POWER ELECTRONICS SYSTEMS FOR ELECTRIC VEHICLES [EE -665]

THREE PHASE TWO LEVEL CONTROLLED BIDIRECTIONAL AC-DC CONVERTER WITH BIDIRECTIONAL DUAL ACTIVE BRIDGE ISOLATED CONVERTER SYSTEM

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1. Objective

To simulate a three phase two level controlled bidirectional ac-dc converter with bidirectional dual active bridge isolated converter system. The details of converter system and other ratings are given in the table below. The charging system has to be designed such that it charges from 75% of State of Charge (SOC) to 85% SOC. The charging system will charge the battery with

- 75% to 80% charging in constant current mode
- 80% to 85% charging in constant voltage mode

Sr. no	Specifications	Value
1	Input Voltage	6.6kV
2	Frequency	50Hz
3	Battery Voltage	400 V
4	Battery Capacity	70kWhr
5	Charging Time (20% to 80% SOC)	45 min
6	Input Power factor	Unity
7	Input Current THD	5%
8	Output voltage ripple (AC/DC)	5%

2. Design

The general schematic of the whole system is as shown below

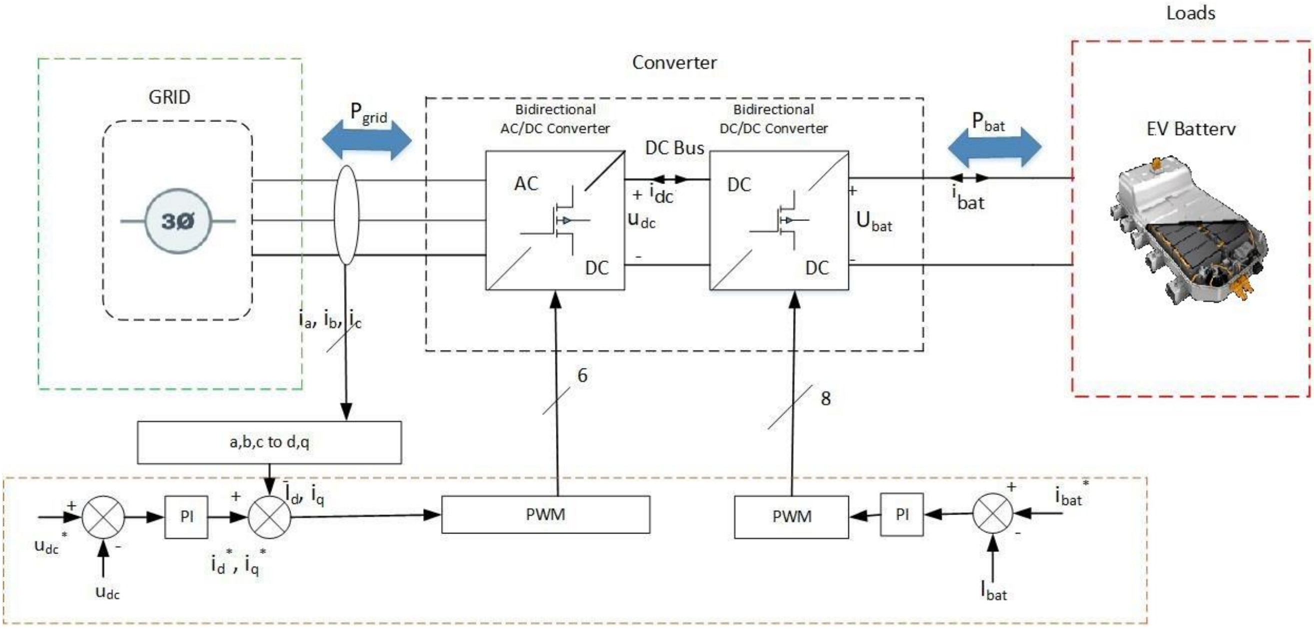

Figure 1: Schematic Diagram of the Charger

The Charger is divided into 2 parts i.e. AC/DC converter and DC/DC rectifier The Design of Each one is discussed below

a. 3-ϕ 2 level AC to DC Converter.

The 3-phase converter is connected to the grid and thus by adding an LCL filter we made sure that the current is below the specified THD

- **LCL Filter**

$$L_1 = \frac{V_{DC}}{4hf_{sw}}$$

f_{sw} = 10kHz

h is calculated to be 0.98

$$L_1 = \frac{8000}{4 * 0.98 * 10000} = 0.4573mH$$

Thus, $L_1 \approx 0.5mH$

The value of capacitor is chosen such that it draws a max 5% of inverter power

$$C = \frac{Q}{6\pi f V^2} = \frac{2800}{6\pi \times (6.6/\sqrt{3})^2} = 458.643\mu F$$

Thus, $C \approx 500\mu F$

$$f_{res} = \frac{1}{2\pi}\sqrt{\frac{1+k}{kL_1 C}}$$

$$f_{res} = 10kHz$$
$$L_1 = 0.5mH$$
$$C = 500\mu F$$

Calculating the above we get $k \approx 1$

Thus $L_1 = L_2 = 0.5mH$

- **DC bus Capacitor**

  DC bus capacitor can be calculated using

$$C = \frac{2\Delta P_m \Delta t}{(V_{DC} + \Delta V_{DC})^2 - (V_{dC})^2}$$

From the above equation we calculated

$$C = 500\mu F$$

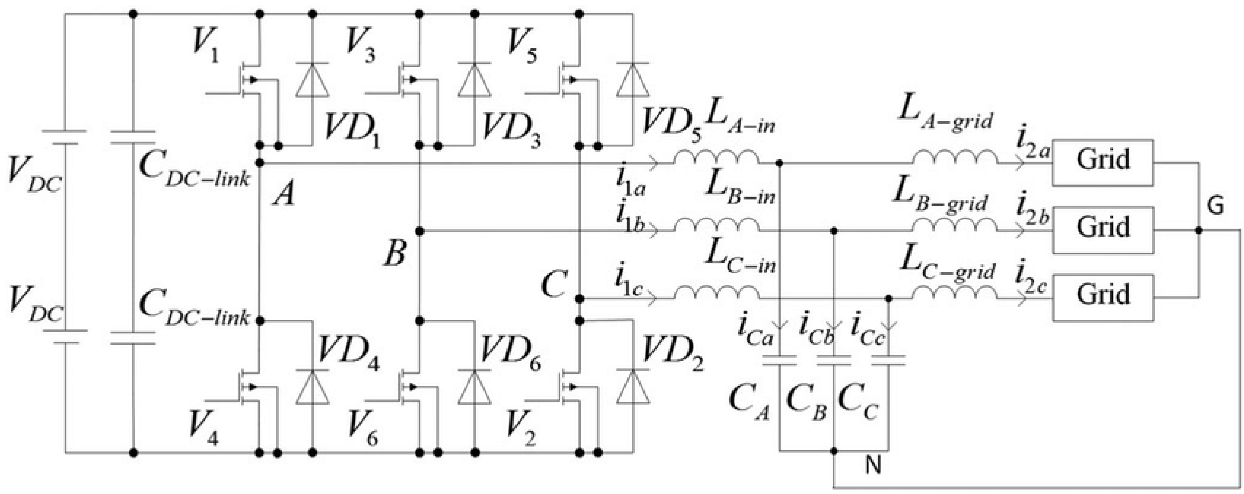

Figure 2: Schematic of 2 level 3-ϕ/DC converter

b. Dual Active Bridge converter.

- Transformer Ratio is chosen as **8000:500** as DC voltage is 8000V and rated output for the battery is 400V which can then be achieved by closed loop control.
- Filter Capacitor:
  Output ripple needs to be less than 5% thus
$$C_f = \frac{V_{DC}(1-D)D}{8f^2 L\Delta V}$$
$$C_f = 190\mu F$$
- Filter Inductance:
  Limiting the output ripple in current to 2.5% the inductor value can be calculated as

$$L_f = \frac{V_{DC}(1-D)\cdot D}{\Delta I_0 f}$$
$$L_f = 2mH$$

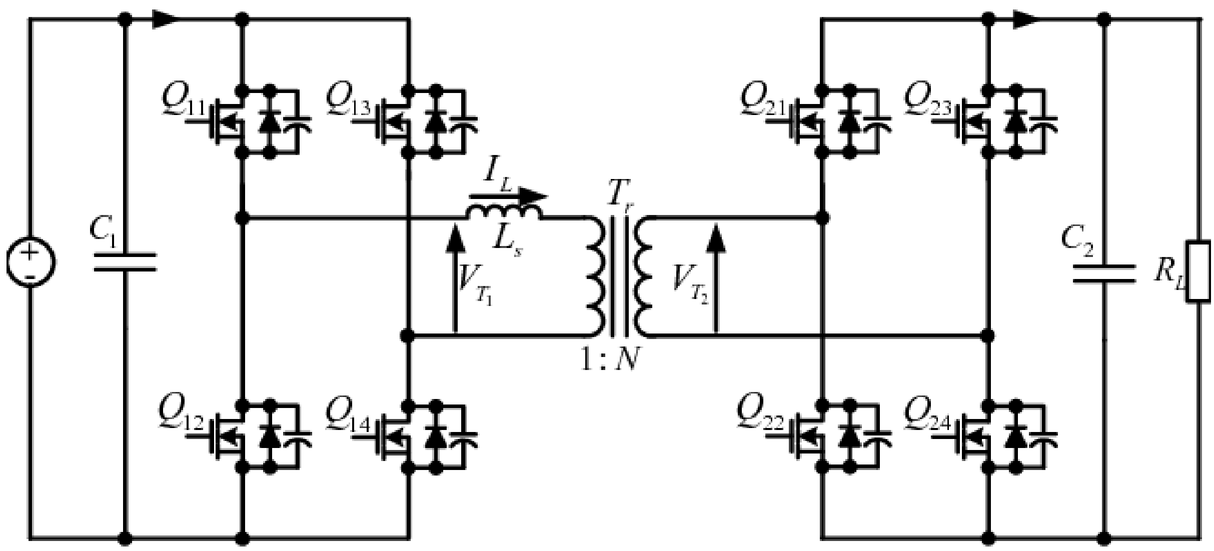

Figure 3: Schematic of DAB converter

3. Control

- **Model of Converter in d-q reference Frame**

$$e_d = L\frac{di_d}{dt} + Ri_d - \omega_0 L i_q + S_d u_{dc}$$
$$e_q = L\frac{di_q}{dt} + Ri_q + \omega_0 L i_q + S_q u_{dc}$$

$$C\frac{du_{dc}}{dt} = \frac{3}{2}\left(i_d S_d + i_q S_q\right) - i_L$$

The above equations are transformed from abc to d/q reference frame and can be represented as a block diagram as shown below

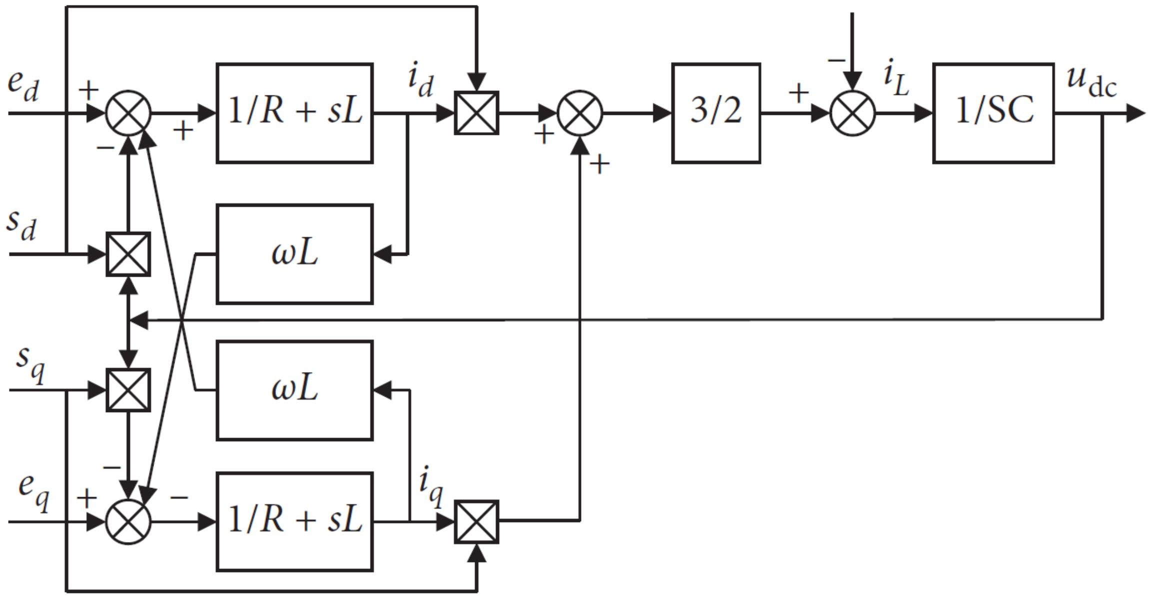

Figure4: Model of converter in d-q reference frame

a. Current control

The control loop for constant current mode of operation is given by

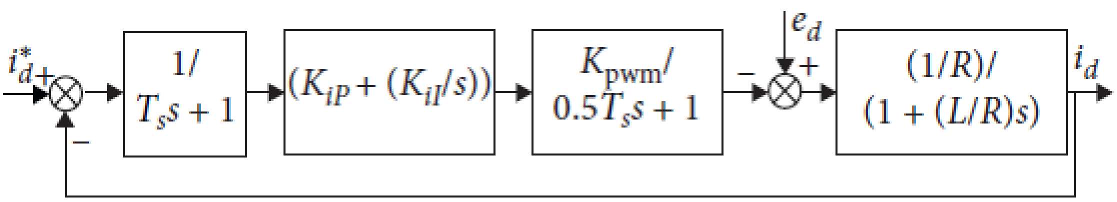

Figure 5: current control loop

The above loop is simplified and we obtain a closed loop transfer function as

$$\boldsymbol{G_{ci}(s) = \frac{1}{1 + (R\tau_i \,/\, K_i K_{pwm})s + (1.5T_s R\tau_i \,/\, K_i k_{pwm})s^2}}$$

b. Voltage Control

Similarly for constant voltage control we have

$$G_{cv}(s) = \frac{1}{1 + \frac{(CT_v s^2 (T_{ev} + 1)}{0.75K_v(T_v s + 1)}}$$

- From both the above Transfer functions we took various values of Ki and Kp and plotted the Bode plot and selected

$$K_p = 0.1 \,;\, K_i = 200$$

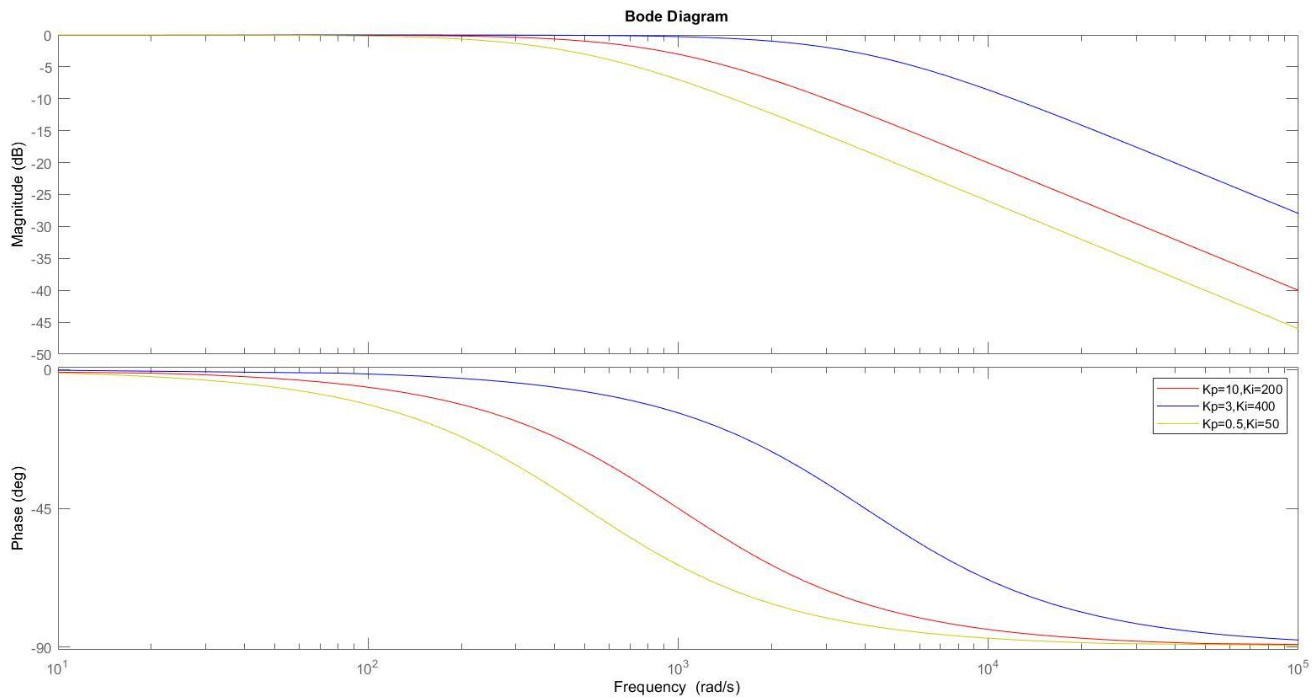

Figure 6: Bode Plot

c. DAB control

The control of DAB is achieved by producing a delay in the firing pulses proportional to the error in the reference signal.

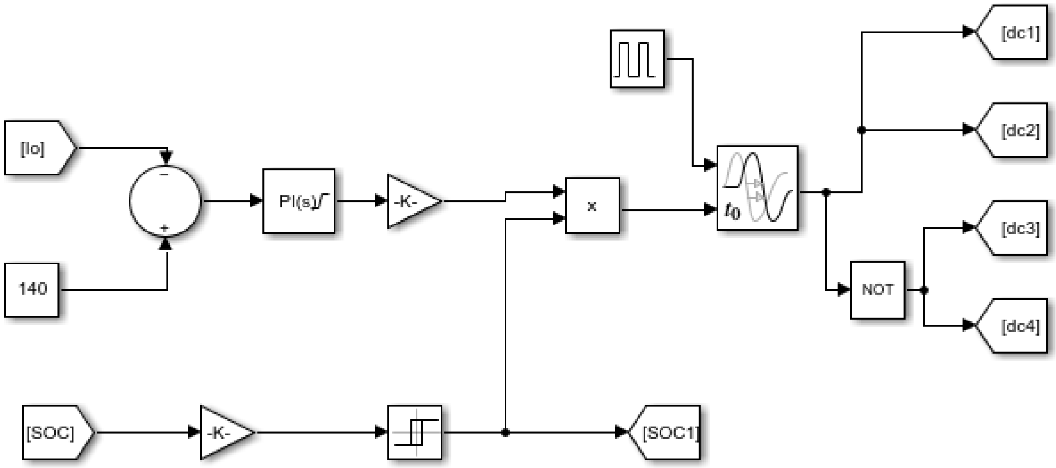

Figure 7: Control strategy for DAB

4. MATLAB models of different subsystems

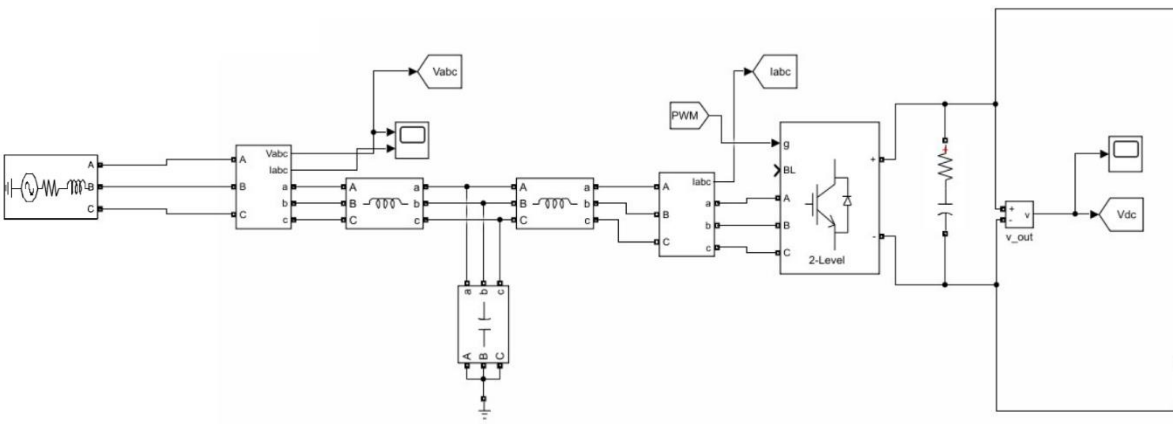

Figure 8: Model of 3-phase two level converter

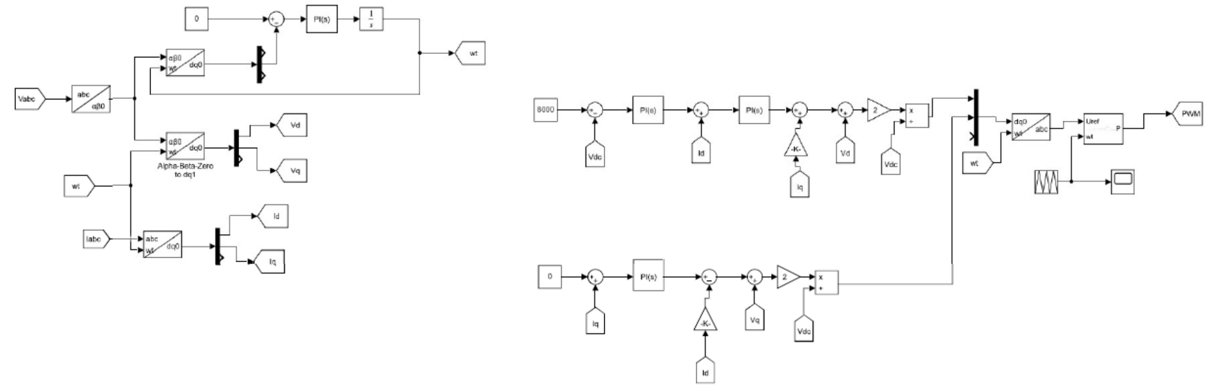

Figure 9: Control of 3-phase converter

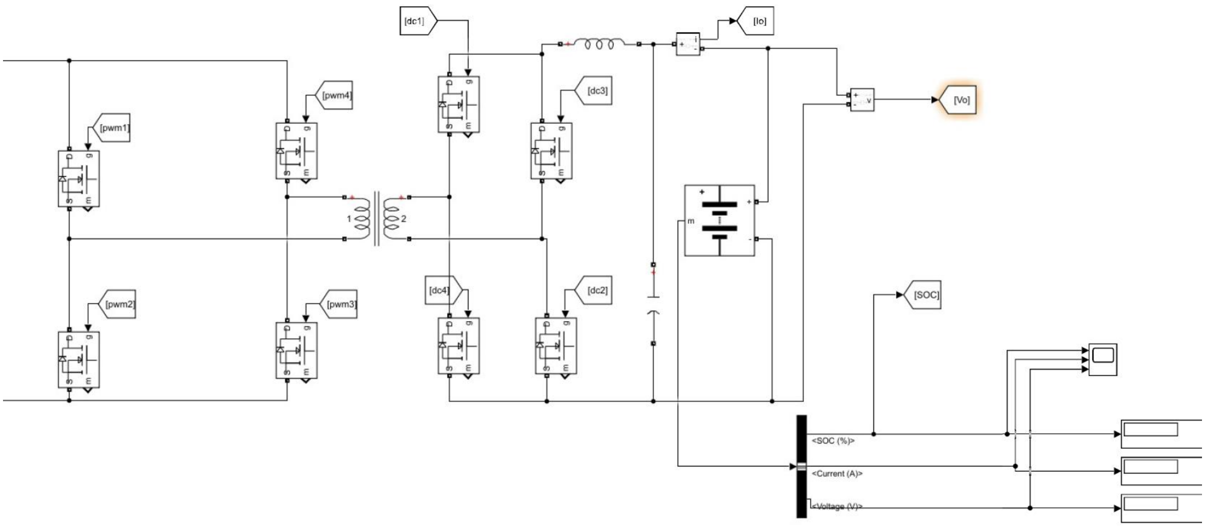

Figure 10: Model of Dual active bridge

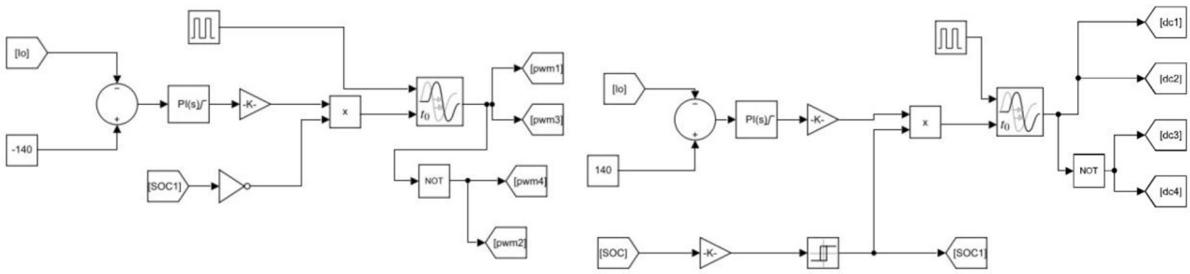

Figure 11: Control of Dual active bridge

5. Simulation Results.

- **Output of 3 phase Rectifier.**

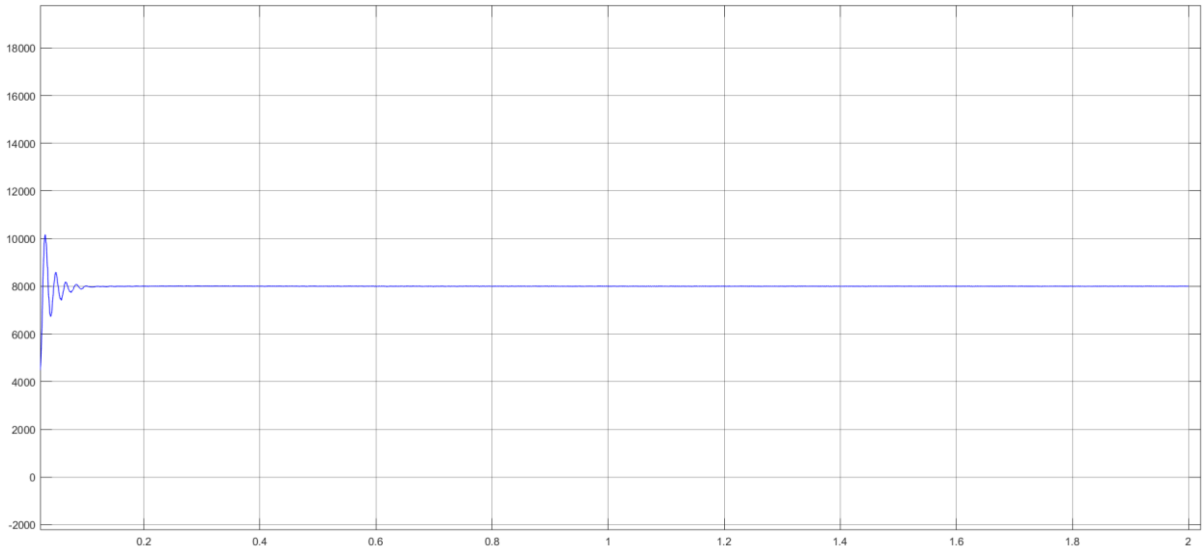

Figure 12: 3 phase converter output

- **Charging of Battery.**
    - **Constant Current mode**

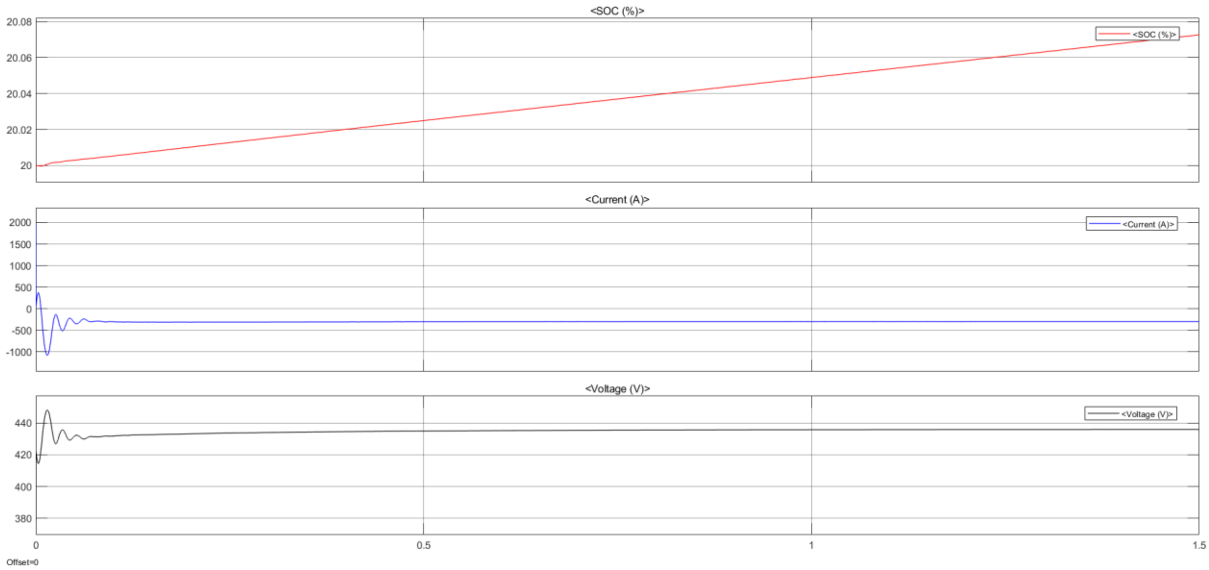

Figure 13: Battery charging (Constant current)

A snippet of the charging of battery starting from 20 % (Figure 13) it can be observed that

- SOC is increasing as seen from the 1st plot
- The current is Stable at 143 A
- Voltage across the battery is Steadily increasing

- **Constant Voltage mode**

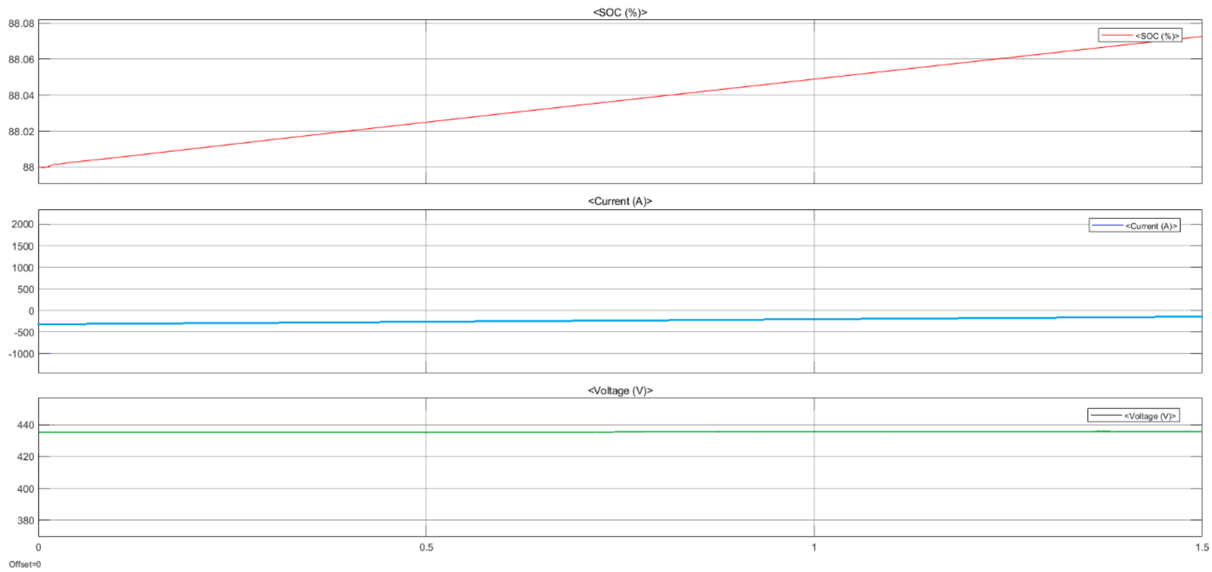

Figure 14: Battery charging (Constant voltage)

A snippet of the charging of battery when at 88 % is attached it can be observed that

- SOC is increasing as seen from the 1st plot
- The current flowing into the battery is decreasing
- Voltage across the battery is Constant

- **Discharging of Battery.**

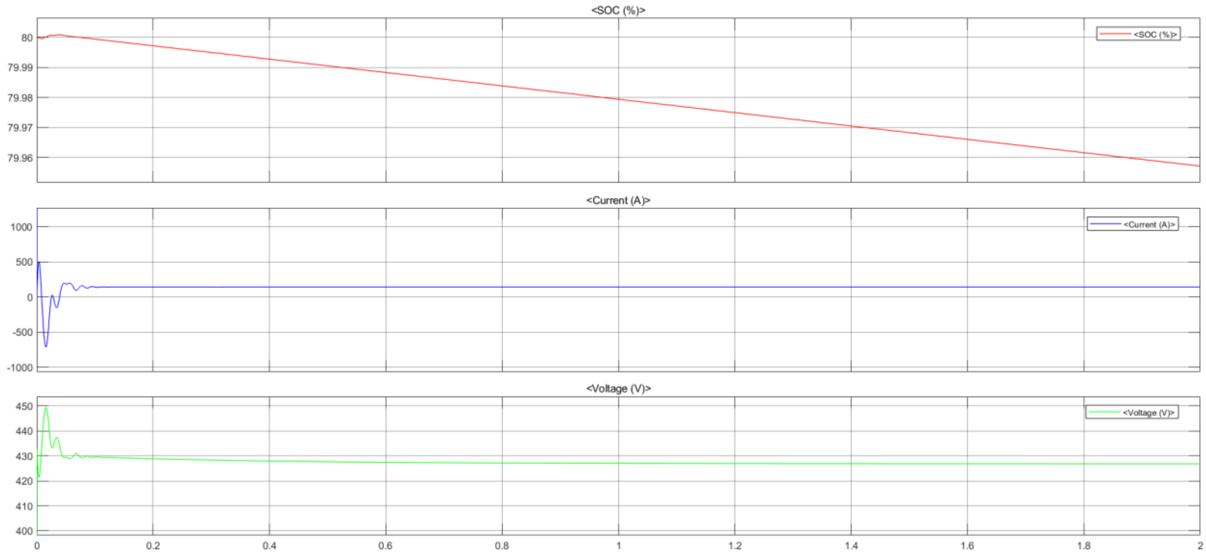

Figure 15: Battery discharging (Constant current)

The Battery when set to discharge it can be observed that

- SOC reduces from 80% to 79.96%
- Current is Constant
- Voltage across the terminals drops a little

- **Grid side current.**

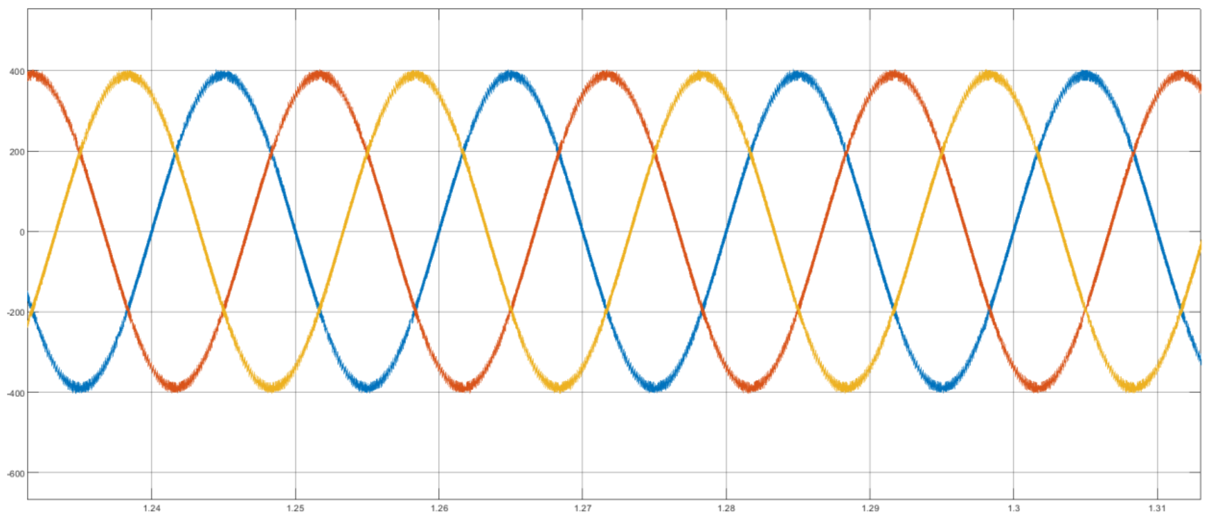

Figure 16: Grid side current

The Current can be as seen above it can be observed that

- THD was at max 3.55% when discharging and was min during constant current charging at 3 %.
- The Voltage and current waveform cross zero at almost the same time indicating unity power factor

6. References

a. A Three-Phase Bidirectional Grid-Connected AC/DC Converter for V2G Applications (https://doi.org/10.1155/2020/8844073)

b. Koji Shigeuchi, Kensuke Sakuma, Jin Xu, Noboru Shimosato, and Yukihiko Sato. A New Modulation Method for a Bidirectional Isolated Three-Phase AC/DC Dual-Active-Bridge Converter to Realize Higher Efficiency in Wide Output Voltage Range

c. Basundhara Singh, Gauri Shankar, Anamika Singh. Modelling of Inverter Interfaced Dual Active Bridge Converter