TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

A FINAL YEAR PROJECT REPORT ON

SMART EV CHARGER WITH REACTIVE POWER COMPENSATION

(A PROJECT REPORT SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE BACHELOR'S DEGREE IN ELECTRICAL ENGINEERING)

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ABSTRACT

The voltage drop is a serious issue that the grid is facing at present due to the penetration of a large number of EVs. For this at present STATCOMs and Capacitor banks are used, however STATCOMs are expensive and Capacitor Banks have less reliability. In this situation we came up with an idea to embed the functions of such compensating devices into the charger itself in order to increase the system reliability and reduce the use of such expensive devices. This paper illustrates the overall procedure of the prototype design of the system and an EV charger that regulates the voltage at the user end.

As our final year project, we sought to develop a smart EV charger that compensates for the reactive power in the grid and maintains the voltage at the user end while charging the vehicle battery simultaneously. The project was carried out first in simulation (MATLAB) and then proceeded with hardware implementation right from the scratch. At first, we simulated the design in a Three phase system and observed the result in MATLAB Simulink. The charger works as a boost rectifier thus we were able to charge a 60 KW charger at unity power factor. While charging, the node voltage was dropped significantly low below the standard limit. Thus, in order to regulate the voltage at the node of connection. We supplied the reactive power to the grid through the charger. This was achieved by drawing the leading current by the charger. The amount by which the current should lead the voltage was determined by sensing the node voltage and was controlled by the help of a PID controller. The both active and the reactive component of the leading current is controlled in order to control the active and the reactive power. This control was implemented in the controller by the cross-coupling strategy.

If we want to charge the battery at unity power factor then we make the reactive component of the current equal to zero and only control the active current.

If we want to operate the charger only as a STATCOM (in this mode, battery is not connected) then we make the active component of the current equal to zero and only control the reactive current.

If we want to charge the battery as well as supply reactive power to the grid (Bidirectional mode) then we control both the active and the reactive component of the current.

Since the three-phase system is bulk and becomes costlier while designing the prototype of the charger, we designed the prototype of the charger on a small scale i.e., single phase. We Simulated the circuit in MATLAB Simulink with the charger of 90W as a load and implemented the same control strategy and working principle in a single phase. Finally, the circuit was fabricated and the control system was implemented using a microcontroller and the programming language used was C for programming microcontroller.

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LIST OF SYMBOLS AND ABBREVIATIONS

AC	Alternating Current
DC	Direct Current
Dc	Duty Cycle
EV	Electric Vehicle
Id	Direct Axis Current
Iq	Quadrature Axis Current
MOSFET	Metal Oxide Semiconductor
MATLAB	Matrix Laboratory
PF	Power Factor
PLL	Phase Locked Loop
PWM	Pulse Width Modulation
THD	Total Harmonic Distortion
Vd	Direct Axis Voltage
Vq	Quadrature Axis Voltage

CHAPTER ONE
INTRODUCTION

1.1 Background

An Electric Vehicle is the vehicle that uses one or more electric motors for propulsion. With technological advancement, there has been resurgence of vehicles in the market focusing on renewable energy and potential reduction of transportation's impact on climate change and other environmental issues.

Development in electric vehicles has greatly pushed forward innovation in various fields such as electric motors, storage of large quantities of energy for longer periods of time, power transfer technology, and so on. Charging has been the most important factor. Delivering the right amount of power with the least amount of losses along with the flexible operation in varying conditions. Extra stresses in the transmission lines and generators should not occur which must be the topmost priority for charger manufacturers increasing stability and flexibility of adding chargers without the addition of any of the reactive power compensating mechanisms at the distribution side.

The main problem with the charging infrastructure is that there are not many of them present. We do have some chargers but this infrastructure is far more to be developed. When the fleet of EVs soars the market there will be the need for every type of charger, let it be level 2 AC charging at home or the fast DC chargers at different places. With every increase in the charger numbers the demand for better power regulation increases so, the charger we are working on can help the hassle of power regulation at the distributed level with the flexibility of addition of chargers where needed without the addition of power compensating mechanisms at the substations.

1.2 Problem Statement

Although the number of Electric Vehicles (EV) in Nepal are limited compared to conventional vehicles, in the near future, it is expected that the EV penetration will increase significantly. Powering these EVs have a major impact on the power grid & distribution networks due to the consequences of huge power demand to charge their batteries.

The significance of stability studies becomes evident through the occurrence of numerous blackouts attributed to power system instability. Electric vehicles (EVs), when charging from the grid, introduce non-linear loads with distinct characteristics compared to conventional loads, thereby exerting stress on the power system. Additionally, uncertainties surrounding EV connection points, charging times, and charging periods pose challenges in accurately predicting the behavior of this new load. Consequently, a substantial increase in the number of EVs being charged raises concerns regarding power system stability [1]. In a study by Onar and Khaligh [2], the impact of integrating EVs into distribution networks was examined, focusing on the injection of current harmonics and reactive power consumption. The findings demonstrated that EV connections led to a deterioration in system stability, prolonging the recovery time required to attain steady-state conditions.Despite the electric and environmental benefits of EVs, drivers are still hesitant to utilize them because they feel they will limit their autonomy. As a result, new convenient and user-friendly ways are required to encourage the greater usage of electric vehicles. Smart EV charger is a technology for this mode of transportation in this context.

1.2.1 Impacts on voltage stability:

We have simulated and verified in hardware as well that the voltage drops in the receiving side of the power transmission system compared to the sending side. This is because charging of EVs draws a large amount of current which causes IX_L in expression to increase resulting in the decrease of receiving side voltage.

1.3 Objectives

The main objective of this project is:

- To ensure stable voltage regulation and minimize voltage drops at the receiving end of an EV charging station
- To develop a smart EV charger that can charge the vehicle and simultaneously supply the reactive power to the grid.
- To increase the reliability of the system
- To eliminate the use of VAR compensation such as capacitors banks, STATCOM

1.4 Scope of project

The scope of the project is to design and develop an EV charging station that is capable of adapting to varying power demands and drawing current with a leading or unity power factor as needed. This includes identifying the specific power demand situations that the charger will encounter and determining the optimal power factor to draw under each of those circumstances. The project will involve researching and selecting appropriate hardware and software components to achieve the desired power factor control, as well as testing and validating the charger's performance under various real-world conditions. The end goal is to provide electric vehicle owners with a reliable and efficient charging experience, while also minimizing voltage drops and ensuring stable voltage regulation at the receiving end of the charging station.

1.5 Limitations

The only limitation of the project is that it can supply a limited supply of the reactive power.

1.6 Report organization

- This project consists of five chapters including the current chapter. This chapter – Introduction includes the theoretical background, problem statement, objectives, and scope of this project.
- Chapter two provides a literature review on theoretical articles or publications from conferences or transactions as well as books from major publishers. The available information and previous results from other research related to the design and fabrication of EV chargers with dynamic control of powers are summarized in this section.
- Chapter three includes the proposed layout of the project and the methods and tools that were implemented to attain the objectives of the project.
- Chapter four presents the results that have been obtained during the implementation of this project. Also, the discussion on the obtained results is performed.
- Chapter five gives conclusions about this project and suggestions for future works.

CHAPTER TWO
LITERATURE REVIEW

2.1 Review of papers

Recent market projections for EV charging markets in transportation applications are encouraging. Consumer aversion to the inconvenient nature of plug-in wires, the requirement for charging infrastructure, and attributes like efficiency and dependability are projected to drive overall demand for EV charging[2]. People who are transitioning to electric vehicles from petroleum have continued to increase and this has opened up market prospects for EV charging. North America and Europe are the leaders in terms of both EVs and its charging applications[4].

The load requirement for EV charging will be rather high, and EV load characteristics differ from those of other traditional system loads. It is impossible to simply forecast in advance the location, time, and length of the charging process, as well as the real and reactive power consumption of the EV load. Various system studies have already identified numerous likely grid implications. Among concerns include potential increases in peak demand, violations of regulatory voltage limits, harmonic issues, over-loadings of distribution system assets, and increased power losse[1].

Diode rectifier bridges architecture cascade with DC-DC are used in the conventional electric vehicle charging system, which reduces energy consumption efficiency and negatively impacts voltage quality. In order to utilize all of the grid energy and to charge the batteries quickly, this calls for a high power factor smart EV charge[6]. Multiple research papers show the conventional method for EV charging is not efficient and causes hassle in the grid. So, there have been multiple attempts by different institutes to develop an EV charger that not only maintains constant output dc voltage but also maintains proper sinusoidal current in the grid with low THD and one of them is Institute of Electrical Engineering, Chinese Academy of Sciences, China[7]. They were able to model a prototype of 10kw that has the ability to reach unity power factor and with THD less than 3%.

Thus, there were various research papers that we reviewed before we jumped into the conclusion of making a prototype of a smart EV charger.

2.2 Related Theory

2.2.1 Real and Reactive Power:

In electrical systems, power factor is a critical parameter that affects power quality, stability, and efficiency. Power factor is the ratio of real power to apparent power in an AC circuit. Real power is the power that is actually used to perform useful work, such as charging an electric vehicle, while reactive power is the power that is stored and released in reactive components such as capacitors and inductors. Reactive power is necessary to maintain voltage and current levels in the circuit, but it does not contribute to useful work. In the context of an EV charging station project, maintaining high power quality and stability is essential to ensure reliable and consistent charging for electric vehicle owners. This requires minimizing voltage drops and maintaining optimal power factor. Low power factor can result in increased power consumption, inefficiencies, equipment damage, and reduced lifespan. To improve power factor in an EV charging station, various methods can be used, including the addition of capacitors or inductors to the circuit or the use of power factor correction devices. These methods help to reduce reactive power and improve power factor, thereby reducing power consumption and improving efficiency. The power distribution system in an EV charging station is also crucial for maintaining high power quality and stability. This includes selecting appropriate conductors, transformers, switchgear, and protection devices, as well as employing advanced communication and control systems to monitor and manage power quality and demand. In summary, understanding the concepts of real and reactive power, as well as power factor, is fundamental to the design and operation of an EV charging station project. Maintaining high power quality and stability is critical for providing reliable and efficient charging for electric vehicle owners.

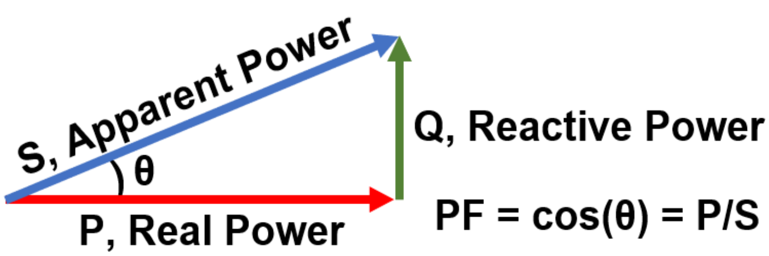

Figure 2. 1: Power Triangle

2.2.2 Voltage Regulation:

Voltage regulation in the power grid is the process of maintaining a stable voltage level throughout the power system, even when there are fluctuations in the demand for electricity or variations in the production of electricity from different sources.

$$Vreg = \frac{Vs - Vr}{Vr} \times 100\% \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$

There are several ways to achieve voltage regulation in the power grid. Some of the most common methods are: Automatic Voltage Regulators (AVRs): These are devices that are installed in power transformers and generators to regulate the voltage output. They monitor the voltage level and adjust the output accordingly to maintain a stable voltage level.

1. Tap Changing Transformers: These transformers have multiple taps on their windings, which allow the voltage to be adjusted by changing the tap position. This method is commonly used in distribution systems to regulate voltage levels.
2. Reactive Power Compensation: Reactive power is the power that is required to maintain the voltage level in the power grid. By adding or removing reactive power to the system, the voltage can be regulated. This can be achieved using devices such as capacitors and reactors.
3. Power Factor Correction: Power factor is the ratio of real power to apparent power in the power grid. A low power factor can cause voltage fluctuations. By correcting the power factor, the voltage can be stabilized.

Overall, voltage regulation is a critical aspect of maintaining a reliable and stable power grid. A well-regulated voltage level ensures that electrical devices operate efficiently and safely and helps prevent damage to the power grid equipment.

2.2.3 Phase Locked Loop

PLL stands for Phase-Locked Loop. It is a feedback control system that generates an output signal whose phase is locked to the phase of an input signal. The output signal of a PLL can be a frequency or a phase multiple of the input signal.

A PLL typically consists of a phase detector, a low-pass filter, a voltage-controlled oscillator (VCO), and a feedback loop. The input signal is fed into the phase detector, which compares the phase of the input signal with the phase of the output signal of the VCO. The output of the phase detector is filtered by the low-pass filter and fed into the VCO to control its frequency. The VCO generates an output signal with a frequency that is proportional to the input signal, and its phase is locked to the input signal.

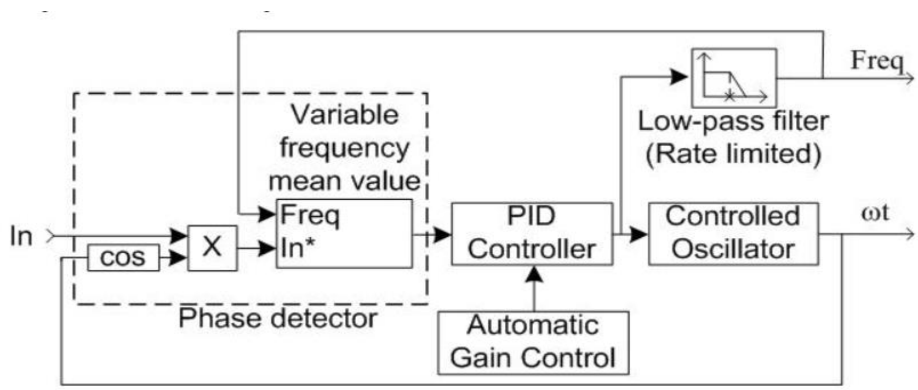

Figure 2. 2: Phase Locked Loop in Single Phase Circuit

2.2.4 Converter

A current-controlled boost rectifier is a type of power electronic converter used to convert AC power into DC power with variable output voltage and current. It is a type of DC-DC converter that uses a boost topology and is controlled by a current control loop.

The basic operation of a current-controlled boost rectifier is to boost the input voltage to a higher level, using a switch and an inductor. The switch is typically a power MOSFET or an IGBT, and the inductor is used to store energy during the on-time of the switch and release it during the off-time. The output voltage of the boost rectifier is controlled by the duty cycle of the switch, which is determined by the current control loop. The current control loop regulates the inductor current, which in turn determines the output voltage.

$$\frac{Vout}{Vin} = \frac{1}{1-D} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots (2)$$

In addition to regulating the output voltage, the current control loop can also provide other functions such as power factor correction and control of the input current.

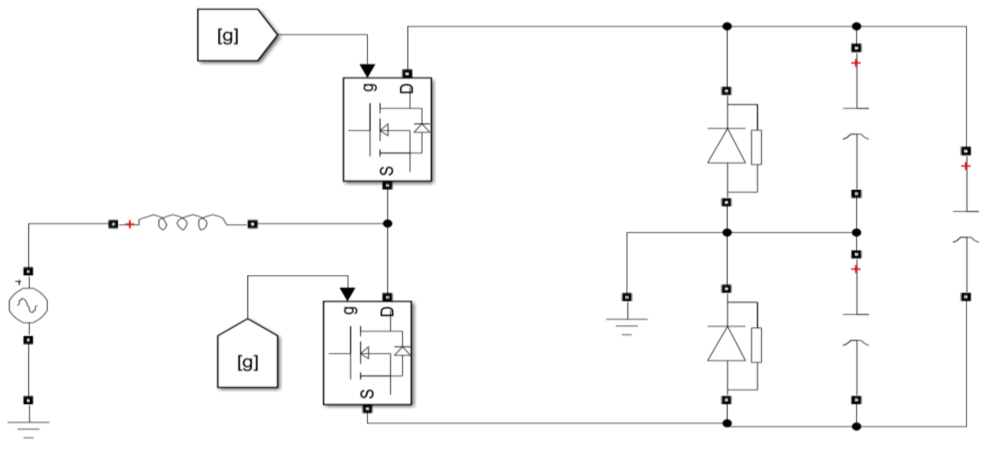

Figure 2. 3: Current Controlled Boost Rectifier Circuit in single phase

The converter used is a single-phase converter consisting of only one arm i.e two switching devices (MOSFET). It is a current controlled converter that acts as a boost rectifier circuit for both positive and negative cycles. The voltage across the DC-Link capacitor is a constant boost DC voltage.

2.2.5 Control strategy

The current control loop implemented in the single-phase PWM boost rectifier/inverter controller regulates the amplitude and phase angle of the currents that flow through the AC side. This controller continuously monitors the currents flowing through the AC side, the line voltages across the AC side, and the voltage across the DC side of the PWM boost rectifier/inverter. Based on these measured values, the controller determines the appropriate switching signals for the single-phase bridge. The objective is to ensure that the line voltages at the AC side generate AC currents with desired amplitude and phase angle, as defined by the active current command and reactive current command of the PWM boost rectifier/inverter.

The reference voltages are generated using a cross coupling method. The Id and Iq component of the current of the ac side of the converter is controlled. The reference signals of Id and Iq are generated via cross coupling. In an inductor the mathematical expression for Vd and Vq is given by.

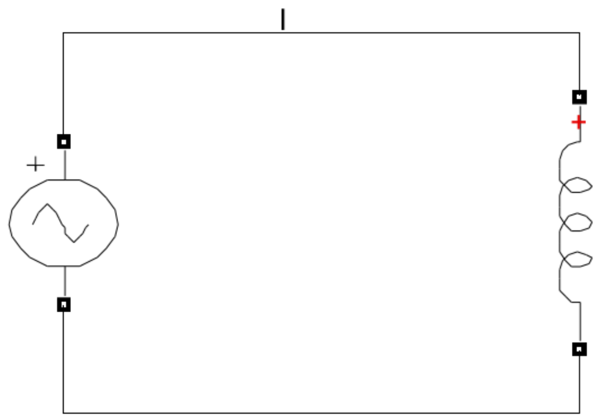

Figure 2. 4: A Basic Inductor Connected to the AC Source

Or, $V_d + j\,V_q = L\,\frac{di}{dt}$ ……………………………...…………….……………(3)

$=L\,(\frac{(Id + j\,Iq)}{dt})$………………………………...…………………………...(4)

$=jwL*(I_d + j\,I_q)$………………………………..…………………………(5)

$=jwL*I_d+(-wL*I_q)$…………………………………………………………(6)

Thus on comparing the real and imaginary part we get,

$\mathbf{V_d = -wL*I_q}$ ……………………………………………………...…(7)

$\mathbf{V_q = wL*I_d}$...………………………………………………………...…(8)

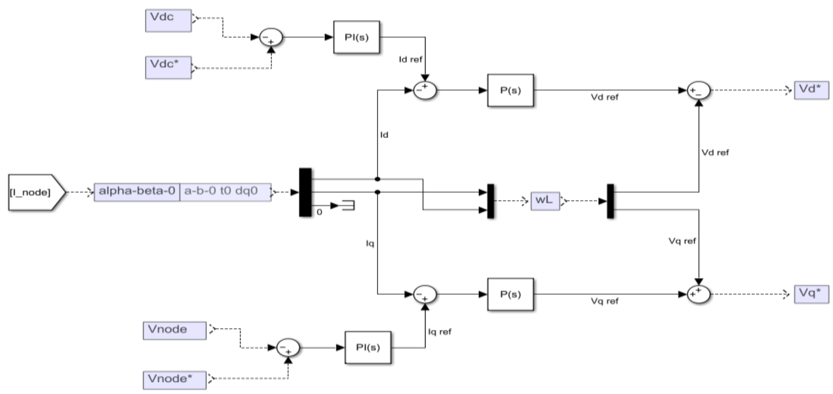

Figure 2. 5: Cross Coupling Control Strategy

2.2.5.1 Active current command of a single-phase PWM boost rectifier/inverter

When the active current command of the single-phase PWM boost rectifier/inverter is adjusted (with the reactive current command set to zero), only active power is transmitted to the charger. In this scenario, the active power flow moves from the source to the charger. As a result, the phasors of the phase voltages and line currents at the AC side of the single-phase PWM boost rectifier/inverter will be in alignment or in phase with each other.

2.2.5.2 Reactive current command of a single-phase PWM boost rectifier/inverter

When the reactive current command of the single-phase PWM boost rectifier/inverter is adjusted (with the active current command set to zero), only reactive power flows through the line. In this case, the power flow direction is from the charger towards the source. It is important to observe the waveforms of the phase voltages and currents at the AC side of the single-phase PWM boost rectifier/inverter during this variation of the reactive current command.

2.2.5.3 Active current command and reactive current command of a single-phase PWM boost rectifier/inverter

When both the active and reactive current commands of the single-phase PWM boost rectifier/inverter are adjusted, both active and reactive power will flow. The active power flow direction will be from the source to the charger, while the reactive power flow direction will be from the charger to the source. During this variation of active and reactive current commands, it is important to observe the waveforms of the phase voltages and currents at the AC side of the single-phase PWM boost rectifier/inverter.

CHAPTER THREE
METHODOLOGY

3.1 Overview

Our project aims to develop a smart EV charger that can operate in unity power factor as well as can compensate the reactive power into the grid. The design process was completed in two major phases:

1. Software Simulation

2. Hardware Implementation

The simulation of the arrangement is done in simulation software like MATLAB, Multisim, and Desmos. The simulation of the circuits like gate driver, power circuits, ac voltage and current measurement, optocoupler circuit, dc voltage measurements etc. were simulated in Multisim, while the control system for the setup was done in MATLAB and Desmos was used to visualize the various graphs and signals that helps in understanding the project in detailed.

3.2 Software Simulation

The main aim of the software simulation is to select and design the appropriate topologies, and control mechanisms. In the simulation phase, the whole process had to be reconsidered for the hardware implementation due to cost limitations and unavailability of the components required. The major tasks performed in this phase are chronologically listed:

1. Three phase boost rectifier

2. Control strategy for active and reactive power flow

3. Single phase boost rectifier

4. Gate driver simulation

5. Measurement circuits simulations

The single phase is fed to the converter operating in the current control mode through the inductor as in figure. The converter is a single arm converter with two Mosfets which simultaneously rectifies and boosts the AC input voltage to the required constant DC output voltage across the DC-link capacitor. The gate signal to the converter is provided through the control system. The measurements are taken for both input AC side and output DC side using measurement circuits and are fed to the stm32 controller which is already provided with reference value for both sides i.e input AC side and output DC side. The comparison of measured and reference value is done by the controller and necessary gate signals are generated which are provided to the gate driver circuit for the conversion of input AC voltage to constant output DC voltage during charging with smooth grid voltage and current.

3.3 Hardware design

After the completion of software simulations and designs, the hardware is then fabricated. But Due to the unavailability of some resources in Nepal, we had to compromise on the design. The charger prototype is done in single phase as the cost and control of the three phase charger is very high and difficult. We used a matrix board to fabricate our circuit for prototype purposes. The major tasks performed in this phase are chronologically listed as:

1. Gate driver circuit
2. Boost rectifier circuit
3. AC current and voltage measurement circuit
4. DC voltage measurement circuit
5. Power circuit
6. Optocoupler circuit
7. Overall circuit completion

3.4 Work Accomplished

3.4.1 Circuit Simulation

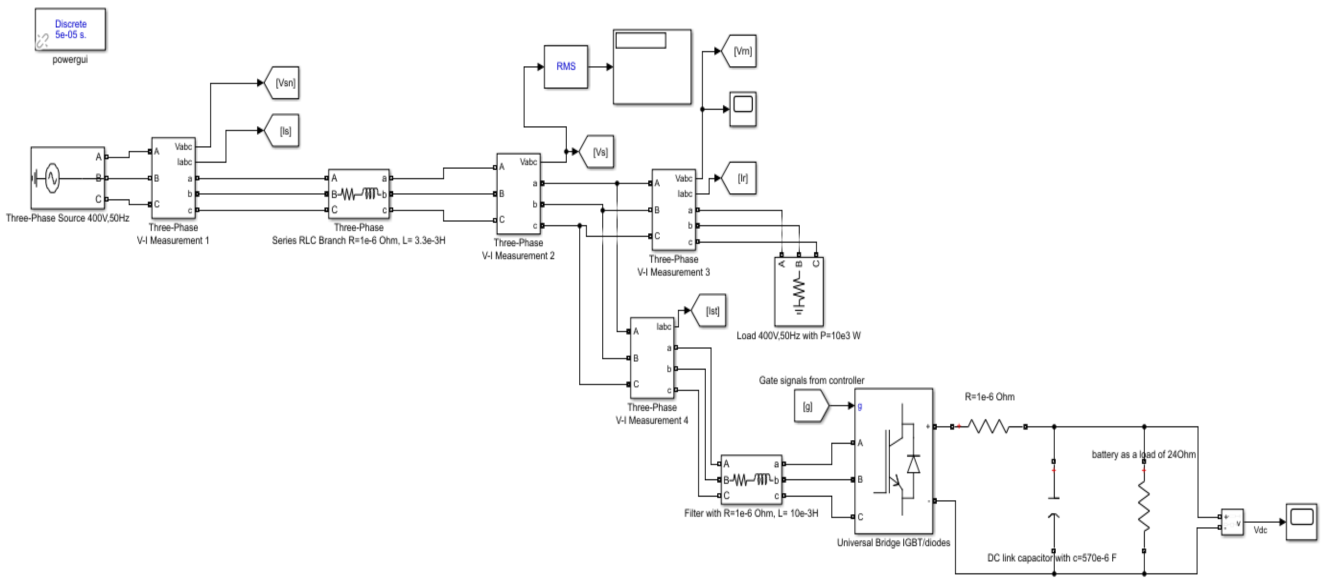

Figure 3. 1: Circuit Diagram of Three Phase Converter

The simulation was done in the MATLAB. Here the three-phase prototype circuit is simulated. The source is connected via a transmission line which is modelled by putting the value of resistance and inductance of the line. The measurement blocks measures the voltage and current of the nodes where the charger is connected i.e at the receiving side and the sending side. A load that is represented as the household load is connected in parallel to the charger and the node voltages and current are measured which are send as a feedback to the control system for controlling. The R and L represent the distribution parameter of the distribution line that can cause permissible voltage drop in the line. The charger is connected in parallel via tapping. The inductor in the converter branch is used as a filter in order to eliminate the harmonics when the converter operates in inverter mode whereas it is used for boost operation when the converter is used in rectifier mode. Here the receiving end side has a resistive load at the point of tapping in parallel, that represents the residential load.

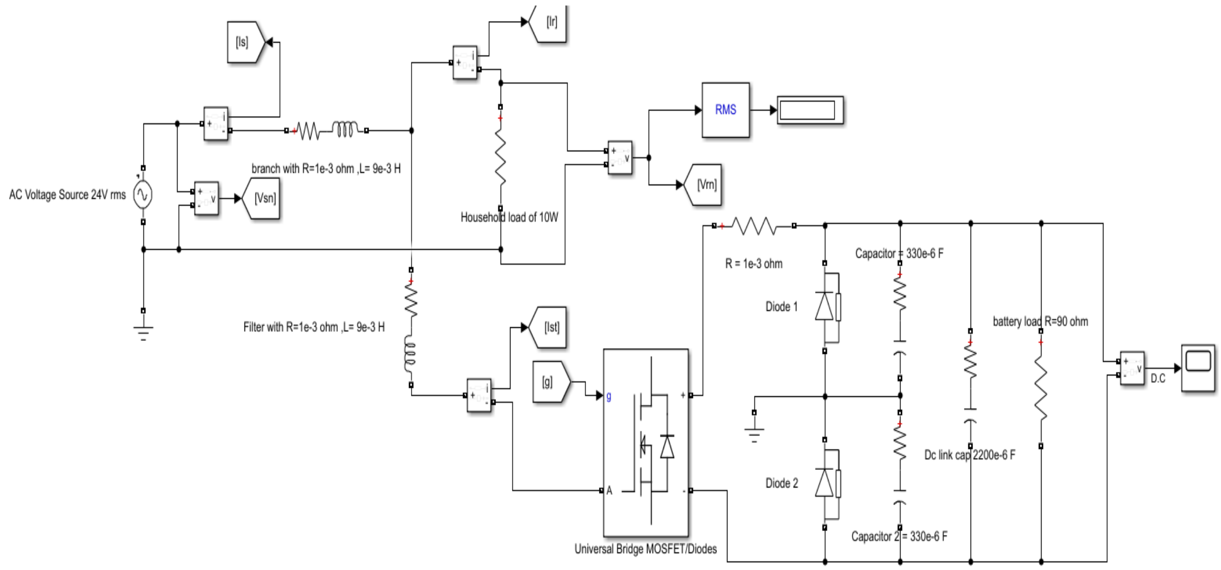

Figure 3. 2: Circuit Diagram of Single-Phase Converter

Although simulation of EV charger is done in three phases but the design of prototype is made for a single phase so the modeling of the single phase becomes easy and cost effective. The source is connected via a transmission line which is modelled by putting the value of resistance and inductance of the line. The measurement blocks measures the voltage and current of the nodes where the charger is connected i.e at the receiving side and the sending side. A load that is represented as the household load is connected in parallel to the charger and the node voltages and current are measured which are send as a feedback to the control system for controlling. The model is the exact replica of three phase EV charger with same motive of getting constant dc output voltage of 90V. The input current and voltage are constantly measured to get pure sinusoidal voltage and current at the point of common coupling. The boost circuit converts the single-phase input voltage of 24V rms to constant dc output of 90V. The branch values are obtained so as to make the desirable voltage drop at the point of EV connection. It represented the Distribution line model.

3.4.2 Controller design

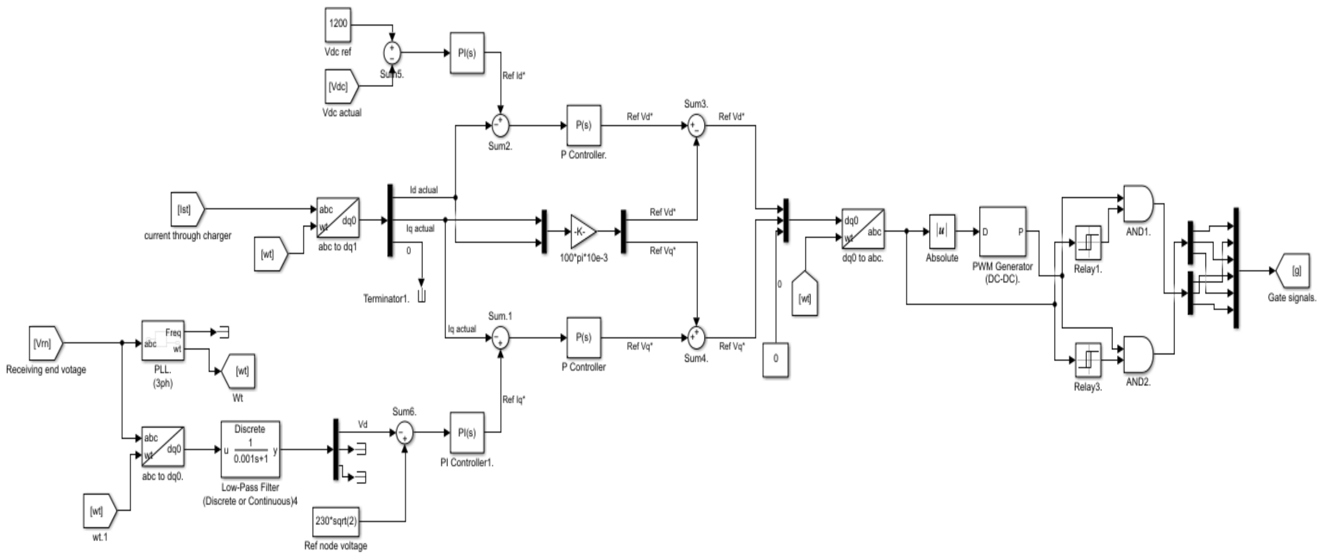

Figure 3. 3: Circuit Diagram of Single-Phase Converter

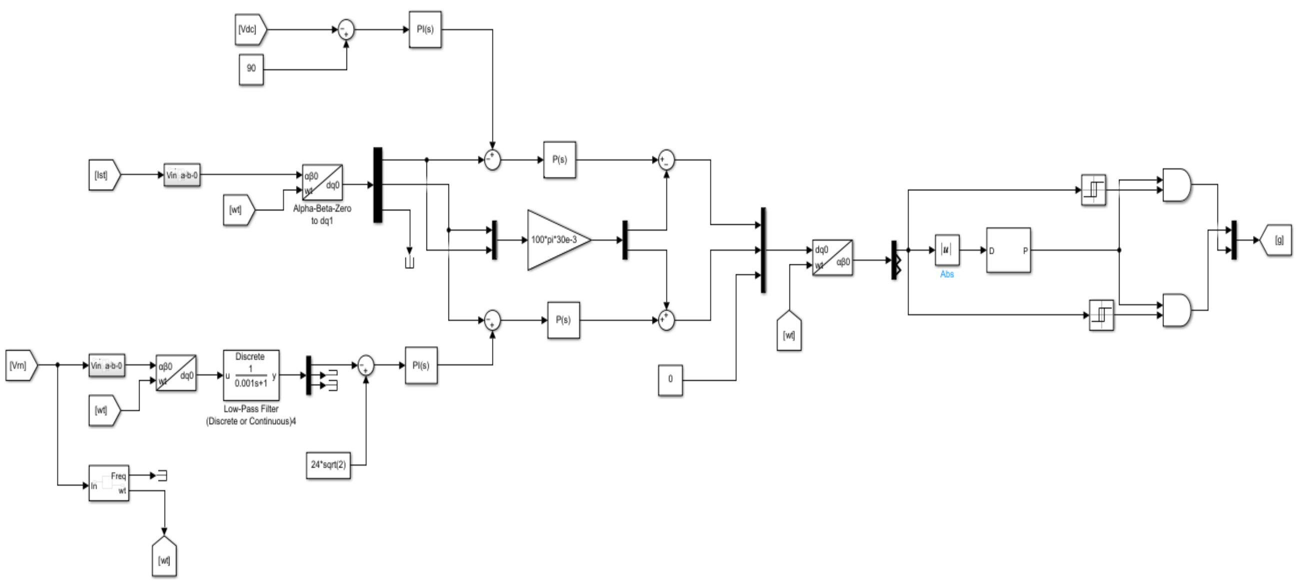

Figure 3. 4: Control System simulation design in single phase system

As the converter is the current controlled boost rectifier/inverter thus the current through the converter is decomposed into I_d and I_q component. Thus, by controlling these active and reactive currents, we generate the reference voltages and gate signals are generated and are fed into the converter.

3.4.2.1 Generation of Reference voltage (V_d)

Here, the output DC voltage is compared with the reference DC voltage to be maintained at the output DC side. The error generated is passed through the PI controller. The controller generates the reference current signal (Id). The generated reference signal is compared with the actual Id component of the converter current and generates the error. The error is passed through the PI controller and generates the reference V_d.

3.4.2.2 Generation of Reference voltage (V_q)

Here, the voltage of the point of tapping is compared with the reference voltage to be maintained at the node of connection. The error generated is passed through the PI controller. The controller generates the reference current signal (I_q). The generated reference signal is compared with the actual I_q component of the converter current and generates the error. The error is passed through the PI controller and generates the reference V_q.

3.4.2.3 Cross coupling control strategy

The reference voltage is generated through a cross coupling method. The name itself suggests that "cross-coupling" i.e. for the generation of reference Vd signal it requires Iq and for the generation of reference Vq signal it requires Id. Thus, the term "cross-coupling" is used.

$$Vd = -wL*Iq$$

$$Vq = wL*Id$$

Thus the generated reference voltages (Vd and Vq) are then converted into alpha beta components and thus the alpha component is passed through PWM generation and thus the gate signals are generated .

3.4.3 Phase locked loop simulation

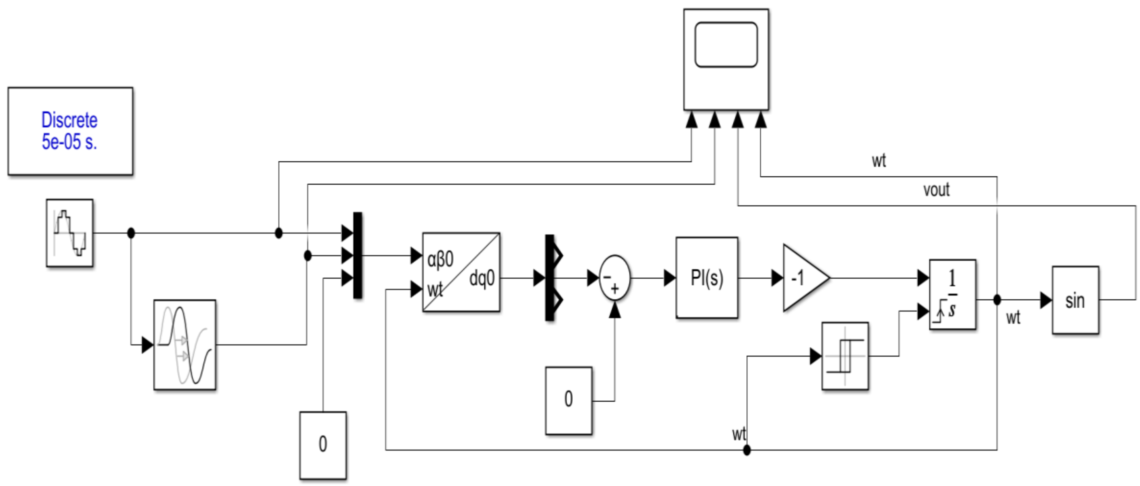

Figure 3. 5: Phase lock loop simulation

The main purpose of the PLL is to synchronize the output oscillating signal with that of input reference signal. The phase of the output signal is locked with the input signal resulting in no phase difference between the signal and same frequency between the signals. This can be achieved by the following control strategy.

Here a sine wave having 50 Hz frequency and a transport delay is used. The function of transport delay is that it generates the sine wave signal of 50Hz that lags behind the sin signal by 90 degrees. This is done in order to obtain the dq0 component because in dq0 , active and reactive components can be easily controlled. Since the output signal should be in phase with the input signal, its Id component must be equal to 0. Thus a controller is used in order to make Iq equals to 0. Thus the generated signal will be in phase with the input signal.

3.4.5 Gate Driver Circuit

The gate driver circuit receives input signal from STM 32 i.e. 3.3V and 12V from the voltage regulator. This 12V signal is supplied to the gate of MOSFET1 and MOSFET2. The transistors are used for switching and discharging of the capacitor. The Zener diodes are used to maintain a constant voltage at the gate of MOSFETS.

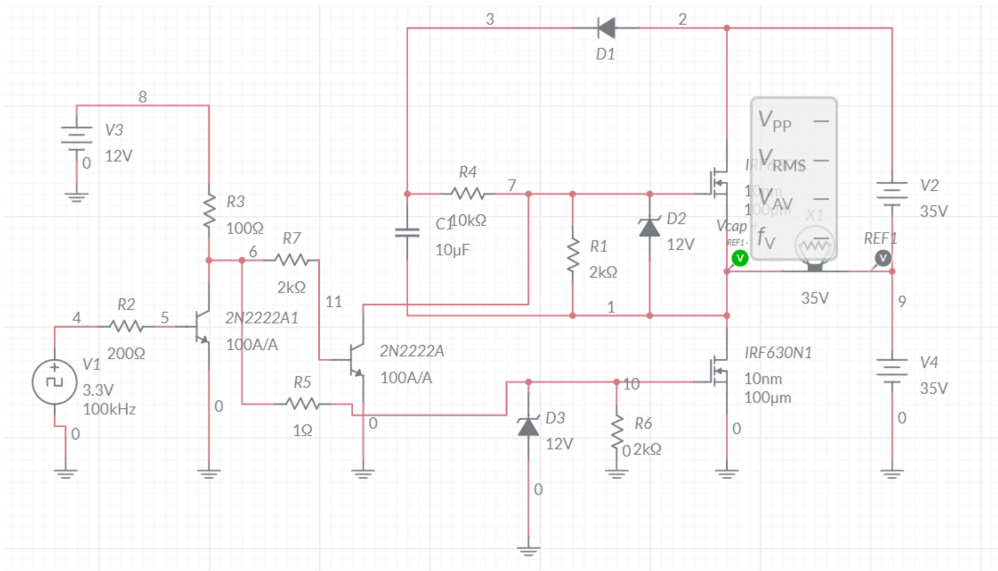

Figure 3. 6: Schematic Diagram of Gate Driver Circuit

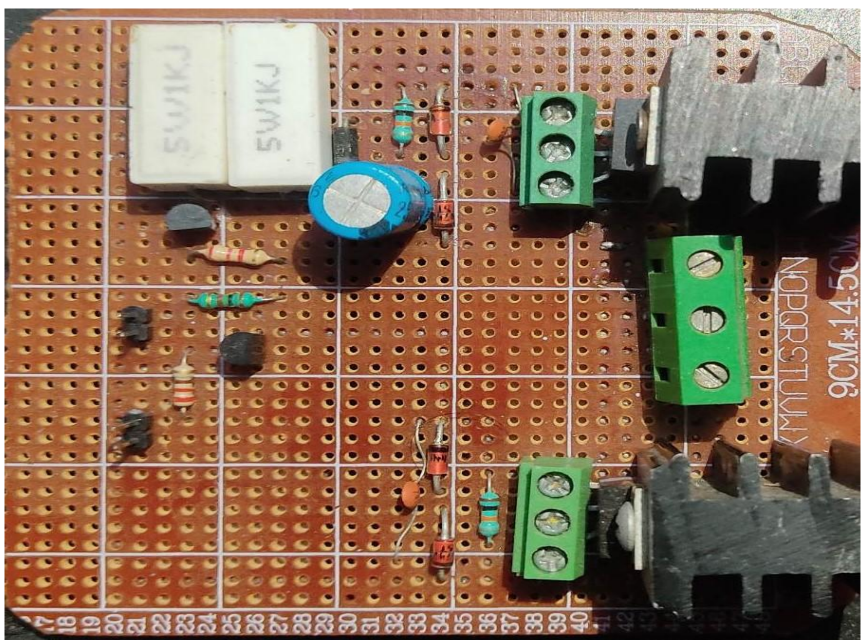

Figure 3. 7: Gate Driver Circuit

3.4.6 Power Circuit:

To drive various components such as optocoupler, MOSFET and STM32, a certain supply is needed. Each component needs a different supply. Thus, a circuit consisting of all the supplies is made as in figure below consisting of voltage regulator to get a constant dc output voltage of 5V, 10V, 12V and ground.

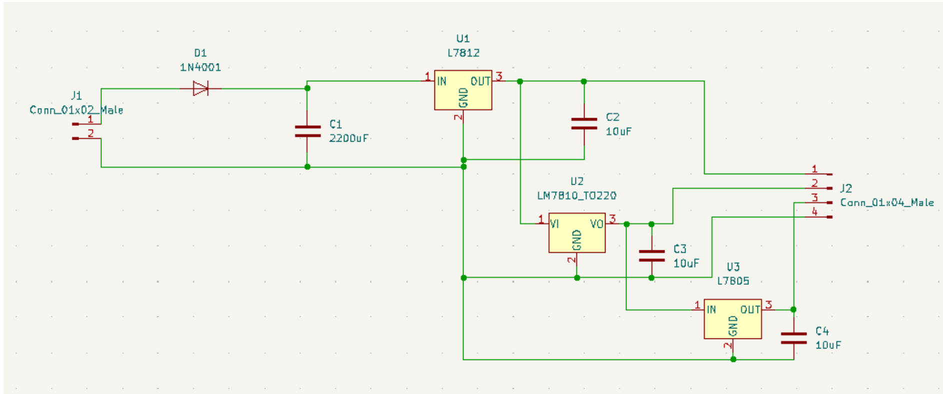

Figure 3. 8: Simulation of Power Circuit

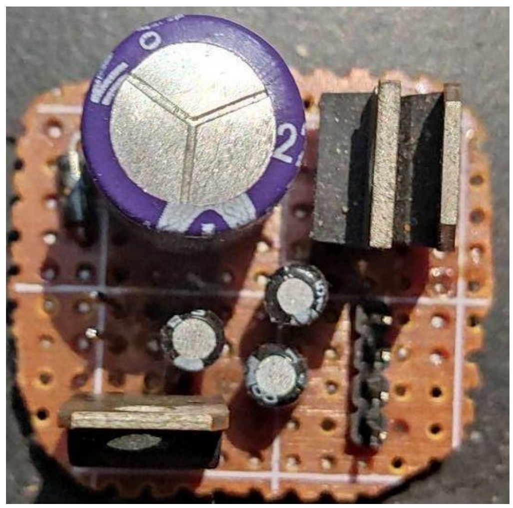

Figure 3. 9: Power Circuit

3.4.7 AC Current and Voltage Measurement Circuit:

To measure the current drawn by the charger and voltage drop we designed a circuit. The simulation circuits are as shown in figure no 3.7.

In our circuit, the current is measured via a resistor. The value of the resistor is chosen very small so that the voltage drop across it is very small and very less power is loss in that resistor.

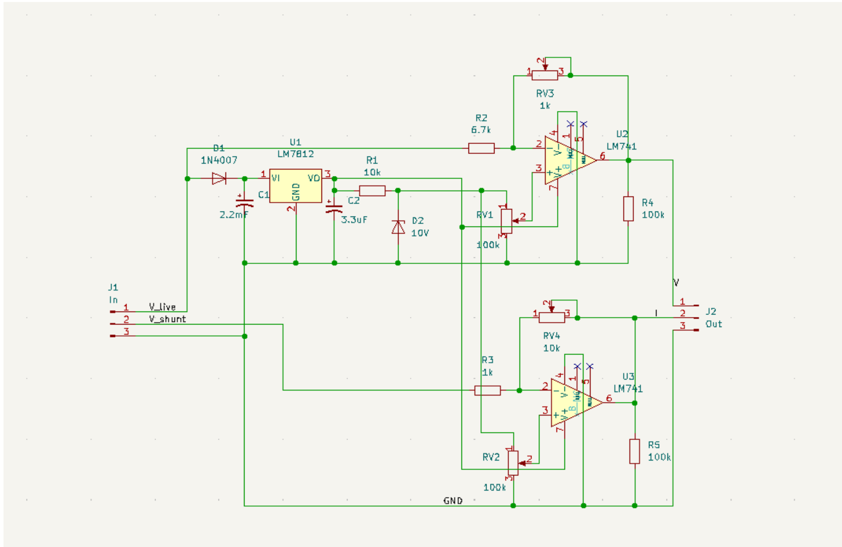

Figure 3. 10: Simulation of AC Current and Voltage Measurement Circuit

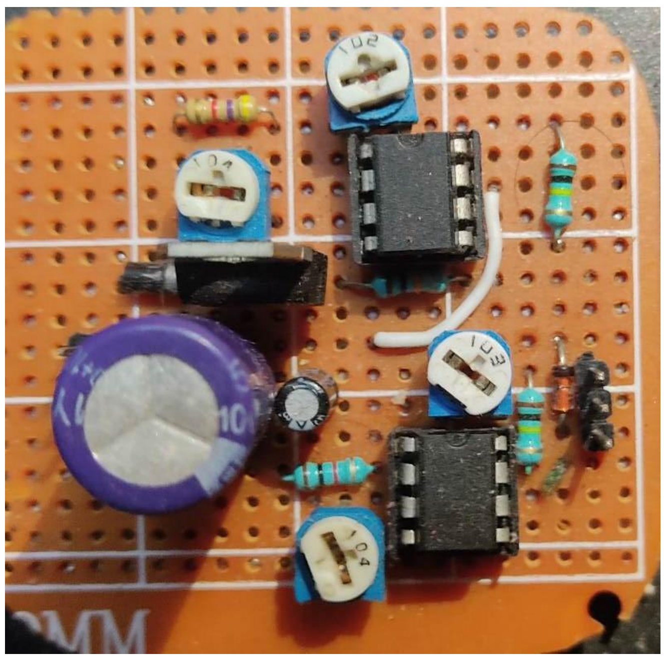

Figure 3. 11: AC Current and Voltage Measurement Circuit

3.4.8 Optocoupler:

Since we have to give measurement signals to STM 32 for controlling, STM32 needs to be protected from voltage spikes greater than 3.3v. Thus for the safety purpose, Optocoupler is used to isolate the STM 32 from the remaining circuit.

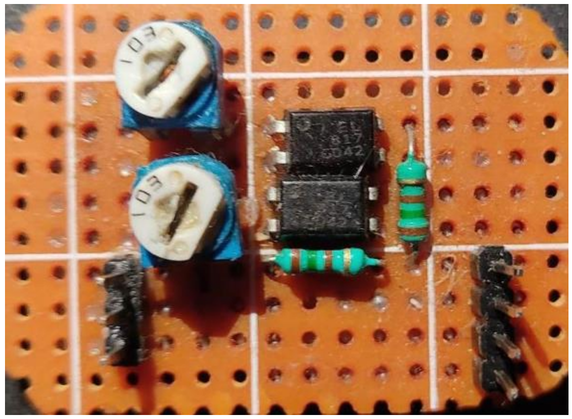

Figure 3. 12: Optocoupler Circuit

3.4.9 DC Measurement Circuit:

To measure the dc output across the dc link capacitor, a dc voltage measurement circuit is used. The circuit integration of optocoupler and voltage divider which 90V dc into 2V. This value is fed to the microcontroller and compared with the reference value to maintain a constant dc output.

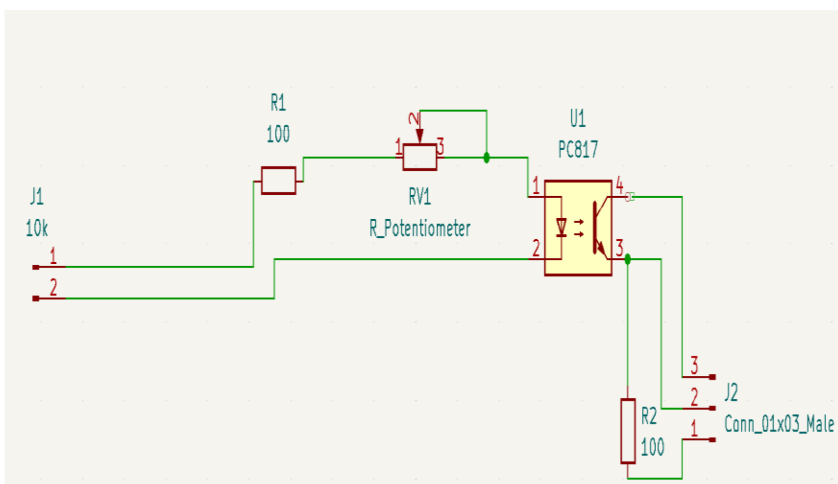

Figure 3. 13: Simulation of DC Voltage Measurement Circuit

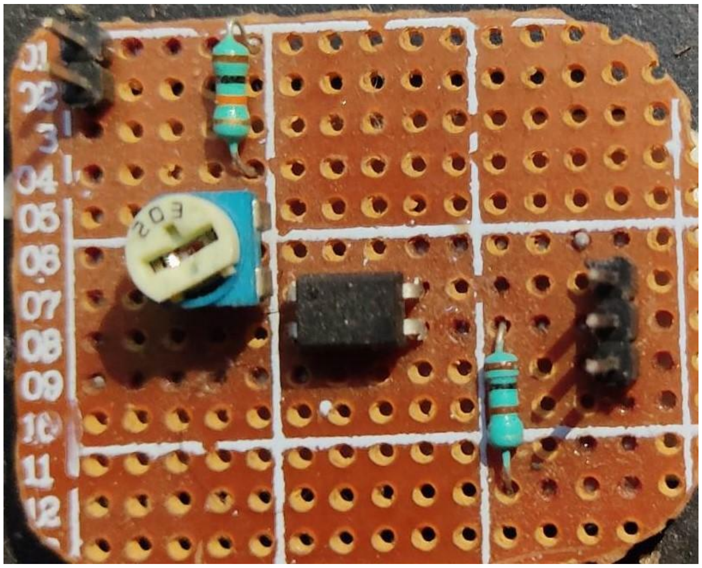

Figure 3. 14: DC Voltage Measurement Circuit

3.4.10 Active power control strategy

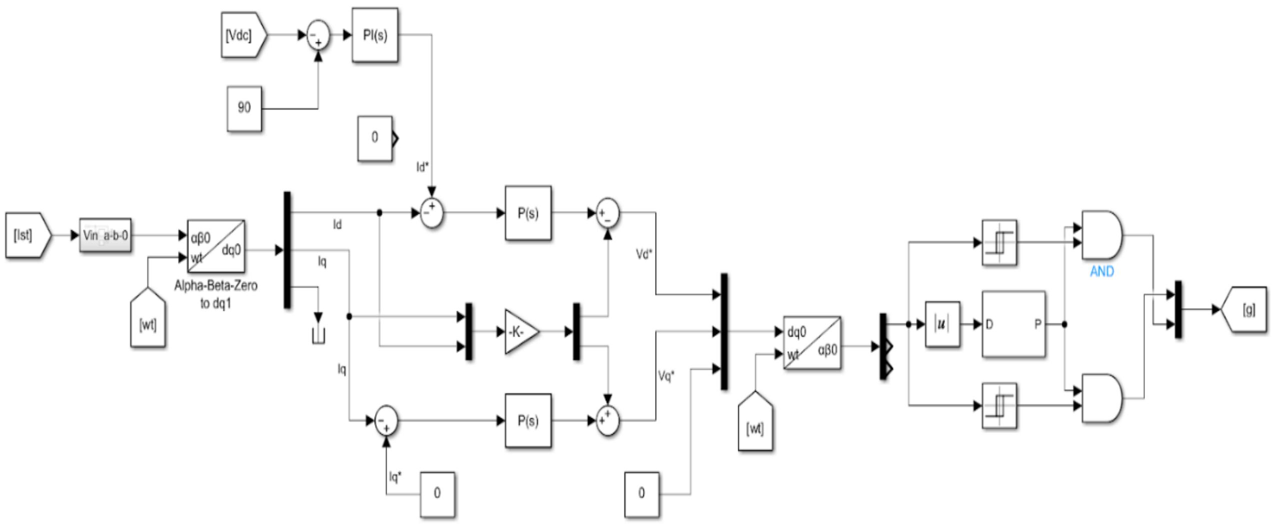

Figure 3. 15: active power control strategy

Here the (Iq) reactive component of the current is set to 0 and only (Id) active component of the current is varied.

3.4.11 Reactive power control strategy

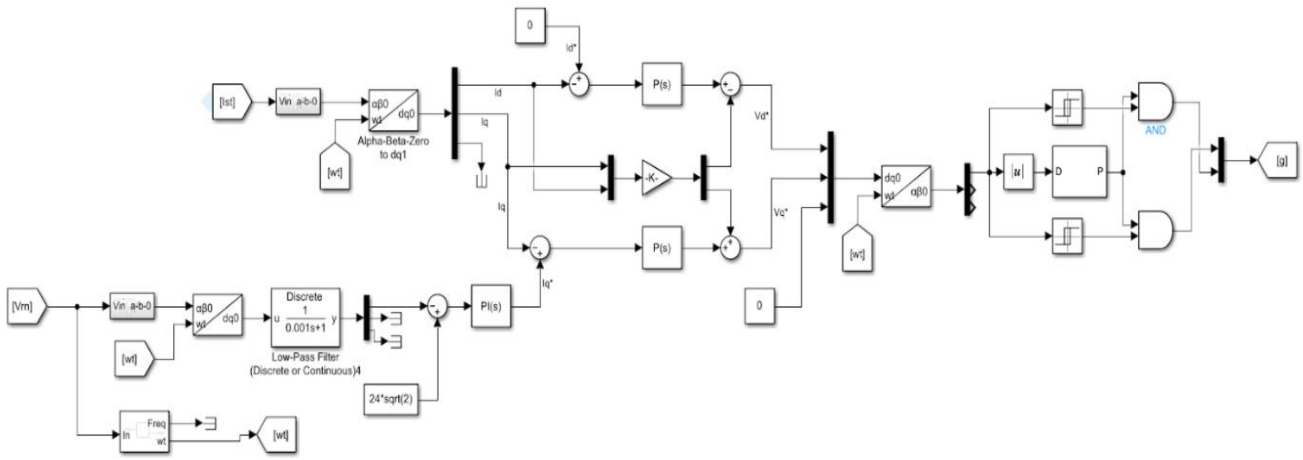

Figure 3. 16: Reactive power control strategy

Here the (Iq) reactive component of the current is varied and (Id) active component of the current is maintained to 0. Thus, the charge acts as STATCOM and supplies reactive power to the grid and maintains the voltage at the connection node.

3.4.12 Active and reactive power (Bidirectional) control strategy

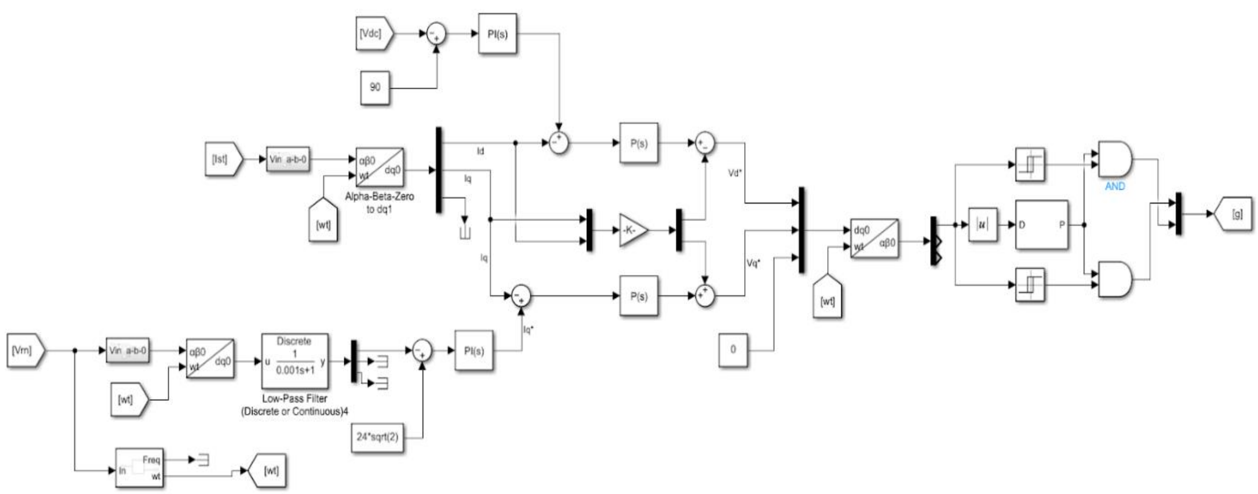

Figure 3. 17: Bidirectional control strategy

Here both Id (active component of the current) and Iq (reactive component of the current) are varied.

CHAPTER FOUR

RESULT AND DISCUSSION

4.1 Collection and interpretation of the data

Here, Firstly the various data were collected within the simulation. Various parameters like Id and Iq were varied to collect the data. In three phases system, the residential load was set to 10KW active power and 1Kvar of reactive load and the charger of 60KW was connected and was charged at 1200V DC. Thus, by operating the charger in different mode we observed the waveforms of current and voltage, power transmission from and into the grid and node voltages. All the observations are well demonstrated below.

Similarly, in single phase for the prototype design purpose the scale was reduced and the residential load was set to 10W. The input voltage was set to 24V rms and the DC voltage was maintained at 90V to charger a 90W battery. All the observations are well demonstrated below.

4.1.1 Active power control:

Here the (Iq) reactive component of the current is set to 0 and only (Id) active component of the current is varied. Thus, the following observations are done.

4.1.1.1 waveform of voltage and current at the point of connection

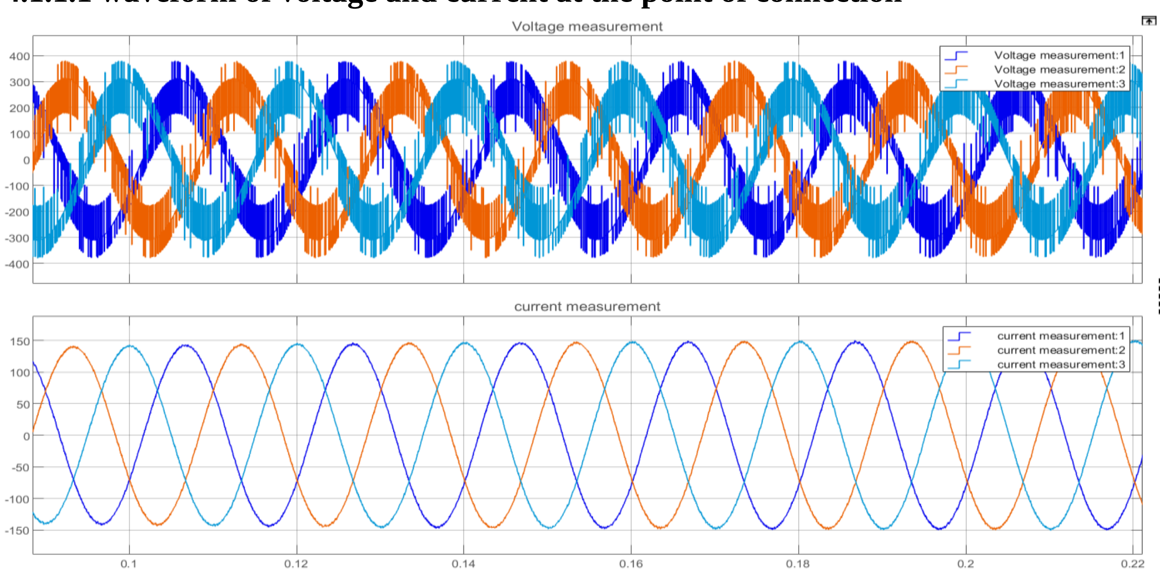

Figure 4. 1: waveform of voltage and current at the point of connection in three phase

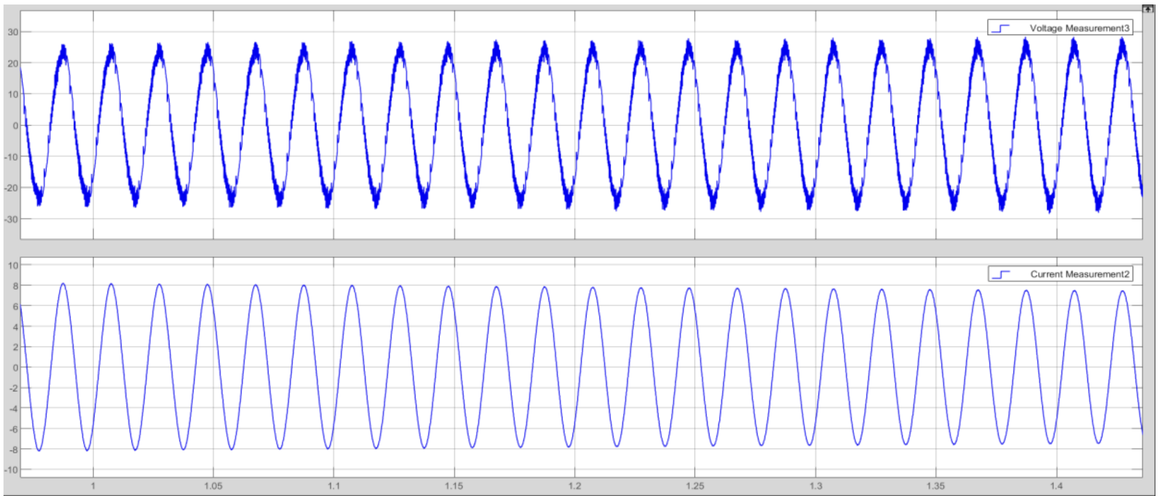

Figure 4. 2: waveform of voltage and current at the point of connection in single phase

Here the voltage and the current are in phase with each other. Thus, only the active power flows in the converter. The direction of active power flow is from source to the charger because the direction of current is measured from source to the charger side and the current is in phase with the voltage and the power flow will be positive. Thus, the charger operates at unity power factor.

4.1.1.2 Sending and receiving end Voltage measurement

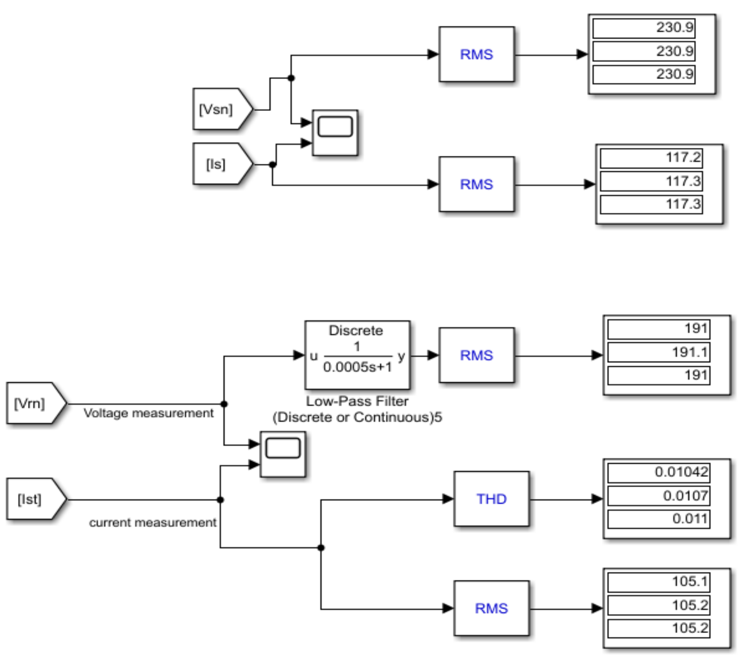

Figure 4. 3: Voltage measurement in three phase

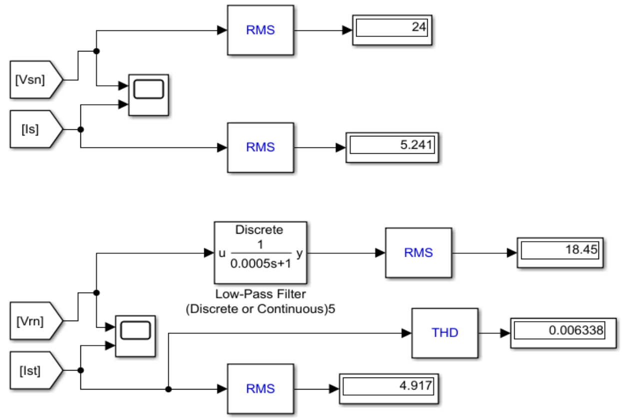

Figure 4. 4: Voltage measurement in single phase

Here it can be observed that in both three and singe phase system the voltage has reduced below significant value although the charger operates at unity power factor. In three-phase system the voltage reduced to 191V at receiving end from 230V sending end. Whereas, in single phase the receiving end voltage dropped to 18.45V from 24V sending voltage. The total harmonics distortion of the current becomes very less due to unity power factor correction strategy.

Voltage regulation (V. R) = $\frac{(V_{no-load} - V_{full-load})}{V_{full-load}} * 100\%$

Thus, in three-phase V. R = 20.41%

Thus, in single-phase V. R = 30.0813%

4.1.1.3 Power measurement

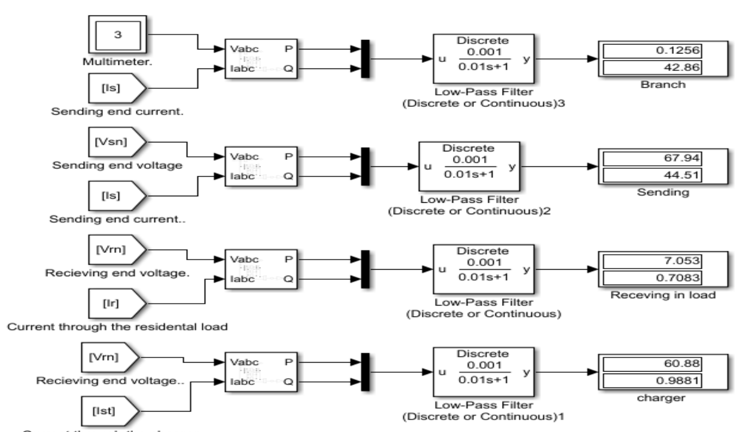

Figure 4. 5: power measurement in three phase

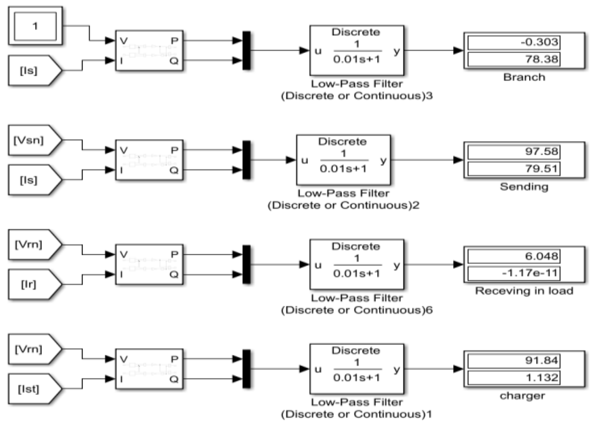

Figure 4. 6: power measurement in single phase

Here, both the charger absorbs their rated capacity of 60KW and 90W in three-phase and single-phase respectively. But due to the voltage drop in receiving end the residential load does not get their rated power and this may result in the serious damage of the equipment in the household. In three-phase system, the residential load in three-phase system was modelled at 10KW and 1Kvar. But due to voltage drop at the receiving node, only 7KW and 0.7Kvar was supplied by the source. The branch absorbs the reactive power of 42.86Kvar.Similarly, in case of single-phase system, the residential load was modelled at 10W. But, only 6.049W was supplied by the source. The branch absorbs the reactive power of 78.38 VAR.

4.1.1.4 DC Voltage measurement

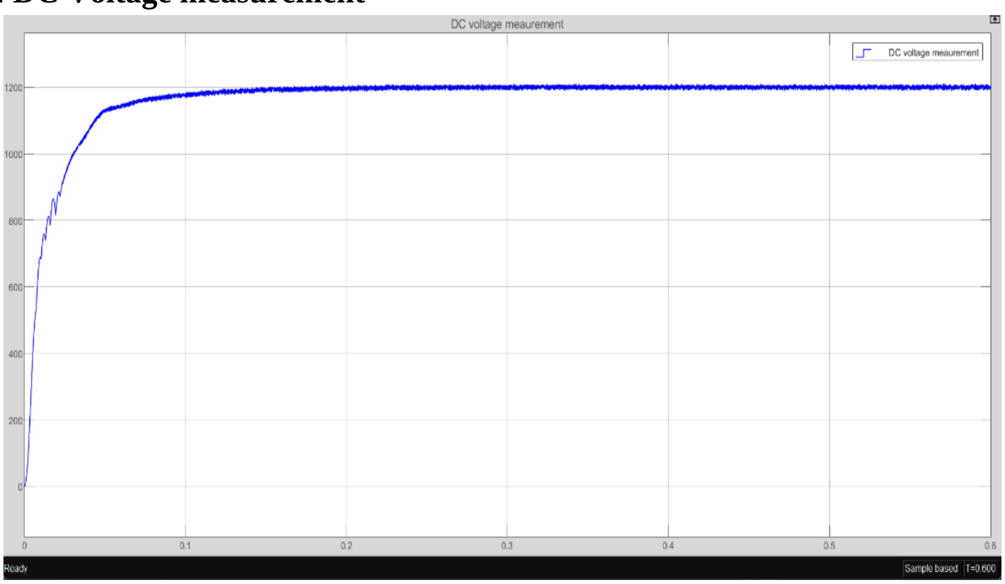

Figure 4. 7: DC Voltage measurement in three phase

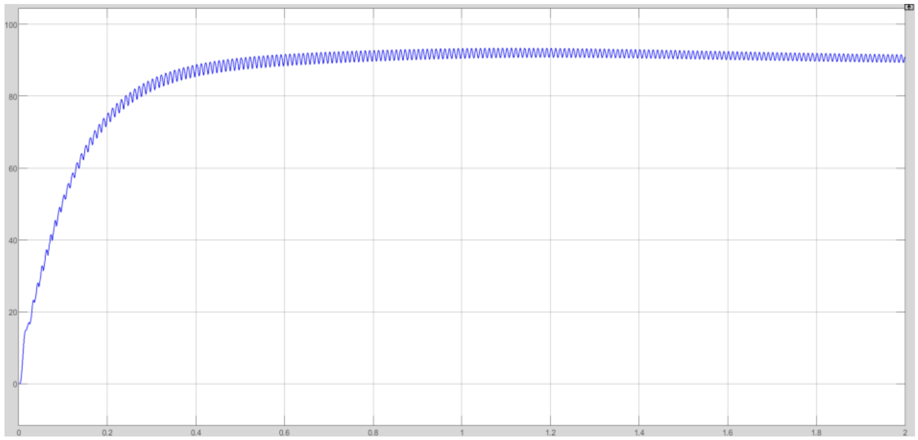

Figure 4. 8: DC Voltage measurement in Single phase

In Three-phase system, the DC voltage was maintained as 1200V to charge the 60KW battery.

In Single-phase system, the DC voltage was maintained as 90V to charge the 90W battery.

4.1.2 Reactive power control:

Here the (Iq) reactive component of the current is varied and (Id) active component of the current is maintained to 0. Thus, the charge acts as STATCOM and supplies reactive power to the grid and maintains the voltage at the connection node. In this mode, the battery will not be connected and the charger only supplies the reactive power to the grid during the heavy traffic of load. Thus, the following observations are done.

4.1.2.1 waveform of voltage and current at the point of connection

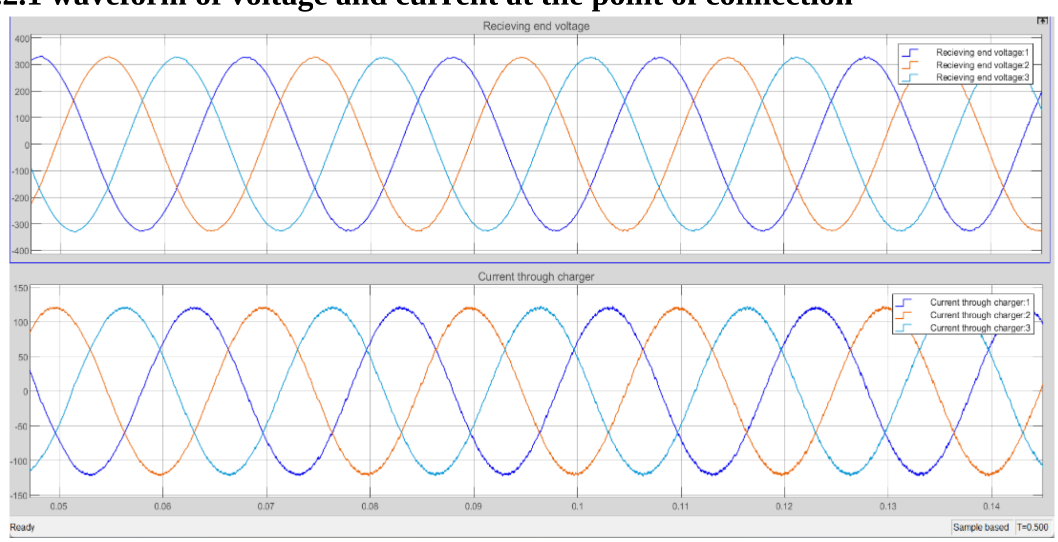

Figure 4. 9: waveform of voltage and current at connected node in three-phase

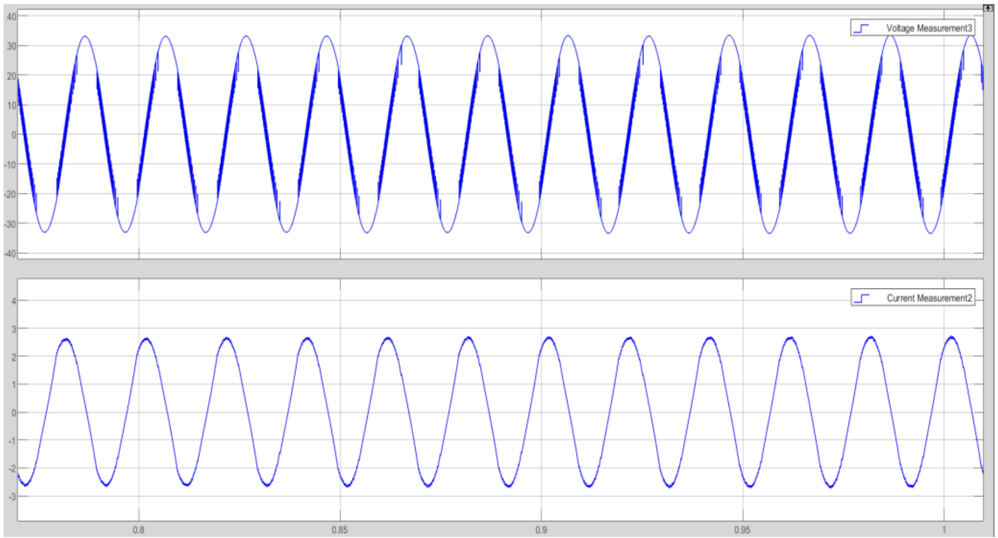

Figure 4. 10: waveform of voltage and current at connected node in single-phase

From the fig 4.9 and fig 4.10 we can clearly observe that current leads the voltage by 90 degree thus giving the effect of capacitor and supplies the reactive power to the grid. This mode can be applied in practice generally in case of heavy traffic in the grid.

4.1.2.2 Sending and receiving end Voltage measurement

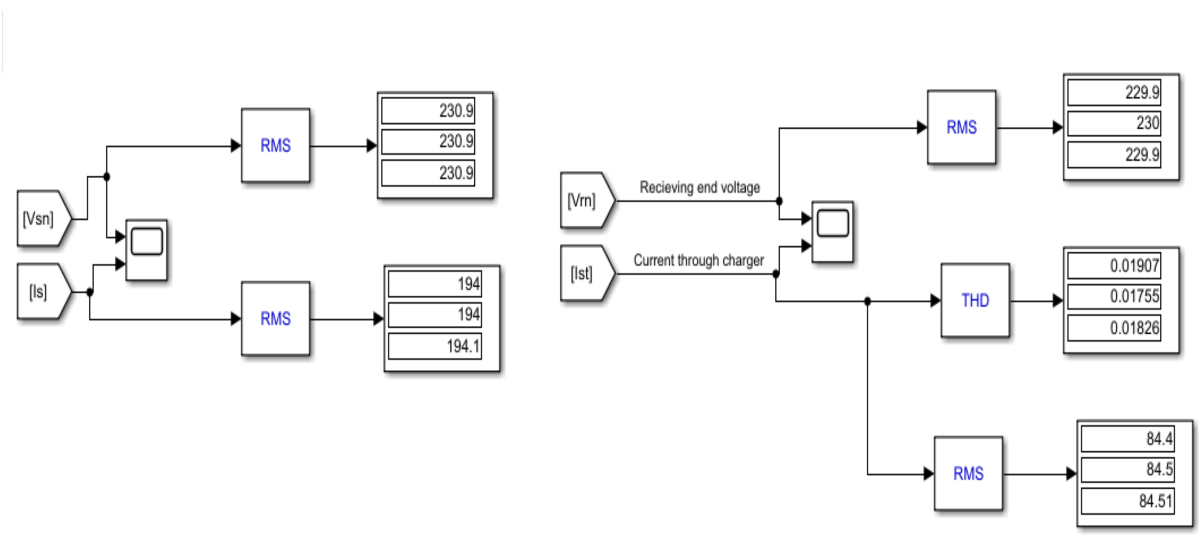

Figure 4. 11: Voltage measurement in three phase

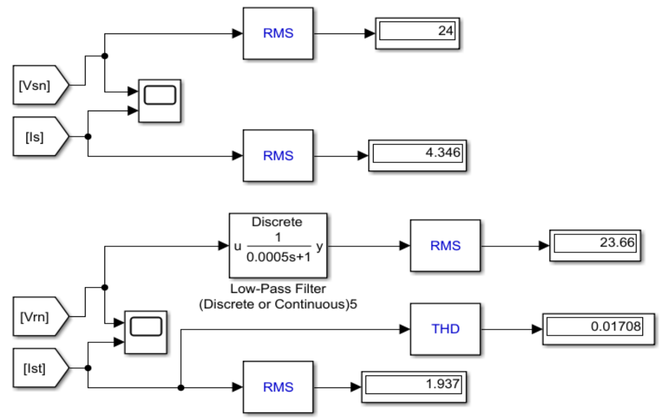

Figure 4. 12: Voltage measurement in single phase

It can be observed that the voltage in the receiving end is now regulated and is nearly equal to sending end voltage in both systems. Here, the STATCOM supplies reactive power into the grid thus regulating the voltage in the grid. The total harmonics distortion of the current is very less in both the systems about 1.708%.

Voltage regulation = $\frac{(V_{no-load} - V_{full-load})}{V_{full-load}} * 100\%$

Thus, the voltage regulation in both the systems are less than 2%. Thus, the system becomes very reliable and stable.

4.1.2.3 Power measurement

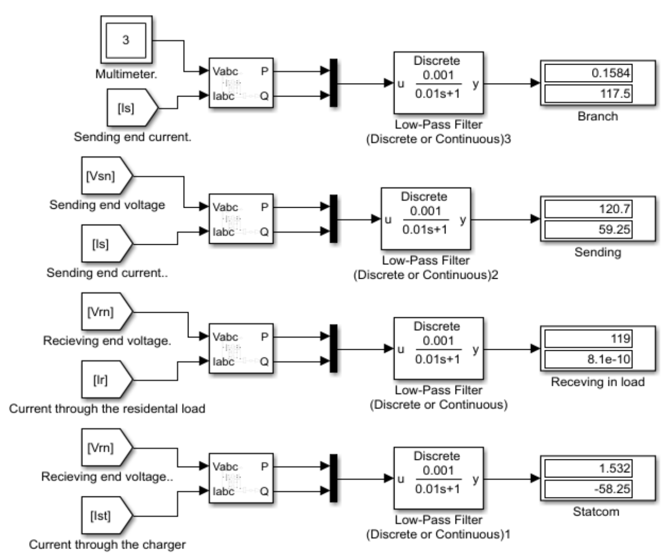

Figure 4. 13: Power measurement in three phase system

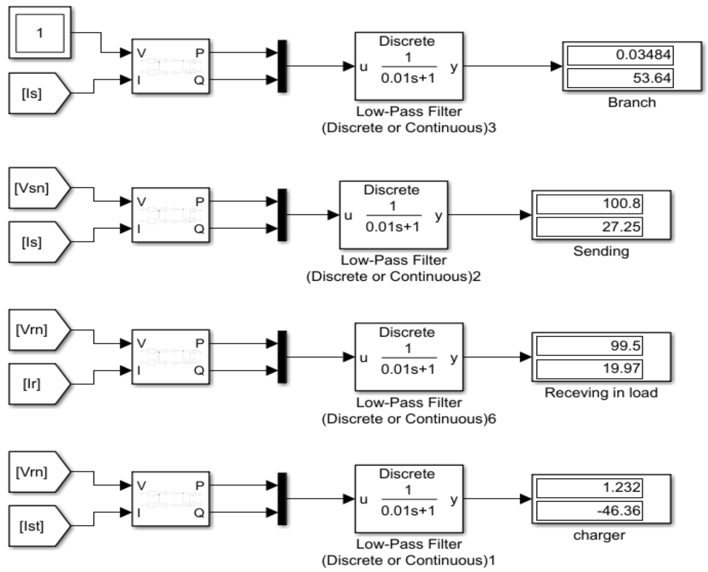

Figure 4. 14: Power measurement in single phase system

For heavy traffic demonstration we increase the residential load to 120KW in three-phase system and 100W, 20Kvar in single-phase system. Thus, the node voltage reduces to significant amount.

Thus the charger and the source provides the reactive power together to the residential loads as well as the distribution branch.

4.1.2.4 DC Voltage measurement

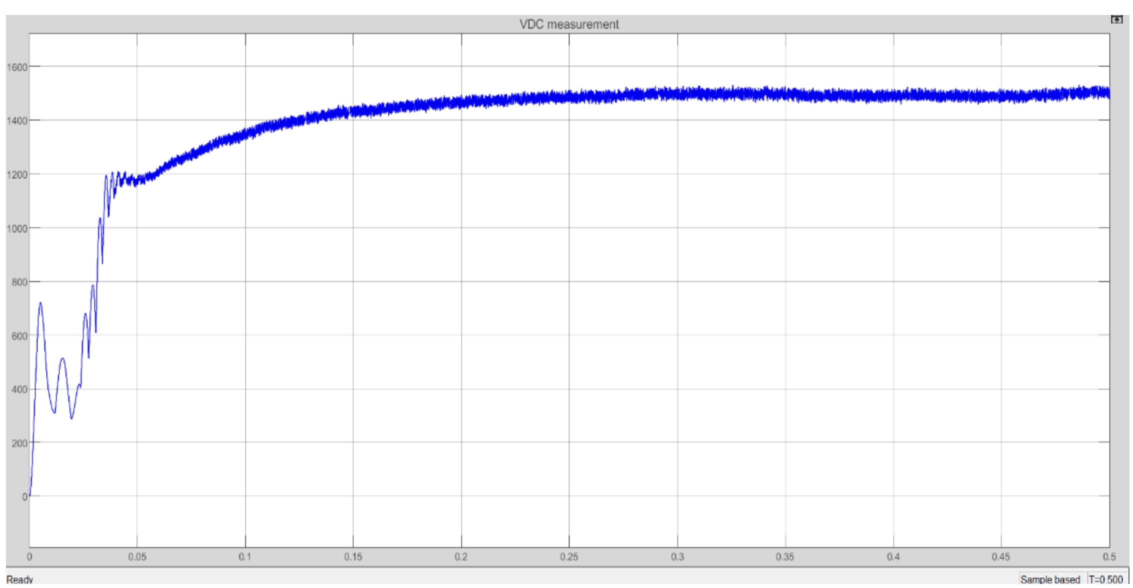

Figure 4. 15: DC voltage measurement in three phase system

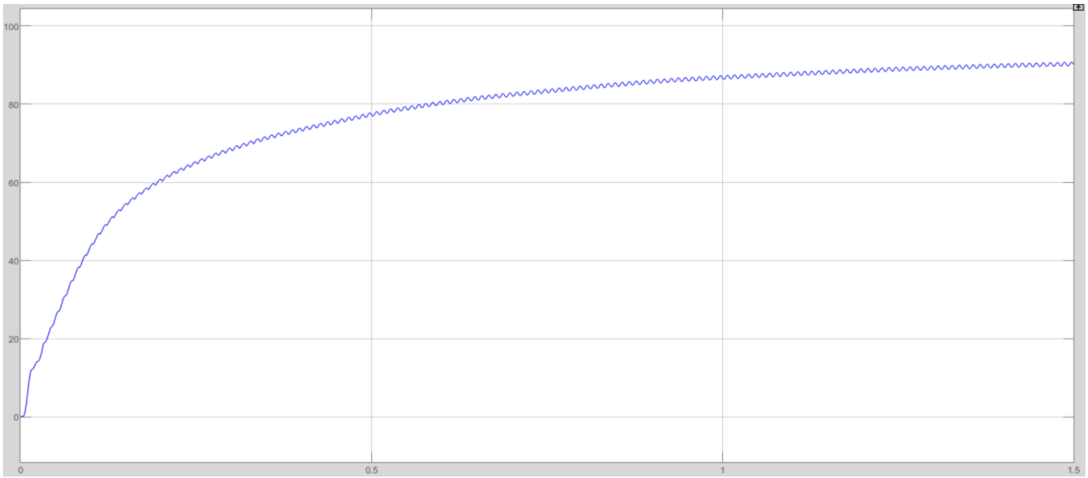

Figure 4. 16: DC voltage measurement in single phase system

In Three-phase system, the DC voltage was maintained as 1500V.

In Single-phase system, the DC voltage was maintained as 90V.

4.1.3 Both Active and Reactive power control: (Bidirectional)

Here both Id (active component of the current) and Iq(reactive component of the current) are varied and the following observations are done. In this mode of operation, charging battery is also connected and both active power and reactive power can be controlled.

4.1.3.1 Waveform of voltage and current at the point of connection of charger

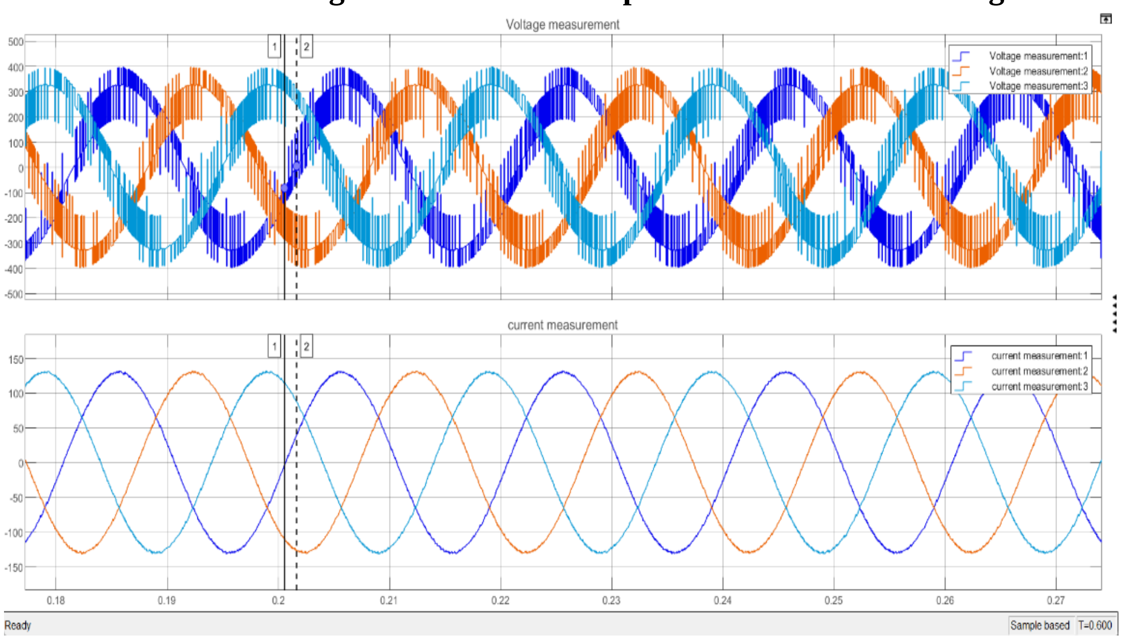

Figure 4. 17: waveform of voltage and current at connection node in three phase system

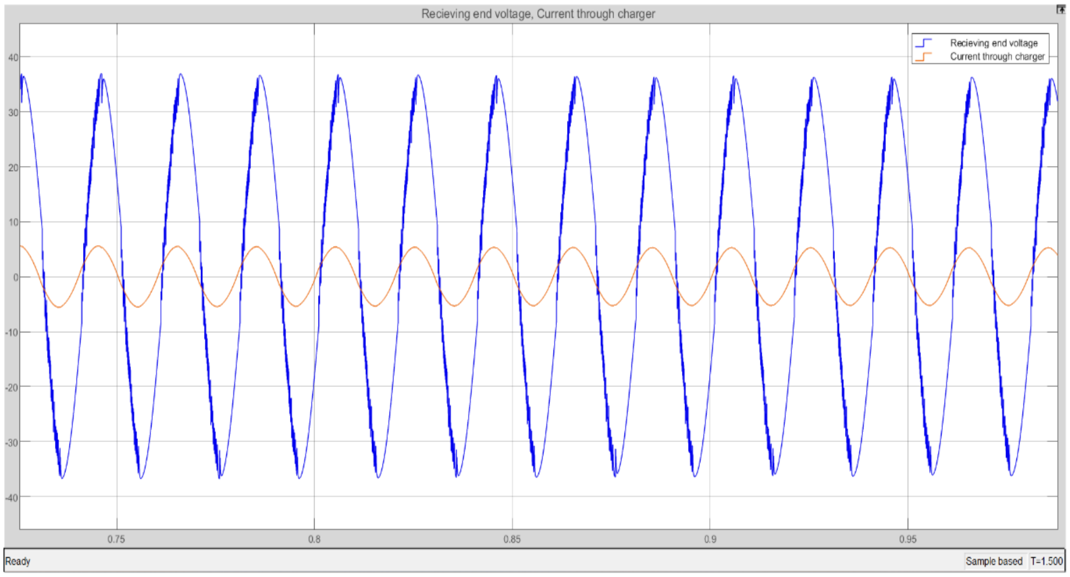

Figure 4. 18: waveform of voltage and current at connection node in single phase system

Here, in order to regulate the voltage at the receiving end while charging the battery the amount of reactive power generated by the charger is controlled via PID controller. Thus, current leads the voltage by some angle. The amount by which the current should lead the voltage is controlled by a closed loop control system with cross coupling method. In order to maintain the grid voltage equals to sending end voltage this control strategy fits perfectly.

4.1.3.2 Sending and receiving end Voltage measurement

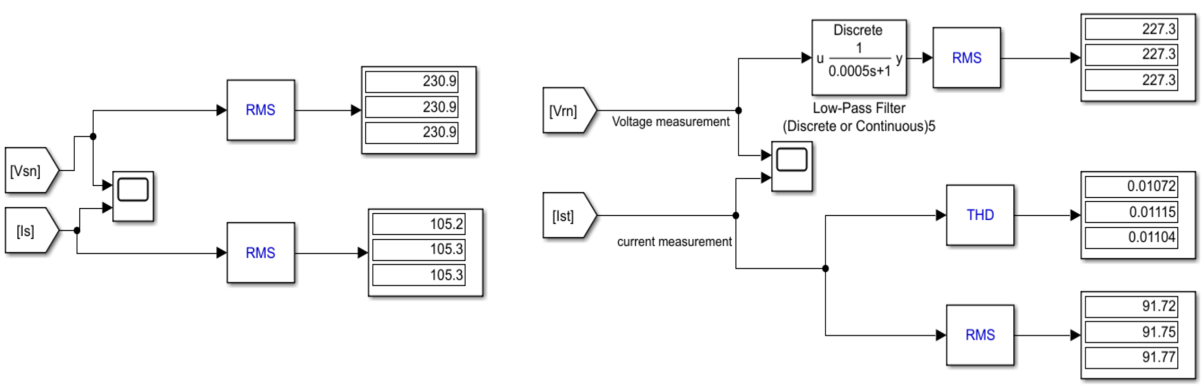

Figure 4. 19: Voltage measurement in three phase system

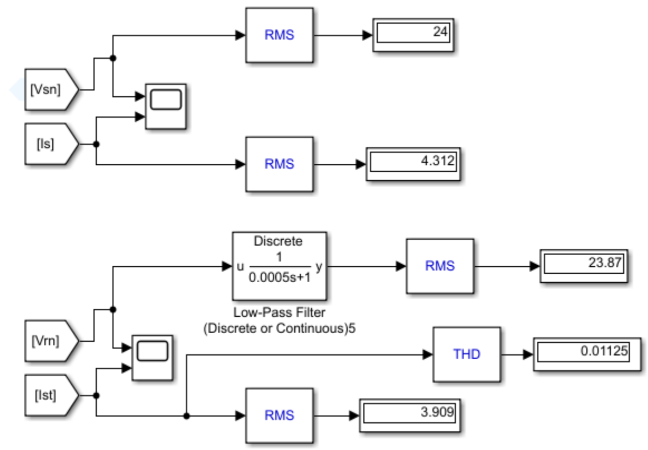

Figure 4. 20: Voltage measurement in single phase system

Here, it can be observed that the voltage in the receiving end is now regulated and is nearly equal to sending end voltage in both systems. Here, the charger supplies reactive power into the grid thus regulating the voltage in the grid along with charging the battery. The total harmonics distortion of the current is very less in both the systems about 1.1%.

Voltage regulation = $\frac{(V_{no-load} - V_{full-load})}{V_{full-load}} * 100\%$

Thus, the voltage regulation in both the systems are less than 2%. Thus, the system becomes very reliable and stable.

4.1.3.3 Power measurement

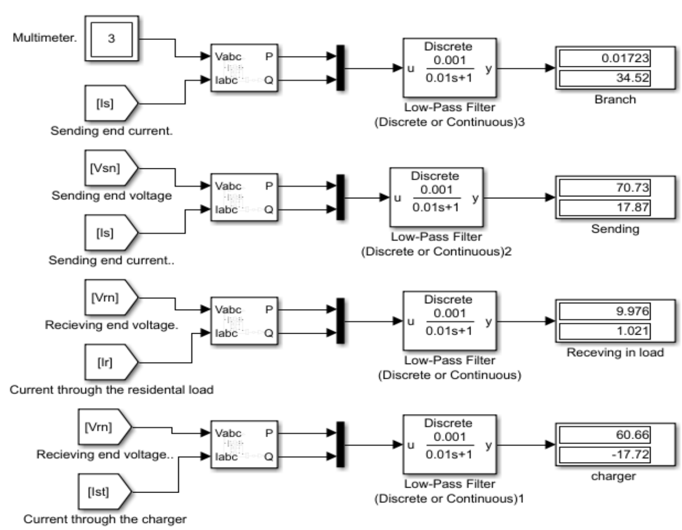

Figure 4. 21: Power measurement in three phase system

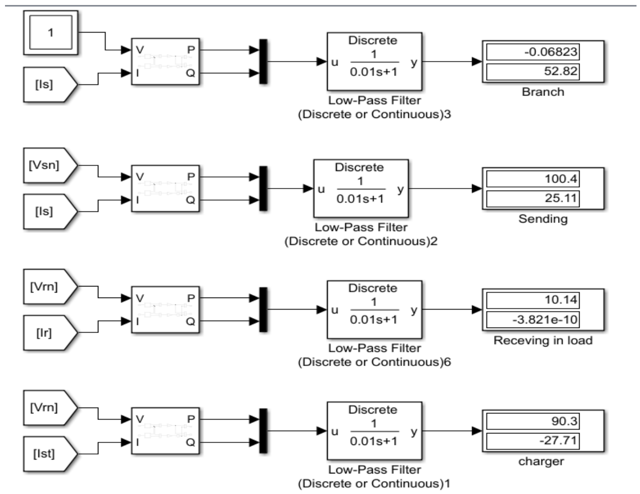

Figure 4. 22: Power measurement in single phase system

Here, from the fig 4.21 and fig 4.22, it can be observed that: In Three-phase system, the charger consumes the active power of 60KW and supplies the reactive power of 17.72Kvar into the grid in order to regulated the voltage at the point of connection. Thus, the residential load now consumes their rated power i.e., 10KW and 1Kvar. Similarly, in case of single-phase system the charger consumes the active power of 90W and supplies the reactive power if 27.71Var into the grid. The residential load now consumes their rated power i.e., 10W. Thus, the grid becomes now stable and more reliable.

4.1.3.4 DC Voltage measurement

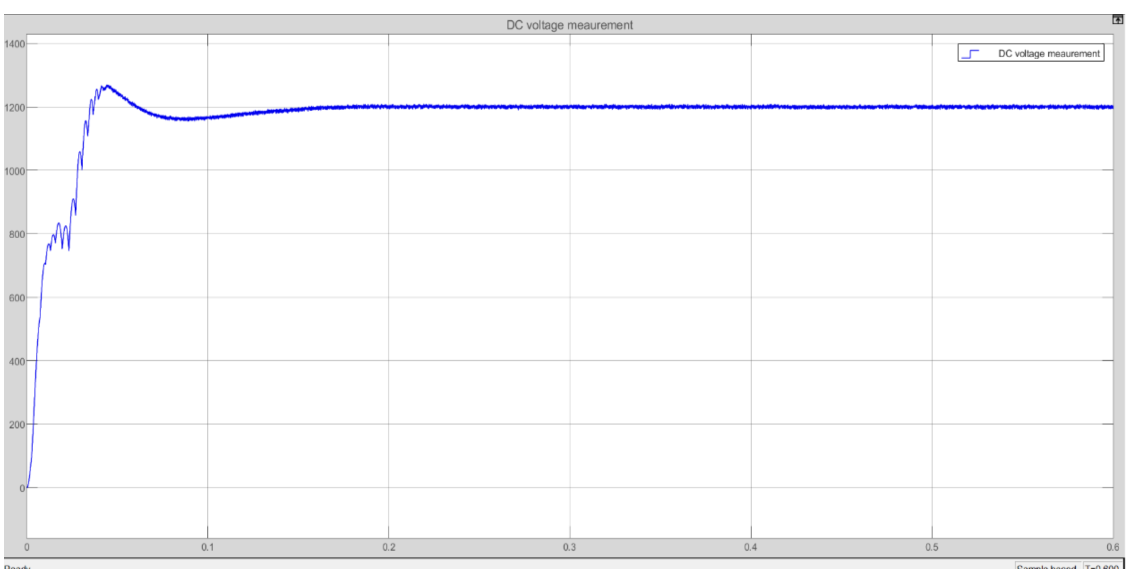

Figure 4. 23: DV voltage measurement in three-phase system

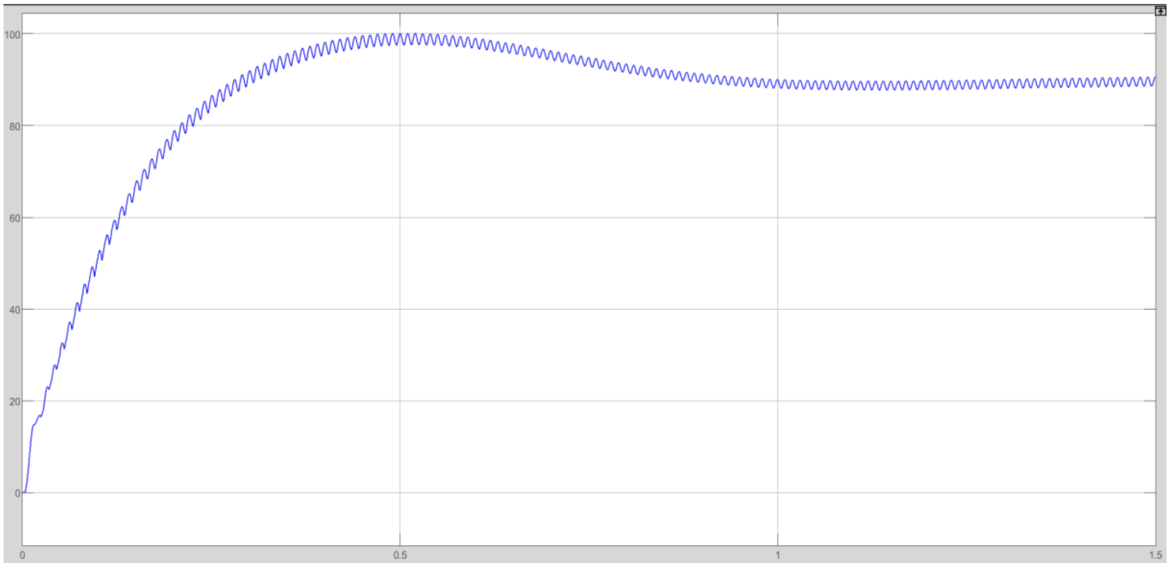

Figure 4. 24: DV voltage measurement in single phase system

In Three-phase system, the DC voltage was maintained as 1200V to charge the 60KW battery.

In Single-phase system, the DC voltage was maintained as 90V to charge the 90W battery.

4.2 Observation of the waveform

The waveforms of the systems at various stages were then observed and compared with the simulated waveforms. The waveforms of the following were observed:-

1. Gate driving circuit output
2. Output of the inverter
3. Waveform of the ac voltage measurement
4. Waveform of the ac current measurement
5. Phase locked loop waveform

4.2.1 Gate driving circuit output

The output of the gate driving transfer which controls the gating signal of the inverter was observed in Fig 4.1

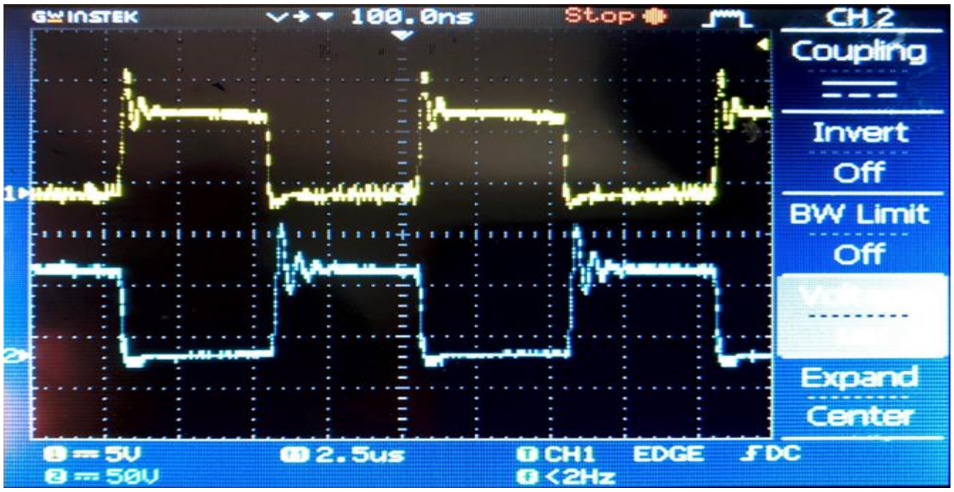

Figure 4. 26: The Output of the Gate Driving Circuit

As we can see, two completely out-of-phase square wave signals were generated from the gate driving circuit. The small number of harmonics can be seen in the waveform which is found to cause a small amount of loss without affecting the gating sequence.

4.2.2 Output of the inverter

The output of the inverter was then observed. As the gating signals were tested, the output of the inverter was expected as a square wave. However, the output was found to be not a perfect square wave, because of the resistance offered by the MOSFET causing some voltage drop across it.

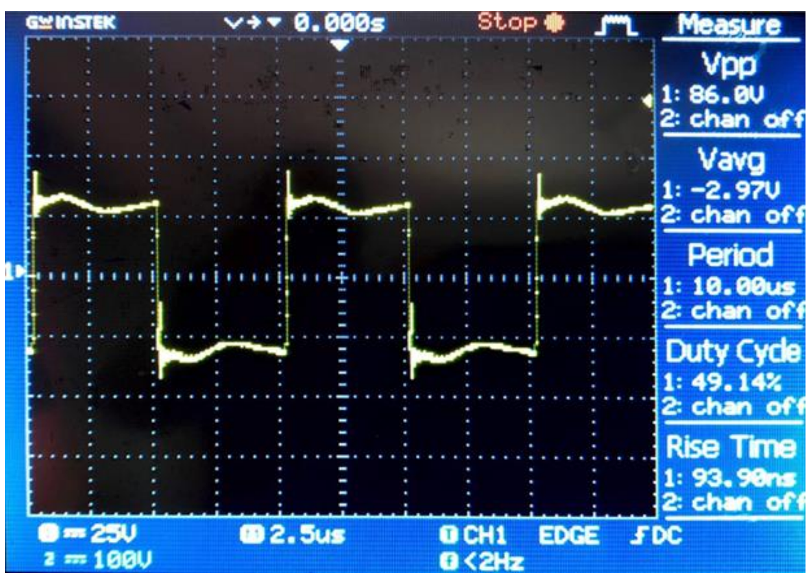

Figure 4. 27: The Output of the Inverter

4.2.3 Waveform of the ac voltage measurement

Here channel 1 is the waveform of input voltage source. The input voltage is 24v rms single phase. The waveform of the input signal is shown in figure 4.3 at channel 1. Since the input voltage has a peak value of 33.9V, this voltage cannot be directly supplied to the microcontroller (STM32). The maximum voltage that can be supplied to the microcontroller is 3.3V. Voltage more than 3.3V when supplied to the microcontroller can severely damage the microcontroller. Thus this input voltage must be step down below 3.3V. This is done by the use of an op-amp. The gain of the op-amp is set below 1 and the op-amp is operated in inverting mode. For safety purposes of the microcontroller, the voltage is reduced to 2V with and offset. The output waveform is shown in channel 2. This output signal is than feed to the

Microcontroller thus measuring the input voltage

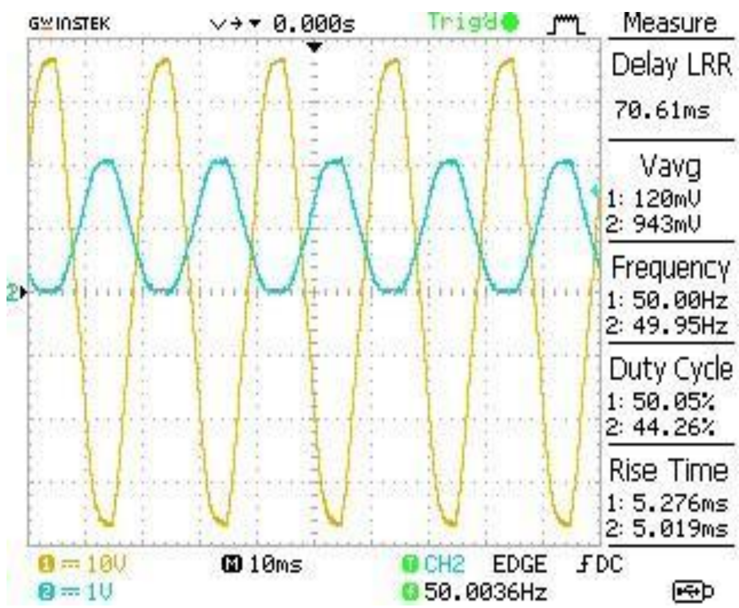

Figure 4. 28: The Input and Output waveform of the ac voltage measurement Circuit

4.2.4 Waveform of the ac current measurement

Here the voltage drop across the small resistor is very small i.e 375mv when 4A current flows through the circuit. Thus the current in the circuit can be measured according to the voltage drop in that resistor. This small value of voltage drop is then amplified by an op-amp. The op-amp is operated in inverting mode. The output signal is amplified to 2V and is passed to the microcontroller for control purpose.

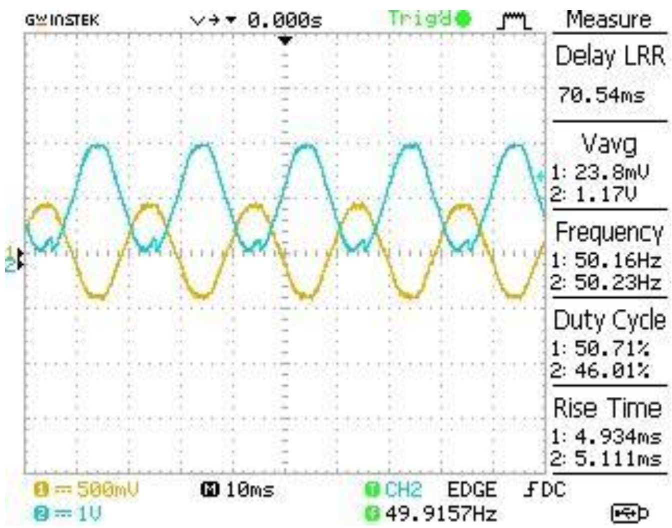

Figure 4. 29: The Input and Output waveform of the ac current measurement Circuit

4.2.5 Overall circuit connection

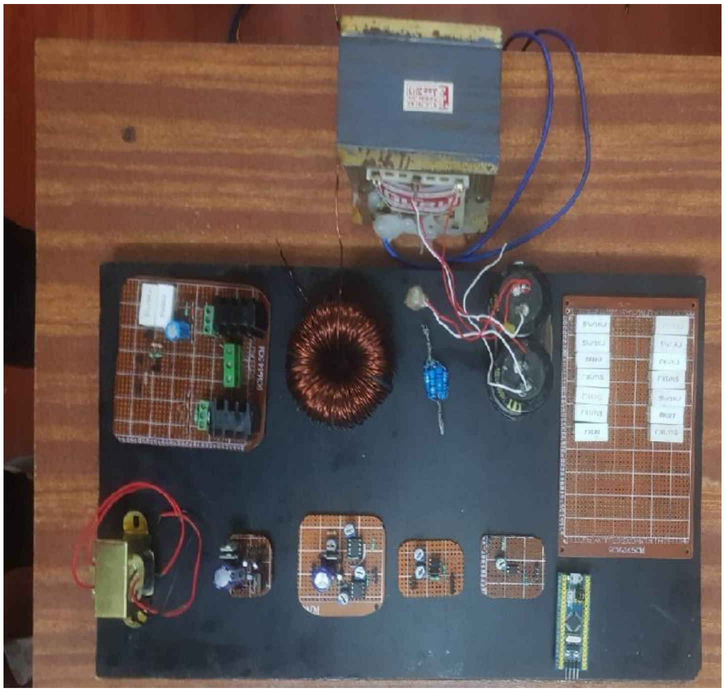

Figure 4. 30: The complete connection of single phase boost converter

The full developed prototype of the EV charger is shown in the above picture. Different circuits are put together in a wooden board. The measurement circuits are on one side while inverter, DC link capacitor with load are in other side. The stm32 blue pipe is also shown in the picture which is used for controlling of the DC output voltage.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The smart EV charger designed in this project is dynamic and reliable. The charger can not only operate in unity power factor but it can also be used to provide reactive power to the grid which helps to maintain required grid voltage at the point of common coupling. It can be operated in three ways:

- **During active power control:**
  The direction of active power flow is from source to the charger. The charger operates at unity power factor and voltage is reduced to 18.45V which brings the voltage regulation around 30.081%. The THD of the charging current is 0.6338%.
- **During Reactive power control:**
  The direction of reactive power flow is from charger to the source and charger operates at 90 degree leading power factor with receiving end voltage of 23.66V and a voltage regulation of 1.437%. The THD of the current is 0.6338% and charger works as STATCOM.
- **During Bidirectional power control:**
  The direction of active power flow is from source to the charger and the direction of reactive power flow is from charger to the source. The receiving end voltage is maintained at 23.87V with 0.54461% voltage regulation and THD of the current is 1.125%.

5.2 Future Recommendations

The concept of EV charging station i.e bidirectional concept can be implemented in industrial machineries as well as household items consuming high power such as induction chulo, microvan, heaters etc such that there will be minimum use of capacitor banks for voltage regulation. This charger can operate as a STATCOM when no vehicle is connected, thus further manufacture of STATCOM can be stopped and use of smart charger should be promoted.

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APPENDIX: A

Technical Specifications

Inductor

- Resistance = 0.6 Ohm
- Inductance = 26 mH
- Core = soft iron core
- Number of turns = 212

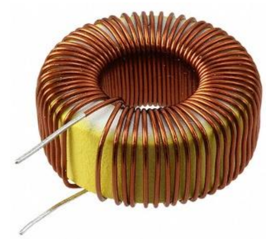

FIGURE A. INDUCTOR

.

Micro controller

- Arm® 32-bit Cortex®-M3 CPU core – 72 MHz maximum frequency, 1.25 DMIPS / MHz (Dhrystone 2.1) performance at 0 wait state memory access – Single-cycle multiplication and hardware division
- Memories – 64 or 128 Kbytes of Flash memory – 20 Kbytes of SRAM
- Clock, reset and supply management – 2.0 to 3.6 V application supply and I/Os – POR, PDR, and programmable voltage detector (PVD) – 4 to 16 MHz crystal oscillator – Internal 8 MHz factory-trimmed RC – Internal 40 kHz RC – PLL for CPU clock – 32 kHz oscillator for RTC with calibration
- • Up to 80 fast I/O ports – 26/37/51/80 I/Os, all mappable on 16 external interrupt vectors and almost all 5 V-tolerant
- DMA – 7-channel DMA controller – Peripherals supported: timers, ADC, SPIs, I 2Cs and USARTs

FIGURE A. 1 STM32 F103C8T6

Voltage Sensor

- Input Voltage: 0 to 25V
- Voltage Detection Range: 0.02445 to 25
- Analog Voltage Resolution: 0.00489V
- Needs no external components
- Easy to use with Microcontrollers
- Small, cheap and easily available
- Dimensions: 4 × 3 × 2 cm

FIGURE A. 2 VOLTAGE SENSOR

Current Sensor

- 80kHz bandwith
- 66 to 185 mV/A output sensitivity
- Can measure upto 30Amperes
- Low-noise analog signal path
- Device bandwith is set via the new FILTER pin
- 1.2 mΩ internal conductor resistance
- Total output error of 1.5% at TA = 25°C
- Stable output offset voltage
- Near zero magnetic hysteresis

FIGURE A. 3 CURRENT SENSOR

LCD

- Operating Voltage is 4.7V to 5.3V
- Current consumption is 1mA without backlight
- Alphanumeric LCD display module, meaning can display alphabets and numbers
- Consists of two rows and each row can print 16 characters.
- Each character is build by a 5×8 pixel box
- Can work on both 8-bit and 4-bit mode
- It can also display any custom generated characters
- Available in Green and Blue Backlight

URE A. 4 LCD DISPLAY MODULE

APPENDIX: B

Source code for Bidirectional power flow:

PID

```
#include "pid.h"
/**
 * It initiates tht PID
 * @param k_i: Integrater constant
 * @param k_p          : Proportional constant
 * return              : instance of PID
 */
PID pid_init(float k_i, float k_p){
        PID pid = {
                        .y_i = 0,
                        .y_p = 0,
                        .y   = 0,
                        .k_i = k_i,
                        .k_p = k_p
        };
        return pid;
}

/**
 * @param pid: pointer to PID
 * @param e            : latest error
 * @param del_t : time deifference
 * return              : control signal
 */
float pid_update(PID* pid, float e,float del_t){
        pid->y_i += pid->k_i*e*del_t;
        pid->y_p = pid->k_p*e;
        pid->y = pid->y_i+pid->y_p;
        return pid->y;
}
```

Filter

```
#include "filter.h"

/**
 * It initiates tht PID
 * @param k_i: Filter constant
 * @param k_p         : Filter constant
 * return             : instance of PID
 */
Filter filter_init(float y0, float tau, float dt){
        Filter filter = {
                .x = 0,
                .y = y0,
                .tau = tau,
                .dt = dt
        };
        return filter;
}

/**
 * @param pid: pointer to PID
 * @param e            : latest error
 * @param del_t : time deifference
 * return             : control signal
 */
float pid_update(PID* pid, float e,float del_t){
        pid->y_i += pid->k_i*e*del_t;
        pid->y_p = pid->k_p*e;
        pid->y = pid->y_i+pid->y_p;
        return pid->y;
}
```

smart ev charger

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