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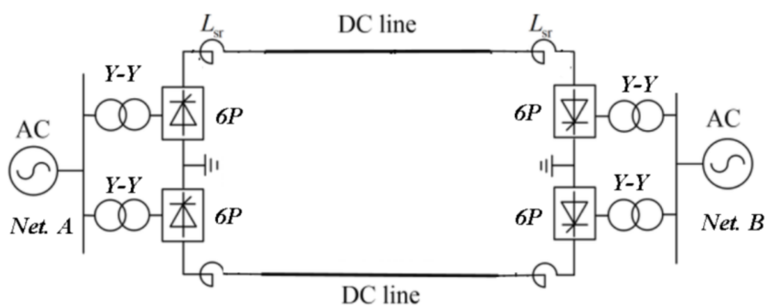
Subject Name: HVDC
Subject Code: EEP 424

Assignment (2) | Bipolar Point-To-Point HVDC-Link | MATLAB Model

Contents

I. System Description:

- A 1600MW 6-pulse bipolar point-to-point HVDC-link shown below. The link interconnects between two AC networks, (network (A): 22kV/50Hz, network (B):20kV/60Hz), through overhead transmission line with a resistance of 10 Ω. The range of firing angle at the rectifier side is (5deg-25deg), while the inverter is operated under minimum γ of 20deg. 1:10 Y-Y ideal transformers with zero leakage inductances are employed. Proper smoothing reactors (L_{sr}) are employed as shown.



II. Six-Pulse Model:

Question (A):

Transferring a power of 1600 MW from side (A) to side (B) during normal operating conditions. Find analytically the suitable firing angle at the rectifier side, and the corresponding dc current.

$$Vdoi = \frac{3\sqrt{2} * 200}{\pi} \cos 20 = 253.81KV$$

$$800 = Vdor * Idc$$

$$Idc = \frac{Vdor - 253.81}{10}$$

$$\therefore 8000 = Vdor^2 - 253.81 * \ Vdor$$

$$\therefore Vdor = 282.16KV$$

$$Vdor = \frac{3\sqrt{2} * 220}{\pi} \cos \alpha = 282.16KV$$

$$\therefore \alpha = 18.25°$$

$$\therefore Idc = \frac{282.16 - 253.81}{10} = 2.835KA$$

Transferring a power of 1200 MW from side (B) to side (A) during normal operating conditions. Find analytically the suitable firing angle at the rectifier side, and the corresponding dc current. (Assume -10% tapping at inverter side, and +10% tapping rectifier side).

$$Vdoi = \frac{3\sqrt{2} * 220 * 0.9}{\pi} \cos 20 = 251.27KV$$

$$600 = Vdor * Idc$$

$$Idc = \frac{Vdor - 251.27}{10}$$

$$\therefore 6000 = Vdor^2 - 251.27 * Vdor$$

$$\therefore Vdor = 273.23KV$$

$$Vdor = \frac{3\sqrt{2} * 200 * 1.1}{\pi} \cos \alpha = 273.23KV$$

$$\therefore \alpha = 23.13°$$

$$\therefore Idc = \frac{273.23 - 251.27}{10} = 2.196KA$$

Transferring a power of 1600MW from side (A) to side (B) during 2.5% voltage swell at network (A).

$$Vdoi = \frac{3\sqrt{2} * 200}{\pi} \cos 20 = 253.81KV$$

$$800 = Vdor * Idc$$

$$Idc = \frac{Vdor - 253.81}{10}$$

$$\therefore 8000 = Vdor^2 - 253.81 * Vdor$$

$$\therefore Vdor = 282.16KV$$

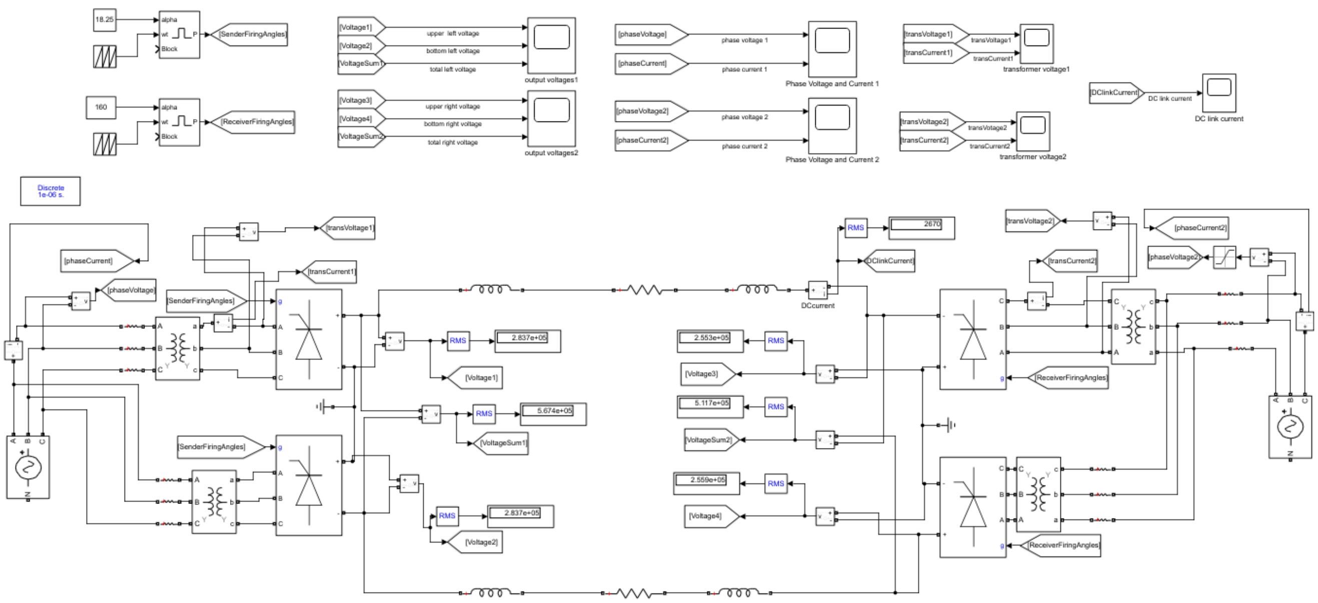
$$Vdor = \frac{3\sqrt{2} * 220 * 1.025}{\pi} \cos \alpha = 282.16KV$$

$$\therefore \alpha = 22.099°$$

$$\therefore Idc = \frac{282.16 - 253.81}{10} = 2.835KA$$

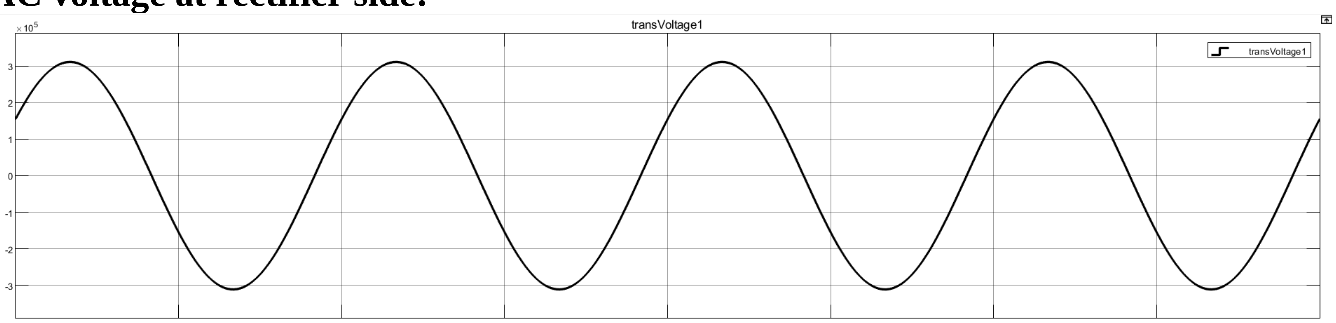
Question (B):

Model Screenshot:

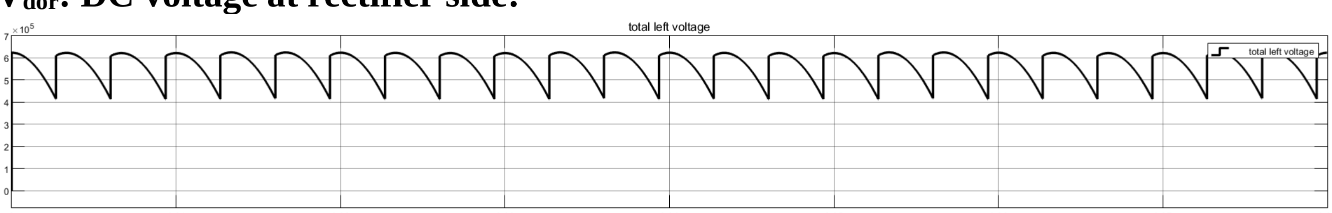


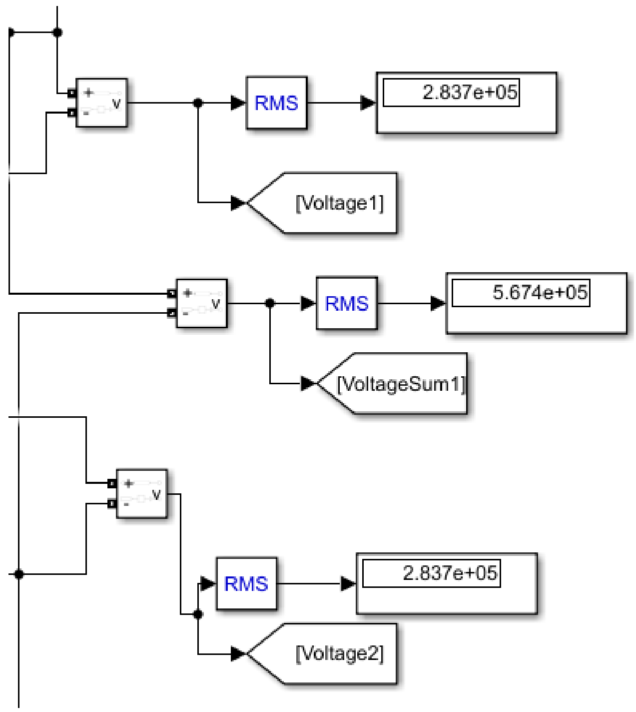
Case (1): 1600MW: Power flow from (A) to (B): Net(A) is rectifier and Net(B) is inverter:

AC voltage at rectifier side:

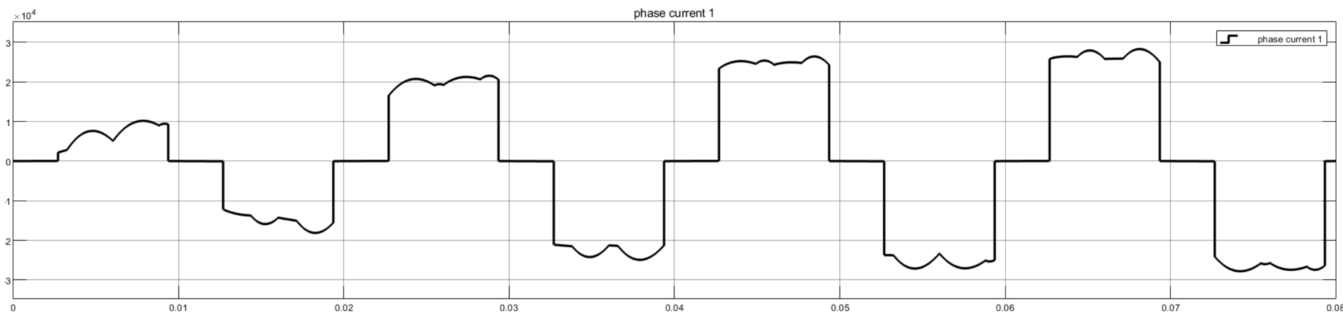


V_{dor}: DC voltage at rectifier side:

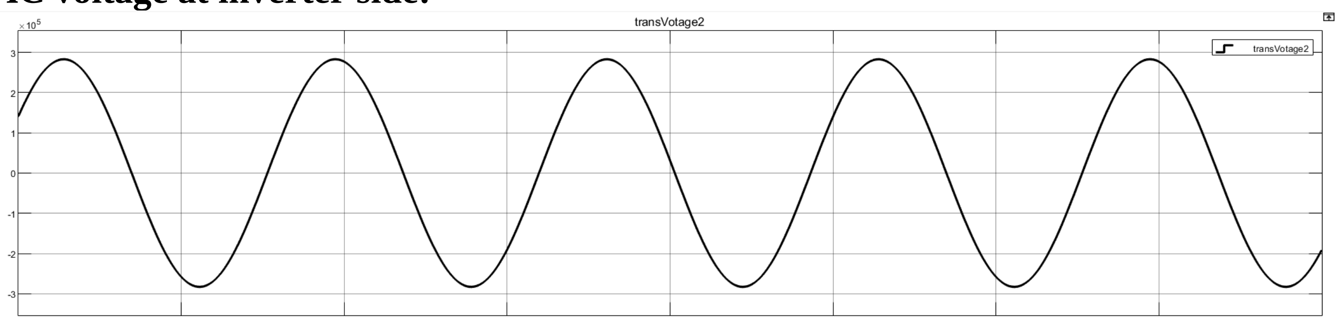




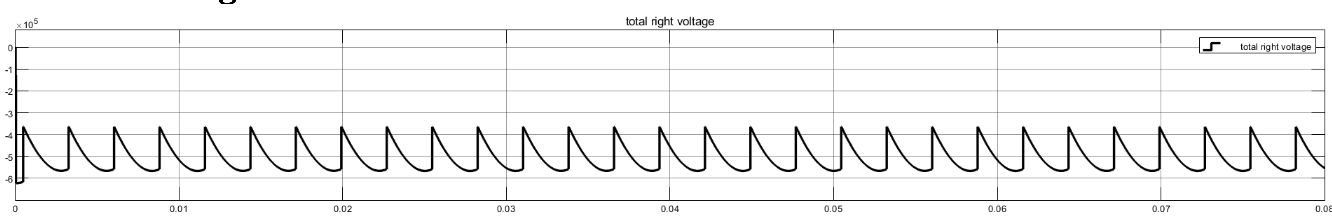
Grid current at rectifier side:

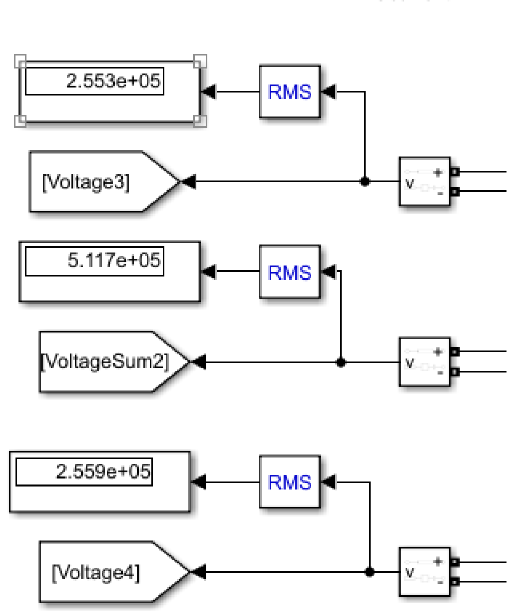


AC voltage at inverter side:

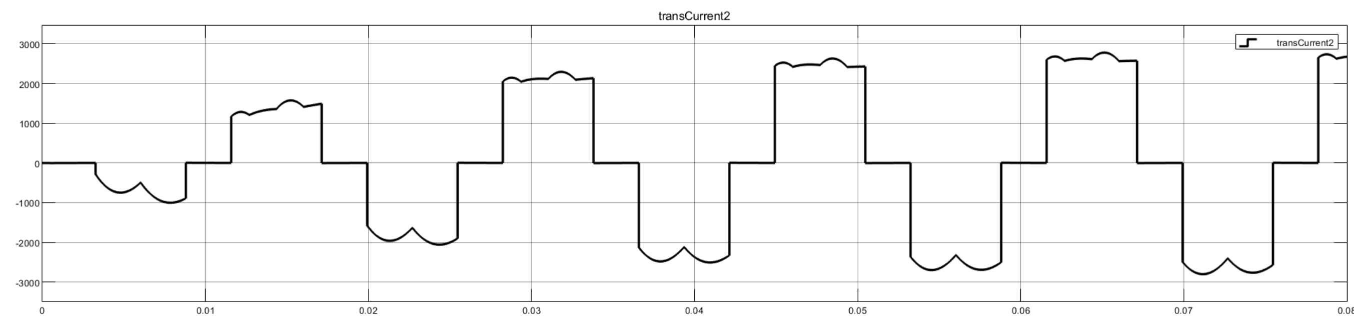


V_{doi}: DC voltage at inverter side:

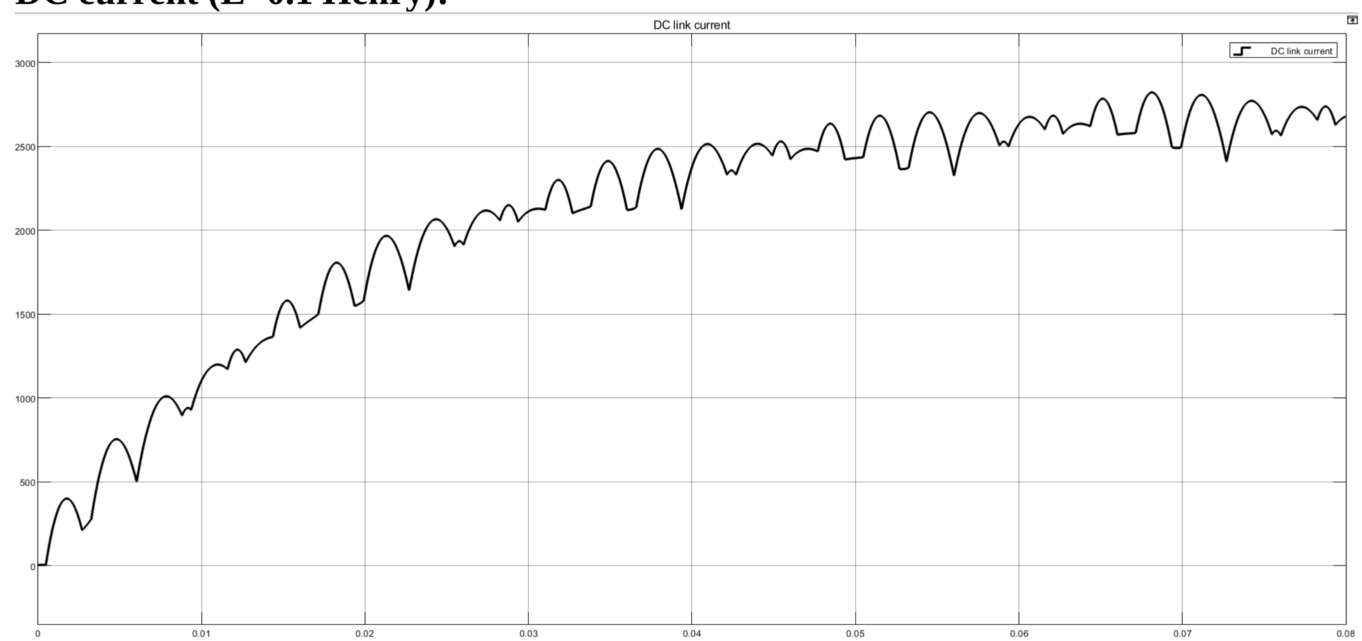


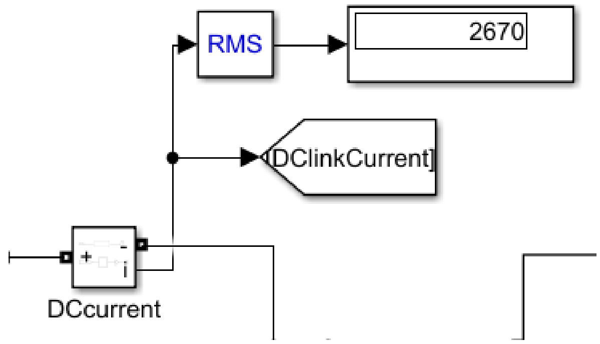


Grid current at inverter side:



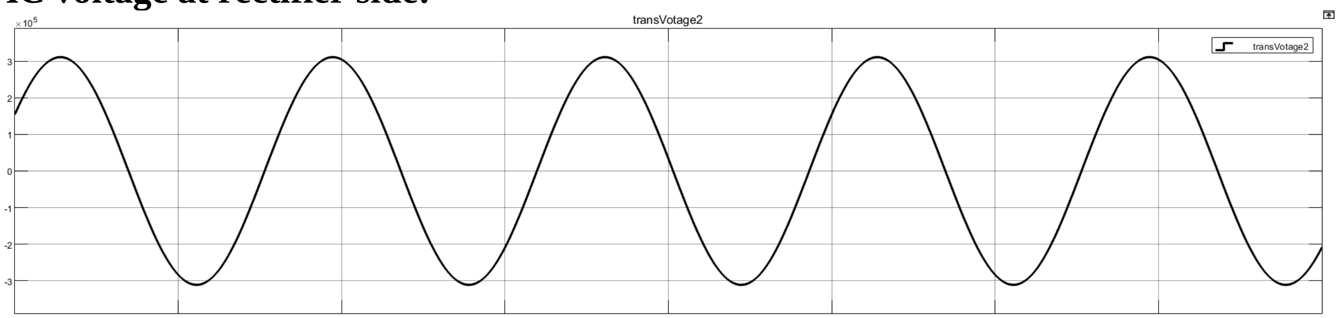
DC current (L=0.1 Henry):



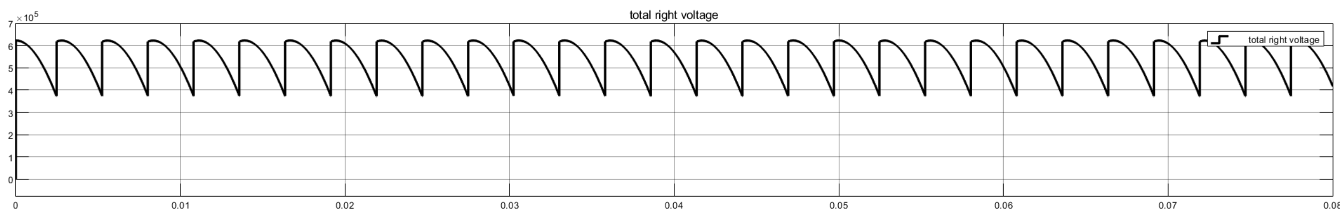


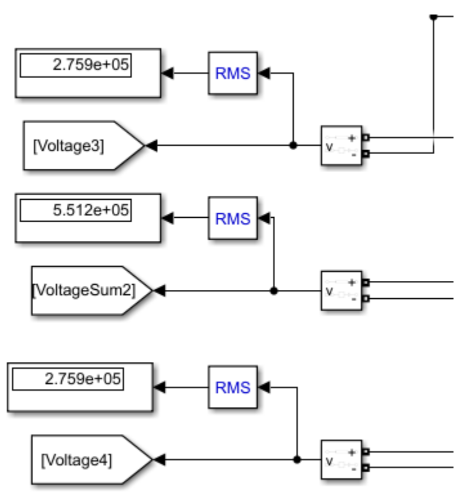
Case (2): 1200MW: Power flow from (B) to (A): Net(B) is rectifier (+10%) and Net(A) is inverter (-10%):

AC voltage at rectifier side:

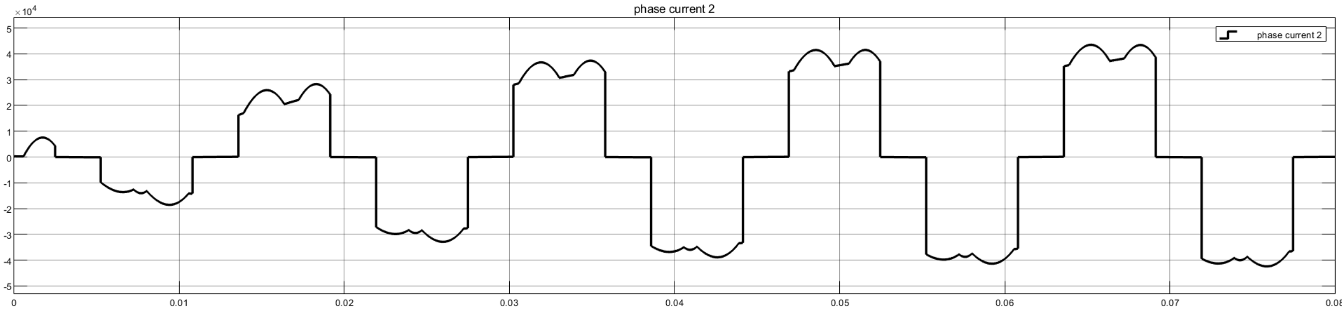


V_{dor}: DC voltage at rectifier side:

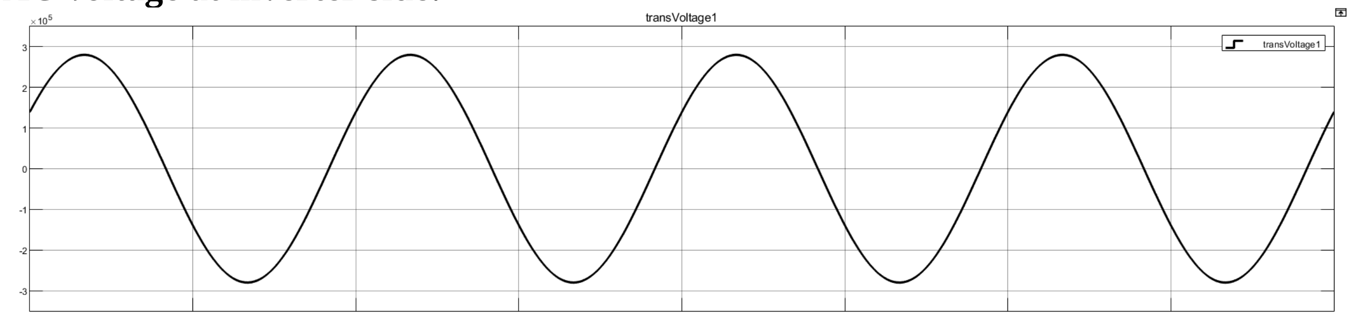




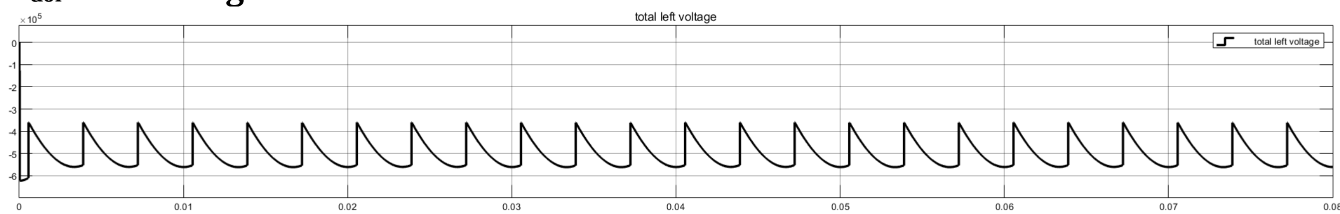
Grid current at rectifier side:

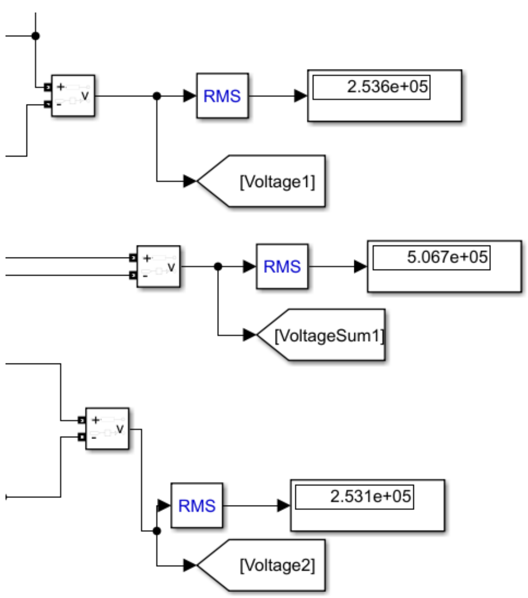


AC voltage at inverter side:

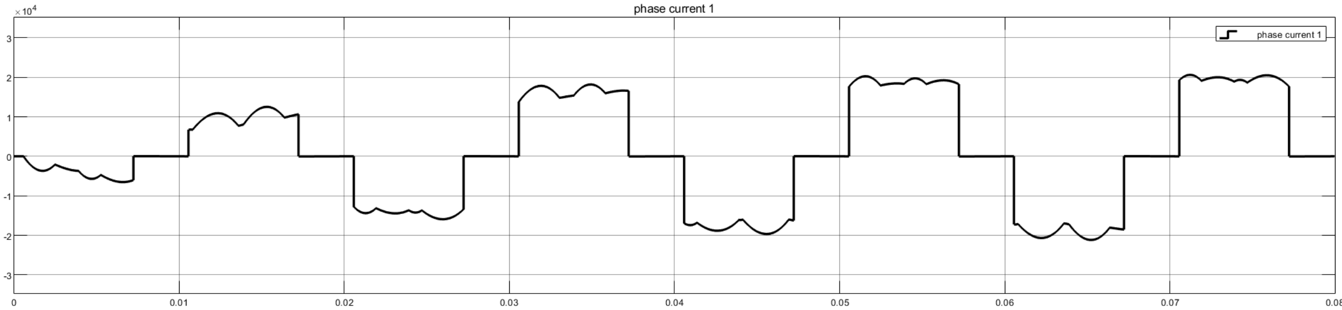


V_{doi}: DC voltage at inverter side:

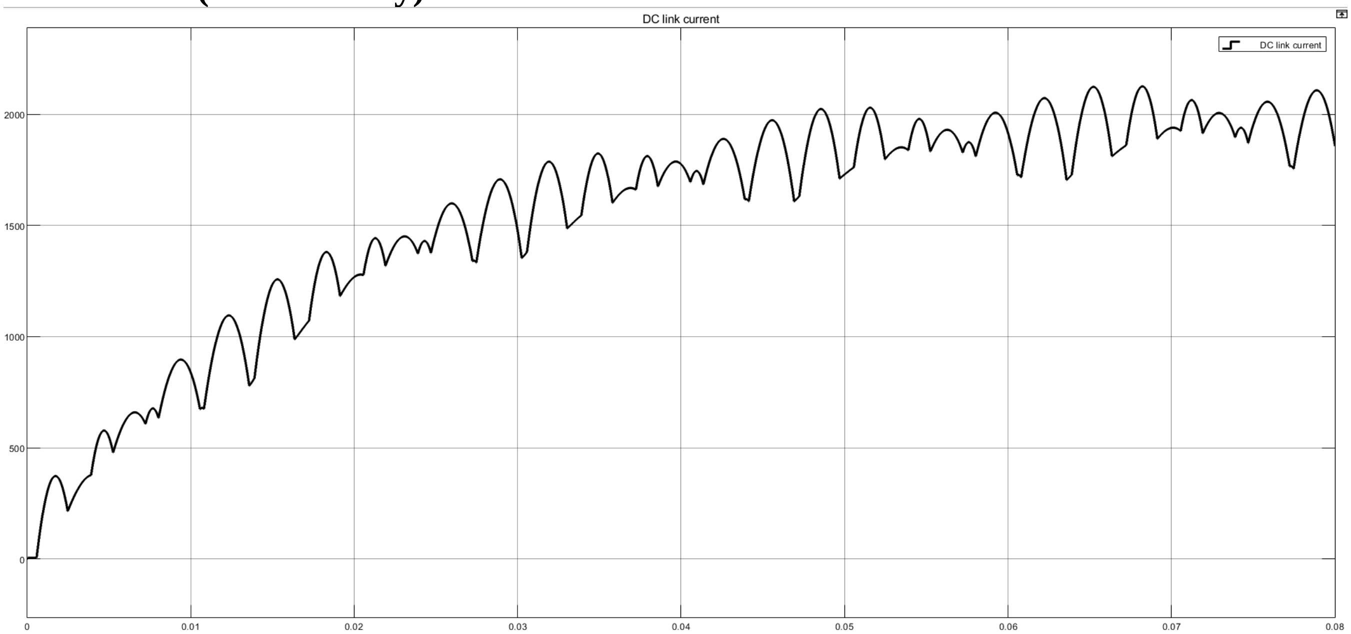


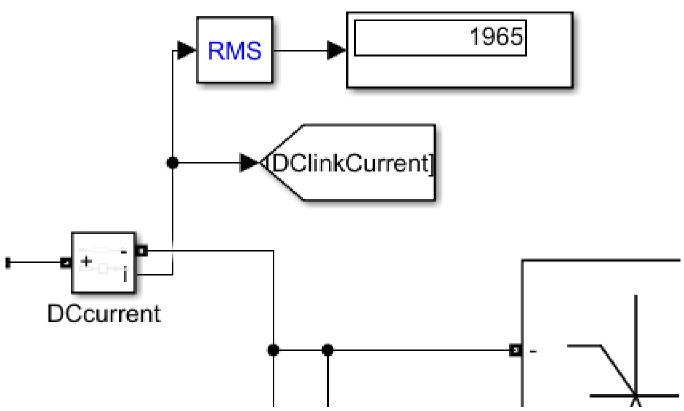


Grid current at inverter side:



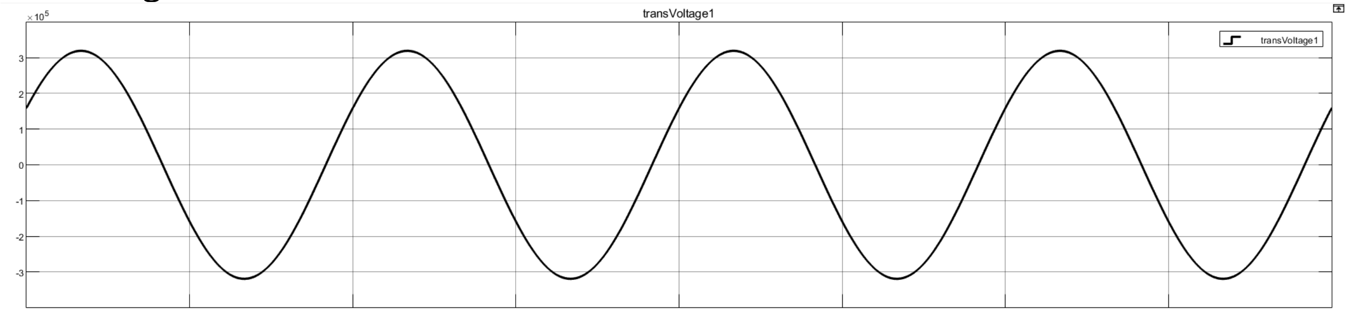
DC current (L=0.1 Henry):



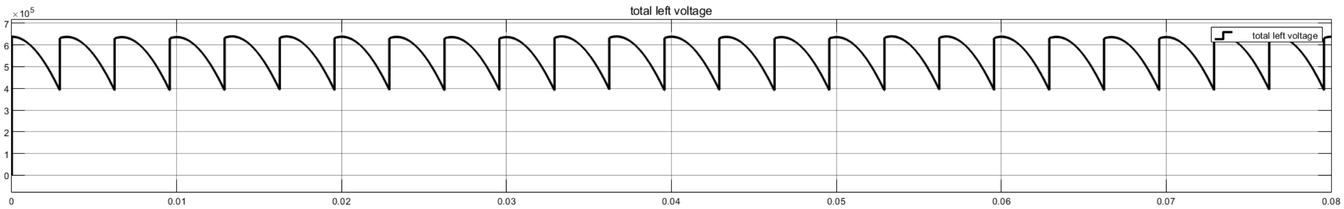


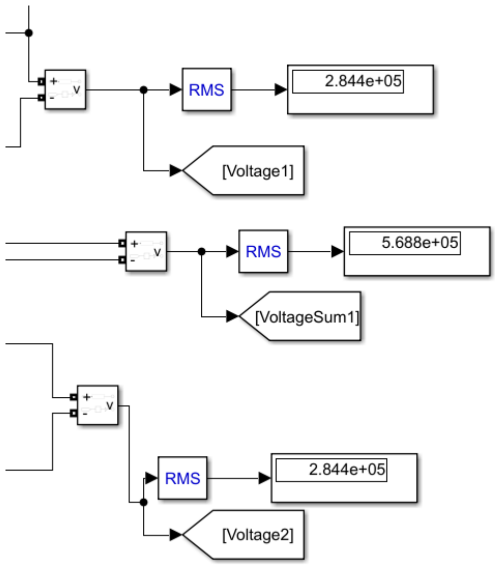
Case (3): 1600MW: Power flow from (A) to (B): Net(A) is rectifier (2.5% voltage swell) and Net(B) is inverter:

AC voltage at rectifier side:

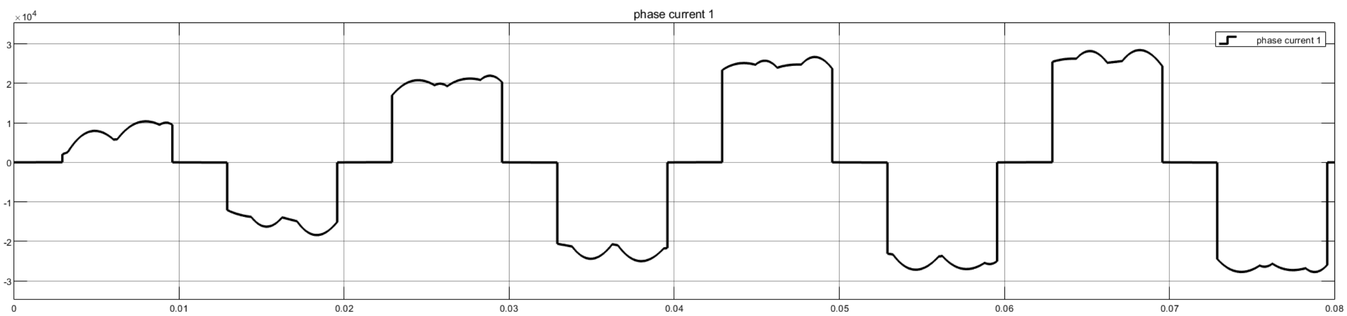


V_{dor}: DC voltage at rectifier side:

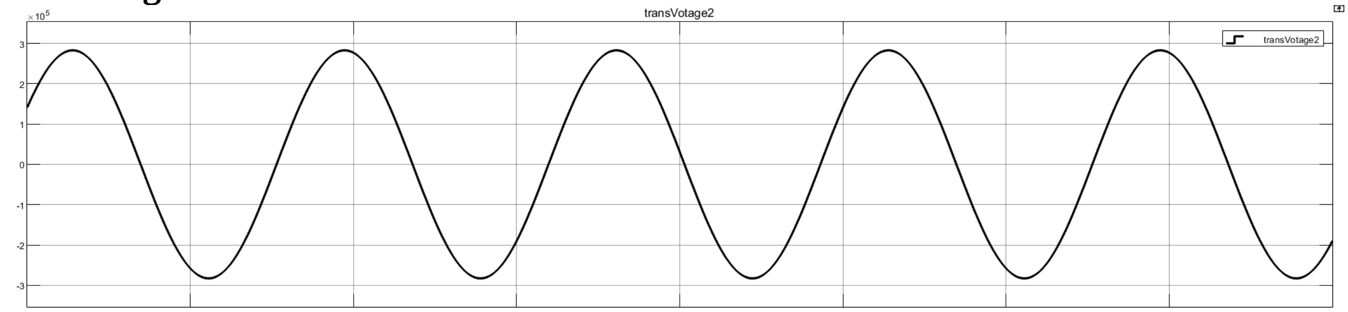




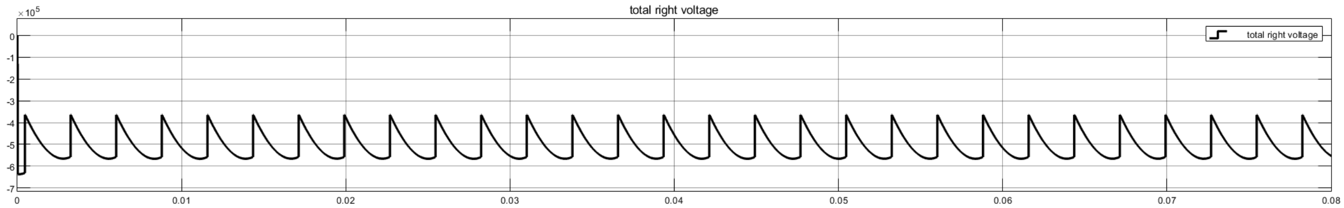
Grid current at rectifier side:

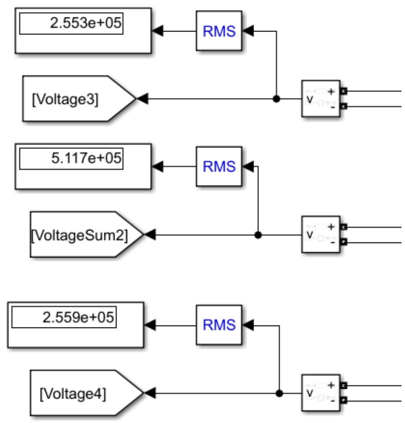


AC voltage at inverter side:

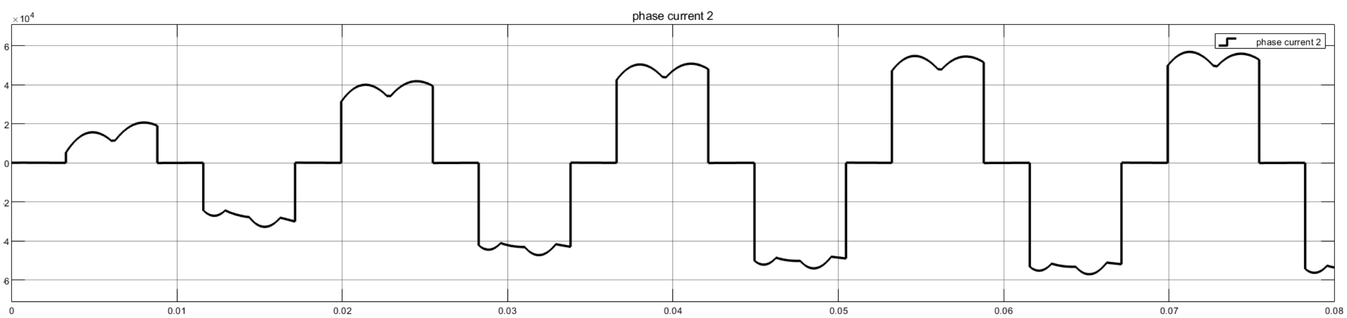


V_{doi}: DC voltage at inverter side:

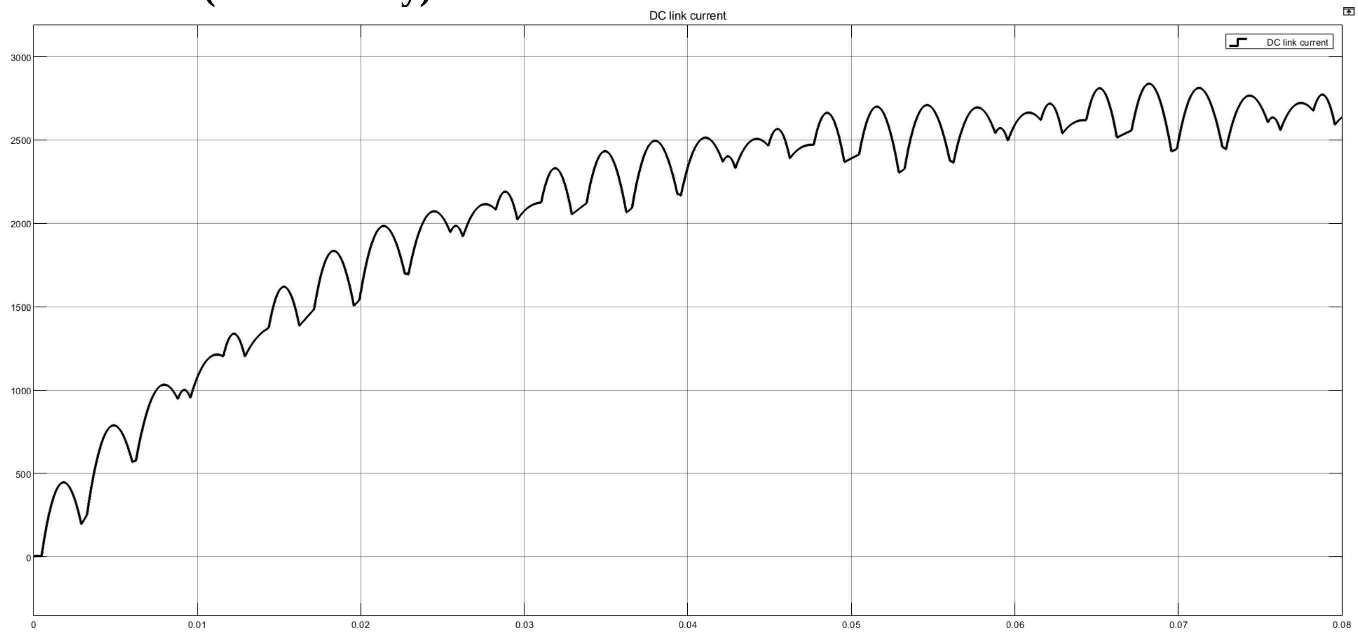


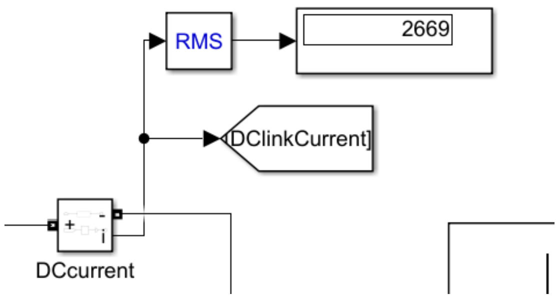


Grid current at inverter side:



DC current (L=0.1 Henry):

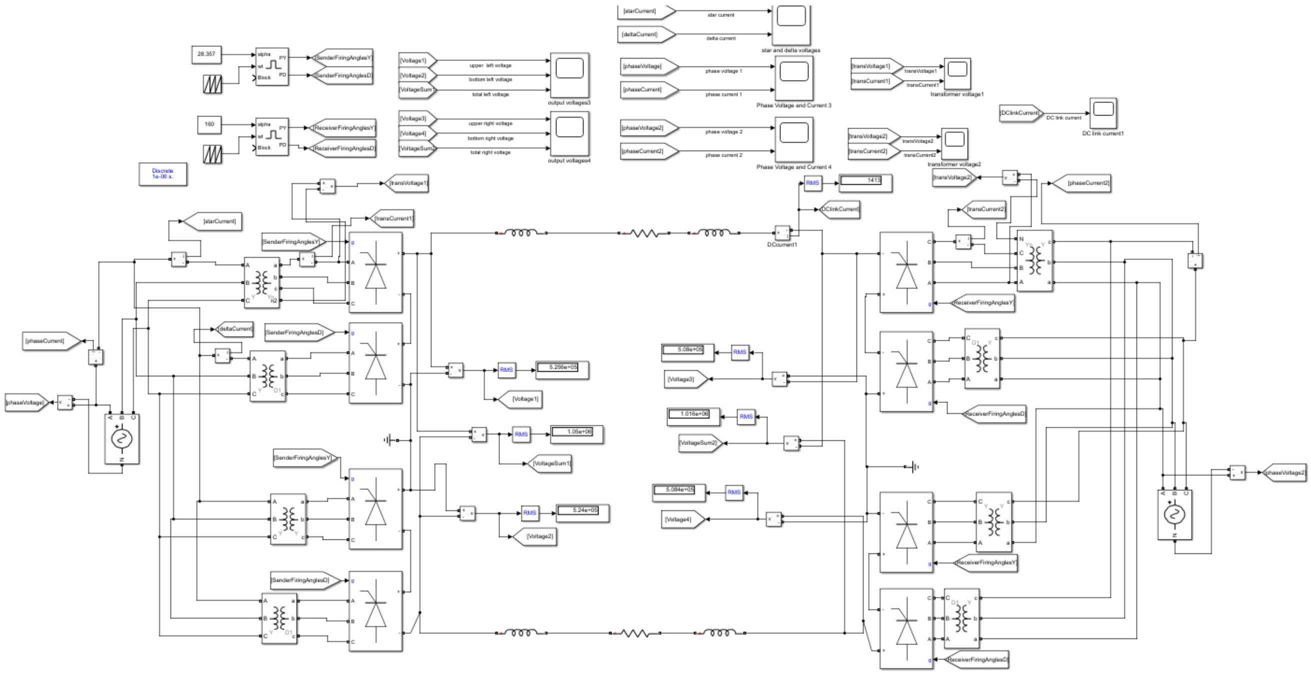




III. Twelve-Pulse Model:

Question (C):

Model Screenshot:



Case (1): 1600MW: Power flow from (A) to (B): Net(A) is rectifier and Net(B) is inverter:

Analytical Calculations:

$$Vdoi = \frac{2 * 3\sqrt{2} * 200}{\pi} \cos 20 = 507.61KV$$

$$800 = Vdor * Idc$$

$$Idc = \frac{Vdor - 507.61}{10}$$

$$\therefore 8000 = Vdor^2 - 507.61 * \ Vdor$$

$$\therefore Vdor = 522.909KV$$

$$Vdor = \frac{2 * 3\sqrt{2} * 220}{\pi} \cos \alpha = 522.909KV$$

$$\therefore \alpha = 28.357°$$

$$\therefore Idc = \frac{522.909 - 507.61}{10} = 1.5299KA$$

- Since alpha (α) here is more than 25 degrees, the maximum permissible limit, I will work with changing the tap transformer ratio to -5% to go back to the allowable range of (5→25degrees); working with -2.5% exceeded the upper range too ($\alpha = 25.5\ degrees$).

$Vdoi = 507.61KV$

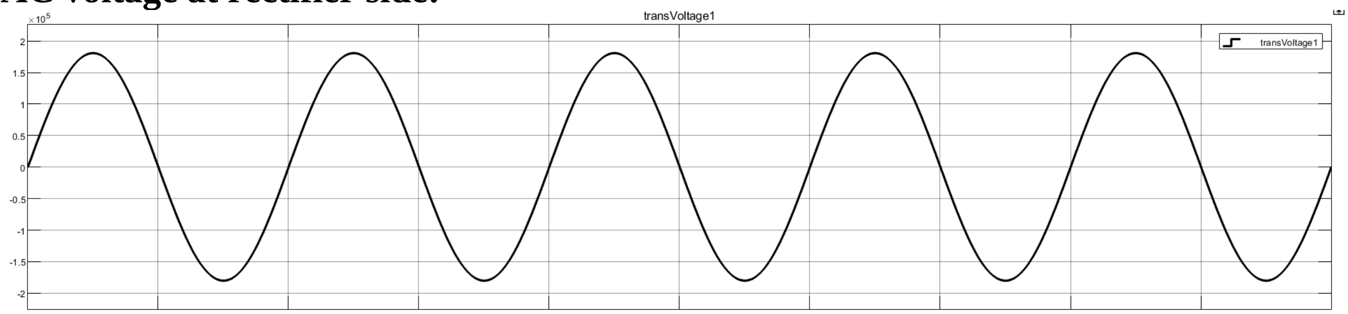
$Vdor = 522.909KV$

$$Vdor = \frac{2 * 3\sqrt{2} * 220 * 0.95}{\pi} \cos\alpha = 522.909KV$$

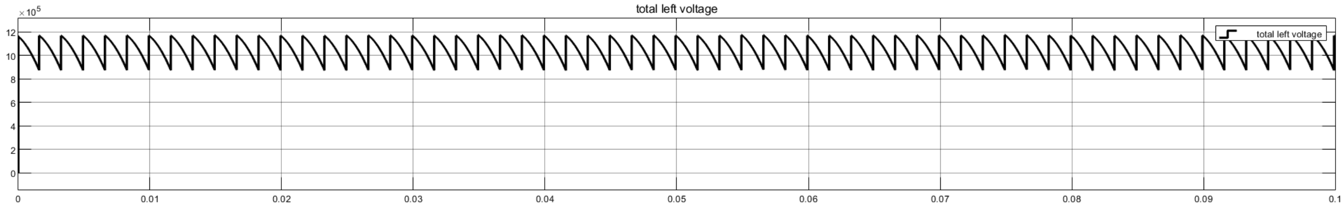
$\therefore \alpha = 22.131°$

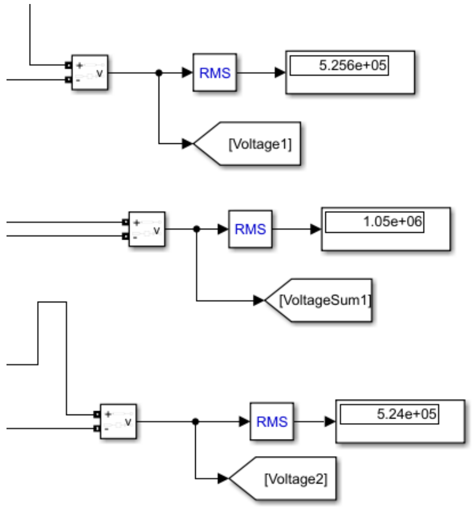
$$\therefore Idc = \frac{522.909 - 507.61}{10} = 1.5299KA$$

AC voltage at rectifier side:

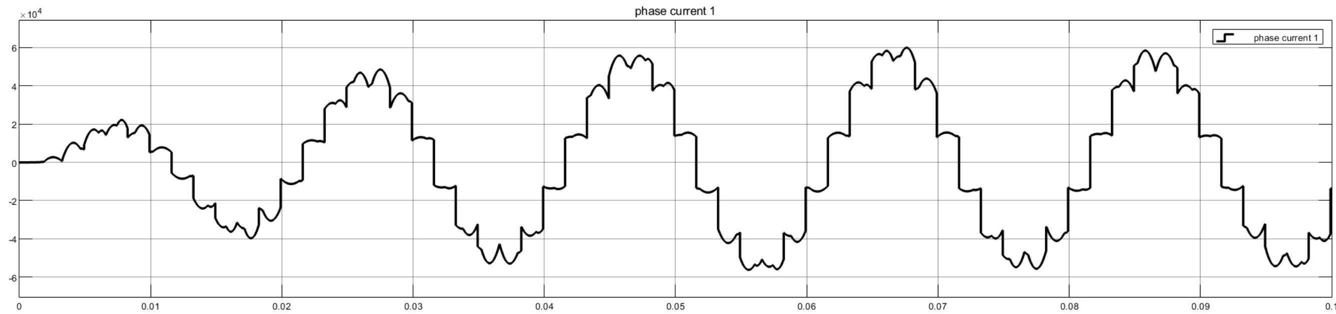


V_{dor}: DC voltage at rectifier side:

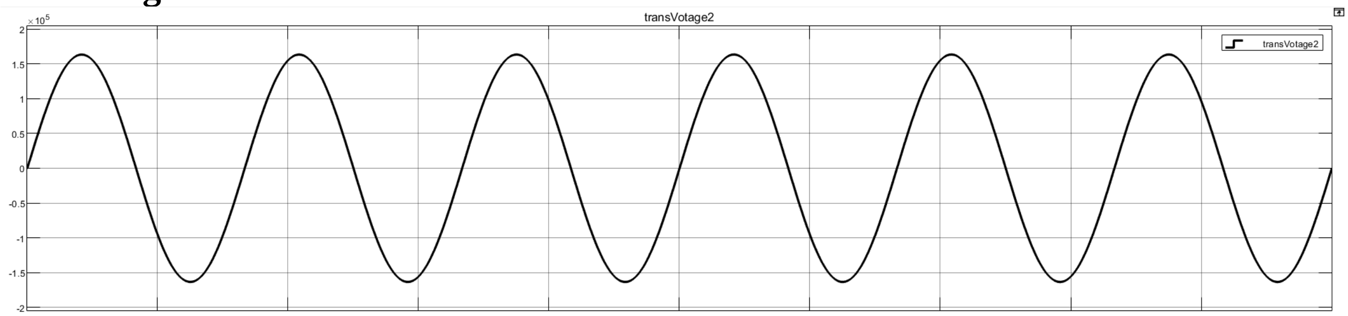




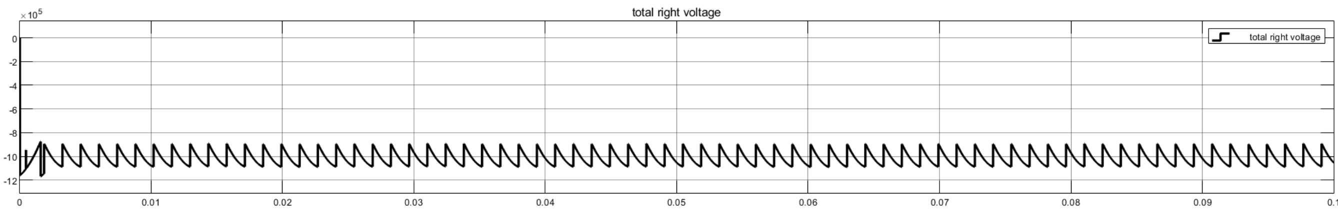
Grid current at rectifier side:

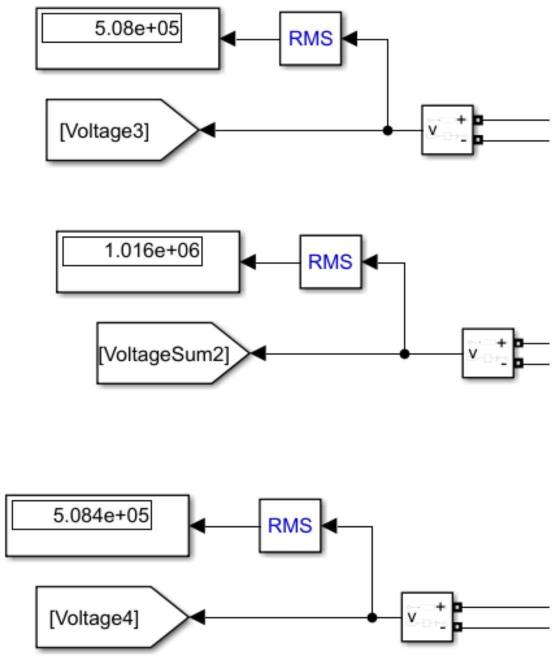


AC voltage at inverter side:

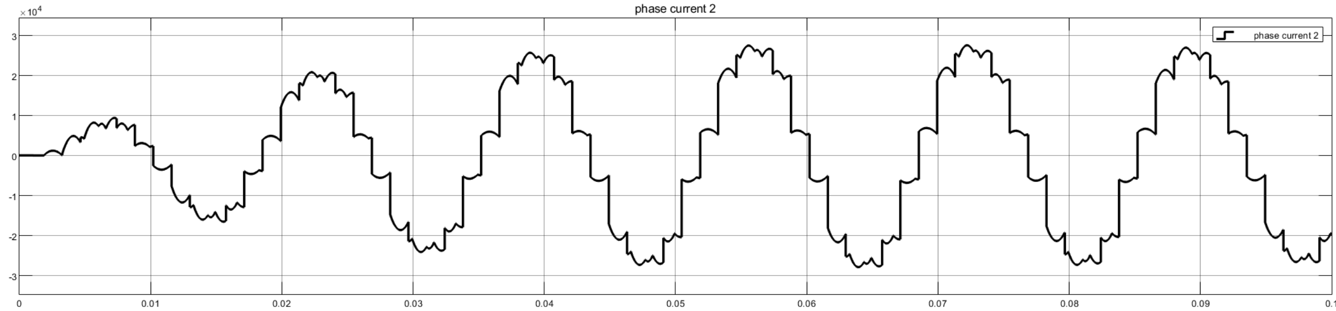


V_{doi}: DC voltage at inverter side:

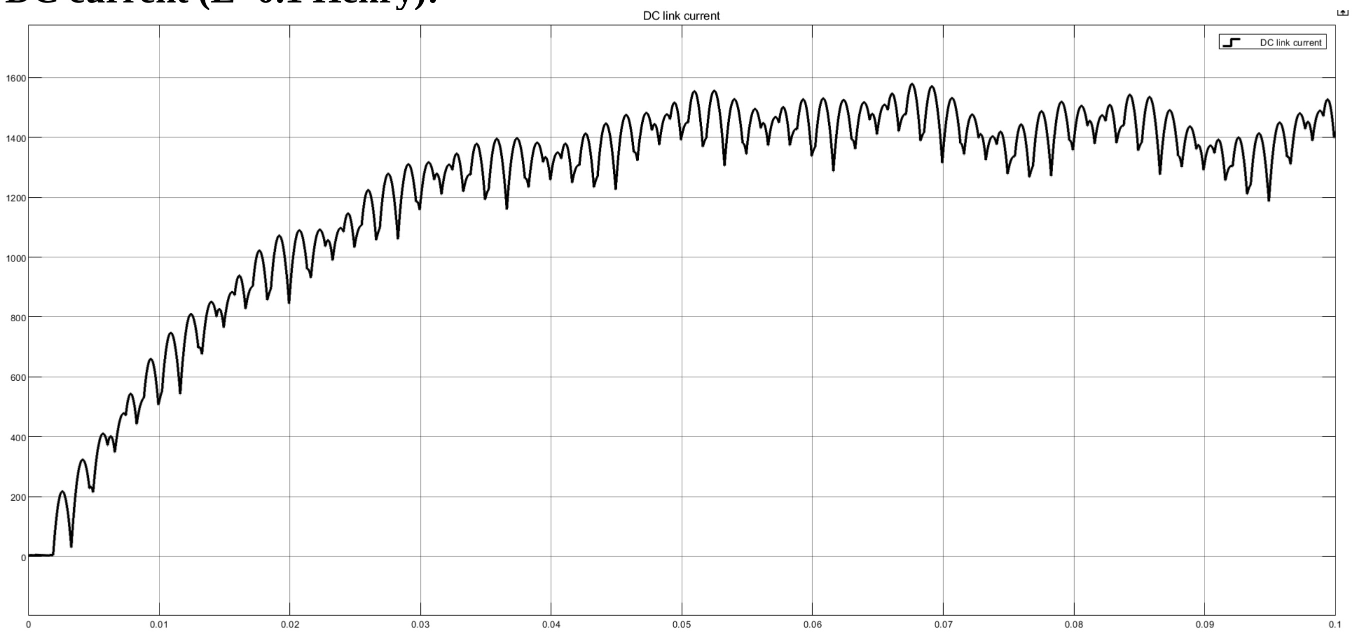


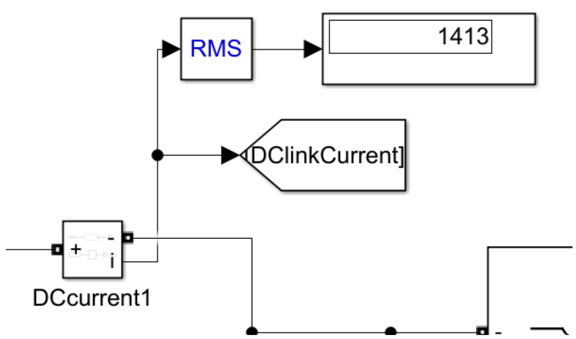


Grid current at inverter side:



DC current (L=0.1 Henry):





Case (2): 1200MW: Power flow from (B) to (A): Net(B) is rectifier (+10%) and Net(A) is inverter (-10%):

Analytical Calculations:

$$Vdoi = \frac{2 * 3\sqrt{2} * 220 * 0.9}{\pi} \cos 20 = 502.54KV$$

$$600 = Vdor * Idc$$

$$Idc = \frac{Vdor - 502.54}{10}$$

$$\therefore 6000 = Vdor^2 - 502.54 * Vdor$$

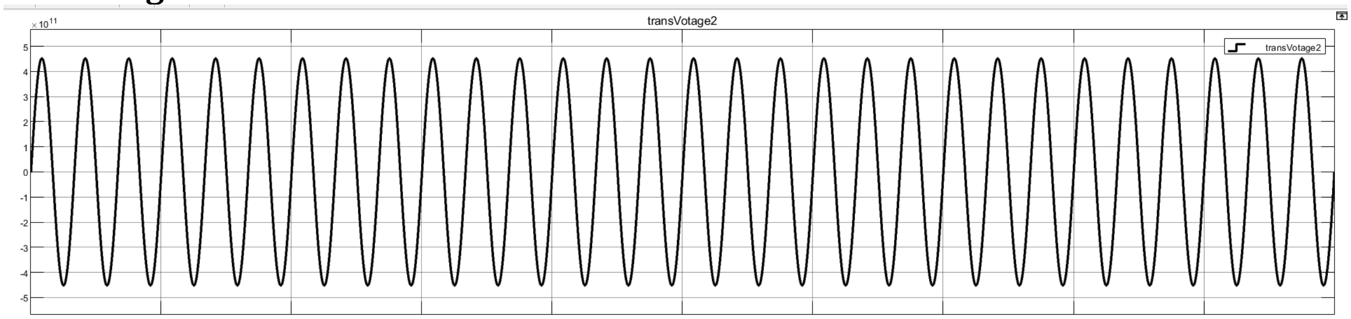
$$\therefore Vdor = 514.21KV$$

$$Vdor = \frac{2 * 3\sqrt{2} * 200 * 1.1}{\pi} \cos \alpha = 514.21KV$$

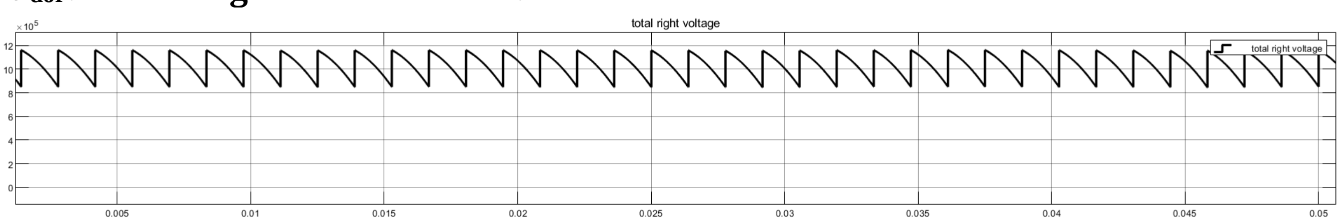
$\therefore \alpha = 30.08°$ → Higher than maximum limit but transformer tapping ratio is already modified I don't know…

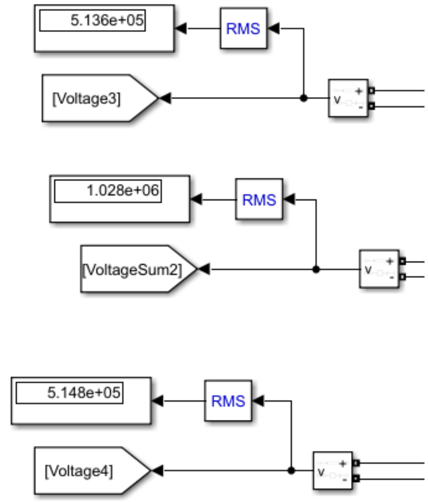
$$\therefore Idc = \frac{514.21 - 502.54}{10} = 1.167KA$$

AC voltage at rectifier side:

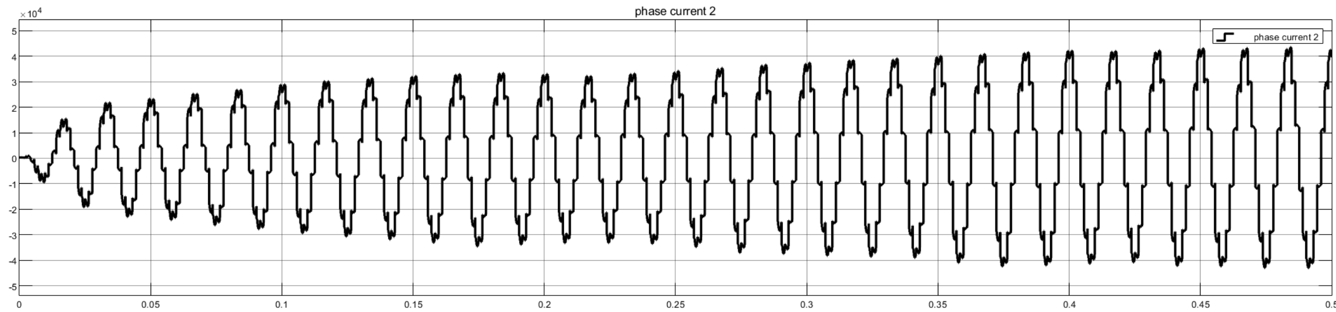


V_{dor}: DC voltage at rectifier side:

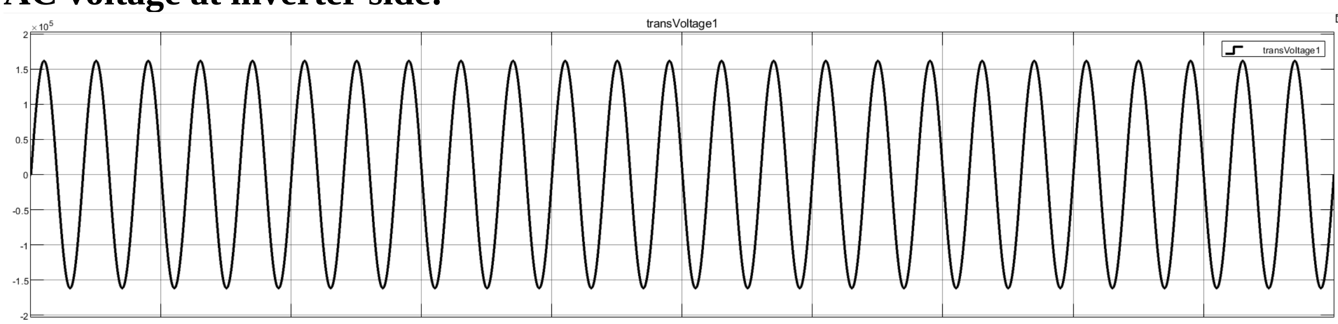




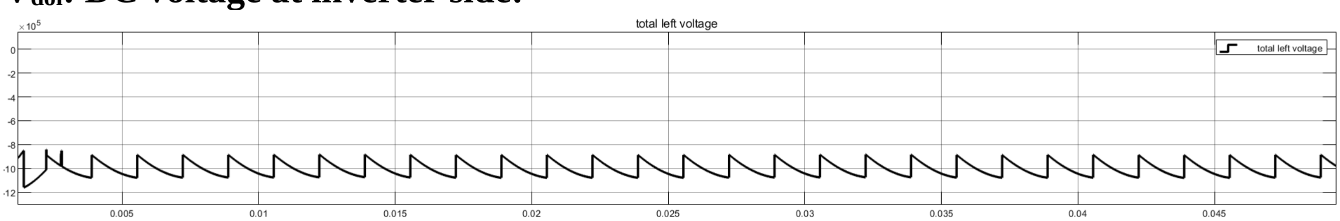
Grid current at rectifier side:

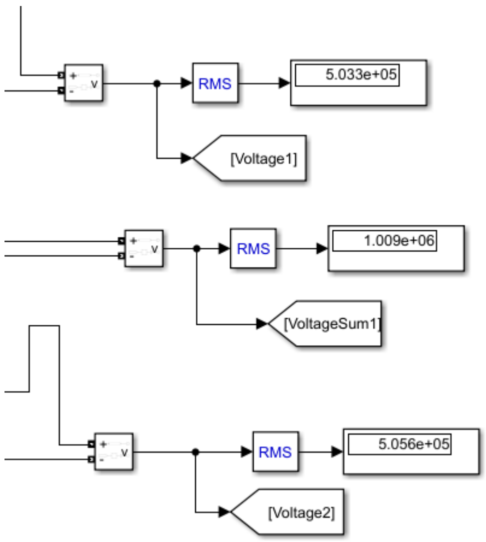


AC voltage at inverter side:

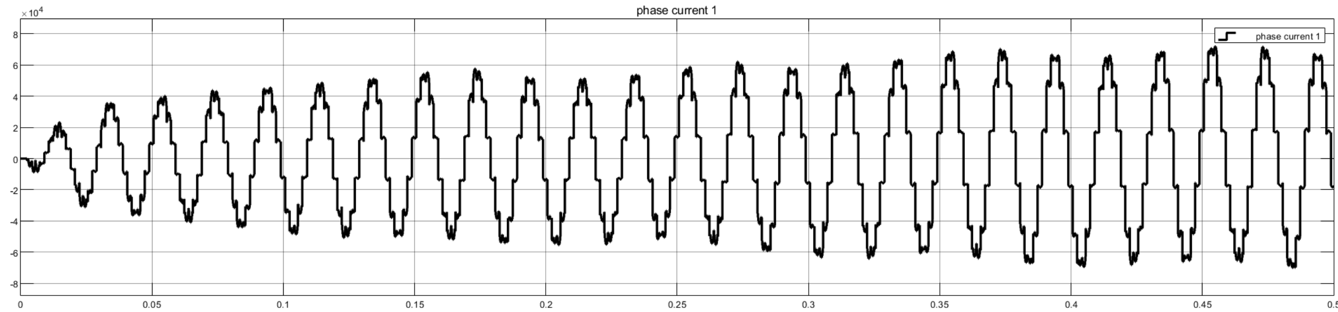


V_{doi}: DC voltage at inverter side:

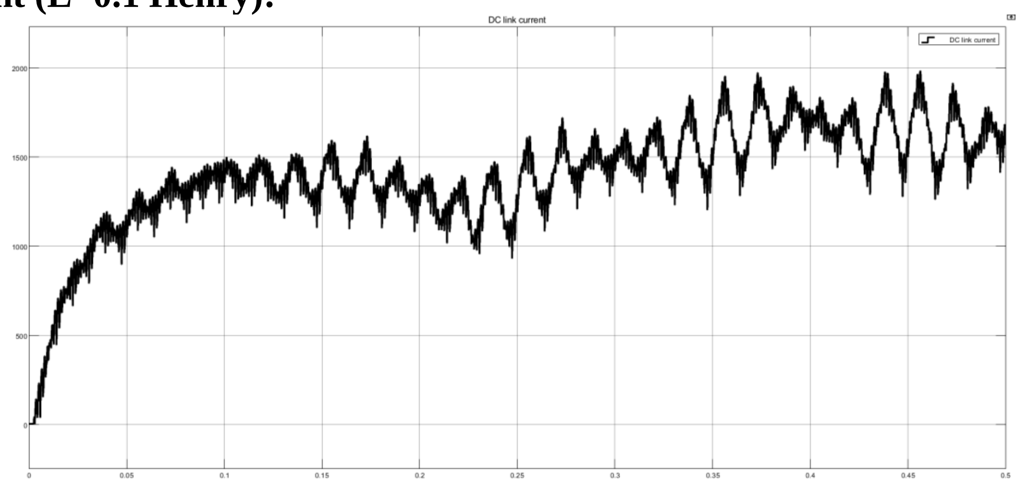


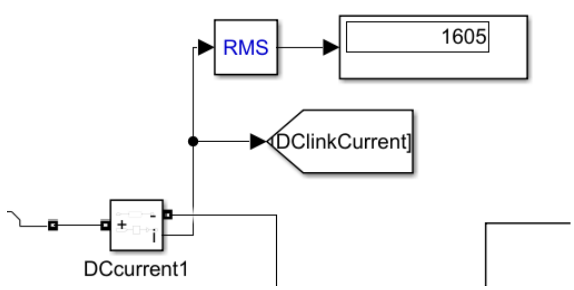


Grid current at inverter side:



DC current (L=0.1 Henry):





Case (3): 1600MW: Power flow from (A) to (B): Net(A) is rectifier (2.5% voltage swell) and Net(B) is inverter:

Analytical Calculations:

$$Vdoi = \frac{2 * 3\sqrt{2} * 200}{\pi} \cos 20 = 507.61KV$$

$$800 = Vdor * Idc$$

$$Idc = \frac{Vdor - 507.61}{10}$$

$$\therefore 8000 = Vdor^2 - 507.61 * \ Vdor$$

$$\therefore Vdor = 522.909KV$$

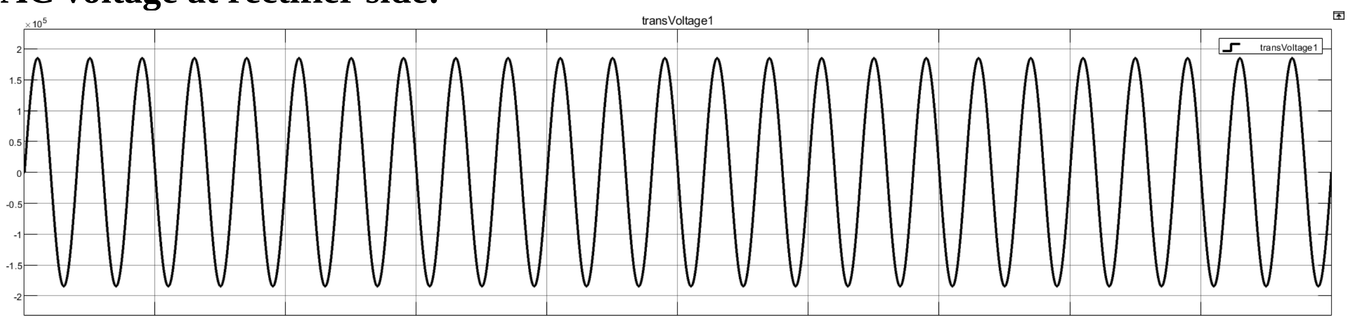
$$Vdor = \frac{2 * 3\sqrt{2} * 220 * 1.025}{\pi} \cos\alpha = 522.909KV$$

$$\therefore \alpha = 30.85°$$

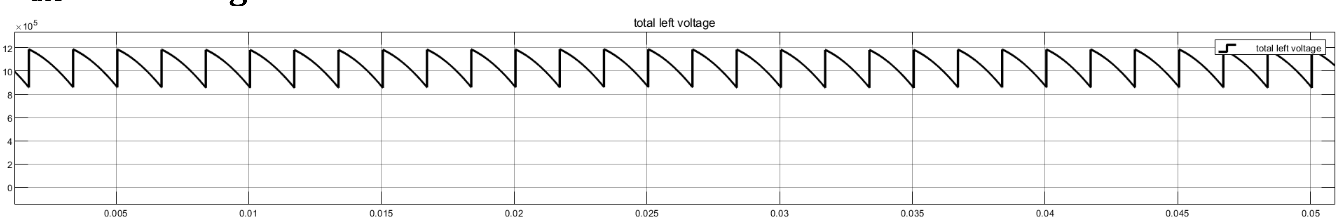
$$\therefore Idc = \frac{522.909 - 507.61}{10} = 1.5299KA$$

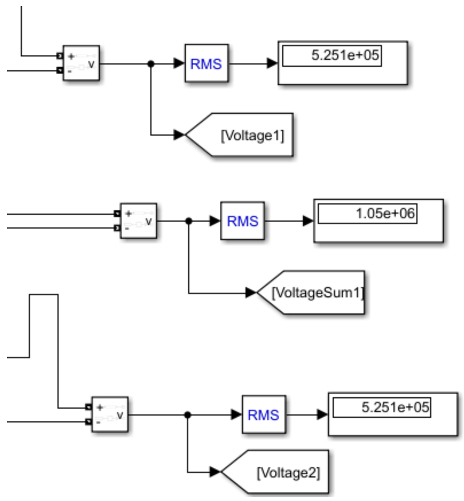
- Again, alpha exceeds the limit, but I will leave it for now...

AC voltage at rectifier side:

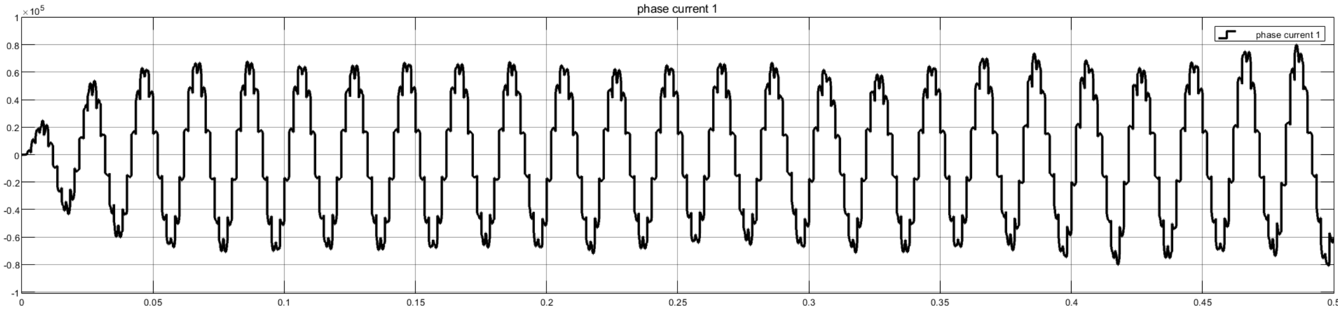


V_{dor}: DC voltage at rectifier side:

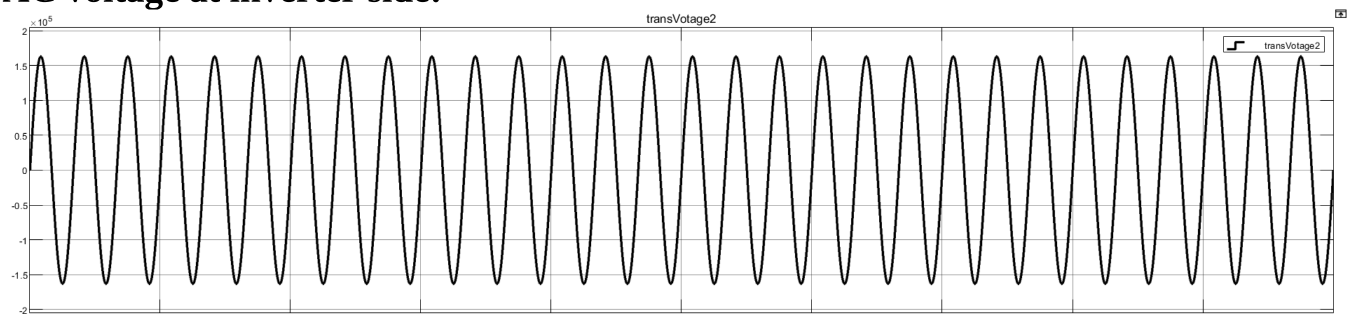




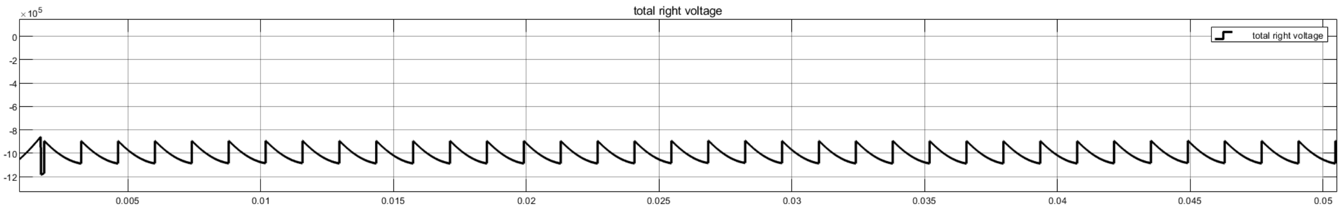
Grid current at rectifier side:

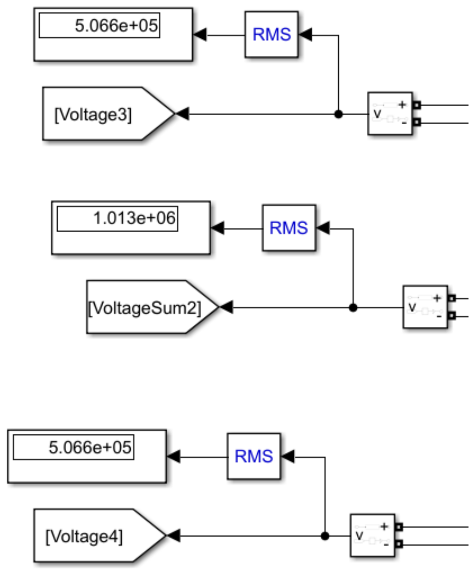


AC voltage at inverter side:

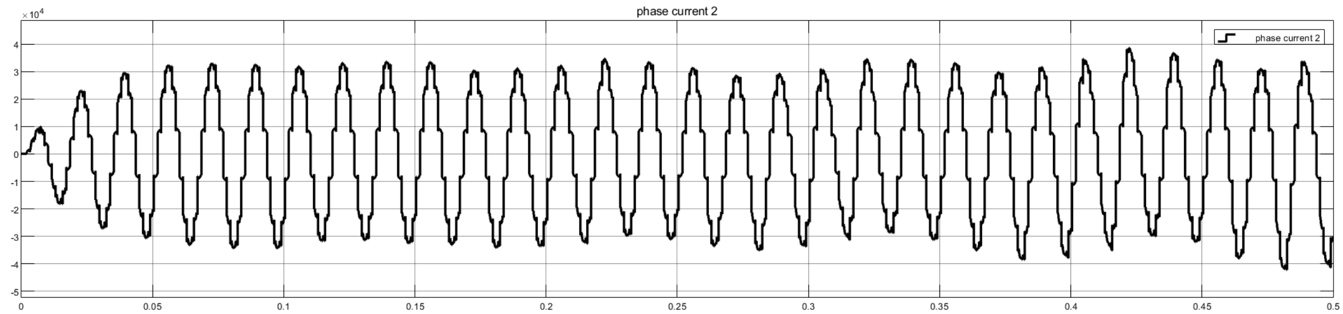


V_{doi}: DC voltage at inverter side:

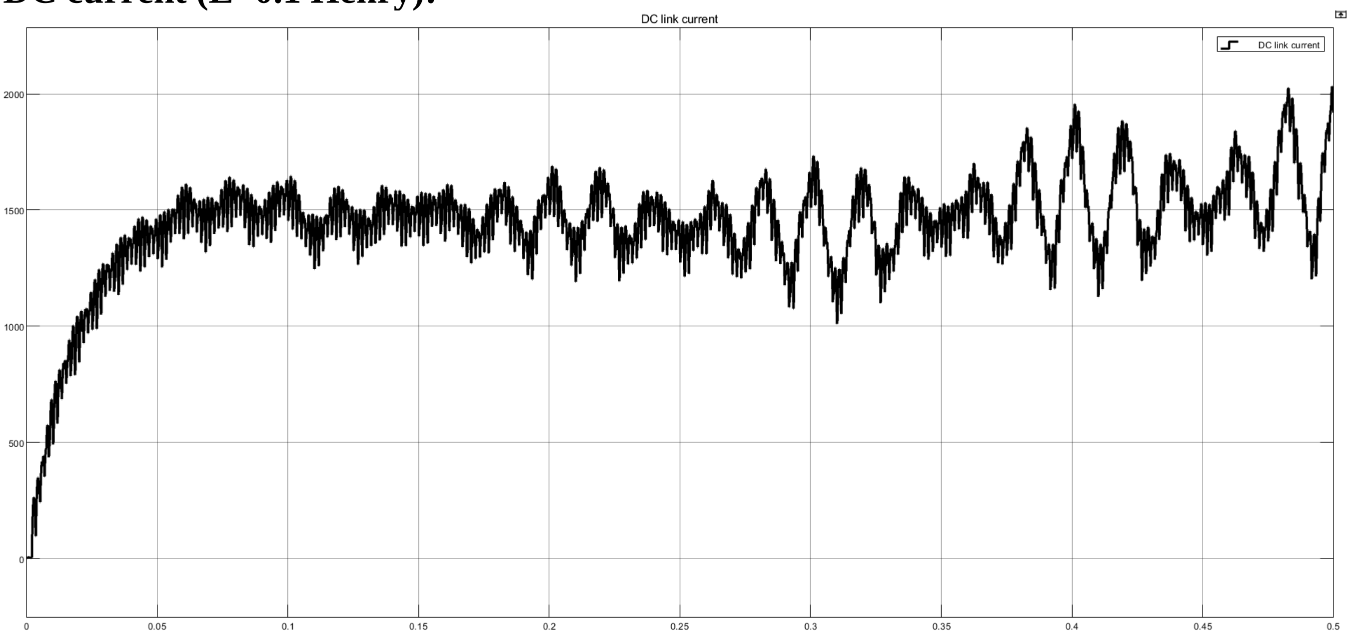


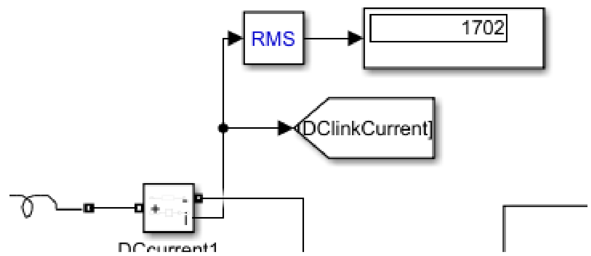


Grid current at inverter side:



DC current (L=0.1 Henry):



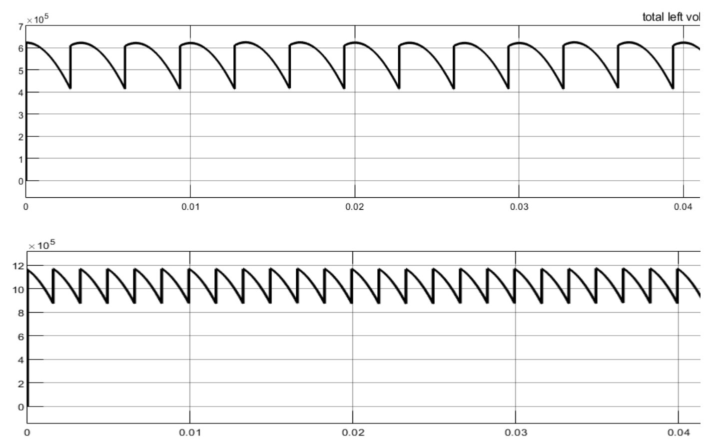


IV. Comparison:

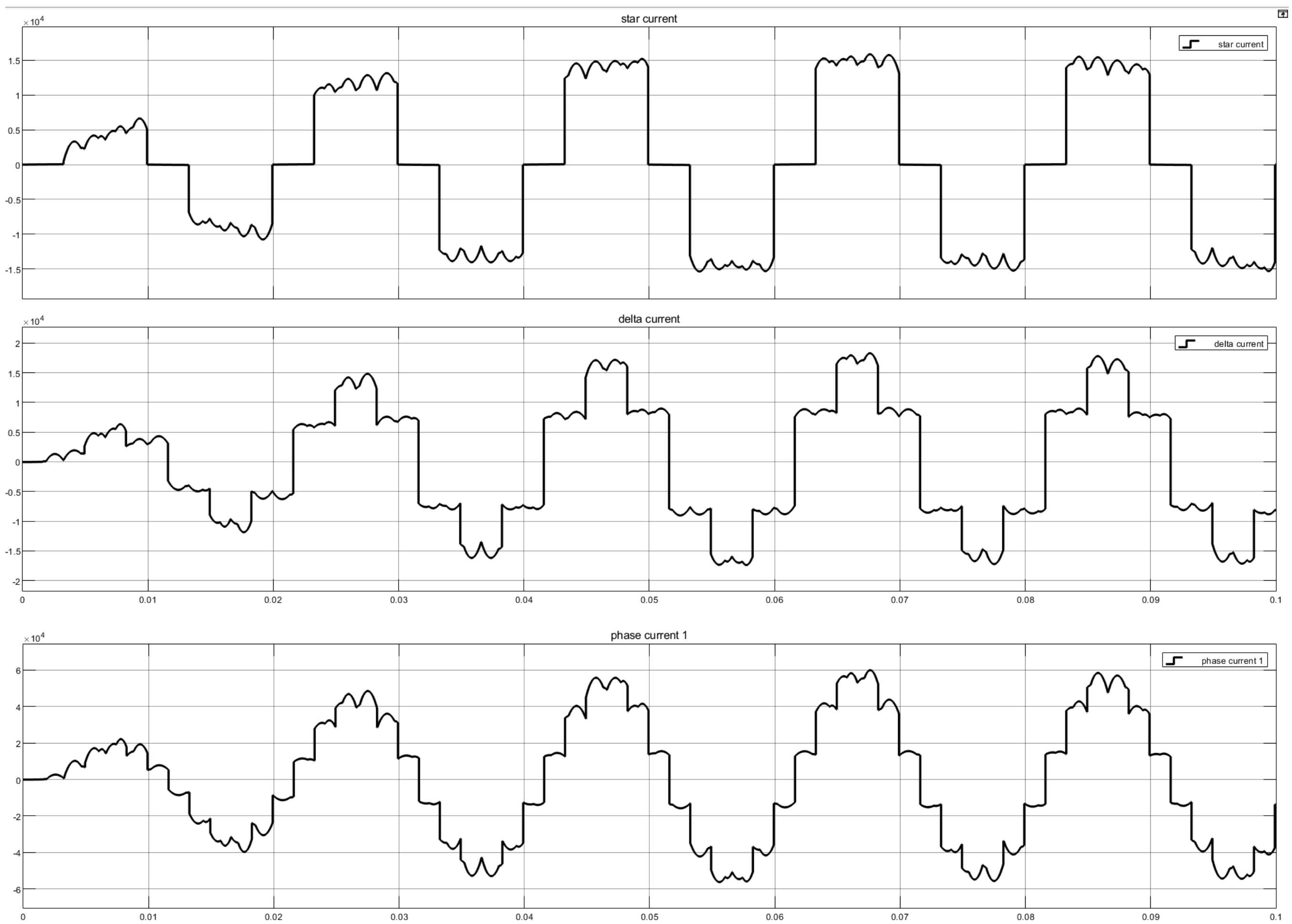
Question (D):

Compare the performance of 6-pulse and 12-pulse converters. Comment.

- 12-pulse instead of 6-pulse are obtained due to the 30 degrees shift between star and delta windings and so a smoother ripple-less voltage is obtained. This results in reduced size filters and lower cost.



- It is also observed that the grid currents at both sides (rectifier and inverter) are enhanced, now curves are closer to the sine wave in a 10-pulse shape) as shown below in curves. (sample curves from 12-pulse case (1)).



V. Attachments:

- [GitHub repo.]