating actual PV Panel to study the V-I and P-V characteristics of a PV Panel. Also the algorithm for Incremental Conductance (InC) MPPT control technique to extract maximum power from the PV Panel is developed in this chapter.

3.2 PV MODULE MODELING: -

Solar cell is basic unit of a PV module and is basically a p-n junction semiconductor device, whose electrical characteristics differ from diode. Also it is the element in charge of transforming sun rays or photons directly into DC supply.

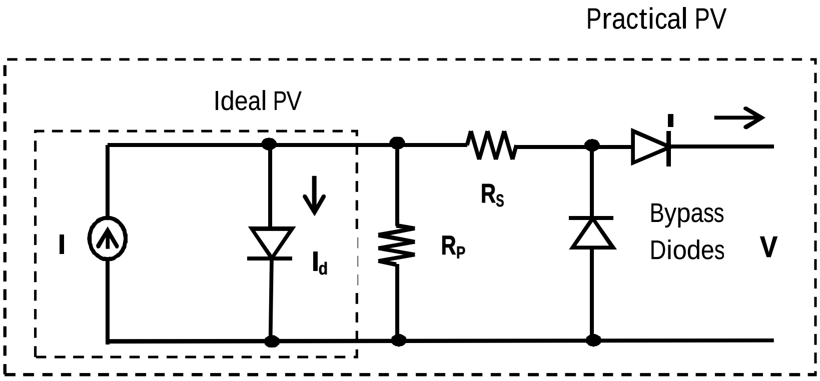

Fig.3.1 Equivalent Circuit of PV Cell

Fig.3.1 shows equivalent circuit of a practical PV cell which has bypass diodes to give safety to the panel against shadow and failure of PV cell [14]. The characteristic equation of a PV cell is output current produced by it and is expressed as [14]:

$$I = I_{PV} - I_o \left[e^{\left(\frac{V+R_S I}{V_t a}\right)} - 1 \right] - \frac{V+R_S I}{R_P} \qquad (3.1)$$

where I_{PV} = Current generated by insolation

I_d = Diode current

I_o = Reverse Saturation or Leakage Current of the Diode

V_t = Thermal voltage of PV Module with Ns PV Cell connected in series

= $N_s KT/Q$

K = Boltzmann Constant = 1.380503 X 10^{-23} J/K

Q = Electron Charge = 1.60217646X10^{-19} C

T= Temperature in Kelvin

a = Diode ideality factor ($1<a<1.5$)

Solar cells are connected in series and parallel to form a module. Increase in series cells leads to increase in output voltage whereas increase in parallel cells results in increase in output current.

For simulation purpose, we have used manufacturer's datasheet for open-circuit voltage, short circuit current, the voltage at the MPP, the current at the MPP, the open circuit voltage or temperature coefficient(K_v), the short-circuit current/temperature coefficient(K_I), and the maximum experimental peak output power ($P_{max,e}$). This information is provided generally as standard test conditions i.e. at 1000 W/m^2 irradiation and 25^oC. The other parameters like the light generated current, diode saturation current, diode ideality constant, series and parallel resistance etc. can be computed as represented in the literature [14].

The current generated by the incident solar radiation depends linearly on the solar irradiation and is also influenced by the temperature according to the following equation.

$$I_{PV} = \left(I_{PV,n} + K_I \Delta T\right) \frac{G}{G_n} \tag{3.2}$$

where, $I_{PV,n}$ is the light generated current at nominal condition i.e. at 25^0C and 1000W/m^2

ΔT= Actual temperature-nominal temperature in Kelvin

G= Irradiation on the device surface

G_n = Irradiation at nominal irradiation

The diode saturation current I_o and its dependence on the temperature may be expressed as

$$I_o = I_{O,n}\left(\frac{T_n}{T}\right)^3 exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_n}-\frac{1}{T}\right)\right] \tag{3.3}$$

where E_g is the band gap energy of the semiconductor and $I_{o,n}$ is the nominal saturation current and is expressed as

$$I_{o,n} = \frac{I_{sc,n}}{exp\left(V_{oc,n}/aV_{t,n}\right)-1} \tag{3.4}$$

where $V_{oc,n}$ = Nominal open circuit voltage of the PV module

The series and parallel resistance of the PV Cell is calculated by using algorithm as reported in literature[14]. R_S basically depends on the contact resistance of the metal base, the resistance of the p and n bodies, and the contact resistance of the n layer with the top metal grid. The R_P resistance exists mainly due to the leakage current of the p-n junction. The value of R_P is generally too high, whereas, the value of R_S is very low.

3.2.1 Model Verification: - For model verifications parameters of KC200GT Kyocera panel is taken which is given in Table 3.1.

I_{mp}	***7.61 A***
V_{mp}	***26.3 V***
$P_{max,m}$	***200.143 W***
I_{sc}	***8.21 A***
V_{oc}	***32.9 V***
$I_{0,n}$	$9.825 \cdot 10^{-8}$ A
I_{pv}	***8.214 A***
A	***1.3***
R_p	***415.405 Ω***
R_s	***0.221 Ω***

Table 3.1: Parameters of the model of KC200GT solar array at nominal operating conditions

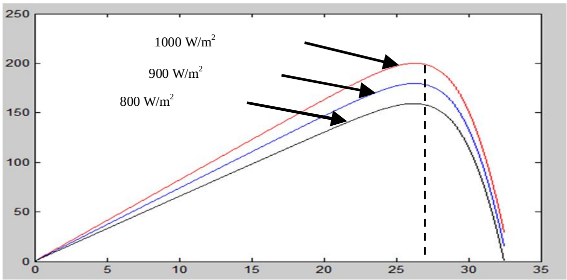

Fig.3.2 (a) I-V Characteristics at different insolation

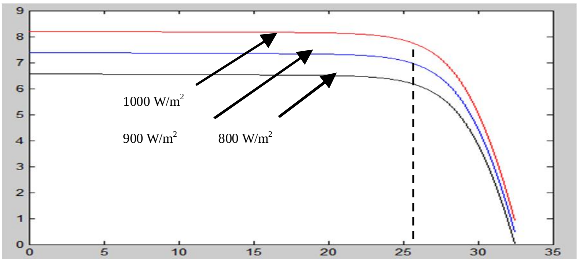

Fig. 3.2 (b) P-V Characteristics at different insolation

These parameters are taken at standard operating conditions i.e. at 1000W/m^2 and temperature at 25^{o}C. Fig.3.2 shows the I-V Curves and P-V curves at different insolation. The simulated result matches closely with datasheet validating the model developed.

3.3 INCREMENTAL CONDUCTANCE (InC) MPPT: -

This method is based on the fact that the slope of the PV array power curve at the MPP is zero, positive on the left, and negative on the right of the MPP [3]. This is shown in Fig.3.3 which is given by:

$$\left\{\begin{array}{ll} dP/dV = 0, & at\ MPP \\ dP/dV > 0, & left\ of\ MPP \\ dP/dV < 0, & right\ of\ MPP \end{array}\right\} \quad (3.5)$$

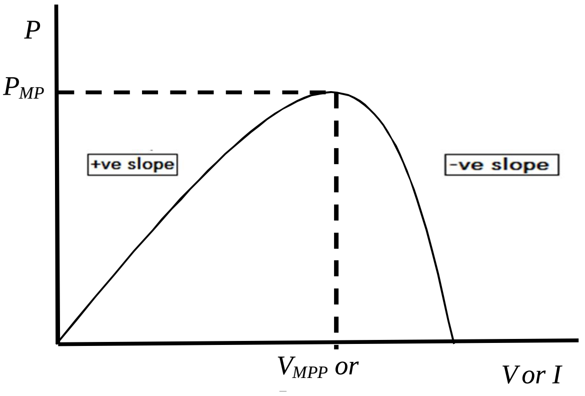

Fig.3.3 PV Array Power Curve

Since,

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \qquad (3.6)$$

Therefore,

$$\left\{\begin{array}{ll} \Delta I/\Delta V = -I/V, & at\ MPP \\ \Delta I/\Delta V > -I/V, & left\ of\ MPP \\ \Delta I/\Delta V < -I/V, & right\ of\ MPP \end{array}\right\} \quad (3.7)$$

The MPP can thus be tracked by comparing the instantaneous conductance (*I/V*) to the incremental conductance (Δ*I*/Δ*V*) as shown in the flowchart in Fig. 3.4. Thus in this method input impedance of switching converter is adjusted to a value that matches optimum impedance of PV Array.

V_{ref} is the reference voltage at which the PV array is forced to operate. At the MPP, V_{ref} equals to V_{MPP}. Once the MPP is reached, the operation of the PV array is maintained at this point unless a change in ΔI is noted, indicating a change in atmospheric conditions and the MPP. The algorithm decrements or increments D (Duty Cycle) to track the new MPP.

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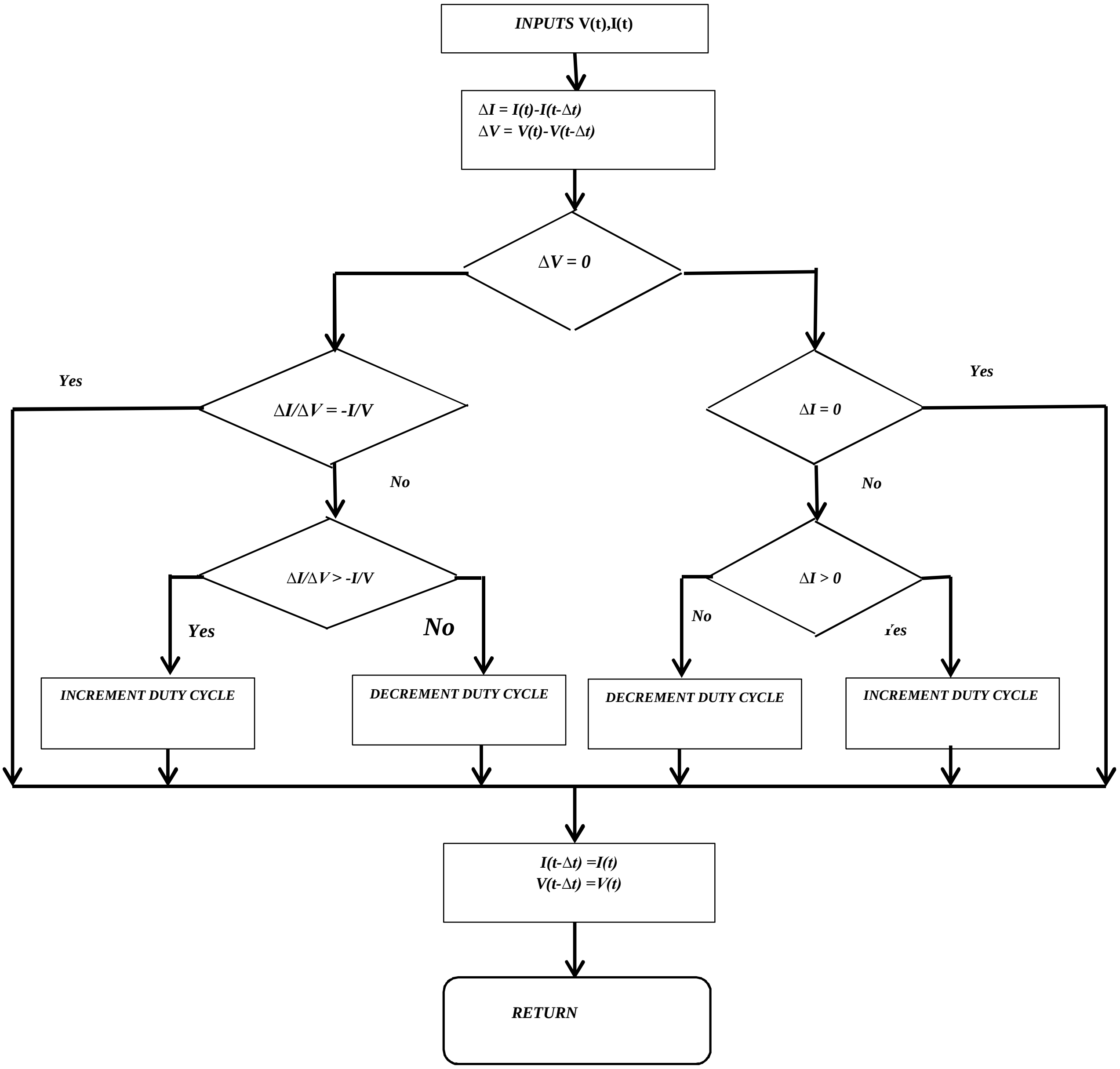


Fig. 3.4. Flow Chart for Incremental Conductance Method

3.4 CONCLUSION: -

The simulated I-V and P-V characteristics of PV panel is verified using the parameters given in the datasheet of KC200GT Kyocera 200W panel under different insolation. As incremental conductance algorithm has fast convergence speed thus rapidly track the variation in output characteristics of PV Panel occurring due to variation in insolation. Also this algorithm is easy to implement.

CHAPTER-4

MODELLING OF HIGH GAIN BOOST CONVERTER (HGBC) AND CASCADED HIGH GAIN BOOST CONVERTER (CHGBC)

4.1 GENERAL INTRODUCTION: -

Various DC-DC converters and their configurations are discussed in literature, which may be used to extract power from renewable energy resources for varied applications. For small wattage PV system, module-integrated converters are needed which may be easily controlled to extract maximum power. Conventionally, Boost Converter is used as MPPT controller for PV Applications, which is briefly discussed in this chapter. Further the analysis of High Gain Boost Converter and its various parameters are calculated. The analysis of CHGBC is also discussed with its different modes of operation.

4.2 BOOST CONVERTER: -

Boost converter is also called as step-up converter and as the name implies its typically application of converting a low input voltage to a high output voltage. Fig.4.1 shows the circuit diagram of boost converter which have an inductor, a switch which is controlled by giving controlled pulses for regulation of voltage gain, a diode used in reverse blocking mode to ensure that no backward flow of current take place and a capacitor to filter out the AC ripples.

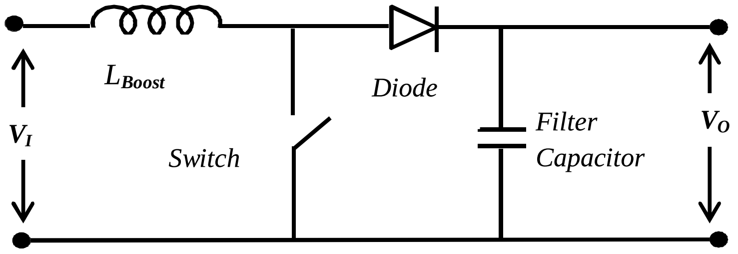


Fig.4.1 Boost Converter

Converter is used in continuous conduction mode. In it, when switch is ON, diode becomes reverse biased thus isolating output stage and inductor is charged. When the switch is OFF, in addition to input, inductor supplies energy to output voltage The relation between the output and input voltages of the boost converter can be given by:

$$\frac{V_o}{V_i} = \frac{1}{1-D} \qquad (4.1)$$

where: V_o is its output voltage

V_i is the input voltage to the boost converter, and D is the duty cycle.

If the output voltage of the boost converter is fixed and the duty cycle is varied, the input voltage of the dc converter (the output voltage of the PV) can be controlled. This converter can be used to provide a high voltage gain range over a high duty ratio which leads to heavy voltage stress on the active power devices like MOSFETs, Power diodes, etc.

4.3 HIGH GAIN BOOST CONVERTER (HGBC): -

High gain boost converter is the another switching converter that operates on the switching inductor in which pair of switches are opened and closed periodically at same time thus charging and discharging of pair of inductors take place respectively.

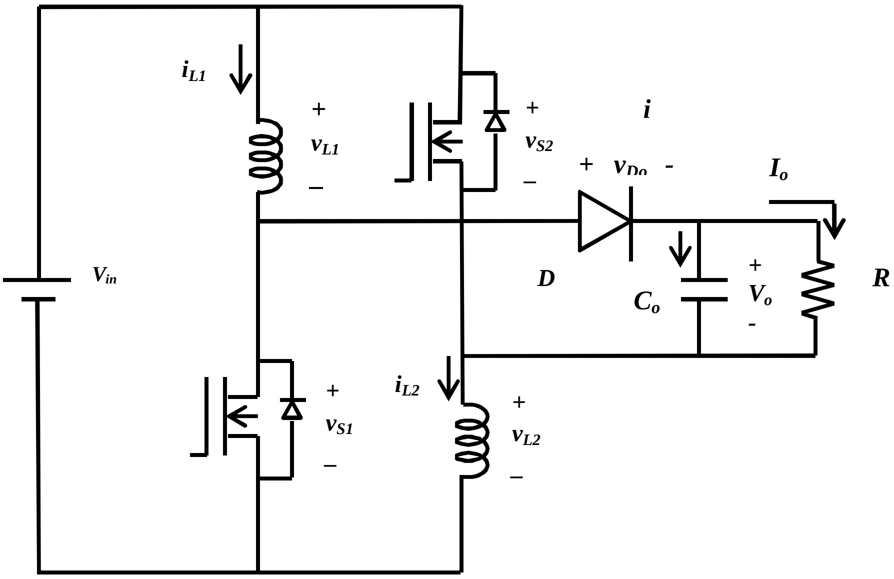


Fig. 4.2 Non-Isolated High Gain Boost Converter

Converter consists of two active switches (S_1 and S_2) and two inductors (L_1 and L_2) having same level of inductance, one diode and one output capacitors. For analysing steady state characteristics of the converter some assumptions are made:- 1) All components are ideal - the ON-state resistance R_{DS}(ON) of the active switches, the forward voltage drop of the diodes, and ESRs of inductors and capacitors are ignored; 2) Switching period is T and switch is closed for *DT* and opened for *(1-D)T*; 3) Inductor current is always continuous (always positive); 4) All capacitors are sufficiently large, and voltages across capacitors are sufficiently large.

4.3.1 Steady State Analysis of HGBC: -

Operating modes are divided into two modes- Mode 1 and Mode 2.

Mode 1: - Switch Closed

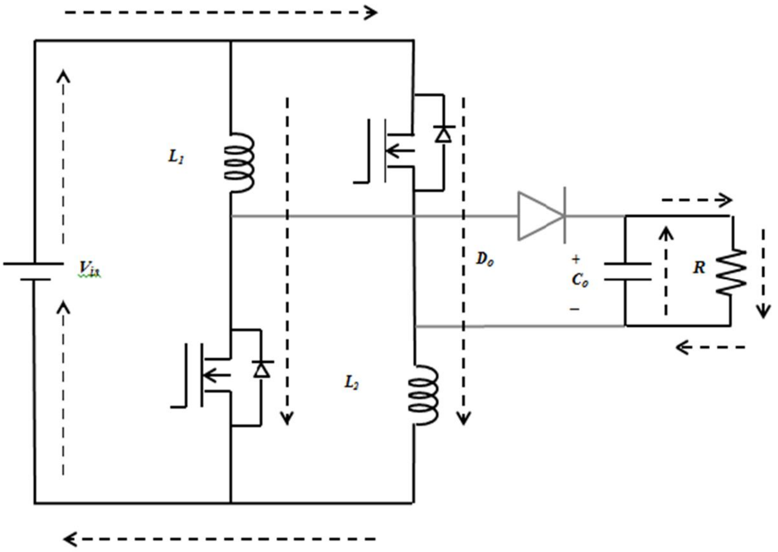


Fig. 4.3(a) Mode 1: When Switch is Closed

When the switch is closed, diode is reverse biased, thus KVL around the path containing source, inductor L1, and switch S1 gives

$$v_{L1} = V_{in} = L_1 \frac{di_{L_1}}{dt} \qquad (4.2)$$

$$\frac{di_{L_1}}{dt} = \frac{V_{in}}{L_1} \qquad (4.3)$$

Similarly, for path having source, inductor L2 and switch S2 gives

$$v_{L2} = V_{in} = L_2 \frac{di_{L_2}}{dt} \qquad (4.4)$$

$$\frac{di_{L_2}}{dt} = \frac{V_{in}}{L_2} \qquad (4.5)$$

The rate of change of current, so current increases linearly while switch is closed. Thus change in inductor currents

$$\frac{\Delta i_{L_1}}{dt} = \frac{\Delta i_{L_1}}{DT} = \frac{V_{in}}{L_1}$$

$$\frac{\Delta i_{L_2}}{dt} = \frac{\Delta i_{L_2}}{DT} = \frac{V_{in}}{L_2}$$

Therefore, Δi_{L_1} for switch closed

$$\left(\Delta i_{L_1}\right)_{closed} = \frac{V_{in}DT}{L_1} \qquad (4.6)$$

$$\left(\Delta i_{L_2}\right)_{closed} = \frac{V_{in}DT}{L_2} \qquad (4.7)$$

Mode 2: - Switch Opened

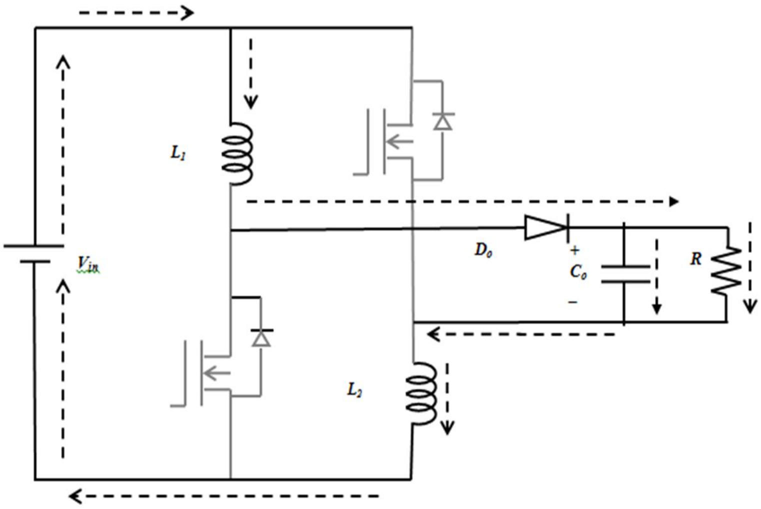


Fig. 4.3(b) Mode 2: When Switch is Opened

When switch is opened, the inductor current cannot change instantaneously, so diode becomes forward-biased providing a path for inductor current. Assuming output voltage V_o be constant, voltage across inductors are

$$v_{L1} = \frac{V_{in}-V_o}{2} = L_1 \frac{di_{L_1}}{dt} \qquad (4.8)$$

$$v_{L2} = \frac{V_{in}-V_o}{2} = L_2 \frac{di_{L_2}}{dt} \qquad (4.9)$$

The rate of change of current is constant, so current must change linearly while switch is open.

$$\frac{\Delta i_{L_1}}{dt} = \frac{\Delta i_{L_1}}{(1-D)T} = \frac{V_{in} - V_o}{2L_1}$$

$$\frac{\Delta i_{L_2}}{dt} = \frac{\Delta i_{L_2}}{(1-D)T} = \frac{V_{in} - V_o}{2L_2}$$

Solving for Δi_L

$$\left(\Delta i_{L_1}\right)_{open} = \frac{(V_{in}- V_O)(1-D)T}{2L_1} \qquad (4.10)$$

$$\left(\Delta i_{L_2}\right)_{open} = \frac{(V_{in}- V_O)(1-D)T}{2L_2} \qquad (4.11)$$

For steady state operation, net change in inductor current must be zero

$$\left(\Delta i_{L_1}\right)_{closed} + \left(\Delta i_{L_1}\right)_{open} = 0 \qquad (4.12)$$

$$\frac{V_{in}DT}{L_1} + \frac{(V_{in} - V_o)(1-D)T}{2L_1} = 0$$

On solving the above expression

$$\frac{V_O}{V_{in}} = \frac{1+D}{1-D} \qquad (4.13)$$

On solving by other inductor current equation results will be same. Also average inductor voltage must be zero. Thus,

$$V_L \ = V_{in}DT \ + \ \frac{(V_{in} - V_o)(1-D)T}{2} = 0 \qquad (4.14)$$

This will also yield the same expression for voltage gain.

Eq. 4.13 shows if switch is always open and D is zero, the output voltage is same as input. As D is increased, denominator becomes smaller and numerator becomes larger thus resulting in higher output voltage.

According to Eq. 4.13 as D approaches 1, output voltage goes to infinity. However Eq. 4.13 is based upon the fact that all components are ideal. Real component have losses.

4.3.2 Waveforms

Fig.4.4 represents typical waveforms obtained during operation.

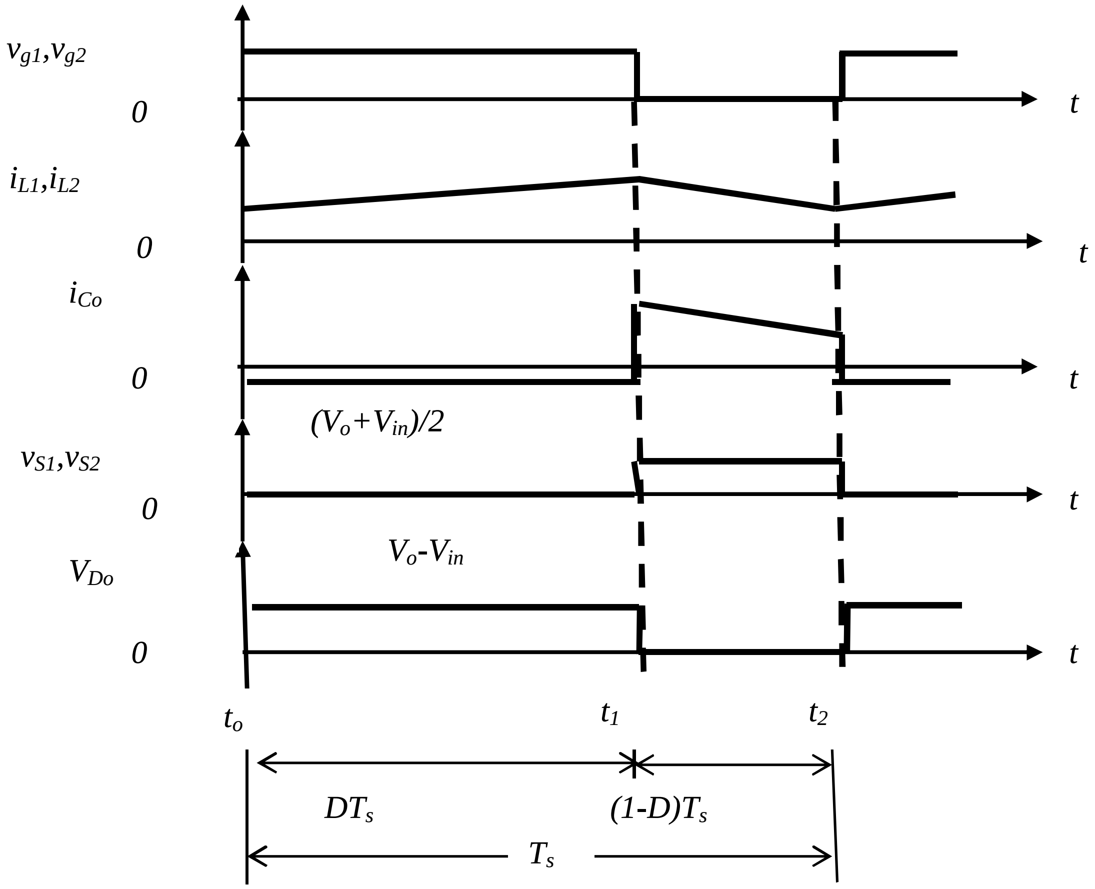


Fig. 4.4 Typical waveform obtained during the operation

4.3.3 Calculation for Parameters

The average current in the inductor is determined by recognizing the average power supplied by the source is equivalent to power absorbed by the load resistor.

$$P_o = \frac{V_o^2}{R} = V_o I_o \qquad (4.15)$$

As input power is $V_{in} I_{in}$ where $I_{in} = I_{L1} + I_{L2}$

Equating input and output powers

$$V_{in} I_{in} = \frac{V_o^2}{R} = \frac{V_{in}^2 (1 + D)^2}{(1 - D)^2 R}$$

$$I_{in} = \frac{V_o^2}{R} = \frac{V_{in} (1 + D)^2}{(1 - D)^2 R}$$

As $L_1 = L_2 = L$

$$I_{L1} + I_{L2} = 2I_L$$

$$2I_L = \frac{V_{in} (1 + D)^2}{(1 - D)^2 R}$$

$$I_L = \frac{V_{in}(1+D)^2}{2(1-D)^2 R} \qquad (4.16)$$

Maximum and Minimum inductor currents are determined by using average value and change in current

$$I_{L_{max}} = I_L + \frac{\Delta i_L}{2} = \frac{V_{in}(1+D)^2}{2(1-D)^2 R} + \frac{V_{in} DT}{2L} \qquad (4.17)$$

$$I_{L_{min}} = I_L - \frac{\Delta i_L}{2} = \frac{V_{in}(1+D)^2}{2(1-D)^2 R} - \frac{V_{in} DT}{2L} \qquad (4.18)$$

Eq. 4.13 was developed with assumption that inductor current is continuous and for that $I_{L_{min}}$ should be positive thus

$$I_{L_{min}} = I_L - \frac{\Delta i_L}{2} = \frac{V_{in}(1+D)^2}{2(1-D)^2 R} - \frac{V_{in} DT}{2L} = 0 \qquad (4.19)$$

On solving the above expression

$$\frac{(1+D)^2}{(1-D)^2 R} = \frac{DT}{L} = \frac{D}{Lf}$$

The minimum combination

$$(Lf)_{min} = \frac{(1-D)^2 R}{(1+D)^2}$$

$$L_{min} = \frac{(1-D)^2 R}{(1+D)^2 f} \qquad (4.20)$$

A high gain boost converter designed for continuous current operation will have an inductance value greater than L_{min}.

$$L_1 or\ L_2 = \frac{V_{in} DT}{\Delta i_L} = \frac{V_{in} D}{\Delta i_L f} \qquad (4.21)$$

4.3.4 Output Voltage Ripple: -

All the above equations were developed on assumption that output voltage is constant implying an infinite capacitance. In practice, a finite capacitance will result in some fluctuation in output voltage or ripple.

The peak to peak output voltage ripple can be calculated from capacitor current waveform. Change in capacitor charge can be calculated from

$$|\Delta Q| = \left(\frac{V_o}{R}\right) DT = C \Delta V_o \qquad (4.22)$$

An expression for ripple voltage

$$\Delta V_o = \frac{V_o DT}{RC} = \frac{V_o D}{RCf}$$

$$\frac{\Delta V_o}{V_o} = \frac{D}{RCf}$$

Where f is the switching frequency in terms of output voltage yields

$$C = \frac{D}{R\left(\Delta V_o / V_o\right)f} \tag{4.23}$$

4.3.5 Voltage Stress on Switches:-

The voltage stresses on S_1, S_2 and D_o are derived as

$$\begin{cases} V_{S1} = V_{S2} = \frac{V_o+V_{in}}{2} \\ V_{D_o} = V_o + V_{in} \end{cases} \tag{4.24}$$

4.4 CASCADED HIGH GAIN BOOST CONVERTER (CHGBC)

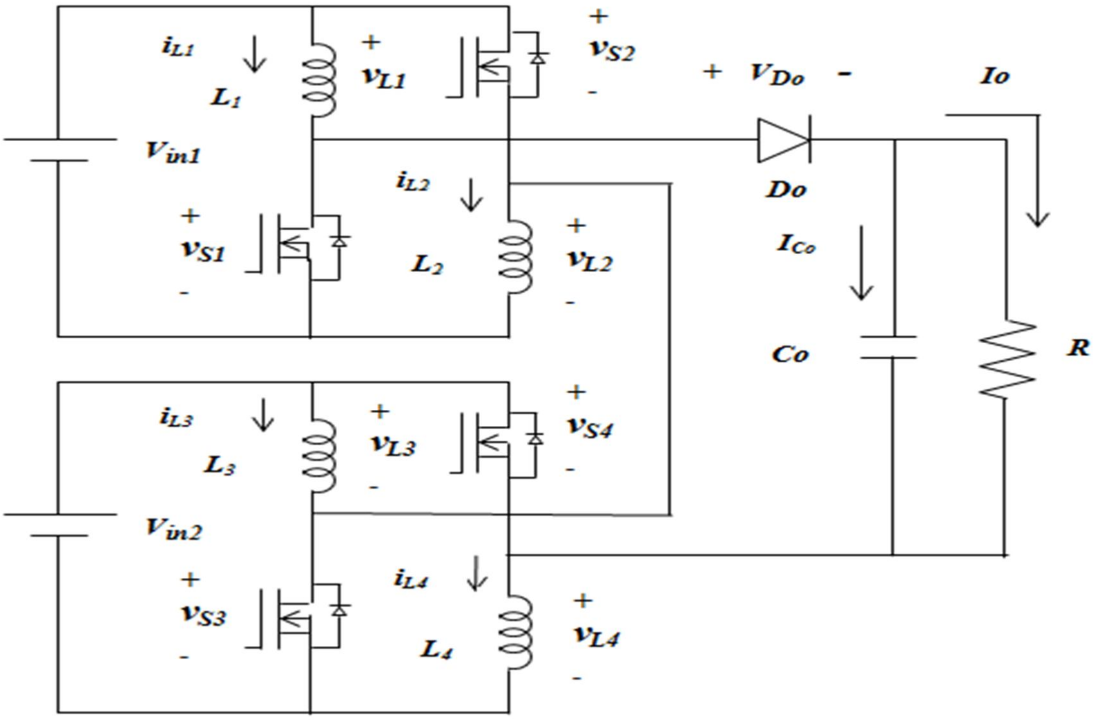
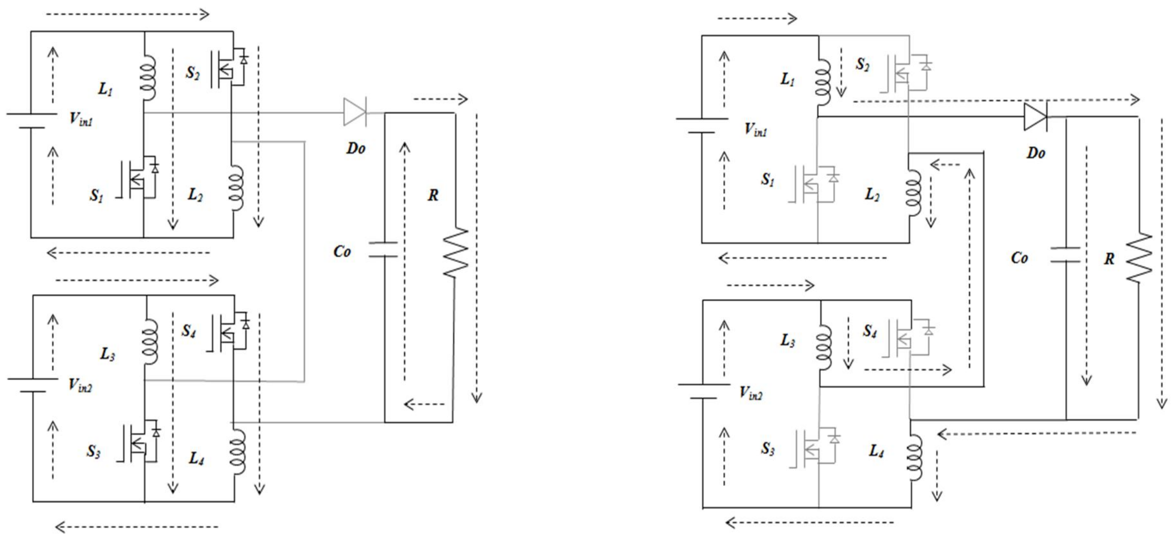


Fig. 4.5 Cascaded Operation of Non-Isolated High Gain DC-DC Converter

This cascaded topology is used where there are two isolated inputs and single system output is needed. These circuits can be integrated with PV module for rooftop PV applications to their small size. Various modes of operation when used in cascaded form in continuous conduction mode are shown in Fig.4.6:-



(a) (b)

Fig 4.6 Modes of Operation: - (a) When switch is closed; (b) when switch is open

1) *Mode 1 [t_0,t_1]* - Fig. 4.6(a) shows operation during interval (t_0,t_1)in which S_1, S_2, S_3 and S_4 switches are ON thus pair of inductors are charged in parallel and energy stored in C_o is released to load.

$$\left.\begin{aligned} v_{L1} = v_{L2} &= V_{in1} \\ v_{L3} = v_{L4} &= V_{in2} \end{aligned}\right\} \tag{4.25}$$

2) *Mode 2 [t_1,t_2]* - Fig 4.6 (b) shows interval (t_1,t_2) in which S_1, S_2, S_3 and S_4 are OFF thus pair of inductors are series connected to transfer energies to C_o and the load.

$$\left.\begin{aligned} v_{L1} = v_{L2} &= \frac{V_{in1}-V_{o1}}{2} \\ v_{L3} = v_{L4} &= \frac{V_{in2}-V_{o2}}{2} \end{aligned}\right\} \tag{4.26}$$

$$V_{out} = V_{o1} + V_{o2} \tag{4.27}$$

By using volt-second balance principle on L_1 and L_2, following equation can be obtained:

$$\left.\begin{aligned} \int_0^{DT_s} V_{in1}dt + \int_{DT_s}^{T_s} \frac{V_{in1}-V_{o1}}{2} dt &= 0 \\ \int_0^{DT_s} V_{in2}dt + \int_{DT_s}^{T_s} \frac{V_{in2}-V_{o2}}{2} dt &= 0 \end{aligned}\right\} \tag{4.28}$$

By simplifying (4.28), voltage gain is

$$M = \frac{V_{o1}}{V_{in1}} = \frac{V_{o2}}{V_{in2}} = \frac{1+D}{1-D} \tag{4.29}$$

The voltage stresses on S_1, S_2 and D_o are derived as

$$\begin{cases} V_{S1} = V_{S2} = \frac{V_{o1}+V_{in1}}{2} \\ V_{D_{o1}} = V_{o1} + V_{in1} \end{cases} \tag{4.30}$$

$$\begin{cases} V_{S3} = V_{S4} = \frac{V_{o2}+V_{in2}}{2} \\ V_{D_{o2}} = V_{o2} + V_{in2} \end{cases} \tag{4.31}$$

From Fig. 4.7 we can state that there is less ripples in output voltage and current and also stress on active devices like switches is reduced.

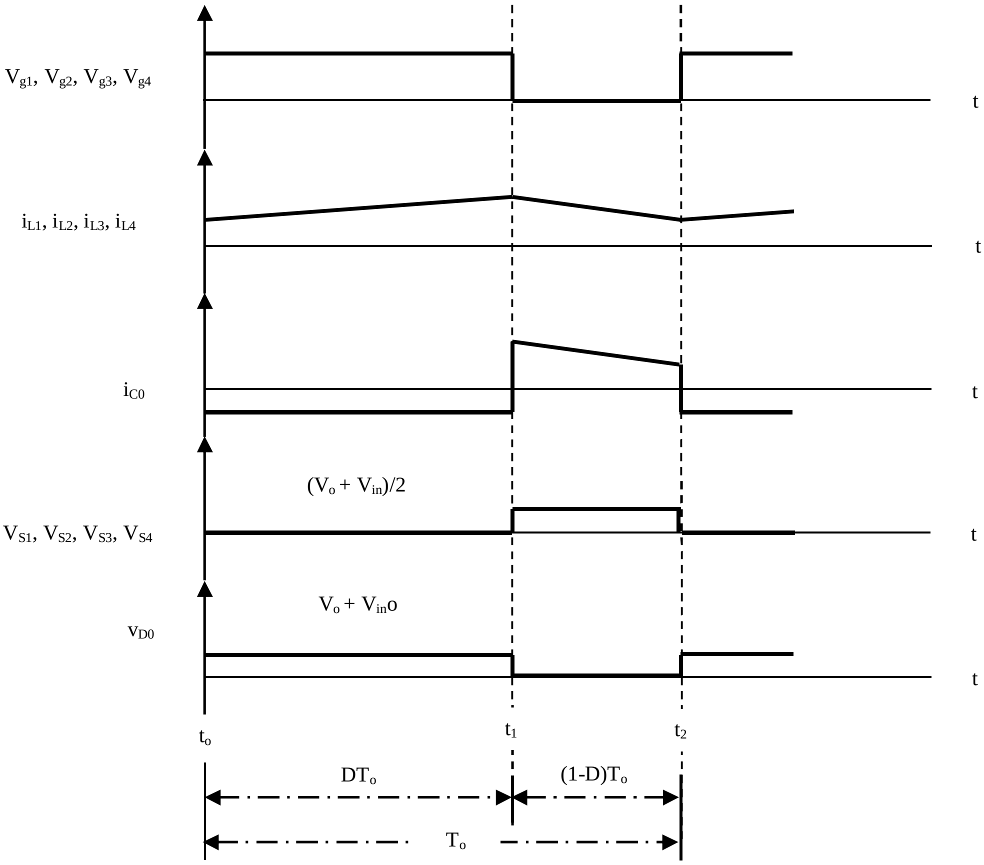


Fig. 4.7: Typical waveform obtained during the operation of CHGBC

4.5 CONCLUSION

Mathematical analysis of high gain boost converter (HGBC) clearly depicts its high gain capability as compared to conventional boost converter. Further the cascaded form may be used to integrate two different sources to supply to a single load.

CHAPTER-5

MATLAB SIMULATION MODEL AND PERFOMANCE EVALUATION

5.1 GENERAL INTRODUCTION:-

A single PV panel is usually about 100W to 300W, and the MPP voltage ranges between 15 to 40 V. These voltage values are low when compared with the required voltage for actual use thus it becomes difficult to harness high efficiency. The difference between low voltage of PV panels and required voltage at input side of the inverter/converter for actual use can be raised by series connection of various PV panel/module. But the generated output power may get decreased due to module mismatch or partial shading, which results in reduction of the system efficiency. Modular power conversion without using a galvanic isolation is a good solution as it is less perturbed with isolation changes or partial shading and thus efficiently transfer power from PV panel to load. Thus, it becomes necessary to investigate non-isolated topologies step-up DC-DC converters as an intermediate stage between the PV modules and their cascade connection to devise a usable voltage level, which can be further used by inverter/converter to cater to the load.

From literature it is evident that various step-up DC-DC converters are available, which can be used for MPPT and stepping up of the voltage for the renewable energy applications, like PV power generation, hybrid systems, telecom applications, hybrid electric vehicles etc. For small PV power generation system, module integrated converter are advocated which can easily be controlled by different MPPT techniques, viz., Incremental Conductance method for maximum power output delivery during intermittent periods. Main advantage of using DC-DC converter as MPPT controller lies in increasing the efficiency of solar power extraction from PV cells/modules and thus making them a competitive solution in the energy market.

Conventionally a boost converter is used to increase the voltage magnitude but its gain is limited due to inductor losses, stress on active power device like power diodes, power switches etc., and switching losses at extreme duty cycle. In this chapter, a simulation studies is carried out for drawing the comparison between Boost Converter and High Gain Boost Converter (HGBC) and Cascaded High Gain Boost Converter (CHGBC). Simulation studies are carried out for two topologies where, either as double stage conversion is done and the other one where as single stage conversion is made for islanded and grid connected applications. Two isolated PV Modules are integrated through CHGBC via separate MPPT charge controller in the two stage conversion, where MPPT charge controller acts as an interfacing unit between HGBC and PV module, and output voltage is controlled using a PI controller executing a double stage conversion. Whereas, for Single-Stage Conversion PV module in an integrated system employ HGBC to deliver as an MPPT controller. To cater with power intermittency problems due to insolation variation or partial shading, battery is used as a storage element which absorbs or supply power otherwise a load controller may be employed to provide power matching in an isolated operation. Both the topologies amidst insolation change and load perturbations are considered and their control is verified through results obtained under MATLAB/Simulink environment.

5.2 COMPARATIVE PERFORMANCE EVALUATION OF BOOST CONVERTER AND HIGH GAIN BOOST CONVERTER (HGBC): -

Comparative performance evaluation of Boost converter and HGBC is initially done to discuss about the relative advantages of HGBC over Boost Converter. For carrying out the relative performance evaluation same value of duty cycle (D) is considered which clearly brings out the differences in voltage gain obtained from the two topologies. Based on both mathematical analysis and simulation studies considering parameters, shown in Table 5.1 and Table 5.2, a considering same value of duty cycle which clearly shows the advantages of HGBC over Boost converter. The initial analysis is carried out considering constant voltage DC source to provide the field for comparative evaluation.

5.2.1 Parameter Selection of Boost Converter: -

Boost converter is the conventional topology used for MPPT controller for photovoltaic energy conversion as PV panel has low output voltage and high current. For carrying out the performance evaluation various parameters that are used are given in Table 5.1. Fig. 5.1 shows the simulation model for simulation done under MATLAB/Simulink environment.

S. No.	Parameter	Value
1.	Input Voltage (Vi)	26 V
2.	Inductor Value (L)	200 µH
3.	Output Capacitor (C_o)	68 µF
4.	Duty Cycle (D)	40%
5.	Switching Frequency (f)	50 kHz
6.	Load Resistance (R_L)	50 Ω

Table 5.1: System Parameter for Analysis of Boost Converter

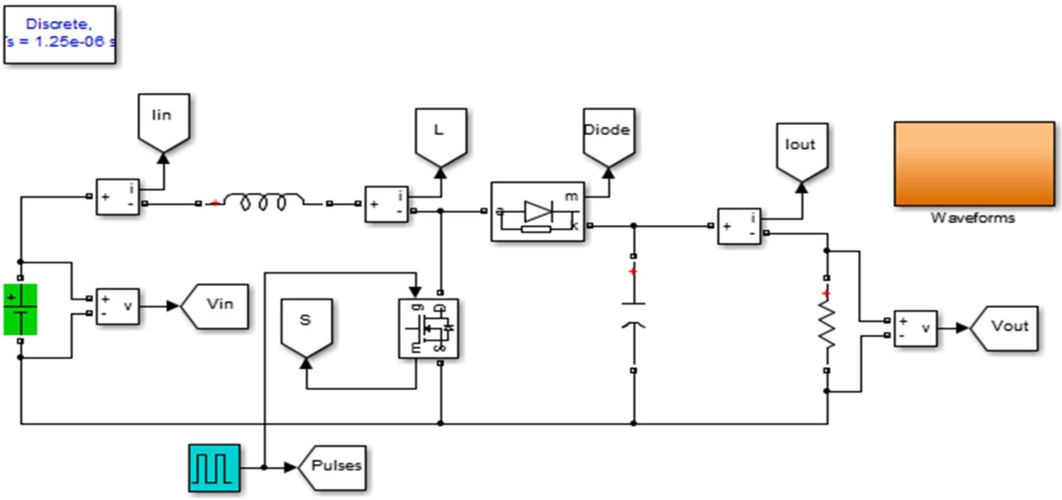


Fig. 5.1: Simulation Diagram for Boost converter

5.2.1.1 Performance Evaluation of Boost Converter:-

Boost Converter voltage gain can be expressed through:

$$\frac{V_o}{V_i} = \frac{1}{1-D} \quad (1)$$

where,

V_o = Output Voltage

V_i = Input Voltage

D = Duty Cycle

As per the calculation, the voltage gain for duty cycle of 40% is 1.67. Thus for input voltage of 26 V, we get 43.42 V as output.

Fig. 5.2 shows the steady state current and voltage on the input side of the boost converter. It may be seen that for a constant DC source of voltage 26 V an output of 42.43 is obtained (shown in fig. 5.5). Fig. 5.3 shows the magnified waveform from instants t = 0.9995 sec to t = 1.0005 sec, where it may be seen that a current ripple of around 0.5 A exist over an average of 1.5 A.

Fig. 5.5 shows the magnified waveform of output voltage and current from instants t = 0.9995 sec to t = 1.0005 sec, where current ripple have been reduced to 0.001 A for an average of 0.848 A, and voltage ripple of 0.05 V over an average of 42.43 V is observed.

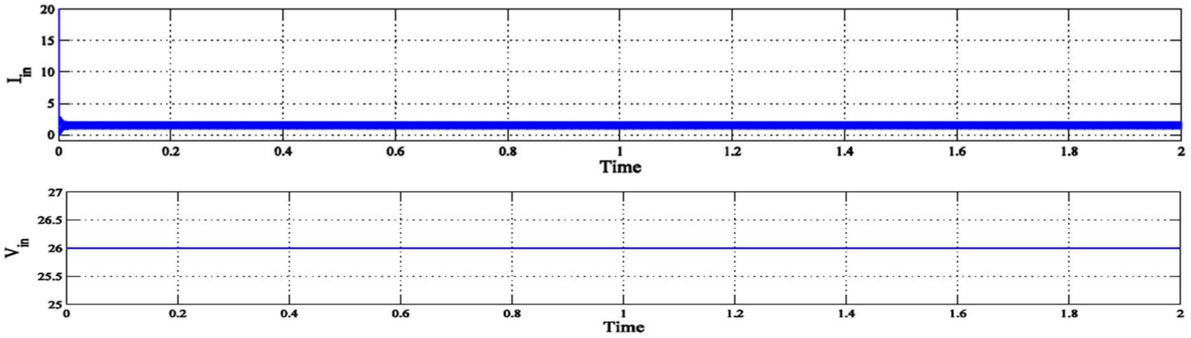


Fig. 5.2: Steady State Input Current and Voltage of Boost Converter

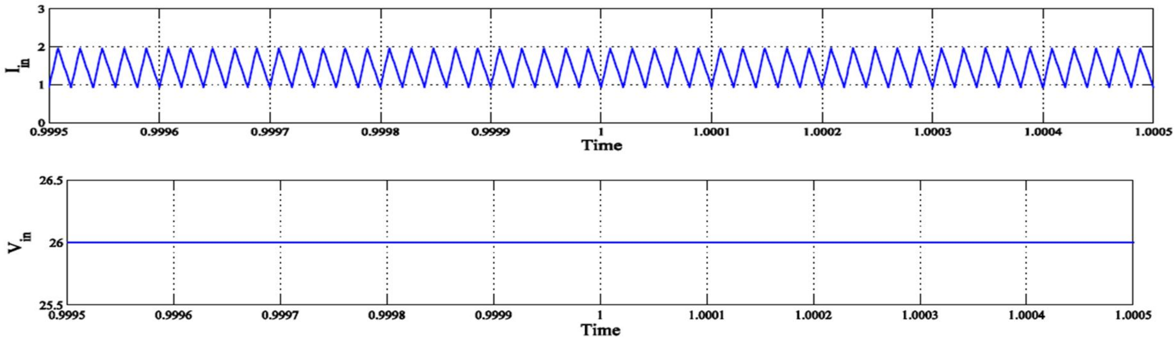


Fig. 5.3: Zoomed Steady State Input Current and Voltage of Boost Converter from t = 0.9995 sec to t = 1.0005 sec

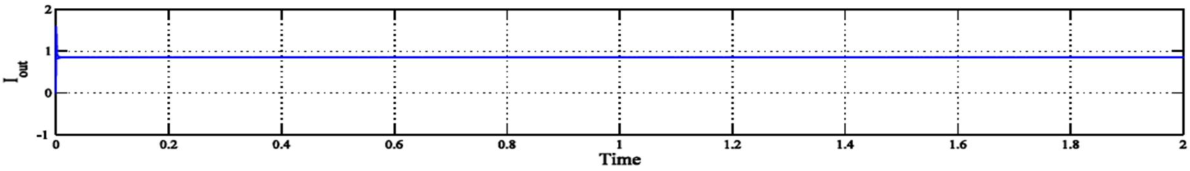


Fig. 5.4: Steady State Output Waveform of Boost Converter from t = 0 to t = 2 sec.

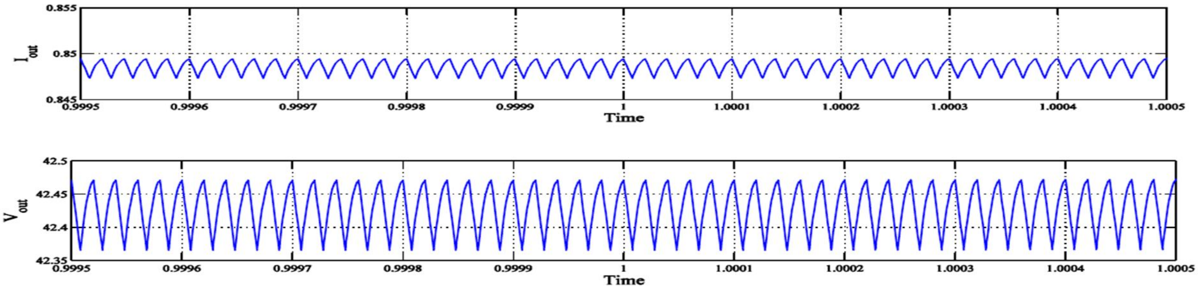


Fig. 5.5: Magnified Steady State Output Waveform of Boost Converter from t = 0.9995 sec to t = 1.0005 sec.

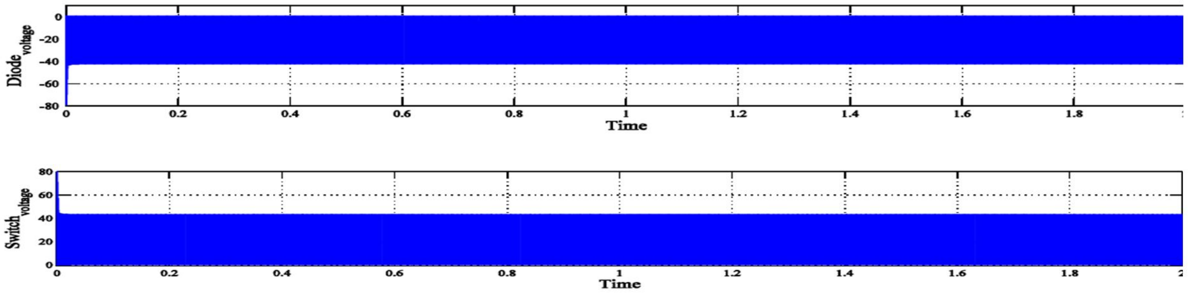


Fig. 5.6: Steady State Voltage across the Diode and MOSFET Switch of Boost Converter from t = 0 to t = 2 sec.

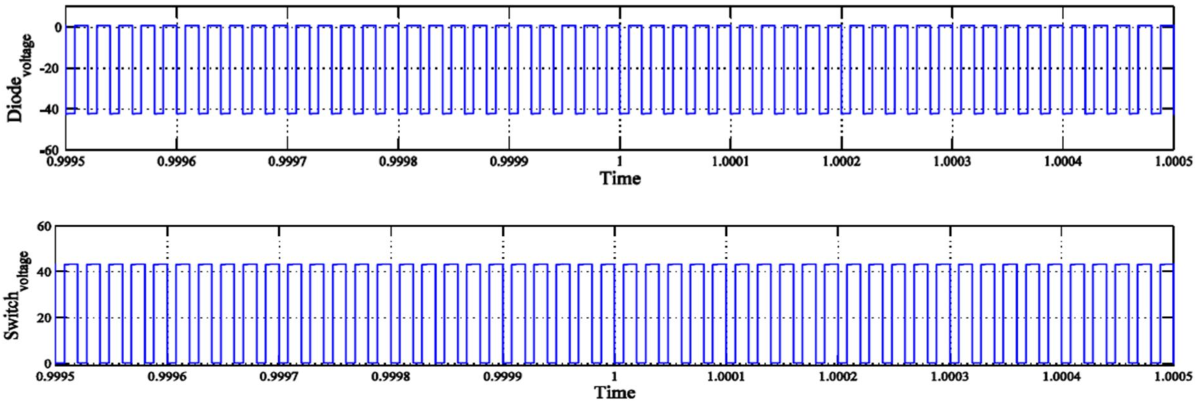


Fig. 5.7: Magnified Steady State Voltage across the Diode and MOSFET Switch of Boost Converter from t = 0.9995 sec to t = 1.0005 sec.

Increasing the D, voltage can be boosted to a higher level, but it causes voltage stress on active devices. Voltage stress on power switches and power diodes at a voltage gain of 1.67 (D = 0.4) is shown in Fig 5.6 and the magnified waveform are shown in figure 5.7.

5.2.2 Parameter Selection of HGBC:-

HGBC is a transformerless high gain boost converter which gives a high voltage gain at a small duty cycle. A pair of switches are switched ON for charging the pair of inductors and when switched OFF the circuit connects them in cascade thereby high gain at the output. For performance evaluation various parameters are shown in Table 5.2 are considered. Fig. 5.8 shows the simulation model under MATLAB/Simulink environment.

S. No.	Parameter	Value
1.	Input Voltage	26 V
2.	Inductor Value (L_1 or L_2)	200 µH
3.	Output Capacitor (C_o)	68 µF
4.	Duty Cycle (D)	40%
5.	Switching Frequency (f)	50 kHz
6.	Load Resistance (R_L)	50 Ω

Table 5.2: System Parameter for Performance Evaluation of HGBC

5.2.2.1 Performance Evaluation of HGBC:-

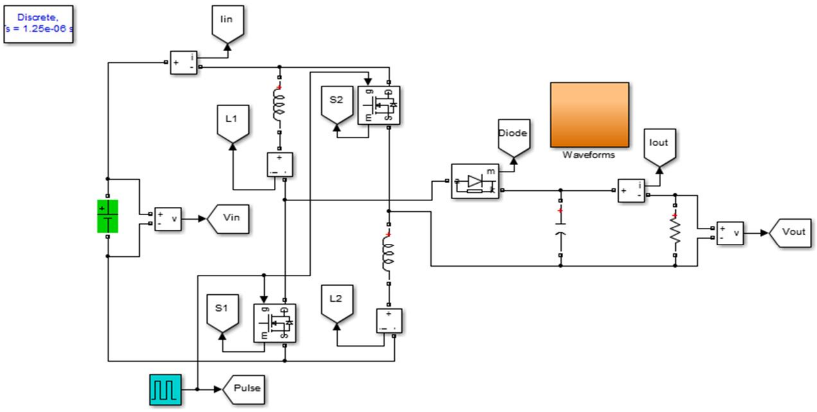


Fig. 5.8: MATLAB Simulation Diagram for HGBC

HGBC, voltage gain can be given by the eq.:

$$\frac{V_o}{V_i} = \frac{1+D}{1-D} \tag{1}$$

Where V_o = output voltage

V_i = input voltage

D= Duty Cycle

As per the calculation, the voltage gain for duty cycle of 40% is 2.33. Thus for input voltage of 26 V, we get 60.58 V as output.

Fig.5.9 shows the steady state current and voltage on the input side of the HGBC.it may be seen that for a constant DC source of voltage 26 V an output of 59.58 V is obtained (shown in Fig. 5.14). Fig. 5.10 shows the magnified waveform from the instants t = 0.9995 s to t = 1.0005 that a current ripple of 2 A exist over an average of 4 A .

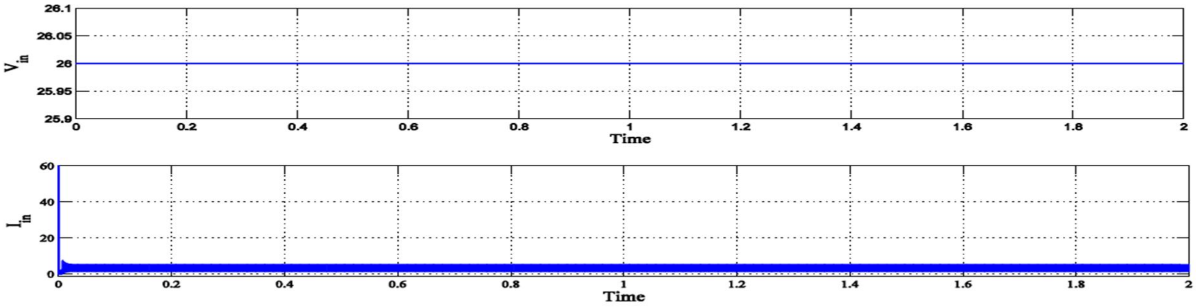


Fig. 5.9 Steady State Input Voltage and Current of HGBC

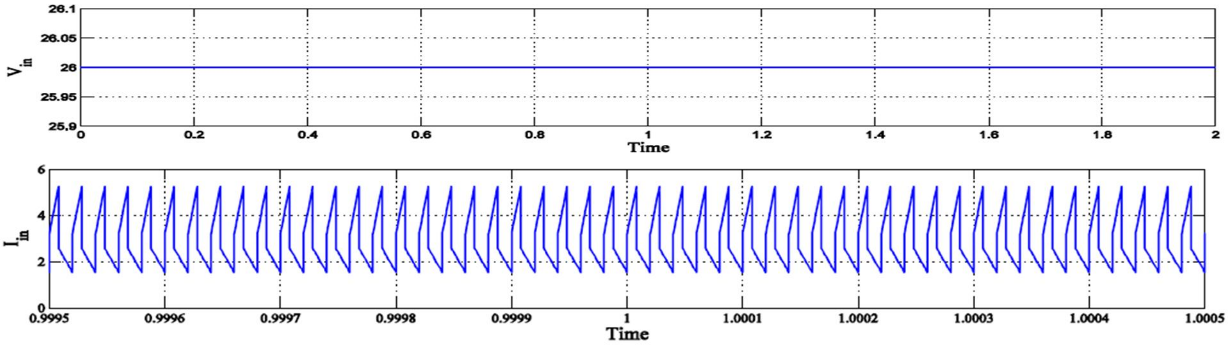


Fig. 5.10 Zoomed Steady State Input voltage and current of HGBC from t = 0.9995 sec to t= 1.0005 sec

Current through inductors is shown in the Fig.5.11 and its magnified form from t = 0.9995 s to t = 1.0005 s is shown in Fig. 5.12.

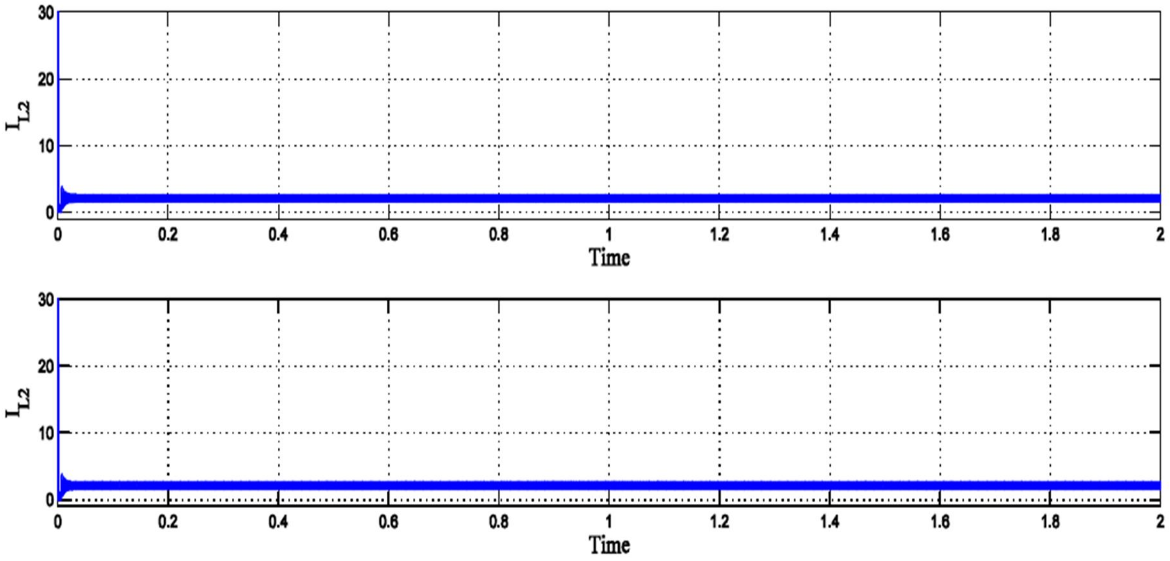


Fig. 5.11 Current waveform through inductors from t = 0 sec to t= 2 sec

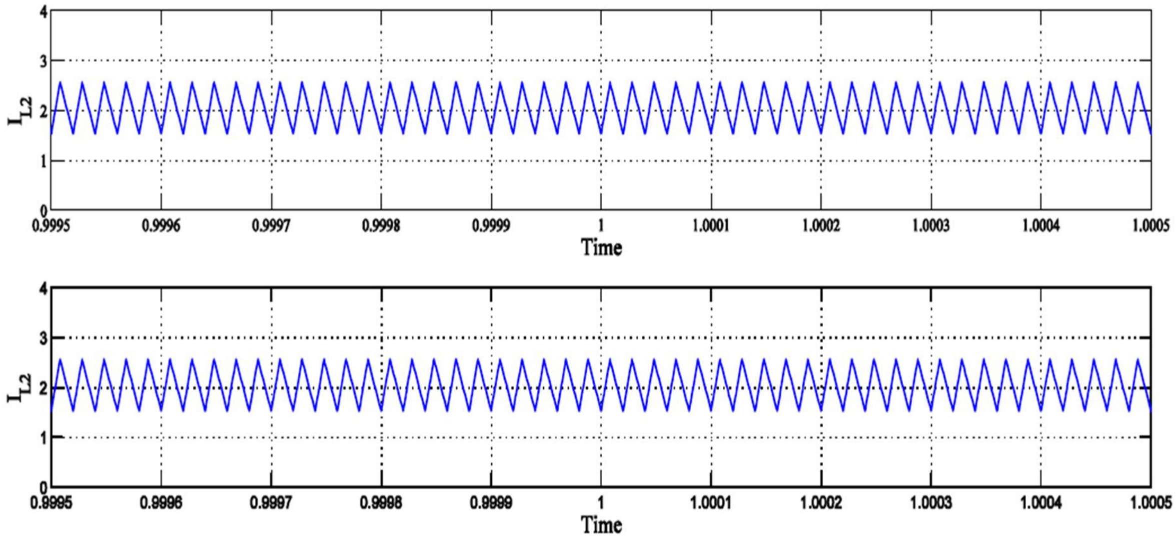


Fig. 5.12 Zoomed Current waveform through inductors from t = 0.9995 sec to t= 1.0005 sec

Fig. 5.14 shows the magnified waveform of output voltage and current from instants t = 0.9995 sec to t = 1.0005 sec, where output current ripple have been reduced to 0.001 A for an average of 1.19 A, and voltage ripple of 0.05 V over an average of 59.58 V is observed.

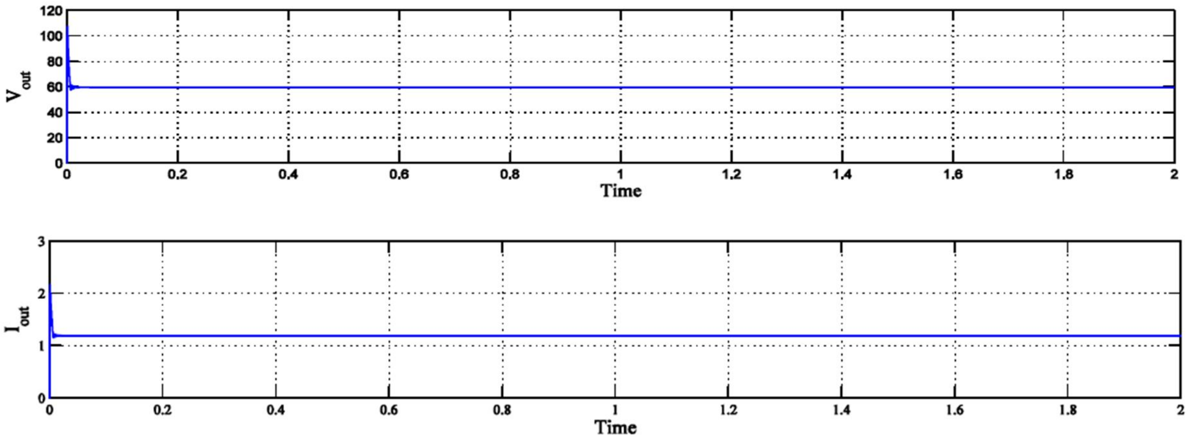


Fig. 5.13 Steady State Output waveform of HGBC

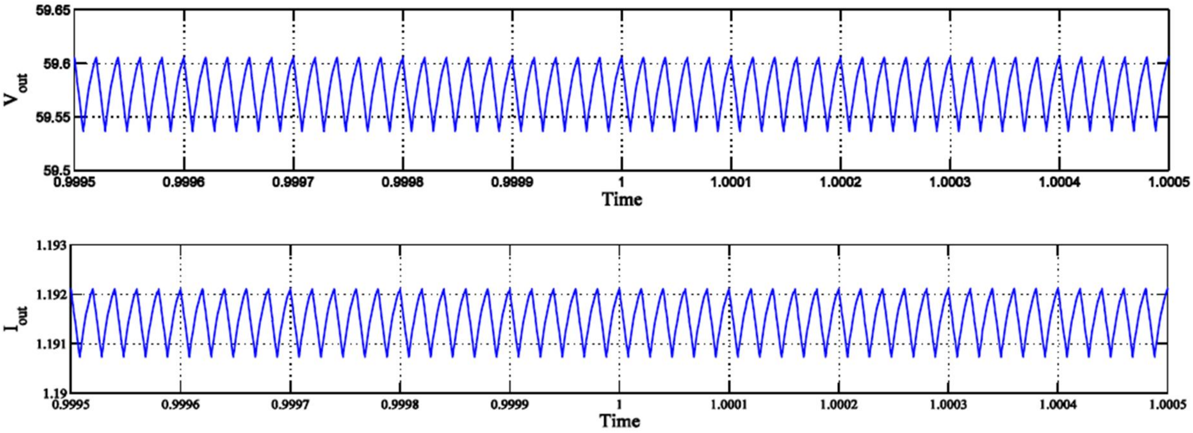


Fig. 5.14 Magnified Steady State Output Waveform of HGBC from t = 0.9995 to t= 1.0005s

It may be observed from the performance evaluation of Boost Converter and HGBC that even at a small duty cycle of 0.4, a gain of 2.3 can be obtained by HGBC whereas conventional boost converter can provide only a gain of 1.67.

As duty Cycle (D) is appreciably small thus there is lesser voltage stress on active power devices like power diodes, power switches etc. Voltage stress on power switches and power diodes when D is 0.4 is shown in Fig.5.15 and its magnified waveform is shown in Fig. 5.16. It may be observed that voltage stress for active devices remaining same for even higher gain of HGBC as compared to Boost Converter, i.e., independent of gain but depends on the duty cycle, whereas the voltage stress on diode increases with gain marginally for HGBC when compared with boost converter.

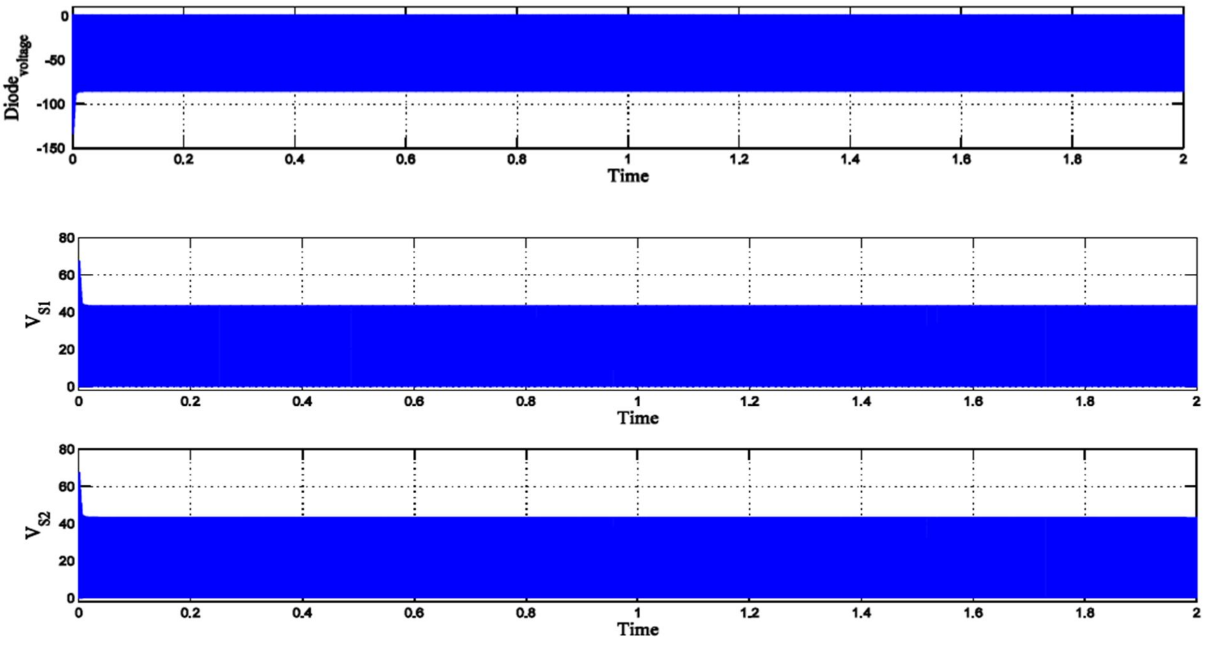


Fig. 5.15Voltage Stress on Diode and MOSFETs from t = 0 sec to t= 2 sec

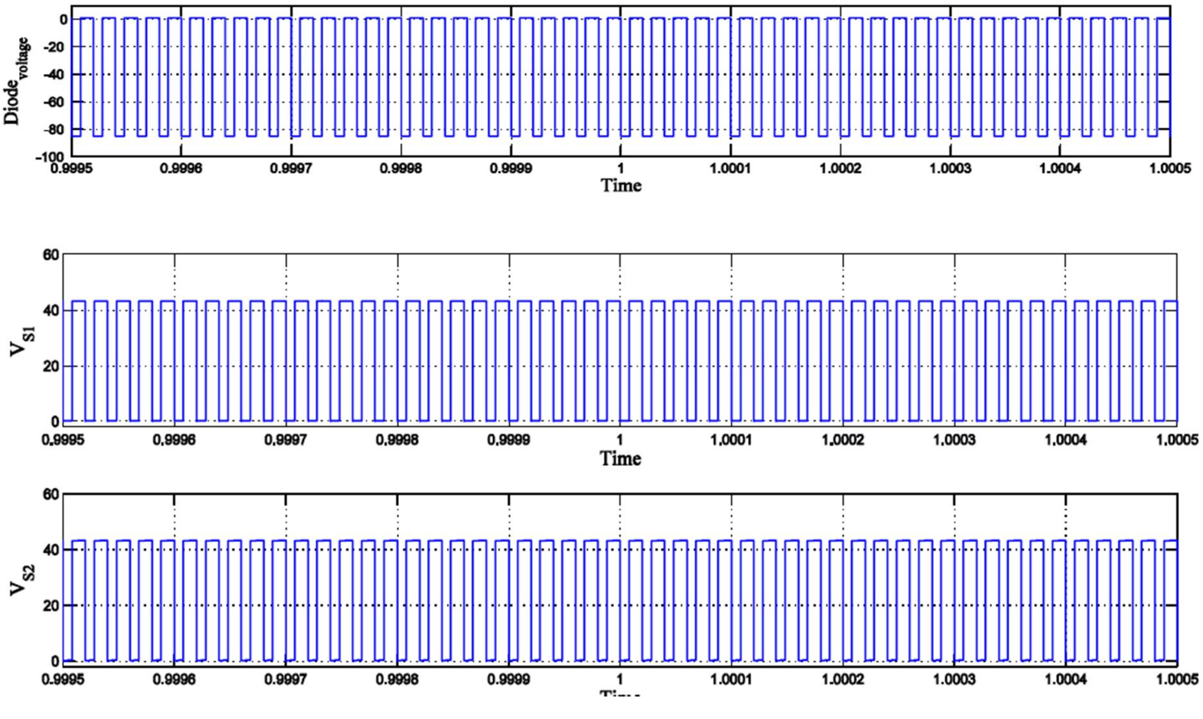


Fig. 5.16 Zoomed waveform of Voltage Stress on Diode and MOSFETs from t = 0.9995 sec to t= 1.0005 sec

5.2.3 Comparison of Boost Converter and High Gain Boost Converter (HGBC): -

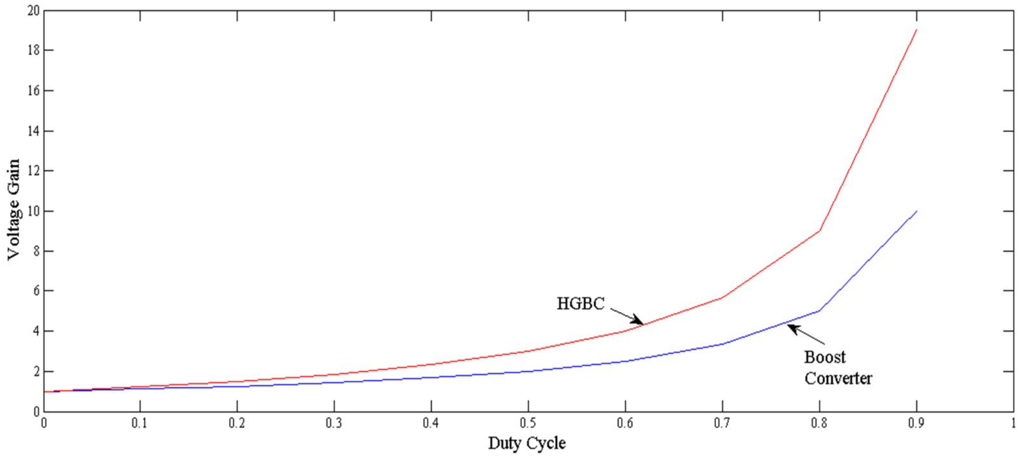


Fig. 5.17 Voltage Gain versus Duty Cycle

Fig. 5.17 shows the comparison of two converters based on the voltage gain. From above, we can conclude that the voltage gain is varied with respect to duty cycle.

In Table 5.3 all the parameters for comparison is represented with results which is perceived during analysis of the two converters.

S. No.	Parameter for Comparison	Boost Converter	High Gain Boost Converter (HGBC)
1.	Voltage Gain	$M = \frac{V_o}{V_i} = \frac{1}{1-D}$ For D = 0.4, M =1.67	$M = \frac{V_o}{V_i} = \frac{1+D}{1-D}$ For D = 0.4, M = 2.33
2.	Efficiency	Lesser efficient	More efficient
3.	Voltage Stress	On higher duty cycle more stress on active power device	Give high gain output even on lower duty cycle, hence lower voltage stresses for same gain
4.	Output Current Ripple	More	Less
5.	Stability	Become Unstable when D is increased for high voltage gain	Stable for higher gain as even for high gain D is not much increased

Table 5.3 Performance Comparison between HGBC and Boost Converter

5.3 CHGBC FOR PV APPLICATION USING DOUBLE – STAGE POWER CONVERSION: -

CHGBC is integrated with two isolated PV Panels via two separate MPPT charge controller. MPPT charge controller works as an interfacing circuit between the PV Panel output and the HGBC converter system to ensure maximum power evacuation from PV Panel by using current controlled InC MPPT technique. Basic block diagram of the system is shown in Fig. 5.18

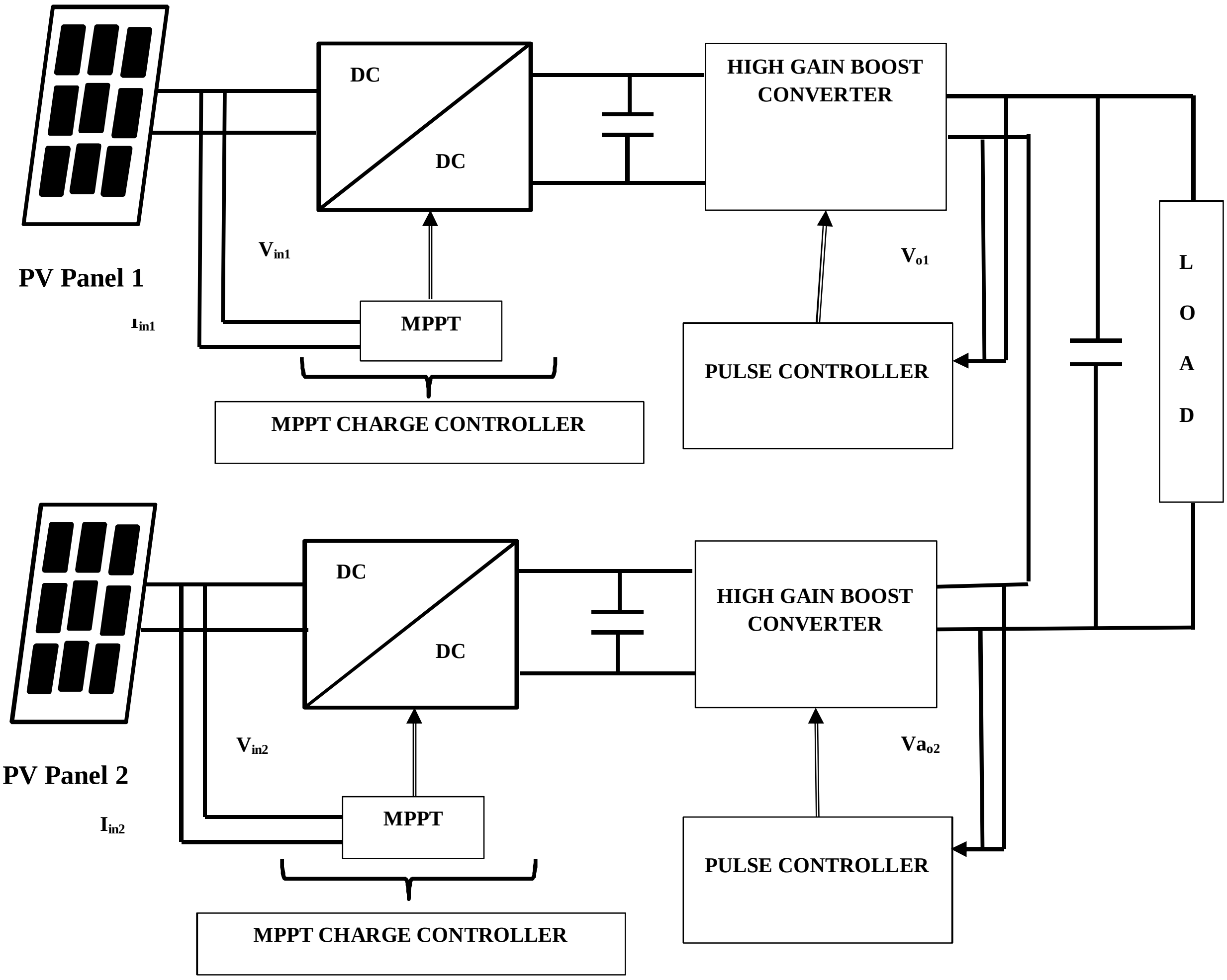


Fig.5.18 Block diagram showing system configuration for simulation

Performance of this system is evaluated under the MATLAB/Simulink environment for the constant insolation

MATLAB Simulation model for cascaded system for two isolated PV system is shown in Fig. 5.19.

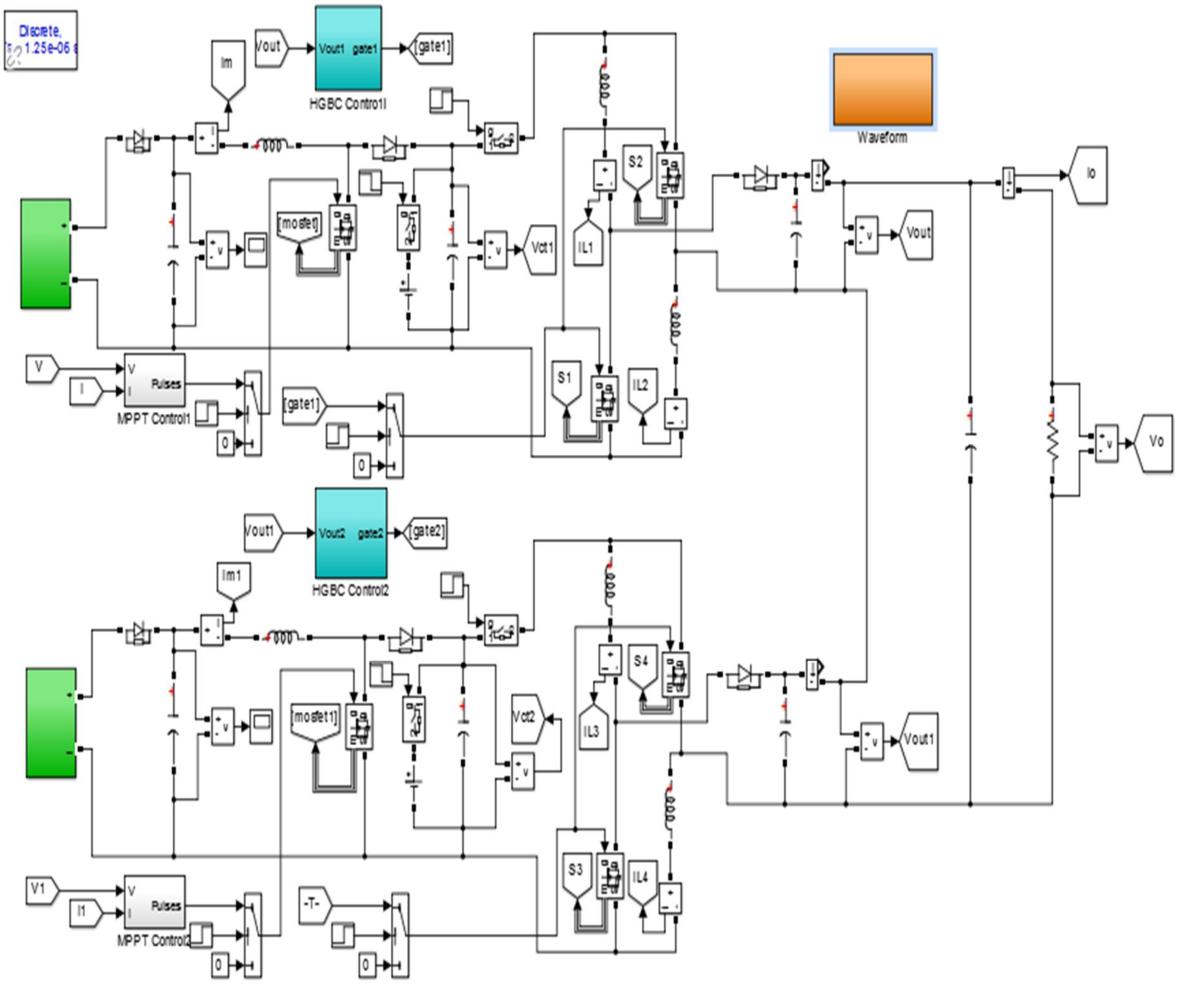


Fig.5.19 MATLAB Simulation for Double stage PV integrated CHGBC

For the considered system, two isolated PV systems having similar I-V and P-V characteristics are used. For simplicity load is considered to be resistive. Also PV Panel is operating at an insolation of 1000 W/m^2 which is shown in Fig. 5.20.

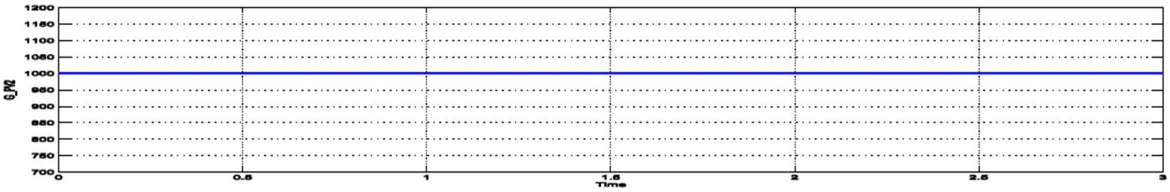


Fig. 5.20 Insolation Level of Two PV systems

In Fig. 5.21 and Fig. 5.22, input from PV Panel-1 is shown which represents that because of MPPT Charge Controller PV Panel is evacuating maximum power at MPP voltage and MPP current.

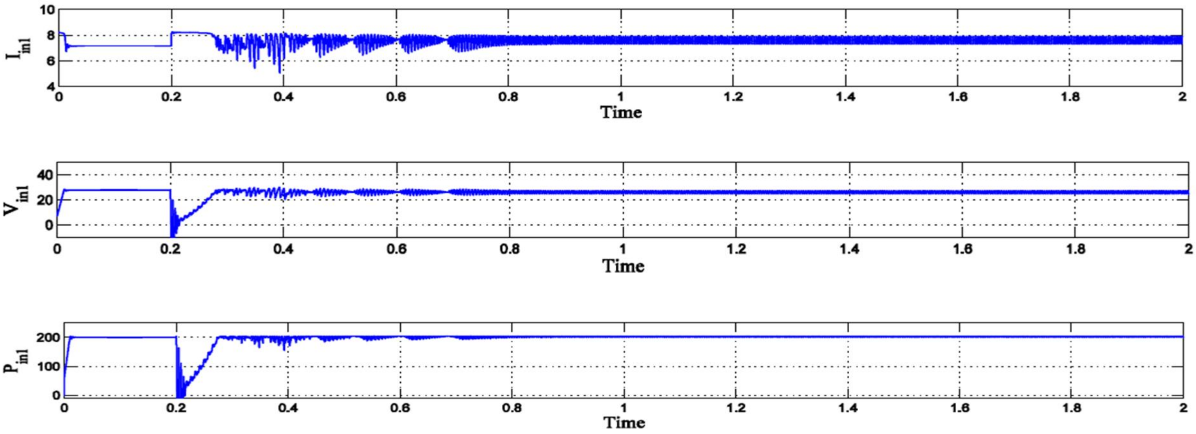


Fig. 5.21 PV Panel-1 Input Waveforms for evaluation of Double Stage CHGBC for PV Application

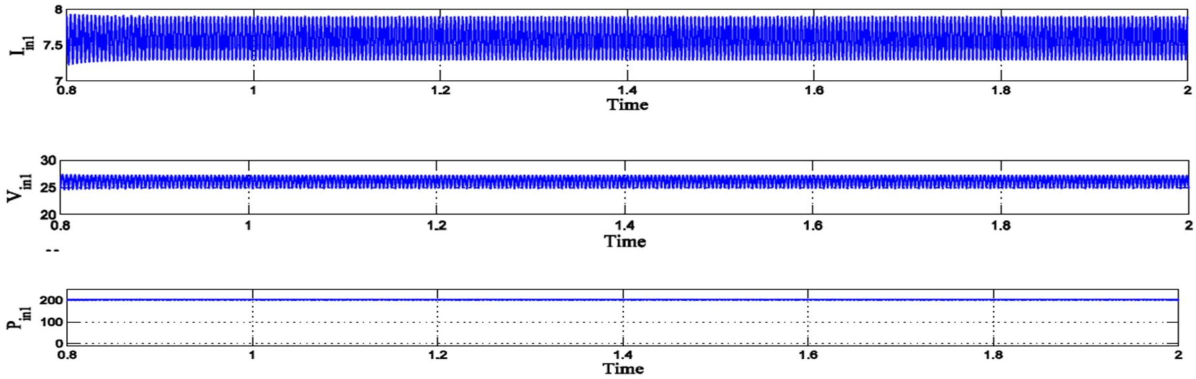


Fig. 5.22 Zoomed PV Panel-1 Input Waveforms for evaluation of Double Stage CHGBC for PV Application from t = 0.8 sec to t= 2sec

Similarly, PV Panel-2 output current and voltage and power from it is shown in Fig. 5.23 and magnified waveform from t = 0.8 to t = 2 s is sown in fig. 5.24.

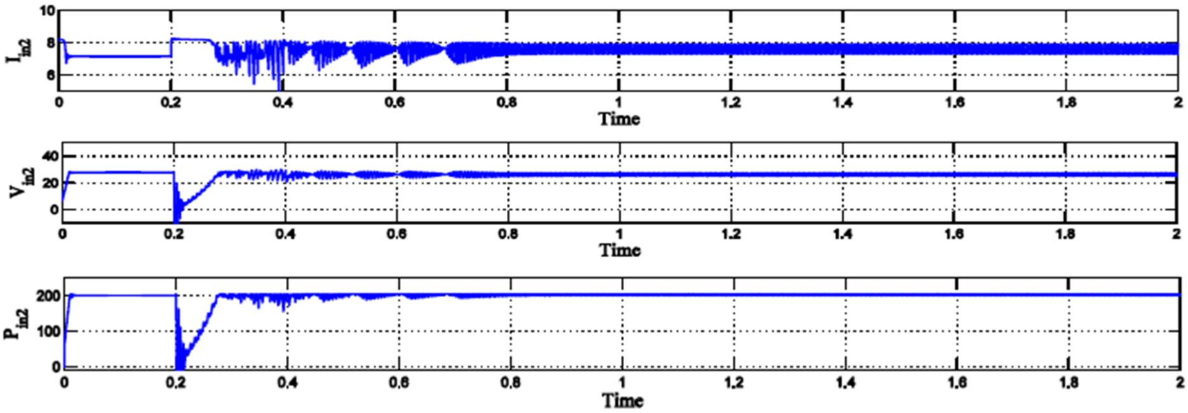


Fig. 5.23 PV Panel-2 Input Waveforms for evaluation of Double Stage CHGBC for PV Application

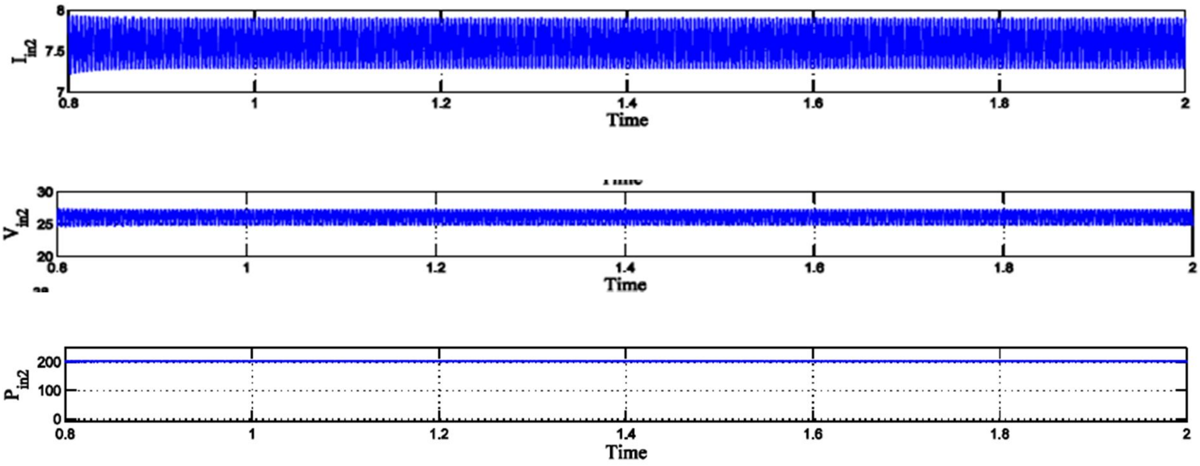


Fig. 5.24 Zoomed PV Panel-2 Input Waveforms for evaluation of Double Stage CHGBC for PV Application from t = 0.8 sec to t = 2 sec

In the Fig. 5.25 voltage at dc-link tank capacitors is shown and its zoomed form from t = 0.8s to t = 2s is shown in Fig. 5.26. Tank capacitor voltage works as an input for HGBC. Switching of HGBC is controlled using PI controller to get desired output voltage for fulfilling the load demand.

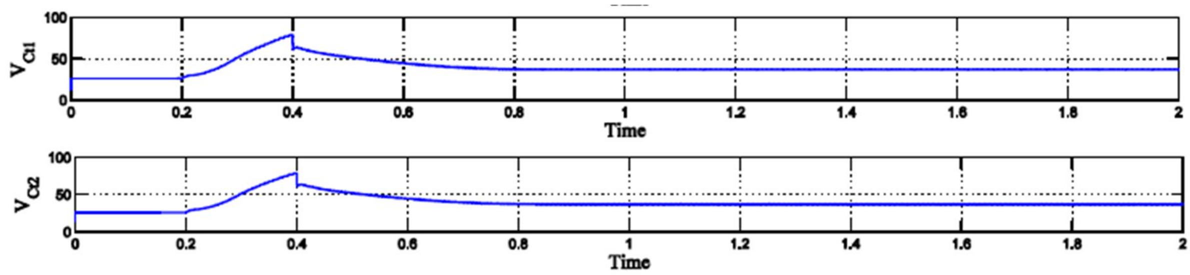


Fig. 5.25 DC Link Tank Capacitor Voltages

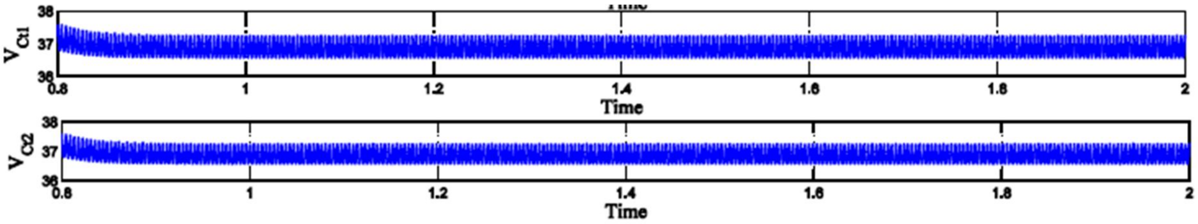


Fig. 5.26 Zoomed DC Link Tank Capacitor Voltages from t = 0.8 sec to t = 2 sec

As we can see from the Fig.5.25 and Fig. 5.26, it is observed that the dc link capacitor voltage is settled at 36.9 V which acts as an input source for CHGBC.

The output boosted voltage and output current from the HGBC is shown in Fig. 5.27.

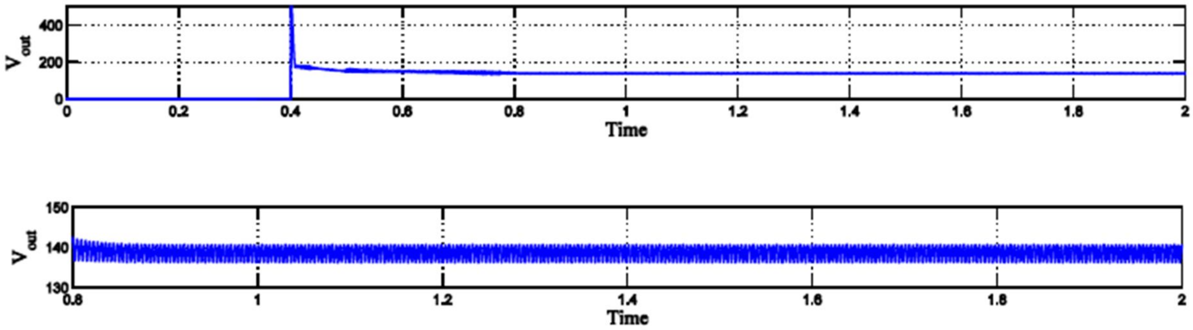


Fig. 5.27 Output Voltage and its Zoomed Waveform

This shows that output voltage is boosted to 140 V which is 2.66 times of the total input voltages from the two PV Panels.

In Fig 5.28, current through the inductors L_1, L_2, L_3 and L_4 are shown. The current from the four inductors is continuous and, charging and discharging of inductor is shown in magnified waveform from t = 0.8 s and t = 2s in Fig. 5.29.

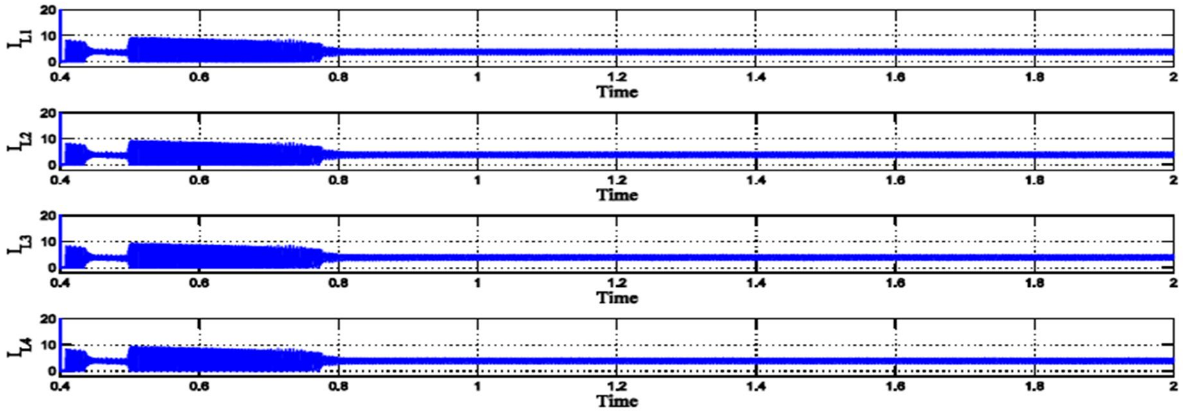


Fig.5.28 Current through Inductors

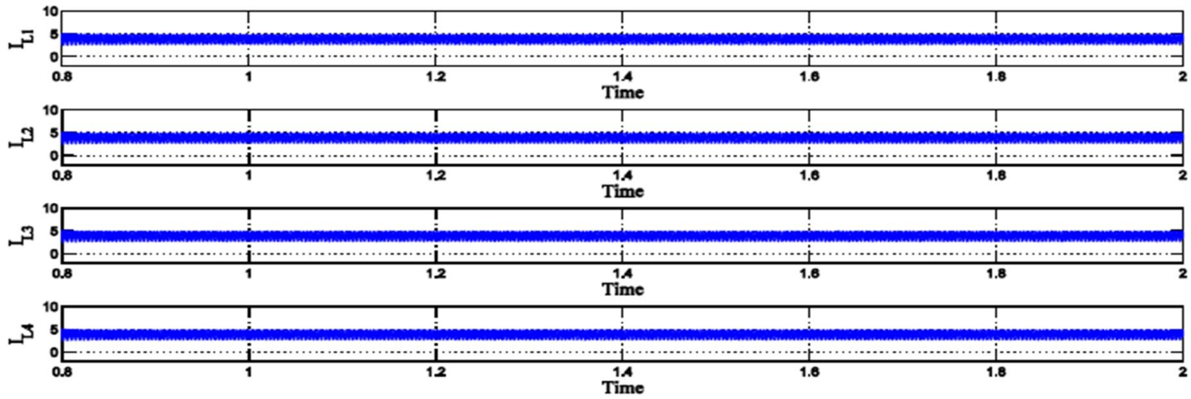


Fig 5.29 Zoomed current waveform through inductors from t = 0.8 sec to t = 2 sec

In Fig. 5.30 and Fig. 5.31, voltage stress on power switches S1, S2, S3 and S4 are shown,

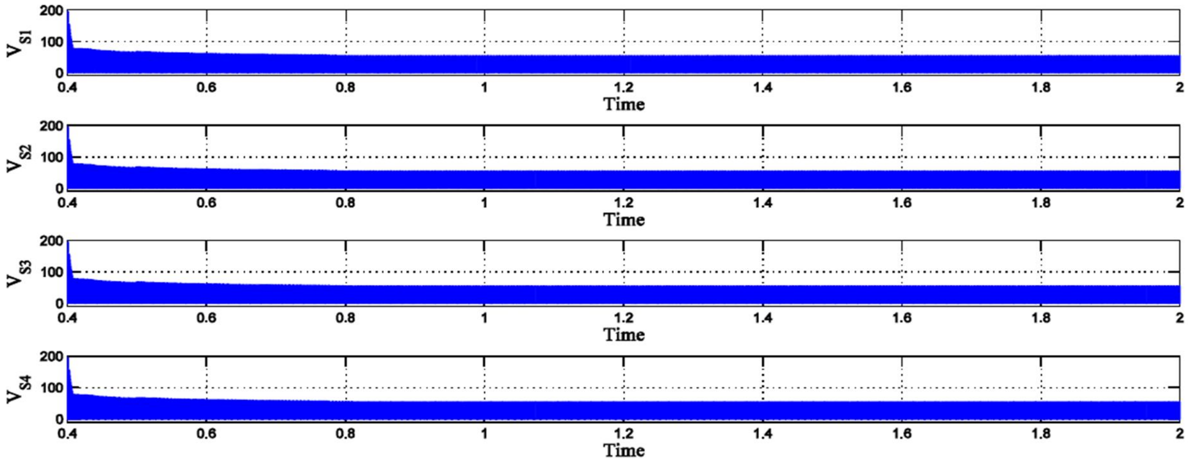


Fig. 5.30 Voltage Stress on Active MOSFET Switches from t = 0.4 sec to t = 2 sec

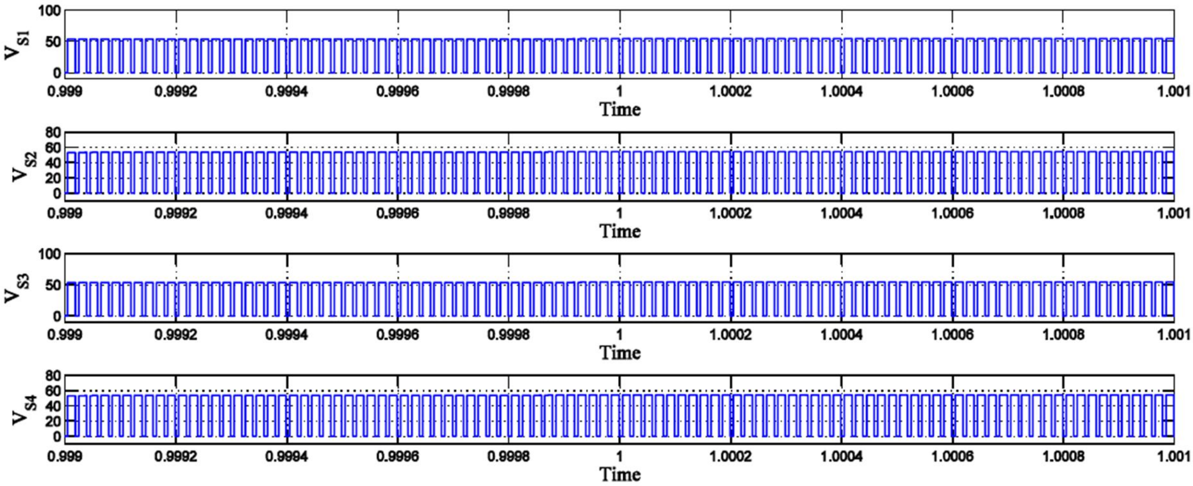


Fig. 5.31 Magnified waveform of Voltage stresses on Active MOSFET switches from t = 0.999s to t = 1.001s

Output power is shown in Fig.5.32. Thus it is observed that output power is 369W. And input power is 400 W.

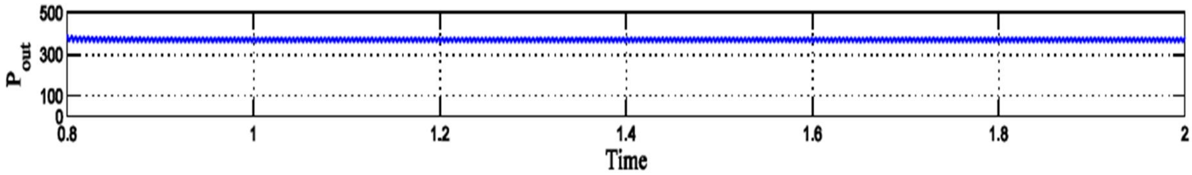


Fig. 5.32 Output Power

Thus efficiency of the overall system = $\eta = \frac{P_{out}}{P_{in}} = \frac{369}{400} \times 100 = 92.25\ \%$

5.4 HARDWARE REDUCTION:-

As a for a PV module integrated cascaded system the CHGBC is integrated with two isolated PV inputs utilizes two DC-DC converters back to back. Boost converter is used as a MPPT charge controller as its switching is controlled by InC MPPT Technique and HGBC is used to boost the output voltage from boost converter to a desired level for fulfilling the load. But this overall system becomes bulky and utilizes many components thus increasing the cost of system. Also overall efficiency of the system is less because of switching losses and various component losses.

Thus come out as a solution to utilize HGBC as MPPT controller. HGBC is integrated with PV module and its switching is controlled by using InC MPPT Technique and two similar modules integrated HGBC is connected in cascade for combining the two input voltage of two isolated PV Module to get a high output voltage. This has resulted in reduction of size of the overall system as complete one stage is eliminated. Also the components used are less thus reducing the cost of the system. Advantages of using CHGBC as MPPT Charge controller for two isolated PV systems: on a low value of D high voltage gain can be obtained, compact and modular structure, reduced cost of the overall system, easy control, and efficiency of the overall system increases.

5.5 CHGBC AS MPPT CONTROLLER FOR SINGLE STAGE CONVERSION FOR PV APPLICATION:-

In this individual HGBC is integrated with PV module and its controlling is done by using InC MPPT technique. Basic schematic diagram of the system is shown in Fig. 5.33.

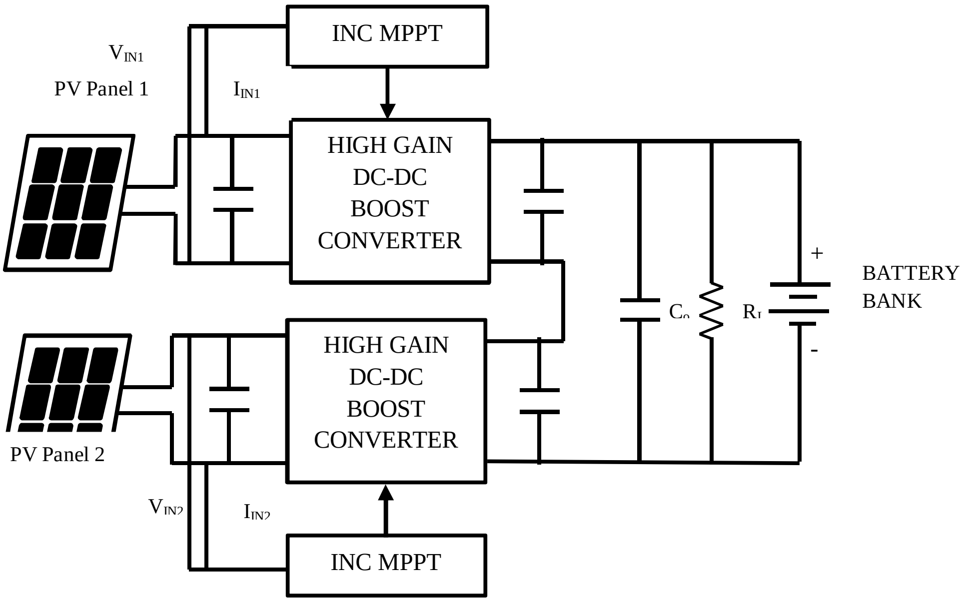


Fig. 5.33 Block diagram showing System Configuration for Simulation of Single Stage Power Conversion

System is simulated under MATLAB/Simulink Environment to analyse that HGBC can be used as MPPT controller. Results are verified using simulation results. Performance of the system is considered under following cases:-

Case 1: Constant Insolation

Fig. 5.34 shows the simulation done to study the integration of PV and CHGBC under constant insolation of 1000 W/m^2 and temperature is considered constant. For simplicity load is considered to be resistive.

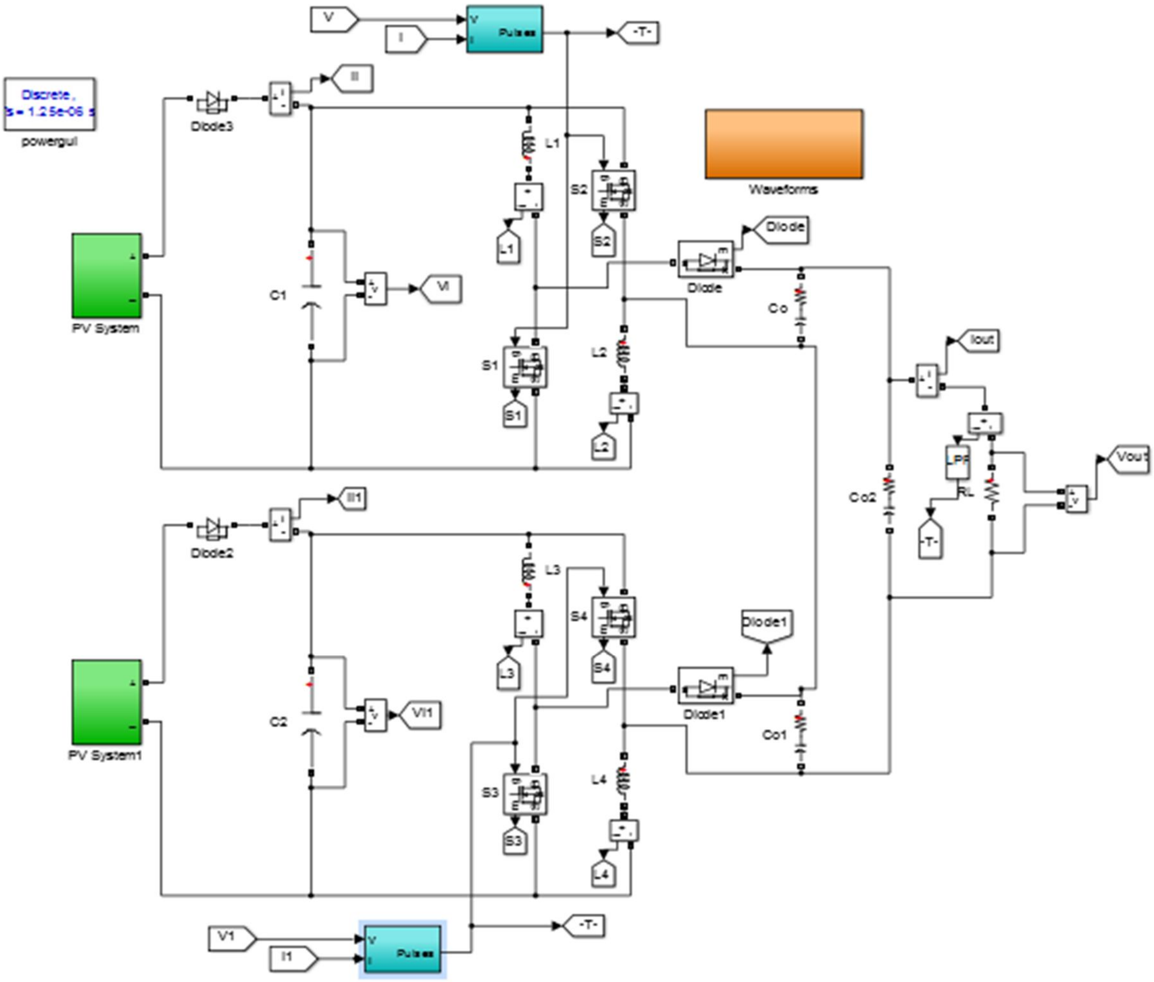


Fig. 5.34 Simulation Model for evaluation of CHGBC as MPPT Charge controller

Insolation level of both the PV Panels is shown in Fig. 5.35:-

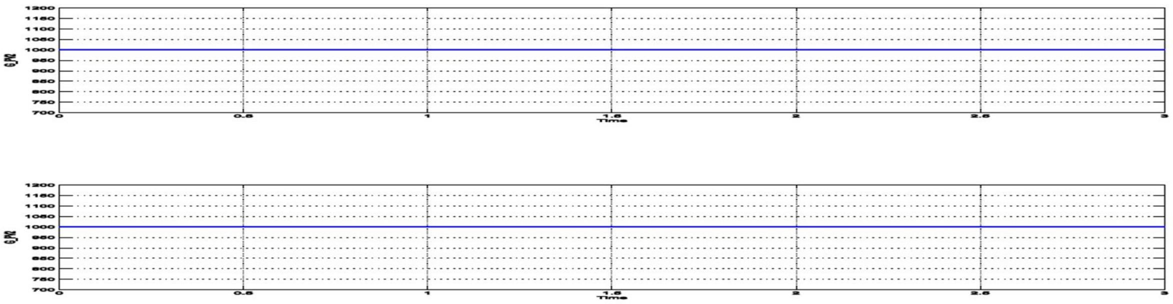


Fig.5.35 Insolation Inputs of Two PV Panels

Fig. 5.36 shows input waveforms of PV panel 1. This Fig.5.36 represents the voltage and current from the PV Panel 1 and the power evacuated from PV Module to the system.

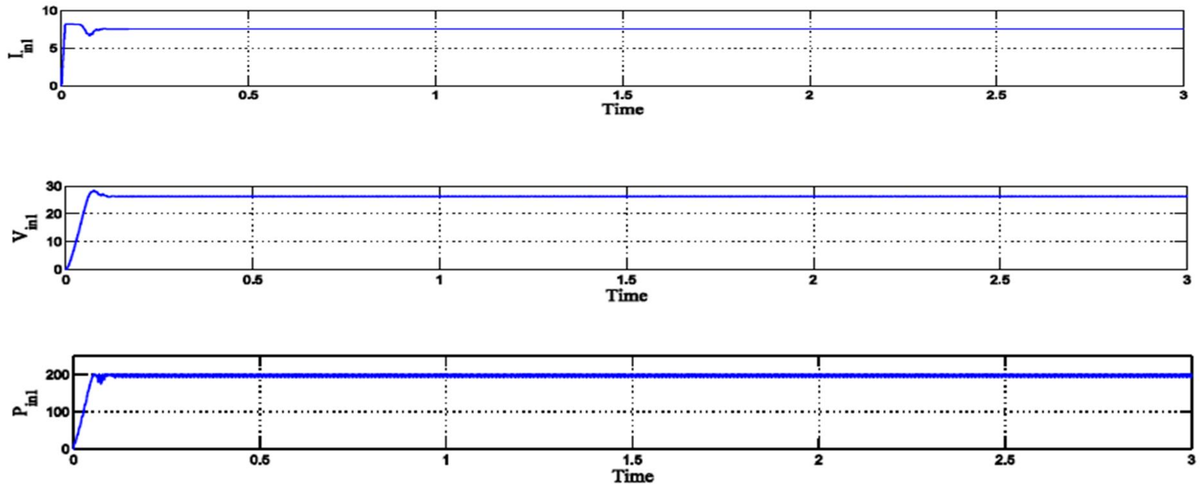


Fig.5.36 PV Panel-1 Input Waveform

Fig.5.37 shows the waveforms of PV Panel 2 thus indicating the input output voltage, current and power from PV Panel.

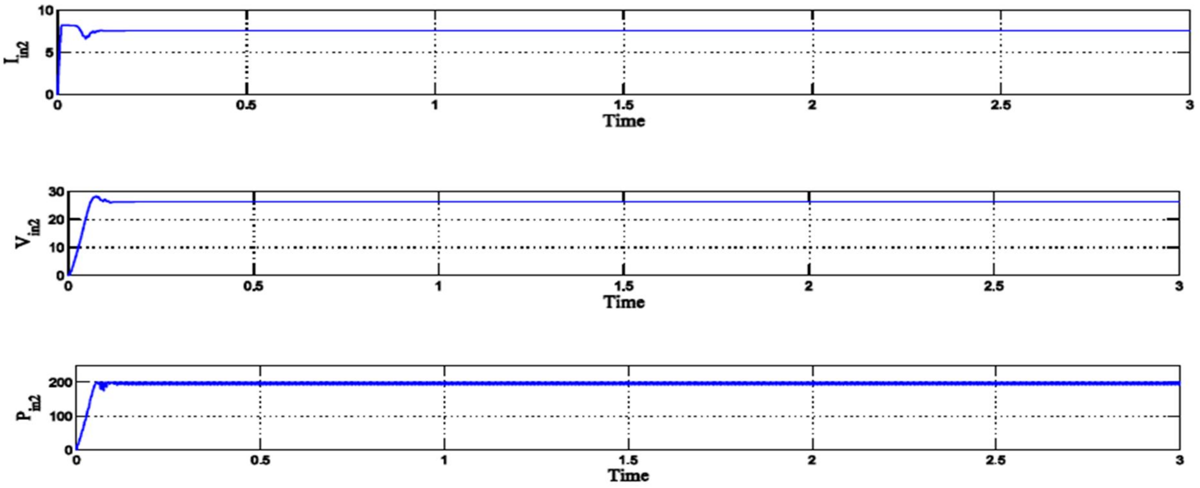


Fig. 5.37 PV Panel-2 Input waveform

Fig. 5.38 shows the output voltage and output current from the CHGBC.

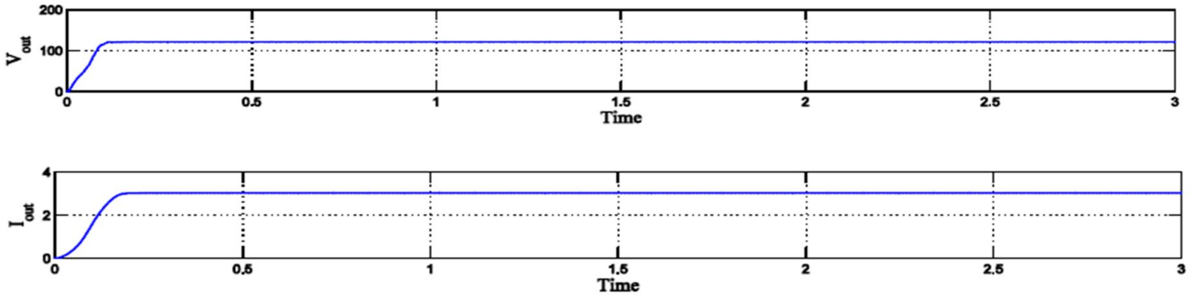


Fig. 5.38 Output Current and Output Voltage Waveforms

Output power is shown in Fig. 5.39, thus it is observed that the output power is 372 W. On calculating the efficiency of the system we can depict that using CHGBC as MPPT charge controller makes the overall system more efficient as, efficiency (η) comes out to be 93% for the overall system which is more than the dual stage system.

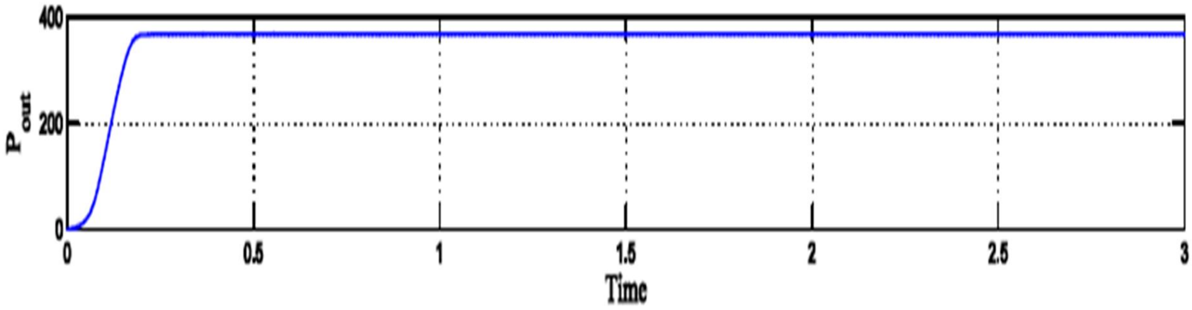


Fig. 5.39 Output Power Waveform

Case 2: Varying Insolation:-

The insolation of PV Panel 1 is varied and constant insolation is applied to PV Panel 2. From t = 0s to 1s, insolation is set to 800 W/m2, then from t = 1s to 2s insolation is set to 900 W/m^2 and from t = 2s to 3s insolation is 1000 W/m^2. This simulation analysis is done under two modes. First case deals with insolation variation without battery but with load controller and other one with battery with fixed passive load. Battery is connected in parallel with load to compensate power intermittency by keeping delivery to load constant. This system is studied under two modes, Mode 1 without Battery at load side and Mode 2 with battery at load side.

Mode 1: Without Battery at the Load Side

Fig.5.40 shows the insolation change, input voltage, input current and input power from PV Panel with its insolation level change from 800 W/m^2 to 900 W/m^2 and then to 1000 W/m^2 under constant temperature condition. As the insolation level changes it results in appreciable change in power output and output current from the PV Panel. From Fig.5.40, it is analyzed that InC MPPT Method fastly converges to MPP so that maximum power at that particular insolation should be evacuated and also system does not become unstable.

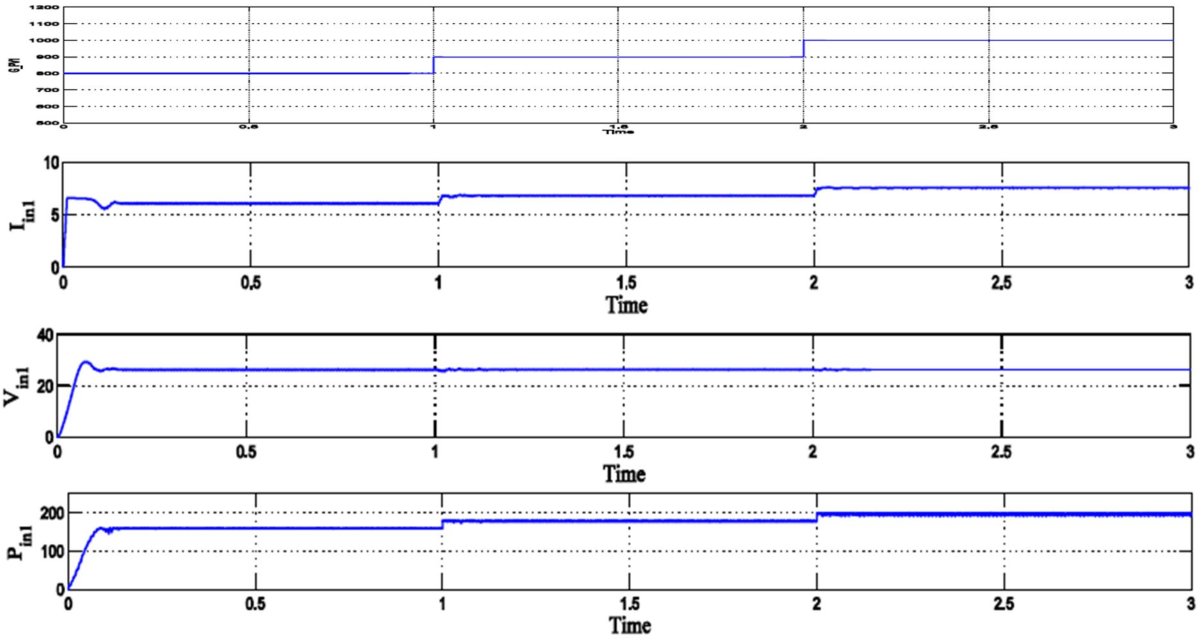


Fig. 5.40 PV Panel - 1 Input Waveform

Fig.5.42 shows the insolation level, input voltage, input current and input power from PV Panel 2 whose insolation and temperature both are maintained constant. INC MPPT Method here ensures maximum power evacuation from PV Panel 2 having constant insolation.

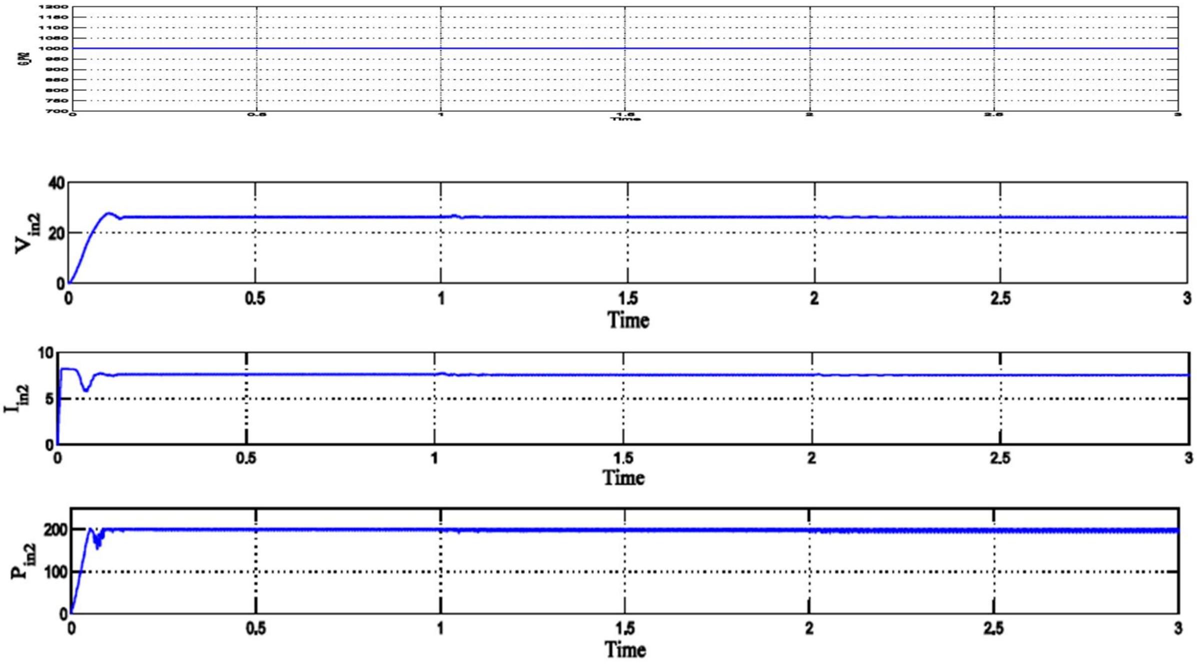


Fig. 5.41 PV Panel - 2 Input Waveform

Fig. 5.42 shows the current waveform through inductors.

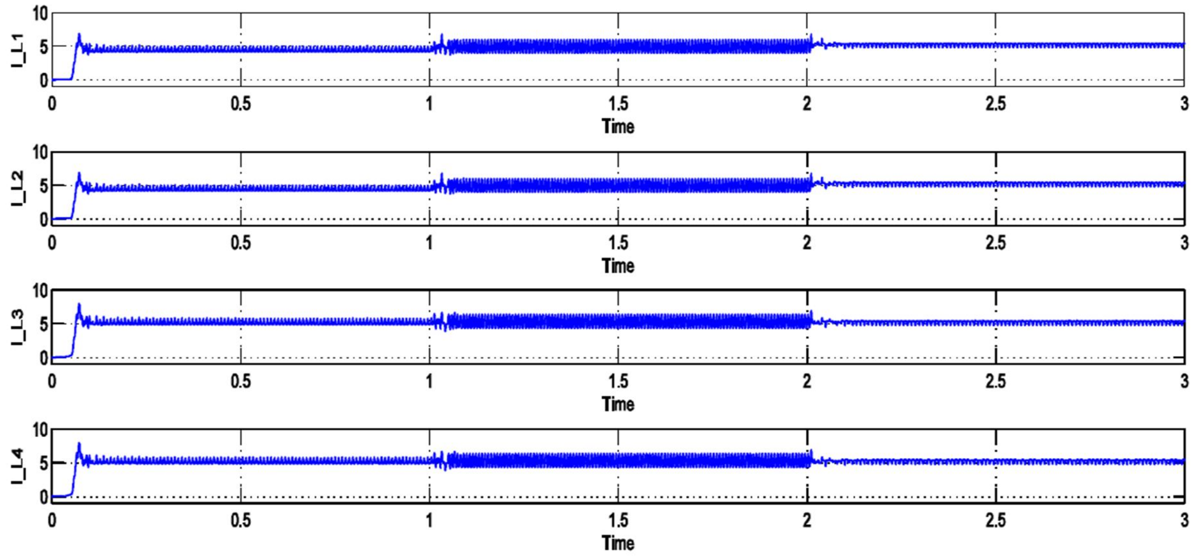


Fig. 5.42 Current Waveform through Inductors

Fig. 5.43, the voltage stresses on the power switches is shown when insolation of one PV Panel varies with time.

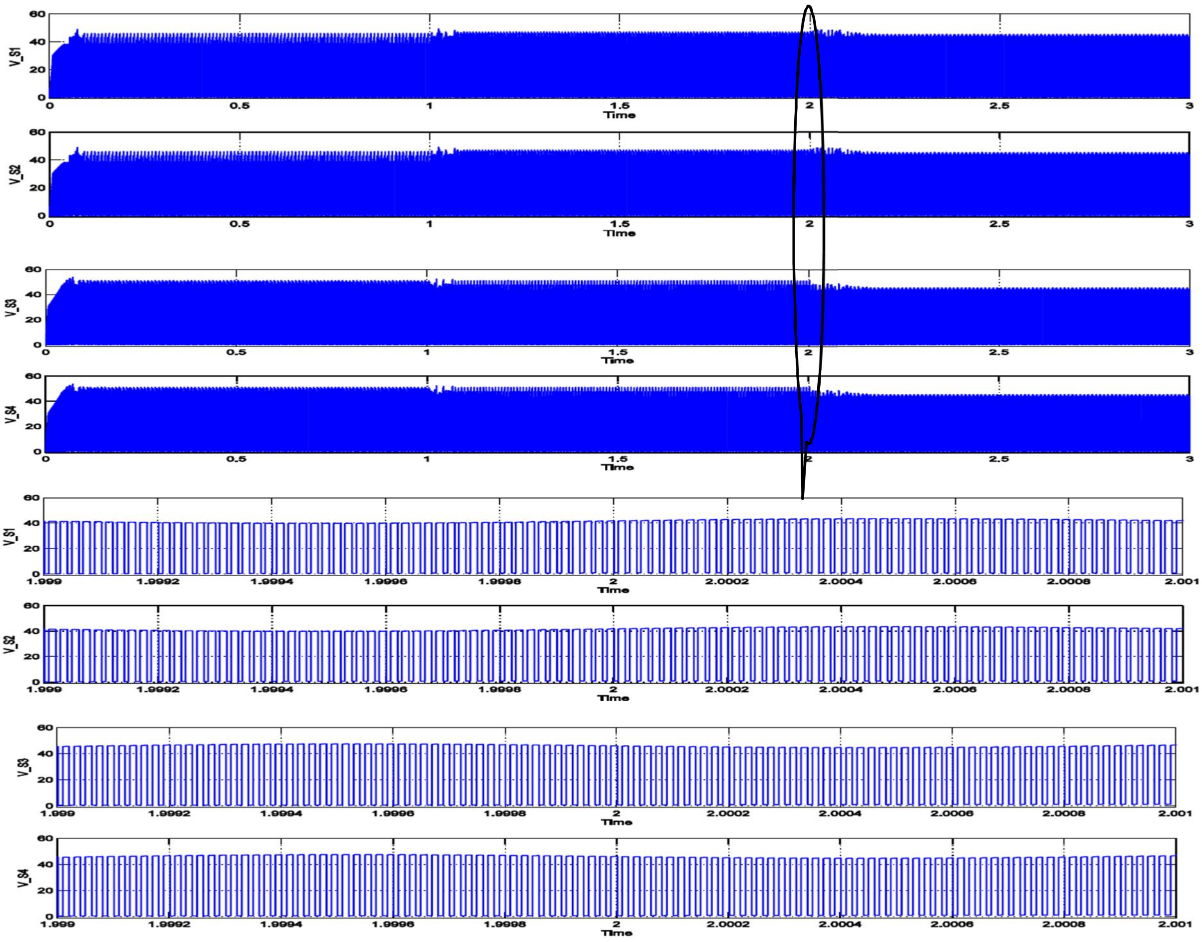


Fig. 5.43 Voltage Stresses on Switches

Thus output boosted voltage and output current is shown in Fig.5.44.

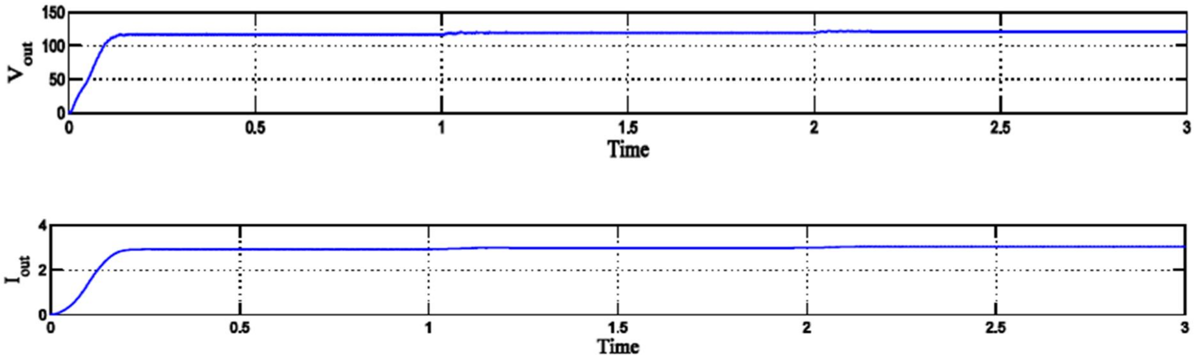


Fig. 5.44 Output Voltage and Current waveform

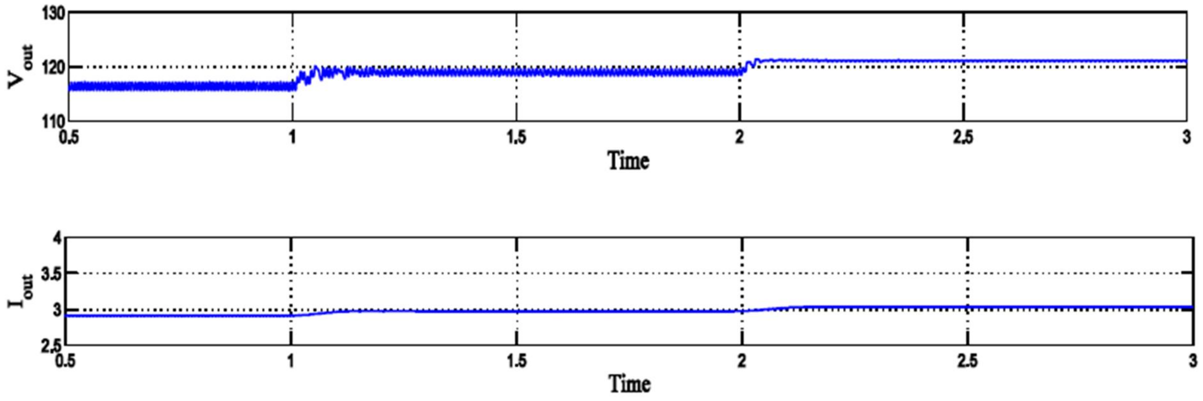


Fig. 5.45 Magnified waveform output voltage and current showing variation due to insolation variation

Fig. 5.45 shows that with varying insolation an appreciable change in power occurs thus fluctuating the voltage at the output side which can cause issues at the consumer side. Thus to overcome the problem of voltage intermittency a battery is used in parallel with load.

Mode 2: Varying insolation with battery

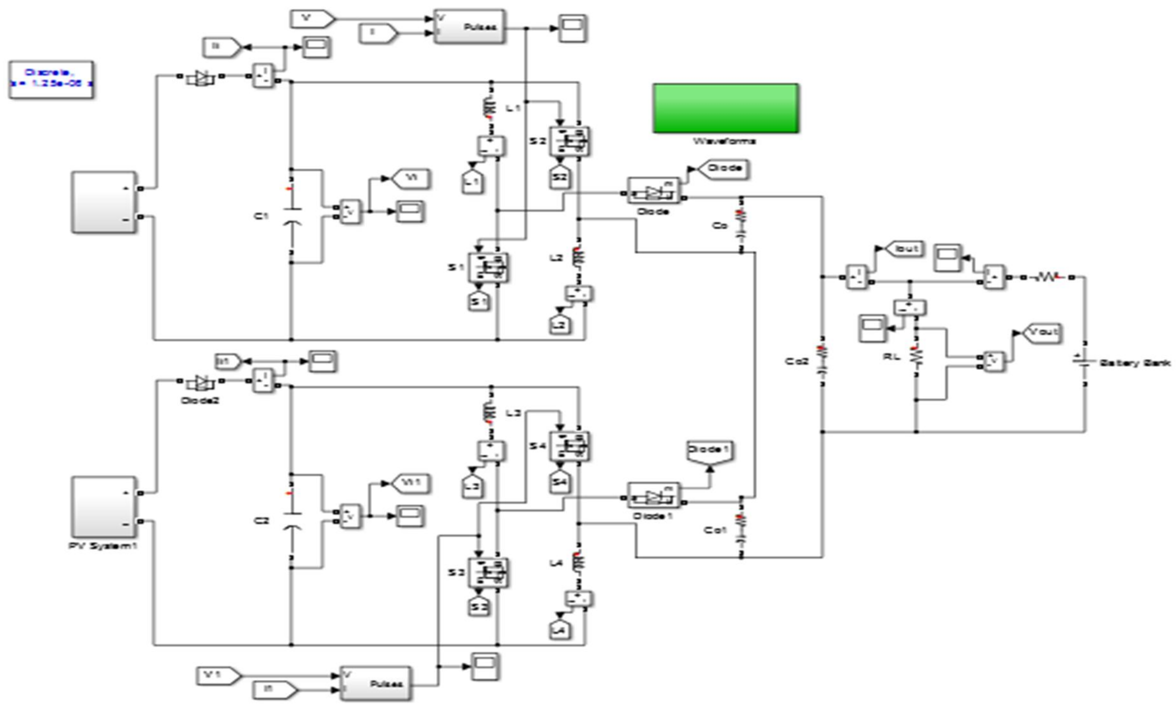


Fig.5.46. Simulation Model for showing the effect of Battery Bank

Fig. 5.46 shows the simulation model used to study the effect of using battery at the load side to reduce the effect of voltage intermittency caused due to insolation variation of one PV panel.

Output boosted voltage and current from the converter system with battery at load side is shown in Fig. 5.47. The boosted voltage is approximately 120 V.

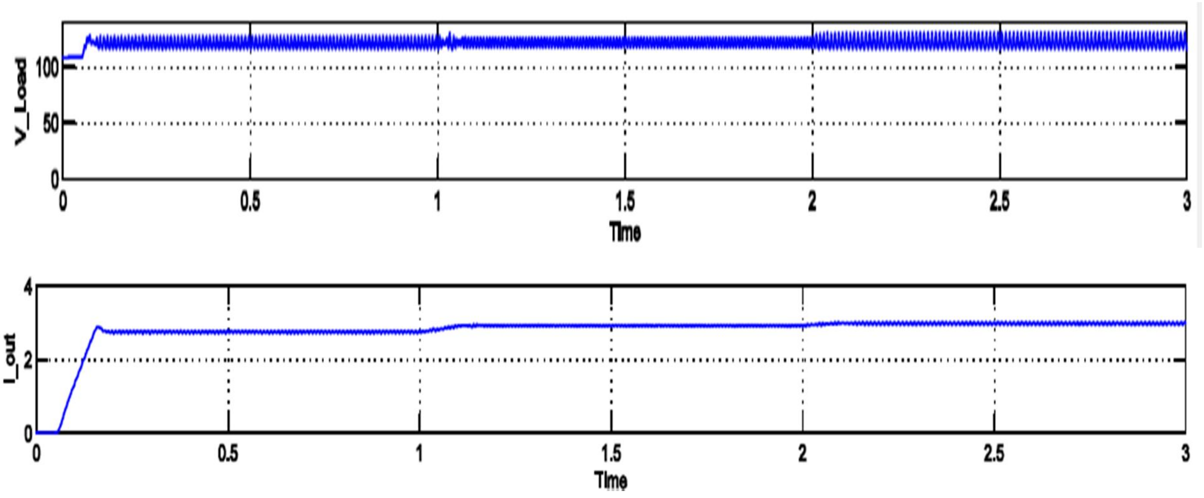


Fig.5.47 Output Current and Voltage Waveform

As seen from Fig.5.47 it can be seen that load is supplied using the battery during the intermittent period, thus load demand can be fulfilled easily.

5.6 APPLICATION OF CHGBC TO GRID-CONNECTED SYSTEM: -

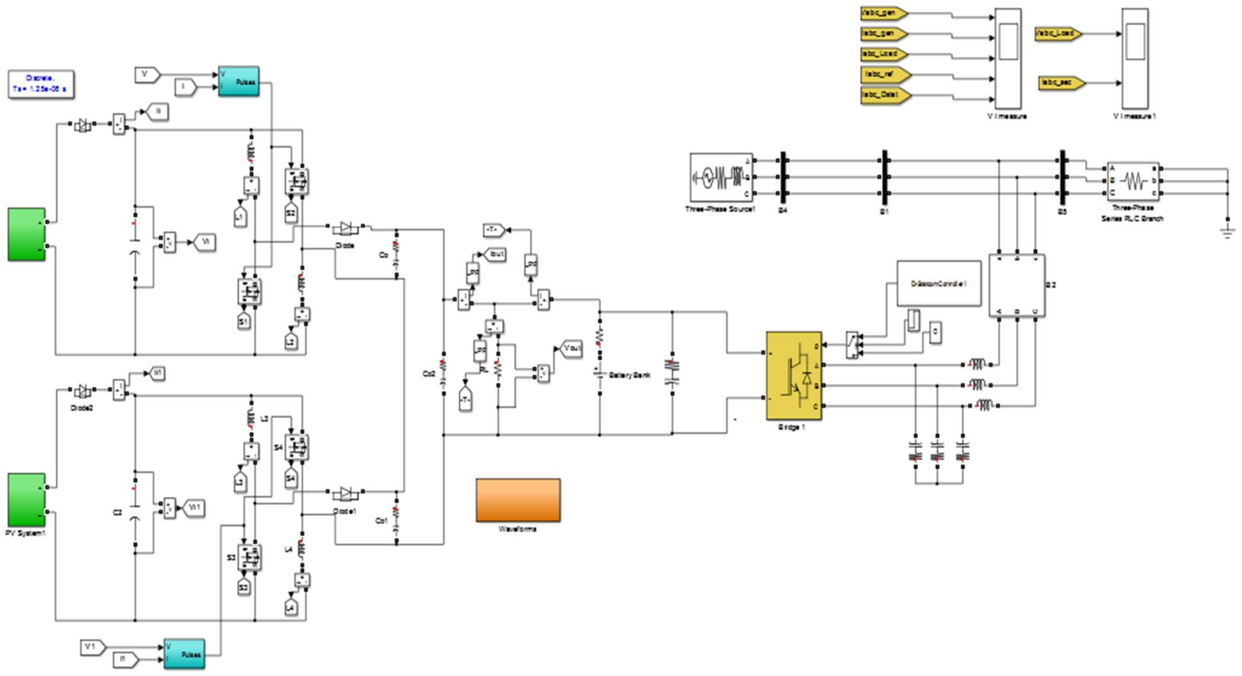


Fig. 5.48 Simulation Model for Grid-Connected System

In Fig.5.48, CHGBC is connected to a grid via an inverter. As insolation varies, output voltage fluctuates thus power intermittency occurs. So grid connected system compensates to power intermittency problem thus this shows the CHGBC can be used as a micro-inverter with an inverter whose control is synchronized with grid voltage by direct current control.

Various results shown below:-

Input from PV Panel 1 which has a varying insolation of 800 W/m2 from t = 0s to 1s, 900 W/m2 from t = 1s to 2s and 1000 W/m2 from t = 2 s to 3s, shown in fig. 5.49.

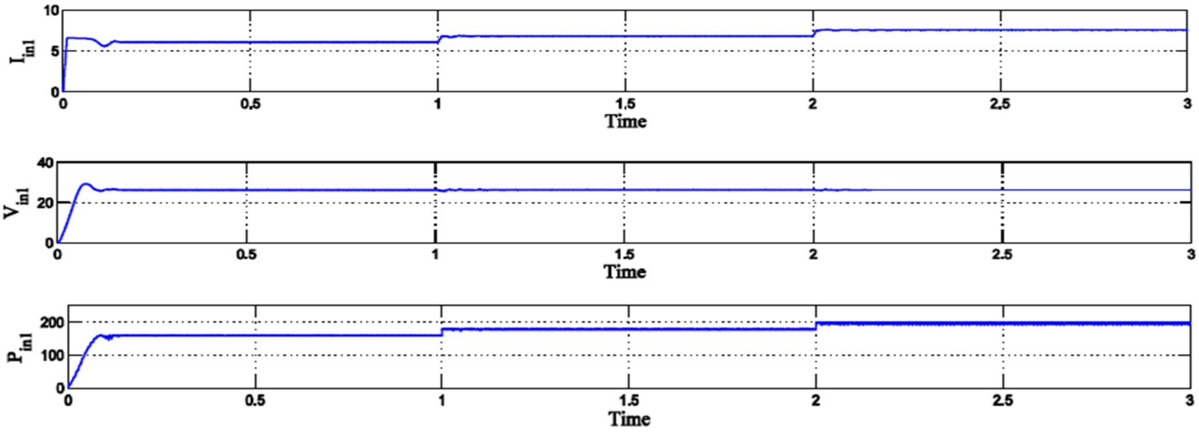


Fig. 5.49 PV Panel – 1 Input Waveform

Fig.5.50 shows the input from PV Panel 2 at a constant insolation of 1000 W/m^2.

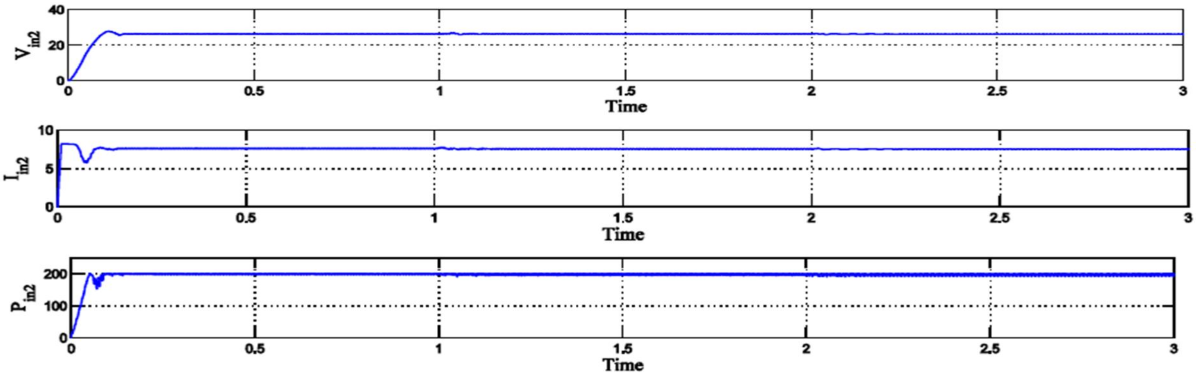


Fig. 5.50 PV Panel - 2 Input Waveform

In fig.5.51 output voltage from CHGBC is shown which is maintained at dc-link capacitor and output current from CHGBC.

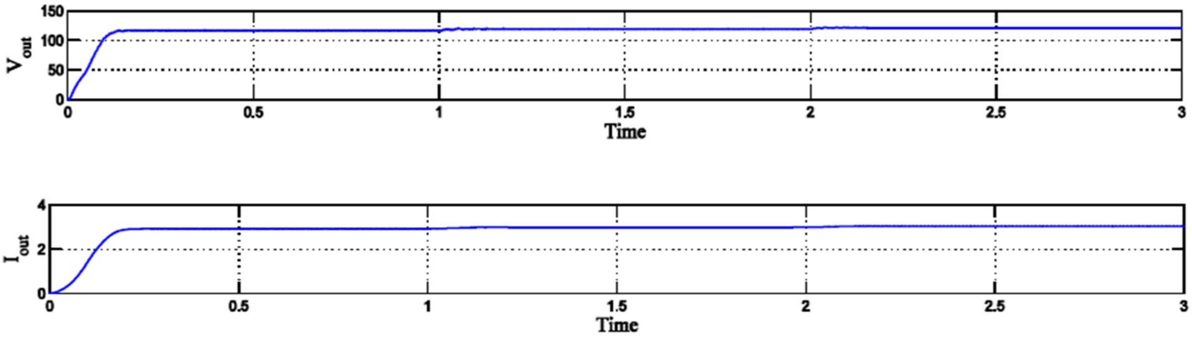


Fig.5.51Voltage at DC Link between CHGBC and Inverter and Output Current from Converter System

Thus inverter is connected to CHGBC output. Inverter switching is controlled in synchronisation with the grid voltage. A direct current control is used as control scheme foe inverter switching.

The grid voltage, grid current is shown in fig.5.52.

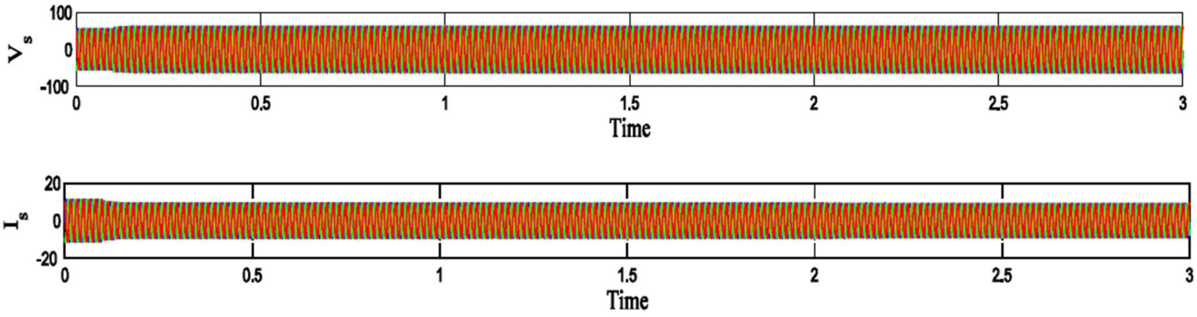


Fig. 5.52 Grid Voltage and Current

The reference current for the controlling the switching of inverter is shown in fig. 5.53.

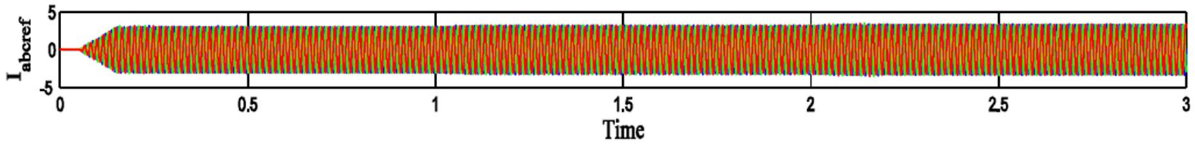


Fig. 5.53 Reference Current for Switching Control for Inverter Control

In fig.5.54 load voltage and current is shown.

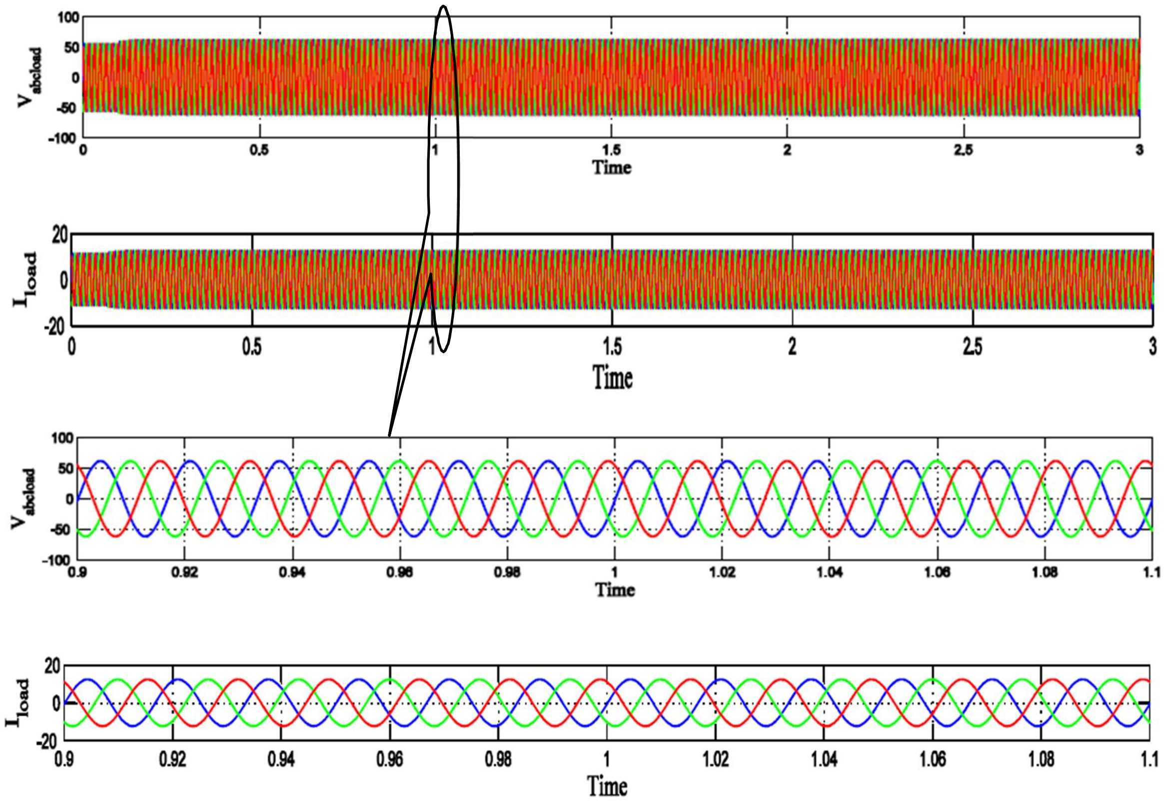


Fig. 5.54 Load Voltage and load current

5.7 CONCLUSION: -

Thus from the above analysis it can be concluded that HGBC is more efficient than Boost Converter. A double –stage PV module integrated CHGBC is discussed for various DC applications from two isolated PV Panel as input sources. In it analysis is done for constant insolation inputted to PV Panel. MPPT charge controller as an interfacing unit ensures maximum power output from the both the PV Panel and PI controlled HGBC is used to boost the voltage to a desired level.

As the system has double –stage, thus more number of components is used thus increasing the size and cost of the converter. Then comes a solution of using HGBC as MPPT controller which makes the system more compact and efficient. Also fewer components are used so it becomes economic to use for rooftop PV system. A grid-connected system is discussed in the analysis which ensures CHGBC as MPPT controller can be used as micro-inverter.

CHAPTER 6
MAIN CONCLUSION AND FUTURE SCOPE OF WORK

6.1 GENERAL INTRODUCTION: -

Power Electronic converter system for Renewable Energy Application is a popular research as renewable energy resources are gaining importance in power generation field. Solar energy, as an abundant source among renewable resources, mainly used for small power generation either grid-connected or for off-grid applications like Telecom, rooftop PV etc. As for small power generation there is need of a compact module-integrated converter system which can be port from one place to another easily and can be interfaced with grid or can be used as a standalone system.

6.2 MAIN CONCLUSION: -

The main aim of this work is to develop a converter system which can be easily integrated with PV module, compact in size, portable, economic, and easy to control. The converter system should be controlled in such a way that the PV Panel operate at maximum efficiency. MPPT technique is basically used to track maximum power point (MPP). As InC technique has fast convergence speed thus track insolation rapidly.

A high gain boost converter is discussed in the proposed work has the advantages: compact size, high voltage gain on a small duty cycle and easy control. This converter based on the switching inductor technique in which inductor charging and discharging take place when Switch is ON and OFF, respectively.

In MATLAB/ Simulink environment, two high gain boost converter is cascaded to form a new topology i.e. cascaded high gain boost converter (CHGBC) which is a MISO topology and can be used to integrate two different sources. two isolated PV panels are integrated with the CHGBC via MPPT charge controller. MPPT charge controller is a boost converter whose switching is controlled by using InC MPPT Technique. Utilizing a dual stage converter increases the system cost and results in less efficiency but through it a desired output voltage can be obtained.

Thus a solution to utilize HGBC as MPPT controller is realized. Thus making the system more efficient and reducing the size of overall system. As fewer components used thus reducing cost of the system and less switching losses. The system is analysed under two cases: constant insolation and varying insolation. For intermittency issues, a battery is connected in parallel at output side to reduce the voltage fluctuation at load side. All the above system are analysed and verified by the simulated results. Also the application of system as micro-inverter is observed under MATLAB/Simulink Environment.

6.3 FUTURE SCOPE OF WORK:-

The presented control schemes pave the way for variety of additional scope to the presented work. For instance converter system voltage gain can be enhanced by using soft-switching technique for control. Soft switching technique is basically a switching technique which results in zero-voltage switching or zero-current switching.

Also this system can be utilized with inverter to form a Micro-inverter topology which can be used at standalone or grid-connected mode. So, for a compact system, this system by controlling its switching technique in the form that it boost the DC input voltage also conversion from DC-AC can be done utilizing the only the switches of converter.

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