PASSIVE CELL BALANCING AND ANALYSIS OF LLC CONVERTER WITH BUCK CONVERTER FOR BATTERY CHARGING USING CCCV TOPOLOGY

DISSERTATION
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CANDIDATE'S DECLARATION

I PRAPHULL PRAKASH GUPTA, Roll No. 2K20/PES/14, Student of M. Tech Power electronics and systems, hereby declare that the Dissertation titled **"PASSIVE CELL BALANCING AND ANALYSIS OF LLC CONVERTER WITH BUCK CONVERTER FOR BATTERY CHARGING USING CCCV TOPOLOGY"** which is submitted by me to the Department of Electrical Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship or other similar title or recognition.

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ABSTRACT

This Project presents the passive cell balancing of a lithium-ion battery cells and battery cell charging with the use CCCV (Constant current constant voltage Topology). When battery cells are connected in series, they frequently become unbalanced. The cell voltages aren't all the same. Variations in cell parameters such as cell difference in SOC of battery cell, impedances, capacity, self-discharge rate, cell temperature and so on can cause this unbalance. Passive cell balancing is constructed and examined in a stand-alone state in this paper. The features of passive balancing are determined in this study by conducting an on-line passive balancing experiment of charge and discharge at various capacities (SOC). In this Project, circuitry for battery charge controller circuit is also designed and the Constant voltage/constant current (CCCV) topology is investigated to prevent overcharging issues.

Passive Balance method for Battery charging using CCCV topology is not effective due to power wastage so I used Cascaded system of LLC resonant converter with Buck converter for CCCV charging because LLC resonant converters are used in various sectors due to their advantages of high efficiency, high energy density, electrical isolation, low electromagnetic interference (EMI), wide output ranges and high frequency. A Good power factor for the LLC resonant tank is required to achieve high efficiency over a wide input voltage range. A unity voltage gain can be accomplished over the whole loading conditions by having switching frequency equal to resonant tank frequency in LLC converter, however it is not suited for constant current – constant voltage (CC-CV) battery applications. The use of a buck converter at the output of an LLC resonant converter to regulate the charging current and voltage for battery charging applications is also proposed in this Project. The use of a buck converter allows the output voltage of the LLC converter to be varied, ensuring CCCV charging. This project is designed CC-CV charging for 48V/40Ah Battery. The proposed system is analysed and studied in MATLAB/Simulink.

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LIST OF SYSMBOL, ABBREBIATIONS

Symbols

Ω	ohm
%	Percentage
V	Volt
A	Ampere
mA	Milli ampere
Q	Quality factor
m	Ratio of inductance
Fn	Normalized Frequency
Rac	Equivalent Resistance
Lr	Resonant inductance
Cr	Resonant capacitance
Nr:Ns	Turns ratio
Fs	Switching Frequency
Fr	Resonant frequency
Ro	Load resistance
Co	Output Capacitance
Vin1	Input Voltage
d	Duty ratio
mH	Milli Henery
uF	Micro Farad
Lm	Magnetizing inductance
Co	Buck converter capacitance
Lo	Buck converter inductance

Abbreviations

CC	Constant Current
CV	Constant Voltage
CCCV	Constant current constant voltage
SOC	State of charge
LLC	Tank of inductances and capacitance
DC	Direct current
BMS	Battery management system
SOA	Safe operation area
PWM	Pulse width modulation
MOSFET	Metal oxide semiconductor field effect transistor
OCP	Optimum charge pattern
OCV	Open circuit voltage
IR	Internal Resistance
SN	Switch N
ZVS	Zero voltage switching
AC	Alternating current

CHAPTER 1

INTRODUCTION

1.1 GENERAL

This project is a combination of two parts. In one part we discuss about Passive cell balancing and design of battery charge controller with CCCV topology but due to power losses in this we design a CC-CV charging with the combination of LLC converter and Buck converter in second part.

1.2 PASSIVE CELL BALANCING AND BATTERY CHARGE CONTROLLER WITH CCCV TOPOLOGY

Electric automobiles, hybrid vehicles, and renewable energy technologies all benefit from energy storage systems. The advantages of lithium-ion batteries include high energy density, extended cycle life, low self-discharge rate, no memory effect, non-toxicity[1] and fast charging, among others. Due to its restricted voltage and power, a single lithium-ion battery cannot match the demand for electric vehicles or large-scale energy storage. As a result, increasing the system voltage and current levels via a series and parallel battery connection approach is required.

When using series and parallel battery connections, however, parameters such as initial battery state, ageing rate, connection method, and environmental are inconsistent among single cells, resulting in internal resistance and State of Charge (SOC) inconsistency between batteries[2].

All of the cells in a new battery pack are usually at the same voltage level. As a result, the pack will always contain balanced cells. EVs and electric vehicles will require battery packs with substantially higher effective power and energy densities, as well as higher voltage than a cell's nominal voltage (about 4.2V)[3]. Lithium-ion battery packs provide a far superior solution to this problem. When SOC1= SOC2=SOC3=------SOC’n where n is the number of cells in the series string of the battery system[3], the cells are considered balanced.

1.2.1 Passive Cell Balancing

Methods for active cell balancing Charge is transferred from higher cells to lower cells[4], while passive cell balancing methods use a resistive device to remove surplus energy from upper cells until the charge matches that of the lower cells in the pack. The battery pack's consistency has a significant impact on the battery system's performance and cycle life. Because of its simple circuit, low cost, and other benefits, battery pack passive balancing technology is widely employed in various fields[5].

1.2.2 Battery Charge Controller with CCCV Topology

Constant current charging is more efficient than constant voltage charging since the charging current in constant voltage charging might be high, causing the battery to overheat during charging. Voltage charging, on the other hand, is faster than constant current charging. The two sorts of sources are used in the practical charging procedure. When the battery is relatively depleted, continuous current charging is used. When the battery reaches a specific voltage, it is close to its maximum voltage[6]. It is possible to charge at a constant voltage.

A charge controller, battery controller, charge regulator, or battery regulator regulates the rate at which electric current is added to or removed from an electric battery. It guards against overcharging and overvoltage, which can reduce battery life and performance while also posing a safety risk[6]. It may also prevent a battery from completely draining or perform controlled discharges to extend battery life, depending on the battery technology.

1.3 LLC RESONANT CONVERTER WITH BUCK CONVERTER

Resonant DC/DC converters are those in which the L-C resonant tank plays a significant role in the power conversion process. The resonant converter's basic premise is that the circulating energy in an L-C resonant circuit may be controlled by changing the operating frequency, allowing the converter to condition the input power to the desired output voltage[7].

Reducing the bulk of switching power supply by increasing the switching frequency has become a global trend in recent years. However, substantial switching losses result in low efficiency due to the high frequency. The resonant converter has been widely employed in the power industry because it has a ZVS or ZCS function for decreasing switching losses[8]. The resonant LLC DC-DC converter.

LLC resonant converters have a number of advantages over traditional LC series resonant converters[9], including limited frequency variation over a wide range of load and input variations, and zero voltage switching even when there is no load. The gain equation is obtained using the fundamental approximation, with the leakage inductance in the transformer secondary side also taken into account. The practical design approach is examined based on the gain equation to maximise the resonant network for a given input/output specification[7].

Switched mode dc-dc converters[10] are among the most basic power electronic circuits, converting one level of electrical voltage to another through switching action. Many people are becoming increasingly interested in these converters. This is due to their vast range of applications, which include power supplies for computers, office equipment, appliance control, telecommunication equipment, DC motor drives, automotive, and aircraft. Switching converter analysis, control, and stabilisation are the most important variables to consider. Switch mode dc-dc converters are controlled by a variety of methods, but the simple and low-cost controller structure is always in demand for most industrial and high-performance applications[11].

1.3.1 Cascaded System of LLC Converter with Buck Converter

In LLC converter, a sophisticated control technique, such as variable frequency control, is frequently used. Other advanced control systems for wide-range input or output voltage applications are also possible. The input voltage was set to 400 V for this paper application. There is no need to consider a large range of input voltage when designing the LLC converter. In such scenario, the LLC converter with open loop control is cascaded with a buck converter as its output to regulate the charging current and voltage in CC-CV battery charging. The CC-CV battery charger will be simple to implement[12].

As a result, the LLC converter's output voltage may not be load independent. The use of a buck converter to regulate[13] the output of an LLC converter allows the output voltage of the LLC converter to vary, ensuring CC-CV charging.

1.4 MOTIVATION

Lithium-ion is the battery chemistry[14] of choice in many applications. Lithium-ion is more volatile than conventional battery chemistry and becomes dangerous when used outside of a small safe operating zone. As a result, using a battery management system (BMS) to help keep the batteries running within a safe zone is critical. Increased cell disintegration allows some cells in a pack to operate outside of a safe zone more easily. When charging, this can result in catastrophic failure.

There's at least one more reason to utilise a BMS, aside from the safety concerns that come with lithium-ion batteries. The state of charge of each cell will become imbalanced as the number of charge cycles increases. This has a detrimental impact on the battery's overall useful capacity. The state of charge of the cells can be brought closer together by using a BMS that can balance cells. Because all cells may now utilise more of their particular capacities, this balance can boost the battery's capacity[15].

Constant current charging is more efficient than constant voltage charging since the charging current in constant voltage charging might be high, causing the battery to overheat during charging[6]. Voltage charging, on the other hand, is faster than constant current charging. The two sorts of sources are used in the practical charging procedure. When the battery is relatively depleted, continuous current charging is used. When the battery reaches a specific voltage, it is close to its maximum voltage. It is possible to charge at a constant voltage.

Power is processed using conventional PWM by adjusting the duty cycle and interrupting the power flow. All of the switching devices are hard-switched, with sudden current and voltage changes, resulting in significant switching losses and noise. Meanwhile, the resonant approach processes power in a sinusoidal manner and softly commutates switching devices. As a result, switching losses and sounds can be minimised significantly. As a result, resonant converters have attracted a lot of interest in a variety of applications[16].

The converter stage must have a high efficiency and a small profile as part of the technology development. Because of their intrinsic soft switching feature, resonant converter topologies are ideal choices for meeting these issues. By attaining soft switching[17], switching losses can be considerably decreased, improving power efficiency, and the operating frequency can be increased to improve power density. Another advantage of using the resonant converter topology over a conventional phase-shift PWM converter is that maintaining the same level of competence for all.

1.5 RESEARCH OBJECTIVE

The use of a cell balancing technique improves battery technology. The use of unbalanced cells repeatedly reduces performance before the average time. Balanced charging of the cells improves performance and battery life. As a result, cell balancing is critical in the field of battery technology. A battery charge controller is one kind of application of passive cell balancing to prevent a battery from over charging which will reduces the battery reliability and life-span[18].

The fundamental goal of this dissertation is to provide a complete and systematic analysis of the operation of resonant converters, particularly the LLC resonant converter, whose topology has the potential to achieve high power density and high-power efficiency.

LLC resonant converter is used in wide range of frequencies and it gives the step -up rectified voltage as well as step-down rectified voltage. But it's not suitable for CC-CV charging applications for battery. By using the Buck converter, we can regulate the rectified voltage of LLC converter which will suitable for CC-CV[19] charging as per the battery specification.
These are some objectives for this Project.

1- To design the Passive cell balancing in stand- alone state.
2- To measure the State of charge (SOC) of Battery cells.
3- To design a battery charging circuit with CCCV topology.
4- To design a LLC resonant converter for high frequency applications.
5- Design of Cascaded system of LLC converter with Buck converter.
6- Design a cascaded system for CCCV charging for a Battery.
7 -Close loop control for constant current, constant voltage charging.

1.6 ORGANISATION OF THESIS

The Thesis have been organized in five chapters.

In chapter 1, the introduction of Passive cell balancing, Battery charge controller with CCCV topology also introduced about the LLC resonant converter with buck converter for battery charging using CCCV topology. This section also includes the motivation and research objective.

The chapter 2 contains the literature review about overall projects. In this, discuss the design and analysis of passive cell balancing with battery charge controller with CCCV topology and also discuss about the LLC resonant converter with Buck converter for Battery charging.

The chapter 3 consists the brief of designing and modelling of Passive cell balancing in stand -alone state for battery cells and designing of CCCV mechanism for Battery charge controller. the simulation has been carried out for passive cell balancing as well as for battery charge controller and results obtained are added.

The chapter 4 consists of brief designing and modelling of LLC resonant converter and cascaded system of LLC converter with Buck converter. It also consists a CC- CV charging topology for particular specified Battery and close loop control of output voltage and current of Buck converter for charging the battery with CC – CV charging. The simulation has been carried out and results obtained are added.

The chapter 5 is the conclusion and future scope of the proposed system has been described.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

This chapter divided in two sections. In first part we discuss about background and previous work done in the area of passive cell balancing and battery charge controller for Battery protection. It also includes previous research about the constant current (CC) and constant voltage (CV) charging. In second part we discuss the background and previous research about the DC-DC converters like LLC Resonant converter and cascaded system with different converters and also about close loop control techniques.

2.2 PASSIVE CELL BALANCING AND BATTERY CHARGE CONTROLLER WITH CCCV TOPOLOGY

In these papers authors focused on the topologies of cell balancing. There are two types of method to do the cell balancing techniques generally present in the battery management system (BMS). BMS is combination of different functions to operate the battery in the safe operation area (SOA). Active cell balancing transfers the extra charge from higher SOC battery cell to other lower cells while passive cell balancing discharges the cell with higher SOC level in battery pack till it become equal the lowest SOC level cell. Authors also explain about the different topologies of active cell balancing and passive cell balancing[1-6].

The passive balancing experiment of charge and discharge under variable capacity, current ratio, and equalising threshold of lithium battery is used to acquire the features of passive balancing in this work. The balancing impact of the discharging state is greater than that of the charging state, and the passive balancing time ratio (ratio of balancing time to charging/discharging time of main circuit) is greater than that of the charging state. The discharging state's passive balance is crucial. The inconsistency of the batteries may be effectively improved by lowering the balancing threshold[1].

The methods of cell balancing in a battery pack are explained in this paper. Both the benefits and drawbacks of passive and aggressive techniques are discussed.

A study of active cell balancing architecture with inductors is also offered. The flaws in traditional inductor-based cell balancing are emphasised and the method is improved to obtain a faster equalisation time. Even or odd cell battery packs may readily be constructed using the suggested design. The technology may be utilised in both electric vehicles and spaceships to equalise lithium-ion battery packs. A modified version of the inductor-based active cell balancing approach is presented in this study[4].

` The design restrictions of the passive balancing circuit for usage with the PWM switching technology are investigated in this paper. The bleeding power for the unity duty cycle should normally be adjusted as high as feasible first. The PWM duty cycle may be changed to change the bleeding power. When draining a large amount of power or current, the MOSFET switch may enter the linear zone, resulting in severe MOSFET losses[28].

The use of an automobile onboard heater equaliser to heat low-temperature batteries and balance cell voltages without the need of external power supply is presented in this research. The suggested integrated architecture requires just one MOSFET per cell, resulting in a small footprint and low cost that may be readily adapted to electric cars[20].

The goal of this work is to develop a battery management system that can safeguard the battery from overcharging and perform passive balancing. When each battery cell is charged, the overcharging protection circuit is checked by concurrently monitoring the voltage and current values of each battery cell. The passive balancing circuit, on the other hand, is based only on sensing the voltage of each battery cell. The suggested circuit, based on the measurements, is capable of protecting against overcharging and balancing each battery cell at a voltage of 3.75 Volt and a charging current of 0.2 Ampere[22].

The lithium-ion battery datasheet explains the basic characteristics of the lithium-ion battery. Characteristics like capacity, nominal voltage, internal impedance, discharge voltage, charging current, charging voltage charging profile in CCCV mode. It also explains about the standard charge and discharge of a lithium-ion battery. Environmental tests result also explained for battery model LIR18650 2600mAh[34].

This study provides an optimum charging control technique for battery packs. Specifically, a multi objective optimization is used to generate an ideal average state-of-charge (SOC) trajectory based on the nominal model of the cells, taking into account both user demand and battery pack energy loss. Then, to ensure that the cells' SOCs follow the predetermined path, a distributed charging technique is provided[12][14-15].

To achieve higher battery usage, an experimental strategy to eliminate variance from cell to cell during battery operation is explored in this work. Thus, for about 1.5 years, the ageing behaviour of two batteries is examined. The active balancing battery management system (BMS) is connected to one battery, while the passive balancing BMS is connected to the other. Each cycle records important battery data including capacity and internal resistance. By analysing the voltage differential between individual cells at the conclusion of discharge and determining the amount of charge balanced by the BMS, the battery behaviour is assessed in great detail. There are significant variances across the BMS systems deployed, demonstrating the benefits of active balancing[2][23-27].

This paper summarises the current status of BMS technology and shows how to create a passive cell balancing network for Lithium-Iron-Phosphate (LiFePO4) batteries using the controller. To show the SOC estimate utilising the Coulombs counting approach and battery cell balancing mechanism, several critical simulation and hardware findings are provided[29].

2.3 DESIGN AND ANALYSIS OF LLC CONVERTER WITH BUCK CONVERTER FOR CCCV TOPOLOGY

The design criteria for the resonant tank of the LLC resonant DC-DC converter are presented in this study. The LLC resonant tank should have a high-power factor to provide great efficiency across a wide input voltage range. Finally, the full bridge LLC resonant converter prototype circuit is fabricated with 48V output voltage and 12A output current to test the proposed design criteria for the resonant tank[7-11].

The history and development of LLC resonant converters are discussed, as well as their benefits. Three of the most prominent LLC resonant converter topologies are also discussed, along with extensive analyses of their strengths and shortcomings. A significant amount of research is also being done on the industrial applications of LLC resonant converters, which primarily include electric vehicle (EV) charging, solar systems, light emitting diode (LED) lighting drivers, and liquid crystal display (LCD) TV power supply. Finally, the LLC resonant converter technology's future progress is examined[16].

This work provides a design and control technique for battery chargers based on parallel resonant converters (PRCs). The suggested method is especially well suited to the CC-CV (constant-current, constant-voltage) charging method. The suggested technique not only streamlines the converter unit's design and implementation procedures, but it also simplifies the output filter configuration design and reduces the number of needed components for charger control[47-53].

While a resonant LLC converter has numerous desirable characteristics, such as high efficiency, low EMI, and high-power density, its design is more time consuming and needs more work to optimise than PWM converters. This article seeks to make this work easier by making it easy to build the resonant tank appropriately. This article gives an overview of how LLC converters work and how to construct them. Finally, schematics, bill of materials, experimental findings, and waveforms are included in a thorough design sample[37-43].

For high-efficiency charging and appropriate protection, constant current/constant voltage (CC/CV) is frequently used to charge lithium-ion batteries. Due to the large variety of load variations, it is difficult to build an IPT battery charger that can charge the batteries with a CC/CV charge[46][30-33].

For unity voltage gain in all the different loading conditions we must have a switching frequency equal to resonant frequency but its not suitable for constant current and constant voltage charging. For a particular battery charging by a constant current (CC) and constant voltage (CV), the author gave a idea with cascading the LLC converter with Buck converter[13].

CHAPTER 3

PASSIVE CELL BALANCING AND BATTERY CHARGE CONTROLLER WITH CCCV TOPOLOGY

3.1 GENERAL

Lithium-ion battery has advantages of high energy density, long cycle life, low self-discharge rate with no memory effect. Every Li-ion battery is thus equipped with an electronic system, called Battery Management System (BMS), to reduce the safety problems[1].We design a Passive cell Balancing and Battery charge controller for Lithium-ion Battery cells and discuss the results in this chapter.

3.2 CELL BALANCING

- The goal of cell balancing is to preserve the battery system's performance by balancing the SOCs of individual cells[4].
- Any balancing scheme's goal is to allow the battery pack to run at its intended level while also extending its useable capacity.
- Cell balancing was created to correct the imbalances in a battery's cells. A defective cell will degrade the performance of the entire battery, reducing the battery's life span[21].

3.2.1 Passive Cell Balancing Stand-Alone State

The most easy and simple way is passive balancing. It is currently the most popular and extensively utilised method in industry because to its simplicity, low cost, and ease of implementation. To achieve cell balancing, the shunting resistor will drain charge[22] or energy from those cells with a higher charge. Bypassing the current of the highest cells and waiting until all cells are the same, the passive balancing approach is achieved. In stand-alone state of Passive cell balancing, we will do the balancing for each cell in separate.

3.2.2 Factors Affecting the Cell Balancing

The cells become imbalanced as a result of the following factors.

A. SOC Imbalance

Over a time, the SOCs of different cells in a battery system will differ, resulting in cell imbalance and limiting the capacity of the entire battery system to that of the weakest. Instead of matching cells with the same voltage levels, ideal cell balancing should match cells with the same SOC[23]. However, because it is practicable to match cells primarily on voltage parameters when creating a pack. Variations in SOC may eventually lead to changes in OCV (open circuit voltage). On the other hand, cell balancing is the process of keeping all of the cell voltages equal and therefore extending the battery life.

B. Internal Resistance

Variation Even if the chemistry and voltage are the identical, finding cells with the same internal resistance (IR) is difficult. The IR of the cells changes as the battery ages. As a result, not all cells in a battery pack[24] will have the same IR. The IR contributes to the cell's internal impedance, which influences how much current flows through it. Because the IR varies, the current through the cell and its voltage varies as well. The internal resistance variation is harmful for the battery cell and it will lead to cell unbalancing.

C. Temperature

The temperature around the cell affects the cell's charging and discharging capacity. In a large battery pack, such as those used in electric vehicles, there may be temperature differences among the cells, leading one cell to charge or discharge quicker than the others, resulting in an imbalance[2].

3.2.3 Impact of Cell Imbalance

- A 5% battery mismatch results in underutilized capacity of 5% of the total capacity. With big batteries, this can result in a significant amount of energy being wasted.

- To ensure maximum efficiency, the voltage levels of each individual cell connected in series to form a battery pack must be kept constant[25].

- Thermal Run-out.

- Cell depletion.

- Incomplete charging of pack.

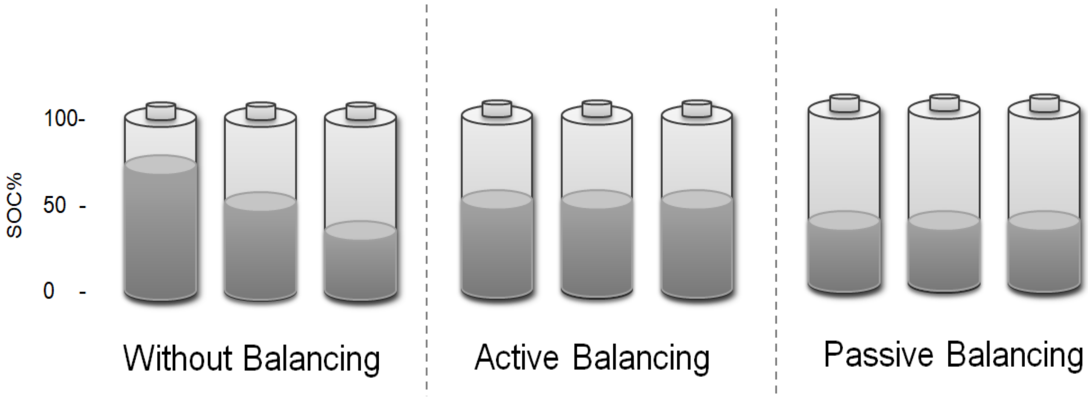


Fig. 3.1 types of cell balancing

Active cell balancing methods remove charge from higher cells and distribute it to lower cells, while passive cell balancing methods use a resistive device to remove surplus energy from upper cells[6] until the charge matches that of the lower cells in the pack. From the fig.3.1, we can understand the basics of active balancing and passive balancing[26].

Table 3.1 Comparison Between Active Cell Balancing and Passive Cell Balancing

Active cell balancing	**Passive cell balancing**
It is a complex process.	It is an easy process as compare to active method.
This Method extract the charge from higher cells and distribute to lower cells.	This method removes the charge from higher charge cells until charge matches with lower one
The efficiency of the overall system is increased.	The efficiency of the overall system is reduced due to power wastage.
Due to complex circuitry, the cost of the system is increased.	Due to easy circuit design, the cost of the system is less as compare to active.
This method is suitable for high power applications	This method is suitable for low power applications.

3.2.4 Flowchart of Passive Cell Balancing

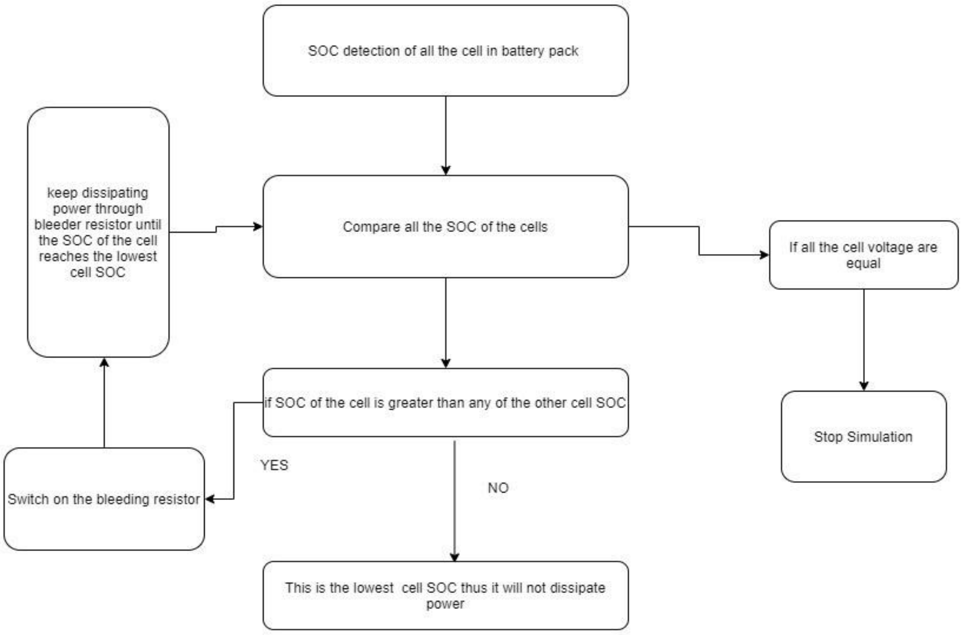


Fig. 3.2 flowchart of passive cell balancing

The logic of passive cell balancing is simulated in a stand-alone condition using MATLAB-Simulink[27]. The following is the switching mechanism of passive cell balancing.

The Fig.3.2 shows the flowchart algorithm[5] of the passive cell balancing. firstly, we will check the SOC of the different cells and compare themselves. After that we find the minimum SOC cell. We will decapitate the extra charge from the top cells by switching on the bleeder resistance path till the cell reaches to the minimum SOC cell. We will do this process for all the cells. The extra energy decapitates in the form of heat energy[28]. At the end when all the cells SOC's at the same level we will end this process. The algorithm of passive cell balancing is easy as compare to the active cell balancing algorithm.

There are two types of passive cell balancing techniques.

- Fixed Shunting Resistor
- Switching Shunting Resistor

We use switching shunt resistor technique[29] in our project.

3.2.5 Circuit Diagram of Passive Cell Balancing

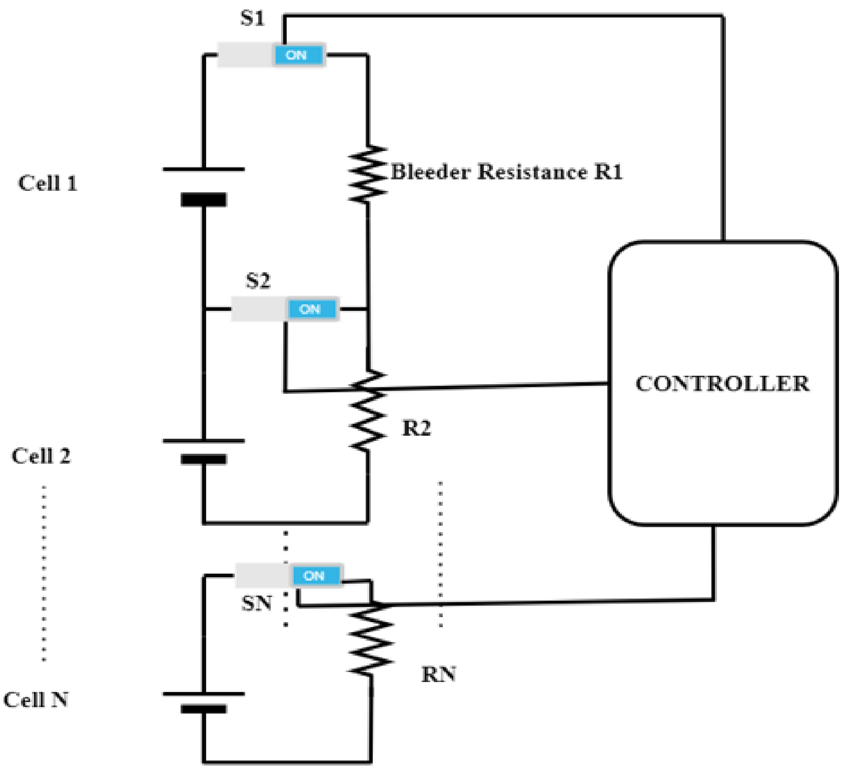


Fig. 3.3 Switching shunting topology of passive cell balancing

Fig. 3.3 topology is Switched shunt resistors topology used for N number of cells with a control algorithm to determines when and which battery cell will lose energy. When draining the battery pack, the bottom most cell has the lowest SOC and drains the most. Taking this into consideration, we picked different resistor values to produce a variable discharge slope. This is called grading of bleeding resistor[22].

This topology is accomplished by simulating the following:

- Each battery was separately controlled.
- There were no connections in series or parallel.
- The switching logic was validated.
- All batteries converged on the lowest battery voltage level.

- The pack's performance is limited by the weakest cell, which has the lowest capacity. The capacity of all cells is the capacity of the weakest cell.

3.3 BLOCK DIAGRAM OF PASSIVE CELL BALANCING FOR EIGHT BATTERY CELLS

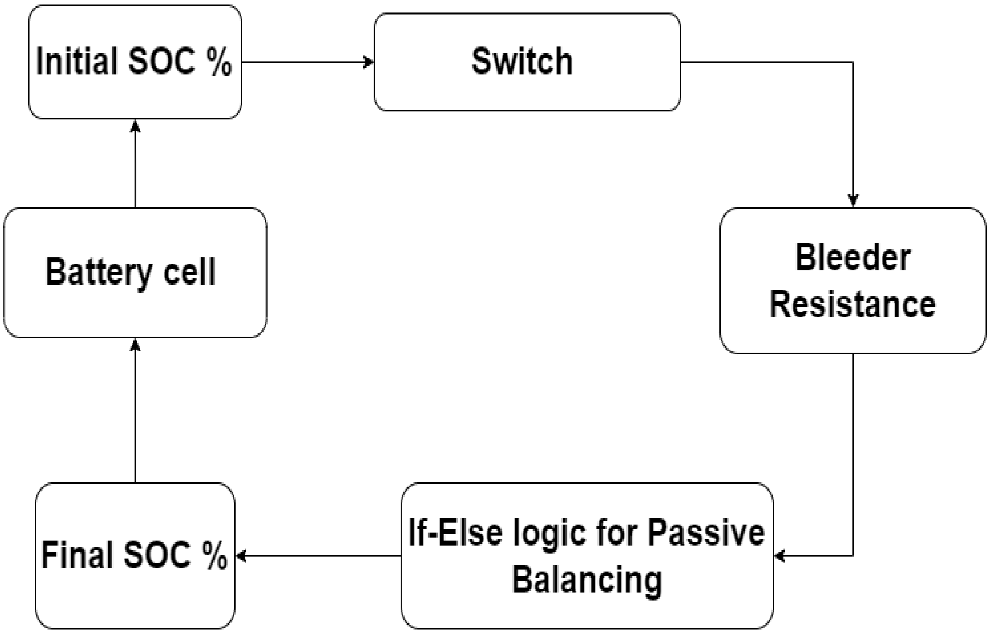


Fig.3.4 Block-diagram of Passive balancing for Stand-alone state of eight battery cells

The Fig.3.4 depicts the Block diagram of balancing circuitry. earliest SOC's of eight calls have been taken into account. They are all independent here, but in practice, they may be joined in series or parallel to build a battery pack of any size. We did the grading of bleeder resistance to minimize the power wastage[22].

We design a switching shunting resistor topology for eight battery cells of different SOC levels. In MATLAB Fig. 3.5 is the main battery cell monitoring circuit. The figure 3.5 depicts the earliest SOCs of Eight calls have been taken into account. They are all independent here, but in practise, they may be joined in series or parallel to build a battery pack of any size.

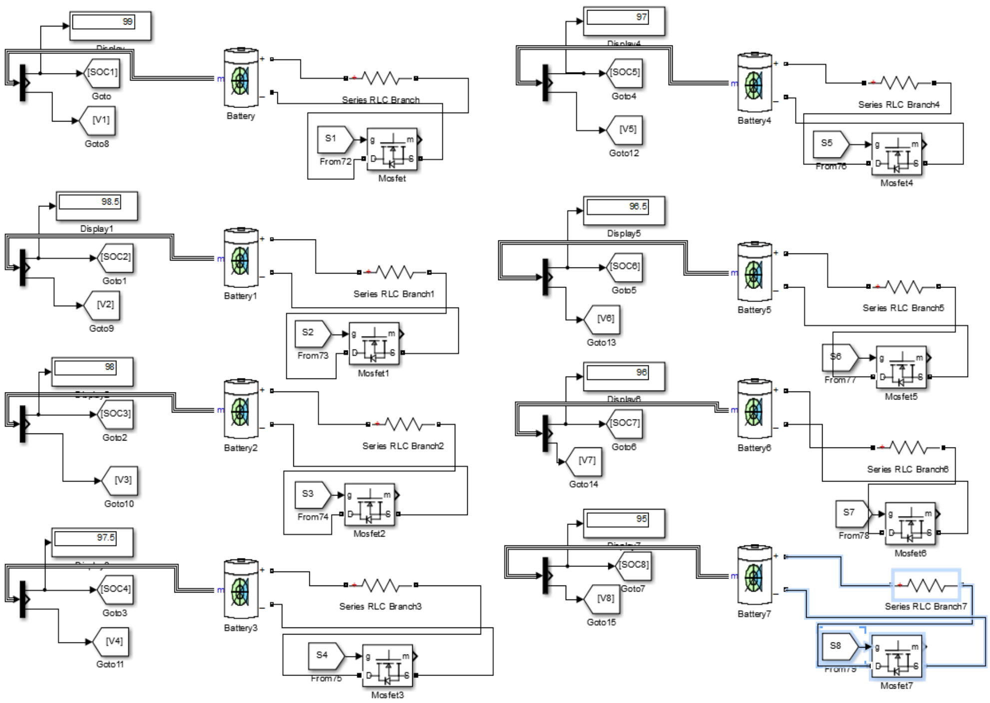


Fig. 3.5 Stand- alone state of eight battery cells

Table 3.2 Parameters Specifications for Eight Battery Cells

Battery cell no.	Initial SOC %	Bleeder Resistance Value(Ω)	Final SOC %
1	99	0.03	95
2	98.5	0.05	95
3	98	0.07	95
4	97.5	0.09	95
5	97	0.11	95
6	96.5	0.13	95
7	96	0.15	95
8	95	0.17	95

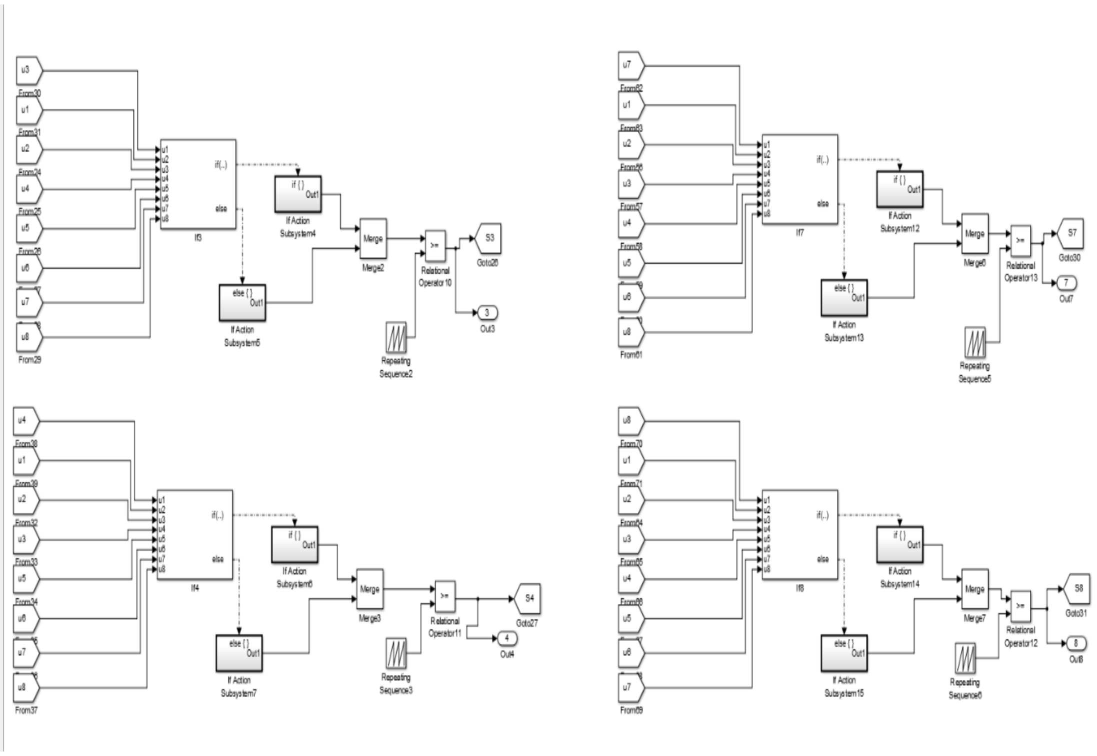


Fig. 3.6 If-else logic of battery cells

These are the separate If-Else logic for all the 8 separate Batteries in Fig. 3.6. Below is the detailed If-else logic explanation for switch 1 attached to MOSFET.

All the SOCs were compared in the I1 block. Logic in the If block is such that if 1st input is greater than any one of the other inputs, then it will give yes as output, otherwise if the input is not greater than any of the other inputs (which means it is the lowest valued input) the output will be false. Then this will send 1 or 0 signal to the output. This then is compared with the Repeating Sequence block to give the pulses to the gate of the MOSFET.

Then, except for the lowest voltage battery, all of the batteries were drained until they reached the same level as the lowest voltage battery. As a result, all batteries eventually reached the same SOC level[23].

3.4 BATTERY CHARGING USING CCCV TOPOLOGY

Constant voltage, constant current and a combination of constant voltage and constant current with or without a smart charging circuit are the three most prevalent methods of charging a battery[30][31].

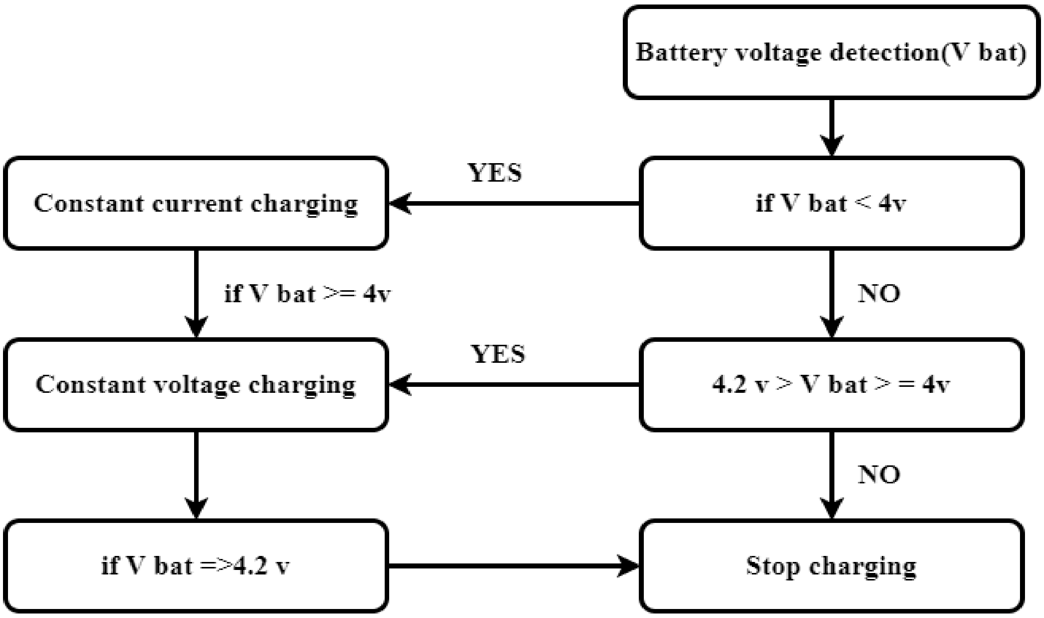


Fig. 3.7 Flow chart of charging algorithm

It can be seen that in Fig. 3.7 the battery charging voltage is equivalent to the battery real voltage when in CC mode. As a result, in this mode, the battery should experience a voltage drop across it that is equivalent to its true voltage. When the battery voltage hits 4.0 V, it must be supplied with a constant voltage equal to the maximum rated voltage of the battery, i.e. 4.2 V. The battery charging current should then begin to decrease, and when it reaches 0.1 C or 100 mA, the battery should be regarded fully charged[32].

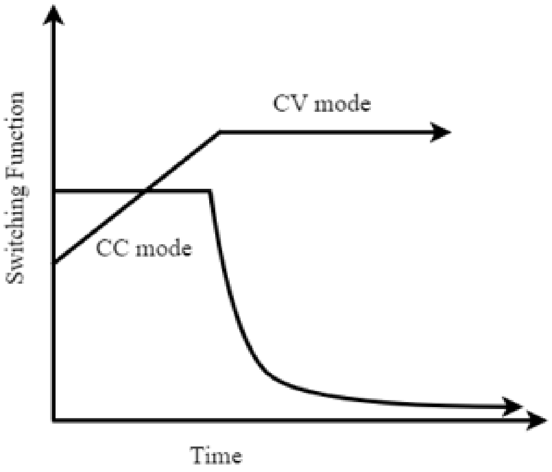


Fig. 3.8 Charging profile of Lithium-ion battery

Fig. 4 is the illustration depicts a CCCV charging cycle for a single lithium-ion cell. The example is for a small cell, but the technique applies to the big scale cells used in our EVs as well. Constant current charging is done at the 0 % SOC at a suitable charging rate. After SOC reaches the 95%, we switch the function from constant current to constant voltage. At CV mode very low current will flow and from 95 % SOC to 100 % SOC current will decreases to 0 ampere[33][34].

3.4.1 Block Diagram of CCCV Switching Mechanism

Fig.3.9 is Battery charge controller block diagram, which includes the bleed resistors and also did the grading to minimize the power wastage[35], the MOSFET that selectively switch the bypass branch on and off according to the relative SOC of the battery cells.

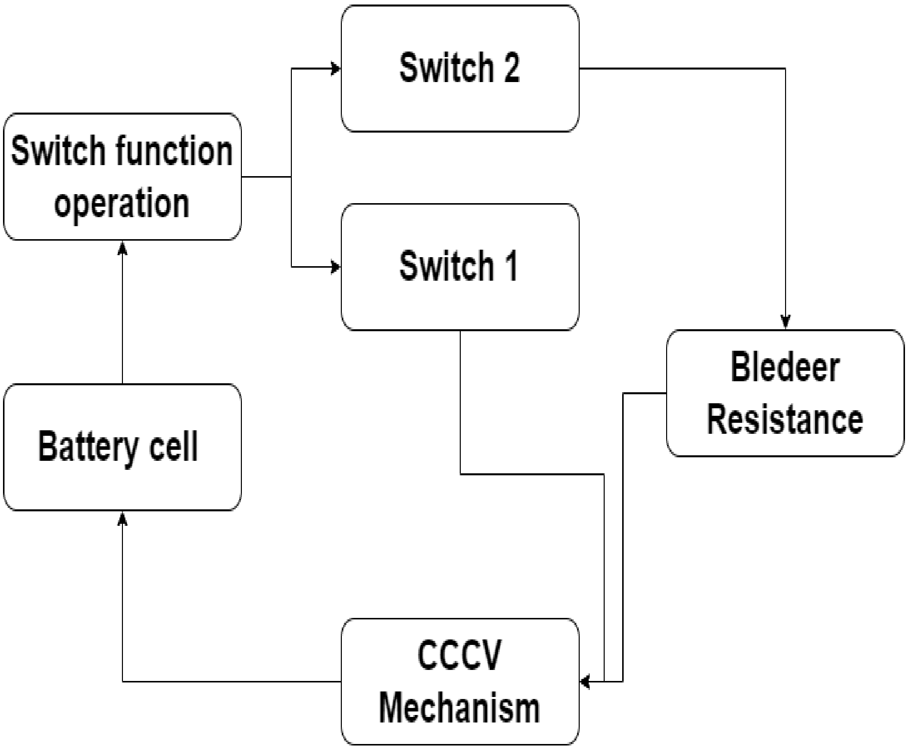


Fig. 3.9 Switching mechanism of Battery charge controller

Fig.3.9 is Battery charge controller block diagram, which includes the bleed resistors and also did the grading to minimize the power wastage[36], the MOSFET that selectively switch the bypass branch on and off according to the relative SOC of the battery cells.

3.4.2 Simulation of Battery Charge Controller

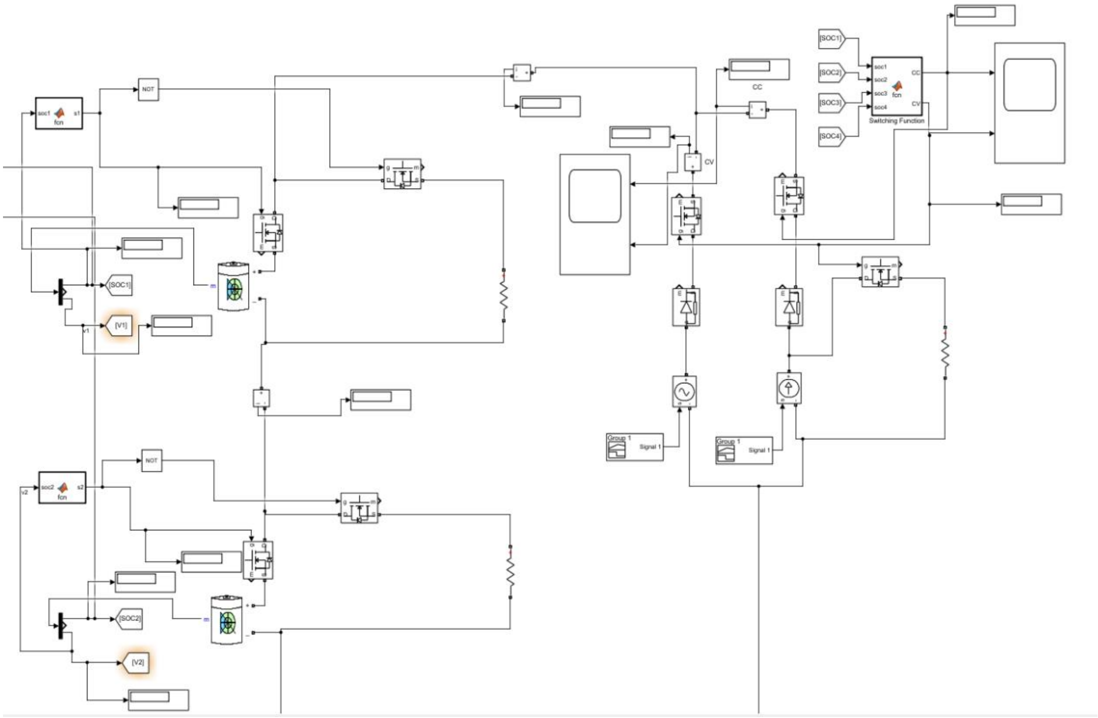


Fig. 3.10 Simulation of battery charge controller

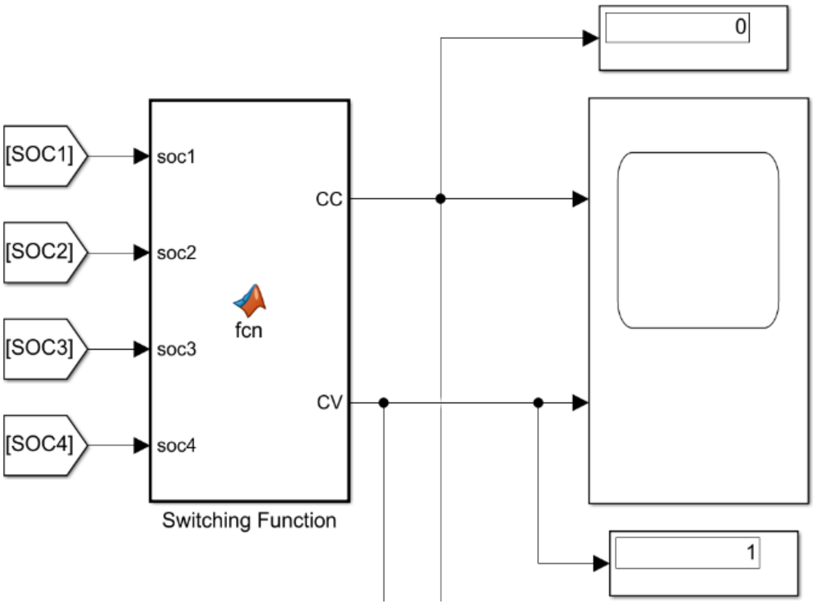


Fig.3.11. Switching function of battery charge controller

Fig.3.11 is showing the how switching changes from constant current charging to constant voltage charging. Where 0 and 1 are output of the switching function for charging the battery cells. These outputs indicate which type of charging is happening either constant current or constant voltage charging at a time.

Table 3.3 Parameters Specifications for Battery Cell Charging

Battery cell no.	Initial SOC %	Resistance value(Ω)	Final SOC %
1	90	0.01	100
2	88	0.015	100
3	84	0.02	100
4	82	0.025	100

Table 3.3 is showing the initial SOC's of the four battery cells and we will charge the all the four battery cells to 100 % SOC by using the CCCV topology. We will also use the resistor for each cell to bypass the extra power after fully charge. It will also protect the system from overcharging. So finally, battery charge controller is one of example of passive balance method.

3.5 MATLAB CODE

3.5.1 MATLAB Function to Operate CC and CV by Switching

```
Function [CC,CV] = fcn (Soc1, Soc2, Soc3, Soc4)
%%V_pack = (V1+V2+V3+V4);
if ((So1 >95) || (Soc2>95) || (Soc3>95) || (Soc4>95))
CC = 0;
CV = 1;
else
CC = 1;
CV = 0;
end
return
```

3.5.2 MATLAB Function for Battery Cell Charging

```
Function S1 = fcn(Soc1)
if (Soc1>=100)
S1 = 0;
else
S1 = 1;
end
return
```

3.5.3 MATLAB Function to Control Switch to Isolate the Battery Pack

```
Function stop = fcn (Soc1 , Soc2 , Soc3 , Soc4)
if ((Soc1<100) || (Soc2<100) || (Soc3<100) || (Soc4<100)
Stop = 1;
else
Stop = 0;
end
return
```

3.6 RESULTS AND DISCUSSIONS

3.6.1 For Passive Cell Balancing of Eight Cells in Stand-Alone State

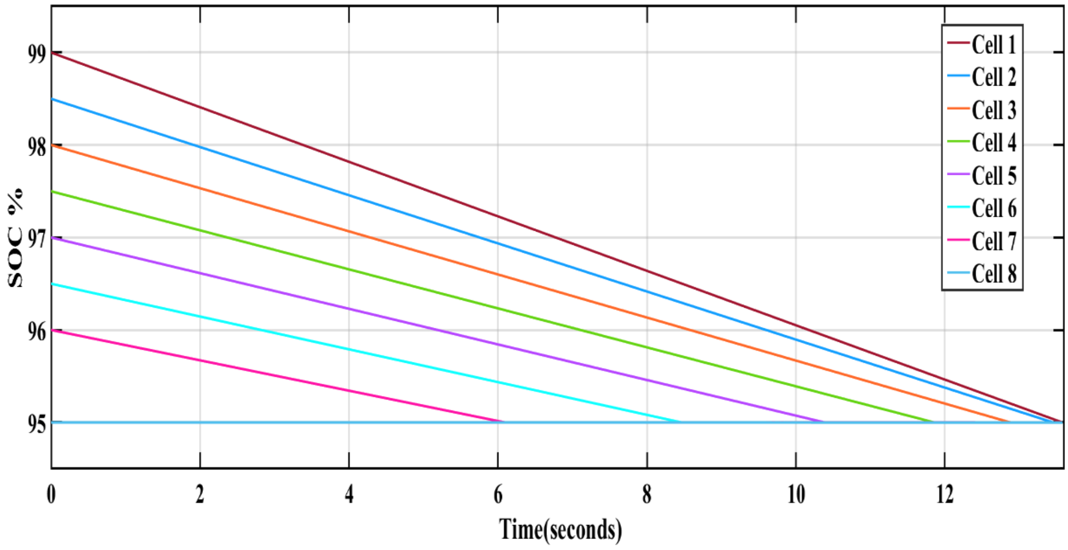


Fig.3.12 Passive cell balancing of eight battery cells

This graph depicts the discharge of each cell. Because of the grading done in bleeding resistors, they have varied slopes. The simulation runs for 15 seconds, but it stops at 12.5 seconds since all of the cells have reached cell balance. The lowest cell has not been discharged at all.

3.6.2 MATLAB Results for Battery Charge Controller

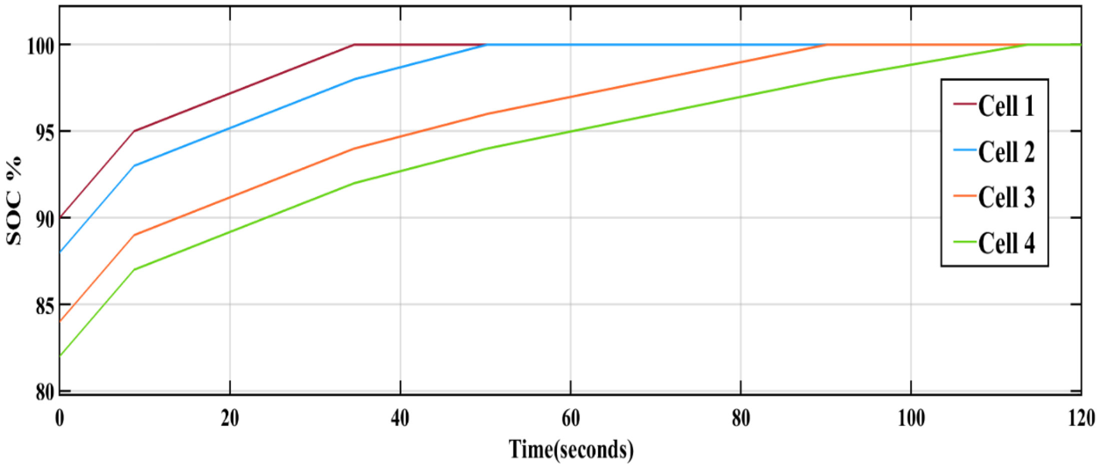


Fig. 3.12 SOCs of cells while charging with CCCV topology

Fig.3.12 is showing the charging characteristics of four battery cells and its run for around 120 sec and around 112 sec all cells reach to 100 % SOC.we also run this simulation for less time to see and understand the process but in Hardware it will take time. It can be observed from fig. that the slope of charging is different for all the battery cell during CC and CV mode.

3.6.3 Switching Mechanism of CCCV Charging

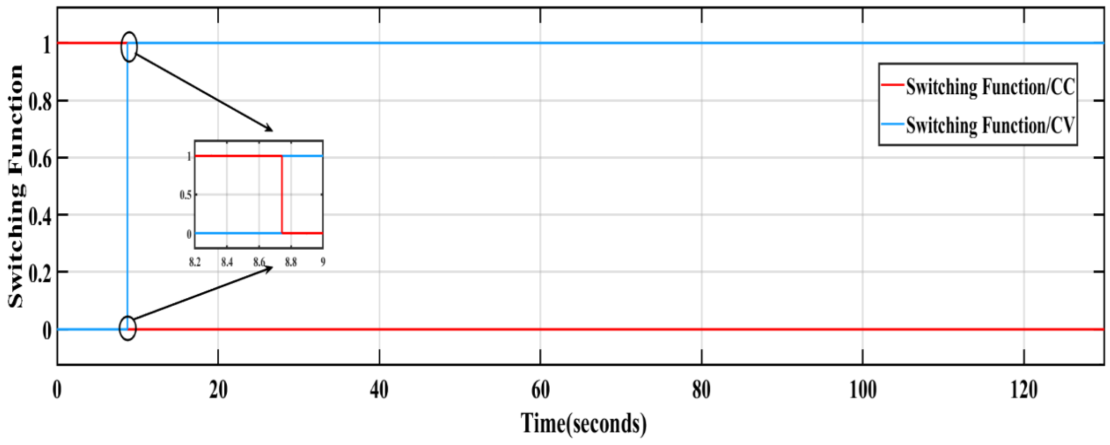


Fig.3.13 Switching mechanism of CC and CV Mode

The Fig.3.13 shows the switching between constant current and constant voltage charging mode. At 8.75 sec switching function change from constant current to constant voltage.

3.7 CONCLUSION

Significant characteristics of Li-ion battery cell balancing technique are analysed in this paper based on cell balancing. Based on the measurements, it is possible to conclude that the proposed circuit is capable of efficiently protecting the battery cell from overcharging and balancing the eight-cell Lithium-ion battery cells in stand-alone state. We know that battery charging and discharging is time taking process. In our model we design and simulate for less time so that we can see results and understand the whole process. A battery charge controller is designed and simulated for four battery cells which are connected in series with the use of CCCV topology.

CHAPTER 4

DESIGN AND ANALYSIS OF LLC RESONANT CONVERTER AND CCCV TOPOLOGY FOR BATTERY CHARGING

4.1 GENERAL

High power efficiency and high-power density are always in demand as power conversion technology advances. For many powers supply and energy-related applications, DC-DC power conversion is a necessary stage[7]. The power capabilities of the DC-DC converter stage are particularly challenged in PV micro-inverters and front-end converters of power supplies, which demand not only high efficiency and density but also the ability to control a broad range of input voltage and load circumstances[37][38]. Due to heat losses in Battery charge controller, we designed a CC-CV charging with the combination of LLC resonant converter and Buck converter for 48 v/40 Ah Lithium-ion Battery.

4.2 BRIEF OF LLC RESONANT CONVERTER

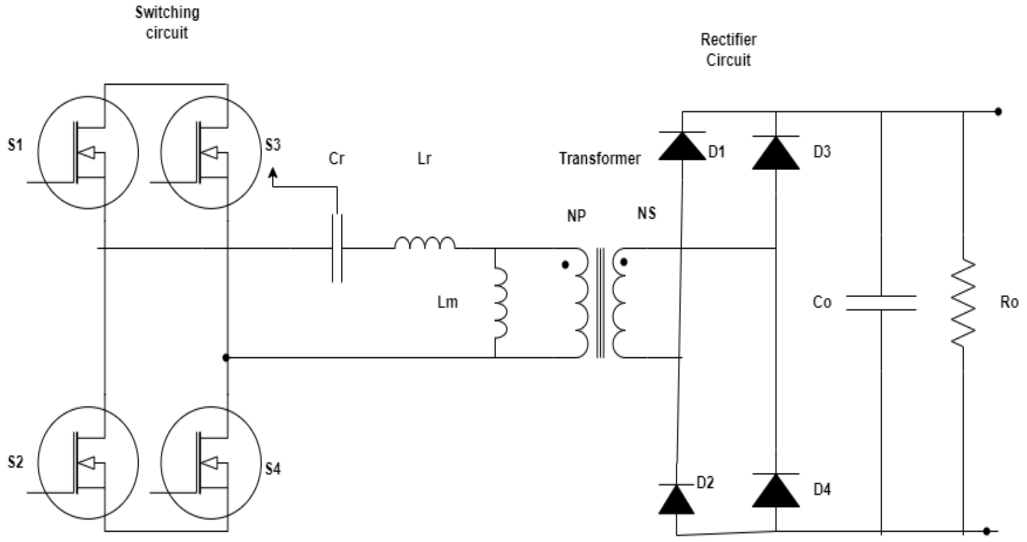


Fig.4.1 Circuit diagram of LLC converter

Fig. 4.1 is general circuit diagram of LLC converter. overall circuit diagram can be divided in following sub circuits.

1- Switching Bridge

2- LLC tank

3- Transformer circuit
4- Rectifier bridge
5- Load

1- **Switching bridge –** The switching bridge is initial sub circuits of LLC converter which will convert the DC input voltage to AC voltage with the help of pulse generator.

2- LLC Tank- LLC tank is second sub-circuits of LLC converter. LLC tank consists of resonant inductor (Lr), resonant capacitance (Cr) and Magnetizing inductance (Lm)[39]. Resonant inductor and resonant capacitance connected in series while magnetizing inductance is connected parallel to combination of both.

3- Transformer circuit – Transformer circuits is used to step-up and step down the input voltage as per the requirement of system. It also used for the isolation of the circuit.

4- Rectifier- After getting the AC voltage from the Secondary side of the transformer, we have to rectify it from AC to DC for the regulated output voltage. That's why we use the full bridge rectifier for this operation.

5- Load (Ro)- We design any power electronics system or power system to satisfy the load demand of the end. Ro is a load value which used in LLC converter as per the specifications.

These are fiver major sub circuits but for designing a LLC resonant converter, a gain Curve should be plotted between Gain and Normalized frequency[7]. LLC converter output depends upon this curve.

4.2.1 Gain Curve for LLC Resonant Converter

In this project 400 V input voltage has been taken and Rectified output voltage of LLC resonant converter around 100 V without Buck converter. Gain margin curve provides the relation between the normalized frequency and Gain. It will give operating range for the working the LLC Resonant converter. By Gain margin curve we get the frequency range for a particular gain. For variable input gain margin gives gain range for operation[40].

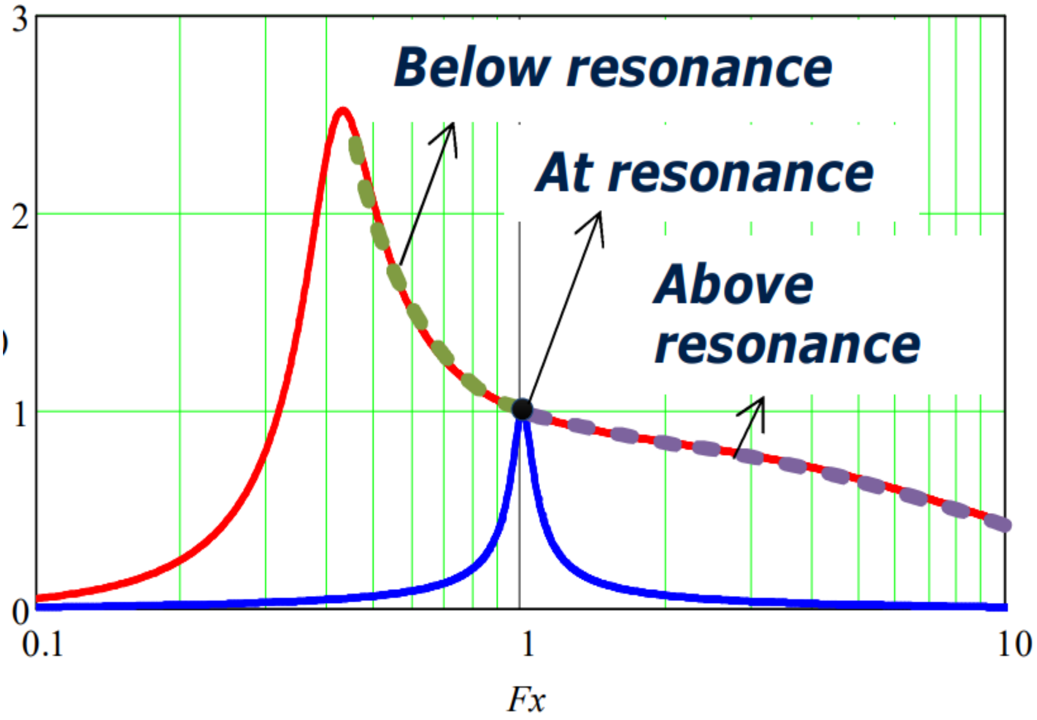


Fig. 4.2 Gain-curve for LLC converter

Because the LLC network gain is frequency modulated, the converter can operate in one of three modes, as indicated, depending on the input voltage and load current.

1- At resonant frequency operation, fs=fr.

2. Above resonant frequency operation fs>fr.

3. Below Resonant frequency operation, fs<fr.

4.2.2 Zero Voltage Switching (ZVS)

When the LLC resonant converter works in the inductive region, the resonant current lags the input voltage. Thus, when the switching state is changed, the direction of the resonant current cannot be abruptly changed, and the current continues to flow in the original direction. zero voltage switching is used as soft switching for the converter. ZVS reduces the switching losses in circuit at the time of switching that’s why soft switching is very useful in high efficiency applications[16]. In this project, we will do ZVS at the turn-on position[41].

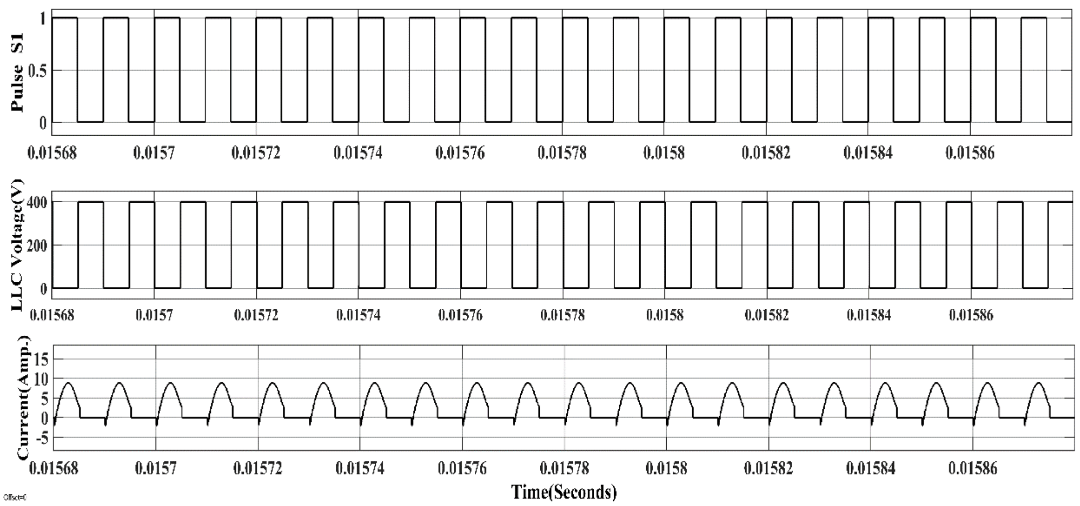


Fig. 4.3 Zero voltage switching in LLC converter

4.2.3 LLC Resonant Tank

LLC resonant tank a one of important sub circuits of the LLC converter. LLC tank is series combination of Resonant inductance (Lr) and Resonant capacitance (Cr), parallel with the Magnetizing inductance (Lm) and equivalent resistance (Rac). at the resonant frequency, Resonance happens in the circuit to make the system to work in resonant frequency which is also equal to switching frequency (fs)[19].

4.2.4 Rectifier Circuit

Choosing the correct bridge and rectifier circuits is a crucial step in achieving the greatest converter performance. On the secondary side, LLC converters can be built with a full-bridge or full-wave rectifier circuit. When compared to a full-bridge rectifier, a full-wave rectifier requires diodes with twice the voltage rating, but it only requires two diodes, whereas the full-bridge rectifier requires four diodes, because each diode in both rectifier circuits carries the same average current. the full-wave rectifier has half the total diode conduction losses compared to the full-bridge rectifier[42].

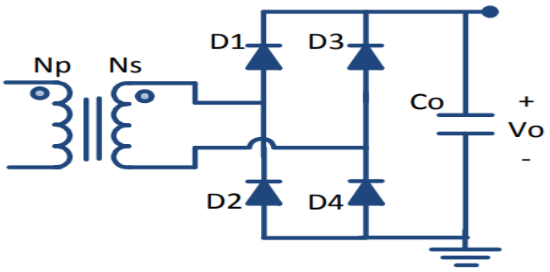


Fig.4.4 Full-bridge rectifier circuit

Full bridge rectifier used in this project the secondary side voltage given to the rectifier which will convert the AC output voltage to DC Regulated output. Output capacitance (Co) to maintain constant the DC output of rectifier[39].

4.3 PROPOSED TOPOLOGY

This project is proposed for the charging a battery with constant current (CC) constant voltage (CV) for our specified battery.

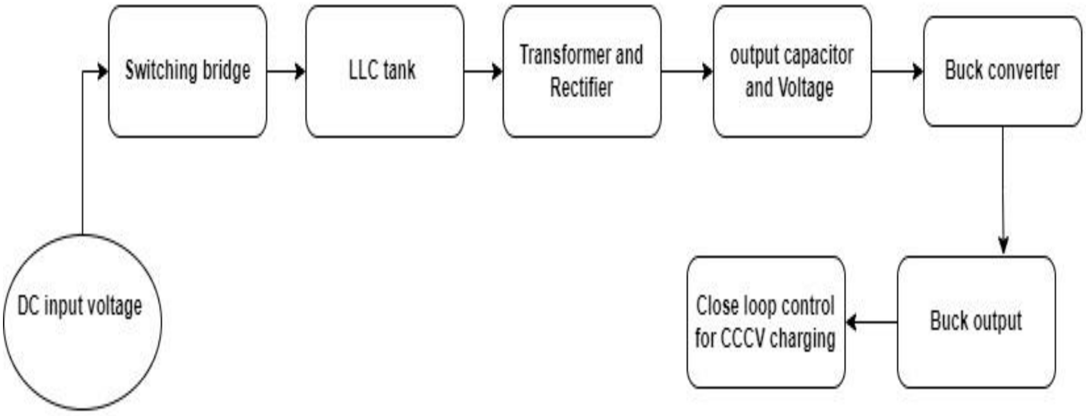


Fig.4.5 Block diagram of Proposed topology

Fig. 4.5 is a block diagram of proposed topology that we used in this dissertation. The Block diagram depicts the DC voltage given to the switching bridge which is bridge circuit. The LLC Resonant circuit gives the Zero voltage switching (ZVS) in the primary side. ZVS reduces the switching losses[41] in Proposed circuit. LLC output is given to the Buck converter, by this we can regulates the charging current and charging voltage for our battery specification[43]. We will regulate the voltage and current by varying the duty cycle of Buck Converter. Close loop control of current and voltage[44] will give the Constant current (CC) and Constant voltage (CV).

Fixed Input voltage of 400 V is given to Full bridge switching bridge circuit that will convert it into AC. We will design the parameter value of LLC tank as per required output for a system. In this project we have to design a system which can charge 48V/40 Ah Lithium- ion battery. for a charging a 48V / 40 Ah battery we need a 50 V constant voltage source at the output and 10 % of battery capacity current for charging. That’s why we have to design a 4 A constant current (CC) source due to 40 Ah capacity.

Zero voltage switching happens because of LLC tank. ZVS reduces the switching losses in circuit. We take a switching frequency (Fs) of 100 KHz which is equal to resonant frequency(Fr). For a unity voltage gain we have to give fixed input as primary. When Fs = Fr , unity voltage gain achieved at every loading condition[13]. We will decide a quality factor(Q) and Raito of magnetizing inductance (Lm) and Resonant Inductance (Lr) which is 'm'[45].

Transformer step down the Input voltage 400 V to 100 V AC and then 100 V AC converted in DC with the help of full bridge rectifier but we will get a rectified voltage around 95V in our project due to nonlinear circuit (Buck converter) connected to it.

LLC converter is not suitable for CCCV topology that’s why we connected a Buck converter at output side of rectifier. using a Buck converter with a LLC converter is easy implementation for CCCV charging. In LLC converter resonant capacitor is choose for resonating with leakage inductance of LLC converter which may cause failure in the resonance condition. It has own its tolerance.so output voltage of LLC converter is not load independent. so Buck converter regulate the output of LLC converter. Buck converter allow the variation in output voltage of LLC converter and ensures the CCCV charging for battery[46]. Buck converter will give the regulated voltage as per battery specification of battery.

We will convert 95 V dc to 50 V with the duty ratio of 0.5 at 100 KHz frequency. The output voltage of Buck converter is 48.5 V and 4.06 A.

By using a close loop control will control the Buck converter output. By using the PI controller[47], the voltage of buck converter is controlled and maintained to 49.6 V for constant voltage (CV)charging and by using a hysteresis control we control the output current and maintained to 4.13 A constant current (CC) charging. We take a tolerance level of 5% for constant current and constant voltage. It is a dual loop control combination of PI controller and hysteresis current control.

4.3.1 Equations and Parameter Value Calculations

$$K(Q,m,F_1) = \left|\frac{V_{o\_ac}(s)}{V_{in\_ac}(s)}\right| = \frac{\mathrm{F_n}^2(m-1)}{\sqrt{(\mathrm{m.F_n}^2-1)^2 + \mathrm{F_n}^2.(\mathrm{F_n}^2-1)^2.(m-1)^2.Q^2}} \tag{1}$$

Equation 1[7] is the Gain equation. It gives the relation between the Gain(K) and the normalized frequency (Fn). Gain equation gives the value of Quality factor and Ratio of magnetizing inductance to resonant inductance.

$Q = \frac{\sqrt{L_r/C_r}}{R}$ Q is Quality Factor.

$R_{ac} = \frac{8N_r^2}{\pi^2 N_S^2}.R_o$ Rac is Equivalent resistance.

$F_n = \frac{f_s}{f_r}$ Fn is Normalized frequency.

$f_r = \frac{1}{2\pi\sqrt{L_r.C_r}}$ fr is Resonant Frequency.

$m = \frac{L_r+L_m}{L_r}$ m is ratio of magnetizing inductance to resonant inductance.

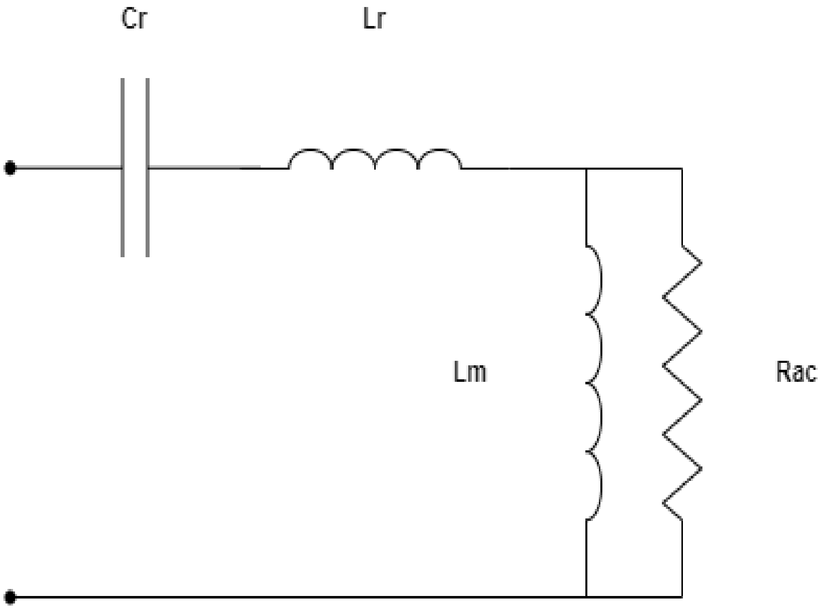


Fig. 4.6 LLC tank of converter

By using those above formula, we will calculate the parameters of LLC converter. We use a quality factor and m value from the Gain curve[48].

Table 4.1 Parameters Specifications of LLC Resonant Converter

Parameters	**Values**
Input voltage (Vin1)	400 V
Switching Frequency(Fs)	100 KHz
Resonant Frequency (Fr)	100 KHz
Quality Factor (Q)	5
m	6
Resonant inductance(Lr)	5,16 mh
Resonant Capacitance(Cr)	491.39 pF
Magnetizing Inductance(Lm)	25.86 mH
Turn Ratio (Nr:Ns)	4:1
Rectified voltage of LLC converter(Vo1)	95 V
Equivalent resistance (Rac)	649.78 Ω
Output capacitor (Co)	200 uF

Table 4.2 Buck Converter Specifications

Parameters	**Values**
Input voltage (Vin)	95 V
Inductance(Lo)	30 uH
Capacitance(Co)	30.4 uF
Switching Frequency (Fs)	100 KHz
Duty cycle (d)	0.5
Output voltage (Vo)	48.5 V
Output current(Io)	4..06 A

4.3.2 Gain Curve MATLAB Code

```
clc;
clear all;
close all;
m = [3 6 8 15];
fn = logspace(-1, 1, 1000);
colors = [‘r’ ‘g’ ‘b’ ‘c’ ‘m’ ‘k’ ‘r’ ‘bl’];
Q = [0.3 0.7 3 5 6 8];
for y = 1:7
  figure
  for  i = 1:8
   Gain = (((10/(pi^2))*(fn.^2)*(m(y)-1))./(((m(y)*(fn.^2)-1).^2+((fn.^2).*((fn.^2)-1).^2).*((m(y)-1).^2)*(Q(i)^2)).^0.5));
   Semilogx(fn, Gain, ‘color’,colors(i), ‘LineWidth’,3)
   hold on
end
 legends('Q = 0.3', 'Q = 0.7', 'Q = 3', 'Q = 5', 'Q = 6', 'Q = 8')
 title['|G|(\omega)vs \omega with m ', num2str(m(y))],'FontSize', 18)
xlabel('\omega_x','FontSize', 18)
ylabel('|G|(\omega_x)','FontSize',18)
grid on
end
```

4.3.3 Gain Curve Plot Results

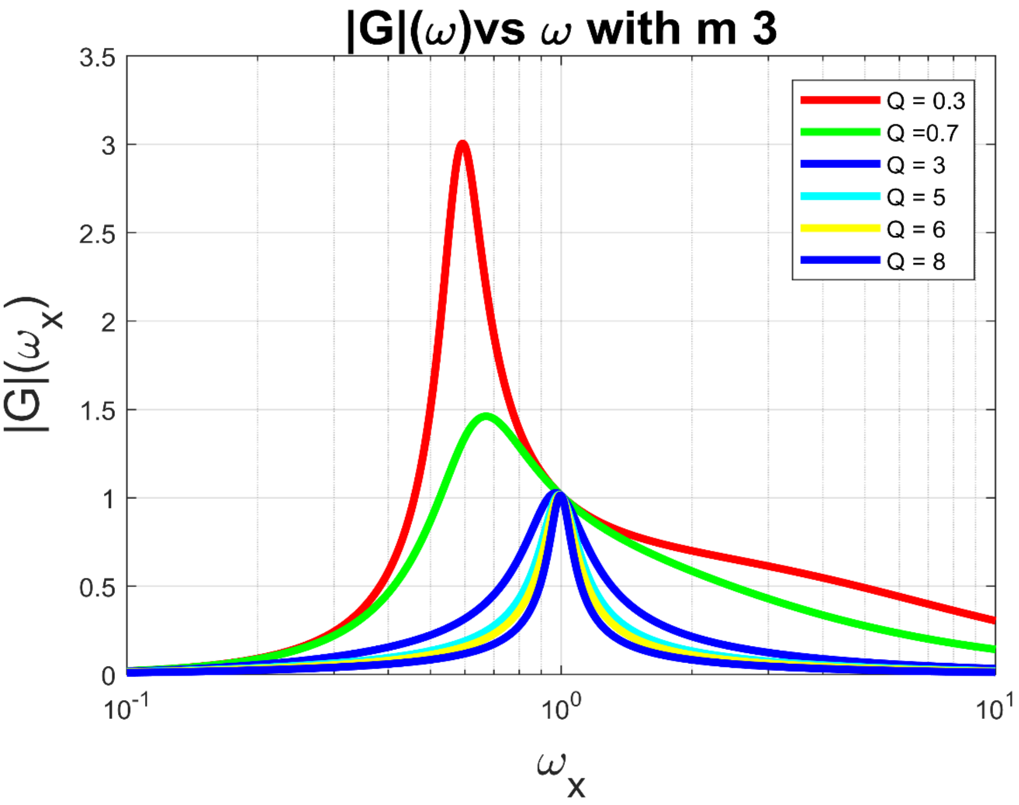


Fig. 4.7 Gain curve with m = 3

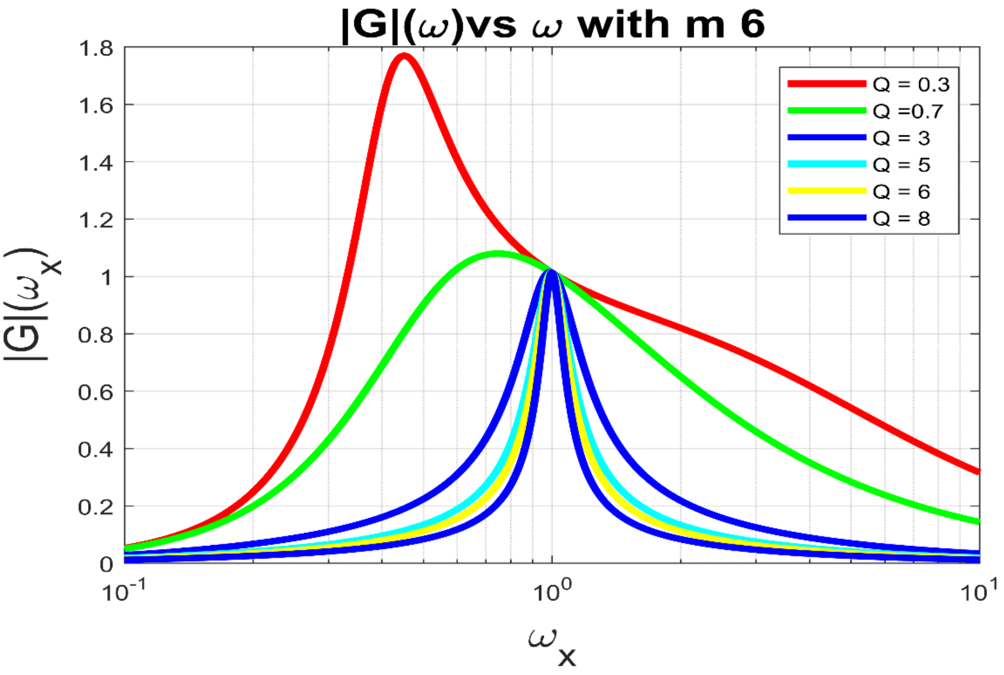


Fig. 4.8 Gain curve with m = 6

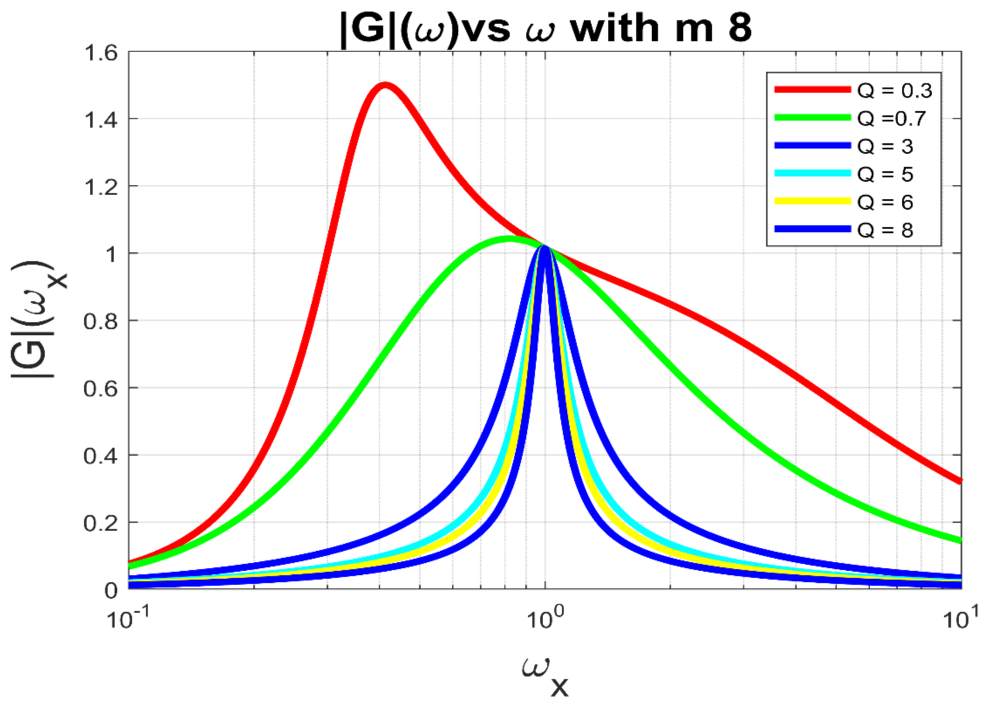
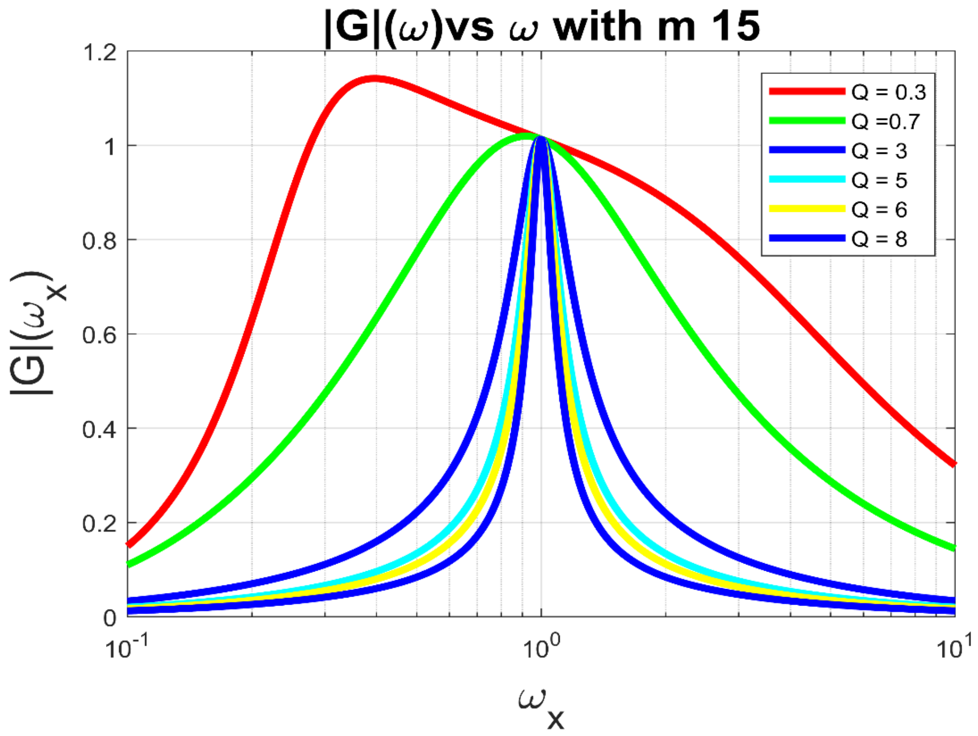


Fig. 4.9 Gain curve with m = 8



(d)

Fig. 4.10 Gain curve with m = 15

These are gain curves are obtained from the Gain curve MATLAB code. These curves plotted with different values of m. we have to choose one of curve as per our requirement.

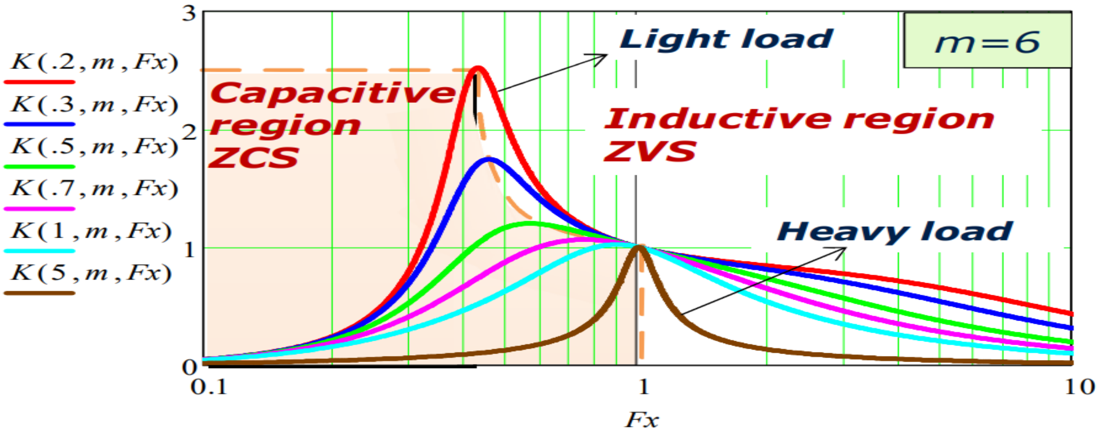


Fig. 4.11 General Gain curve

Fig. 4.11 is general Gain curve which tells us the region of working with respect the loading conditions[37]. This curve is plot with m = 6. When resonant frequency equal to switching frequency voltage gain 1 is achieved. Low Q curves correspond to light load operations, whereas larger Q curves correspond to high loads, as seen in Figure 18. All Q curves (load conditions) intersect at the resonant frequency point (at Fx=1 or fs=fr) and have the unity gain[49]. We choose a Gain curve with the value of m= 6 and from this we can take a value of Q is 5 which is suitable for LLC converter[50].

4.4 SIMULATION AND RESULTS

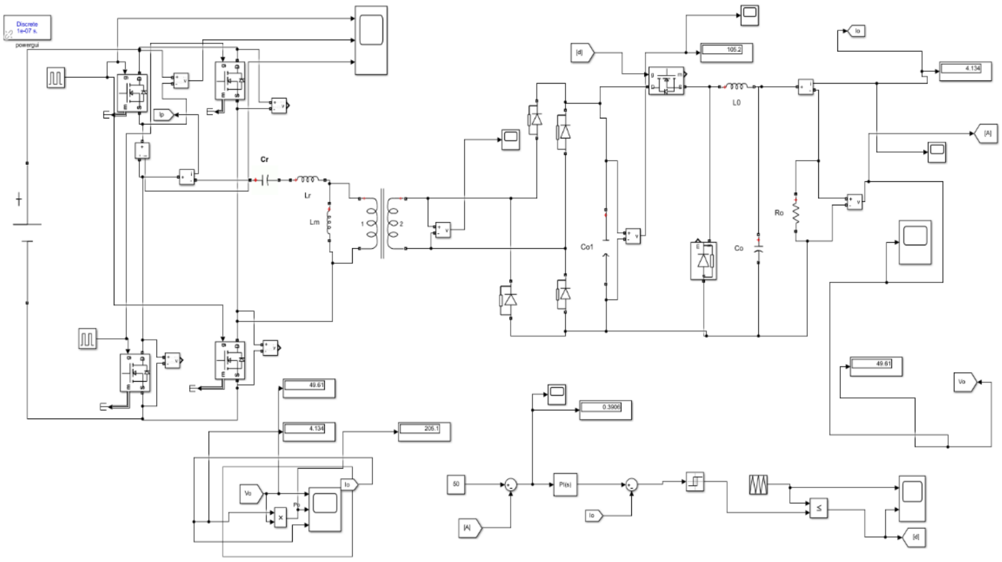


Fig. 4.12 Simulation of LLC resonant converter with Buck converter for CCCV topology

This is the overall simulation of LLC resonant converter with Buck converter for the implementation of CCCV charging for battery. This simulation is combination of Proposed topology and Closed loop control for constant current (CC) and constant voltage (CV)[51]. Constant voltage is controlled by using PI controller and constant current is controlled by Hysteresis current control. It is a dual loop control combination of current and voltage also by using signal builder varying the input and check the close loop results[52][53].

Results of Simulation

4.4.1 Zero Voltage Switching of LLC Converter

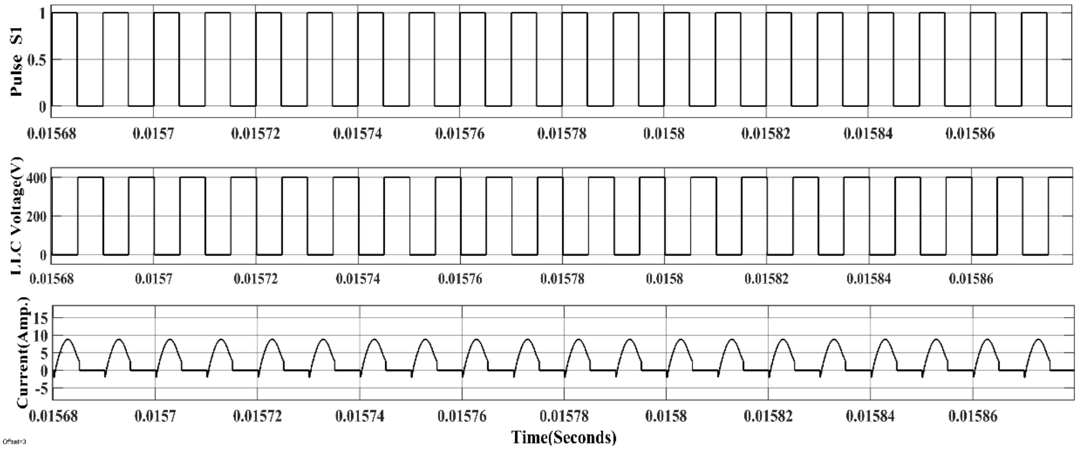


Fig.4.13 ZVS of LLC resonant converter

When switch S1 is on, at this time voltage across the switch becomes zero and current start from the negative value. This is perfect ZVS condition. ZVS will reduces the switching losses of the converter and increases the efficiency.

4.4.2 Secondary Side Output Voltage of Transformer

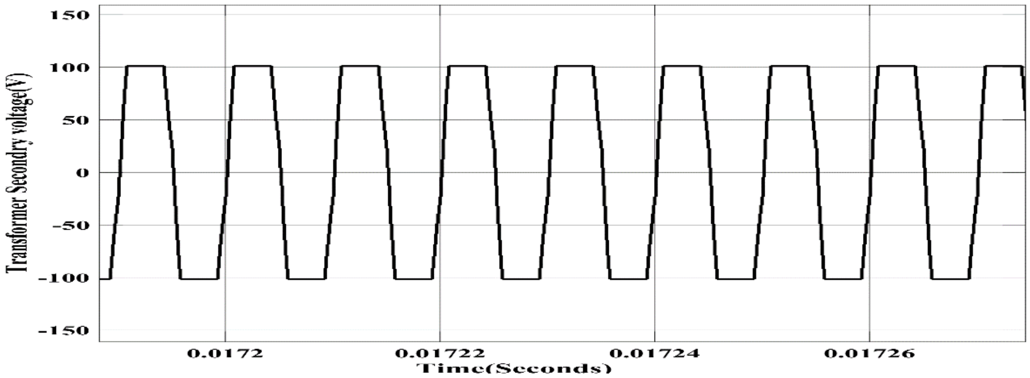


Fig. 4.14 Transformer voltage without Buck converter

Without Buck converter transformer voltage is perfectly converting 400 to 100 V as shown in fig. 4.14.

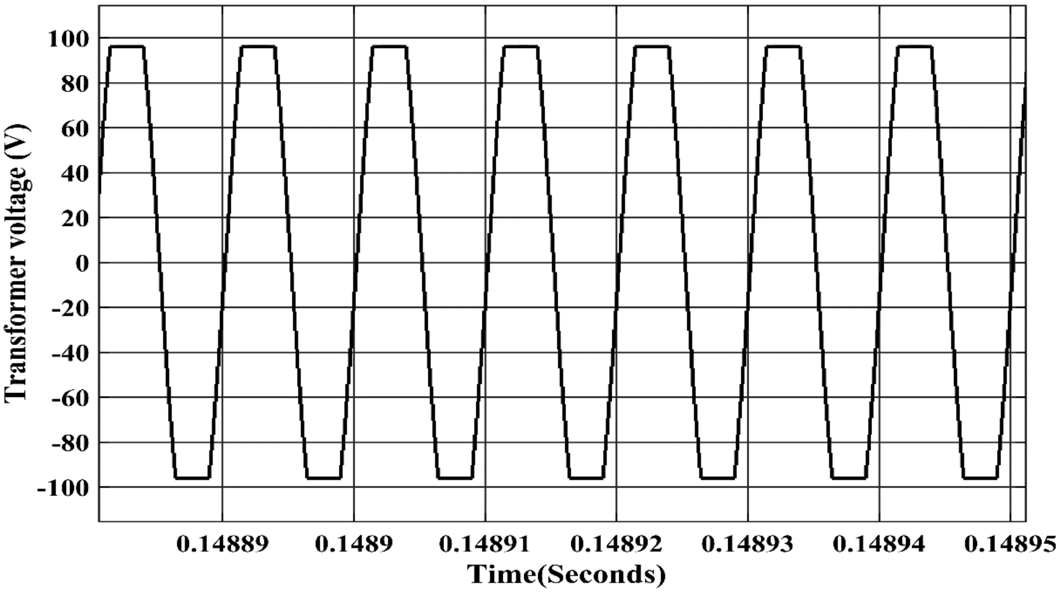


Fig. 4.15 Transformer voltage with Buck converter

Transformer has turn ratio of 4:1so it will step down the 400 V input to 100 Volt in the secondary side. It is when we did not cascade the Buck converter to Rectifier output. Fig. 4.14 depicts the same result of 100 V. but when Buck converter is cascaded with Rectifier side the transformer secondary voltage changes to around 95 V. it is because Buck converter contains the non- linear components like inductor and capacitor, it will affect the voltage of transformer as Fig. 4.15 showing the same.

4.4.3 Rectified Output Voltage of LLC Converter

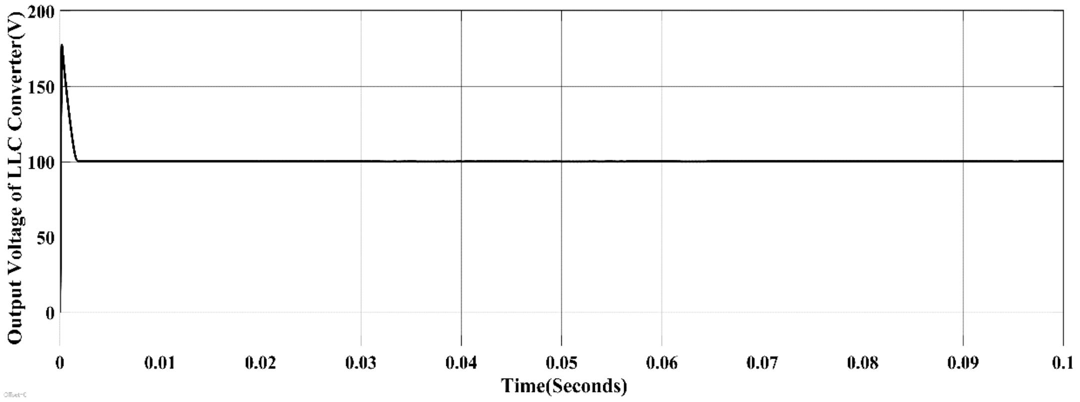


Fig. 4.16 Rectified output voltage of LLC converter without buck converter

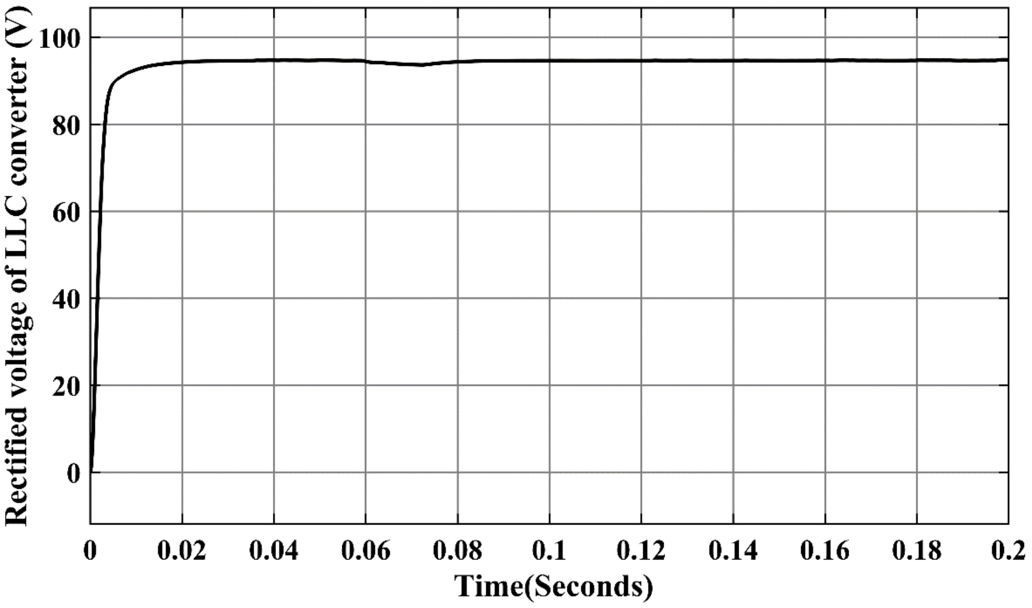


Fig. 4.17 Rectified output voltage of LLC converter with Buck converter

Fig. 4.16 is Rectified output voltage of LLC converter it is coming around 100 V. it is a regulated constant DC voltage which is given to the Buck converter output. Fig. 4.17 is Rectified output voltage of LLC converter with Buck converter in cascade.

4.4.4 Buck Converter Output Voltage and Current

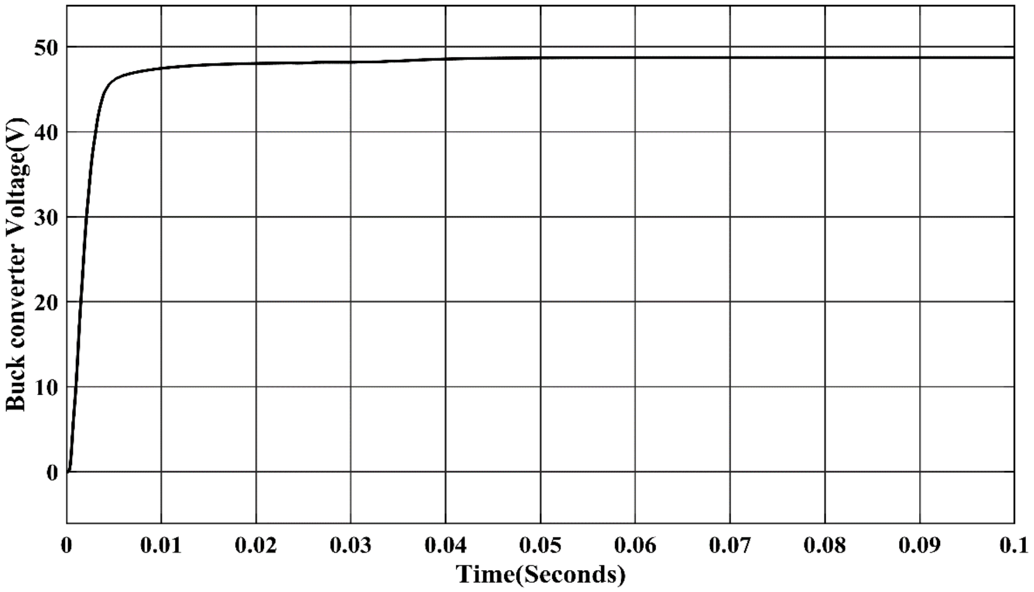


Fig. 4.18 Buck converter output voltage

It can be seen from Fig. 4.18 Buck converter output voltage coming out 48.5 V with a duty cycle of 0.5.

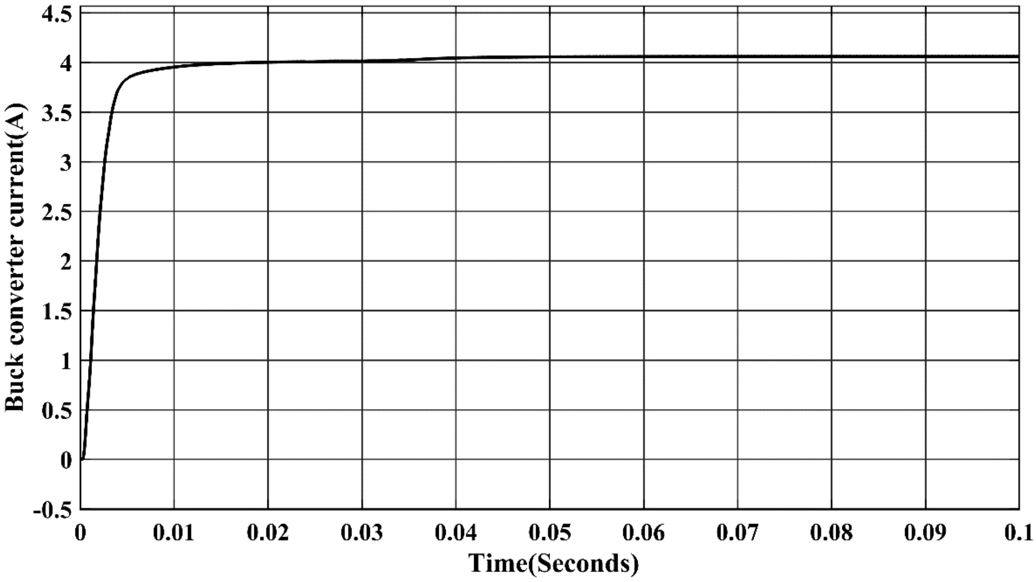


Fig. 4.19 Buck converter output current

Buck converter gives the regulated constant output voltage of 48.5 V and constant current of 4.06 A. we want 50 V constant voltage and 4 A constant current for changing a battery of 48V/40 Ah capacity. We have to close loop control for it. Duty cycle we used of 0.5. buck converter gives the highest efficiency when we used it around 0.5 duty cycle.

4.4.5 Close Loop Control of Buck Converter Output

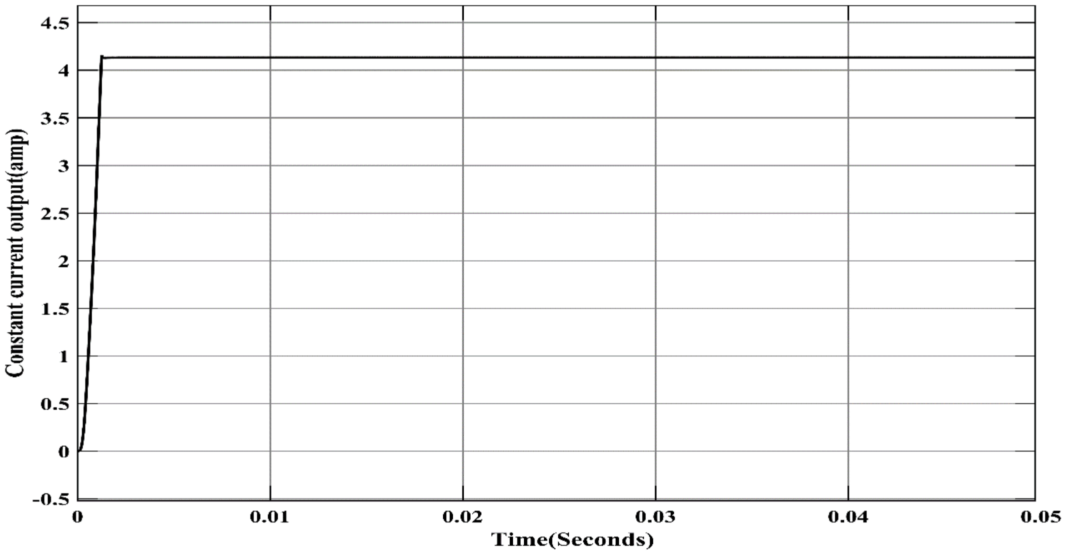


Fig. 4.20 Buck converter output current with close loop control

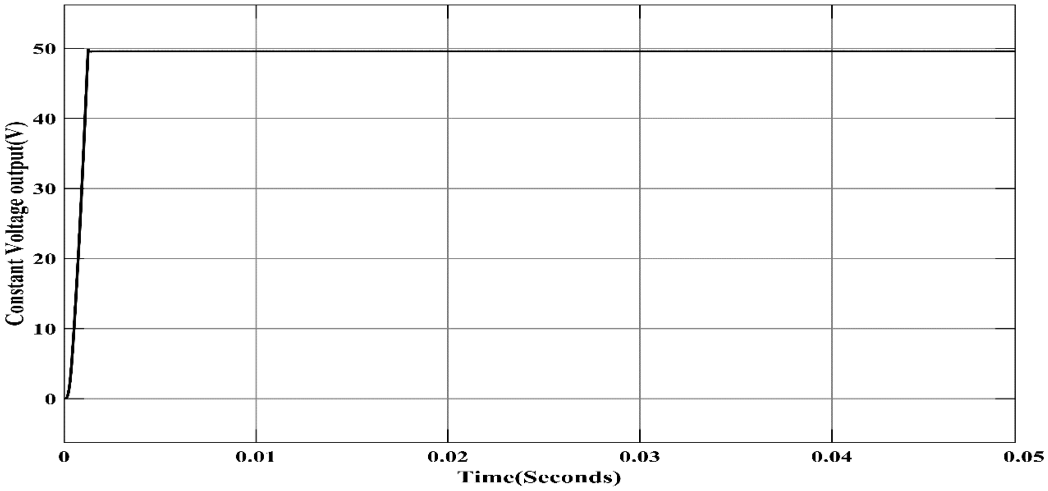


Fig. 4.21 Buck converter output voltage with close loop control

Close loop control is very important when we want a constant value at the output side at any different loading conditions. We did a dual loop control here for controlling the Buck output voltage and Buck output current as per the battery charging specification. We control the output voltage by the use of PI controller and for the current control we use a hysteresis current control. Dual loop is combination of PI controller and hysteresis current control. At the end we get a constant current of 4.13 A and constant voltage of 49.6 V which is suitable for CCCV charging for our battery of 48V/40Ah capacity.

Table 4.3 Buck Converter Output with and without Close Loop Control

Output Parameters	**Without close loop control**	**With close loop control**
Output voltage	48.5 V	49.6 V
Output current	4.06 A	4.13 A

4.4.6 Buck Converter Power Output

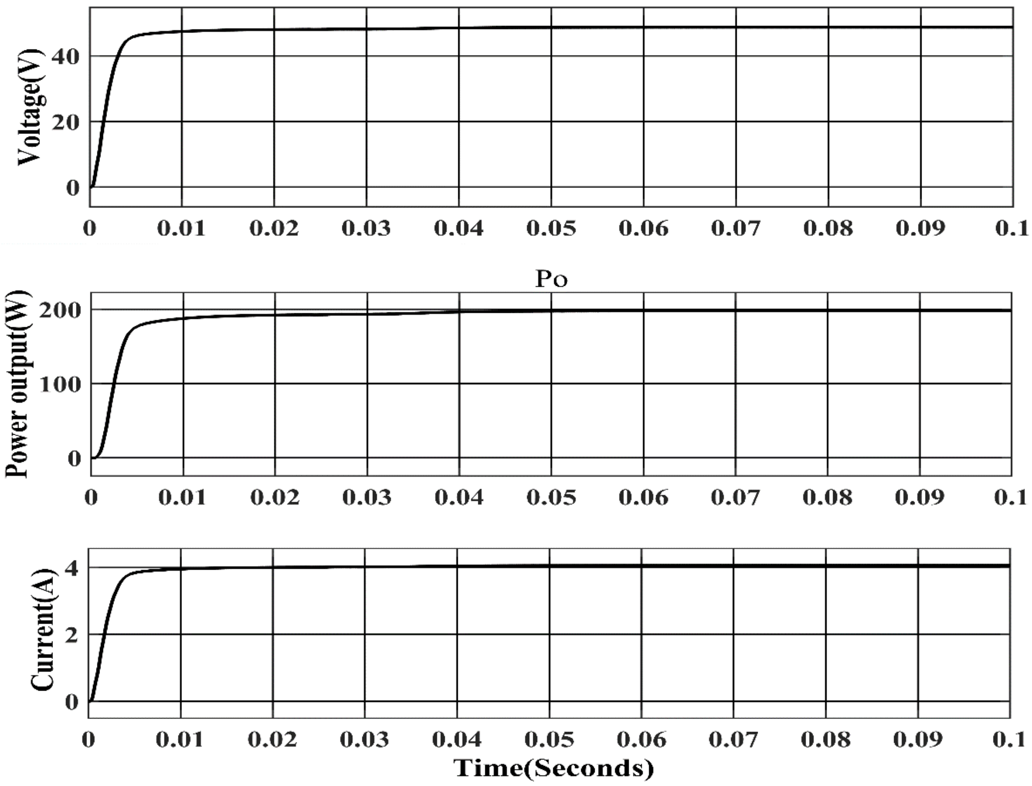


Fig. 4.22 Buck converter output without close loop control

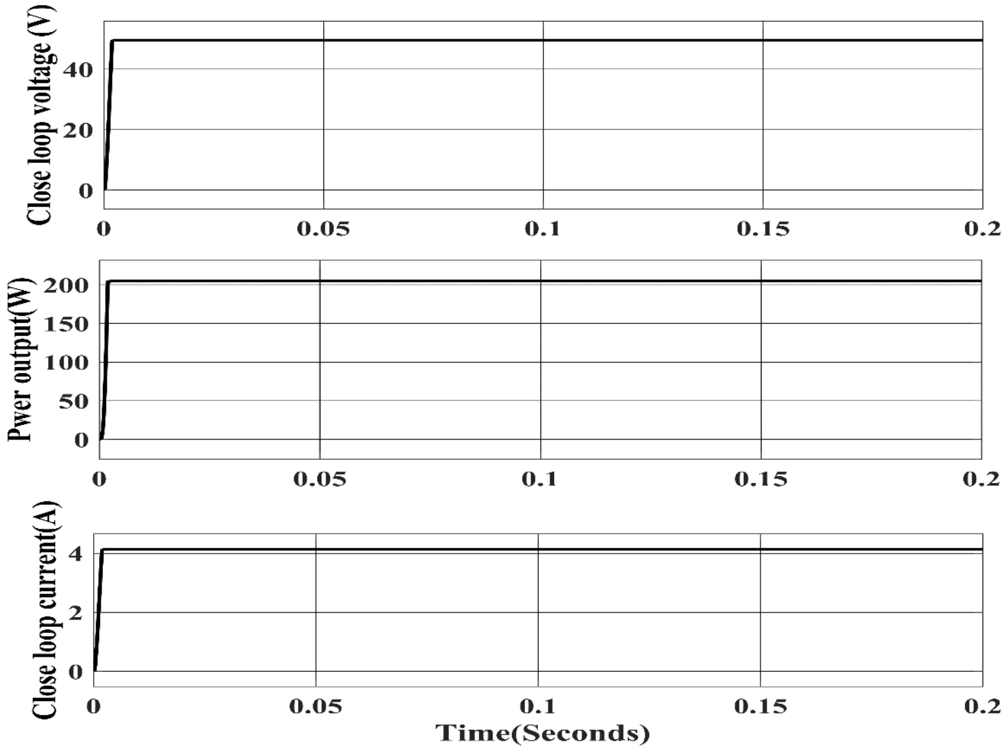


Fig. 4.23 Buck converter output with close loop control

Table 4.4 Power and Efficiency Comparison of Buck Converter

Parameter	Power	Efficiency
Buck converter input	95 *2.261 = 215 W	-
Buck converter output power with close loop	49.6*4.13 = 205 W	95.34 %

Buck converter working efficiency greater than 95 % in close loop control.so cascading of LLC converter with Buck converter very much suitable for CC – CV charging.

4.4.7 Buck Converter Output with Signal Builder

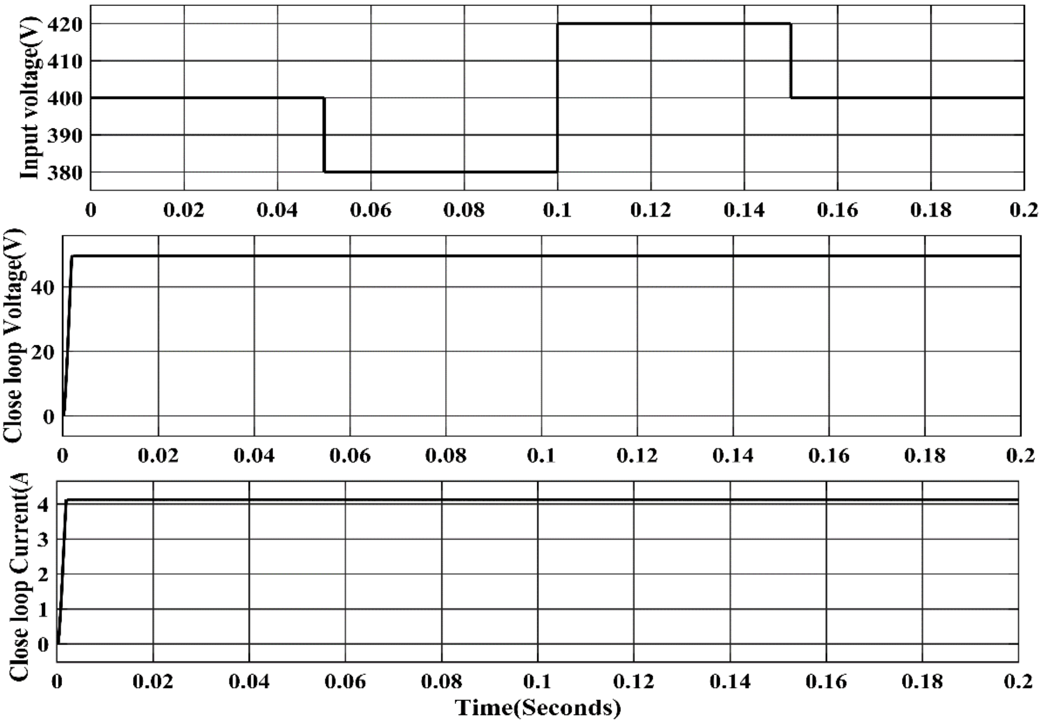


Fig. 4.24 close loop output with signal builder

When we varying the input by signal builder from 400 V to 380 V and after some time from 380 V to 420 V and last to 400 V, the close loop voltage and current is 49.6 V and 4.13 A. the close loop perfectly tunned it also support the input variation.

4.5 CONCLUSION

This project presents an LLC converter with Buck converter for CC- CV charging. LLC converter improves the switching losses by Zero voltage switching. The simulation is presented for proving that the idea is Achievable and Suitable for CC-CV charging for a battery. The Buck converter gives the option to get required output current and voltage as per the battery specifications. The closed loop control of current and voltage gives the Constant current and constant Voltage (CC-CV) for charging the Battery as per Battery specifications.

CHAPTER 5

CONCLUSIONS AND FUTURE SCOPE

5.1 CONCLUSIONS

In today world, electrical vehicles are used in world wide. Battery is one of the most important part of electric vehicles. How can a EV's is better than petrol / diesel engine vehicles its only because battery better performance and charging a battery is very crucial part. Lithium-ion battery packs, unlike multi-cell lead-acid battery packs, cannot be equalised by an overcharge, necessitating a different approach.for charging a Battery there are many chargers present in the market. But for efficient and easy charging Constant current (CC) and Constant voltage charging (CV) is used generally. In our project we design the CCCV charging by using passive method and also design a battery charge controller using CCCV mechanism for four battery cells.

Constant current charging is done for charging up to 95 % SOC level of cell or its between to 3.7 V to 4.0 V of a lithium- ion battery cell so generally we use constant current charging but after 95 % SOC or after nominal voltage around 3.7 V, we charge it by constant voltage (CV).

Passive cell balancing achieved by using a switching shunting resistor technique for eight battery cell of lithium-ion battery in stand-alone state. We also did the grading of bleeder resistance which is used to bypass the extra charge in passive cell balancing and battery charge controller.

Passive cell balancing may be easy, cost effective and simple circuitry as compare to active cell balancing but efficiency wise it is not very good because by passing the extra charge from the bleeder resistance, heat energy is produced in the circuit and power wastage in very much amount. This is the main reason we did not prefer the simple passive cell balancing. We can use energy storage devices like inductor or capacitor to store the power wastage but they will make the system bulky and very costly. Battery charge controller is a example of passive method. For power wastage I use a one more switching function at the end when one battery cell charges the switch function automatic open the switch of that cell and at the end when all the cells charge switch function disable to flow current in circuit.

Due to power wastage in Battery charge controller the CCCV charging is not effective in that circuit so i use a power electronic converter to design a battery charging system so that we can achieve the maximum efficiency from the circuit and can make the constant current (CC) and Constant voltage (CV) charging for a particular Battery.

We design a LLC converter cascaded with Buck converter for CC- CV charging of battery. We design a CC – CV charging system for 48V/40Ah battery. As per the battery specification we design constant current of 4 A for constant current charging and constant voltage of 50 V for constant voltage charging by using the closed loop control. LLC converter work in 100 KHz switching frequency which is equal to resonant frequency for unity voltage gain at any loading condition. Zero voltage switching is helping to get efficient system by reducing the switching losses at the primary switching bridge of LLC converter. Gain curve is plotted for the value of quality factor and m to design the LLC tank of LLC converter. LLC converter gives the rectified output at the rectifier side around 95 V but in transformer we use the ratio of 4:1 so it should be 100 V but due to non-linear circuit like Buck converter it gives around 95 V. this is one demerits of this project. Buck converter regulate the output voltage and current of LLC converter into 48.5 V and 4.06 A.

Buck converter also gives the constant voltage and constant current to charge a battery but it will not constant under any loading condition.so we use dual close loop control for current and voltage. By using PI controller, control the output voltage of buck converter 48.5 V to 50 V but it's coming constant 49.6 V with 5 % tolerance level. By using the hysteresis current control, controlled the output current of Buck converter of 4.06 A to 4 A but it's coming 4.13 A with 2% tolerance level. Close loop current and voltage is very much suitable for our battery of 48 V/40Ah. The objectives of our project are achieved successfully.

5.2 FUTURE SCOPE

We did the cascading of Buck converter with LLC converter for CCCV charging. For improvement of efficiency, we can do the regulation of LLC resonant converter using variable resonant frequency.

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LIST OF PAPERS

[1] Praphull Prakash Gupta, Narendra Kumar, Uma Nangia "Passive Cell Balancing and Battery charge controller with CCCV Topology", *IEEE 3rd International Conference of Emerging Technologies 2022*, Belgaum, Karnataka, India(27-28 May 2022) **(Presented)**

[2] Praphull Prakash Gupta, Narendra Kumar, Uma Nangia "Analysis and Design of LLC Resonant Converter and CCCV topology for Battery Charging", 2022 *IEEE 2nd ASIAN conference on Innovation in Technology*, Pune, India **(Communicated)**