DESIGN OF SERIES RESONANT DC-DC CONVERTER FOR EV BATTERY CHARGING

Project Report submitted by,

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Under the guidance of
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Design and Simulate a 1KW Series Resonant DC-DC Converter For EV Battery Charging Input Voltage = 400V , Output Voltage = 48V,

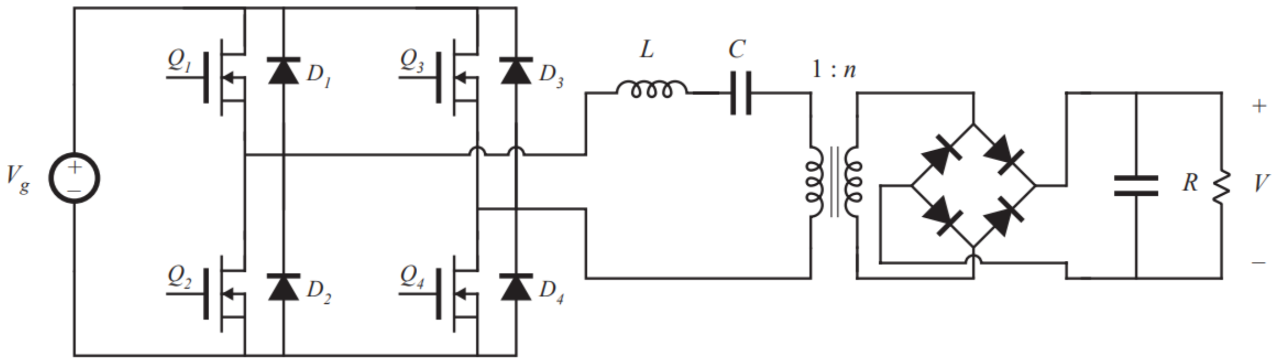
Choose appropriate transformer turn ratio , Leakage Inductance, Switching Frequency etc.

Ignore Magnetizing Current

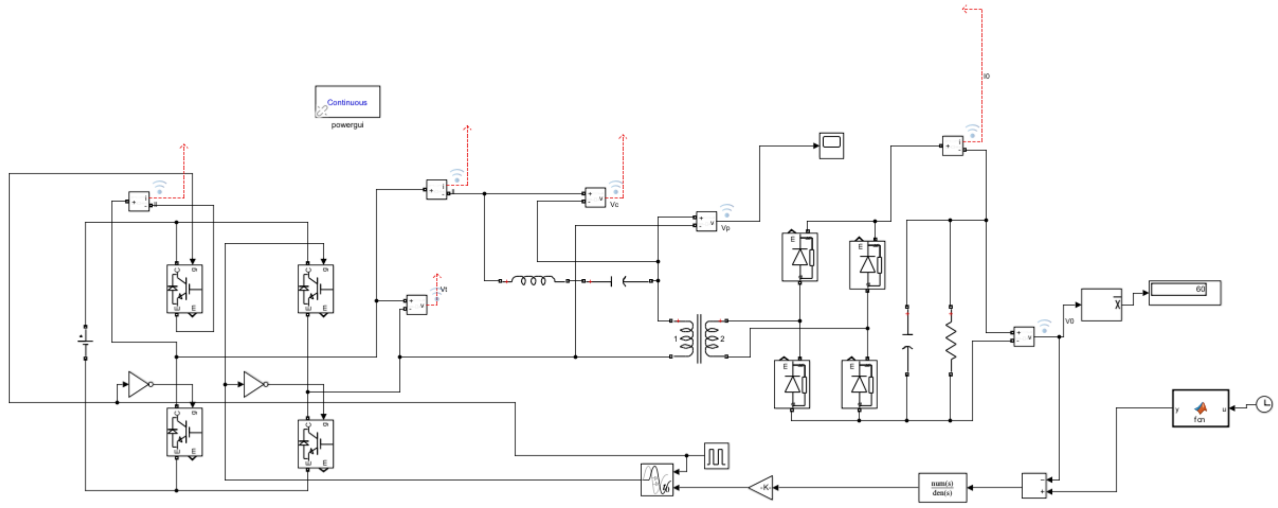
Topology :Full Bridge VSI And Full Bridge Diode Rectifier in the load side

Design a single loop control with appropriate SSE, Settling Time and the Phase Margin , Show a Step

Response in simulation and verify Settling time



Matlab Model :



Given Data :

Vg = 400v

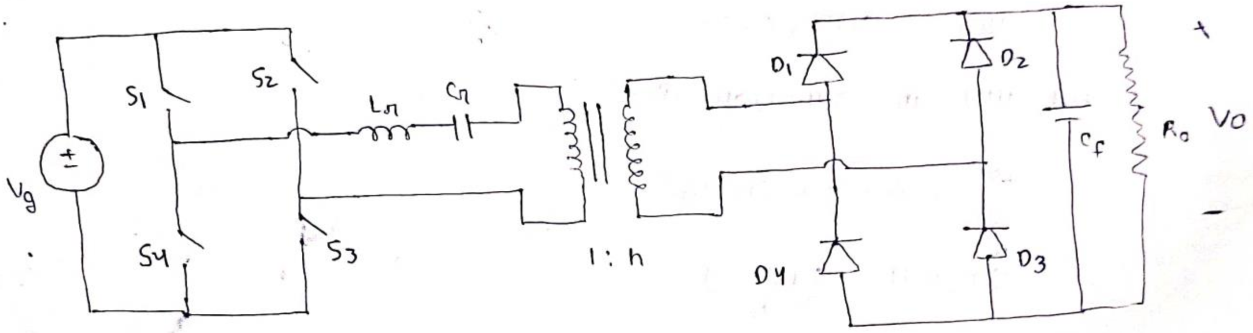
Vo = 48V

Po= 1000W

Calculations :

Given data $V_g = 400V$, $V_o = 48V$, $P_o = 1KW$

DC-DC series resonant converter



$$R = \frac{V_o^2}{P} = \frac{48 \times 48}{1000}$$

$$R = 2.304 \Omega$$

We know that DC voltage gain

$$\frac{V_o}{V_g} = nH(s) \cdot \sin(\pi d)$$

Let $Q = 20$, $f_{sw} = 100KHz$, $f_o = 98KHz$

$$\frac{V_o}{V_g} = nH(s) \cdot \sin(\pi d)$$

$$\frac{48}{400} = n \cdot H(s) \cdot \sin(\pi d). \quad \text{—— (1)}$$

We know that

$$H(s) = \frac{\frac{s}{Q_e \cdot W_o}}{1 + \frac{s}{Q_e \cdot W_o} + \left(\frac{s}{W_o}\right)^2} = \frac{\frac{J100 \times 10^3 \times 2\pi}{20 \times 2\pi \times 98 \times 10^3}}{1 + \left(\frac{J100 \times 10^3 \times 2\pi}{20 \times 2\pi \times 98 \times 10^3}\right) + \left(\frac{J2\pi \times 100 \times 10^3}{2\pi \times 98 \times 10^3}\right)^2}$$

$$H(s) = \frac{\frac{J100}{20 \times 98}}{1 + \left(\frac{J100}{20 \times 98}\right) + \left(\frac{J100}{98}\right)^2}$$

$$H(s) = \frac{j0.05102}{1 + (j0.05102) - 1.0412}$$

$$= \frac{j0.05102}{-0.0412 + j0.05102}$$

$$H(s) = 0.778 \angle -38.92$$

Put H(s) in equation ①

$$\frac{48}{400} = 0.778 \, n \sin(\pi d)$$

$$\sin(\pi d) = \frac{0.15424}{n}$$

Let $n = 0.4$

$$\sin(\pi d) = \frac{0.15424}{0.4} = 0.3856$$

$$\pi d = \sin^{-1}(0.3856)$$

$$d = 0.126$$

As $\quad Q_e = \frac{\omega_o L}{R_e} \cdot n^2$

$$L = \frac{Q_e \cdot R_e}{\omega_o \cdot n^2}$$

$$L = \frac{20 \times 1.86944}{(0.4)^2 \times 2\pi \times 98 \times 10^3}$$

$$L = 379.4 \, \mu H$$

$$\omega_o = \frac{1}{\sqrt{LC}} \qquad C = \frac{1}{\omega_o^2 L}$$

$$C = \frac{1}{(2\pi \times 98 \times 10^3)^2 \times 379.4 \times 10^{-6}}$$

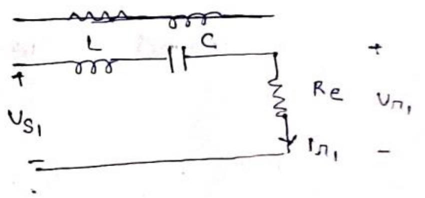
$$C = 6.676 \times 10^{-9}\ F$$

$$\frac{\tilde{V}_o(s)}{\tilde{d}(s)} = \underbrace{\frac{\tilde{V}_{s1}}{\tilde{d}}}_{\text{Inverter T/F}} \cdot \underbrace{\frac{\tilde{I}_{r1}}{\tilde{V}_{s1}}}_{\text{Tank T/F}} \cdot \underbrace{\frac{\tilde{V}_o}{\tilde{I}_{r1}}}_{\text{Rectifier T/F}}$$

$\frac{\tilde{V}_o(s)}{\tilde{d}(s)}$ is Plant transfer function.

(i) $$\frac{\tilde{V}_{s1}}{\tilde{d}} = 4V_g \cos(\pi d) = 4 \times 400 \times \cos(\pi \times 0.126) = 1476.276 \quad \text{—— (ii)}$$

(ii) For $\frac{\tilde{I}_{r1}}{\tilde{V}_{s1}}$



$$\frac{\tilde{I}_{r1}}{\tilde{V}_{s1}} = \frac{\tilde{V}_{r1}}{\tilde{V}_{s1}} \cdot \frac{\tilde{I}_{r1}}{\tilde{V}_{r1}}$$

$$= \frac{Re}{\left(Re + SL + \frac{1}{SC}\right)} \cdot \frac{1}{Re}$$

$$\frac{\tilde{I}_{r1}}{\tilde{V}_{s1}} = \frac{1}{Re + SL + \frac{1}{SC}} = \frac{1}{Zin}$$

$$= \frac{1}{1.878 + (j2\pi \times 100 \times 10^3 \times 379.4 \times 10^{-6}) + \frac{1}{(j2\pi \times 100 \times 10^3 \times 6.676 \times 10^{-9})}}$$

$$= \frac{1}{1.878 + j238.384 - j238.3986}$$

$$= \frac{1}{(1.878 - j0.0146)}$$

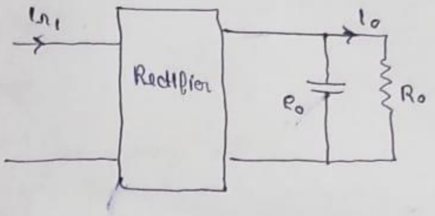
$$\frac{\tilde{I}_{r1}}{\tilde{V}_{s1}} = 0.5324 \angle 0.445 \quad \text{—— (iii)}$$

Switching Frequency = 628 Krad/s

Wgc < Switching Frequency/10

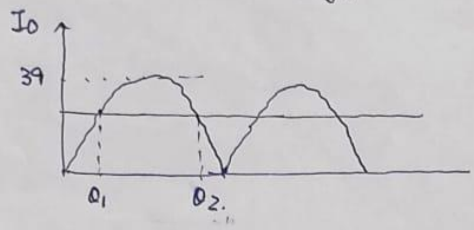
(iii) Rectifier

$$\frac{\tilde{V}_o(s)}{\tilde{i}_{r1}(s)} = \frac{2/\pi}{(sC + 1/R_o)}$$



$$I_o(avg) = \frac{V_o}{R_o} = \frac{48}{2.304} = 20.833$$

O/P capacitor design-



$\theta_2 = \pi - \theta_1$

For θ_1 : $34\sin\omega t - 20.833 = 0$

$34\sin\omega t = 20.833$

$\theta_1 = 0.6595$

$\theta_2 = 2.48$

Now we know that

$$Q = C \cdot \Delta V$$

$$Q = \frac{1}{2\omega}\int_{\theta_1}^{\theta_2}(34\sin\omega t - 20.833)\,d\omega t$$

$$= \frac{1}{2\pi \times 200 \times 10^3}\left[\int_{0.6595}^{2.48} 34\sin\omega t\, d(\omega t) - \int_{0.6595}^{2.48} 20.833\, d(\omega t)\right]$$

$$= \frac{1}{2\pi \times 200 \times 10^3}\left[34\{\cos 2.48 - \cos 0.6595\} - 20.833(2.48 - 0.6595)\right]$$

$$= \frac{1}{2\pi \times 200 \times 10^3}\left[53.6966 - 37.93\right]$$

$$Q = \frac{15.766}{2\pi \times 200 \times 10^3} = C\,\Delta V$$

$\Delta V = 0.48$

$$C = \frac{15.766}{2\pi \times 200 \times 10^3 \times 0.48}$$

$C = 26.15\,\mu F \simeq 30\,\mu F$

We have taken $C_o = 100\mu F$ to minimise ripple.

$$\frac{\bar{V}_o(s)}{\bar{I}_{in}(s)} = \frac{0.6366}{s(100\times10^{-6}) + 0.4340}$$

New Plant T/F = $4V_g \cos(\pi d) \cdot \frac{1}{\left(R_e + sL + \frac{1}{sC}\right)} \cdot \frac{2/\pi}{(sC + 1/R_o)}$

Putting all value of eq. (ii), (iii) and (iv)

$$T(s) = 1476.276 \times 0.532 \angle 0.445 \cdot \frac{2/\pi}{(sC + 1/R_o)}$$

$$T(s) = \frac{500.617 \angle 0.445}{s(100\times10^{-6}) + 0.4340}$$

(1) For Settling time $\leq 5ms$

$$T_s \leq 5ms$$

$$\frac{4}{\omega_{gc}} \leq 5ms$$

$$\omega_{gc} \geq 800 r/s$$

also

$$\omega_{switching} = 628 k\, r/s$$

$$\omega_{gc} < 62.8k \left(\omega_{sw}/10\right)$$

$$800 < \omega_{gc} < 62.8k$$

We have taken $\omega_{gc} = 9.1\times10^3$ r/s

Also ω_{gc} for uncompensated system is coming $= 5.01\times10^6$ r/s

So we have to Reduce ω_{gc} for this we have used PI controller

We added first Integrator at origin to reduce Steady state error and w_{gc}

Now our transfer function become

$$T_1(s) = \frac{500.617}{s(100\times10^{-6}) + 0.4340} \cdot \frac{K_i}{s}$$

after this we are getting $w_{gc} = 1.12\times10^3$ r/s

we want to make our desired cross over at 9.1 Krad/s so we added Proportional derivative controller

overall, we added PI controller

we added a zero at $\omega = 1500$ rad/s

So our transfer function become

$$T_2(s) = \frac{500.617}{s(100\times10^{-6}) + 0.4340} \cdot \frac{K_i}{s} \cdot \left(\frac{s}{1500} + 1\right)$$

Now at $w_{gc} = 9.1\times10^3$ r/s

$$|GH| = |T_2|_{@\omega = 9.1\times10^3} = 1$$

$$\Rightarrow \left| \frac{500.617}{j(9.1\times10^3)(100\times10^{-6}) + 0.4340} \cdot \frac{K_i}{(j\times9.1\times10^3)} \cdot \left(\frac{j\times9.1\times10^3}{1500} + 1\right) \right| = 1$$

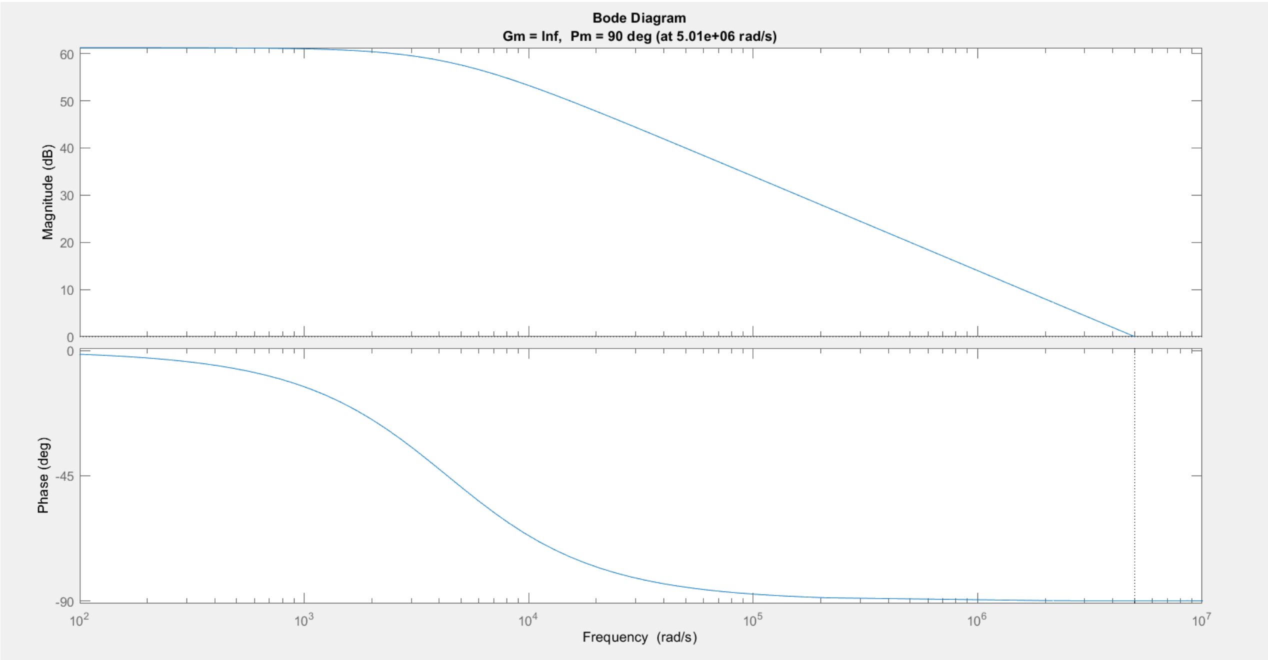
On solving, we get

$$K_i = 3$$

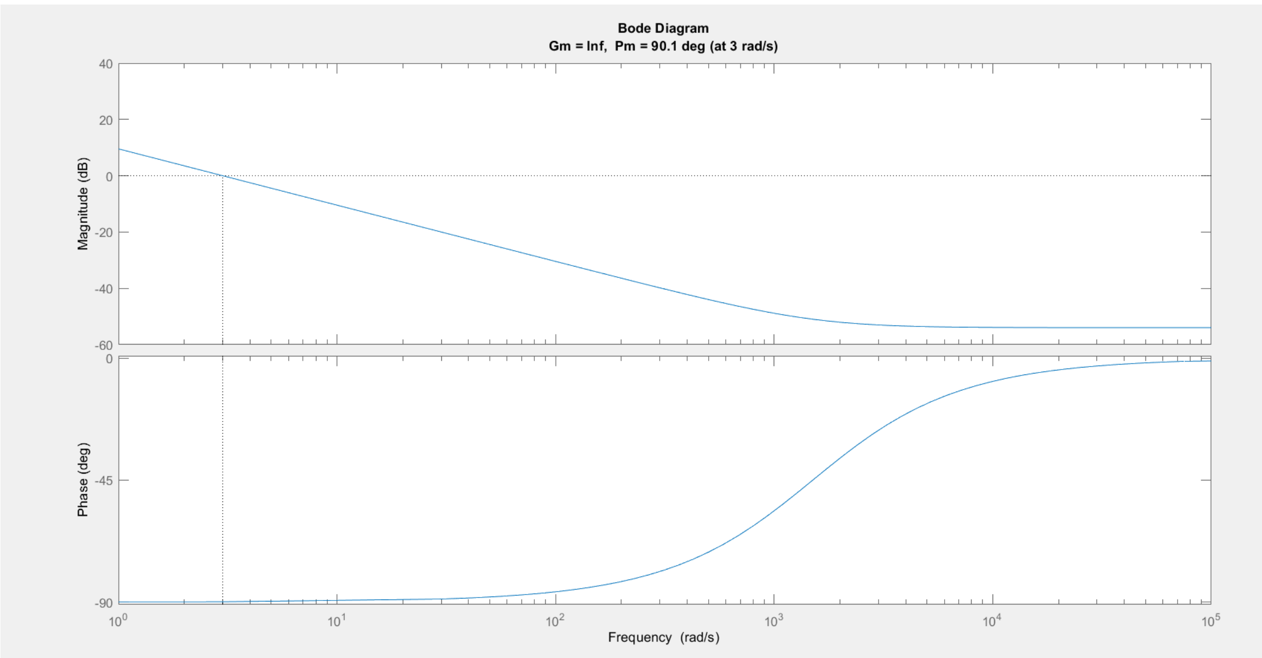
Overall Transfer function

$$|GH| = \left(\frac{1501.851}{s(100\times10^{-6}) + 0.4340}\right) \frac{1}{s}\left(1 + \frac{s}{1500}\right)$$

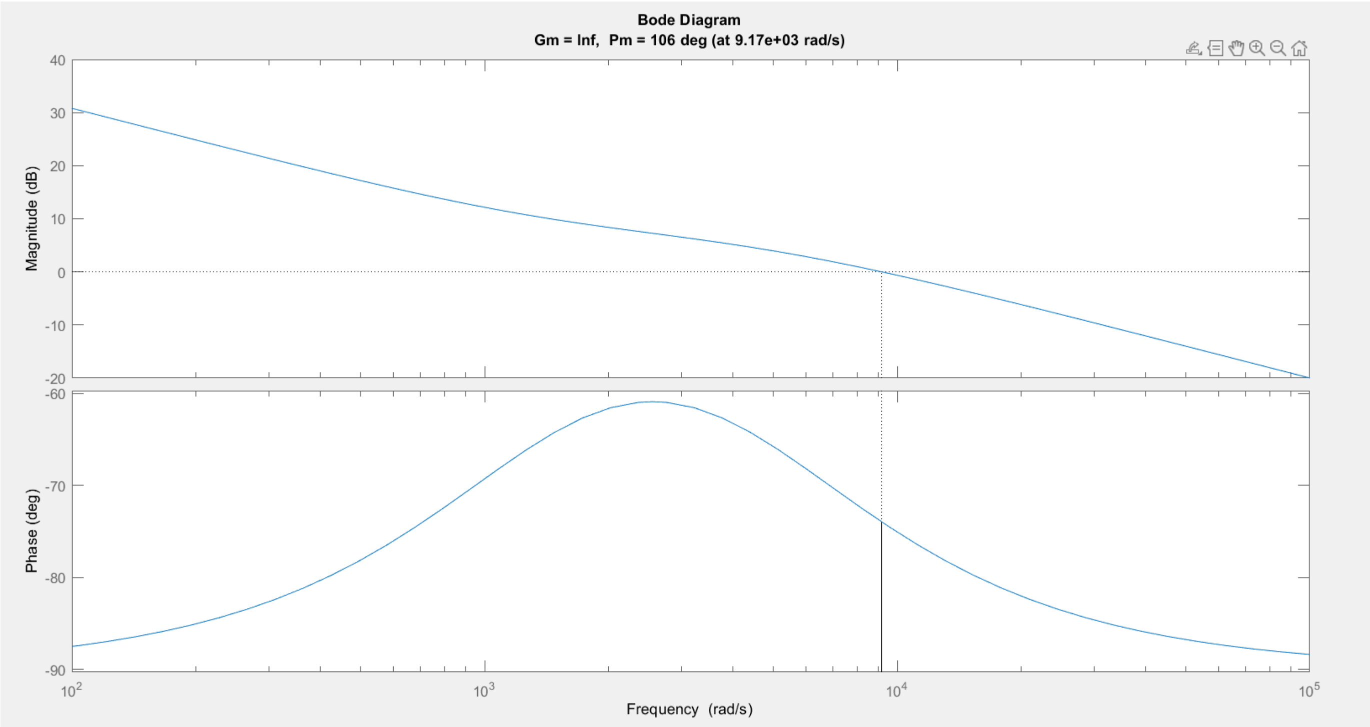
Bode Plot Of Uncompensated System :



Bode Plot of Compensator :



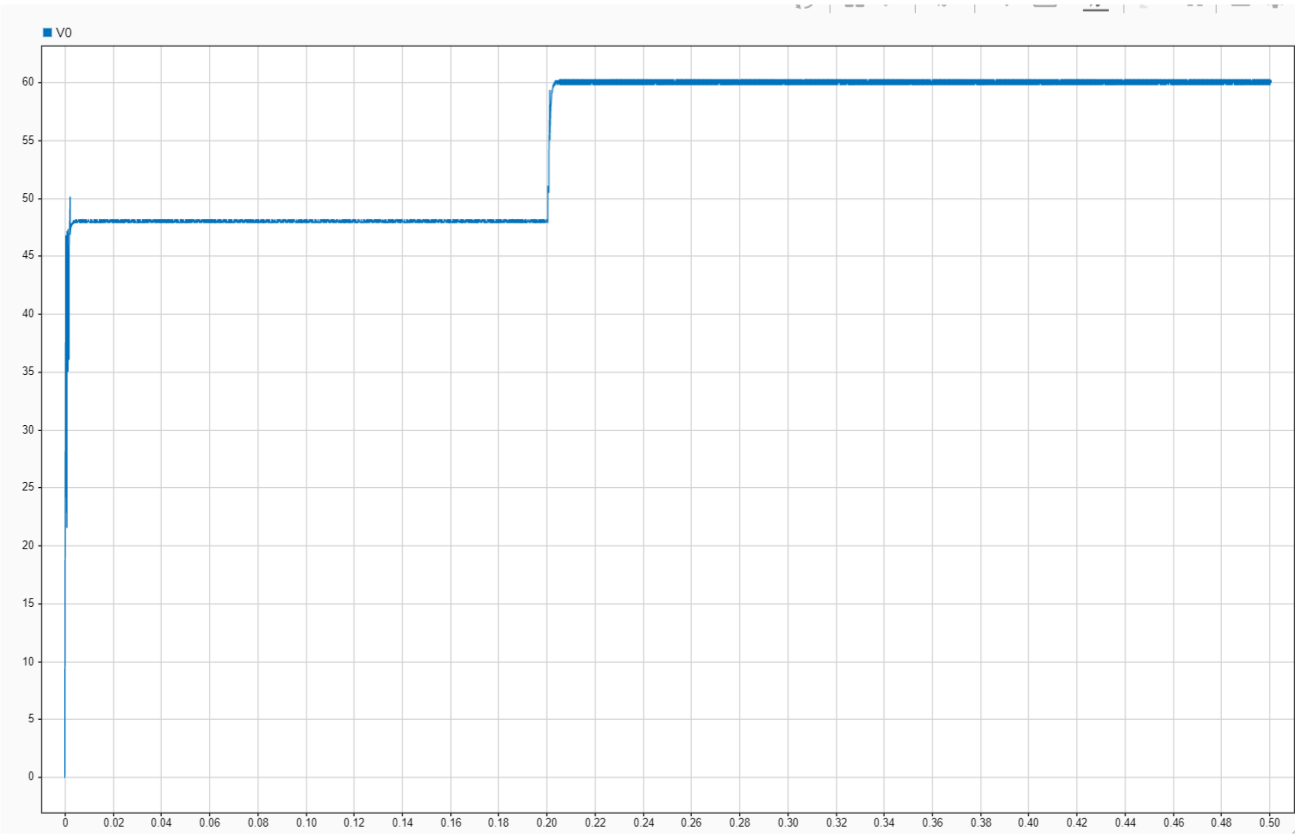
Bode Plot of Compensated System:



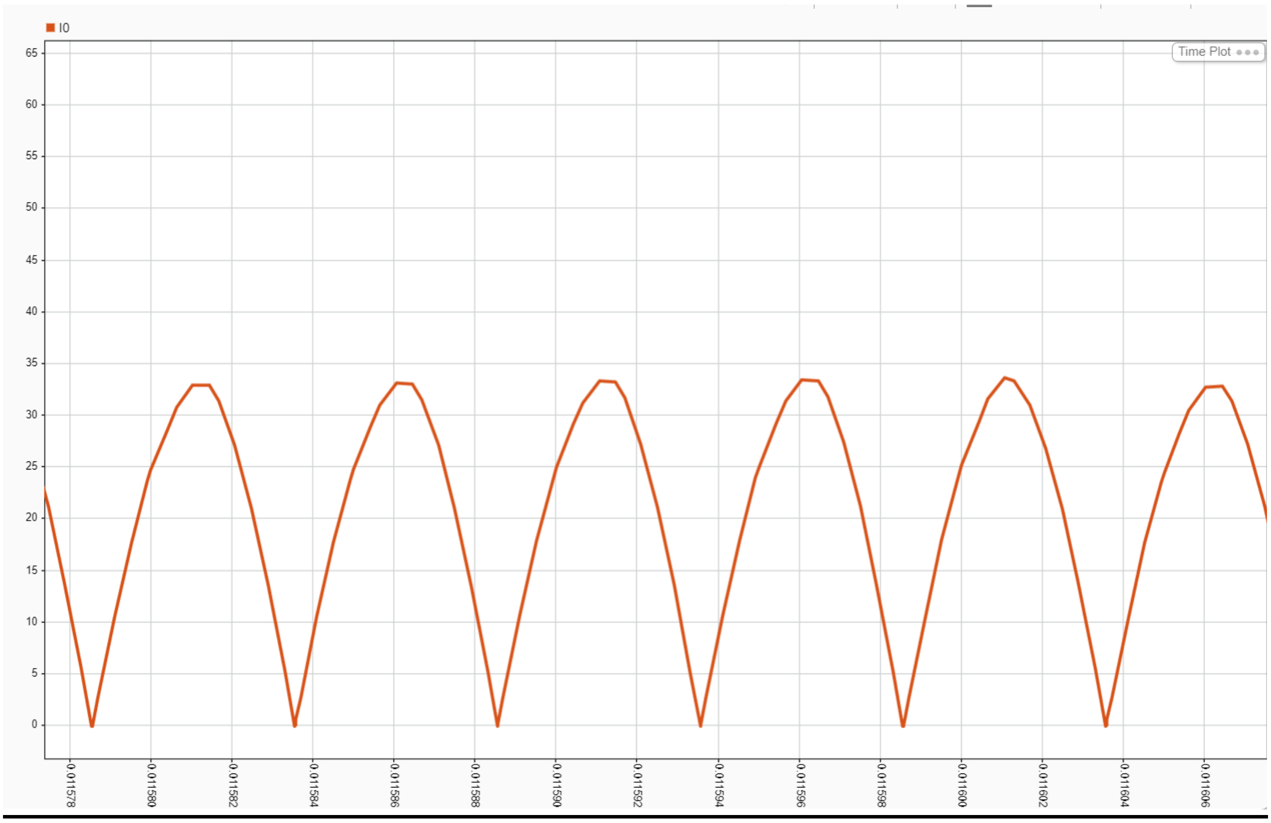
- In the Compensated system we are having Cross over at 9.17*10^3 rad/sec
- And we are getting Phase Margin =106 degree

Output Voltage of Series Resonant DC- DC Converter

After application of step input at 0.2s :



Output Current (Io) :



Switch Ratings :

For Mosfet :

- RMS Current Rating = 6.65A
- Voltage Rating = 400V
- RMS Current Rating Taken = 13.3A Safety factor =2)
- Voltage rating Taken = 600V (Safety Factor =1.5)
- Hyperlink for Datasheet : https://www.mouser.in/datasheet/2/196/Infineon_IPB65R190CFD7A_DataSheet_v02_01_EN-3362448.pdf

For Diode :

- Average Current Rating = 13.375A
- Voltage Rating = 60 V
- Average Current Rating = 20.6A Safety factor =1.5)
- Voltage rating Taken = 90V (Safety Factor =1.5)
- Hyperlink for Datasheet :

https://www.taiwansemi.com/assets/datasheet/pdf.php?pn=SRS2090

Final Results :

As overall T/F is type-1, For unit step I/P, steady

Steady state error $(e_{ss}) = 0$

Result:

- $V_{in} = 400V$
- $V_o = 48V$
- Step applied at 0.25 of 60V (48+12V)
- $f_{sw} = 100KHz$
- $f_{resonant} = 90KHz$
- $\eta = 0.4$
- $L_r = 379.9\mu H$
- $C_r = 6.676nF$
- $C_o = 100\mu F$
- Ripple in output voltage
  1. Before $t < 0.25$, $V_o = 48V$ - without step

     $\Delta V_o = 48.12 - 47.88 = 0.24$ (Peak to Peak).
  2. After $t > 0.25$, $V_o = 48+12V = 60V$ → with step

     $\Delta V_o = 60.20 - 59.82 = 0.38V$ (Peak to Peak)
-