DESIGN A FULL BRIDGE LLC RESONANT CONVERTER USING MATLAB/SIMULINK

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Contribution

1.3 Name : Vishal Chandra

Figure and block diagram on VISIO.

1.4 Name : Aditi Gupta

Literature review on existing converter topology.

Chapter 2

Introduction

2.1 Introduction

LLC resonant converter utilizes soft-switch technology, which results in the increase in power density and efficiency by utilising increased switch Frequency with lesser switching losses.

2.2 Description

The Full-Bridge LLC converter is a resonant DC-DC converter topology that utilizes a combination of inductors and capacitors to form a resonant tank circuit, enabling efficient power conversion with minimal switching losses. By operating at or near its resonant frequency, the converter achieves soft switching, typically zero-voltage switching (ZVS), which reduces stress on switching components and enhances overall efficiency. The Full-bridge configuration simplifies the design and reduces component count, making it a popular choice in applications requiring high power density and efficiency, such as server power supplies and industrial converters.

2.3 Circuit Diagram

Typical circuit for Full Bridge LLC converter is given by:-

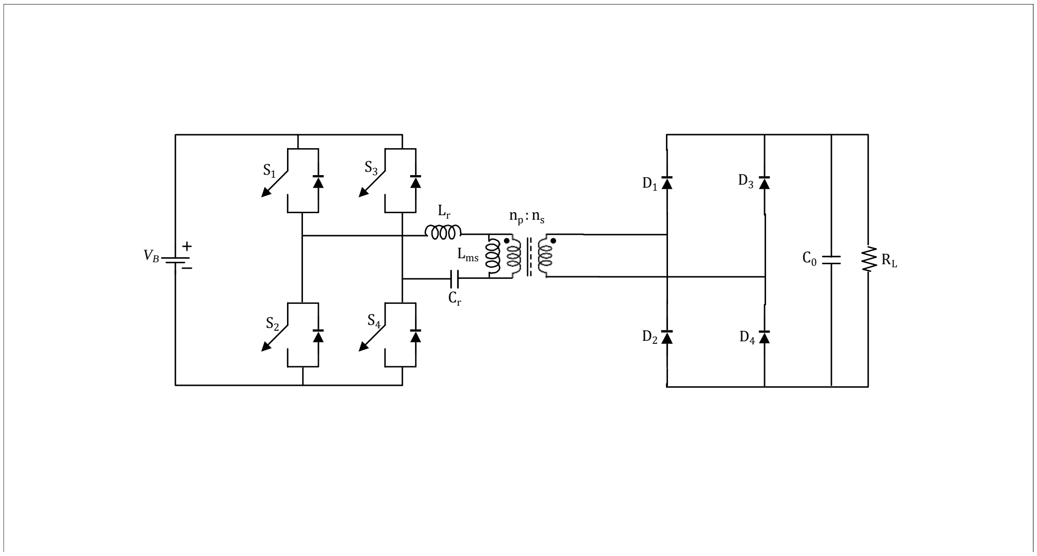

Figure 2.1: Full Bridge LLC converter

Full bridge LLC Converter consist of three networks :- Switching network , Resonant tank circuit and Rectifier Network.

Figure 2.2: Block Diagram of LLC converter

Full Bridge LLC converter consist of four switches (typically MOSFET's) that alternately turn on and off, creating a square wave voltage at the input of the resonant tank.
Resonant tank composed of a series inductor,the transformer magnetizing inductance and a resonant capacitor, converts this square wave into sinusoidal wave.By operating at or near the resonant frequency,the LLC converter acheives soft switching- either Zero Voltage switching (ZVS) or zero current switching (ZCS) - significantly reducing switching loss and improving efficiency.
The converter adjusts its output voltage by varying the switching frequency. Below the resonant frequency, the converter operates with a higher voltage gain, while above resonance, the gain decreases, making the Full-Bridge LLC converter capable of maintaining

output regulation under varying loads and input voltages. This makes it suitable for high-efficiency applications with wide input and output voltage ranges.

2.4 Working

The converter is limited to two specific operations during each switching cycle, as detailed below:-

1. POWER DELIVERY OPERATION

MODE 1: In this mode, switches S_1 and S_2 are turned on whereas S_3 and S_4 are turned off . In this mode, Resonant tank is excited by Positive voltage, so the current flows in positive direction. The equivalent circuit is shown in Figure 2.4.

MODE 2: In this mode, switches S_1 and S_2 are turned off whereas S_3 and S_4 are turned on. In this mode, Resonant tank is excited by Negative voltage, so the current flows in negative direction. The equivalent circuit is shown in Figure 2.6.

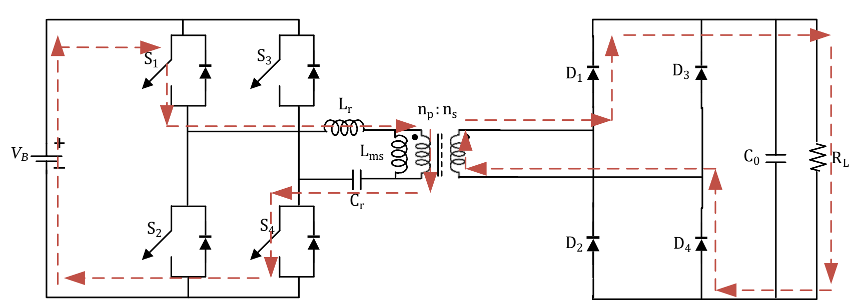

Figure 2.3: Mode 1(Power Delivery Operation)

In this Power Delivery Operation, Inductor will get charge and discharge, respectively.The difference between the resonant current and magnetizing current will flow across primary winding of Transformer.

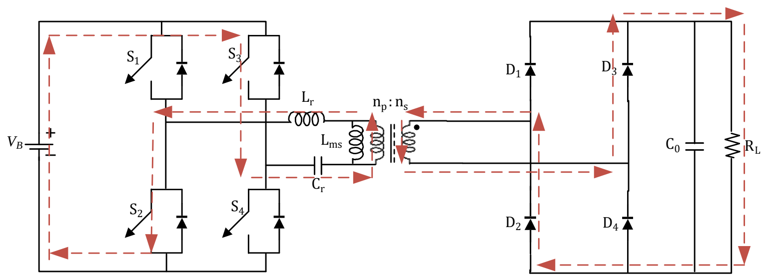

Figure 2.4: Mode 2 (Power Delivery Operation)

2. FREE WHEELING OPERATION

This mode of operation occurs when $f_s > f_r$. In this scenario, the secondary current of the transformer becomes zero, leading to its disconnection. Consequently, the magnetizing current equals the resonant current.

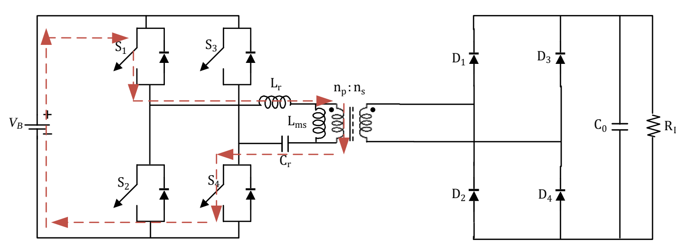

Figure 2.5: Mode 1 (Free wheeling Operation)

Additionally, the frequency of this second resonance is lower than the original resonant frequency f_r , especially occur at high value of m, where $L_m >> L_r$ So, the primary current will be approximately unchanged.The equivalent circuits of freewheeling operation in both halves of switching cycle are shown in Figure (2.6) and Figure (2.7).

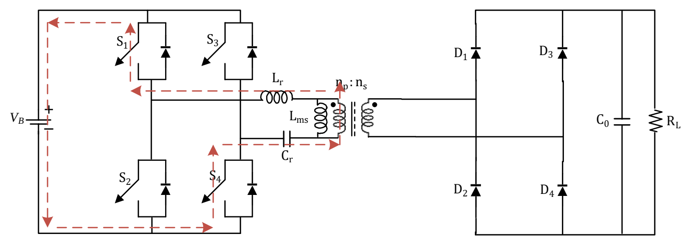

Figure 2.6: Mode 2 (Free wheeling Operation)

2.5 Mode Of Operation

Since the LLC network gain is frequency modulated, the converter can operate in three modes, as listed below and shown in Figure 2.4:

1. At resonant frequency operation, $f_s = f_r$.

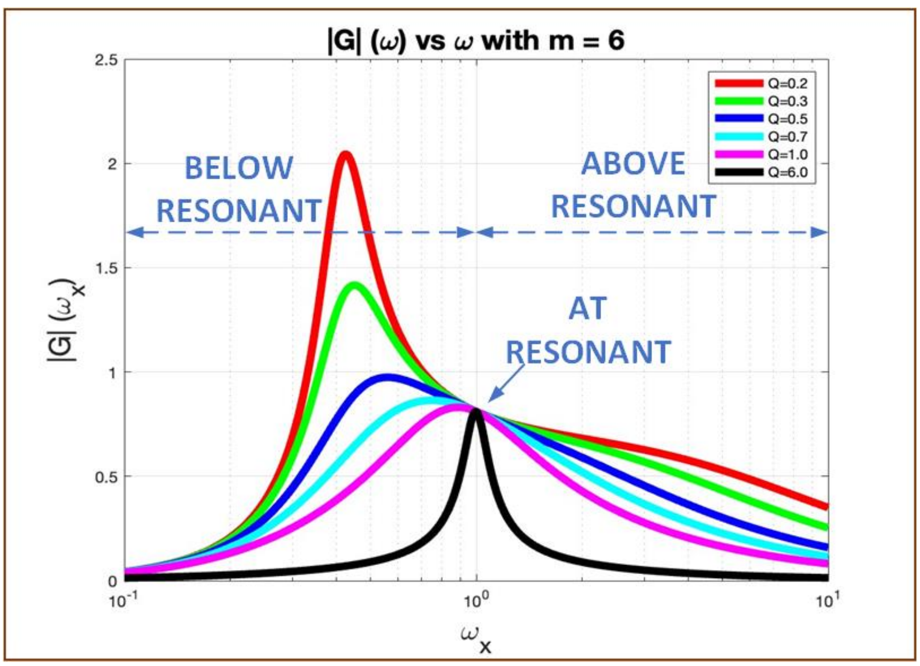

Figure 2.7: Mode Of Operation

2. Above resonant frequency operation, $f_s > f_r$.

3. Below resonant frequency operation, $f_s < f_r$.

Among this three modes, Each modes may contain one or both of operations mentioned above (i.e. Power Delivery Operation and Free wheeling Operation).

1. At resonant frequency operation, $f_s = f_r$:

During resonant frequency operation, each half of the switching cycle includes a complete power delivery process. By end of the switching half cycle, $I_L r$ reaches $I_L m$, and the rectifier current reaches zero.
The resonant tank achieves unity gain, providing optimal operation and efficiency, therefore, transformer turns ratio is designed such that the converter operates at this point at nominal input and output voltages.

2. Above resonant frequency operation, $f_s > f_r$:

During this operation, each half of the switching cycle includes partial Power Delivery process. But it differs as that the resonant Full cycle is not completed and interrupted by the start of the other Full of the switching cycle, hence primary side MOSFETs have increased turn off losses and secondary rectifier diodes have hard commutation.

The converter operates in this mode at higher input voltage, where a step down gain or buck operation is required.

3. Below resonant frequency operation, $f_s < f_r$:

Each half of the switching cycle contains a power delivery operation as well as Freewheeling Operation. The time when resonant half cycle is completed and resonant inductor current $I_L r$ reaches the magnetizing current, the freewheeling operation starts and carries on to the end of the switching half cycle, hence primary side have increased conduction losses due to the circulating energy.

The converter operates in this mode at lower input voltage, where a step up gain or boost operation is required.

Chapter 3

Design Procedure

3.1 Converter Voltage Gain

Converter Gain = Switching Network Gain * Resonant Tank Gain * Transformer Turn Ratio (Ns/Np) The resonant tank gain can be derived by analyzing the equivalent resonant circuit shown in Figure 2.3.

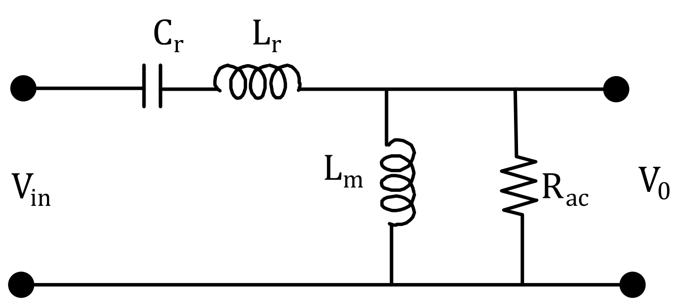

Figure 3.1: Equivalent Resonant Circuit

The Resonant Tank Gain is the magnitude of its transfer function as in Eq. 1.

$$\text{Gain} = \frac{8}{\pi^2} \cdot \frac{(f_x)^2(m-1)}{\sqrt{(m(f_x^2)-1)^2 + (Q^2(f_x^2)(f_x^2-1)^2(m-1)^2)}}$$

where,

$$QualityFactor, \quad (Q) = \frac{\omega_r L_r}{R_{ac}}$$

$$ReflectedLoadResistance, \quad (R_{ac}) = \frac{8}{\pi^2}\left(\frac{N_1}{N_2}\right)^2 R_L$$

$$ResonantFrequency, \quad (\omega_r) = \frac{1}{\sqrt{L_r C_r}}$$

$$NormalizedSwitchingFrequency, \quad (f_x) = \frac{f_s}{f_r}$$

Ratio of total primary inductance to resonant inductance,

$$m = \frac{L_m + L_r}{L_r}$$

3.2 Selection Of Quality Factor(Q) and m

To find the parametersL_r , C_r and L_m.First we have to find the value of Q and m for which gain of converter is 1. To find Q and m , we use iterative method in MATLAB/Simulink. In this method, we plot gain of converter versus f_x for different values of Q and m. From here, we choose Q and m value such that it gives unity gain for resonant circuit.

3.3 Calculation of Elements of Resonant Circuit

Here, we have taken Q = 0.4 and m = 6.4.

Given Data ,

$$V_{\text{in}} = 400\,\text{volts},$$

$$V_{\text{out}} = 48\,\text{volts},$$

$$P_{\text{rated}} = 1\,\text{KW},$$

$$f_{\text{sw}} = 100\,\text{KHz},$$

In LLC converter , the resonant frequencyf_r is generally close to f_{sw}.

So , $f_{sw} = f_r = 100$ KHz ,

Now , Load resistance ,

$$R_L = \frac{V_{out}^2}{P_{rated}} = \frac{48^2}{1000} = 2.304 ohm,$$

$$\text{Reflected Load Resistance,} \quad R_{ac} = \tfrac{8}{\pi^2}\left(\tfrac{N_1}{N_2}\right)^2 R_L = 129.718\,\text{ohm},$$

$$QualityFactor, \quad (Q) = \frac{\omega_r L_r}{R_{ac}}$$

$$L_r = \frac{QR_{ac}}{\omega_0} = 82.616 \times 10^{-6} H$$

$$ResonantFrequency, \quad (\omega_r) = \frac{1}{\sqrt{L_r C_r}}$$

$$C_r = \frac{1}{2\pi f_0 Q R_e} = 30 \times 10^{-9} F$$

$$m = \frac{L_m + L_r}{L_r}$$

$$L_m = (m-1)L_r = 446.126 \times 10^{-6} F$$

Chapter 4

Simulation Setup

4.1 Simulated Circuit

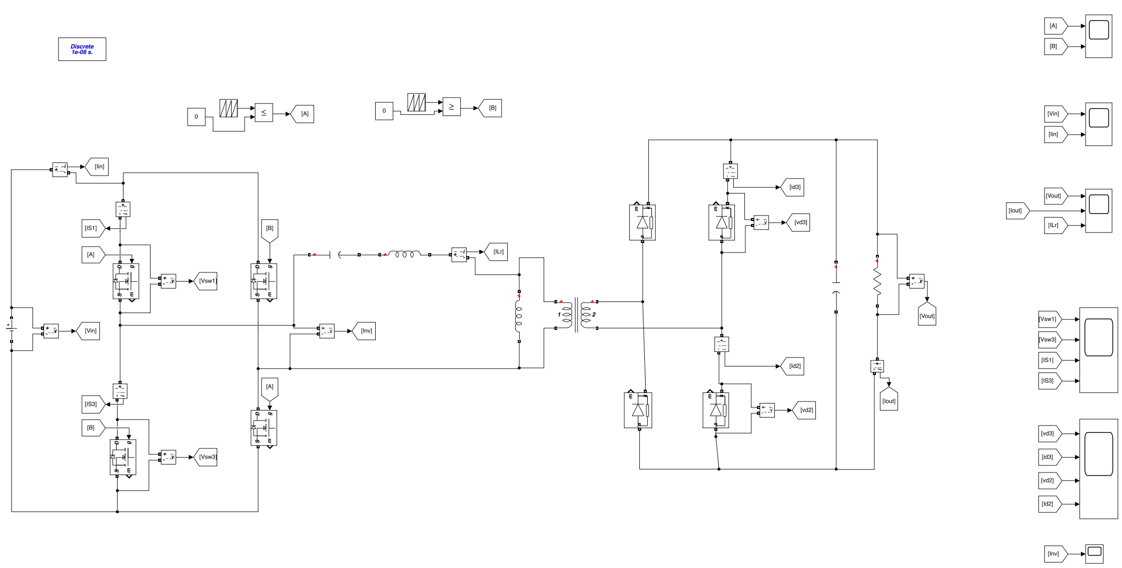

Figure 4.1: Simulated Circuit

4.2 Simulated Results

4.2.1 Switching Signal

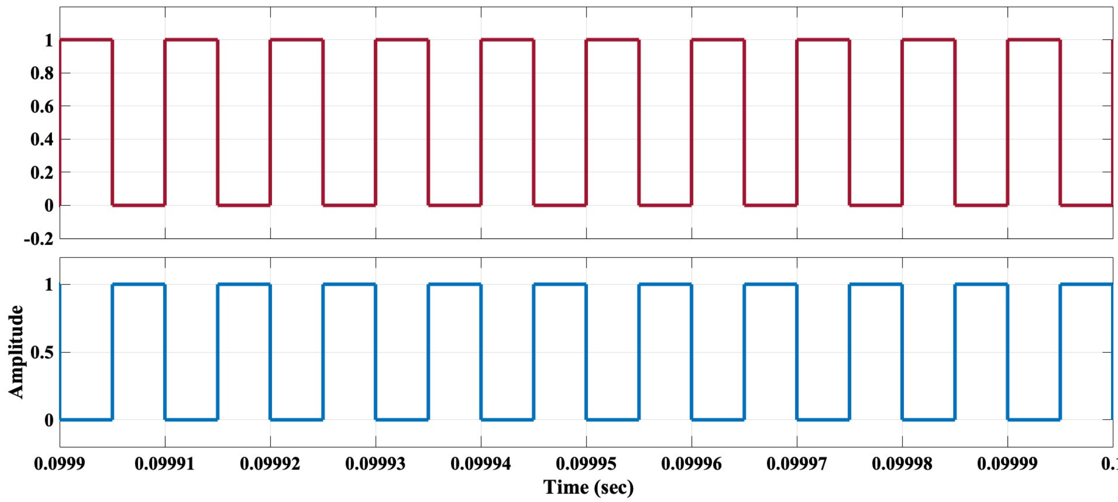

Figure 4.2: Switching Signal

4.2.2 Input Voltage and Input Current

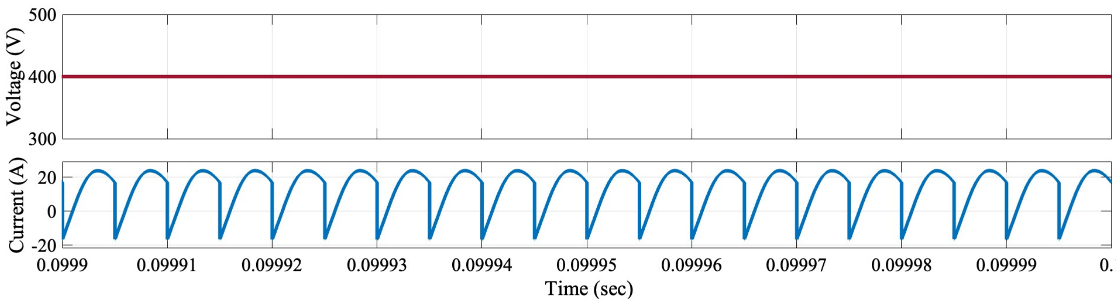

Figure 4.3: Input Voltage and Current

4.2.3 Inverter Output

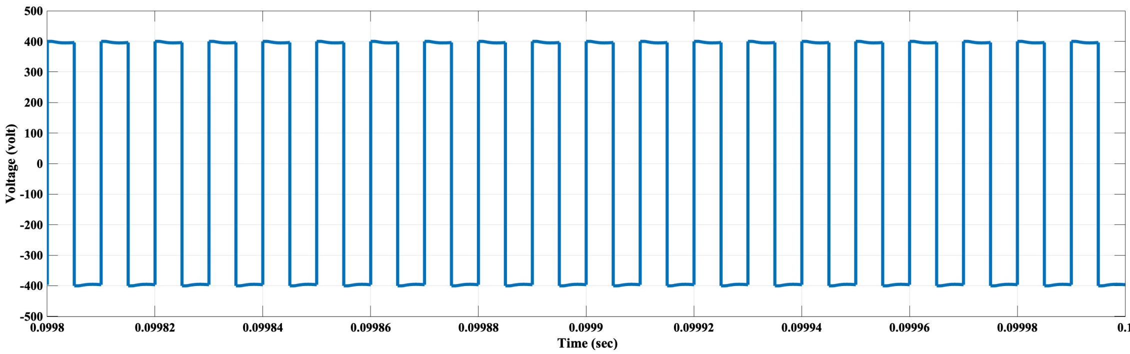

Figure 4.4: Input Voltage and Current

4.2.4 Switch Voltage and Switch Current

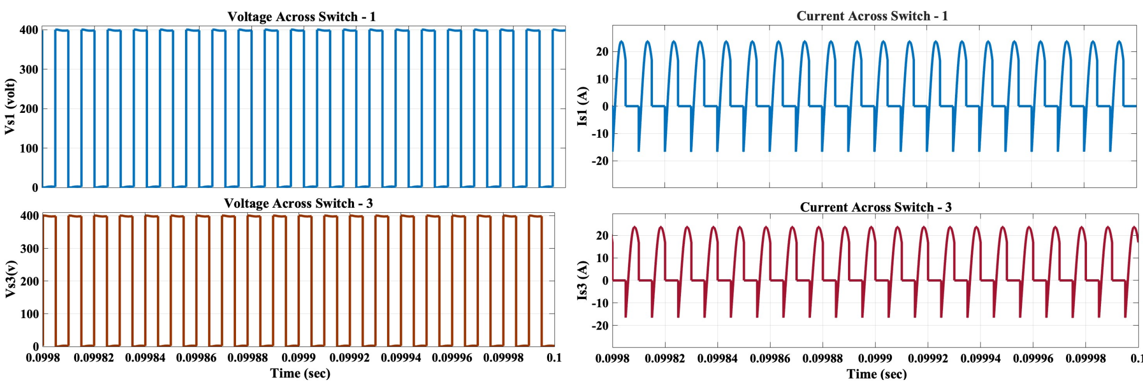

Figure 4.5: Output Across Switch

4.2.5 Resonant Inductor Current

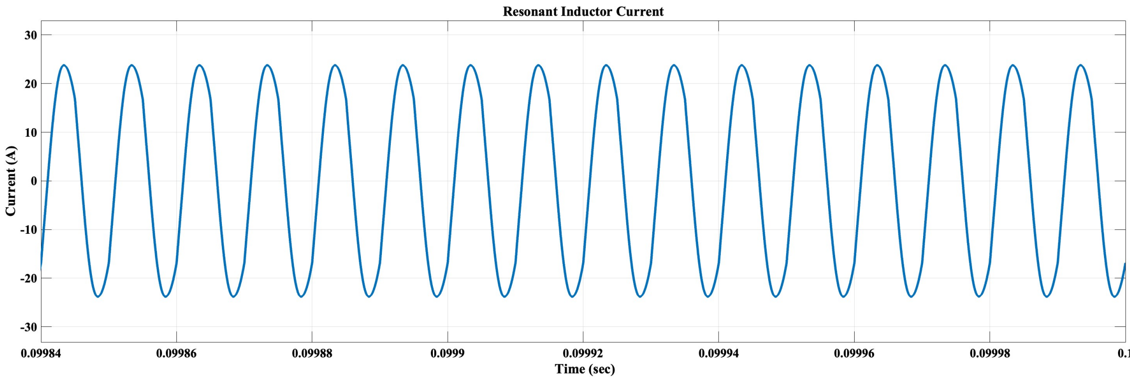

Figure 4.6: Resonant Inductor Current

4.2.6 Output Voltage and Output Current

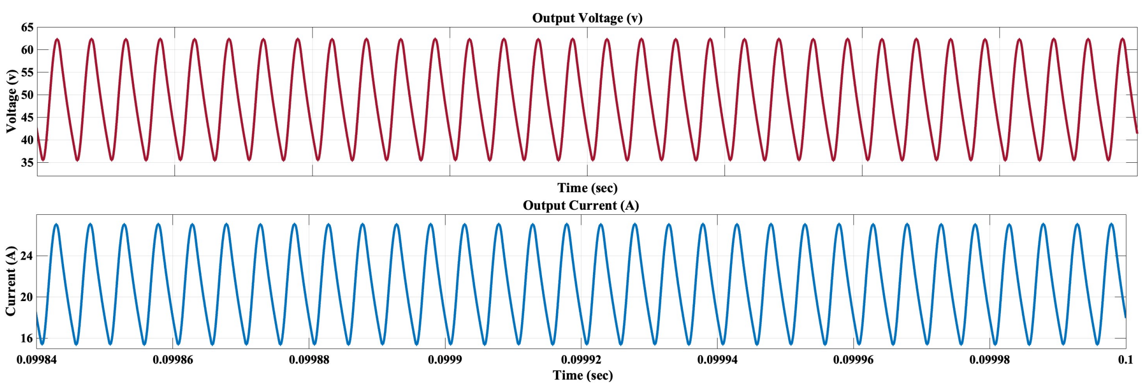

Figure 4.7: Output Voltage and Output Current

Chapter 5

Conclusion

The utilisation of LLC resonant converter represents a significant advancement in technology, enabling efficient power transfer. Throughout this report, we have explored the fundamental principles, components, working and operational basics of the converter, highlighting its importance in applications. In this study, we successfully designed and analyzed Full Bridge LLC Resonant Converter.Using a quality factor Q = 0.4 and m = 6.4. In the simulation , The output voltage was measured to be 48.79 V, which is close to our target output voltage.

The output current was found to be 21.41 A. This design meets the desired power output of 1 kW, demonstrating the converter's ability to achieve soft switching (Zero Voltage Switching) with a well-balanced design. The use of a moderate quality factor ensures efficient operation, and the resonant tank design, along with proper selection of the switching frequency, allows for stable voltage and current regulation.