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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TABLE OF CONTENTS

List of Figures

LIST OF ABBREVIATIONS

EV	Electric Vehicle
DAB	Dual Active Bridge
ZVS	Zero Voltage Switching
FPGA	Field Programmable Gate Array
IGBT	Insulated-Gate Bipolar Transistor
DSP	Digital Signal Processor
PFC	Power Factor Correction
EVSE	Electric Vehicle Supply Equipment

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:

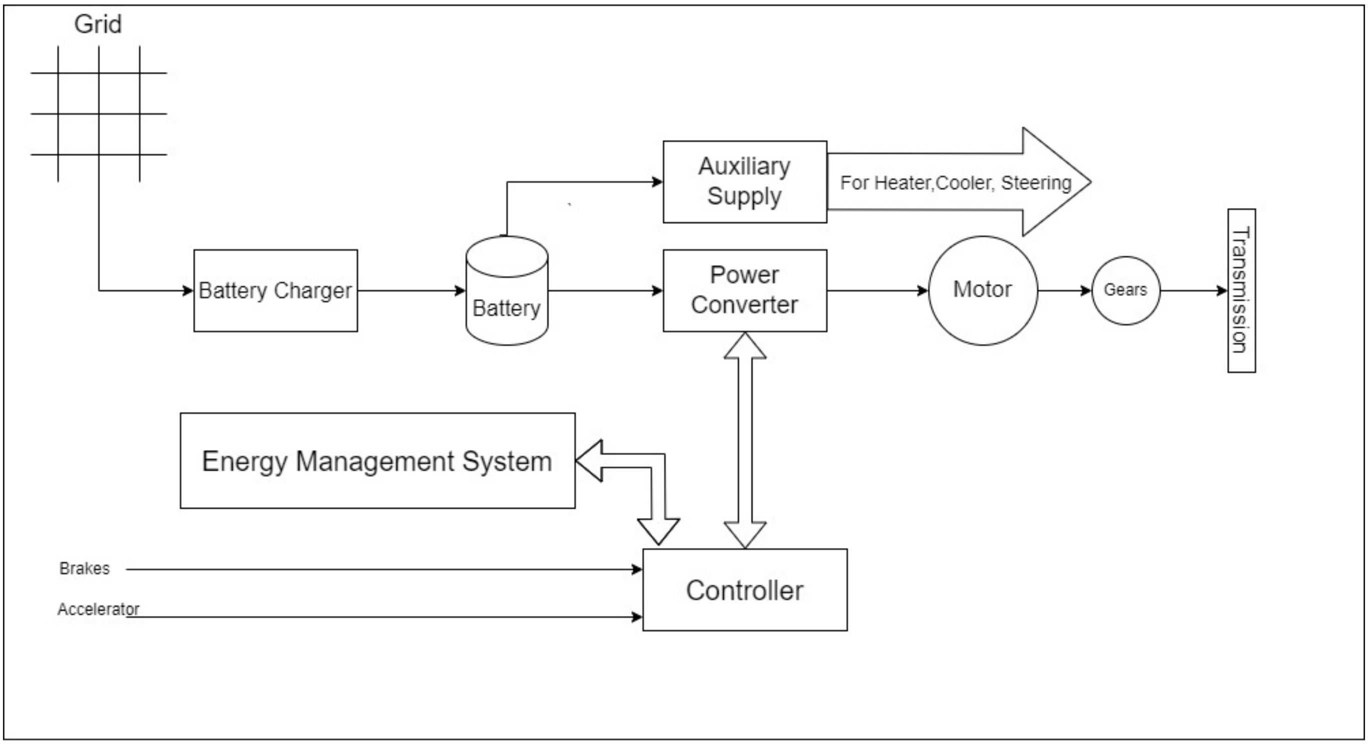


Figure 1.1: Basic Block Diagram of EV

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

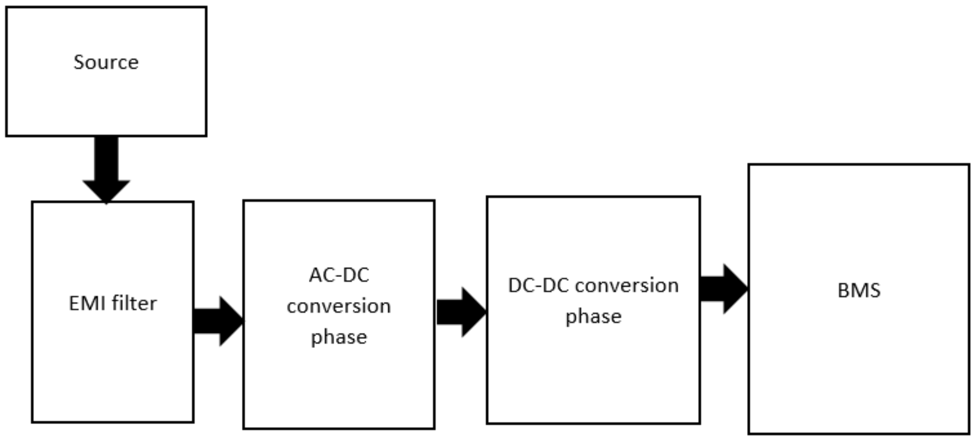


Figure 1.2: general block diagram for on board chargers

CHAPTER 2

2. LITERATURE REVIEW

2.1. Introduction

Different research such as [1] has shown over the years that Dual Active Bridge Converters are the best available topology for DC-DC converters.However, author in [2] suggest that the main disadvantage associated with the traditional DAB is that its switching ZVS range is limited. To solve this problem the author suggest a series resonant boost converter which is similar to DAB converters except for additional resonant capacitors.However there is still a problem in this type of circuit as there is still high turn off loss of rectifier bridge. To overcome this problem the author in paper [3] suggest a modified DAB converter with two active bridge separated by high frequency transformer connection of auxiliary inductors connected to 4 quadrant switches. Also two IGBTS with an anti parallel diode connected in anti series implementing the 4 quadrant switches. Paper [2] suggests use of FPGA for design and implementation in digital control.

In the paper[4], the authors introduce a modified phase shift control algorithm with a variable duty cycle to enhance the efficiency of the bidirectional onboard EV chargers.The paper provides a detailed mathematical model using state space averaging techniques to analyze the steady-state voltage and current dynamics of the converter. This helps in understanding the interdependencies between the phase shift ratio and power transfer limits. The DAB topology with a high-frequency isolating transformer is used which is critical for the bidirectional power flow. The variable duty cycle in the phase shift control of the DAB allows for efficient power transfer while minimizing losses. This approach ensures that the power drawn from or supplied to the grid is smooth and stable.Also, it introduces a direct power control (DPC) algorithm with a cost-optimizing function to generate the switching pulses for the front-end converter. This ensures fast and accurate control during the transition between charging and discharging modes.The authors validate the system through MATLAB/SIMULINK which results the variable duty cycle approach leads to improved efficiency and power quality, demonstrating reduced total harmonic distortion(THD) and better voltage regulation across grid.

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:

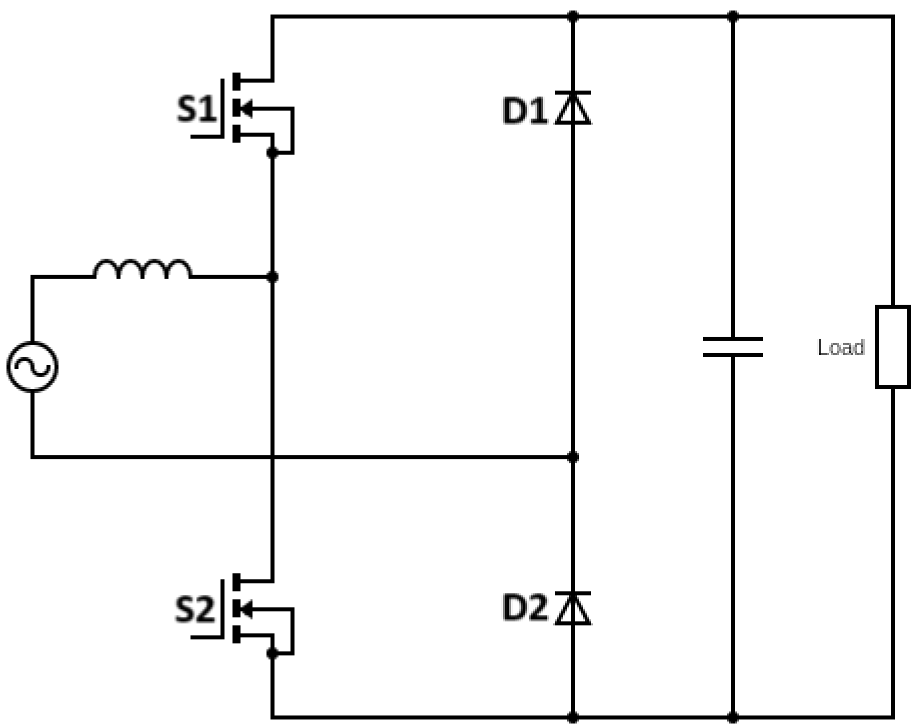
  1. Passive PFC:

     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.

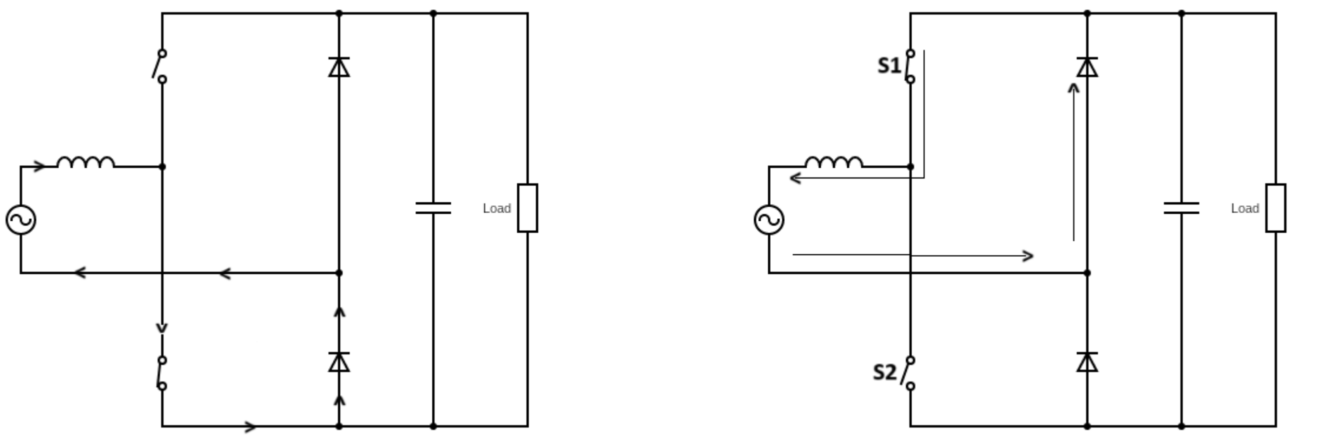
- **Totem Pole Power Factor Correction:**



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

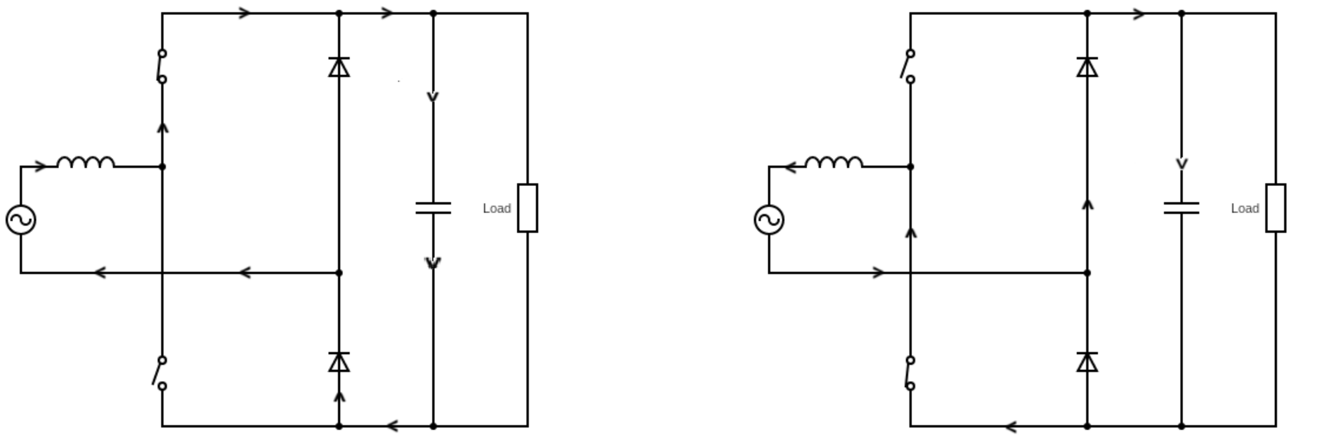
1. **Zero State:** In this state, the inductor is charged by the AC supply and the load is charged through the capacitor. During the positive half state, switch S2 is turned on for duty cycle D and during the negative half cycle, the switch S1 is turned on for duty cycle D.



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

- **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.

    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.

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.

Secondary 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:

- **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.

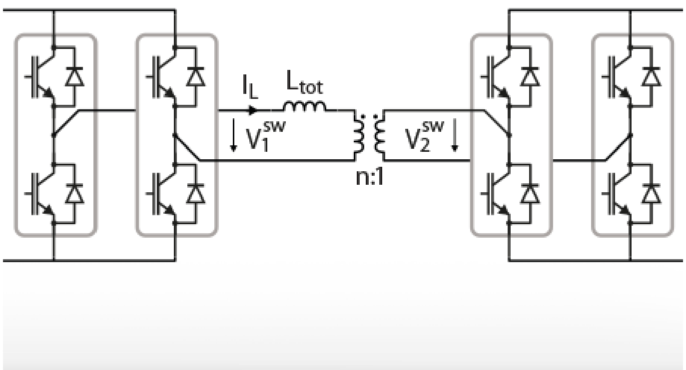


Figure 2.3: DAB Converter Circuit

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.

Field Programmable Gate Arrays (FPGAs), which are a type of integrated circuit, possess the unique capability of being reconfigured after the manufacturing process to perform specific tasks. This adaptability and resilience are derived from their ability to execute customized hardware functions. FPGA coprocessors, also known as hardware IP blocks, can seamlessly integrate into a processor-based system to manage tasks that require substantial computational power. This smooth integration is facilitated by standardized hardware interfaces, design automation tools for system assembly, and a standardized software API, collectively shaping the concept of FPGA coprocessors.

3. METHODOLOGY

3.1. System Block Diagram

Basic block diagram of the whole system is as shown below:

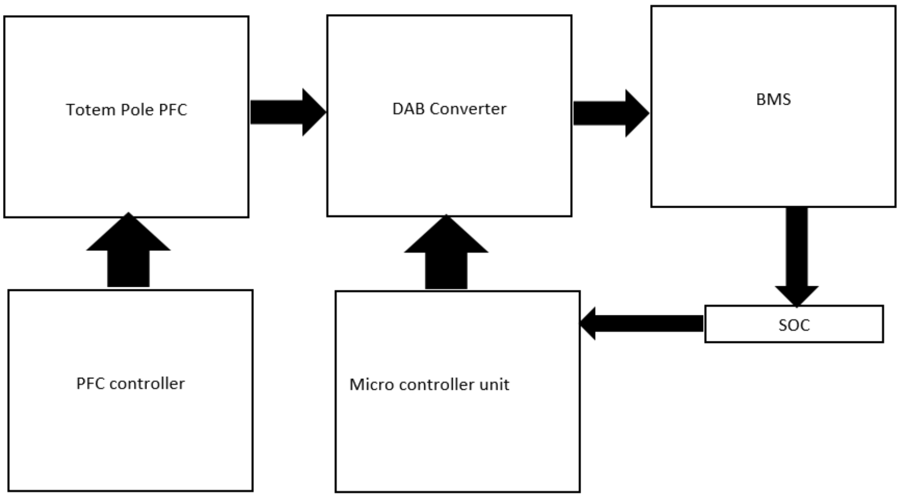


Figure 3.1: Basic block diagram of the system

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.

3.3. For DAB converters:

Figure above represents a proposed block diagram of control of Dual Active Bridge . As shown in the figure DAB consists of two Bridge Primary and Secondary connected with the help of High frequency transformer.Current and voltage are sensed with the help of sensors and data is sent to fpga control system. Now the current and voltage error are calculated and error signals are sent to PI controller. PI control is done within the FPGA itself and a phase shift control signal is generated which is used to generate a Pulse Width modulation signal which is now sent to DAB converter.

3.4. Components

3.4.1. 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:

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

3.4.2. Phase Shift Control:

Phase Shift Control is 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 method such as:

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

3.4.3. 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:

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

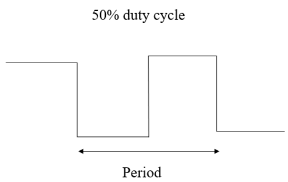


Figure 3.2: Duty Cycle illustration

CHAPTER 4

4. RESULTS AND DISCUSSION

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:

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.

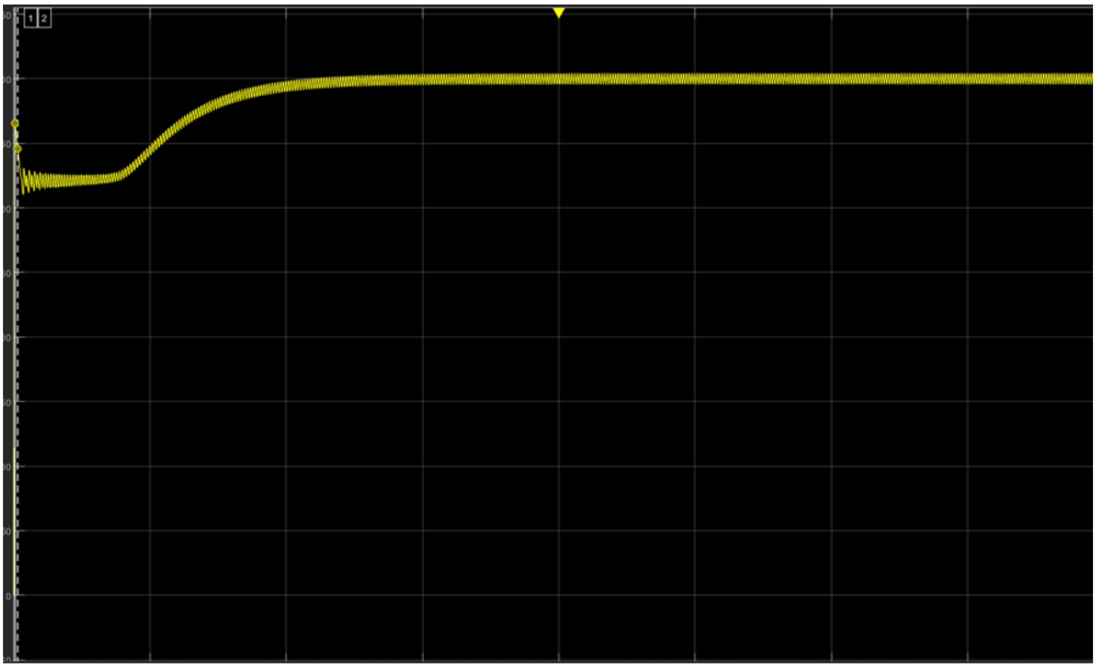


Figure 4.1: voltage output of totem pole pfc

4.2. DC/DC phase

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

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

Given constants:

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

Calculations:

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

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

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

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

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

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

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

$$\phi = 0.85$$

Implementing the above circuit we obtained following voltage level:

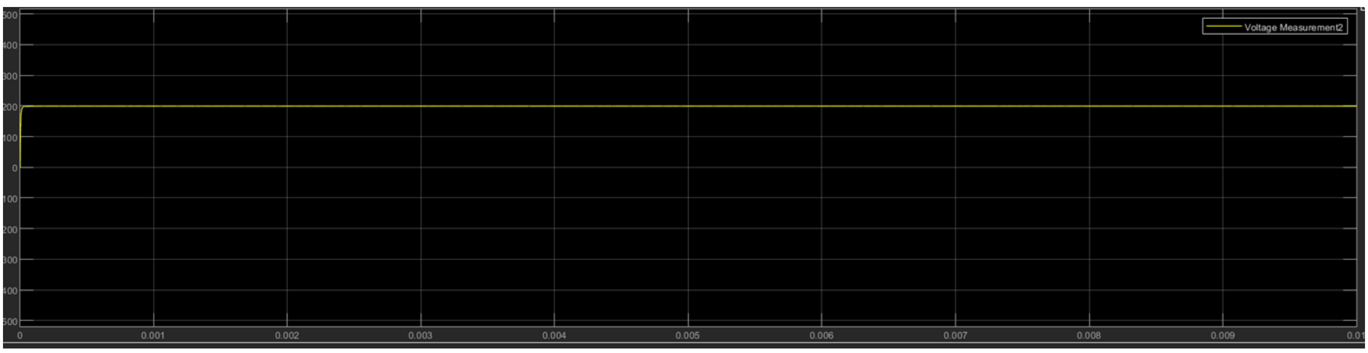


Figure 4.2: voltage output of dab converter

CHAPTER 5

5. CONCLUSION

Till now we have made decent progress in the project. We have completed basic simualtion and control,though a significant portion of the work is still left we are sure to complete our time targets.

5.1. Work completed:

- Literature review
- Basic system design
- Totem Pole PFC and DAB circuit implementation

5.2. Work left:

- PFC and DAB optimization
- Control mechanism creation and optimization
- FPGA implementation and system integration

References

[1] 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.

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A. SIMULINK MODELS

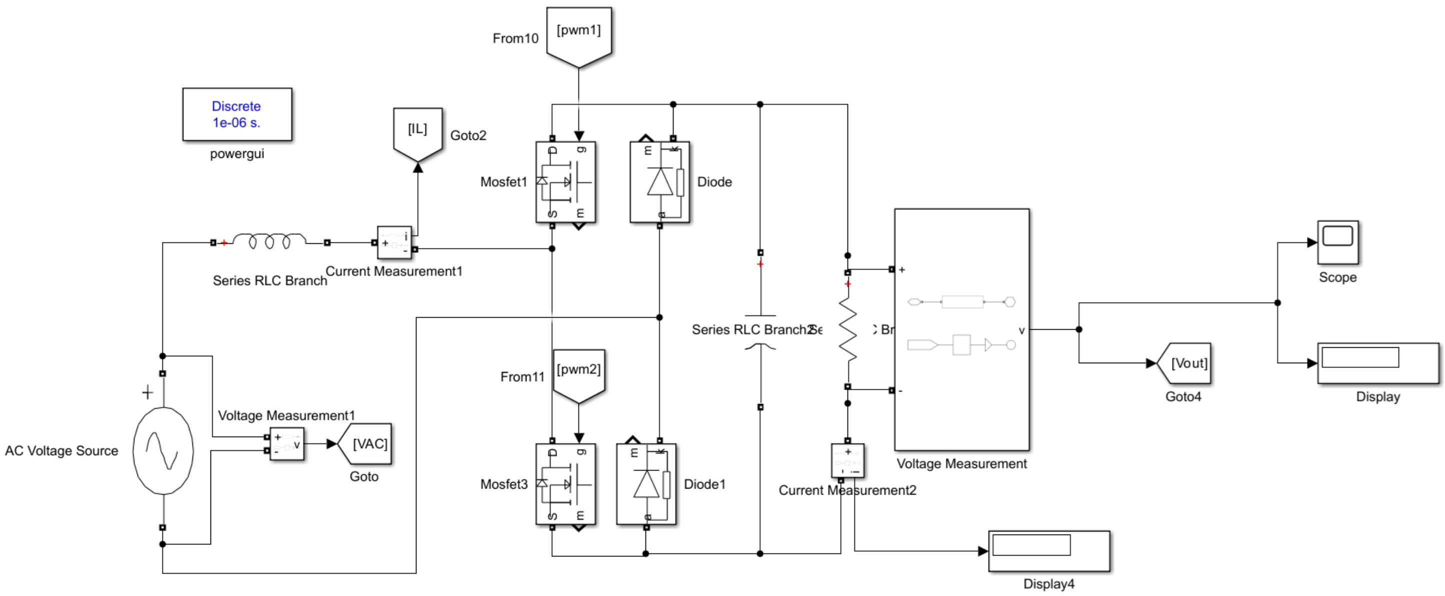

Figure A.1: Totem Pole PFC

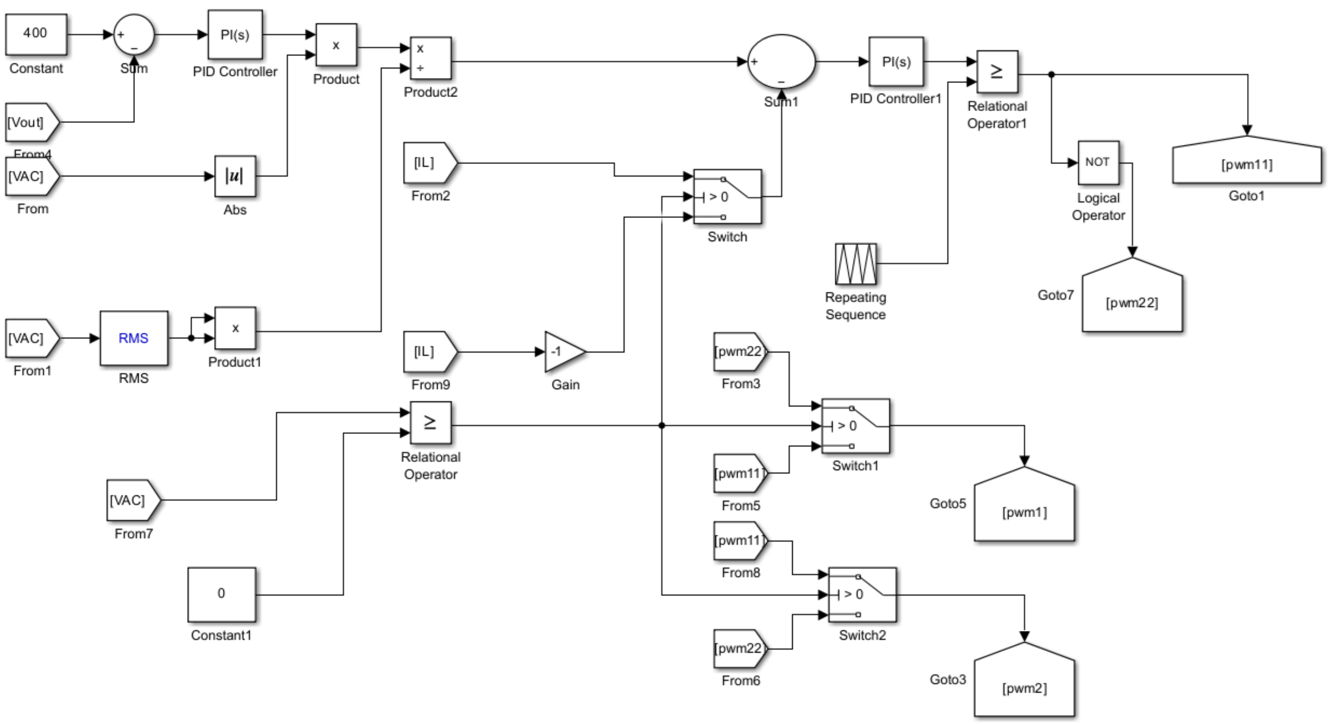

Figure A.2: Closed Loop Control of Totem Pole PFC

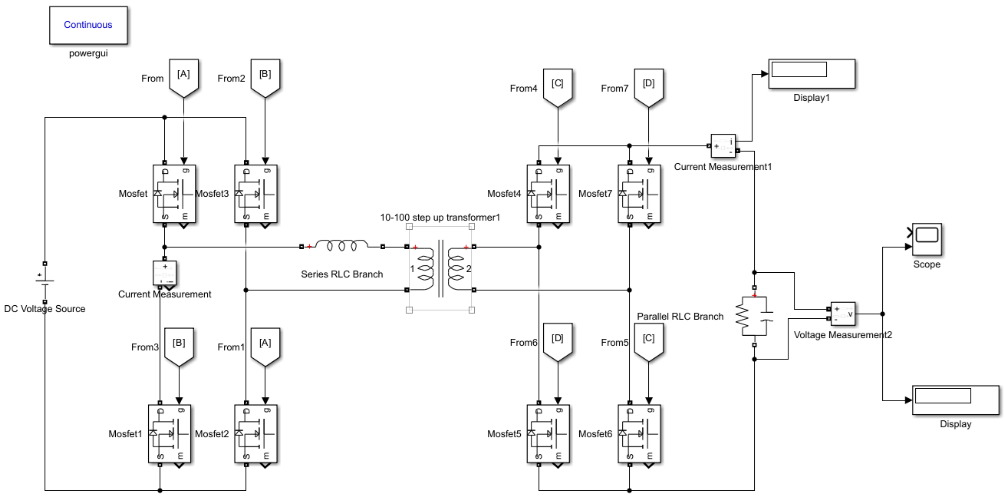

Figure A.3: DAB Converter Circuit

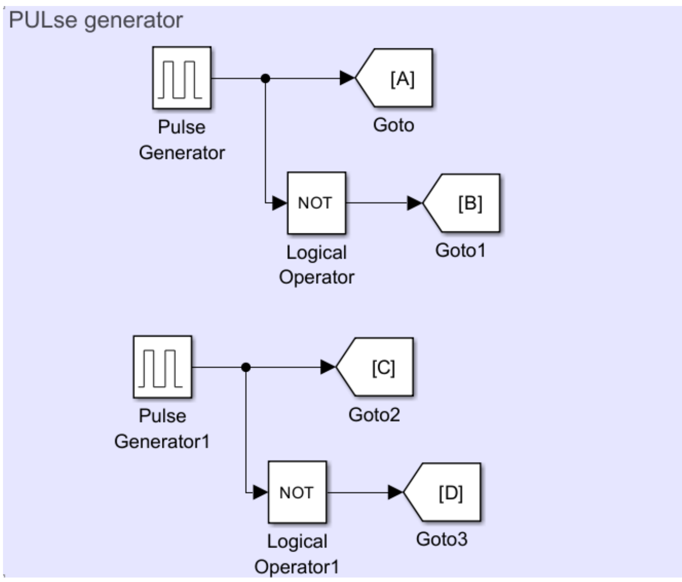

Figure A.4: Pulse Generator