# DESIGN AND CONTROL OF SOLAR PV BASED CHARGING STATION FOR ELECTRIC VEHICLE

*A project report on partial fulfillment submitted for the dissertation work*

*of*

**MASTER OF ENGINEERING**

*in*

**POWER SYSTEMS**

*Submitted by*

Surabhi Bagherwal
(Registration no.: 801742023)

*Under the guidance of*

Dr. Manoj Badoni
Assistant Professor, EIED

THAPAR INSTITUTE
OF ENGINEERING & TECHNOLOGY
(Deemed to be University)

**2019**

**Electrical and Instrumentation Engineering Department**
**Thapar Institute of Engineering & Technology, Patiala**
***(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)***
**Post Bag No. 32, Patiala – 147004**

# DECLARATION CERTIFICATE

I hereby certify that the work which is presented in dissertation entitled, "**Design and control of solar PV based charging station for electric vehicle**", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Power Systems, submitted to Electrical & Instrumentation Engineering Department of Thapar Institute of Engineering & Technology (Deemed to be University) is as authentic record of my own work carried under the supervision of Dr. Manoj Badoni. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Place: Patiala

Date: 31/07/2019

**Surabhi Bagherwal**

**Roll No.: 801742023**

It is certified that the above statement made by the student is correct to the best of my knowledge and belief.

31/07/19

Date: 31/07/2019

**Dr. Manoj Badoni**

**Assistant Professor, EIED**

Electrical & Instrumentation Engineering Department

Thapar Institute of Engineering & Technology, Patiala

# ACKNOWLEDGEMENT

It would be a my pleasure to extend thanks firstly to Thapar Institute of Engineering and Technology, Patiala for giving me this great opportunity to work in TIET for M.E. Dissertation.

I wish to express my heartfelt sense of gratitude and indebtedness to my mentor, **Dr. Manoj Badoni**, Assistant professor, EIED, TIET, Patiala for guiding me whenever I came across any trouble or question in my mind. Without his help and guidance, it would never been possible to gain a lot of experience and knowledge.

I would like to thank Sr. Prof **Dr. R.S. Kaler**, Head, EIED, TIET; for providing a healthy learning environment to explore as much we can. It would be unfair to forget the great efforts being done by all the TIET staff members for cooperating with me at every moment.

Finally, I would like to thank my family and friends who have always been a motivation and support for me during the thesis.

**(Surabhi Bagherwal)**

**(Registration no.: 801742023)**

# TABLE OF CONTENT


| CONTENT | PAGE NO. |
| --- | --- |
| **DECLARATION CERTIFICATE** | **i** |
| **ACKNOWLEDGE** | **ii** |
| **TABLE OF CONTENTS** | **iii-v** |
| **LIST OF FIGURES** | **vi-vii** |
| **LIST OF TABLES** | **viii** |
| **ABBREVIATION** | **ix** |
| **ABSTRACT** | **x** |
| **CHAPTER 1: INTRODUCTION** | **1-13** |
| 1.1 Overview | 1-2 |
| 1.2 Existing control techniques | 3-7 |
| 1.2.1 Voltage mode control | 4 |
| 1.2.2 Current mode control | 5 |
| 1.2.3 PI controller | 6 |
| 1.2.4 Fuzzy logic controller | 7 |
| 1.3 Literature review | 8-11 |
| 1.4 Research gap identified | 11 |
| 1.5 Motivation | 12 |
| 1.6 Contribution | 12 |
| 1.7 Organization of the thesis | 13 |

| | | |
|---|---|---|
| **CHAPTER 2:** | **SYSTEM CONFIGURATION** | **14-21** |
| 2.1 | Introduction | 14 |
| 2.2 | Schematic diagram of the proposed system | 14 |
| 2.2.1 | Isolated system | 14 |
| 2.2.2 | Grid connected system | 15 |
| 2.3 | Design of components of the proposed system | 16 |
| 2.3.1 | Design of solar photovoltaic | 16-17 |
| 2.3.2 | Design of DC-DC boost converter | 17-18 |
| 2.3.3 | Modeling of battery energy storage system | 18-19 |
| 2.3.4 | Design of bidirectional AC-DC converter | 19-21 |
| 2.4 | Conclusion | 21 |
| **CHAPTER 3:** | **CONTROL ALGOROTHMS** | **22-33** |
| 3.1 | Overview | 22 |
| 3.2 | Design of incremental conductance based MPPT algorithm | 22-24 |
| 3.3 | Design of SMC based on washout filter | 24-28 |
| 3.4 | Design of control for bidirectional AC-DC converter | 28 |
| 3.4.1 | Mode selector | 28 |
| 3.4.1.1 | Working | 28-29 |
| 3.4.2 | Inverting mode control | 29-30 |
| 3.4.2.1 | Double band hysteresis current controller | 30-32 |
| 3.4.3 | Rectifying mode control | 32-33 |
| 3.5 | Conclusion | 33 |

**CHAPTER 4: RESULTS AND DISCUSSION** **34-43**

4.1 Introduction 34

4.2 Isolated solar PV battery system 34

4.2.1 Case study 34

4.2.1.1 Performance of the system with variation in solar irradiance 35-36

4.2.1.2 Regulation of voltage at DC link with SMC and PI 37

4.2.1.3 Performance of the system with variation in load 38

4.3 Grid connected system for electric vehicle 39

4.3.1 Case study 39

4.3.1.1 Battery is fully charged 39-41

4.3.1.2 Battery is discharged 41-43

**CHAPTER 5: CONCLUSION** 44

**REFERENCES** 45-47

**PLAGIARISM REPORT**

# LIST OF FIGURES


| | | |
|---|---|---|
| 1.1 | Block diagram of voltage mode control | 4 |
| 1.2 | Block diagram of current mode control | 5 |
| 1.3 | Block diagram of controller using PI | 6 |
| 1.4 | Block diagram of fuzzy logic controller | 7 |
| 2.1 | Proposed configuration of solar PV-battery based system with DC loads | 15 |
| 2.2 | Proposed configuration of solar PV-battery based G2V and V2G energy transfer | 15 |
| 2.3 | Equivalent circuit of PV cell | 16 |
| 2.4 | Model of lithium-ion battery | 18 |
| 2.5 | Equivalent circuit of battery | 18 |
| 2.6 | Vector diagram of different modes | 20 |
| 3.1 | Basic diagram of an INC method on P-V characteristics of the solar PV module | 23 |
| 3.2 | Incremental conductance flow chart | 24 |
| 3.3 | Simplified model of solar-PV battery model | 24 |
| 3.4 | Simulation diagram of sliding mode controller based on washout filter | 28 |
| 3.5 | Mode selector | 29 |
| 3.6 | Schematic diagram of single phase inverting mode control | 30 |
| 3.7 | Double band hysteresis current control technique | 30 |

| | | |
|---|---|---|
| 3.8 | Block diagram of hysteresis current controller | 31 |
| 3.9 | Schematic diagram of single phase rectifying mode control | 33 |
| 4.1 | P-V and I-V characteristics of solar PV array | 35 |
| 4.2 | Output voltage of DC link capacitor with variation in solar PV irradiance | 36 |
| 4.3 | Inductor current during variation in solar PV irradiance | 36 |
| 4.4 | Power balance in standalone solar PV-battery system | 36 |
| 4.5 | Output voltage of DC link capacitor with DC bus voltage regulation | 37 |
| 4.6 | Inductor current during DC bus voltage regulation | 37 |
| 4.7 | Output voltage of DC link capacitor with variation in load | 38 |
| 4.8 | Inductor current during variation in load | 38 |
| 4.9 | Starting response of PV voltage, current and power (SOC is 100%) | 40 |
| 4.10 | Dynamic response of system parameters with varying irradiance level and 100% SOC | 41 |
| 4.11 | Starting response of PV voltage, current and power (SOC is 20%) | 42 |
| 4.12 | Dynamic response of system parameters with varying irradiance level and 20% SOC | 43 |

# LIST OF TABLES


| | | |
|---|---|---|
| 4.1 | System parameters for simulation design of isolated solar PV-battery system | 34 |
| 4.2 | System parameters for simulation design of grid connected system for electric vehicle's | 39 |

# ABBREVIATIONS

| | |
|---|---|
| RES | Renewable energy resources |
| EVs | Electric vehicle's |
| PI | Proportional-plus integral |
| SMC | Sliding mode control |
| OCC | Open cycle control |
| MPPT | Maximum power point tracker |
| PV | Photovoltaic |
| V2G | Vehicle to grid |
| G2V | Grid to vehicle |
| D | Duty cycle |
| INC | Incremental conductance |

# ABSTRACT

In this paper, a solar photovoltaic-battery based isolated and grid connected system for electric vehicle's is proposed. The configuration of control of bidirectional buck-boost converter is proposed for charging (buck) and discharging (boost) the battery system. Due to solar energy sources irregular nature and variations in load demand, system mostly depend on control methods, to overcome with DC link voltage variations and power stability. Sliding mode controller based on washout filter is applied because it's good strength for unexpected change of energy resources and loads. This system includes for isolated system is a solar photovoltaic array basis on MPPT from PV, boost converter to maximize power from the PV. A bidirectional DC-DC buck-boost converter is proposed being charging battery in buck mode and discharging battery in boost mode, DC loads and for the grid connected system includes a solar photovoltaic array basis on MPPT from PV, boost converter to maximize power from the PV. A bidirectional DC-DC buck-boost converter is proposed being charging battery in buck mode and discharging battery in boost mode, a bidirectional AC-DC converter. Incremental conductance (IC) implemented to obtain maximum power from photovoltaic array. In this paper study of comparison between PI (proportional-plus integral) method and sliding mode controller based on washout filter is also simulated and verified that SMC gives a superior reaction on the transients in cases of variable solar irradiation or the consumption of the loads is changing and Sliding mode control based on washout filter provides better results in compared with PI Control on voltage overshoot and voltage undershoot, in the MATLAB using Simulink and the Sim Power System toolbox.

# CHAPTER 1

# INTRODUCTION

## 1.1 OVERVIEW

Fast depletion of limited to fuel resources more carbon emission and huge transmission losses are focusing the concern of power sector companies towards the use of renewable energy resources (RES). Renewable energy resources are the sources which can be achieved from the boundless source. Appropriate use of renewable energy resources is popular discussion going nowadays. It is exceptionally fundamental to pick which source of energy we should be utilized and why we need to use it? Greater part of components for example, neatness, cost, stability, proficiency and natural impacts must be considered. It is a harsh reality that, numerous productions far and wide are as yet needy on non-renewable energy sources for power generation. Presumably, these energizes are extremely successful to the extent control generation quality is concerned; however over the long haul they are not beneficial. Non-renewable energy sources will drain one day and the enterprises must turn to inexhaustible sources as quickly as time permits [1]. Additionally, these petroleum derivatives represent a colossal danger to ecological parity and are a reason for some natural risks.

Among all the renewable resources, solar power source is the successful contenders because of kind highlights, for example, accessibility of sun on earth, simplicity of establishment, improve of maintenance, moving parts unavailable, and insignificant dirtiness level etc. One of the important disadvantages of solar system is unpredictable nature of sun light due to rotation of earth and bad climate condition. This issue can without much of a stretch be understood by using a mixture comprising of a photovoltaic cluster and a battery. This course of action gives consistent, continuous and autonomous power supply to the framework load. The hugest element of renewable power source is its ample supply. Renewable power sources are clean source of energy that have an a lot lesser negative ecological effect than customary fossil vitality advancement [2].

Uses of renewable power sources are comprehensively performed on-grid and off-grid. A framework is essentially a coordination of production, transmission and circulation which supplies power to purchasers. On-grid and off-grid are the terms which portray the manner in which power is conveyed. On-grid manages power stations which are straightforwardly associated with grids, for example, wind turbine and sun oriented boards. Off-grid applications, by and large, serve just one burden, for example, a little home or a town house, charging batteries for electric vehicle, organizations can depend on on-grid solar systems to meet their every day necessities, as well as gain pay from the overabundance power created and on splendid radiant days, structures can produce enough sunlight based power to control machines, lights, water warming frameworks, etc. Off-grid applications can take numerous structures, from solar PV modules for a singular town home to unified windmills to control a town, water siphon or a business battery charging office or charging station for electric vehicles. These off-grid applications are most commonly utilized in remote or on the other hand rustic settings [3]. A noteworthy on-lattice application is to create power in mass sums.

The world is moving towards electric vehicles as a substitute wellspring of fuel vehicles, in this manner diminishing the impact of a worldwide temperature alteration and concern over greenhouse gases. Likewise, fuel vehicles are consuming over 50% of the fuel assets, resulting in the bringing about the generation of a lot of ozone depleting substances. The day isn't far when these conventional resources will depleted completed if the utilization of these resources keeps on being expended at a similar rate. In this way, there is an incredible requirement for redevelopment of the transportation part to have less reliance of human being on conventional sources. Hence, electric vehicles should be operated by clean, energy productive sources, for example, a battery with the goal that the reliance on non-renewable power sources limits. Thusly, numerous nations over the world are effectively taking part and checking out the redesign of the vehicle area and moving towards electric vehicles [4].

Reason behind moving from fuel vehicles toward electric vehicles (EVs) is the quick increment in the crude oil price and carbon emission. However, if there should be an occurrence of plug-in hybrid vehicle the battery is charged through the grid or renewable power sources, for example, photovoltaic, wind, fuel cell. Energy storage device, for example, batteries are frequently related in renewable energy producing framework because renewable power sources are helpless to weather factors which result in unpredictable production of power and unbalanced supply of power [5]. With the developing worry about a worldwide temperature alteration, nations have started to target lessening ozone harming substance outflows. With the end goal of ecological security and fuel cost decrease, automobile producers have put incredible endeavors into creating electric vehicles (EVs). Soon, EVs are relied upon to be the standard of the transportation division [6].

To combine energy storage device with the renewable energy sources, a DC-DC bidirectional converter is normally utilized in a renewable energy producing system. A DC-DC bidirectional converter operates in two modes.

- Charging Mode
- Discharging Mode

When the renewable power resources generate more than the power demanded by load then surplus power will stored in the battery and this is called charging mode. Oppositely when the renewable power resources generate lower than the power demanded by load then power flows from battery to the load and required power by the load comes through storage device and this is called discharging mode. For the charging process, if the DC link capacitor voltage is less from the voltage of battery, in this case system will step up the voltage and battery will charge, else if DC link capacitor voltage is grater from the voltage of the battery then system will step down the voltage and battery will charge. For the discharging process, if the voltage of DC link capacitor is less from the voltage of battery, in this case system will step down the voltage and battery will discharge, else if the voltage of DC link capacitor is grater from voltage of battery than system will step up the voltage and battery will discharge [7].

The principle issue with activity of DC-DC bidirectional converter is the supplied power is not regulated, which prompts the irregular function of converter. There are different simple and computerized control strategies utilized for DC-DC bidirectional converter. The desired output of DC-DC bidirectional converter should be fixed or steady voltage but because of the intermittent nature of the renewable resources the input voltage of the DC-DC bidirectional converter is irregular. The main function of voltage regulator is to keep the fixed or constant output voltage. Different sorts of voltage regulators are used with different types of control strategies for the good efficiency of DC-DC converters [8].

## 1.2 EXISTING CONTROL TECHNIQUES

There are various control techniques for the DC-DC bidirectional converter. Some techniques are discussed below for the DC-DC bidirectional buck- boost converter

**1.2.1 Voltage Mode Control: -** Voltage mode control technique is utilized in industry application as well as research because of its simple execution. In this type of control technique first we need to measure the irregular output voltage and then compare it with the reference voltage and this control technique contains single loop control [9]. It utilized irregular measured output voltage and reference voltage to produce control output voltage. To calculate the switching duty ration this controlled output is utilized by contrast with fixed frequency waveform and then this duty ratio is utilized to keep the normal voltage over the inductor. This will finally carry the output voltage to reference voltage value. It will provide constant or fixed output voltage with no variations.

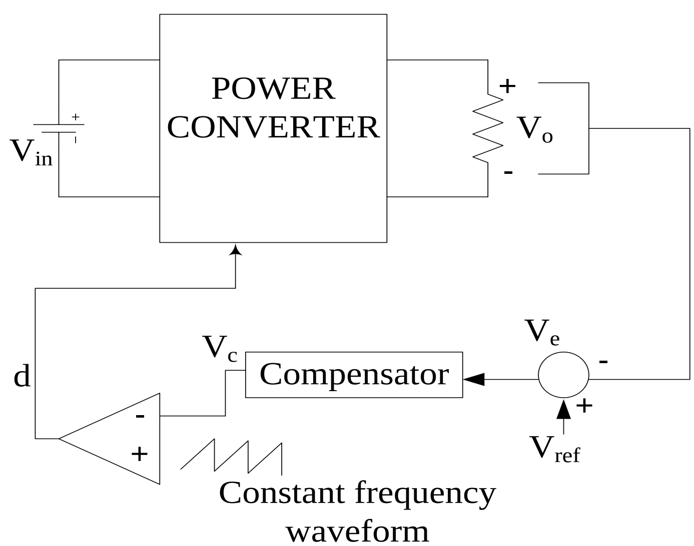



Fig. 1.1 Block diagram of voltage mode control

Figure 1.1 shows block diagram of voltage control mode of converter. Where $V_{in}$ is input voltage of battery, $V_o$ is measured output voltage of battery, $V_{ref}$ is reference voltage, $V_e$ is the error generated, $V_c$ is controlled output voltage and d is switching duty ratio.

**Advantages:**

- Easy Implementation

**Disadvantages:**

- Less reliable and unstable
- Less stable when the more converters are in parallel
- Slow system for switching cycle
- **1.2.2 Current Mode Control: -** Current mode control is more composite compare with voltage mode control because CMC carry double control loop and these are current and voltage loop. There are many different uses of current mode control for different application [10-11]. In this type of control irregular output voltage is compared with the reference voltage and then an error signal is produced and this error signal generate reference inductor current. We need to sense actual inductor current value then compare both the reference and measured inductor current value and it will generate a control signal for duty cycle. Figure 1.2 shows the block diagram of current mode control for DC-DC bidirectional converter. Where $V_{in}$ is input voltage of battery, $V_o$ is measured output voltage of battery, $V_{ref}$ is reference voltage, $V_e$ is the error generated, $I_c(t)$ is controlled output current, $I_L(t)$ is inductor current and $d$ is switching duty ratio.

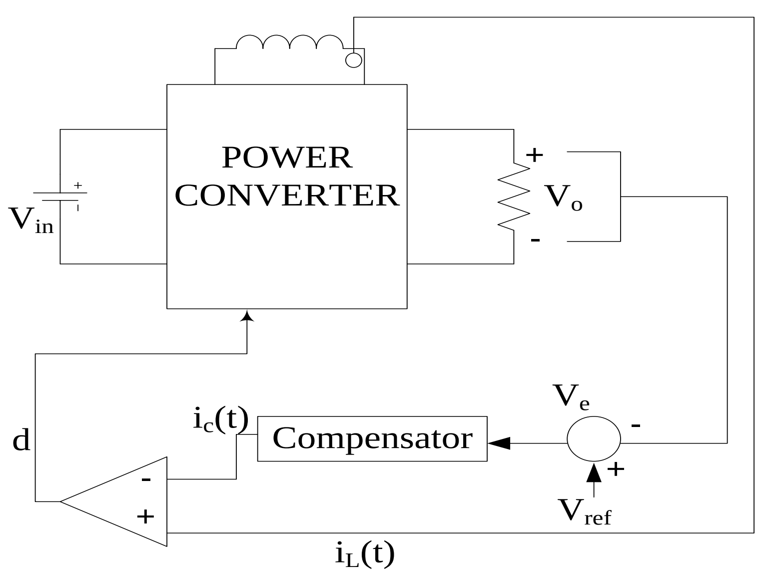


Fig. 1.2 Block diagram of current mode control

**Advantages:**

- Improved transient response
- Suitable for more converters in parallel
- Main switch adopt more security

**Disadvantages:**

- Unstable when duty ratio overreach 0.05sec.
- Sub-harmonic oscillations present

**1.2.3 PI Controller: -** The DC-DC bidirectional buck-boost converter is constrained by two PI (Proportional-plus integral) controllers which connected in cascaded including external voltage control by methods for internal current control. Voltage of DC bus is detected and contrasted with the reference voltage of DC bus to deliver the error. This error is limited by the PI controller and reference current is created. This reference current must be constrained to greatest passable charging and discharging flows by methods for battery current regulation work. As far as possible rely upon the battery evaluations. The present reference is contrasted and the genuine battery current and the error are tuned again, it produces the pulses which is complimentary to drive the switches [12]. Fig. 1.3 shows the block diagram of PI control method. Where $V_o$ is output voltage, $V_{ref}$ is reference output voltage, $I_L$ is the inductor current of the bidirectional DC-DC converter.

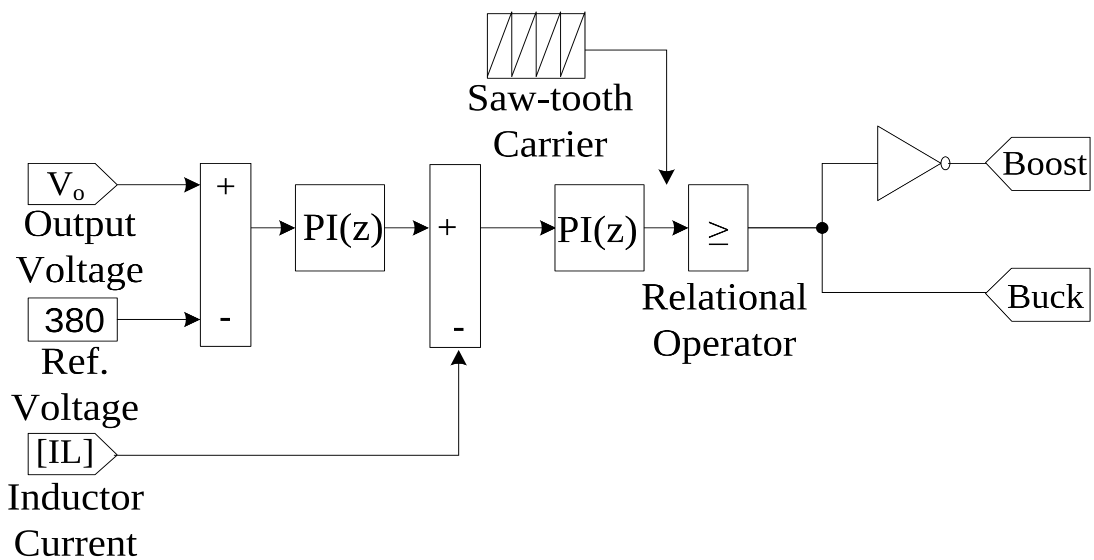



Fig. 1.3 Block diagram of controller using PI

**Advantages:**

- Easy Implementation
- Easy to understand

- Stable for Linear control system

**Disadvantages:**

- It is not stable for non-linear system
- It is experiences dynamic reaction and generates overshoot influencing the output voltage regulation and generates overshoot.

**1.2.4 Fuzzy Logic Controller: -** The idea of Fuzzy control is non-linear and versatile and it is a practical option for different control applications [13]. There are four fundamental components in the fuzzy logic controller framework structure named as: Fuzzifier, rule base, Inference engine and defuzzyfier. The working of fuzzy logic controller structure can be effectively comprehended from the block diagram. Its working is isolated in 3 primary steps:

i. Fuzzification.

ii. Derivation

iii. Defuzzification.

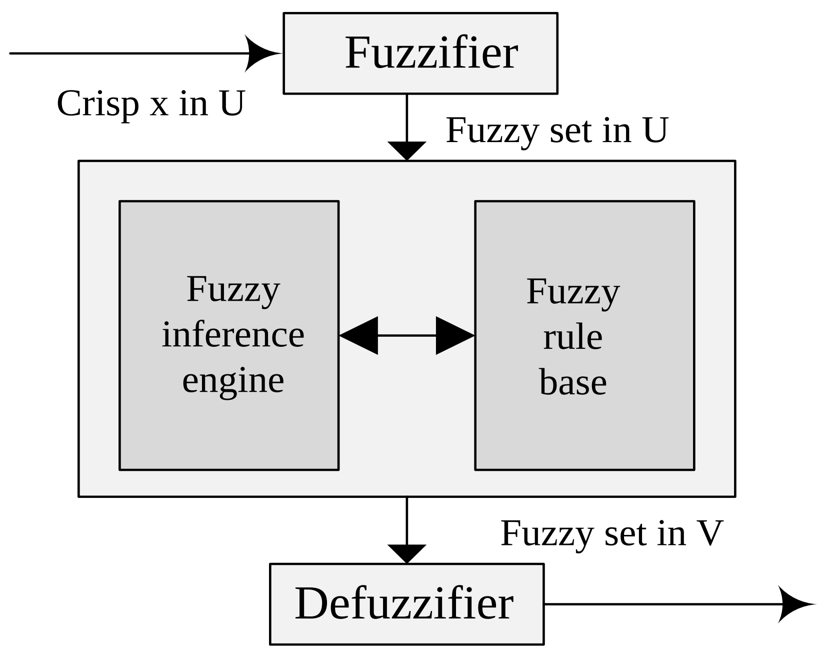



Fig. 1.4 Block diagram of fuzzy logic controller

**Advantages:**

- Low cost

- These frameworks can be effectively overhauled by adding new principles to improve execution or include new highlights.
- Improvement of classical controllers

**Disadvantages:**

- Lack of real time response
- Lower speed and longer run time of system

## 1.3 LITERATURE REVIEW

The literature review on problems with control of DC-DC bidirectional buck-boost converter is briefly summarized.

- Sahin *et al*. [14] has explained and designed a fuzzy logic controller based DC-DC buck-boost converter and performed this controller on MATLAB/Simulink. In this controller designed a FLC and a feedback added. An irregular output voltage is contrast with the reference voltage and produced error signal. This error signal is run by the fuzzy logic controller then fuzzy logic controller is contrast with the saw toot carrier wave to generate pulse width modulation signal which runs the MOSFETs. Also, the results of FLC are compared with the conventional proportional-plus integral controller and have proposed that FLC has batter response than proportional-plus integral controller.

- Verma *et. al*. [15] used a proportional-plus integral control technique to charge and discharge the battery for electrical vehicle. In this system a grid to vehicle and vehicle to grid power transferred by utilizing DC-DC bidirectional buck-boost converter or single phase ac/dc bidirectional converter. Converter has conveyed the alternating current from the grid and AC current to the grid at UPF and reduced harmonics which eventually delays the life of converter and the storage device.

- Hongfei *et. al*. [16] has proposed a deliberate methodology of the deduction of nonisolated TPC topography designed for combining an inexhaustible source, a storage device and a load at the same time. The energy flow in triple port converter has investigated and then applied on dual input converters and dual output converters. In this system explained a triple port converter attributes and which results in high efficiency and high assimilation.

- Levy *et. al.* [17] has designed another nonisolated buck-boost type 5-level DC-DC converter reasonable for higher power and higher voltage application. In this system displayed the fundamental highlights of this topology are: lower voltage over the semiconductors and diminished volume of output channel. The hypothetical investigation is completed for a multilevel bidirectional structure of that converter. The designed topology displays a few capacitors and their voltage level should be fit for legitimate activity of the converter. In this manner, a capacitor voltage adjusting dynamic control utilizing a feed forward procedure is proposed and broke down in detail. So as to approve the hypothetical investigation, a model with 10 kW output control capacity.

- Hamasaki *et. al.* [18] has explained a power levelling framework is connected to keep up a harmony between power supply and such an unpredictable control age. The PLS is required to work charge or release of capacity and bidirectional power stream. Accordingly the PLS comprises of a bidirectional buck-boost DC-DC converter. In this investigation, the bidirectional buck-boost DC-DC converter and twofold electric layer capacitor are connected to the PLS. The yield current of power levelling system is controlled so as to keep control parity and DC transport voltage. PLS ought to work control levelling rapidly for prompt change of intensity age framework. In this examination, Control of the DC-DC Converter applying to miscreant (DB) control dependent on linearization is proposed to acquire fast reaction.

- Simoes *et. al* [19] the primary objective of this paper is to structure and investigate a bidirectional drifting interspaced DC-DC buck-boost converter connected to a private photovoltaic control framework with vitality stockpiling. The drifting interspaced bidirectional converter produces a higher DC voltage addition contrasted with customary converters, decreasing the required number of arrangement associations for the solar photovoltaic and battery system. This paper demonstrates a transitional control technique from grid connected to islanded working modes, just as the back association with the buck-boost working modes for the bidirectional DC-DC converter. The paper portrays the DC connect the board and voltage control where the guideline strategies are shown by investigation and re-enactment results appearing total framework activity.

- Andres *et. al.* [20] few electrical topography of circulated stockpiling units are portrayed by the utilization of bidirectional converters that store  in a battery bank at specific minutes and supply this to micro grid transport when essential. The OCC (open-cycle control) system has been utilized in the exchanging converters to enable quick reaction to homeless people, no overshoots and zero relentless state mistake. The target of this work is to utilize OCC procedure in a bidirectional Buck-Boost converter to charge a battery bank when they are released, and to supply the battery power to the load when important, guaranteeing insurance to the load and to the storage device.

- Montoya *et. at.* [21] In numerous grid associated applications a DC-DC exchanging converter is generally associated between the solar photovoltaic arrays and the dc-ac converter. This paper shows an improvised technique to structure a sliding mode controller for the solar photovoltaic framework, which runs the photovoltaic voltage to pursue a reference given by an outer maximum power point tracking calculation and mitigates the annoyances brought about by the irradiance changes and motions in the mass voltage. By taking into account that the exchanging surface is the straight mix of the input capacitor current and the photovoltaic voltage blunder, the designed plan displays preferences in examination with existing arrangements that depend in the linearization of internal current circle elements. The designed basic topology, by considering the impacts in the shut circle framework elements of a reference channel, guarantees a stable sliding routine in all the ideal task scope of the framework, while the settling time, what's more, overshoot of the solar photovoltaic voltage required by a maximum power tracking calculation are given.

- Dylen *et. al.* [22] a client programmable energy the executive's framework arranged on structuring custom charging and releasing characteristics for electric vehicle's batteries was planned and tried. The charging procedure is accountable for a Buck converter constrained by a particular current and voltage controller with bump less control move, and provided by a AC-DC converter that could utilize both single-stage and three-stage source. For battery releasing, a MOSFET filling in as a dynamic resistor is utilized.

- Vidal *et. al.* [23] the adaptable DC-DC buck-boost converter is discovered appropriate for a specific solar PV application that demands either a voltage up or a voltage down task infusing the most extreme accessible current into a middle of the road voltage battery. This system is designed to execute the converter adjust giving consistent switches between the boost and buck working modes. In light of the sliding-mode control procedure, a hysteretic-balance based controller is structured permitting the tuning of the exchanging recurrence around both of the two conceivable working focuses. The presentation of little adjustments into the hysteretic-balanced based usage results in a PWM controller that jams the consistent changing highlights among buck and lift working modes while giving a fixed exchanging recurrence. Trial results exhibit that the two arrangements permit the converter input voltage managed by appearing ideal following of 1-kHz square-type references, like those given by an old style annoy and-watch (P&O) MPPT calculation yet a lot quicker.

## 1.4 RESEARCH GAP IDENTIFIED

The energy emergency has as of late turned into a significant issue. To illuminate this, the improvement of renewable power source is necessary. With the rapid increase in population and correspondingly depletion of crude oil resources, EV's are becoming popular. Therefore, there is a great need to shift from conventional vehicles towards electric vehicles. But, major problem being faced in electric vehicles is the balance of power at DC link capacitor when there is combination of renewable energy sources and storage system and grid connect at same DC bus. Renewable power sources are helpless to weather factors which result in unpredictable production of power and unbalanced supply of power so that energy storage devices are frequently related in renewable energy producing framework. However, the power balance using batter control techniques of DC-DC bidirectional buck-boost converter for nonlinear characteristics is less studied in literature. Therefore, the development of batter controller is required, which can give stability in non-linear system and regulate the DC link voltage.

- An adaptive SMC based on washout filter is identified suitable for the control of DC-DC bidirectional converter.
- The comparative performance of developed controller with the conventional controller is always required which has been identified and presented in this work.

## 1.5 MOTIVATION

The main motivation in this work is on shifting from fuel vehicles towards electric vehicles. Hence, electric vehicles should be operated by clean, energy productive sources, for example, a battery with the goal that the reliance on conventional power sources limits. To combine energy storage device with the renewable energy sources, a DC-DC bidirectional converter is normally utilized in either it is integrated with grid or in islanding mode. But the main problem being observed is that this nonlinear nature and the incessant difference in the accessibility of power sources make this control defective.

Thus, intent of the work is to search for optimum solution of balancing of power at DC bus. There is need of nonlinear stability of the power. A SMC (sliding mode controller) based on washout filter is proposed which manage the balance of power.

## 1.6 CONTRIBUTION

Hence, the major contributions of this paper are summarized below.

- Unlike conventionally used proportional-plus integral control technique, the proposed sliding mode controller based on washout filter is used for charging and discharging the battery energy storage system.
- The proposed scheme intends to search optimum solution of balancing of power at DC bus.
- The comparative performance of developed SMC based on washout filter with the conventional proportional-plus integral controller has been done.
- The results are obtained in the MATLAB using Simulink and the Sim Power System toolbox.

## 1.7 ORGANIZATION OF THE DISSERTATION

The work carried out in this project has been coordinated in 5 chapters.

Chapter 1 includes Introduction and Literature Review.

Chapter 2 deals with the Designing of System Configuration.

Chapter 3 deals with the Control techniques of the system framework, mathematical modelling and problem formulation.

Chapter 4 includes Results and Discussion.

Chapter 5 deals with Conclusion and References.

# CHAPTER 2

# SYSTEM FRAMEWORK

## 2.1 INTRODUCTION

This segment gives information about designing of the system configuration. There are two configurations which include isolated system and grid connected system. Isolated system includes solar photovoltaic array which produces power from the sun irradiance and this power in DC form, a boost converter which boost the voltage of the solar PV array. Output of the boost converter connected to the DC bus. A bidirectional DC-DC buck-boost converter is designed to charge and discharge the battery energy storage system and it is also connected to the DC bus and resistive load. Grid connected system includes solar photovoltaic array, boost converter, a bidirectional DC-DC buck-boost converter and grid is connected through a bidirectional single phase AC-DC converter.

## 2.2 SCHEMATIC DIAGRAM OF THE PROPOSED SYSTEM

This proposed system divided into two parts.

**2.2.1 Isolated system:** Fig. 2.1 shows the configuration of solar PV-battery system with DC loads. This system configuration includes a solar photovoltaic array as DC source of 1442W then a DC-DC boost converter which boost the voltage upto 380V, a bidirectional DC-DC Buck-Boost converter for charging and discharging the battery as DC storage and DC loads.

**2.2.2 Grid connected system:** Fig. 2.2 shows the configuration of solar PV based grid to vehicle and vehicle to grid energy transfer. This system configuration includes a solar photovoltaic array as a DC source of 1442W then a DC-DC boost converter which boost the voltage upto 380V, a bidirectional DC-DC Buck-Boost converter for charging and discharging the battery as DC storage and a bidirectional AC-DC converter which is grid connected.

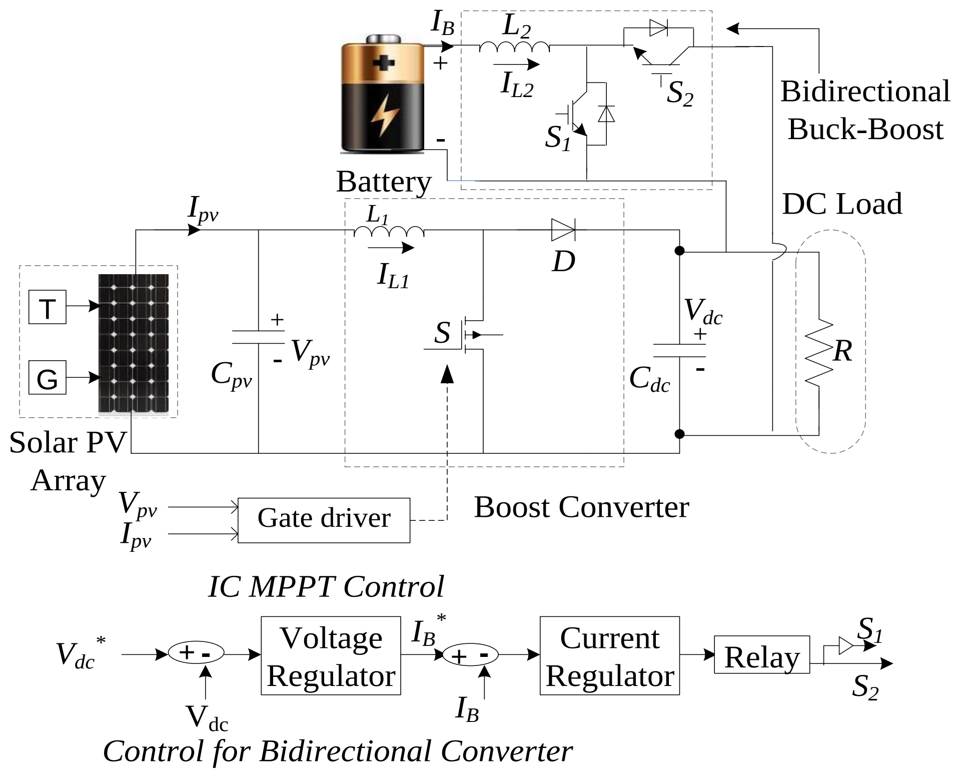



Fig. 2.1 Proposed configuration of solar PV-battery system with DC loads

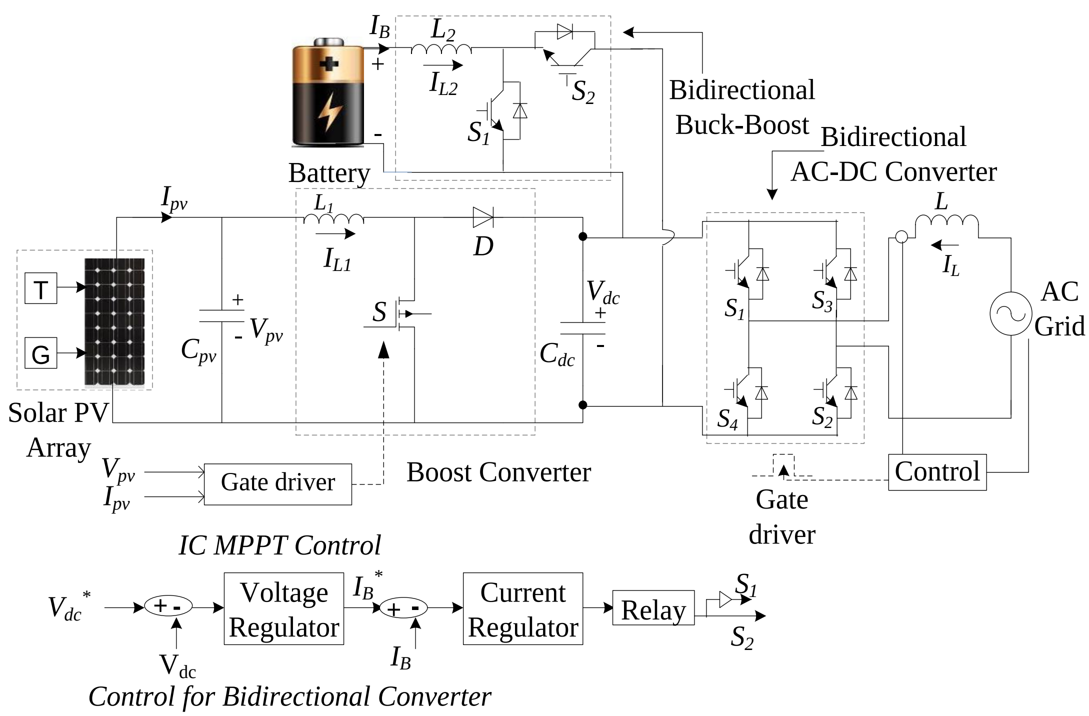



Fig. 2.2 Proposed configuration of solar PV-based G2V and V2G energy transfer

## 2.3 DESIGN OF COMPONENTS OF THE PROPOSED SYSTEM

### 2.3.1 Design of Solar Photovoltaic Array

Representation of a sunlight based PV cell, consisting of a current source with diode in parallel. At the output side series resistor ($R_s$) and shunt resistor ($R_p$) are associated. The identical circuit of a sunlight based photovoltaic cell is displayed below.

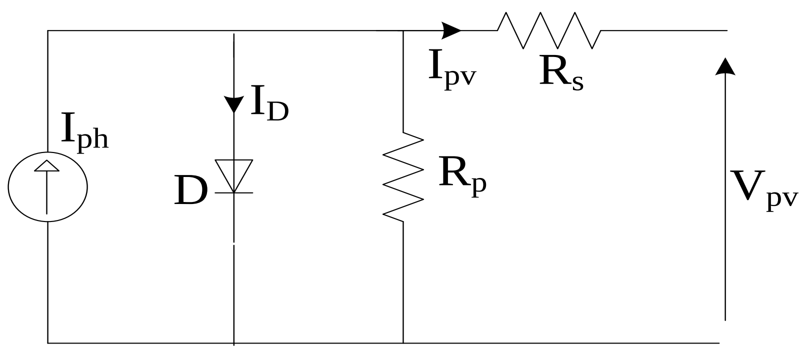



Fig. 2.3 Equivalent circuit of photovoltaic cell

The design of solar PV panel is modeled by the equation given below:

$$I_{pv} = n_p I_{ph} - n_p I_{sat}\left[exp\left(\left(\frac{q}{AKT}\right)\left(\frac{V_{pv}}{n_s} + I_{pv}R_s\right)\right) - 1\right] \quad (2.1)$$

$$I_{ph} = \left(I_{sso} + k_i(T - T_r) * \frac{s}{1000}\right) \quad (2.2)$$

$$I_{sat} = I_{rr}\left(\frac{T}{T_r}\right)^3 exp\left(\left(\frac{qE_{gap}}{kA}\right) * \left(\frac{1}{T_r} - \frac{1}{T}\right)\right) \quad (2.3)$$

where $I_{pv}$ is Photovoltaic current, $n_p$ & $n_s$ is Number of cells in parallel and series, $I_{ph}$ is photocurrent, $I_{sat}$ is reverse saturation current, q is electron charge which is 1.602 x 10-19 C, A is ideality factor, K is Boltzman constant which is 1.38 x 10-23 J/K, T is temperature of the PV, $V_{pv}$ is photovoltaic voltage, $R_s$ is series resistance of PV cell, $I_{sso}$ is short-circuit current, $k_i$ is short circuit current temperature coefficient, $T_r$ is Reference temperature which is 300 K, $s$ is Solar irradiation level, $I_{rr}$ is Reverse saturation current at $T_r$, $E_{gap}$ is Energy of the band gap for silicon which is 1.12 eV [2].

The peak power capacity of solar PV array is considered around 1.4kW in this work. As indicated by structure consideration one solar module has $V_{oc}$ of 53.9V and $I_{sc}$ of 3.41A. The general equation of an active (P) power for solar photovoltaic is given below,

$$P_{maxM} = V_{mppM} * I_{mppM} \tag{2.4}$$

$P_{max}$ = (85% of $V_{oc}$ * 85% of $I_{sc}$) thus $I_{mppM}$ is 2.89A and $V_{mppM}$ is 45.89V of every module. The measured peak power is give below,

$$P_{maxM} = V_{mppM} * I_{mppM} = 1442W \tag{2.5}$$

It demands peak input voltage of 122.4V and peak input current of 11.78A equivalent to maximum power of 1442W, to reach up to this voltage (122.4/53.9) and current (11.78/2.89) 3 modules are associated in series and 4 are associated in parallel respectively [3]. $V_{oc}$ is open circuit voltage, $I_{sc}$ is short circuit current, $P_{max}$ is maximum power, $V_{mpp}$ is maximum voltage, $I_{mpp}$ is maximum current.

**2.3.2 Design of DC-DC Boost Converter**

The DC-DC boost converter is constructed to increase the voltage and the maximum voltage is followed by IC (Incremental conductance) control method [24] which is 122.4V and this voltage is boosted up to 380V. Parameters of the boost converter are as per following:

$$L_b = \frac{V_{pv}D}{2\Delta i_1 f_{sh}} \tag{2.6}$$

$$D = 1 - \frac{V_{in}}{V_b} \tag{2.7}$$

Where $L_b$ is input inductor, $D$ is duty cycle, $V_{in} = V_{pv}$ is solar PV output voltage, $\Delta i_1$ is input current ripple and $f_{sh}$ is the switching frequency.

$$V_{in} = V_{pv} = 122.4V \text{ to } V_{dc} = 380V \tag{2.8}$$

The measured value of $D$ is 0.678 and for this converter value of $f_{sh}$ is 10KHz and input current ripple is considered as 10% of input current $I_1$.

$$I_1 = P/V_{in} = 11.78A \text{ and } \Delta i_1 = 1.178A \tag{2.9}$$

The value of input inductor $L_b$ is calculated and selected slightly higher value as 5mH

### 2.3.3 Modelling of Battery Energy Storage

Batteries are an important element in any standalone PV system. As different sorts of batteries are accessible in the market. Most regularly connected in EVs among all are the lithium-ion batteries because of huge energy thickness, long- life stable operation. Equivalent circuit of lithium-ion batteries is displayed in Fig. 2.4.

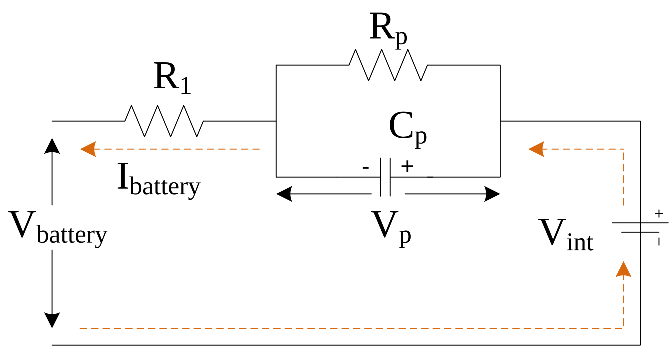



Fig. 2.4 Model of lithium-ion battery

| | | |
|---|---|---|
| Where: $R_p$ | = | parasitic resistance |
| $C_p$ | = | parasitic capacitance |
| $V_{int}$ | = | internal voltage |
| $R_1$ | = | internal resistance |

When the battery is energized the parallel RC network appeared in Fig. 2.4 depicts the transient state of the battery [4]. Subsequently, there will be a few reductions happening over the internal resistance of the battery during this situation. Along these lines, voltage over the battery isn't equal as that of internal battery voltage. Fig. 2.5 shows equivalent circuit of the battery.

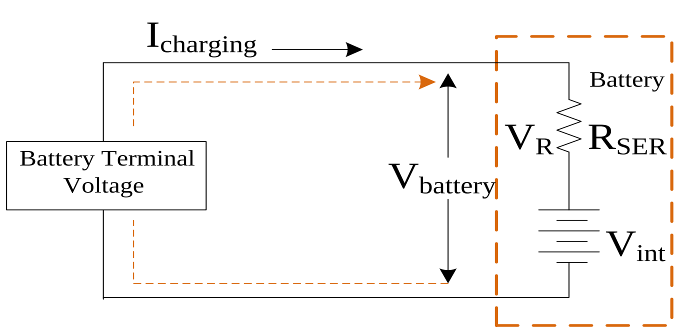



Fig. 2.5 Equivalent Circuit of Battery

$$V_R = I_{charging} * R_{SER} \tag{2.10}$$

Therefore,

$$V_{battery} = V_R + V_{int} \tag{2.11}$$

Hence,

$$V_{battery} = V_{int} + I_{charging} * R_{SER} \tag{2.12}$$

Also, cell charge battery voltage is given as,

$$V_{battery} = \frac{1}{C_{cell}} \int I_{charging} dt + V_{int} + I_{charging} * R_{SER} \tag{2.13}$$

The maximum cut-off voltage of the lithium-ion battery $V_{Battery\ cutoff}$ can be calculated using equation (2.13) as,

$$\Delta t = \frac{1}{I} (V_{battery\,cutoff} - V_{int} - V * C) \tag{2.14}$$

Hence, equation (2.14) represents the charge time taken by the battery. Here, $V_{int}$ is the intial battery voltage before charging, $R_{SER}$ is the series equivalent resistance of the battery.

### 2.3.4 Design of Bidirectional AC-DC converter

The fundamental idea of vehicle-to-grid power is utilized in electric drive vehicles. When the electric vehicle is parked or left, at that time electric vehicle can provide electric power to the AC grid. When connections are made to enable this electricity to pass to grid from electric vehicle, then it is called vehicle to grid (V2G) energy transfer but when connections are made for battery charging of electric drive vehicles from grid, then it is named as Grid to Vehicle (G2V) energy transfer [8].

The connection between the bidirectional AC-DC converter and grid is the main concern when the electricity transfers from the grid and to the grid. As appeared in Fig.2.2 during the investigation, electricity from the grid to a bidirectional AC-DC converter is appraised as the direction of the current is positive.

$$v_s(t) = \sqrt{2} V_s \sin(\omega t) \tag{2.15}$$

The voltage of grid is observed as sinusoidal and it is given by the equation (2.15). The fundamental component of converter and Grid current is given as below;

$$v_c(t) = \sqrt{2V_c \sin(\omega t - \delta)} \quad (2.16)$$

$$i_s(t) = \sqrt{2I_s \sin(\omega t - \theta)} \quad (2.17)$$

Where $v_s(t)$ is grid instantaneous voltage whose rms value is$V_s$. Fundamental component rms value is $V_c$ and $\delta$ is the angle between AC converter voltage and grid voltage. $\theta$ is the angle between AC converter voltage and grid current.

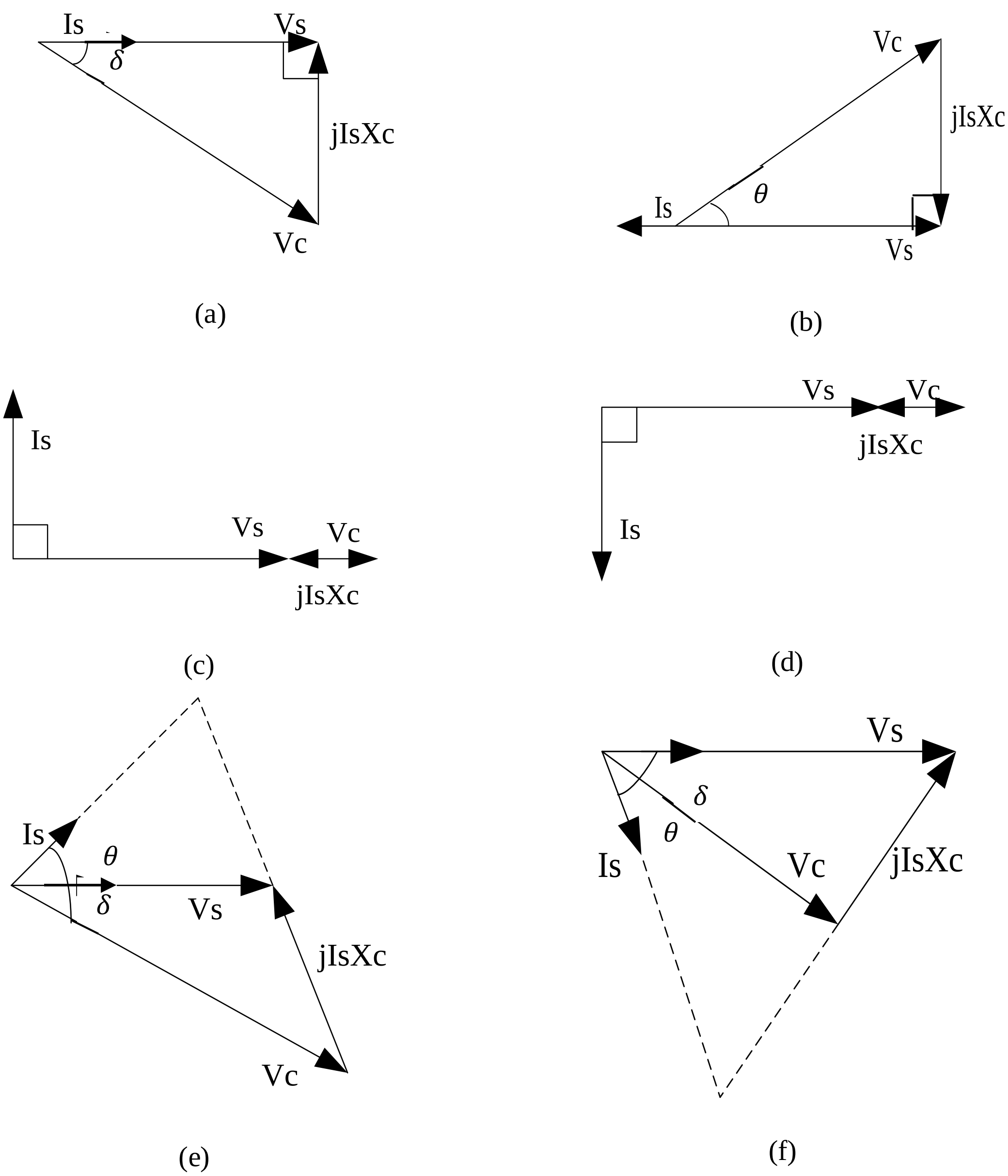



Fig. (2.6) Vector diagram for (a) Charging (**b**) Discharging (c) Inductive mode (d) Capacitive mode (e) Charging with capacitive mode (f) Charging with inductive mode

When $v_c(t)$ lags $v_s(t)$ Fig. 2.6 (a), active power supplied by the grid and $v_c(t)$ leads $v_s(t)$ Fig. 2.6 (b), active power sent to the grid. Grid current is sinusoidal because AC converter voltage and grid voltage is sinusoidal. The direction of the flow of reactive power decides the angle $(\theta)$ between grid current and AC converter voltage. Reactive power sent to the grid when angle $(\theta)$ is positive and reactive power supplied by the grid when angle $(\theta)$ is negative.

Bidirectional AC-DC converter is invented to converge the demand of bidirectional flow of power with increased power quality and good regulated DC link voltage. Fundamental voltage of converter $V_c$ is set by the below equation,

$$V_c = \frac{mV_{dc}}{\sqrt{2}} \tag{2.18}$$

Where $V_{dc}$ = 380V (DC link voltage)

m = 0.9 (modulation index)

The value of *Vc* is calculated as 241.86V. The grid inductance value is provided by the below equation and this equation is also named as relation between *Vc* and source voltage (*Vs*).

$$V_c = \sqrt{V_s^2 + (I_s^2 * X_l^2)} \tag{2.19}$$

Where *Vs* = 230V (source voltage or rms grid voltage)

The value of inductor is compute as 2.1mH.

## 2.4 CONCLUSION:

In this chapter, designing of the system configuration has been done. For the designing of solar PV array of 1.4kW, 3 modules are associated in series and 4 modules are associated in parallel. The DC-DC boost converter is constructed to increase the voltage and in this system voltage is boosted up to 380V. For the charging and discharging of the battery a bidirectional DC-DC buck-boost converter has been designed. For the grid connected system for electric vehicles AC grid is connected through a bidirectional AC-DC converter has been successfully designed.

# `CHAPTER 3

# CONTROL ALGORITHMS

## 3.1 OVERVIEW

This segment gives information about control methods for various blocks of proposed system. For the extracting maximum power from the solar PV array an Incremental conductance (INC) algorithm, for the charging and discharging of the battery an adaptive sliding mode controller based on washout filter and for the bidirectional flow of energy in AC grid an inverting and rectifying mode controller has been designed. It assumes a significant job in the activity of such system and clarified as per following.

## 3.2 DESIGN OF INCREMENTAL CONDUCTANCE BASED MPPT

MPPT (maximum power point tracking) is utilized to obtain the extreme power from sun irradiance. MPPT cooperates with DC-DC boost converter to control the duty cycle (D) of the boost converter by following the maximum current and voltage of solar PV system [24]. Incremental conductance (INC) based MPPT algorithm for solar PV system is developed here.

The equation for implementing the INC algorithm can be easily gotten from the basic power equation. The equation for power is given as,

$$P = V * I \tag{3.1}$$

Differentiating the above equation with respect to voltage. The condition for MPPT is that the incline dP/dV should be equal to 0 (zero).

$$\frac{\mathrm{dP}}{\mathrm{dV}} = 0 \tag{3.2}$$

$$\frac{\mathrm{dP}}{\mathrm{dV}} = \frac{\mathrm{d\,(V*I)}}{\mathrm{dV}} \tag{3.3}$$

$$\frac{\mathrm{dP}}{\mathrm{dV}} = \mathrm{I} + \mathrm{V} * \left(\frac{\mathrm{dI}}{\mathrm{dV}}\right) \tag{3.4}$$

Therefore,

$$I + V * \left(\frac{dI}{dV}\right) = 0 \tag{3.5}$$

Hence,

$$\frac{dI}{dV} = -\left(\frac{I}{V}\right) \tag{3.6}$$

Fig. 3.1 shows the P-V characteristics of the solar photovoltaic array and it is clear that the curve at the maximum power point is 0 (zero).

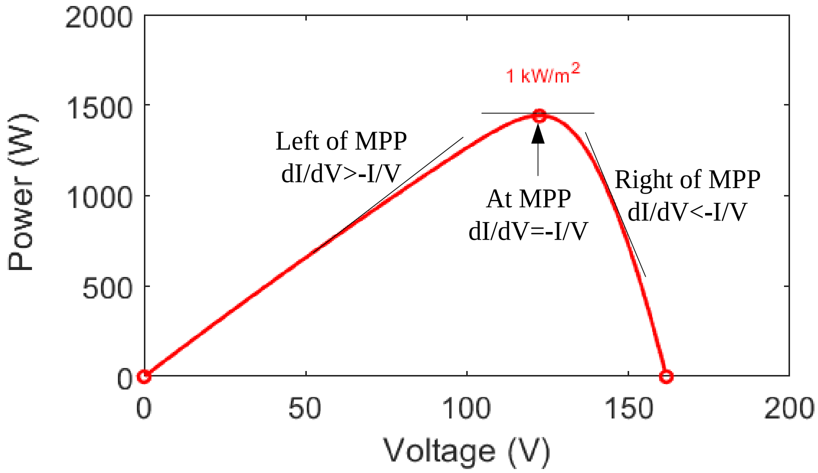



Fig. 3.1 Basic diagram of an INC method on P-V characteristics of the solar PV module

It is clear from the Fig. 3.1 that the curve from left side is increasing and from right side it is decreasing and the equations (3.6) can be written as:

$$\frac{dI}{dV} = -\left(\frac{I}{V}\right) \quad \text{At maximum power point} \tag{3.7}$$

$$\frac{dI}{dV} > -\left(\frac{I}{V}\right) \quad \text{Left of maximum power point} \tag{3.8}$$

$$\frac{dI}{dV} < -\left(\frac{I}{V}\right) \quad \text{Right of maximum power point} \tag{3.9}$$

Where $I$, $V$ and $P$ are the output current, voltage and power of the solar PV array respectively. The duty cycle (D) is determined, as stated by maximum power point tracking algorithm. The flow chart explaining the INC algorithm is appeared in Fig. 3.2

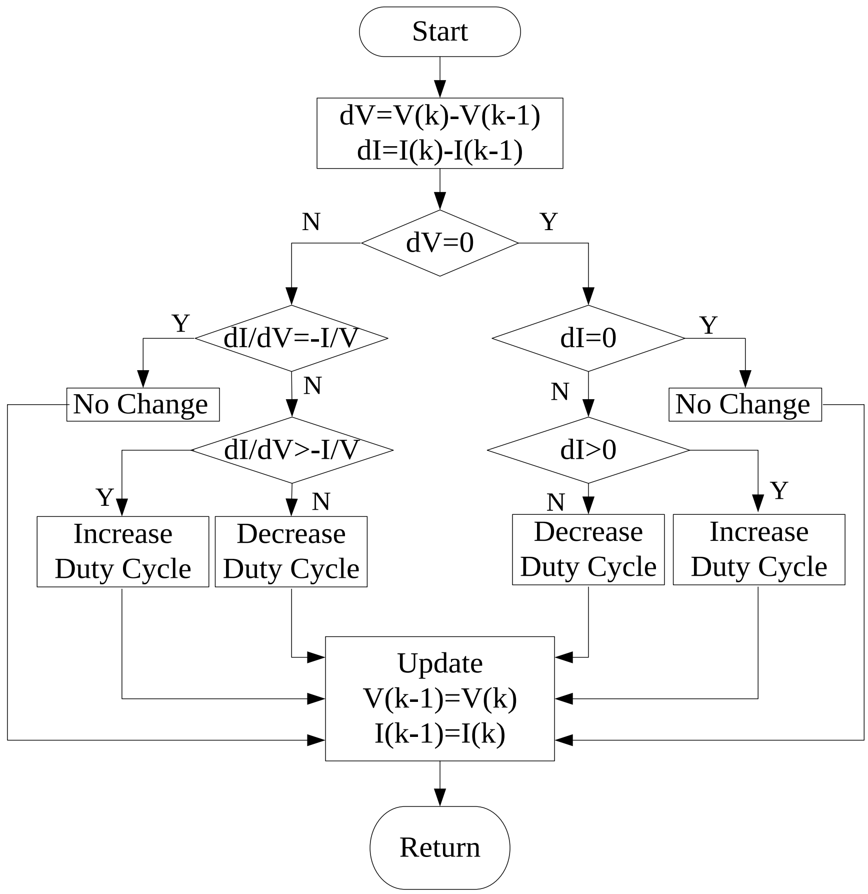



Fig. 3.2 Incremental conductance flow chart

## 3.3 DESIGN OF SLIDING MODE CONTROLLER BASED ON WASHOUT FILTER

As to obtain the ideal task of battery, a DC-DC buck-boost bidirectional converter is utilized. A SMC based on washout filter is utilized to control $I_b$.

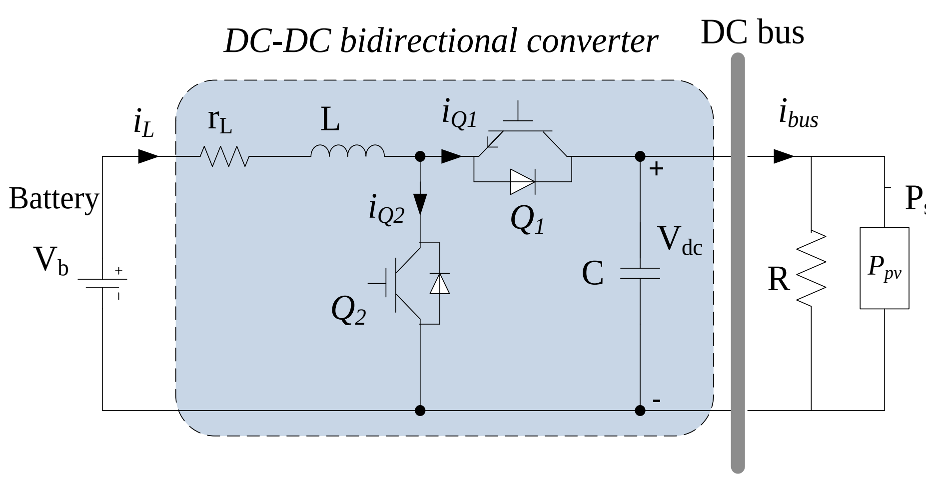



Fig. 3.3 Simplified model of PV-battery model

Battery storage converter is planned to keep up power stability of the system and the battery is viewed as a perfect DC voltage source. Fig. 3.3 shows the simplified model of solar PV-battery model. By this we can calculate bus current ($i_{bus}$) and equivalent resistive load ($R_{eq}$).

$$i_{bus} = \frac{V_{dc}}{R} + \frac{P}{V_{dc}} \tag{3.10}$$

$$R_{eq} = \frac{V_{dc}}{i_{bus}} \tag{3.11}$$

| | | |
|---|---|---|
| Where $V_{dc}$ | = | DC bus voltage |
| $V_b$ | = | Input battery voltage |
| $i_L$ | = | Inductor current |
| $r_L$ | = | Series resistor of the inductor |
| Q1 & Q2 | = | Control input switches |
| $i_{bus}$ | = | DC bus current |
| R | = | Equivalent resistive load |
| $P_s$ | = | Source power |

This equation can create two situations, in first, when the generated power is greater than or equal to the power demand then load can directly feeds through source power; mean $\{|P_s| \geq |P_L|\}$. In second, when the generated power is less than power demand than a small disturbance can occur in voltage and current; means$\{|P_s| < |P_L|\}$. [21]

So the equivalent load is not linear and because of the varieties in accessible energy source, load can fluctuate over a wide scope of bends. That's why a nonlinear examination is required for a stable operation.

The dynamics of this model can be represent as

$$\frac{di_L}{dt} = \frac{1}{L}[V_b - r_L i_L - uV_{dc}] \tag{3.12}$$

$$\frac{dV_{dc}}{dt} = \frac{1}{C}\left[ui_L - \frac{V_{dc}}{R} - \frac{P}{V_{dc}}\right] \tag{3.13}$$

In which, u is a control input modeled for switches Q1 and Q2. We assume when Q1 switch is on then Q2 is off and when Q2 is on then Q1 is off. Therefore $u \in \{0,1\}$.

The dynamics can be simplified by scaling the system in amplitude and time.

As $t = \tau\sqrt{LC}$ and $\{i_L, V_{dc}\} = \left\{\sqrt{\frac{C}{L}}V_b x, V_b y\right\}$ respectively.

$$\frac{dx}{d\tau} = 1 - bx - uy \tag{3.14}$$

$$\frac{dy}{d\tau} = ux - ay - \frac{d}{y} \tag{3.15}$$

Where $a = \frac{1}{R}\sqrt{\frac{L}{C}}$; $b = \sqrt{\frac{C}{L}}r_L$ ; $d = \sqrt{\frac{L}{C}}\frac{P}{V_b^2}$

Where $P$ is the variation between generated power and load demand as $P_{BES} = P = P_S - P_L$

The Sliding Mode Control based on Washout filter is provided all together to accomplish the following targets:

(1) To regulate DC bus voltage

(2) To reduce the transient response during the changing load

(3) To guarantee robustness under changes.

When the standardized inductor current $x$ is gone through a washout filter then we get another signal $x_F$. Transfer function of $x_F$ is given as,

$$G_F(s) = \frac{X_F(s)}{X(s)} = \frac{s}{s+\omega_n} = \frac{1-\omega_n}{s+\omega_n} \tag{3.16}$$

Where $\omega_n$ is the cut off frequency of this filter. In this way, the consideration of the filter include to equation an extra differential condition given by,

$$\frac{dz}{dx} = \omega_n(x - z) \tag{3.17}$$

Where $z = x\text{-}x_F$. Representation of the sliding surface which utilized is given as follows.

$$h_n = y - y_r + k_n(x - z) \tag{3.18}$$

Where $y_r$ is the desired DC link voltage, $k_n$ is positive scalar control parameter, z is the lower frequency part of signal x. Control input $u$ for switch control is given as,

$$u = \begin{cases} u^+ = 1, if\ h_n(x) > \mu \\ u^- = 0, if\ h_n(x) < -\mu \end{cases} \tag{3.19}$$

Where $\mu$ is constant which limits the hysteresis band is expressed as,

$$\mu = \frac{V_b(V_{dc} - V_b)}{2Lf_sV_{dc}} \tag{3.20}$$

Now it's important to denormalize the factors of the system.

$$\omega = \frac{\omega_n}{\sqrt{LC}} \tag{3.21}$$

$$k = k_n\sqrt{\frac{L}{C}}$$

After all the parameters have been resolved, the estimations of those parameters are at that point connected in the control block. Calculated parameters are as follows

C = $50\mu F$ (Capacitance)

L = 2.5mH (Inductance)

$r_L$ = 5mΩ (Inductor series resistance)

$f_s$ = 100kHz (Switching frequency)

$\mu$ = 0.3796A (Hysteresis band)

$V_b$ = 196V (Battery voltage)

$V_{dc}$ = 380V (DC link capacitor voltage)

$\omega$ = 283rad/s (cut-off frequency)

k = 10 (scalar parameter)

Q = 150Ah (Battery capacity)

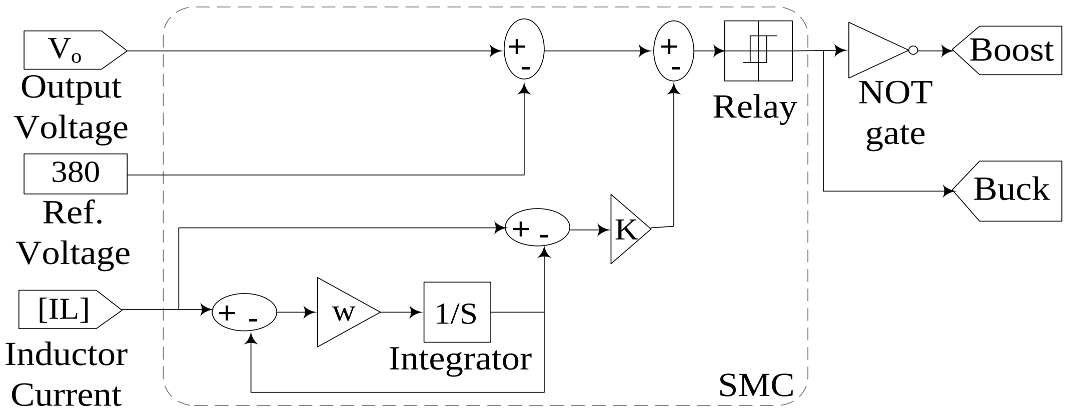



Fig. 3.4 Simulation diagram of sliding mode controller based washout filter

### 3.4 Design of Control for Bidirectional Single-Phase AC-DC Converter

A power flow between AC grid and DC bus are empowered. Bidirectional power converter has an indispensable job to empower a conversable power flow in the microgrid. As long as energy transformation between AC grid and DC bus is required, power converter must be capable to supply bidirectional flow of energy like inversion as well as rectification. In rectification mode control, energy transferred from AC grid to DC bus and in inverting mode control, energy transferred from DC bus to AC grid. This process works in three steps. First is "mode selector" which decides when the inverting and rectifying mode should be done, second is "inverting mode" in which power flow from DC bus to Ac grid and third is "rectifying mode" in which power flow from AC grid to DC bus [25].

**3.4.1 Mode Selector:** Fig. 3.5 demonstrates a logic circuit. This logic circuit decides when the inverting and rectifying mode should be done. The mode of the operation of bidirectional single phase AC-DC converter is decided by a mode selector circuit which decides the mode of operation of converter based on PV output power and battery SOC %.

**3.4.1.1 Working:** If the %SOC is greater than 70 and the solar PV power is insufficient, the converter operates in inverting mode and the battery send the required power back to the AC grid. If the %SOC is less than 70 but solar PV power is sufficient the converter operates in inverting mode and the PV provides power both for charging the battery and sending power to the grid. If %SOC is less than 70 and PV power is insufficient, in that case the converter will operate in rectifying mode to provide necessary power to charge the battery.

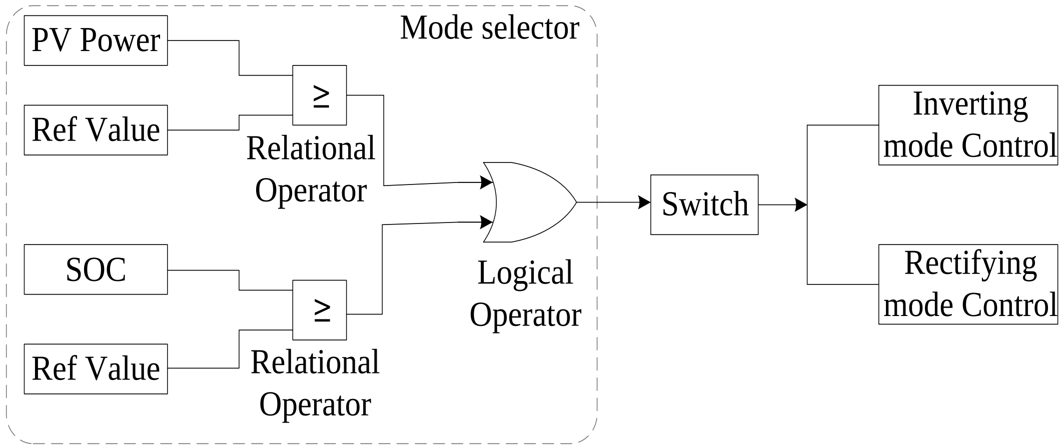



Fig. 3.5 Mode Selector

**3.4.2 Inverting mode control:** Fig. 3.6 shows a grid connected control technique for inverting mode control. It is a type of closed-loop system. Phase-locked loop and the current controller are the fundamental parts of this circuit. Phase-locked loop generates an output signal and the phase of this signal is related with the phase of an input signal. Here synchronization of the current with voltage is done by phase-locked loop. Synchronization between induced sine wave and AC grid phase angle is done by phase-locked loop. In inverting mode, phase-locked loop is also utilized to calculate the required amount of active and reactive power provided to the AC grid side. An inverter output current is controlled by hysteresis current controller. In this scheme a double band hysteresis current controller is utilized. The output current of an inverter is synchronized with the AC grid voltage by utilizing this control technique. By the required power factor angle we can decide the phase angle betwixt AC grid voltage and AC grid current. The active and reactive powers required by the AC grid is decides the value of current reference and the output AC grid current is then compared with this current reference value.

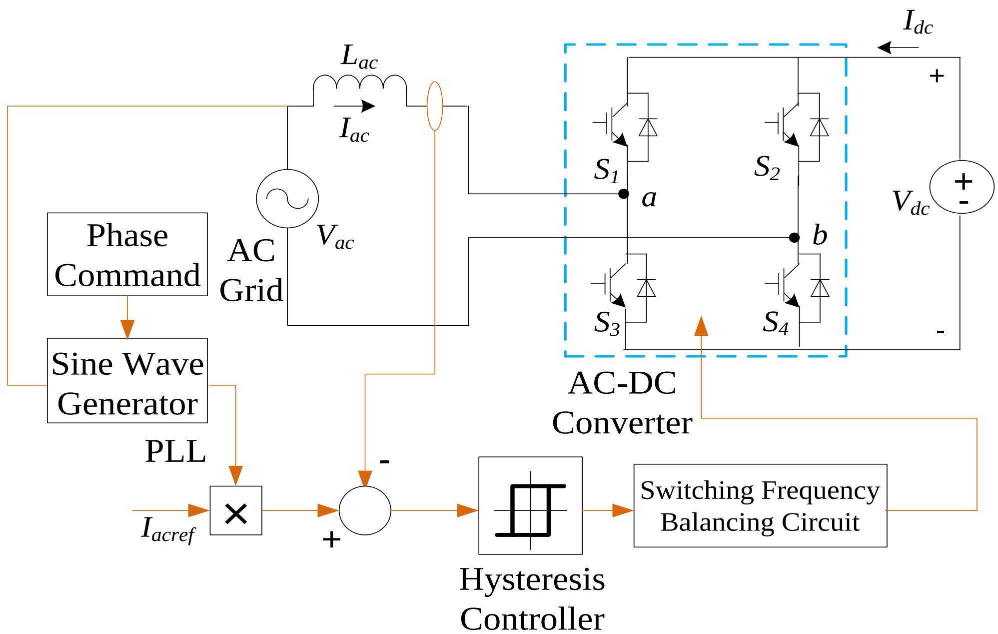



Fig. 3.6 Schematic diagram of single phase inverting mode control

### 3.4.2.1 Double band hysteresis current controller:

The idea of double band hysteresis current controller is expressed in Fig. 3.7. The output current of the inverter is controlled using three levels. The DC bus voltage which is input voltage is varied from $+V_{dc}$ to 0 and 0 to - $V_{dc}$.

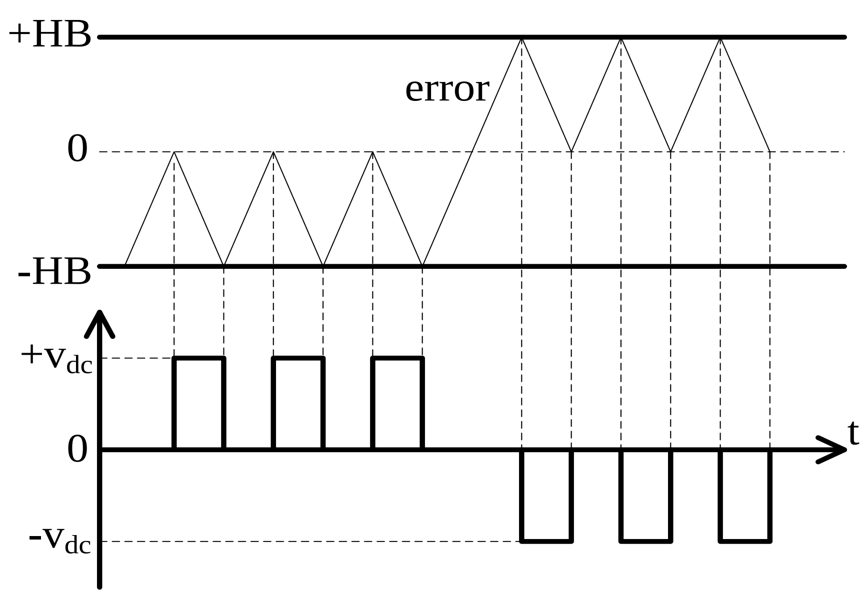
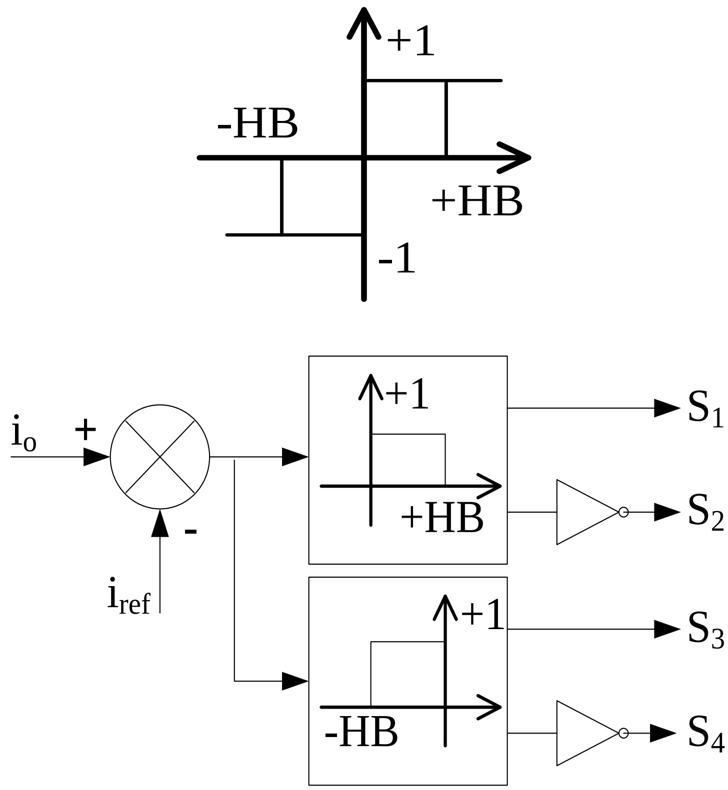



Fig. 3.7 Double band hysteresis current control technique

The block diagram of double band hysteresis current controller is shown in Fig. 3.8. The hysteresis band is separated by two uniform levels, which is *–HB* to 0 and 0 to *+HB*.




(b)

Fig. 3.8 Block diagram of double band hysteresis current controller

The switching frequency of the double band hysteresis current controller is determined as follows,

$$T_{ON} = \frac{L_f HB}{V_{dc} - V_g} \tag{3.22}$$

During the $T_{on}$ period (positive cycle) $S_1$ and $S_4$ switches will ON and the variation in voltage as $+V_{dc}$ to *0*. $S_2$ and $S_3$ switches will ON during $T_{OFF}$ period which forms $V_{dc}$ zero. During the negative cycle same procedure will be followed. Hence, $T_{off}$ period is expressed as,

$$T_{OFF} = \frac{L_f HB}{V_g} \tag{3.23}$$

Where $L_f$ is AC side inductor, *HB* is hysteresis band, $V_{dc}$ is DC bus voltage, $V_g$ is grid voltage.

$$T_s = T_{ON} + T_{OFF} \tag{3.24}$$

$$T_s = \frac{2V_{dc}L_fHB}{(V_{dc}-V_g)(Vg)} \tag{3.25}$$

Switching frequency of double band hysteresis current controller which is $f_s^{DBHCC}$ determined as,

$$f_s^{DBHCC} = \frac{1}{T_s} \tag{3.26}$$

$$f_s^{DBHCC} = \frac{(V_{dc}-V_g)(Vg)}{2V_{dc}L_fHB} \tag{3.27}$$

$$f_s^{DBHCC} = \frac{(V_{dc}.V_g - V_g^2)}{2V_{dc}L_fHB} \tag{3.28}$$

$$f_s^{DBHCC} = \frac{V_{dc}\left(\frac{V_g}{V_{dc}} - \frac{V_g^2}{V_{dc}}\right)}{2L_fHB} \tag{3.29}$$

$$f_s^{DBHCC} = \frac{V_{dc}\left(Ksin(\omega t) - K^2 sin^2(\omega t)\right)}{2L_fHB} \tag{3.30}$$

Where $V_g = V_m sin(\omega t)$ and $K = \frac{V_m}{V_{dc}}$

Maximum frequency of switching is obtained at $\frac{2}{\pi}$ . So the average switching frequency is determined as,

$$f_{s,av}^{DBHCC} = \frac{V_{dc}}{2L_fHB}\left(\frac{2}{\pi}K - \frac{1}{2}K^2\right) \tag{3.31}$$

**3.4.3 Rectifying mode control:** Fig. 3.9 shows a control technique for rectifying mode control. Phase-locked loop and the current controller are the fundamental parts of this circuit. Phase-locked loop generates an output signal and the phase of this signal is related with the phase of an input signal. In rectifying mode, when the AC current is synchronized, unity power factor is obtained at the input side and this synchronization is done by the phase-locked loop. As appeared is Fig. 3.9, input current of the rectifier is formed by the hysteresis current controller. In this scheme a double band hysteresis current controller is utilized. The controlling of the input current of rectifier is done because it should be sinusoidal with unity power factor.

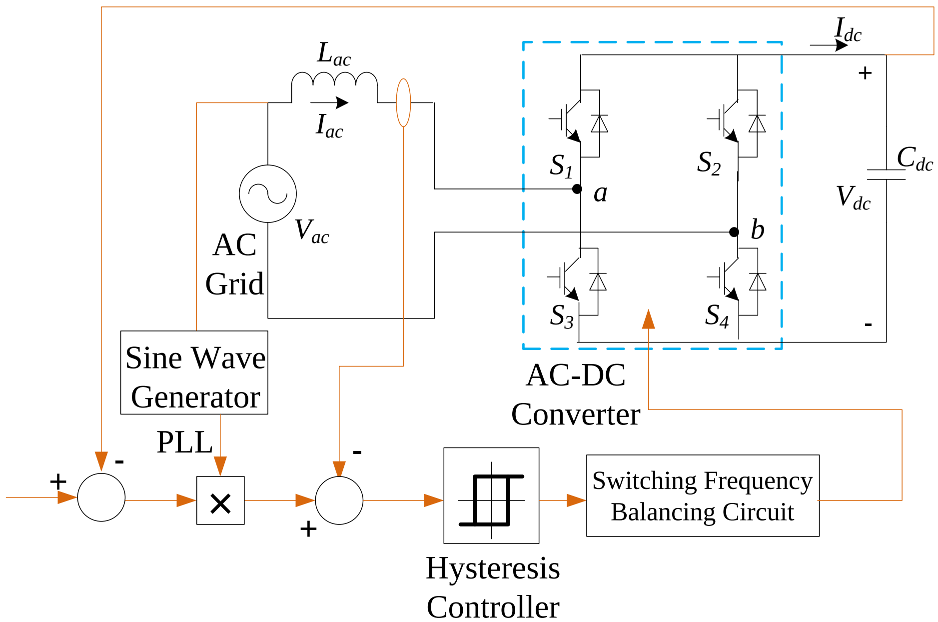



Fig. 3.9 Schematic diagram of single phase rectifying mode control

**3.5 CONCLUSION:**

In this chapter, control methods for various blocks of proposed system have been studied. For the tracking of solar PV power and controlling the duty cycle of boost converter, Incremental conductance MPPT has been implemented. For the bidirectional DC-DC buck-boost converter controlling a sliding mode controller based on washout filter has been implemented. For the controlling and managing of bidirectional AC-DC converter, inverting and rectifying mode has been designed.

# CHAPTER 4

# RESULTS AND DISCUSSION

## 4.1 INTRODUCTION:

Results of the isolated solar PV-battery power producing system and grid connected system for electric vehicle are explained in this segment. Isolated system includes solar photovoltaic array, boost converter, BESS (bidirectional power flow) and resistive load. Grid connected system for electric vehicle includes solar photovoltaic array, boost converter, BESS (bidirectional power flow) and AC grid connected through bidirectional AC-DC converter.

## 4.1 ISOLATED SOLAR PV BATTERY SYSTEM:

MATLAB simulation is performed to prove the SMC based on washout filter in the isolated system. Results are obtained as the comparison of conventional proportional-plus integral control method with sliding mode controller based on washout filter.

**4.1.1 Case study:** There are three cases which have been performed. Table 4.1 shows the system parameters planned for the simulation.

Table 4.1 System parameters for simulation design

| Sr. No. | Parameters | Value | Units |
|---|---|---|---|
| 1. | Solar PV power ($P_{pv}$) | 1.4 | kW |
| 2. | Capacitance (C) | 50 | $\mu$F |
| 3. | Inductance (L) | 2.5 | mH |
| 4. | Inductor resistance ($r_L$) | 5 | mΩ |
| 5. | Hysteresis band ($2\delta$) | 0.3796 | A |
| 6. | Battery voltage ($V_b$) | 196 | V |
| 7. | Initial capacitor voltage ($V_c$) | 196 | V |
| 8. | Cut-off frequency ($\omega$) | 283 | rad/s |
| 9. | Scalar control parameter (k) | 10 | - |
| 10. | Battery capacity (Q) | 150 | Ah |

**4.1.1.1 Performance of the system with variation in solar irradiance:** Depending upon the solar irradiance, power generated by the solar panel is vary with time. For these changes, various irradiance values for the solar-PV input power are simulated for this case. The main reason behind this case is to check the response of sliding mode controller whether it can give better response when the solar power is fluctuated. The peak power capacity of solar PV array is considered around 1.4kW in this work and the load is 210Ω. The total time of simulation run is 035s. Fig. 4.1 shows the output plot of PV module at 500 W/m$^2$ & 1000 W/m$^2$. Power balance in this case is as, when the irradiance is high that time load feeds through PV power and the surplus power goes in battery and when PV irradiance is low then PV generates less power and has insufficient power to feed the load, at that time load feeds through battery.

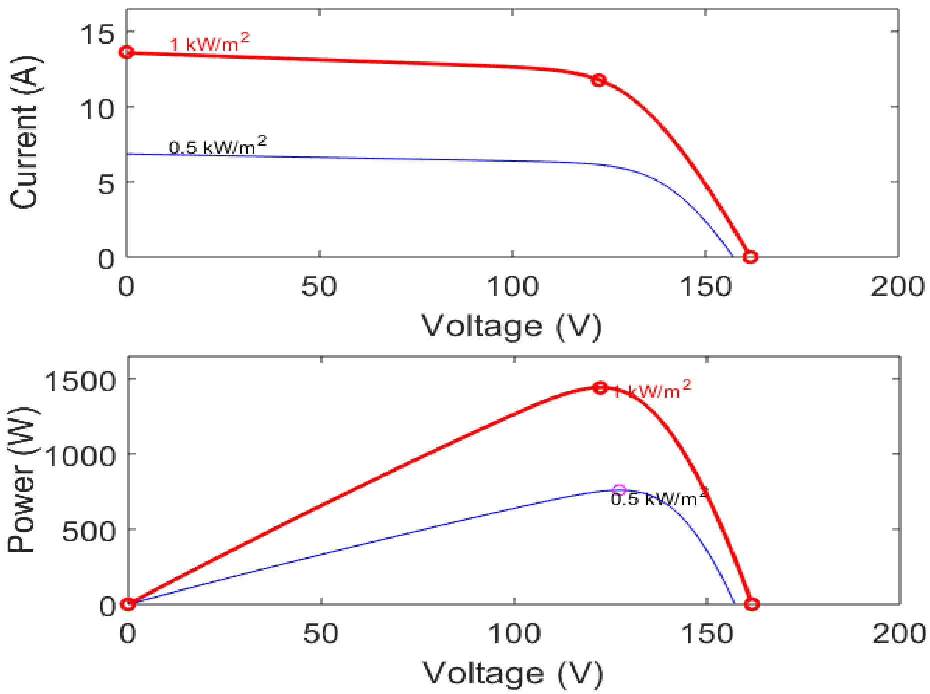



Fig. 4.1 P-V and I-V Characteristics of Solar photovoltaic Array

Results of the output voltage of DC link capacitor shown in fig. 4.2. Battery energy storage can mark the bus voltage with the variation in solar photovoltaic array. Inductor current simulation result is shown in figure 4.3. In this the Proportional-plus integral control moreover induces the comparative outcome with the Sliding mode control, main distinctive is proportional-plus integral control generates additional oscillation with the Sliding mode control when the transients occur. In Fig. 4.1 & 4.2 SMC drawn with red line and PI drawn with dashed blue line.

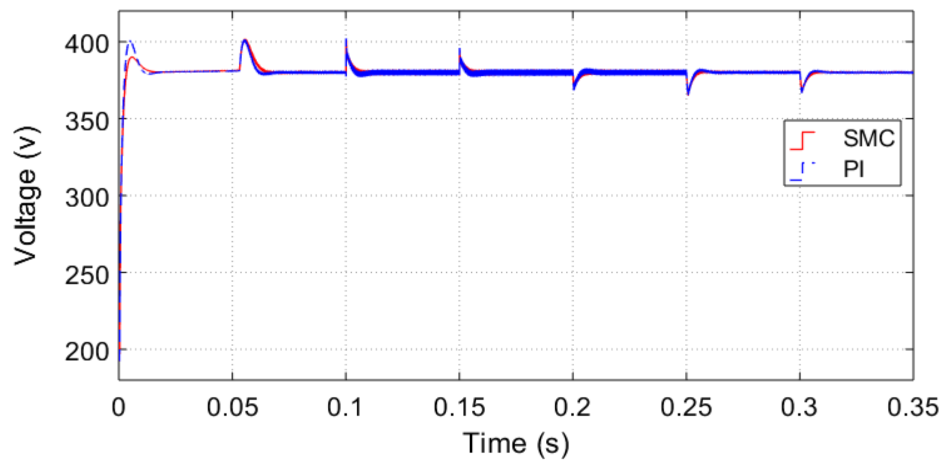



Fig. 4.2 Output voltage of DC link capacitor with in solar irradiance

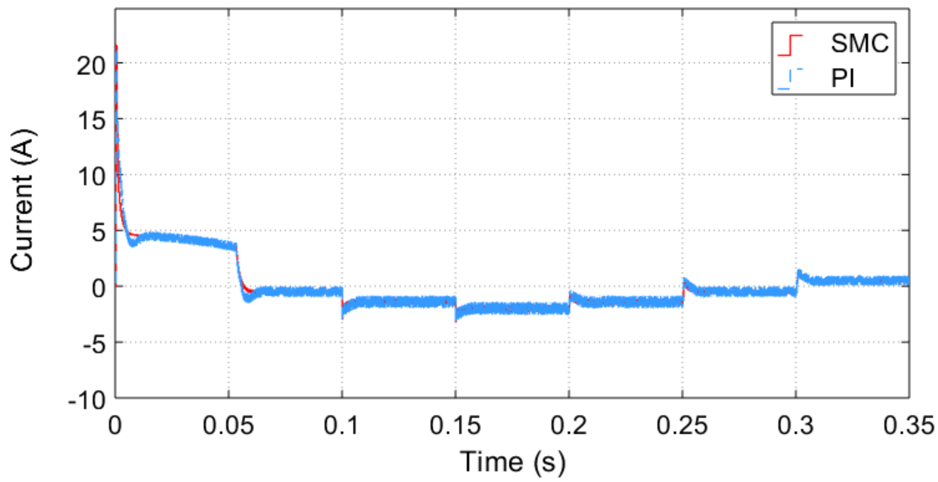



Fig. 4.3 Inductor current during variation in solar irradiance

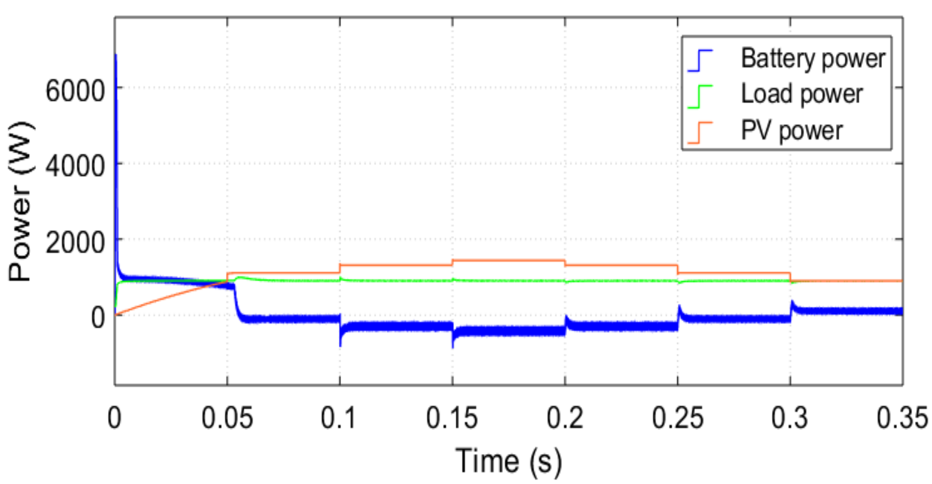



Fig. 4.4 Power Balance in Standalone Solar PV System

Fig. 4.4 shows the power balance in standalone mode. Consumption of the load power is around 657 W. Solar power, Battery power and load power drawn with red, blue and green respectively.

**4.1.1.2 Regulation of Voltage at DC Link with SMC and PI:** In this case the load is set as 160Ω and simulation time to run it up to 0.05sec. These result shows there is no overshoot in SMC when we compare it with PI and also SMC has faster settling time than PI. Fig. 4.5 shows DC link capacitor output voltage and Fig. 4.6 shows the inductor current results. PI drawn with dashed blue line and SMC drawn with red line.

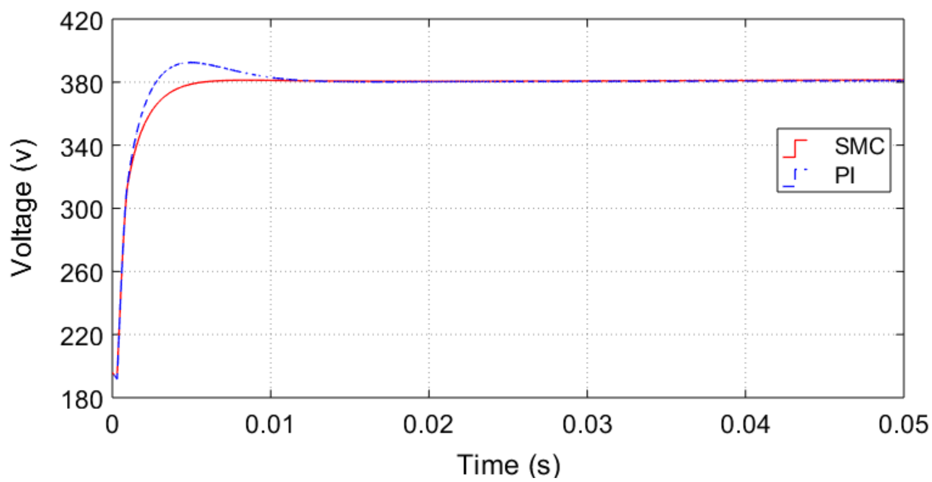



Fig. 4.5 Output voltage of DC link capacitor with DC bus voltage regulation

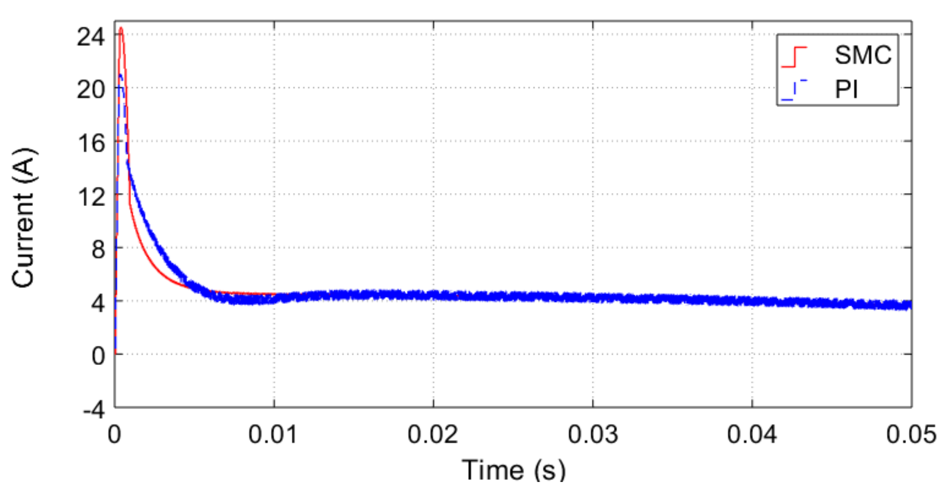



Fig. 4.6 Inductor current during DC bus voltage regulation

**4.1.1.3 Performance of the system with variation in load:** The result of load variety is examined in this section. In this case the load resistance will change the value as 350Ω, 250 Ω, 150 Ω , 250 Ω and 350 Ω sequentially with the time duration of 01sec and the total simulation time is 0.5s. Fig. 4.7 shows the DC link capacitor voltage and Fig. 4.8 shows the inductor current result. We can see when the resistance load is minimized then voltage dip is occurring in result and when resistance load is maximized then voltage swell is occurring. When the overshoot voltage and undershoot voltage is occur SMC has a little better results than PI control.

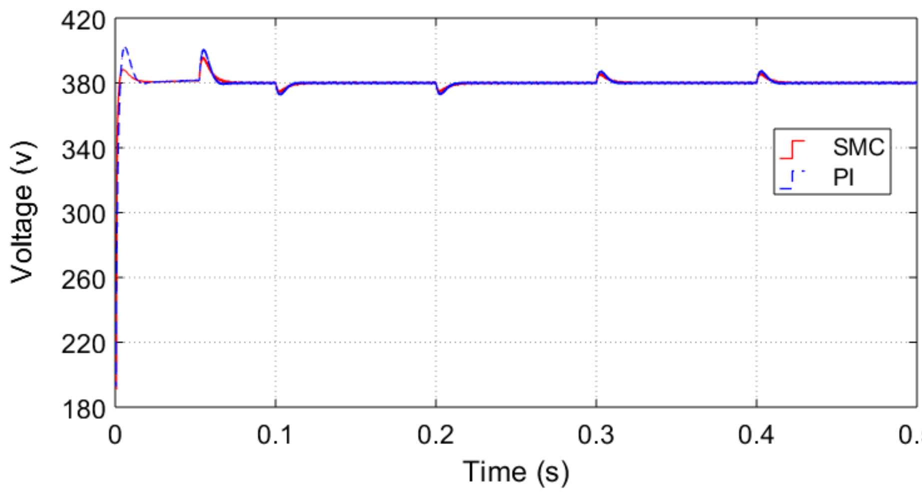



Fig. 4.7 Output voltage of DC link capacitor with variation in load

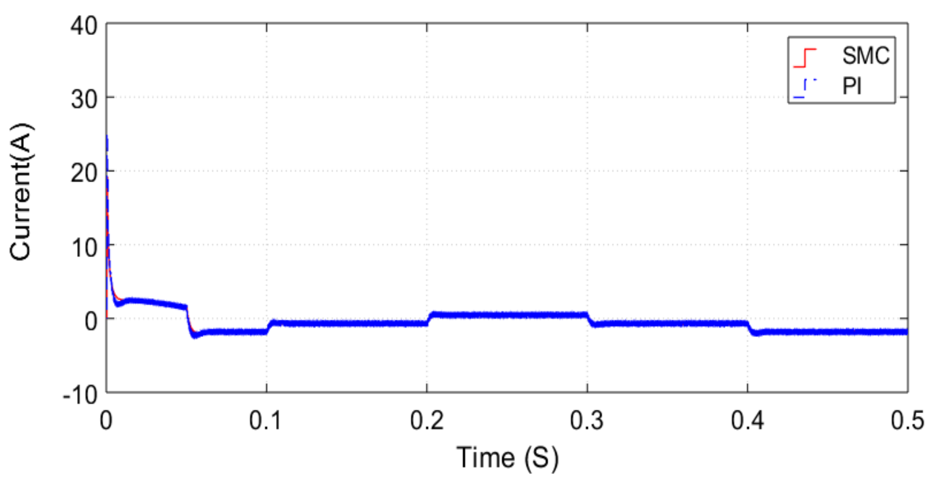



Fig. 4.8 Inductor current Results during variation in load

### 4.2 GRID CONNECTED SYSTEM FOR ELECTRIC VEHICLE:

MATLAB simulation is performed with the SMC based on washout filter for the controlling of bidirectional DC-DC buck-boost converter. Results are obtained as variation in solar irradiance and battery %SOC.

**4.2.1 Case study:** There are two cases based on %SOC which have been performed. Table 4.2 shows the system parameters planned for the simulation.

Table 4.2 System parameters for simulation design

| Sr. No. | Parameters | Value | Units |
|---|---|---|---|
| 1. | Solar PV power ($P_{pv}$) | 1.4 | kW |
| 2. | Capacitance (C) | 50 | $\mu$F |
| 3. | Inductance (L) | 2.5 | mH |
| 4. | Inductor resistance ($r_L$) | 5 | mΩ |
| 5. | Hysteresis band ($2\delta$) | 0.3796 | A |
| 6. | Battery voltage ($V_b$) | 196 | V |
| 7. | Initial capacitor voltage ($V_c$) | 196 | V |
| 8. | Cut-off frequency ($\omega$) | 283 | rad/s |
| 9. | Scalar control parameter (k) | 10 | - |
| 10. | Battery capacity (Q) | 150 | Ah |
| 11. | Grid voltage ($V_{grms}$) | 230 | V |
| 12. | Frequency (Hz) | 50 | Hz |
| 13. | Inductor at AC side ($L_{ac}$) | 2.1 | mH |
| 14. | DC bus voltage ($V_{dc}$) | 380 | V |

#### 4.2.1.1 Case 1: Battery is fully charged

In this case variation in solar PV irradiance level is 1000 W/m$^2$ and 500 W/m$^2$ and the battery %SOC is 100% means battery is already charged. In this case waveforms depicts as if the solar irradiance level is at 1000 W/m$^2$ and battery %SOC is 100% means, PV should feeds the AC grid and at 500W/m$^2$ or PV has less power than power should be flow from battery to grid. In both of cases bidirectional AC-DC converter should works in inverting mode. In this case if the battery is already fully charged then we can see the discharging process of the battery into the grid. Fig. 4.9 shows the starting and steady state response of solar PV current, voltage and power. Fig. 4.10 shows the dynamic behavior of the system. Varying irradiance level of solar PV is shown in Fig. 4.10. Fig. 4.10 demonstrates the tracking of voltage at maximum power point under different irradiance level. Fig. 4.10 depicts that if the irradiance of the solar PV is going to decrease then solar PV current ($I_{pv}$) and solar PV power ($P_{pv}$) is also decreased with constant solar PV voltage ($V_{pv}$). Fig. 4.10 also demonstrates that when solar irradiance level going to decrease battery current is increased because at this point power flow from battery to grid and battery is going to discharge.

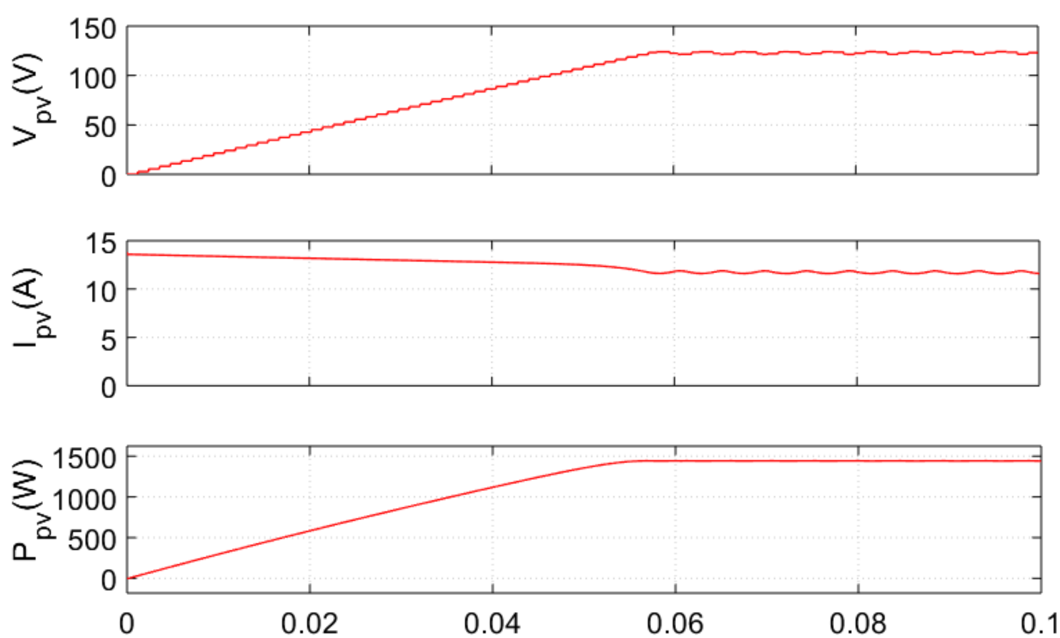
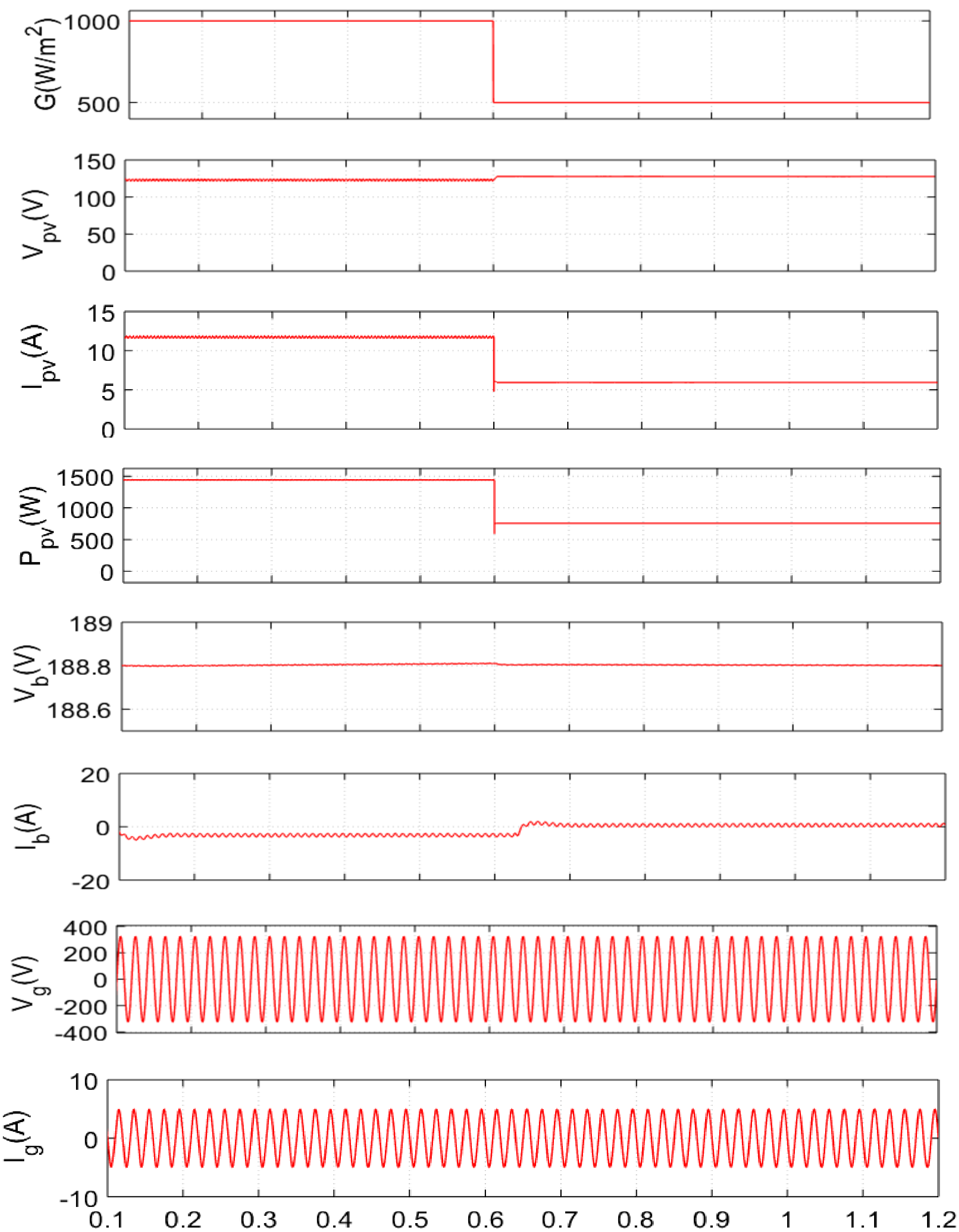



Fig. 4.9 Starting response of PV current, voltage and power (SOC is 100%)




4.10 Dynamic response of system parameters under varying irradiance and SOC is 100%

#### 4.2.1.2 Case 2: Battery is discharged

In this case variation in solar PV irradiance level is 1000 W/m$^2$ and 500 W/m$^2$ and the battery %SOC is 20% means battery is already discharged. In this case waveforms depicts as if the solar irradiance level is at 1000 W/m$^2$ and battery %SOC is 20% means, PV should feeds the battery and surplus power should go in AC grid, and at 500W/m$^2$ or PV has less power than power should be flow from grid to battery. When PV irradiance level is 1000 W/m$^2$ than bidirectional AC-DC converter should works in inverting mode, and when PV irradiance level is 500W/m$^2$ bidirectional AC-DC converter should works in rectifying mode, means power should flow from grid to battery. In this case if the battery is already discharged then we can see the charging process of the battery from the grid. Fig. 4.11 shows the starting and steady state response of solar PV current, voltage and power. Fig. 4.12 shows the dynamic behavior of the system. Varying irradiance level of solar PV is shown in Fig. 4.12. Fig. 4.12 demonstrates the tracking of voltage at maximum power point under different irradiance level. Fig. 4.12 depicts that if the irradiance of the solar PV is going to decrease then solar PV current ($I_{pv}$) and solar PV power ($P_{pv}$) is also decreased with constant solar PV voltage ($V_{pv}$). Fig. 4.12 also demonstrates that when solar irradiance level going to decrease battery current is also decreased because at this point power flow from grid to battery and battery is going to charge.

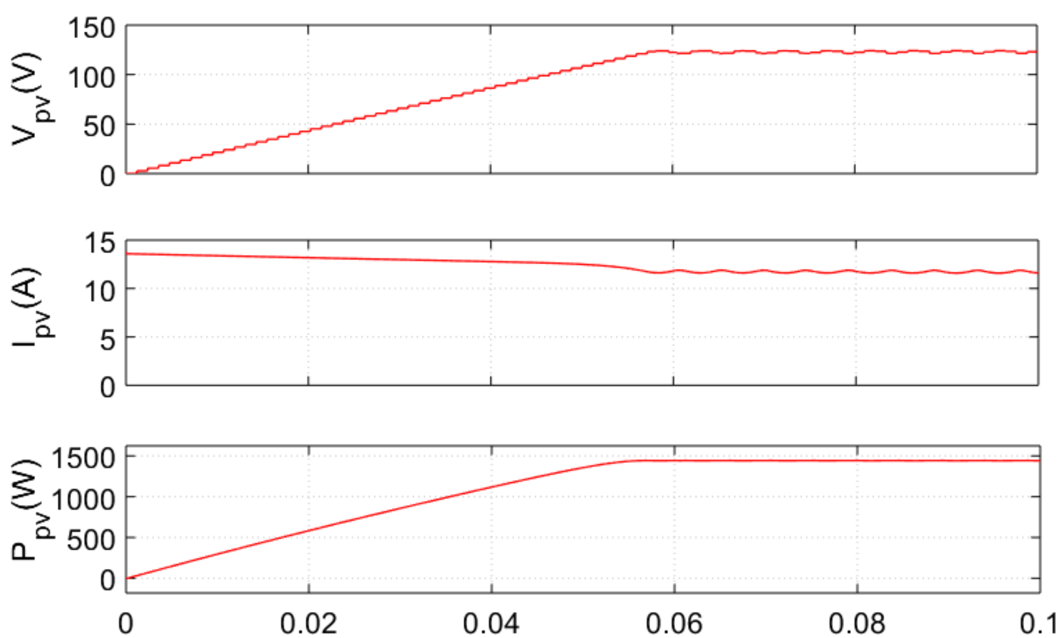
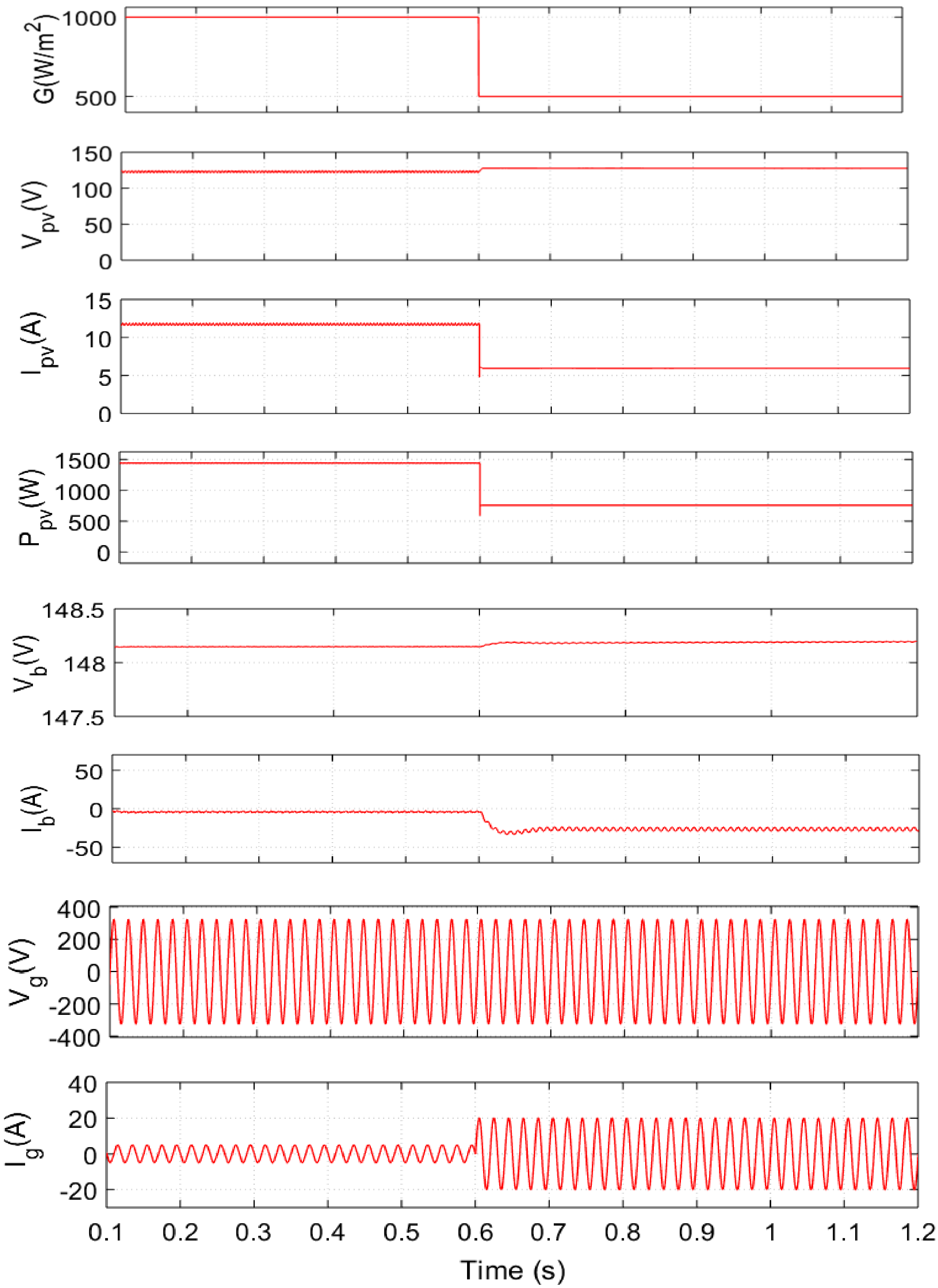



Fig. 4.11 Starting response of PV current, voltage and power (SOC is 20%)




4.12 Dynamic response of system parameters under varying irradiance and SOC is 20%

Surbhi MEPS

ORIGINALITY REPORT

| 14% | 5% | 13% | % |
| --- | --- | --- | --- |
| SIMILARITY INDEX | INTERNET SOURCES | PUBLICATIONS | STUDENT PAPERS |

PRIMARY SOURCES

| | | |
| --- | --- | --- |
| 1 | Tahim, Andre P. N., Daniel J. Pagano, and Enrique Ponce. "Nonlinear control of dc-dc bidirectional converters in stand-alone dc Microgrids", 2012 IEEE 51st IEEE Conference on Decision and Control (CDC), 2012.<br>Publication | 1% |
| 2 | id.scribd.com<br>Internet Source | 1% |
| 3 | Arun Kumar Verma, Bhim Singh, D.T. Shahani. "Grid to vehicle and vehicle to grid energy transfer using single-phase bidirectional AC-DC converter and bidirectional DC-DC converter", 2011 International Conference on Energy, Automation and Signal, 2011<br>Publication | 1% |
| 4 | www.ajol.info<br>Internet Source | 1% |
| 5 | P.A. Dahono. "New current controllers for single-phase full-bridge inverters", 2004 International Conference on Power System | 1% |

Technology 2004 PowerCon 2004, 2004
Publication

| | | |
|---|---|---|
| 6 | Lecture Notes in Electrical Engineering, 2015.<br>Publication | 1% |
| 7 | Joao T. de Carvalho Neto, Andres O. Salazar, Andre L. Maitelli. "One Cycle Control applied to a stand-alone photovoltaic system for DC microgrid applications", IECON 2016 - 42nd Annual Conference of the IEEE Industrial Electronics Society, 2016<br>Publication | 1% |
| 8 | Bhim Singh, Shailendra Dwivedi, Utkarsh Sharma, Chinmay Jain. "Solar PV array fed direct torque controlled induction motor drive for water pumping", 2015 Annual IEEE India Conference (INDICON), 2015<br>Publication | <1% |
| 9 | pt.scribd.com<br>Internet Source | <1% |
| 10 | ijasem.org<br>Internet Source | <1% |
| 11 | "Power Electronics for Renewable and Distributed Energy Systems", Springer Nature, 2013<br>Publication | <1% |
| 12 | R. Singh, B. S. Rajpurohit. "Chapter 5 | |

Performance Evaluation of Grid-Connected Solar Photovoltaic (SPV) System with Different MPPT Controllers", Springer Science and Business Media LLC, 2014

Publication

<1%

---

13 Leonardy Setyawan, Wang Peng, Xiao Jianfang. "Implementation of sliding mode control in DC microgrids", 2014 9th IEEE Conference on Industrial Electronics and Applications, 2014

Publication

<1%

---

14 Shuvangkar Shuvo, Eklas Hossain, Tanveerul Islam, Abir Akib, Sanjeevikumar Padmanaban, Md. Ziaur Rahman Khan. "Design and Hardware Implementation Considerations of Modified Multilevel Cascaded H-Bridge Inverter for Photovoltaic System", IEEE Access, 2019

Publication

<1%

---

15 Lei Zhu, Hongfei Wu, Tiantian Mu, Fan Yang, Xudong Ma. "An asymmetrical three-level dual-input bidirectional DC/AC converter with improved conversion efficiency for vehicle-to-grid application", 2017 IEEE Applied Power Electronics Conference and Exposition (APEC), 2017

Publication

<1%

---

16 Dong-Keun Jeong, Ho-Sung Kim, Ju-Won Baek, Hee-Je Kim, Jee-Hoon Jung. "Autonomous

<1%

Control Strategy of DC Microgrid for Islanding Mode Using Power Line Communication", Energies, 2018
Publication

| | | |
|---|---|---|
| 17 | users.abo.fi<br>Internet Source | <1% |
| 18 | Vijaytarang Narayana, Anjanee Kumar Mishra, Bhim Singh. "Design of autonomous solar powered SRM based water pump utilizing modified CSC converter", IECON 2017 - 43rd Annual Conference of the IEEE Industrial Electronics Society, 2017<br>Publication | <1% |
| 19 | www.ijritcc.org<br>Internet Source | <1% |
| 20 | Arun Kumar Verma, Bhim Singh, D.T Shahani. "Electric vehicle and grid interface with modified PWM rectifier and DC-DC converter with power decoupling and unity power factor", 2012 IEEE 5th India International Conference on Power Electronics (IICPE), 2012<br>Publication | <1% |
| 21 | portal.fke.utm.my<br>Internet Source | <1% |
| 22 | Maulik Kandpal, Ikhlaq Hussain, Bhim Singh. "Grid integration of solar PV generating system | <1% |

using three-level voltage source converter", 2015 Annual IEEE India Conference (INDICON), 2015
Publication

---

23 Wu, Hao, Siu Chung Wong, Chi Tse, and qianhong chen. "Control and Modulation of Bidirectional Single-Phase AC-DC Three-phase-leg SPWM Converters with Active Power Decoupling for a Minimal Storage Capacitance", IEEE Transactions on Power Electronics, 2015. <1%
Publication

---

24 Lisheng Shi, Andrew Meintz, Mehdi Ferdowsi. "Single-phase bidirectional AC-DC converters for plug-in hybrid electric vehicle applications", 2008 IEEE Vehicle Power and Propulsion Conference, 2008 <1%
Publication

---

25 Verma, AK, B Singh, and DT Shahani. "Grid to vehicle and vehicle to grid energy transfer using single-phase half bridge boost AC-DC converter and bidirectional DC - DC converter", International Journal of Engineering Science and Technology, 2012. <1%
Publication

---

26 www.greentechcenter.dk <1%
Internet Source

---

27 www.rroij.com

Internet Source

<1%

28 Ryu, Myung-Hyo, Ho-Sung Kim, Ju-Won Baek, Heung-Geun Kim, and Jee-Hoon Jung. "Effective Test Bed of 380-V DC Distribution System Using Isolated Power Converters", IEEE Transactions on Industrial Electronics, 2015.
Publication

<1%

29 "Coordinated control scheme for stand-alone PV system with nonlinear load", IEEE PES T&D 2010, 2010
Publication

<1%

30 pastel.archives-ouvertes.fr
Internet Source

<1%

31 Bor-Ren Lin. "Power converter control based on neural and fuzzy methods", Electric Power Systems Research, 1995
Publication

<1%

32 Maria Mantilla, Giovanni Quinones, Carol Castellanos, Johann Petit, Gabriel Ordonez. "Analysis of maximum power point tracking algorithms in DC-DC boost converters for grid-tied photovoltaic systems", IECON 2014 - 40th Annual Conference of the IEEE Industrial Electronics Society, 2014
Publication

<1%

| | | |
|---|---|---|
| 33 | repository.up.ac.za<br>Internet Source | <1 % |
| 34 | ir.uiowa.edu<br>Internet Source | <1 % |
| 35 | Reza Noroozian. "Combined operation of converter-based distributed generation unit in DC distribution system in order to have premium power quality", European Transactions on Electrical Power, 05/2012<br>Publication | <1 % |
| 36 | Syed Zulqadar Hassan, Hui Li, Tariq Kamal, Jawad Ahmad, Muhammad Hussnain Riaz, Muhammad Abbas Khan. "Performance of Different MPPT Control Techniques for Photovoltaic Systems", 2018 International Conference on Electrical Engineering (ICEE), 2018<br>Publication | <1 % |
| 37 | Bhim Singh, Shailendra Dwivedi. "Resonant based control algorithm for grid supportive solar PV power generating system", 2015 39th National Systems Conference (NSC), 2015<br>Publication | <1 % |
| 38 | digital.library.unt.edu<br>Internet Source | <1 % |
| 39 | T. Monai. "A Collaborative Operation Method | |

Between New Energy-Type Dispersed Power Supply and EDLC", IEEE Transactions on Energy Conversion, 9/2004
Publication

<1%

---

40 repository.tudelft.nl
Internet Source

<1%

---

41 Zeng, Zheng, Huan Yang, Rongxiang Zhao, and Chong Cheng. "Topologies and control strategies of multi-functional grid-connected inverters for power quality enhancement: A comprehensive review", Renewable and Sustainable Energy Reviews, 2013.
Publication

<1%

---

42 Hengyu Li, Chongyang Zhao, Hao Wang, Shaorong Xie, Jun Luo. "An improved PV system based on dual axis solar tracking and MPPT", 2014 IEEE International Conference on Mechatronics and Automation, 2014
Publication

<1%

---

43 Julie Jacko, V Kathlene Emery, Paula J Edwards, Mahima Ashok et al. "The effects of multimodal feedback on older adults' task performance given varying levels of computer experience", Behaviour & Information Technology, 2004
Publication

<1%

---

44 ijesc.org

Internet Source

<1%

45 Ayad, M.Y.. "Voltage regulated hybrid DC power source using supercapacitors as energy storage device", Energy Conversion and Management, 200707
Publication
<1%

46 dspace.daffodilvarsity.edu.bd:8080
Internet Source
<1%

47 mirror.thelifeofkenneth.com
Internet Source
<1%

48 Lin Ba, , Wei Xiao, Jialin Lin, and Haifeng Liang. "Research on stability control of AC/DC hybrid micro-grid based on multi agent system", International Conference on Renewable Power Generation (RPG 2015), 2015.
Publication
<1%

49 Ravi Nath Tripathi, Alka Singh, Manoj Badoni. "A MATLAB-simulink-based solar photovoltaic array (SPVA) module with MPPT", 2013 International Conference on Emerging Trends in Communication, Control, Signal Processing and Computing Applications (C2SPCA), 2013
Publication
<1%

50 Ajay Patsariya, Shiwani Rai, Yogendra Kumar, Mukesh Kirar. "Noble-TLBO MPPT Technique
<1%

and its Comparative Analysis with Conventional methods implemented on Solar Photo Voltaic System", IOP Conference Series: Materials Science and Engineering, 2017
Publication

---

| | | |
|---|---|---|
| 51 | L. Umanand. "Multi Power Port Converter for Hybrid Electric Vehicles Using Multi Phase Bidirectional Fly-Back Topology", 2006 IEEE International Conference on Industrial Technology, 12/2006<br>Publication | <1% |
| 52 | Sridhar, Arjun Raj Prabu Andhra, and Nathan Weise. "DC ripple current rejection in a bidirectional SiC single-phase AC-DC converter for V2G application", 2015 IEEE Transportation Electrification Conference and Expo (ITEC), 2015.<br>Publication | <1% |
| 53 | www.omgroup.edu.in<br>Internet Source | <1% |
| 54 | www.ijedr.org<br>Internet Source | <1% |
| 55 | www.riverpublishers.com<br>Internet Source | <1% |
| 56 | Chao, K.H.. "Modeling and fault diagnosis of a photovoltaic system", Electric Power Systems | <1% |

Research, 200801
Publication

| | | |
|---|---|---|
| 57 | Munish Kumar, Mukhtiar Singh. "Simulation and analysis of grid connected photovoltaic system with MPPT", 2012 IEEE Fifth Power India Conference, 2012<br>Publication | <1% |
| 58 | slideplayer.com<br>Internet Source | <1% |
| 59 | S.A. Nabavi-Niaki, M.R. Iravani. "Visualization and investigation of unified power flow controller (UPFC) nonlinearity in power flow", 2003 IEEE Power Engineering Society General Meeting (IEEE Cat. No.03CH37491), 2003<br>Publication | <1% |
| 60 | G.K. Venayagamoorthy, R.P. Kalyani. "Two Separate Continually Online-Trained Neurocontrollers for a Unified Power Flow Controller", IEEE Transactions on Industry Applications, 2005<br>Publication | <1% |
| 61 | Srinivasa Rao, Y., and Mukul Chandorkar. "Electrical load emulator for unbalanced loads and with power regeneration", 2012 IEEE International Symposium on Industrial Electronics, 2012.<br>Publication | <1% |

62 D. Iannuzzi. "Use of Supercapacitors, Fuel cells and Electrochemical Batteries for Electric Road Vehicles: A Control Strategy", IECON 2007 - 33rd Annual Conference of the IEEE Industrial Electronics Society, 11/2007 <1%
Publication

---

63 Kannan Sreenivasachar, S. Jayaram, M.M.A. Salama. "Dynamic stability improvement of multi-machine power system with UPFC", Electric Power Systems Research, 2000 <1%
Publication

---

64 R. D. Thombare, N. B. Deshmukh, D. S. More. "Nine switch bidirectional converter for hybrid AC/DC microgrid system", 2016 International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT), 2016 <1%
Publication

---

65 J. M. Ramirez, R. E. Correa. "Modeling and simulation of a solid state transformer for distribution systems", 2012 IEEE Power and Energy Society General Meeting, 2012 <1%
Publication

---

66 Hao Qian, Jianhui Zhang, Jih-Sheng Lai. "A grid-tie battery energy storage system", 2010 IEEE 12th Workshop on Control and Modeling for Power Electronics (COMPEL), 2010 <1%
Publication

---

| | | |
|---|---|---|
| 67 | Maria Isabel Milanes Montero. "Power Injection Control System and Experimental Model based on Manufacturer Characteristic Curves for a Photovoltaic Generation System", 2007 Compatibility in Power Electronics, 05/2007<br>Publication | <1 % |
| 68 | Bellamkonda Pragathi, Rajagopal Veramalla, Fazal Noorbasha, Bangarraju Jampana. "Power quality improvement for grid interconnected solar PV system using neural network control algorithm", International Journal of Power and Energy Conversion, 2018<br>Publication | <1 % |
| 69 | S. Premrudeepreechacharn. "Voltage control in power system using expert system based on SCADA system", 2002 IEEE Power Engineering Society Winter Meeting Conference Proceedings (Cat No 02CH37309) PESW-02, 2002<br>Publication | <1 % |
| 70 | Hassan Youssef Mahmoud, Ahmed Hussien Besheer, Hany Mohamed Hasanien, Almoataz Youssef Abdelaziz. "Different Control Strategies for Converter Based DC Energy Transmission in Offshore Wind Power: A Literature Survey", 2018 Twentieth International Middle East Power Systems Conference (MEPCON), 2018<br>Publication | <1 % |

71 P Venkata Subramanyam, C Vyjayanthi. "Integration of PV and battery system to the grid with power quality improvement features using bidirectional AC-DC converter", 2016 International Conference on Electrical Power and Energy Systems (ICEPES), 2016 <1%
Publication

72 Sinan Li, Wenlong Qi, Siew-Chong Tan, S. Y. Hui. "Integration of an Active Filter and a Single-Phase AC/DC Converter With Reduced Capacitance Requirement and Component Count", IEEE Transactions on Power Electronics, 2016 <1%
Publication

73 IFIP Advances in Information and Communication Technology, 2014. <1%
Publication

74 Schiefer, Peter. "", Visual Communications and Image Processing 92, 1992. <1%
Publication


| | | | |
|---|---|---|---|
| Exclude quotes | Off | Exclude matches | Off |
| Exclude bibliography | Off | | |