TRIBHUVAN UNIVERSITY

INSTITUTE OF ENGINEERING

PULCHOWK CAMPUS

A

PROGRESS REPORT

ON

ONBOARD CHARGING IN EV USING DUAL ACTIVE BRIDGE AND TOTEM POLE PFC

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LIST OF ABBREVIATIONS

EV	Electric Vehicle
DAB	Dual Active Bridge
ZVS	Zero Voltage Switching
IGBT	Insulated-Gate Bipolar Transistor
DSP	Digital Signal Processor
PFC	Power Factor Correction
EVSE	Electric Vehicle Supply Equipment
EMI	Electro Magnetic Interference

CHAPTER 1

1. INTRODUCTION

1.1. Background

Electric Vehicles have a quite interesting history with the earliest mass produced EVs appearing in the US market in 1900s. However due to limited technology the electric vehicles couldn't match the efficiency and price of petroleum powered vehicles. With the rapid progression of technology now EVs have again started gaining popularity and with people becoming more aware about the climatic consequences of using traditional petroleum powered vehicles EVs have not only gained popularity but also are being projected as the inevitability in automobile sector.

Electric Vehicle can be defined as the vehicles using one or more electric motor for propulsion. Some of the key components of EV are:

- Battery Pack
- Electric Motor
- Charging System
- Thermal Management System
- Regenerative Braking System
- Electric Vehicle Control Unit
- AC-DC Converter
- Filters
- Communication Interface

1.2. General Block Diagram of EV system

The basic block diragram of Electric Vehicle can be seen in the figure below:

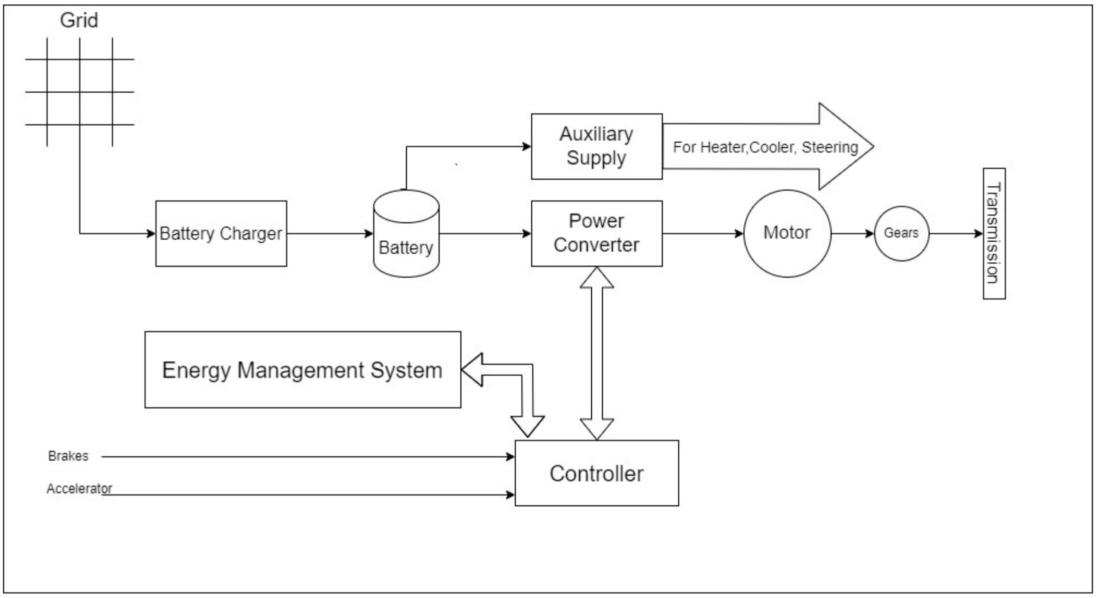


Figure 1.1: Basic Block Diagram of EV

1.3. On board charging

On board charging in a EV is a bridge between EVSE and battery. On board charging system converts alternative current available in grid to direct current which charges battery in the vehicle.An onboard charger (OBC) is a critical component in electric vehicles (EVs), enabling them to charge their batteries from standard electrical outlets or dedicated charging stations.

Components of On board charging are:

- EMI filter
- Power Factor Correction
- AC-DC converter
- DC-DC converter

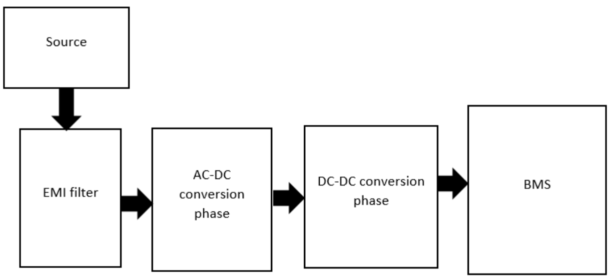


Figure 1.2: general block diagram for on board chargers

1.4. Problem Statement:

Compact, effective, and reasonably priced on-board chargers are becoming more and more in demand as EVs become more widely used. Conventional isolated DC-DC converters can be large and inefficient, and boost-based PFC topologies suffer from higher conduction losses because of input bridge diodes.

By removing the diode bridge, a Totem-Pole Power Factor Correction (PFC) stage provides a remedy, lowering conduction losses and increasing efficiency. In the DC-DC stage, a Dual Active Bridge (DAB) converter produces high power density, supports bidirectional power flow, and offers galvanic isolation.

1.5. Objective:

1.5.1. Main Objective:

- To design an efficient topology of the onboard charging system for ev application.

1.5.2. Specific Objective:

- To study various circuit topologies for deisng on on board charging systems.
- To design Totem Pole PFC circuit as an AC-AC component of obc system.
- To design a Dual Active Bridge circuit as a DC-DC component of obc system.
- To design the overall topology of obc system integrating both AC-AC and DC-DC systems.

1.6. Scope and Limitations:

With the rise of Electric Vehicles, there is a need for an efficient charging system for the vehicles.So there is a need to design and test various charging circuit topologies. Thus this project suggests one topology for a two-stage onboard charging system using totem pole PFC for AC-AC phase and DAB for DC-DC phase.

Though there is also a need for new topologies, new research is being focused on the single-stage OBC system. While our project on two-stage OBC is still relevant for the design of OBC, this project does not focus on new single-stage circuits.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction

Various circuit topologies can be implemented for creation of on board chargers used in EV. Generally, there are two phases in a two-stage on-board charger, with the first phase consisting of some PFC circuit topology and the second phase consisting of some type of DC-DC converter. Various circuits are being used in current days OBC systems for PFC stage, the paper [1] suggests the use of interleaved bridgeless type PFC. However recent studies in the field have found bridgless topologies to have EMI and high losses issues [2]. With the advent of totem pole circuits the losses and EMI have been reduced.The study [3] compares the conduction losses of various circuit topologies and suggest the use of totem pole cirucit for its reduced conduction losses and relatively simpler control systems.
Different research such as “Overview of dual-active-bridge isolated bidirectional dc–dc converter for high-frequency-link power-conversion system” [4] has shown over the years that Dual Active Bridge Converters are the best available topology for DC-DC converters. The study [5] compares different control techniques for control of dual active bridge converters. For the purpose of simplicity we have chosen the single phase shift control mechanism for control of our dual active bridge converter. Though the paper [1] suggests the use of phase shifted bridge converters for OBC system, however we have chosen DAB converters for our system design.

The paper [6] suggests the design of communication circuit for design of OBC, however this lies beyond the scope of this project as this project study deals with only the various circuit topologies that have been used in OBC system.

2.2. Related Theories

2.2.1. AC-DC converter

The conversion of AC (Alternating Current) to DC (Direct Current) is a fundamental process in onboard chargers (OBC) for electric vehicles (EVs). This conversion is essential because EV batteries require DC for charging. The efficiency, reliability, and safety of this conversion process significantly impact the overall performance of the OBC and the charging system.

Key Components of AC-DC Conversion

- **Rectifiers**: They are the first stage of AC-DC conversion. There are two main types of rectifiers used in OBCs:

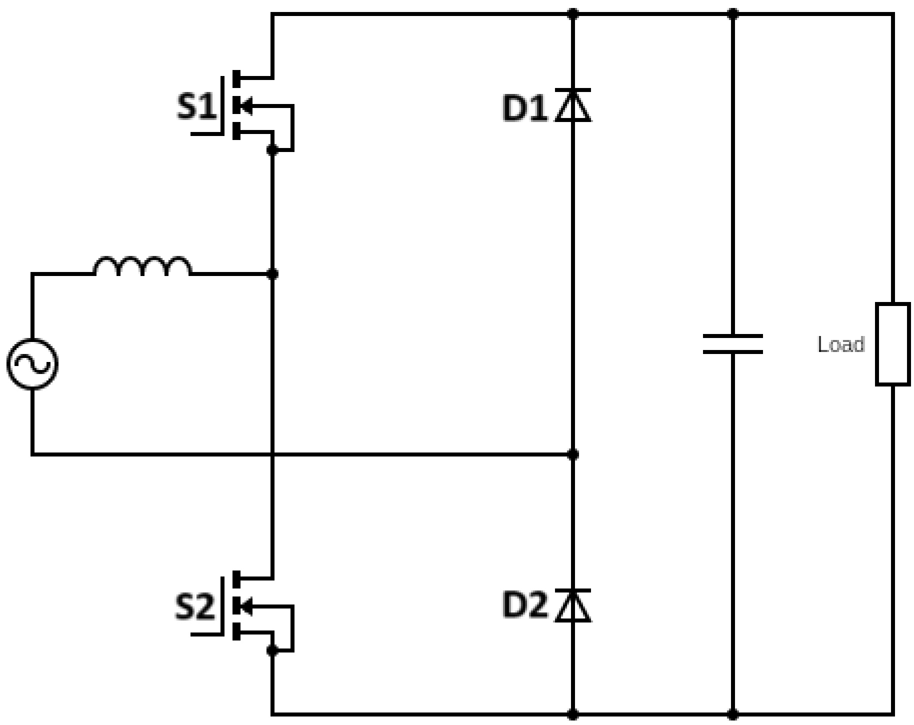
1. Diode Rectifier
2. Controlled Rectifier

1. Diode Rectifier
   (a) Half-Wave Rectifier:
   Uses a single diode to allow only one half of the AC waveform to pass through, resulting in a pulsed DC output. It's simple but not very efficient or practical for high-power applications.
   (b) Full-Wave Rectifier:
   Utilizes multiple diodes to convert both halves of the AC waveform to DC. Can be implemented using:
      i. Center-Tapped Transformer with Two Diodes: Uses a center-tapped transformer and two diodes. This setup requires a larger transformer, which can be bulky.
      ii. Bridge Rectifier (Four Diodes): A more common configuration in which four diodes are used to form a bridge, allowing both halves of the AC waveform to be used efficiently.
2. Controlled Rectifiers
   (a) Thyristor-Based Rectifiers:
   Utilize thyristors (silicon-controlled rectifiers, or SCRs) to control the output DC voltage by adjusting the firing angle of the thyristors.
   (b) IGBT/MOSFET Rectifiers:
   Implement Insulated Gate Bipolar Transistors (IGBTs) or MOSFETs for even finer control and higher efficiency.

- **Power Factor Correction (PFC)**: Power factor correction (PFC) is an important aspect of the AC/DC conversion process in OBCs. It ensures that the input current waveform is in phase with the voltage waveform, thus minimizing reactive power and improving efficiency. PFC can be passive or active:

  1. Passive PFC:
     Uses passive components like inductors and capacitors to filter harmonics and improve the power factor. They are easier to design but less efficient for high-power applications.
  2. Active PFC:
     Provides higher efficiency and better control over power factor, suitable for high-power OBCs. It utilizes digital signal processors (DSPs) or FPGAs to implement control algorithms for optimal performance. The most common topology, which actively controls the input current waveform to match the voltage waveform is the boost converter topology. This is what we'll be using in the project.

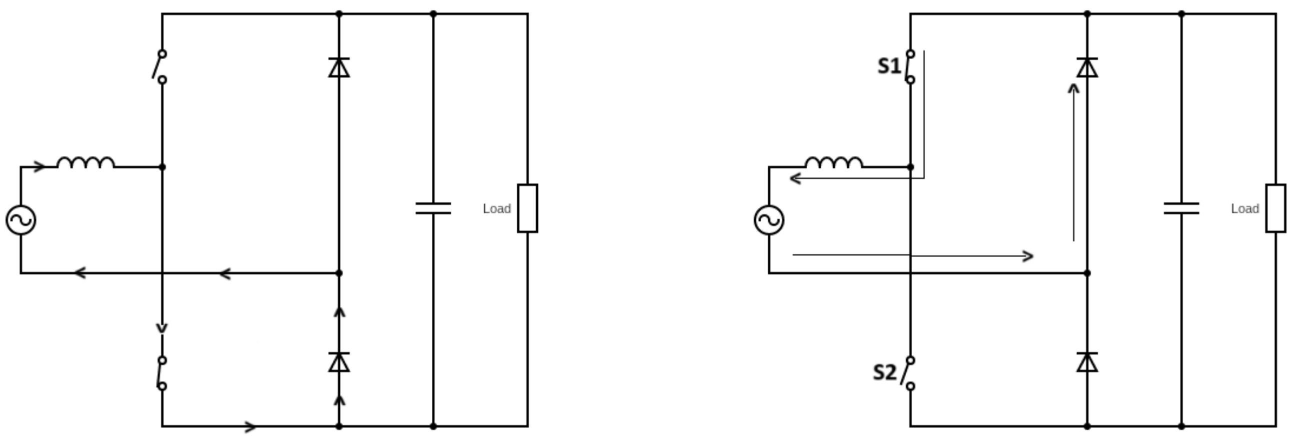
- **Totem Pole Power Factor Correction:**



Here, rather than the usual four diodes as a bridge, two active switches are present in one leg with the familiar diodes on the other leg. It operates in two states:

1. Zero State
2. Active State

1. **Zero State:** In this state, the inductor is charged by the AC supply and the load is charged through the capacitor. During the positive half state, switch S2 is turned on for duty cycle D and during the negative half cycle, the switch S1 is turned on for duty cycle D.

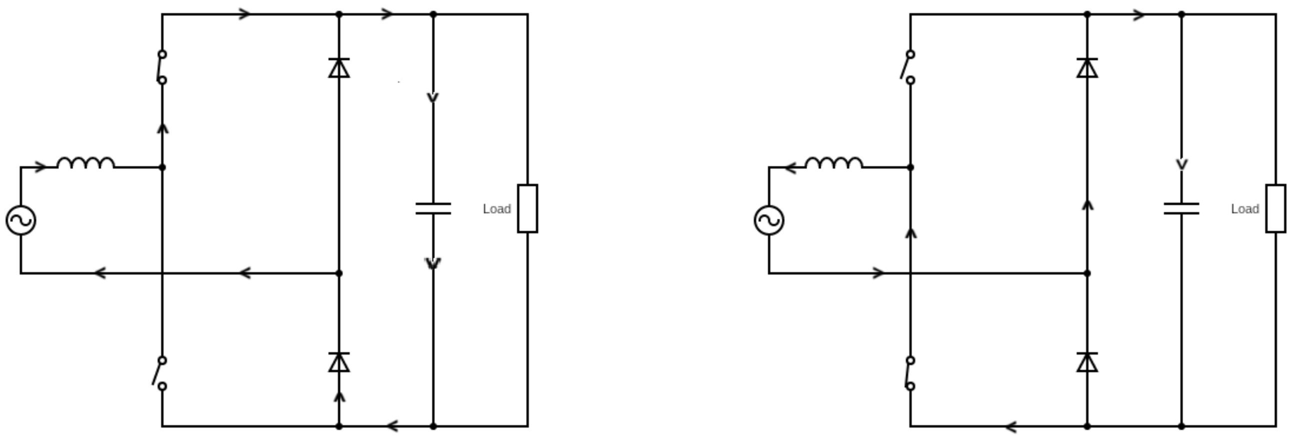


During positive half cycle

During negative half cycle

Figure 2.1: Zero State Operation

2. **Active State:** In this state, the capacitor and the load is charged through the AC source and the current is discharged through the inductor. During the positive half cycle, the switch S1 is turned on for duty cycle (1-D) i.e. after Zero State and during the negative half cycle, the switch S2 is turned on after S1 is turned off for duty cycle (1-D).



During positive half cycle During negative half cycle

Figure 2.2: Active State Operation

- **Interleaved Totem Pole Power Factor Correction:**
  E. Firmansyah et al in 2010 introduced a novel PFC topology that combines the benefits of interleaving and totem-pole configurations to enhance efficiency and performance in AC-DC conversion systems.[7].
  Key Features:
  - **Interleaving Technique:** Two parallel PFC stages operate **180° out of phase**, reducing input current ripple and improving thermal performance.
  - **Totem-Pole Structure:** Uses a **bidirectional switch** (GaN or SiC MOSFETs) for seamless rectification, eliminating diode losses.
  - **High Efficiency:** Operates in **Critical Conduction Mode (CRM)** or **Continuous Conduction Mode (CCM)** to minimize switching losses.
  - **Low Harmonics:** The interleaved approach helps **reduce total harmonic distortion (THD)** and ensures compliance with **power quality standards**.
  - **Compact and Cost-Effective:** Requires fewer passive components compared to traditional **boost PFC** designs, making it ideal for **high-power applications** such as *data centers, EV chargers, and industrial power supplies*.

- **DC-DC Conversion Stage**: The DC-DC conversion stage follows the rectification process, further regulating and transforming the DC output to the required voltage and current levels for battery charging. This stage often involves:

  1. Buck Converter:
     Steps down the voltage from a higher level to the battery's charging voltage.

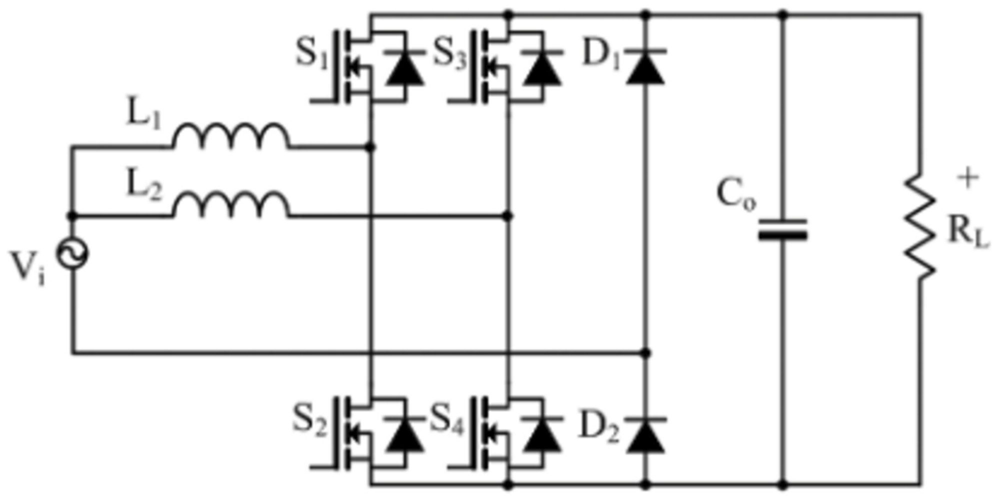


Figure 2.3: Interleaved Totem Pole PFC

2. Boost Converter:

   Steps up the voltage when necessary, though less common for OBCs.

3. Buck-Boost Converter:

   Capable of both stepping up and stepping down the voltage, providing flexibility for varying input/output conditions.

4. LLC Resonant Converter:

   Offers high efficiency with soft-switching techniques, reducing losses and improving thermal performance.

- **Filters**: Filters are used to smooth out the rectified DC output and reduce harmonic distortion. They typically include:

  1. LC Filters:

     Use inductors and capacitors to reduce ripple and smooth the DC signal.

  2. Active Filters:

     Provide more advanced filtering capabilities, often controlled by digital processors for precise performance.

2.2.2. DC-DC Converter

The DC-DC Converter is an essential electronic circuit designed to efficiently convert DC from one voltage level to another. This type of electric power converter can handle power levels ranging from very low to extremely high.

In the era before the development of power semiconductors, a common method for increasing the voltage of a DC power supply for low-power applications involved converting it to AC using a vibrator, step-up transformer, and rectifiers. Historically, in situations where significant power was required, a motor-generator unit was utilized. In this setup, the motor operated the generator to generate the required voltage.

Although these designs were not very efficient and were costly, they were the go-to solution for powering car radios due to the lack of alternative methods at that time.

DC-DC converters play a crucial role in powering a wide variety of portable electronic devices, including but not limited to cellular phones, laptops, and computers. These devices are typically powered by batteries. Within these devices, there are multiple subcircuits, each with its specific voltage level requirements, and DC-DC converters are employed to ensure that the different voltage levels are appropriately managed and supplied to the respective subcircuits.

Among the various designs and architectures for onboard chargers, the Dual Active Bridge (DAB) converter for DC-DC conversion phase is gaining attention due to its high efficiency, bidirectional power flow capability, and compact design. This section explores the functionality of DAB-based onboard chargers and related components, emphasizing their role in enhancing EV charging efficiency and performance.
A Dual Active Bridge (DAB) converter is a type of DC-DC converter that uses two active bridges (one on the primary side and one on the secondary side) and a high-frequency transformer to transfer energy. The primary and secondary bridges are typically composed of MOSFETs (Metal-Oxide-Semiconductor Field-Effect Transistors) or IGBTs (Insulated Gate Bipolar Transistors), which switch on and off to convert and regulate power.

Key Features of DAB Converters:

Bidirectional Power Flow: DAB converters support bidirectional power flow, allowing energy to be transferred in both directions. This capability is essential for vehicle-to-grid (V2G) applications, where the EV can supply power back to the grid.
High Efficiency: By operating at high frequencies and using soft-switching techniques (such as zero-voltage switching or zero-current switching), DAB converters minimize switching losses, leading to higher efficiency.
Compact Size: The use of high-frequency operation reduces the size of passive components (such as inductors and capacitors), resulting in a more compact and lightweight charger design.
Isolation: The high-frequency transformer provides galvanic isolation between the input and output, enhancing safety and reducing electromagnetic interference (EMI).

Operating Principle:

Primary Side: The primary bridge converts the input DC voltage (from the AC-DC conversion stage) into a high-frequency AC voltage.
Transformer: The high-frequency AC voltage is transferred through the transformer, which adjusts the voltage level based on the turns ratio.
Side: The secondary bridge rectifies the high-frequency AC voltage back into DC voltage, suitable for charging the EV battery.
Phase Shift Strategies: In Dual Active Bridge (DAB) converters, power transfer is controlled by adjusting the phase shifts between voltage waveforms. The control methods are divided into three main categories:

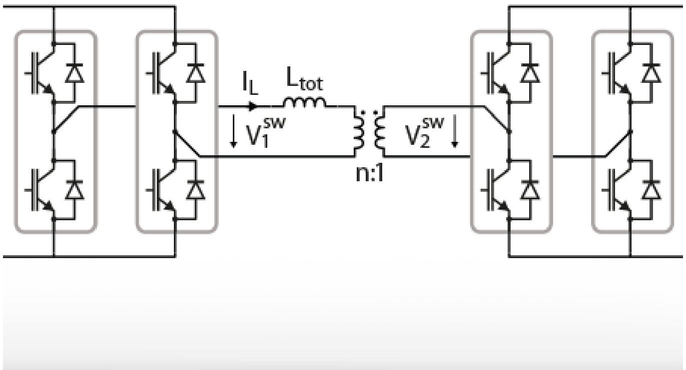


Figure 2.4: DAB Converter Circuit

- **Single-Phase Shift (SPS)**: Only one phase shift between the two bridges.
- **Dual-Phase Shift (DPS)**: Two phase shifts – one between the bridges and one within the bridges.
- **Triple-Phase Shift (TPS)**: Three phase shifts – one between the bridges and two within each bridge.

Comparison of Control Strategies

The following table summarizes the characteristics of each phase-shift strategy:

Control Mode	Complexity	Efficiency (Full Load)	Efficiency (Light Load)	ZVS Range	Power Control Flexibility
Single-Phase Shift (SPS)	Low	Moderate	Low	Narrow	Limited
Dual-Phase Shift (DPS)	Medium	Higher	Higher	Wider	More Flexible
Triple-Phase Shift (TPS)	High	Highest	Highest	Widest	Most Flexible

Table 2.1: Comparison of DAB Converter Phase-Shift Strategies

Single-Phase Shift (SPS) In the simplest form of control, a single phase shift, denoted by ϕ, is applied between the primary and secondary bridges. Power transfer increases as the phase shift increases. This method is simple to implement but is not very efficient at light loads and has a limited range of zero-voltage switching (ZVS). It is the most commonly used strategy.

Dual-Phase Shift (DPS) Dual-phase shift control introduces two phase shifts: one between the bridges and another within the bridges themselves. This provides more flexibility in power control, better efficiency at light loads, and an expanded ZVS range. However, it is more complex than SPS.

Triple-Phase Shift (TPS) Triple-phase shift adds a third level of control, introducing phase shifts within both bridges and between the bridges. This control method offers the highest efficiency, especially over varying loads, and maximizes the ZVS range. However, it requires the most complex control and precise timing.

Chapter 3

3. METHODOLOGY

This chapter deals with the methodology of our study, for this purpose we have first presented the circuits that were simulated with the intention of highlighting the historical development in the field and also the possible alternative that can be used for development OBC system.This includes the simulink of circuits such as Interleaved Boost PFC converter , Phase shifted brdige converters etc. We have just highlighted these topologies and are mainly focused on totem pole pfc and dual active bridge converters as we are dealing with mainly these two in our project.

3.1. For Interleaved Boost PFC converter:

This topology was initially used for the design of an onboard charging system , however these were eventually phased out due to higher conduction losses[3].This topology can be modeled as: Its simulink

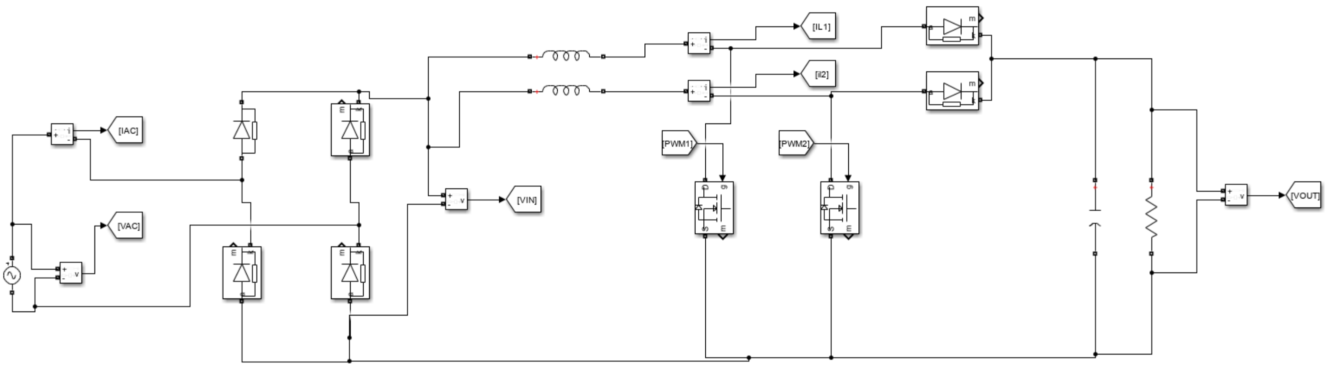


Figure 3.1: Interleaved boost PFC converter

model for control algorithm is as:

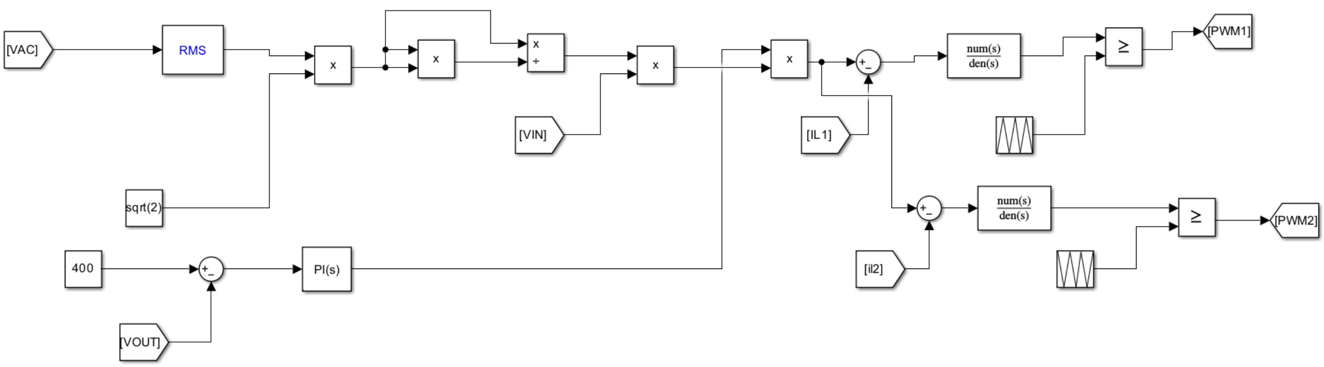


Figure 3.2: Control algorithm for interleaved boost PFC converter

3.2. For Totem Pole PFC:

The Totem Pole Power Factor Correction (PFC) topology is an advanced method of power factor correction used in AC/DC converters. It is known for its high efficiency, improved power factor, and reduced component count compared to traditional PFC methods. This approach has gained popularity, especially in high-performance applications like electric vehicle onboard chargers, due to its capability to meet stringent efficiency and power quality standards.

Our totem pole simulink model is as follows:

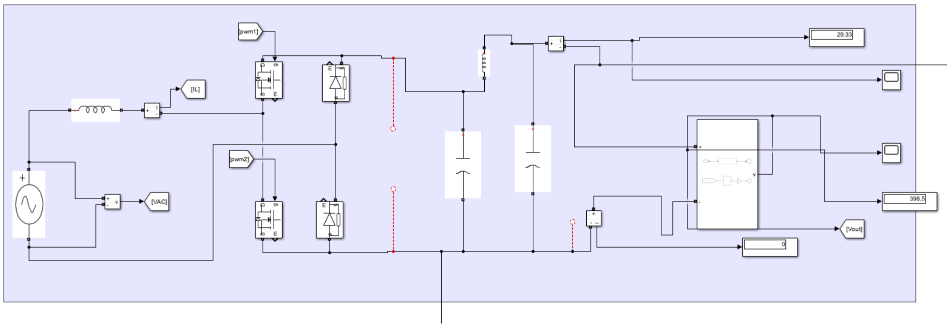


Figure 3.3: Totem Pole simulink Model

We have following control algorithm used for control totem pole pfc: As we can see there is an emphasis on the polarity detection as the circuit has different switching sequence at different polarity.

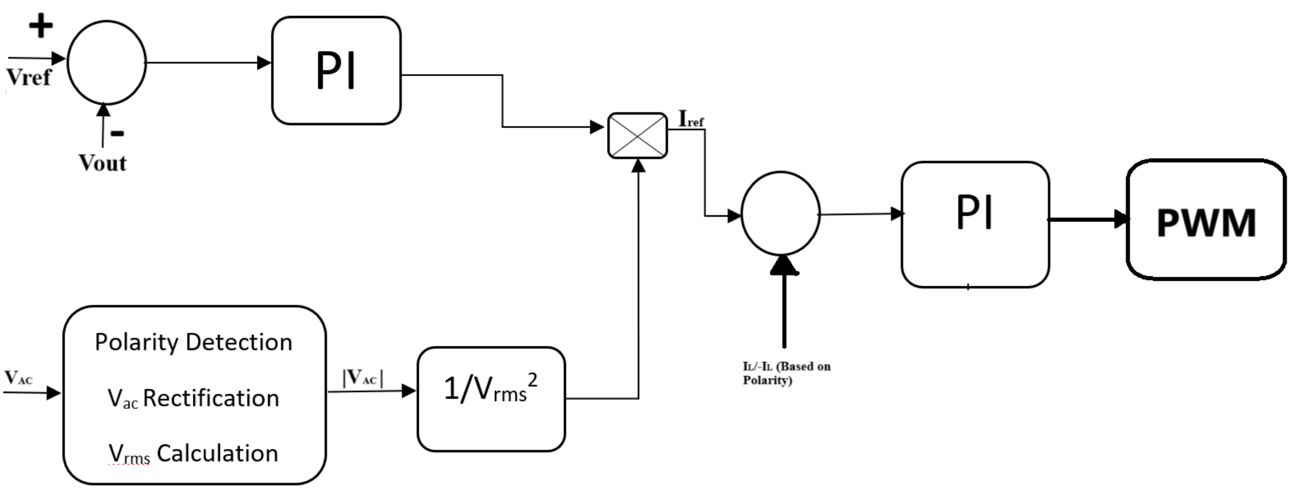


Figure 3.4: Control Algorithm for Totem Pole

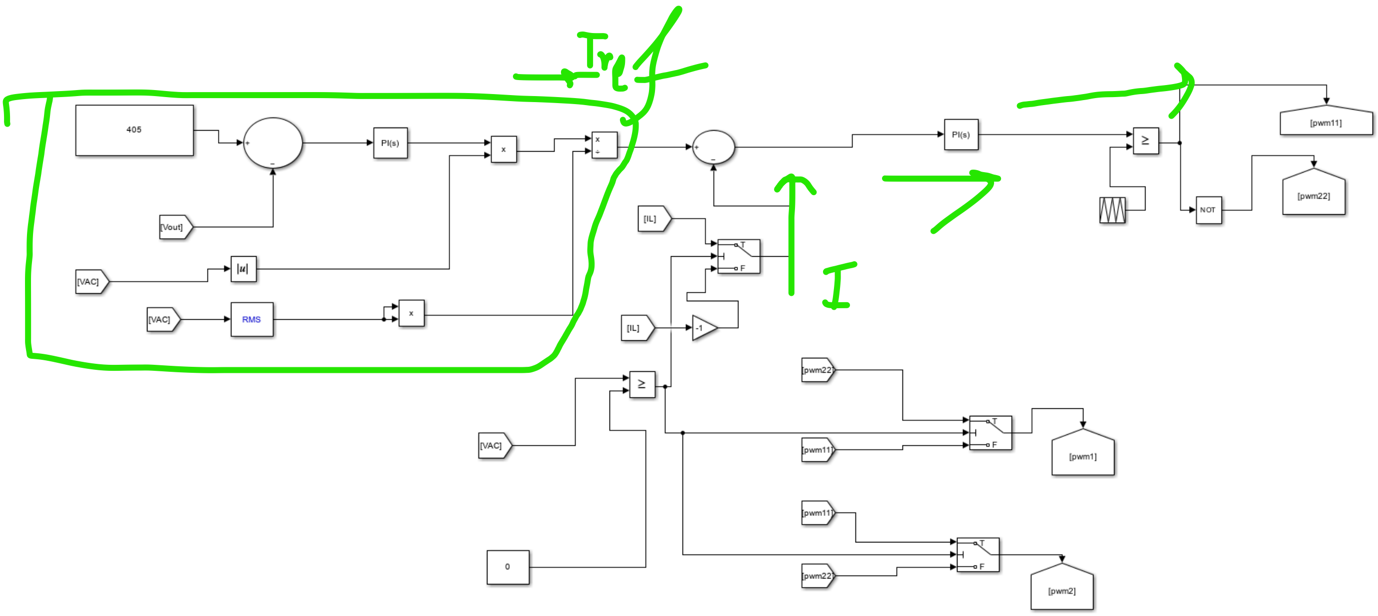


Figure 3.5: Control algorithm simulink mode for totem pole pfc circuit

3.2.1. For Interleaved totem pole PFC circuit:

For totem pole circuit can be interleaved. The benifit of this type of topology is increased efficiency and reduced conduction losses[3].This simulink model for this circuit is as:

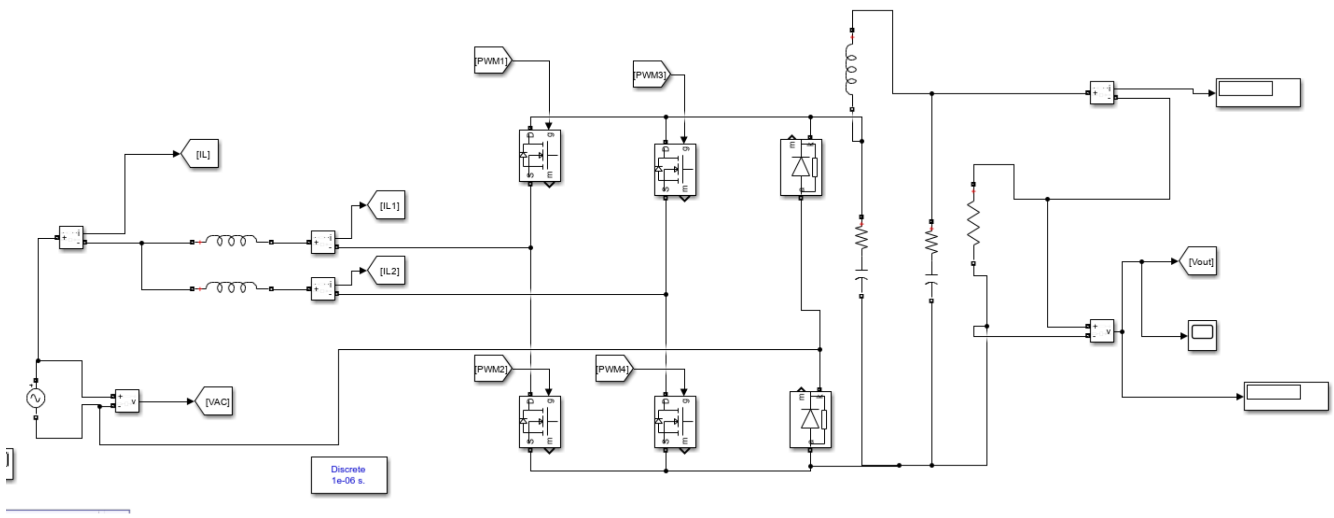


Figure 3.6: Interleaved Totem Pole PFC simulink

The control algorithm is similar to totem pole with addition of another current polarity detection for the interleaved circuit.

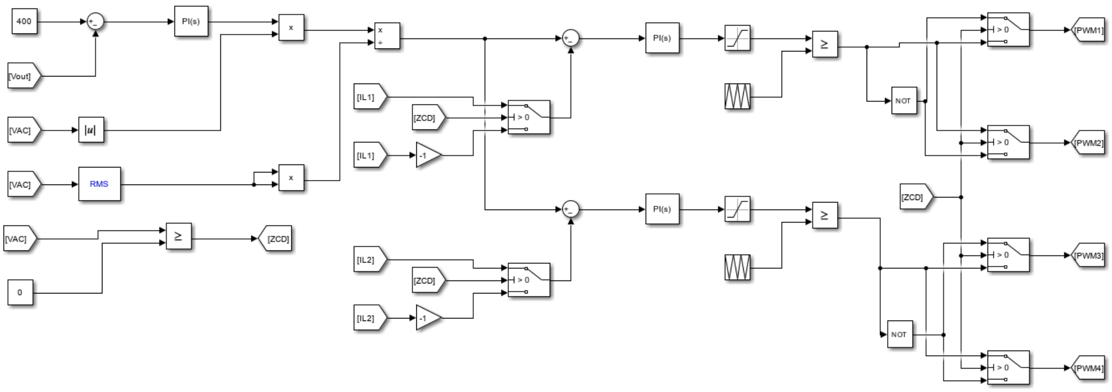


Figure 3.7: Control algorithm for interleaved totem pole circuit

3.3. For 180^o Phase Shifted bridge converter:

This type of circuits is typically used for the DC DC phase where you need the advantages of DAB for single direction power flow.This type of converter is relatively simple and provides galvanic isolation.These are also called phase shifted full bridge converters.

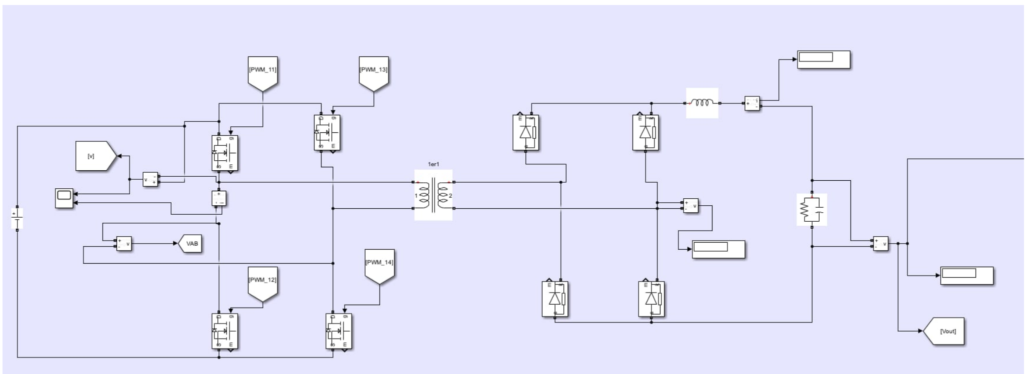


Figure 3.8: SIMULINK model of 180 degree Phase Shifted Converter

3.4. For DAB converters:

As we have already mentioned, there can be different control strategies for a dual active bring converter but for the purpose of our project we have used a simple single phase shift control.The control in this strategy is simple as we only have provide only on phase shift between primary and secondary bridges.

$$P_o = \frac{1}{X_l} V_i^2 d\phi \left(1 - \frac{\phi}{\pi}\right)$$

In the single phase shift system , the phase difference between primary and secondary bridge is the phi given by the above formula.

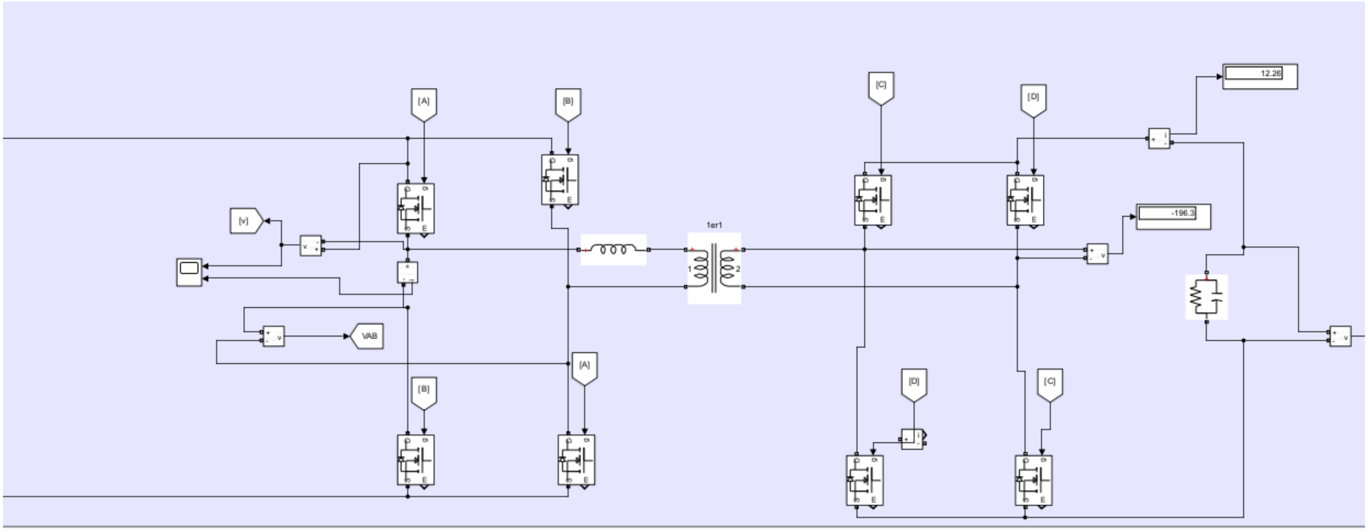


Figure 3.9: Dab simulink model

3.4.1. Phase Shift Control:

Phase Shift Control is a technique in power electronics where one wave is timed relative to another to influence the performance of the system,power quality, and stability.There are different phase shift control methods such as:

- Single phase shift control.
- Extended phase shift control.
- Dual phase shift control.

The most commonly used phase shift control strategy in the dual active bridge converter is the single phase shift control.

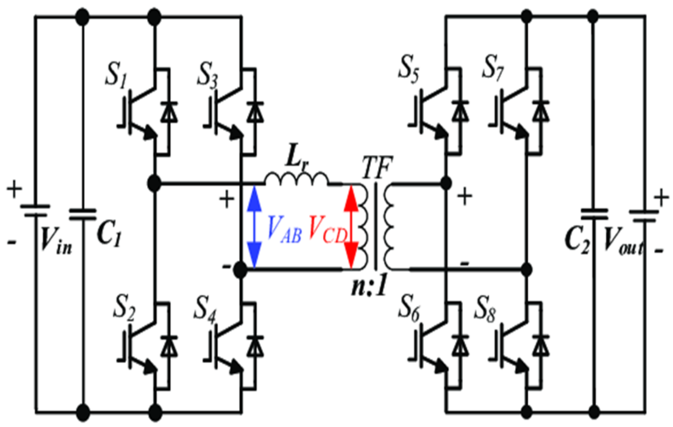


Figure 3.10: dab converter circuit for switching sequence

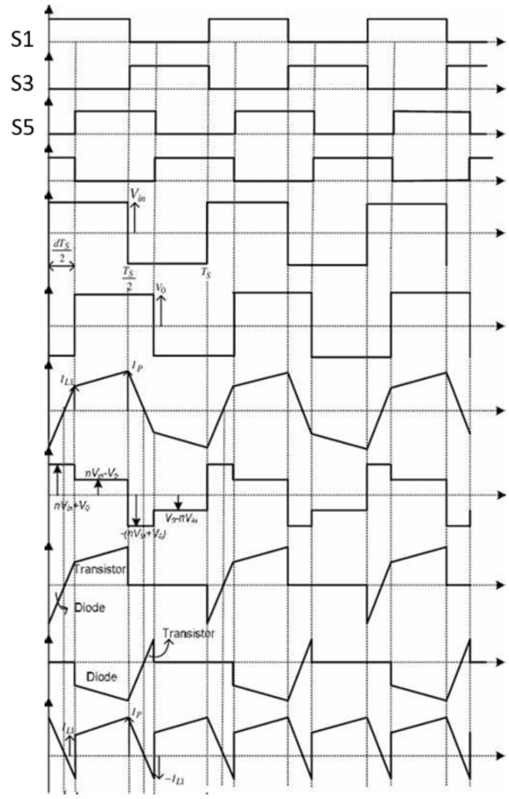


Figure 3.11: switching and current waveform of dual active bridge converters

Now the S1 switch is triggered at the beginning of operation, then at some phase delay phi, we trigger the switch S5. It is to be noted that the switch S4 is to be triggered at the same time as S1. And switch S5 and S8 are triggered at the same time.S1 switch remains on for 50 percentage duty cycle, then switch S2 and S3 are triggered.

This phase delay between S1 and S5 is used to control the amount of power flow in the circuit. However this is to be noted that at zero phase angle delay, there is no power flow and for proper power flow phase angle is to be limited between -90 to 90.And the main problem associated with the design of dab converters is the choice of correct value of this phase angle delay.

For calculation of phase delay, we can calculate manually and provide phase shift as shown in the figure below:

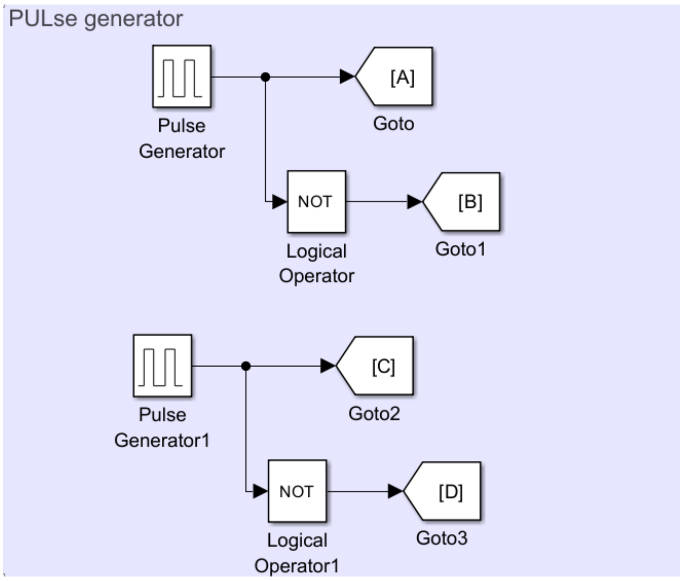


Figure 3.12: Pulse Generator

The figure above represents the way in which we can manually provide pulse to the circuit. First pulse generator is provided directly to A and to B through a NOT gate. The second pulse generator is provided a certain delay which can be calculated, and this delay can be used to vary the voltage delivered.

There is another way where we can calculate delay with the help of the output obtained and a constant value which can be fed to a pi controller as shown in the figure below: In the figure above the signal fed to A and B doesn't change but if we look at the C and D block they are now fed through a variable time delay system which has two input system where one of the input is derived from the pulse generator which feeds the A and B block, another input is the phase delay by which the second signal is now delayed which is the difference between output voltage and constant value.

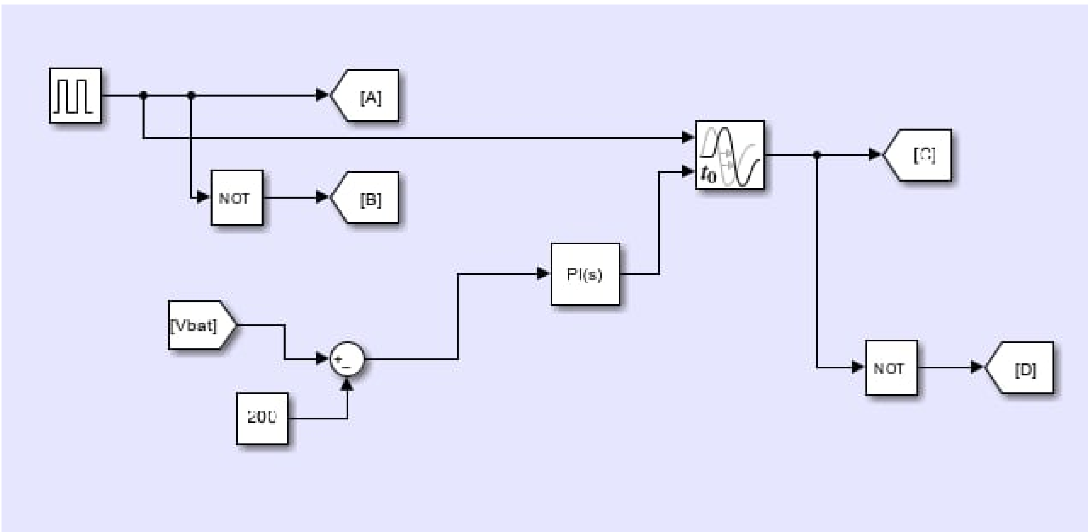


Figure 3.13: DAB control with constant and PI control

3.5. PI control

PI controller are generally the controller used in control system that combines proportional control and integral control.It is used to provide a control signal that helps to reduce error between desired setpoint and actual output of system.

- Proportional Control (P):This part of controller produces an output that is proportional to current error value.
- Integral Control(I):This part of controller that sums error over time and produces output that is proportional to accumulated error.

The general equation for a Proportional-Integral (PI) controller is given by:

$$u(t) = K_p e(t) + K_i \int_0^t e(\tau)\, d\tau \tag{3.1}$$

where:

$$\begin{aligned} u(t) &: \text{Control output at time } t \\ K_p &: \text{Proportional gain} \\ K_i &: \text{Integral gain} \\ e(t) &: \text{Error at time } t \\ \tau &: \text{Dummy variable of integration} \end{aligned}$$

3.5.1. Pulse Width Modulation:

Pulse Width Modulation or PWM is a control technique where output is modulated pulse signal is generated form analog signal with the help of micro controllers.This technique has various application such as in motor control techniques, in dc-dc conversion techniques etc.

Duty cycle:

Duty Cycle is percentage of time for which is modulated signal is on.The duty cycle of a signal can be calculated as below:

$$\text{Duty Cycle} = \frac{\text{turn on time}}{\text{turn on time} + \text{turn off time}} \tag{3.2}$$

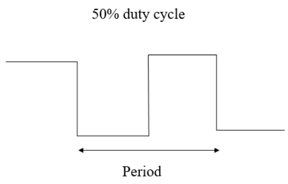


Figure 3.14: Duty Cycle illustration

Hence our final model for the system looks as:

4. RESULTS AND DISCUSSION:

In this chapter we deal with the result of our project and discussion surrounding it.For the final project model we have included two model mainly with the first model containing a dual active bridge converter with manual phase shift provided and in the second model we have employed a dual active bridge converter with phase shift provided by the difference between a constant value and output at load.

At first we begin with the implementation of AC/DC phase and secondly our discussion heads with towards DC-DC with first section of this paper describing the model with manual phase shift.

4.1. AC/DC phase

For implementation of AC/DC phase we have used Totem Pole Power Factor Correction (pfc) circuit.

For the following parameter:

- $V_{in} = 85 - 265\,V$
- $V_{out} = 400\,V$
- $P_{out} = 2 - 5\,kW$
- $F_{line} = 50\,Hz$
- $f_{sw} = 40\,kHz$
- $I_{ripple} = 0.3$
- $V_{ripple} = 0.01$

We have calculated the value of inductor and capacitor with the help of following formulas:

$$I_L = \frac{2500}{0.95 \times 85} = 30.96A$$

$$I_{peak} = \sqrt{2} \times 30.96 = 43.78A$$

$$L = \frac{V_{out}}{4 \times f_{sw} \times I_{ripple}} = \frac{400}{4 \times 40 \times 10^3 \times 0.3} = 190.3\,\mu H$$

$$C_{out} = \frac{P_{out}}{V_{out} \times 4 \times F_{line} \times V_{ripple}} = \frac{2500}{400 \times 4 \times 50 \times 0.01} = 2486.7\,\mu F$$

The output characterstic obtained is as follows:

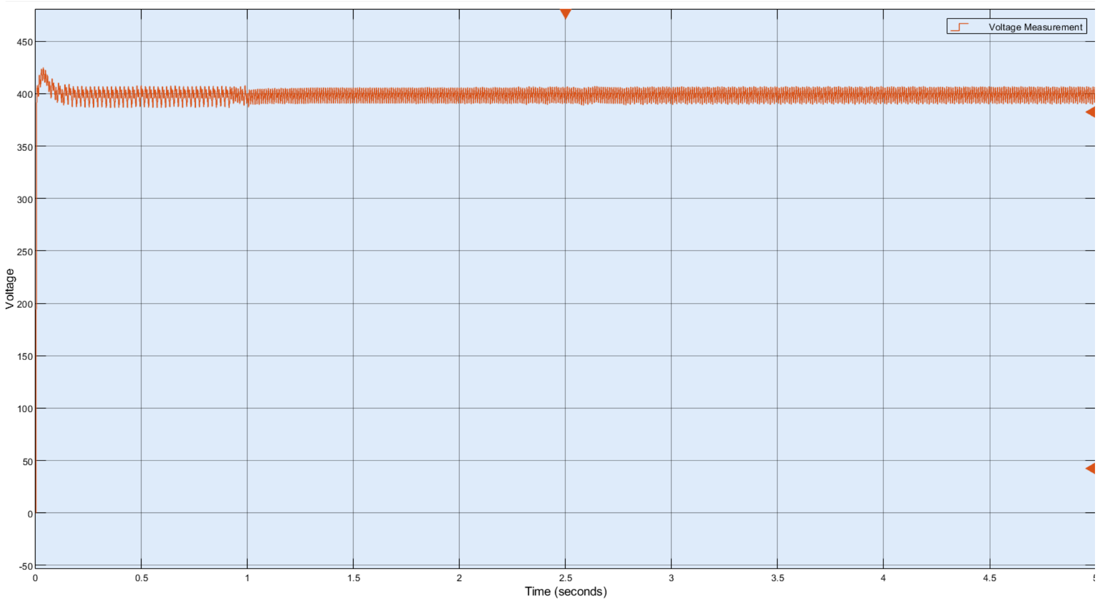


Figure 4.1: voltage output of totem pole pfc

We did obtain a 400V output but the ripple we obtained was excessive.So the control mechanism of this phase has to be re adjusted to obtain desired ripple.For this purpose we need to design a filter circuit, in the practical on board charging system there are use of input filters such as EMI filters but for our purpose we will be loooking at a LC filter which will be included after integration of both the circuit as the ripple increases considerably after the integration of both the circuit.

One of the main reasons for using totem pole pfc circuit was to make the current follow the voltage which can be seen as in the figure below:

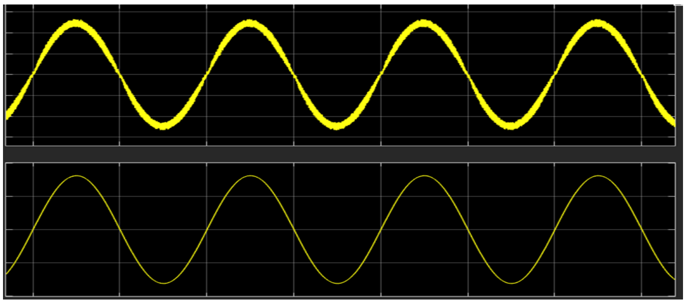


Figure 4.2: Voltage and current input relation for totem pole

The figure above shows current and voltage relation in the input of totem pole pfc. The first graph is the I(current) vs t(time) graph and the second one is V(voltage) vs t graph and we can see the that the first graph follows the suit of the second graph closely. If we look at the same graph in traditional rectifier circuit with capacitor we can see following graph:

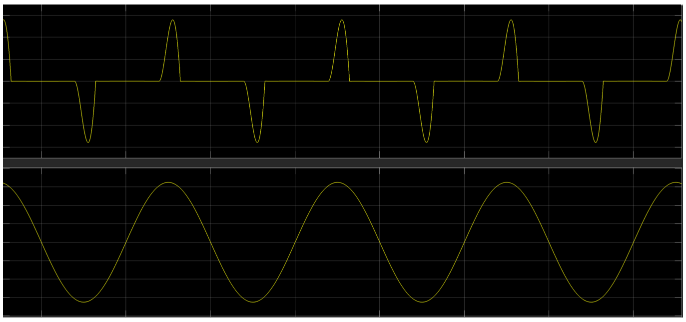


Figure 4.3: Voltage and current input relation for traditional rectifier circuit with capacitor

Here we can see the current is seen in the portions only when the capacitor is charged and the current waveform does not follow the voltage waveform which is not desired for any on board charging circuits.

4.2. DC/DC phase

In this section, we have used the manual phase shift to calculate this; we have:

For DC/DC phase, we have used DAB converters. Main equation:

$$P_o = \frac{1}{X_l} V_i^2 d\phi \left(1 - \frac{\phi}{\pi}\right)$$

Given constants:

- $P_o = 2500$
- $V_i = 400$
- $L = 0.3\mu H$
- $d = \frac{V_o}{nV_i}$
- $n = 1:2$

Calculations:

$$d = \frac{2 \times 200}{400} = 1$$

$$2500 = \frac{400^2}{2\pi \times f \times 0.3 \times 10^{-6}} \phi \left(1 - \frac{\phi}{\pi}\right)$$

$$f = 500 \text{ kHz} = 500 \times 10^3$$

$$2500 = 169765.2726\,\phi(1-\phi)$$

$$0.0463 = \pi\phi - \phi^2$$

$$\phi^2 - \pi\phi + 0.0463 = 0$$

$$\phi = \frac{3.1831 \pm \sqrt{0.1148}}{1.9933}$$

$$\phi = 0.85$$

Implementing the above circuit we obtained following voltage level:

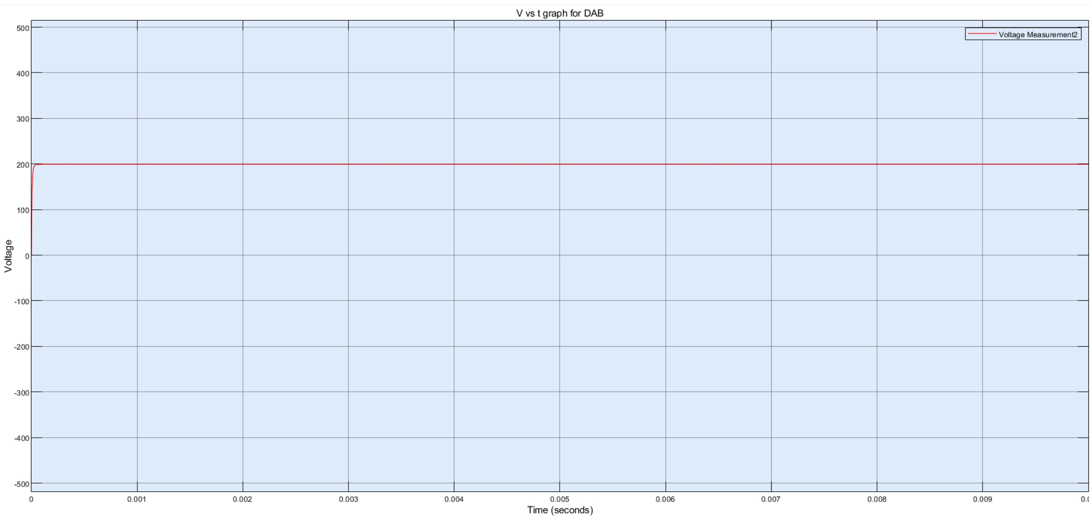


Figure 4.4: voltage output of dab converter

Now we move towards a DAB circuit with automatic phase shift provided.For this, we have the following type of control:

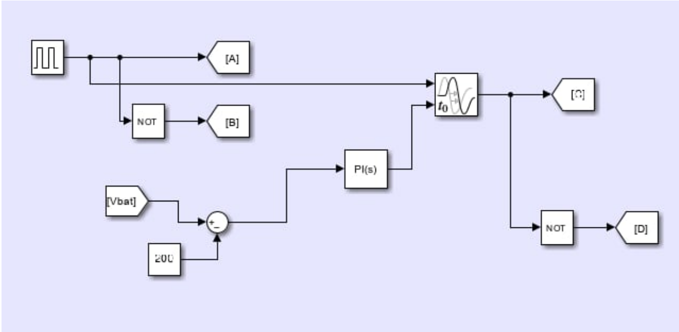


Figure 4.5: Closed loop DAB control

Output from DAB circuit with the above control is:

4.3. Integration of DAB and Totem Pole circuit with manual phase shift:

Now we integrate our two circuits, that is, DAB converters and Totem pole PFC.The first problem we notice is that the output voltage level from the totem pole circuit has reduced significantly and is becoming more unstable as time progresses. The output from the DAB converter also follows suit.

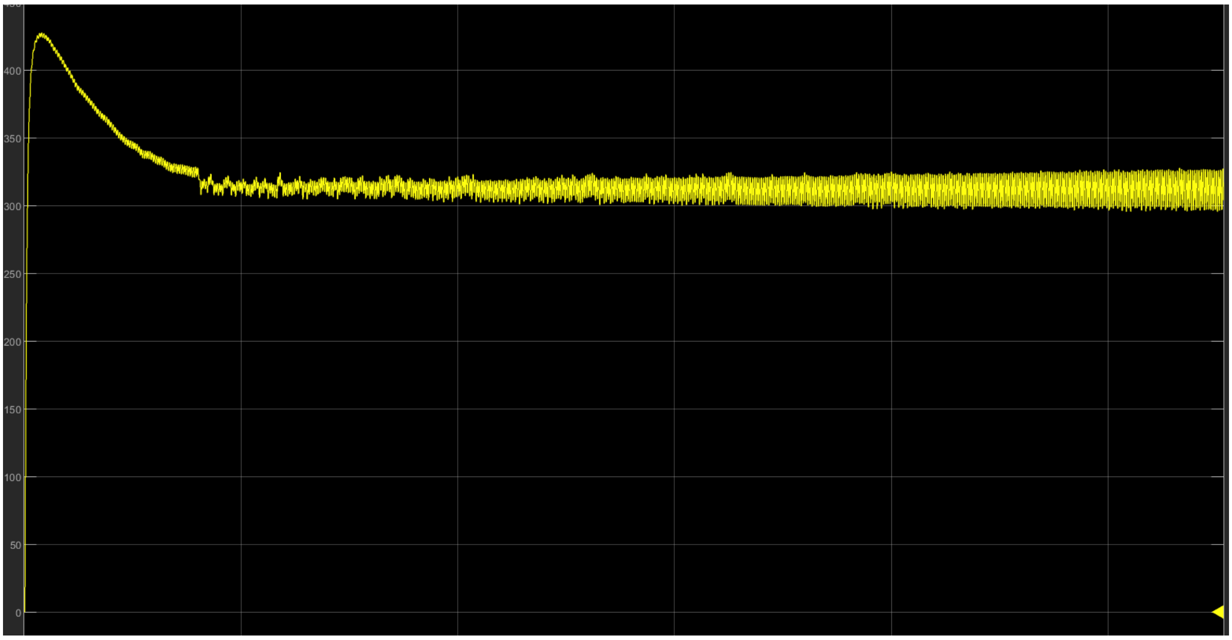


Figure 4.6: Integrated output from totem pole PFC

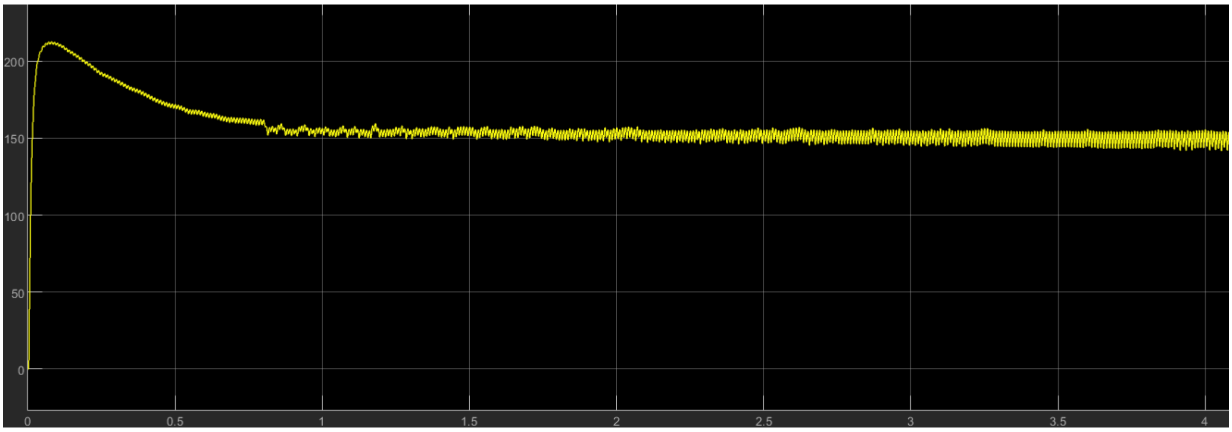


Figure 4.7: Integrated output from dab circuit

The obvious problem that could produce this decrease in voltage level we noticed was the mismatch of the switching frequency in the two circuits. The totem pole PFC circuit was designed to operate at the switching frequency of 40 kHz while the DAB circuit was initially designed to be operated at 500 kHz , so this was fixed and the DAB circuit was brought down to the switching frequency of 40 kHz and the output voltage level was checked.
The voltage level has somewhat returned to the normal level, but the ripple content is again very high.The output of the DAB converter also follows the input to it.

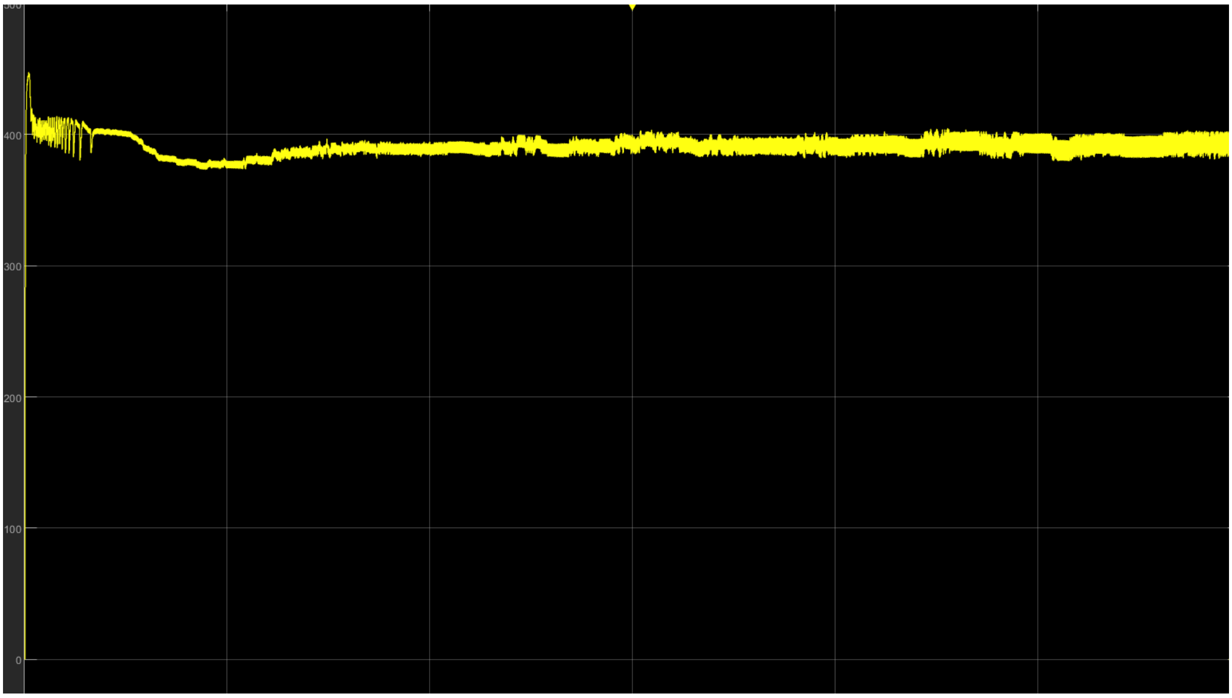


Figure 4.8: Totem pole pfc circuit at switching frequency 40khz

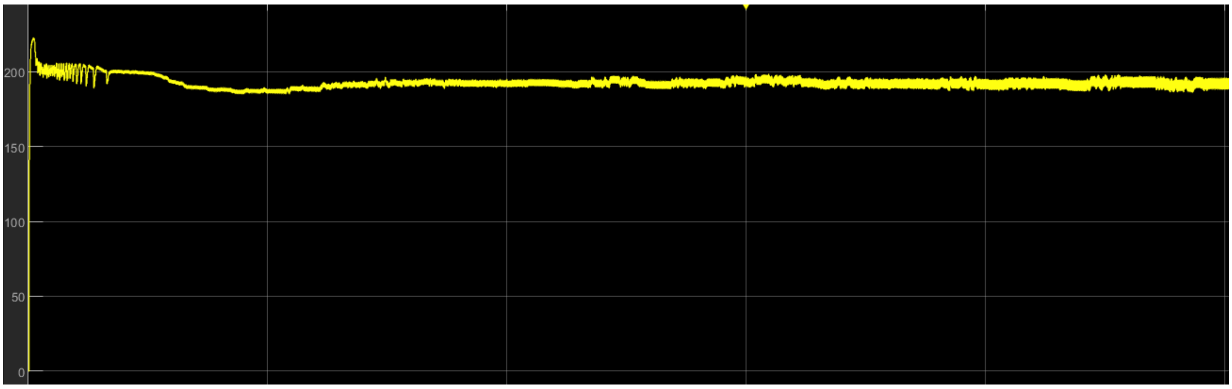


Figure 4.9: dab output at 40khz switching frequency

Though a high switching frequency dab converter is preferred but we also need to maintain a good voltage level at the output side, so we look at the various switching frequencies and choose one that gives best voltage level . We checked this phenomenon by adjusting the dab circuit switching frequency at various values such as 20 kHz , 80 kHz , 30 kHz, 100 kHz and obtained the following outputs: **At DAB switching frequency=20 kHz:**

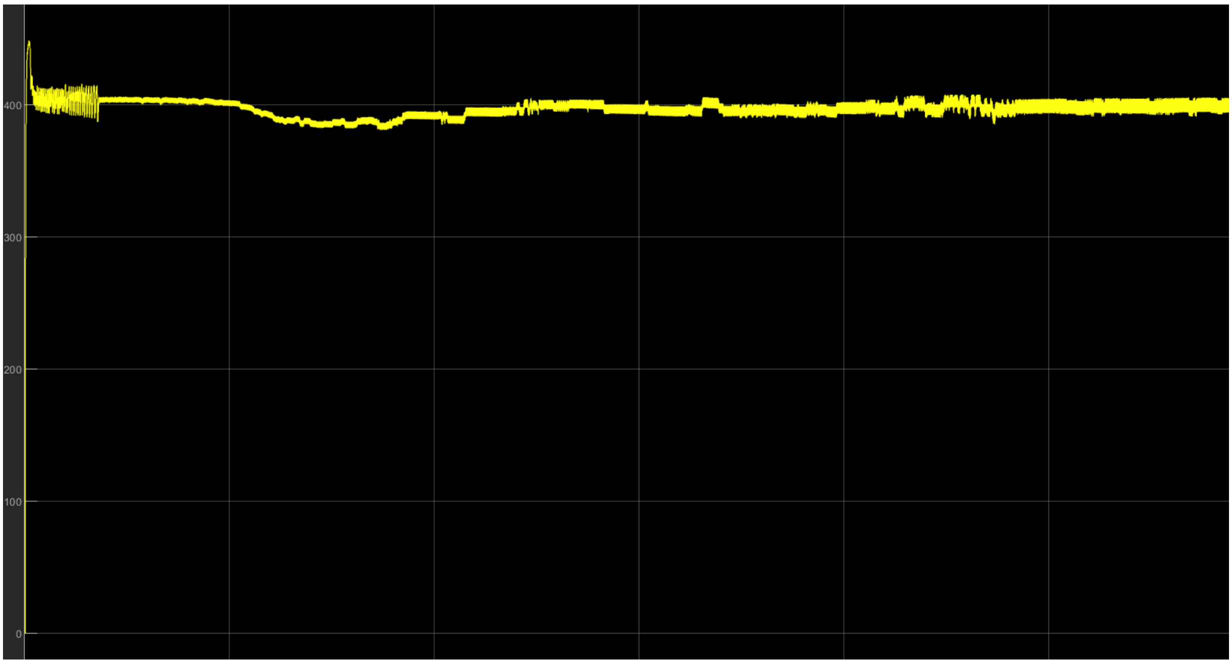


Figure 4.10: totem pole output for dab 20khz switching freq

The voltage level is very stable though the output still contains a lot of ripple.

At DAB switching frequency=30 kHz:

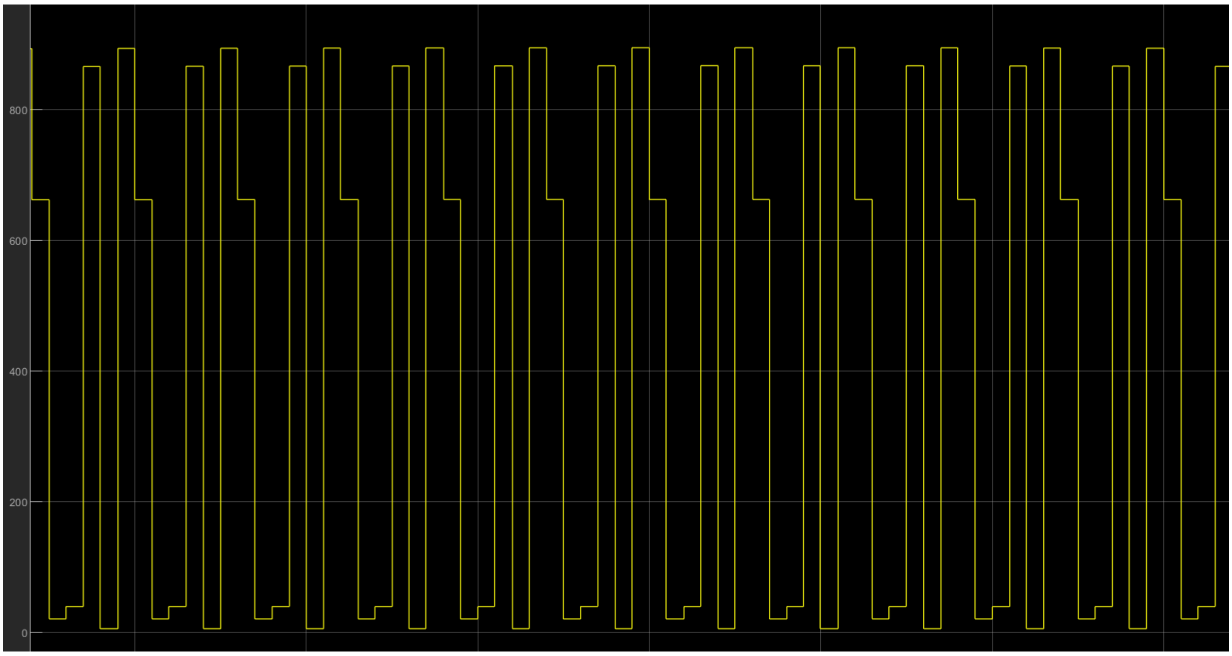


Figure 4.11: totem pole output for dab 30khz switching freq

The voltage level is very unstable and unusual at 30 kHz switching frequency.

At DAB switching frequency=80 kHz:

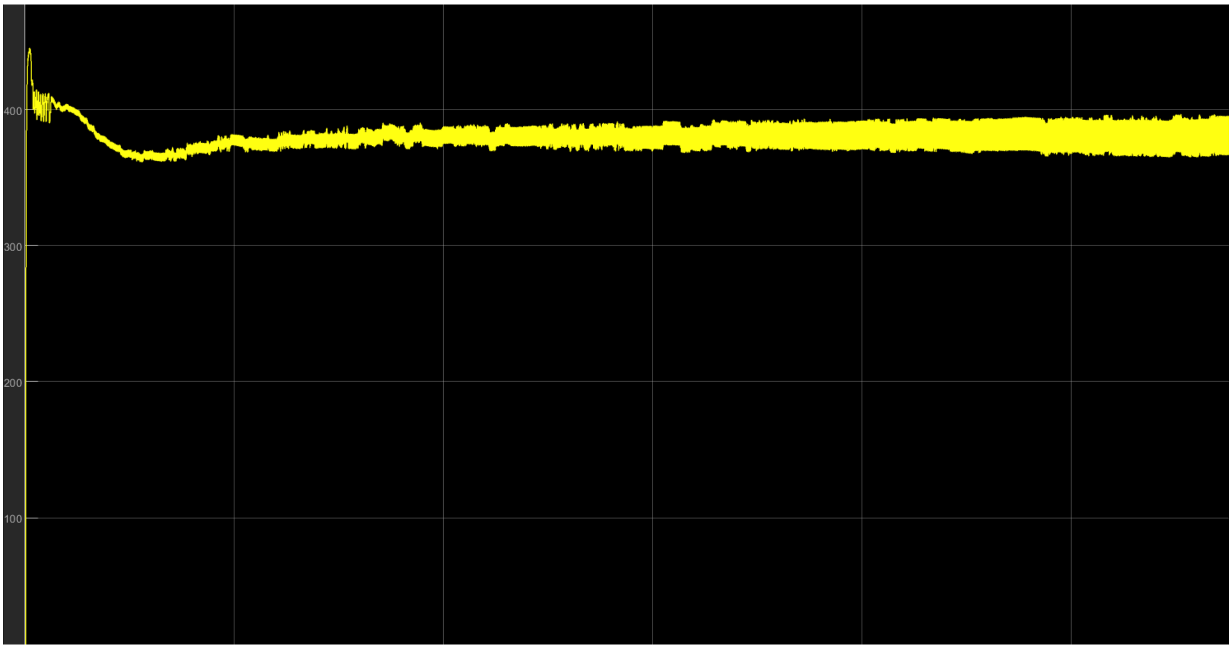


Figure 4.12: totem pole output for dab 80khz switching freq

Though the voltage level is not as stable and up to the level as in the case of 20 kHz, it is still better than the 30 kHz one.

At DAB switching frequency=100 kHz:

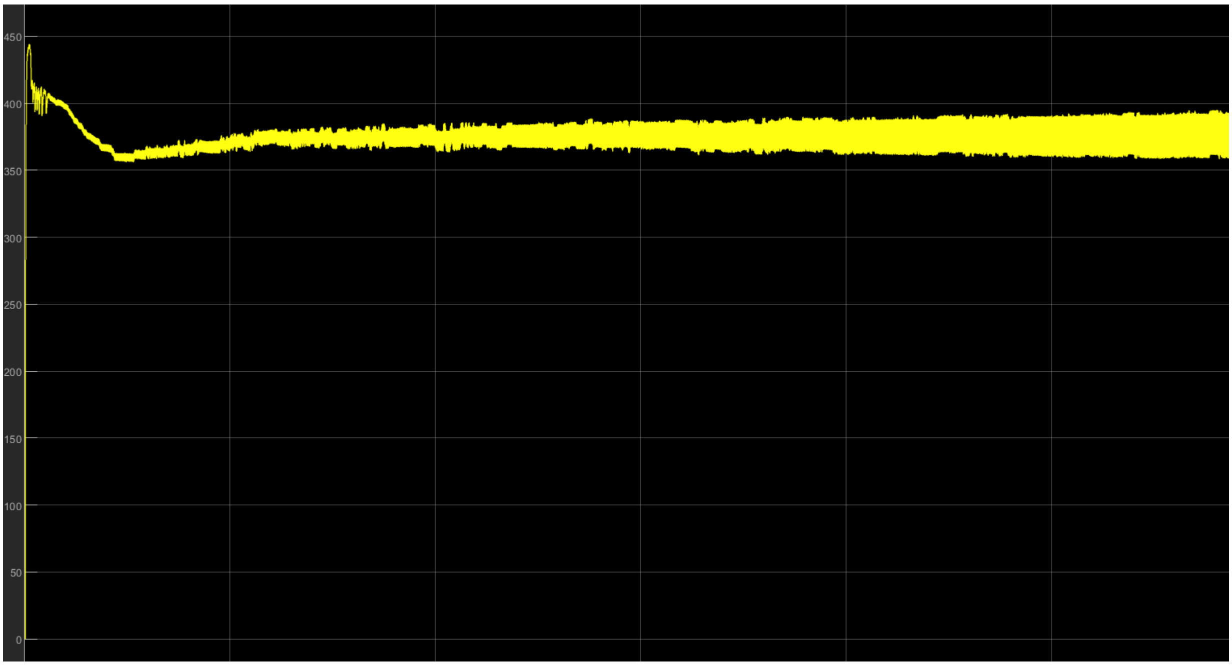


Figure 4.13: totem pole output for dab 100khz switching freq

Though the voltage level is not as unstable as in the case of 30 kHz, we can see a trend of decreasing voltage level as the switching frequency of the dab circuit increases. So at the end, we can choose the dab circuit of **20 kHz** switching frequency to obtain the appropriate voltage level. Now that we have chosen an appropriate switching frequency, now we have to redesign the LC filter as the ripple content is still present in the output value.

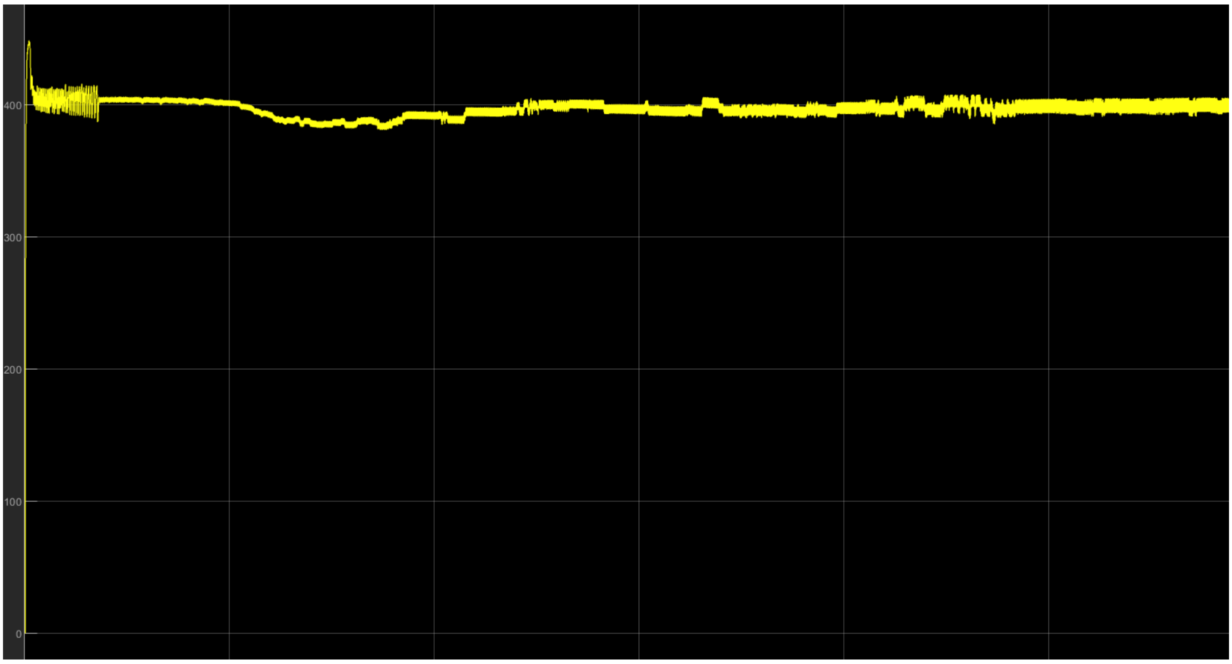


Figure 4.14: totem pole output for dab 20khz switching freq

Designing the LC filter iteratively using Matlab simulation and also designing the overall totem pole circuit for 405V we get:

$$L = \frac{V_{out}}{4 \times f_{sw} \times I_{ripple} \times I_{peak}} = \frac{405}{4 \times 40 \times 10^3 \times 0.3 \times 43.78} = 193\,\mu H$$

Iteratively, L=500mH C=2.3mF

And for values of LC circuit:

From iterative solution:

L=550mH

C=2.3mF

The output we received is as:

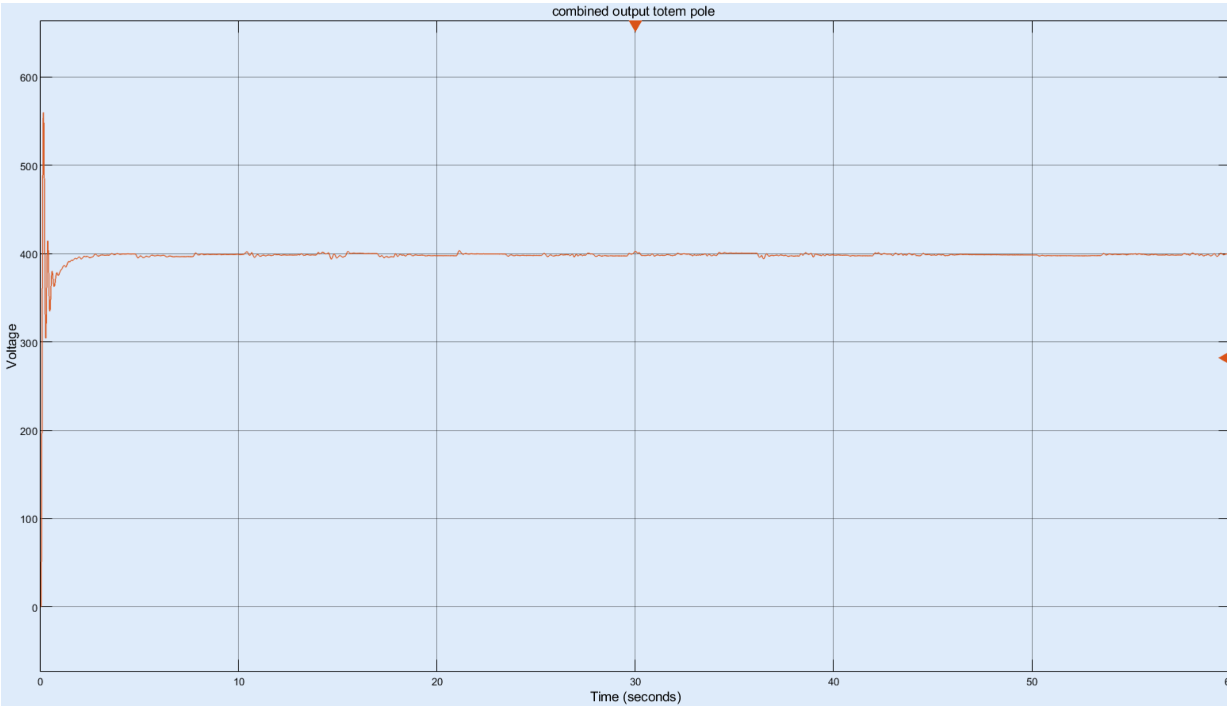


Figure 4.15: Totem Pole final output

The output from DAB is:

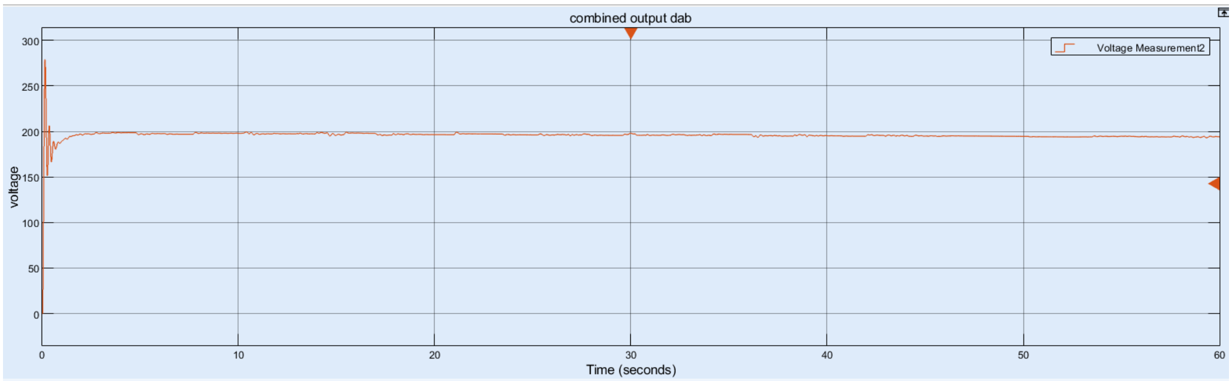


Figure 4.16: DAB output final

The final output voltage at the end of simulation is about 194 V and current value is 12.1A. So the power value is:

P=V*I=2.35kW

Efficiency=2.35/2.5 *100=94

For the final redesign, we use the following parameters:

	AC/AC phase
fs	40kHz
L	500mH
C	2.3mf
	Filter
L	550mH
C	2.3mf
	Link Capacitor
C	25mf
	DAB
fs	20KHz
L	0.03 e-6h

Table 4.1: Final system parameter

After the final parameter, the design output at dab is as:

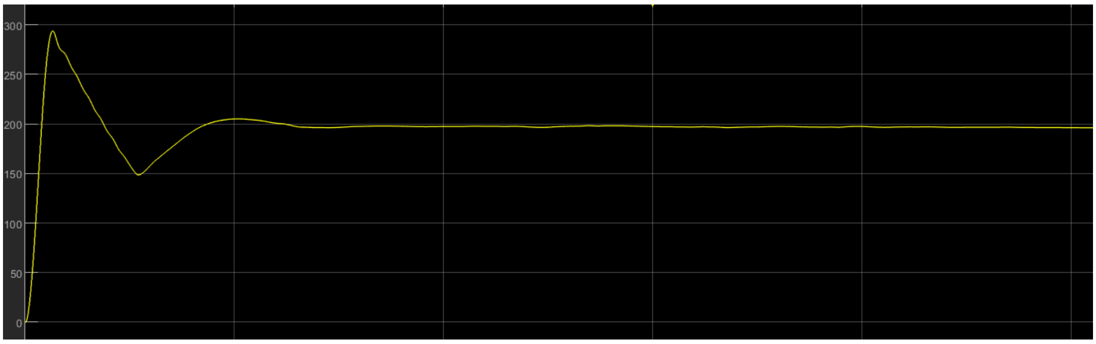


Figure 4.17: Final output for dab totem pole circuit

Hence we obtain a stable dc output stagnating at around 196V for our simulation time with an efficiency of 96 percent.

Output at the end of totem pole is:

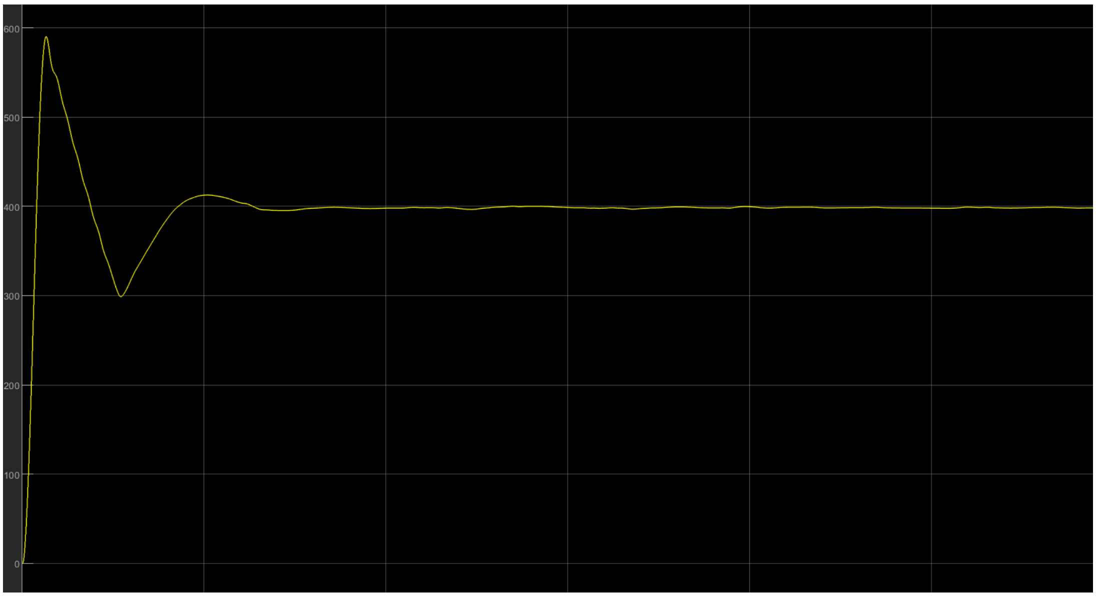


Figure 4.18: Output at totem pole final

4.4. Integration of DAB and Totem pole circuit with phase from the difference between output voltage and constant value:

We have obtained following output with this type of circuit, one of the advantage of using this is that the voltage level does not drop even at the higher simulation as it did in the open loop model and voltage is maintained constant at value around 201 Volts. This model was also found be compatible with higher switching frequencies and had flexible switching option.

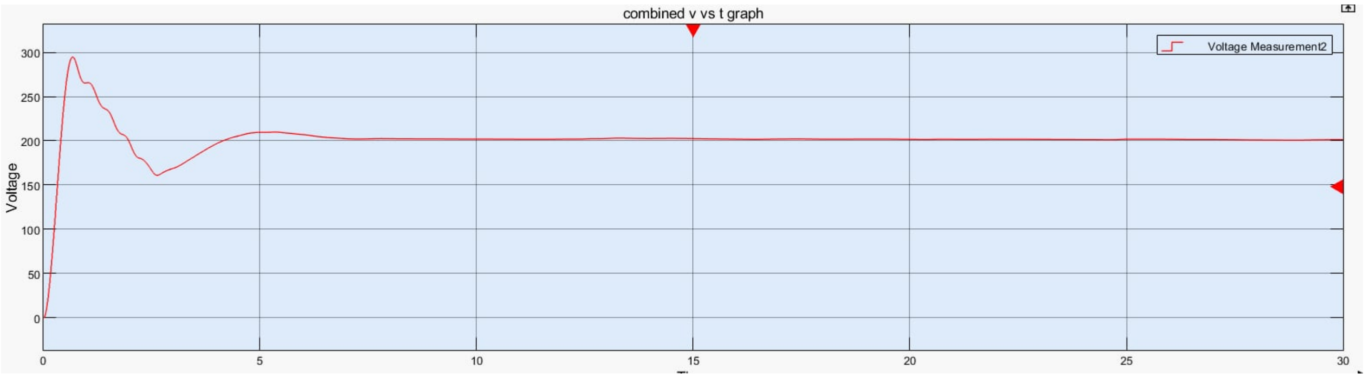


Figure 4.19: Final model output at dab side

4.5. Possible sources of mistake:

Even though we have been careful while designing the circuit its possible that we have missed different sources of mistakes which might exist in the circuit. So following are possible sources of mistakes:

- **Incorrect phase shift:**Providing correct phase shift becomes critical in the DAB converters as if the provided phase shift is small the power that is supplied decreases and if it is too large there can exist excessive current flow which might result in high conduction losses.
- **Incorrect switching frequencies:**Choosing correct switching frequencies is also essential in these type of circuits as the incorrect switching frequencies may result in voltage instability, incorrect core sizes and efficiency issues.Though in our project we have primarily used a 20 KHZ switching frequency to maintain a appropriate voltage level, this might not be the case in all the designs as the switching frequency we choose also depends upon the sophistication of the control mechanism as well.
- **Incorrect selection of parameters:**Though calculation of parameters holds for individual circuit design, while integrating different circuits its necessary to reevaluate different circuit parameters based on the output received and in course of reevaluation there is possibility of incorrect parameter selection which may also result in the incorrect performance of the system.

CHAPTER 5

5. CONCLUSION

In this study, the design and implementation of an on-board charging system utilizing Totem-Pole Power Factor Correction (PFC) and Dual Active Bridge (DAB) DC-DC conversion were investigated, with a focus on efficiency. The use of Totem-Pole PFC allowed for high power factor operation, meanwhile, the DAB converter facilitated for efficient DC/DC conversion phase.

Simulation and experimental results indicated that Totem-Pole PFC reduced total harmonic distortion (THD) while maintaining a high power factor close to unity, improving grid interaction. The system achieved stable voltage regulation making it well-suited for modern EV charging applications.

However, challenges were regarding advance control of circuit under various conditions and the hardware implementation. Future research should focus on advanced digital control strategies to optimize phase-shift modulation in DAB,and test the current findings in a hardware prototype. Additionally, further research should also be based on single stage onboard charging system integration advantages of both pole pfc circuit and dab circuit in a signle stage circuit.

These findings highlight the importance of Totem-Pole PFC and DAB integration in developing next-generation EV on-board chargers that support both fast charging and V2G applications while ensuring grid stability, high efficiency, and sustainability.

References

[1] M. S. Khan, S. Sathyan, H. Sugali, and S. S. Chandra Bommagani, “Design of on-board battery charger using interleaved bridgeless type pfc and phase shifted full bridge converter,” in *2020 IEEE International Students’ Conference on Electrical,Electronics and Computer Science (SCEECS)*, 2020, pp. 1–5.

[2] A. K. Singh, A. K. Mishra, K. K. Gupta, and T. Kim, “Comprehensive review of nonisolated bridgeless power factor converter topologies,” *IET Circuits, Devices Amp; Systems*, vol. 15, pp. 197–208, 2021.

[3] E. Network, “A comparison of interleaved boost and totem-pole pfc topologies,” *EDN*, 2025. [Online]. Available: https://www.edn.com/a-comparison-of-interleaved-boost-and-totem-pole-pfc-topologies/?fbclid=IwY2xjawImIaVleHRuA2FlbQIxMAABHSUxXUnO5GSOGUTTPXGTOQRbuDPqmWQ3InHB4ffOxnnCKl aem_a1Emh_dB2O8x7FLmjHiWZg

[4] B. Zhao, Q. Song, W. Liu, and Y. Sun, “Overview of dual-active-bridge isolated bidirectional dc–dc converter for high-frequency-link power-conversion system,” *IEEE Transactions on Power Electronics*, vol. 29, no. 8, pp. 4091–4106, 2014.

[5] B. Kumar, A. Kumar, A. Bhat, and P. Agarwal, “Comparative study of dual active bridge isolated dc to dc converter with single phase shift and dual phase shift control techniques,” in *2017 Recent Developments in Control, Automation and Power Engineering, RDCAPE 2017*, ser. 2017 Recent Developments in Control, Automation and Power Engineering, RDCAPE 2017. United States: Institute of Electrical and Electronics Engineers Inc., May 2018, pp. 453–458, publisher Copyright: © 2017 IEEE.; 2017 Recent Developments in Control, Automation and Power Engineering, RDCAPE 2017 ; Conference date: 26-10-2017 Through 27-10-2017.

[6] W. Qiufeng, X. Yong, and Z. Xiangwen, “Research and design of control strategy for on-board charging system in electric vehicle,” in *2017 29th Chinese Control And Decision Conference (CCDC)*, 2017, pp. 6901–6905.

[7] E. Firmansyah, S. Tomioka, S. Abe, M. Shoyama, and T. Ninomiya, “An interleaved totem-pole power factor correction converter,” in *Proceedings of the 15th International Power Electronics and Motion Control Conference (EPE-PEMC)*, 2010, pp. 1298–1303.

APPENDIX

A. SIMULINK MODELS

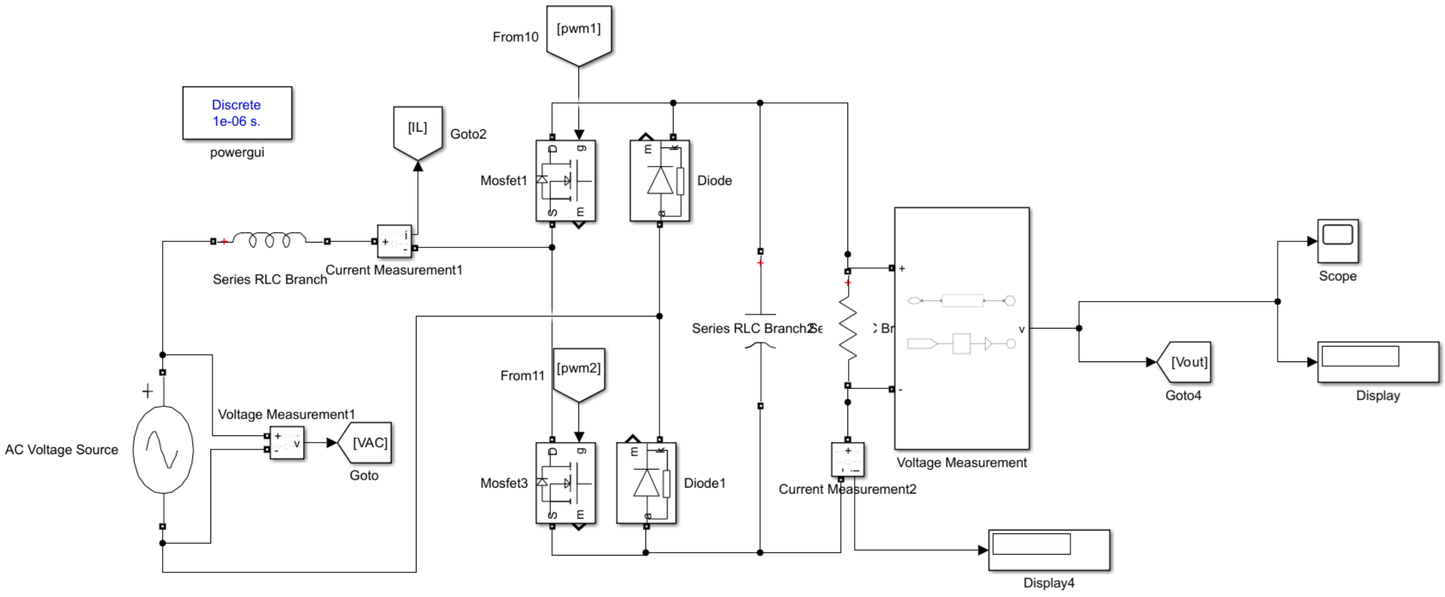


Figure A.1: Totem Pole PFC

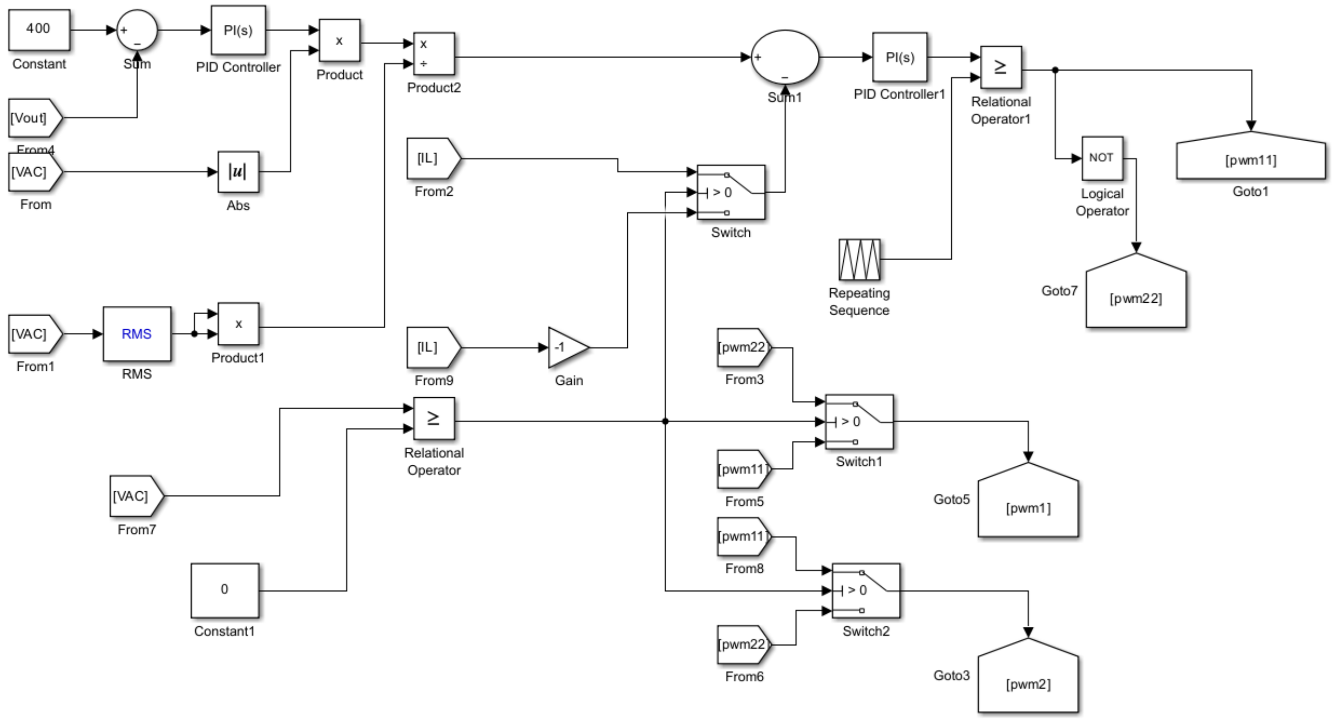


Figure A.2: Closed Loop Control of Totem Pole PFC

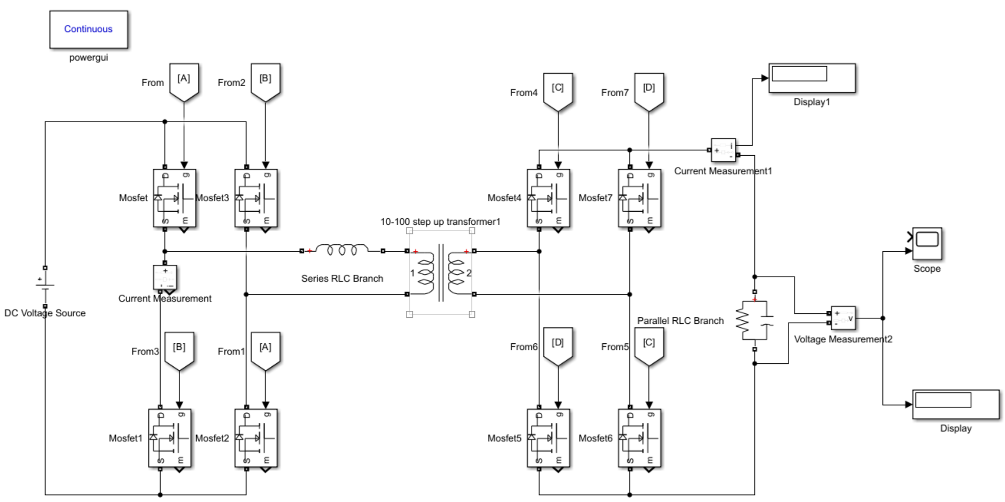


Figure A.3: DAB Converter Circuit

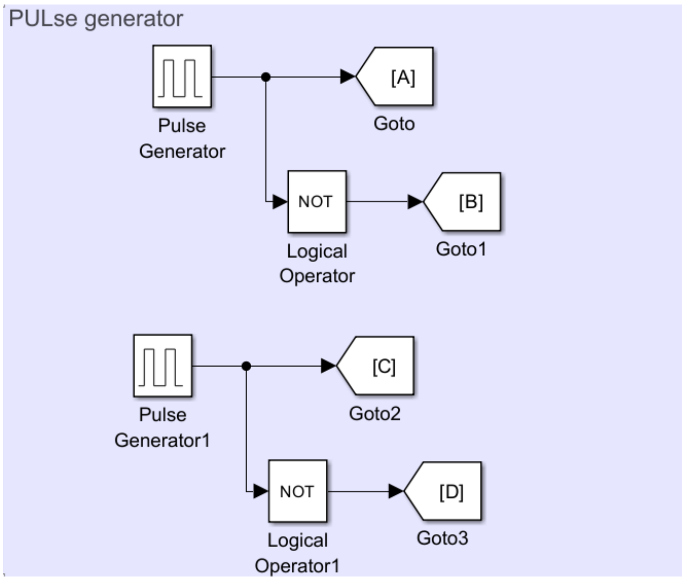


Figure A.4: Pulse Generator