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Subject Name: HVDC

Subject Code: EEP 424

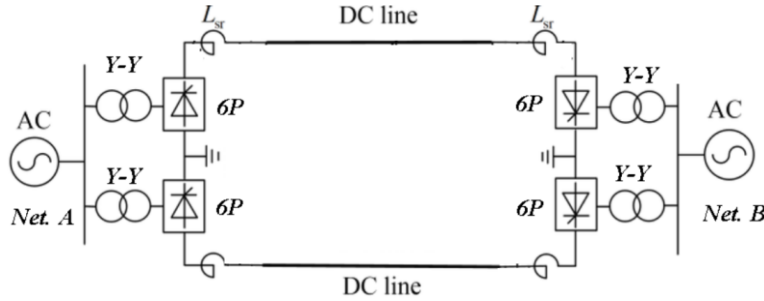
Assignment (2) | Bipolar Point-To-Point HVDC-Link |  
MATLAB Model

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## 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  $\Omega$ . The range of firing angle at the rectifier side is (5deg-25deg), while the inverter is operated under minimum  $\gamma$  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.**

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

$$800 = V_{dor} * I_{dc}$$

$$I_{dc} = \frac{V_{dor} - 253.81}{10}$$

$$\therefore 8000 = V_{dor}^2 - 253.81 * V_{dor}$$

$$\therefore V_{dor} = 282.16KV$$

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

$$\therefore \alpha = 18.25^\circ$$

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

**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).**

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

$$600 = V_{dor} * I_{dc}$$

$$I_{dc} = \frac{V_{dor} - 251.27}{10}$$

$$\therefore 6000 = V_{dor}^2 - 251.27 * V_{dor}$$

$$\therefore V_{dor} = 273.23KV$$

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

$$\therefore \alpha = 23.13^\circ$$

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

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

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

$$800 = V_{dor} * I_{dc}$$

$$I_{dc} = \frac{V_{dor} - 253.81}{10}$$

$$\therefore 8000 = V_{dor}^2 - 253.81 * V_{dor}$$

$$\therefore V_{dor} = 282.16KV$$

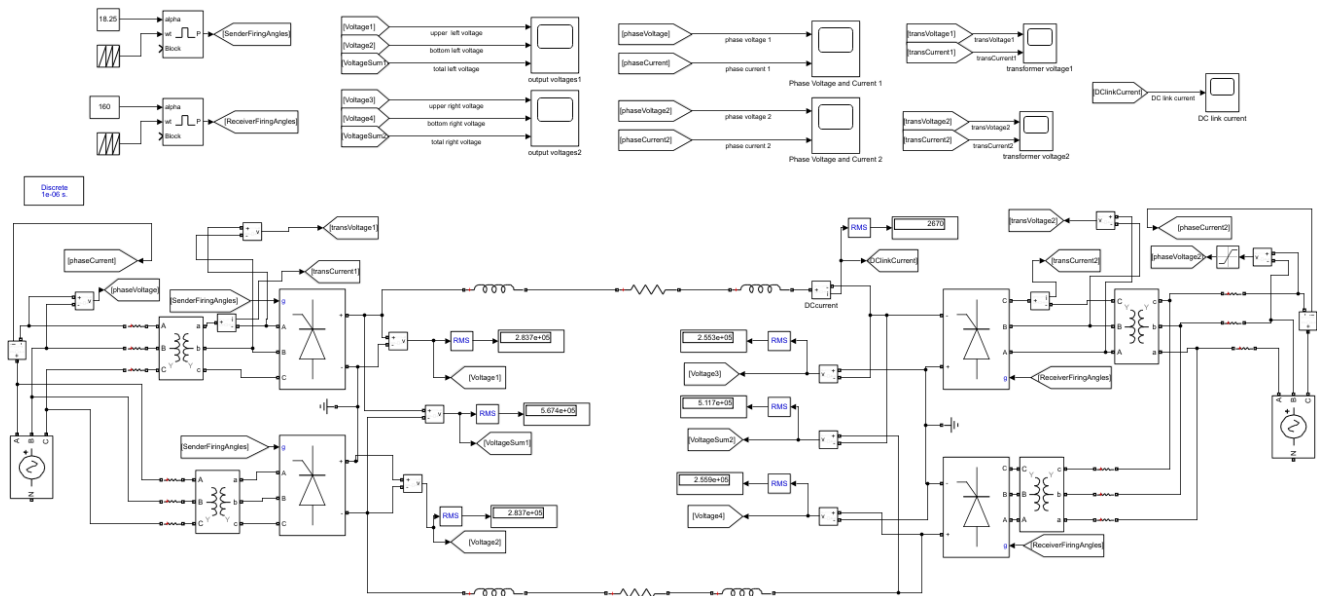
$$V_{dor} = \frac{3\sqrt{2} * 220 * 1.025}{\pi} \cos \alpha = 282.16KV$$

$$\therefore \alpha = 22.099^\circ$$

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

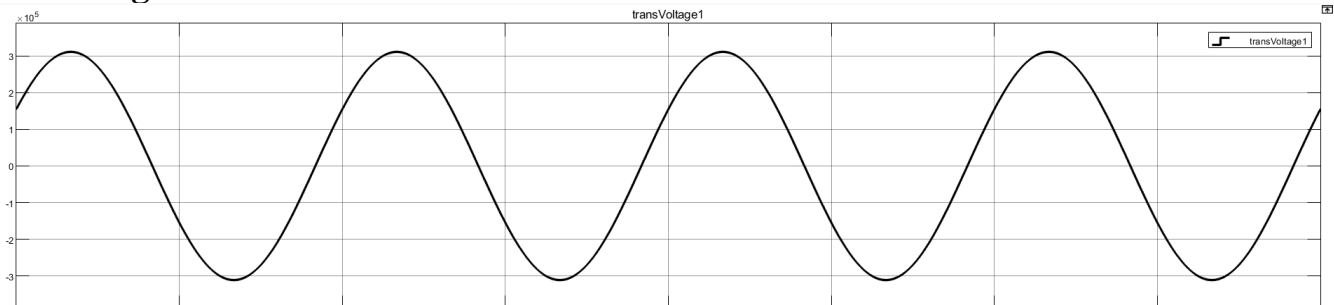
## Question (B):

### Model Screenshot:

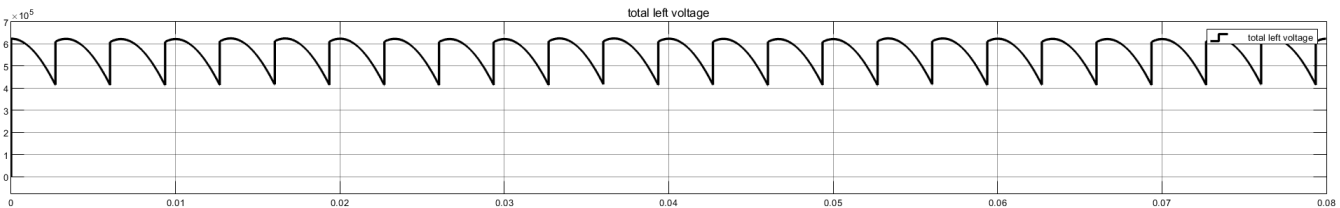


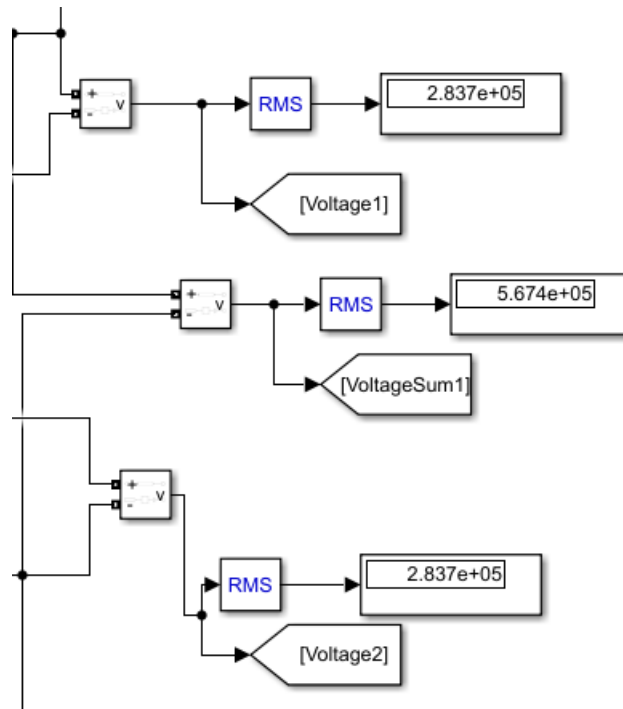
**Case (1): 1600MW: Power flow from (A) to (B): Net(A) is rectifier and Net(B) is inverter:**

**AC voltage at rectifier side:**

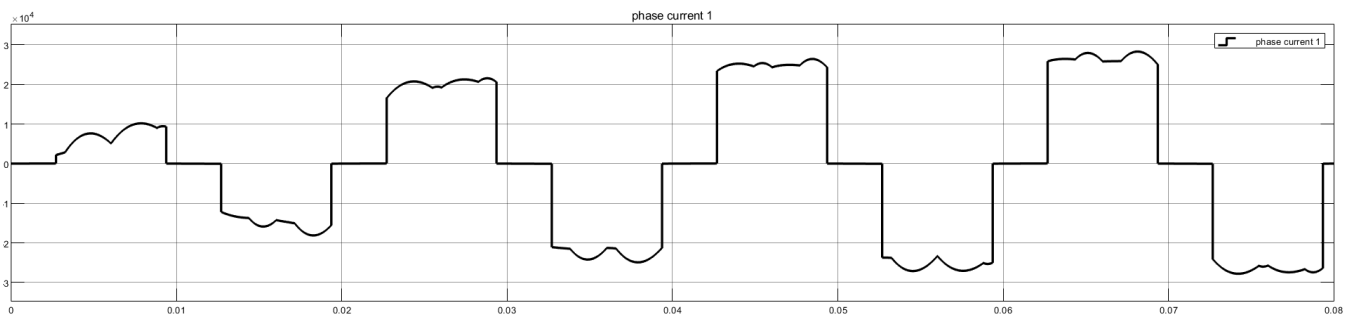


**$V_{dor}$ : DC voltage at rectifier side:**

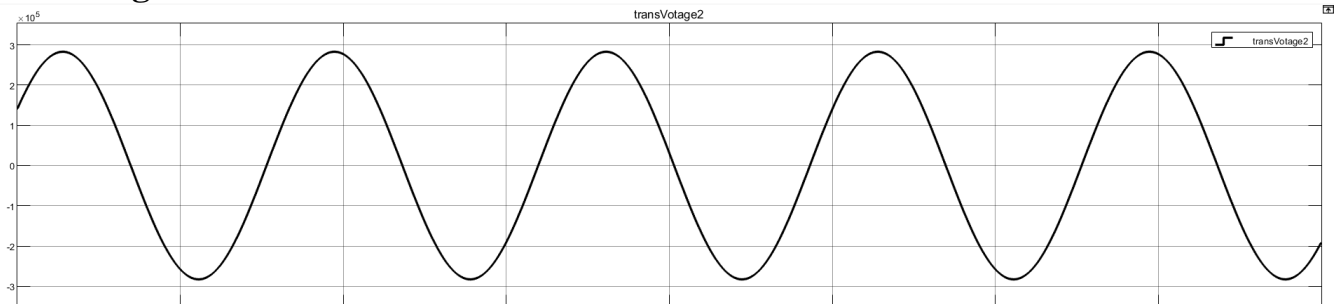




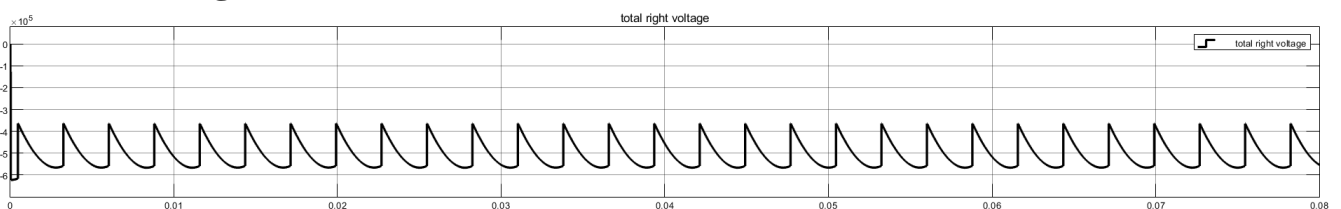
### Grid current at rectifier side:

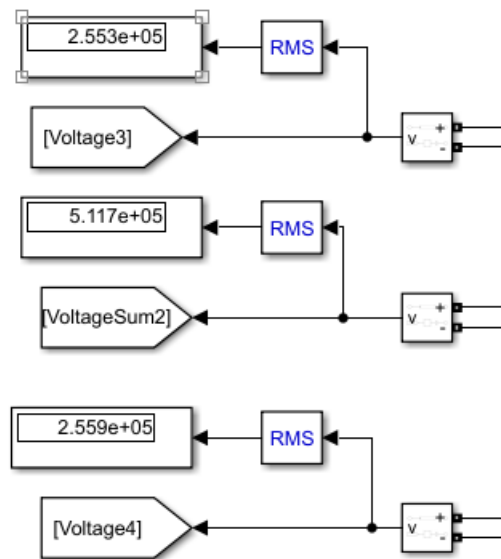


### AC voltage at inverter side:

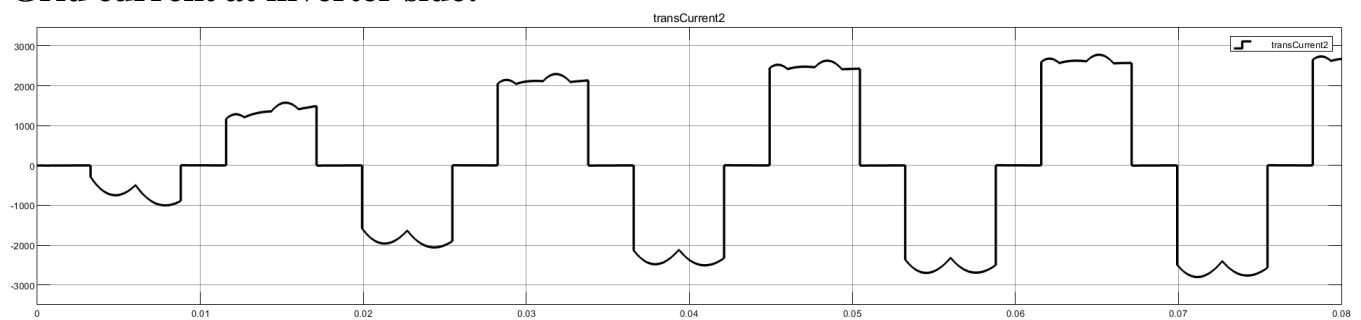


### $V_{doi}$ : DC voltage at inverter side:

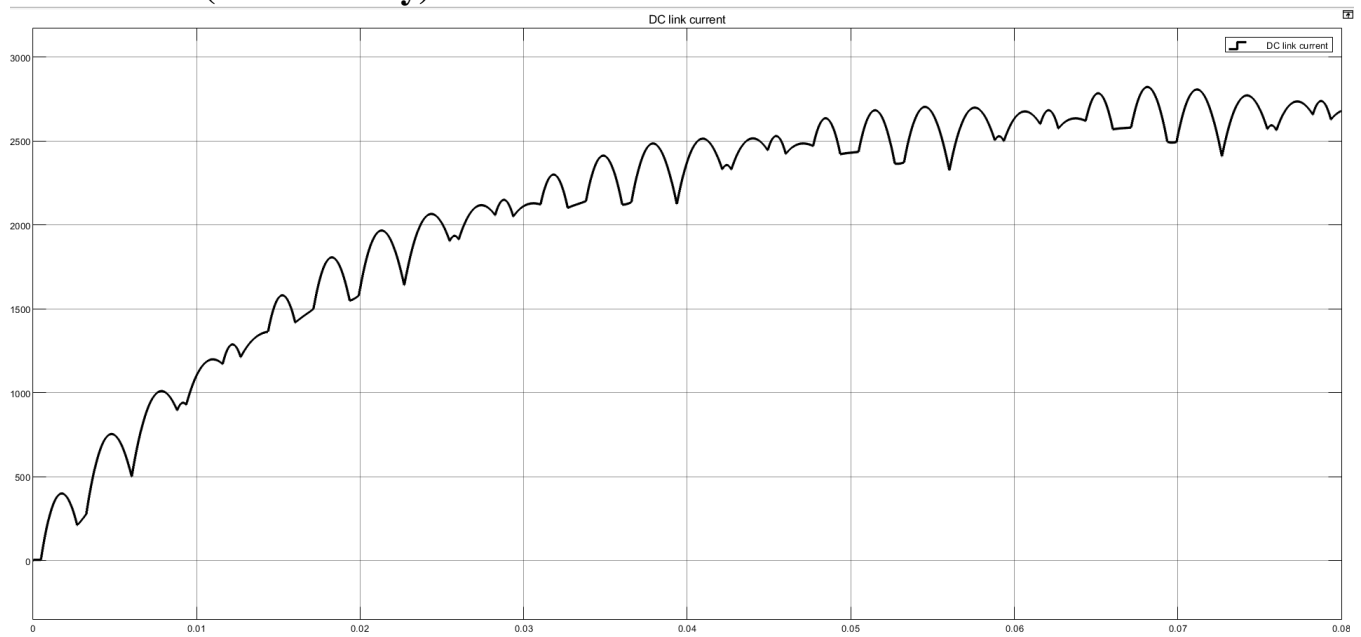


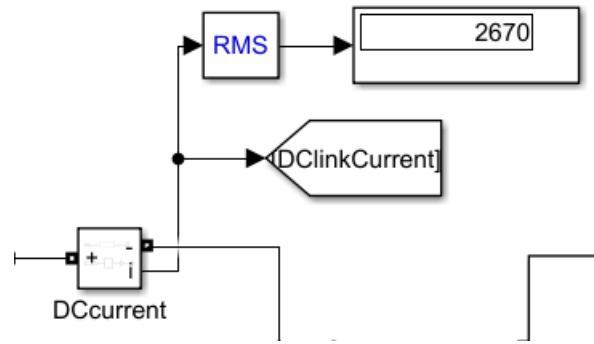


### Grid current at inverter side:



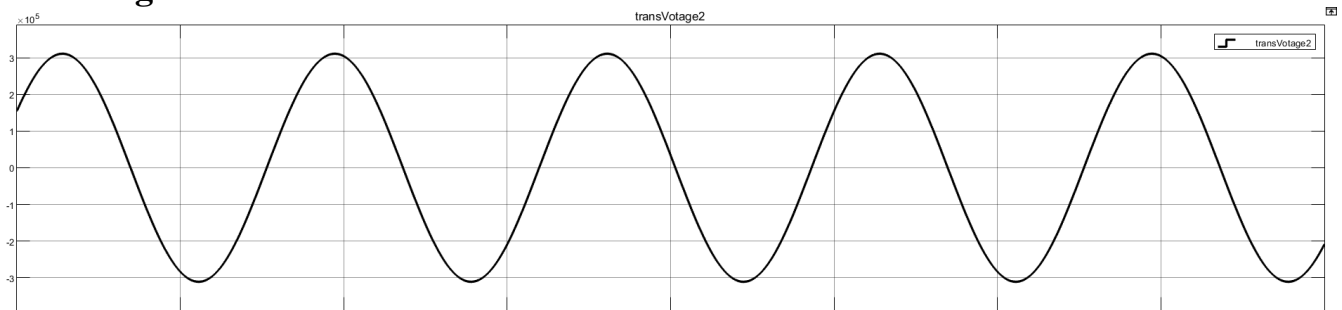
### DC current (L=0.1 Henry):



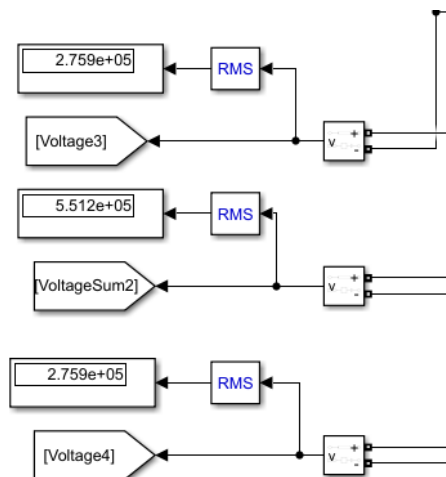
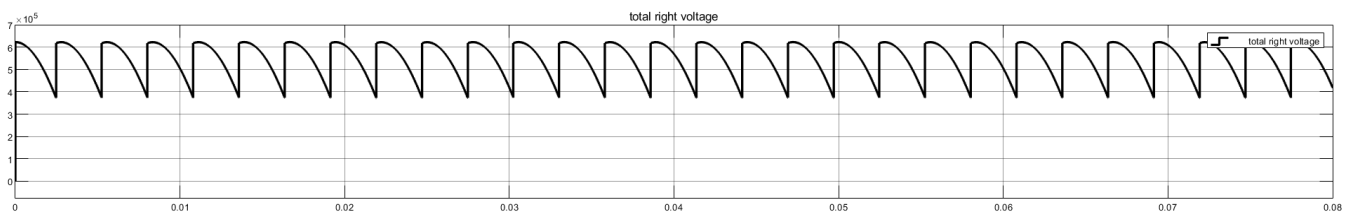


**Case (2): 1200MW: Power flow from (B) to (A): Net(B) is rectifier (+10%) and Net(A) is inverter (-10%):**

**AC voltage at rectifier side:**

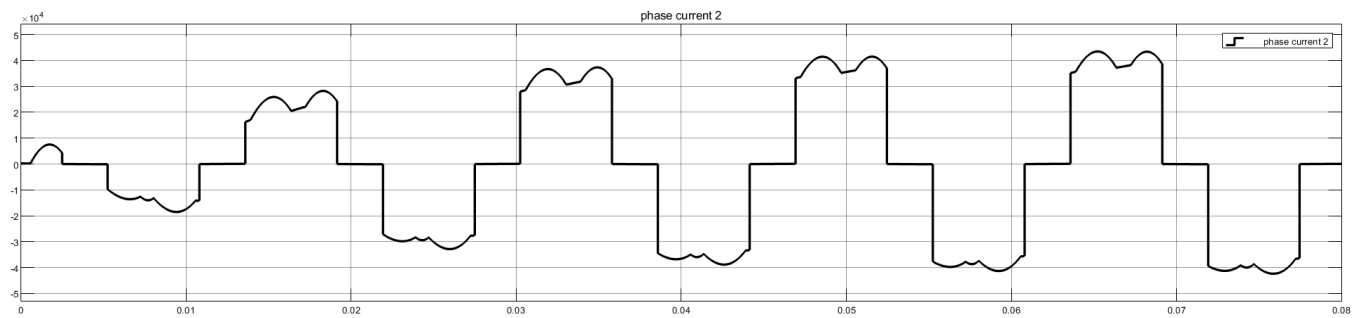


**$V_{dor}$ : DC voltage at rectifier side:**

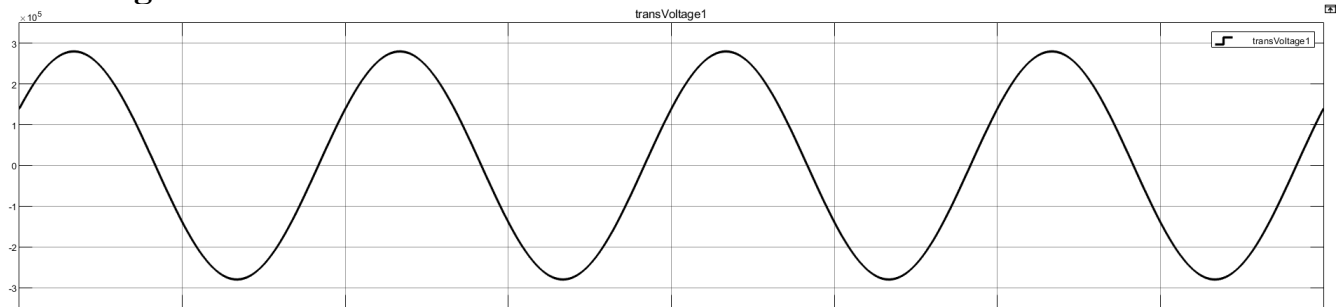




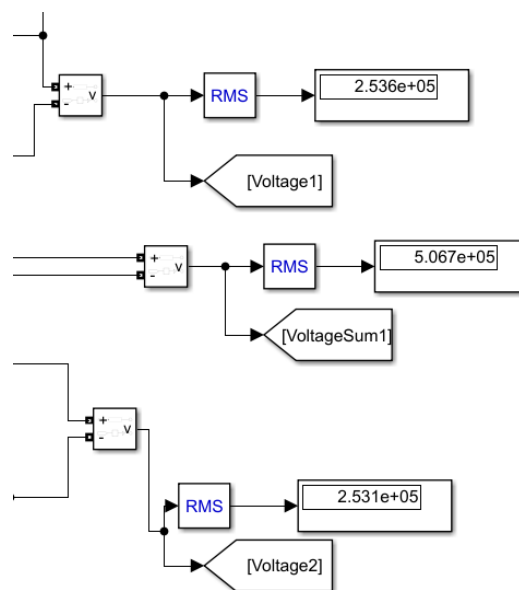
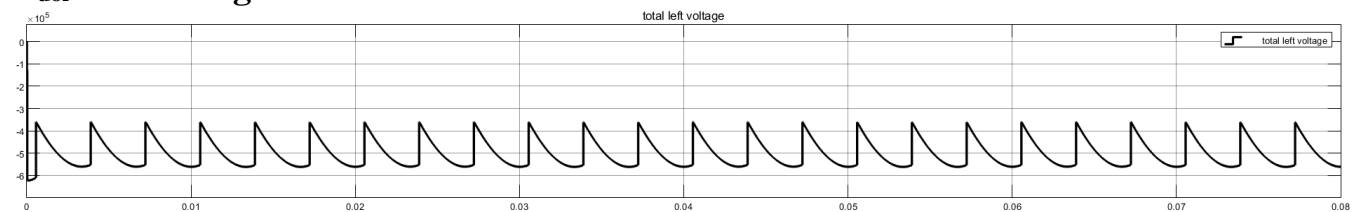
## Grid current at rectifier side:



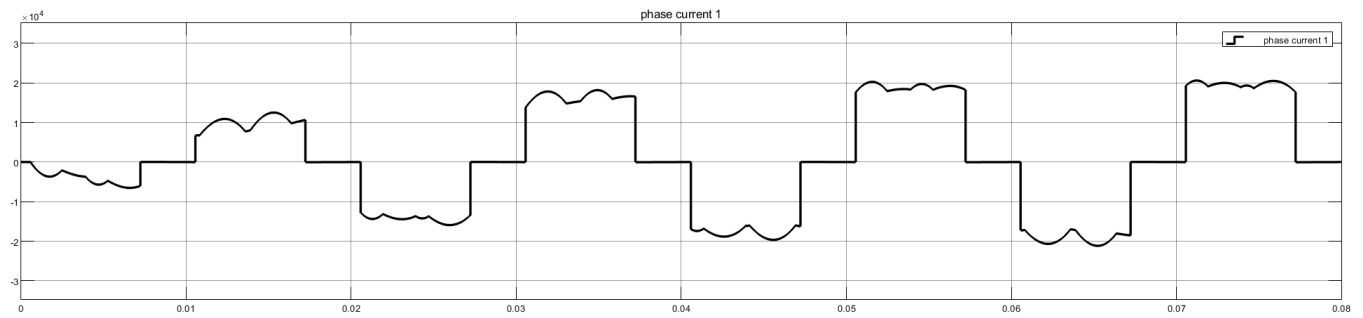
## AC voltage at inverter side:



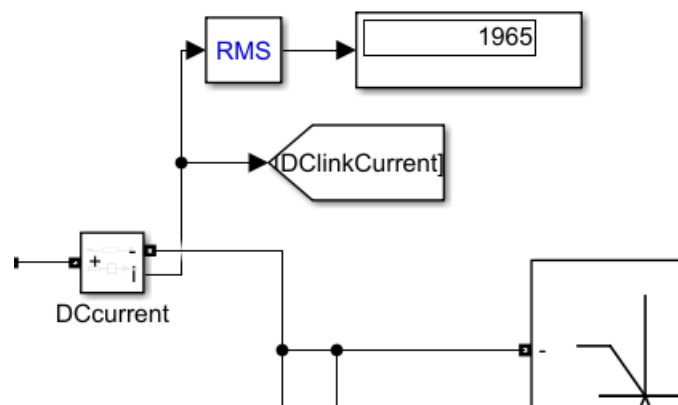
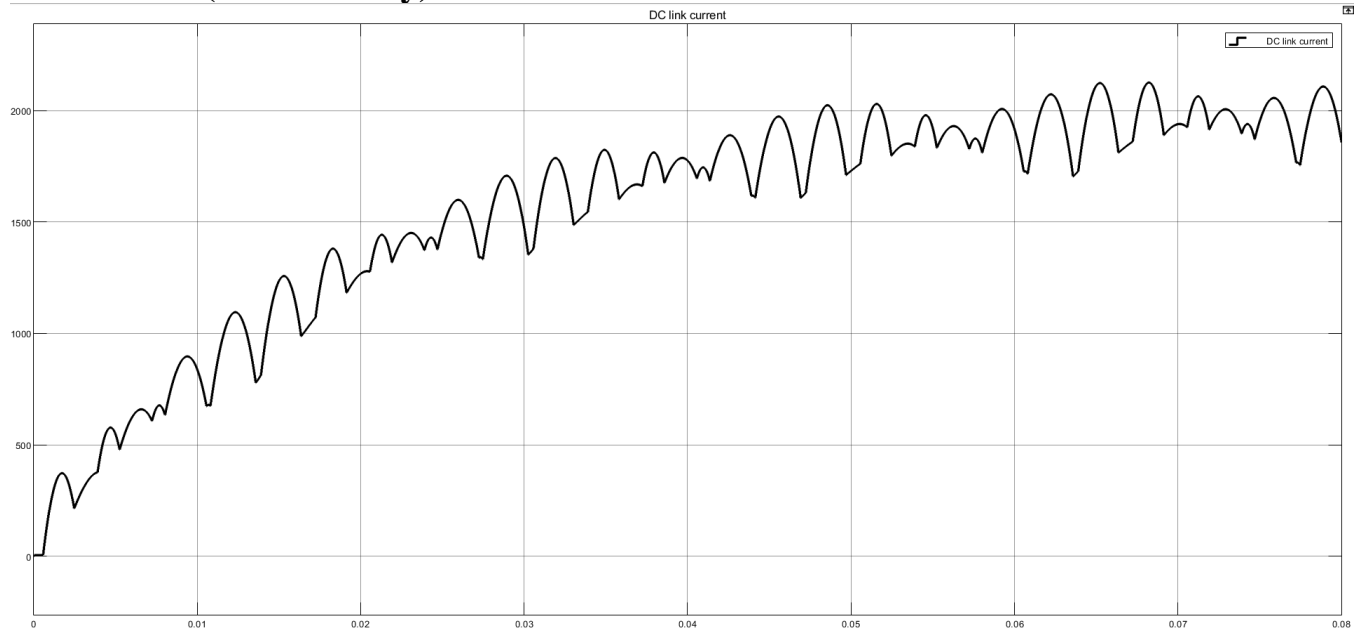
## $V_{doi}$ : DC voltage at inverter side:



## Grid current at inverter side:

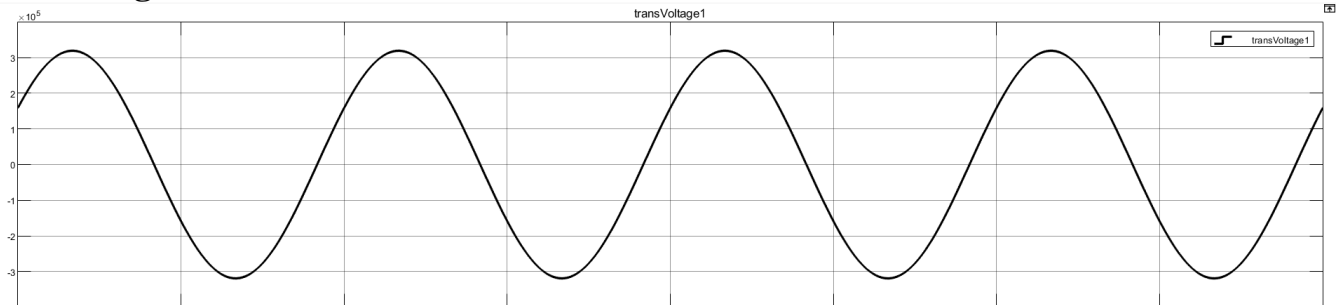


## DC current (L=0.1 Henry):

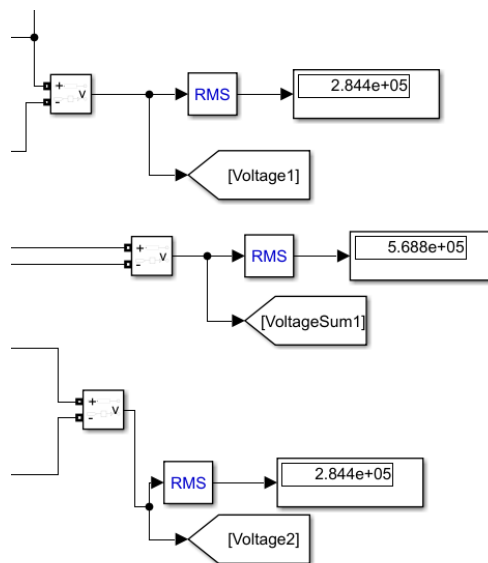
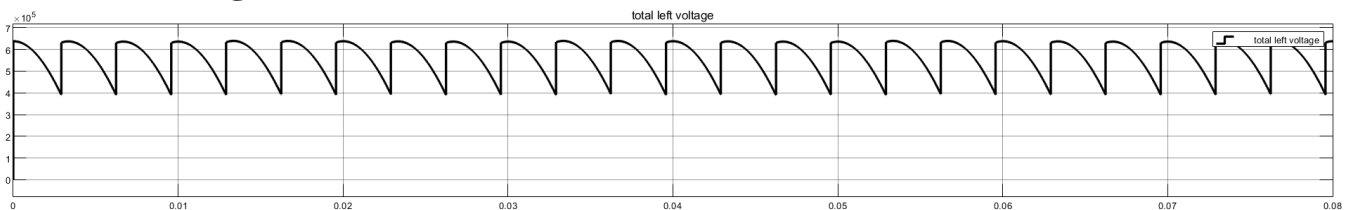


### Case (3): 1600MW: Power flow from (A) to (B): Net(A) is rectifier (2.5% voltage swell) and Net(B) is inverter:

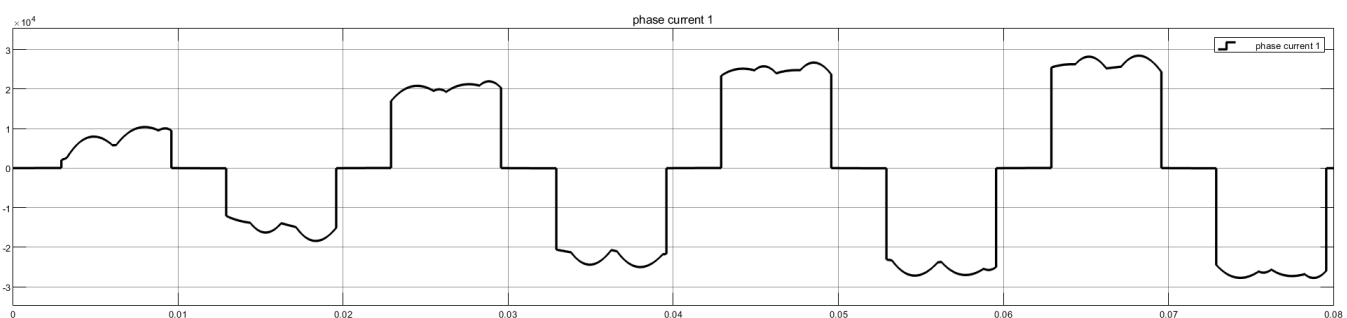
**AC voltage at rectifier side:**



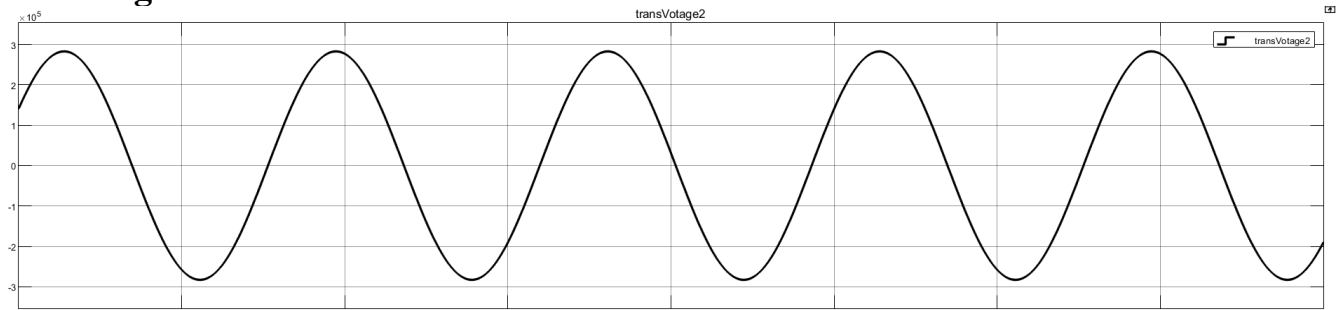
**$V_{dor}$ : DC voltage at rectifier side:**



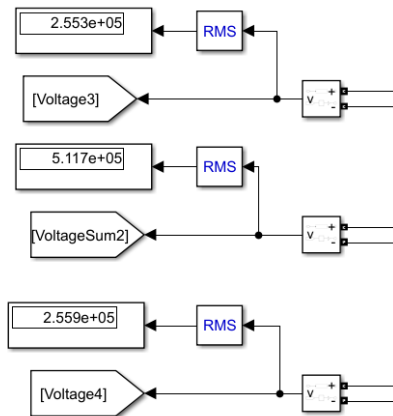
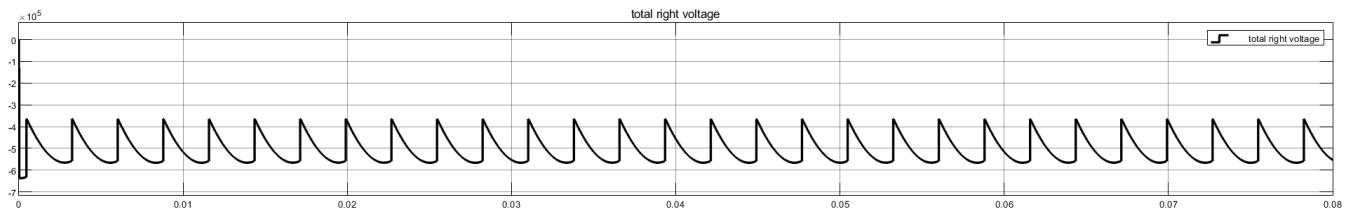
**Grid current at rectifier side:**



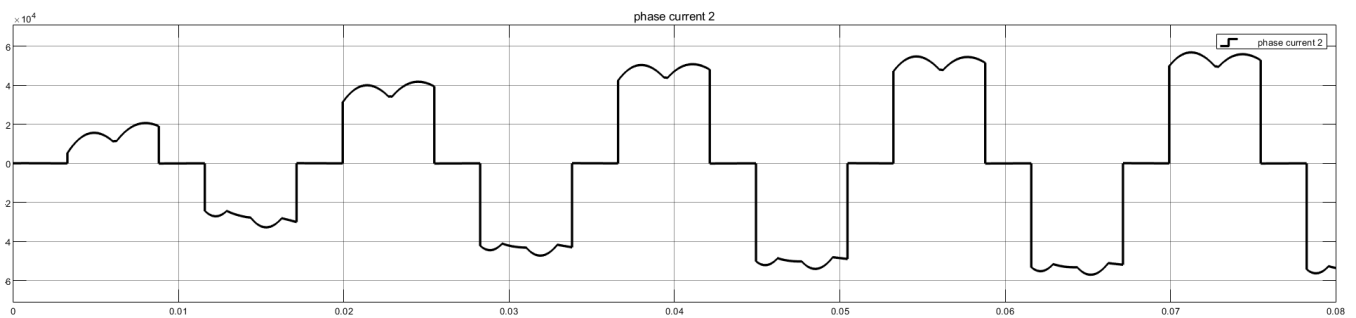
## AC voltage at inverter side:



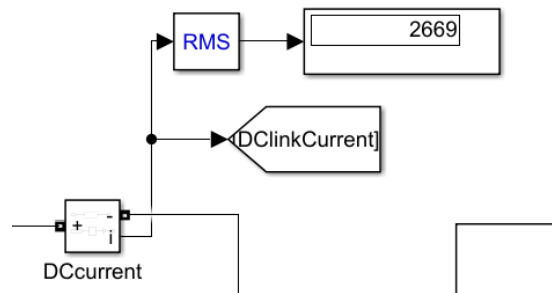
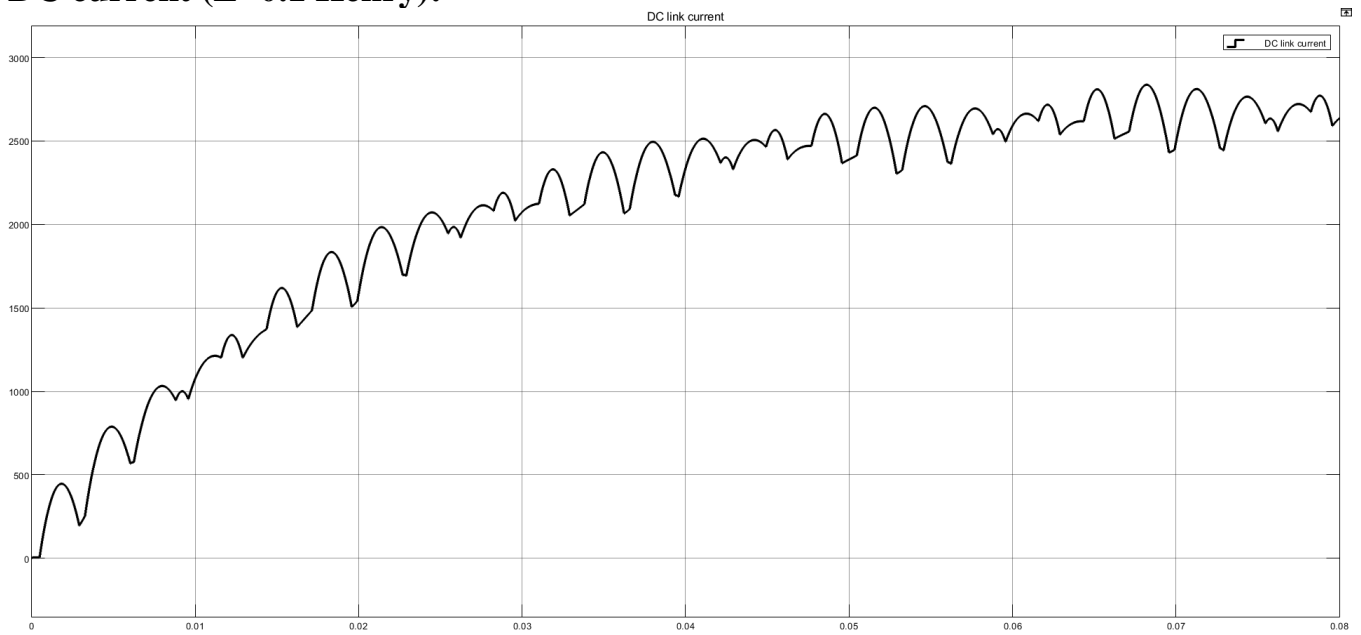
## $V_{doi}$ : DC voltage at inverter side:



## Grid current at inverter side:



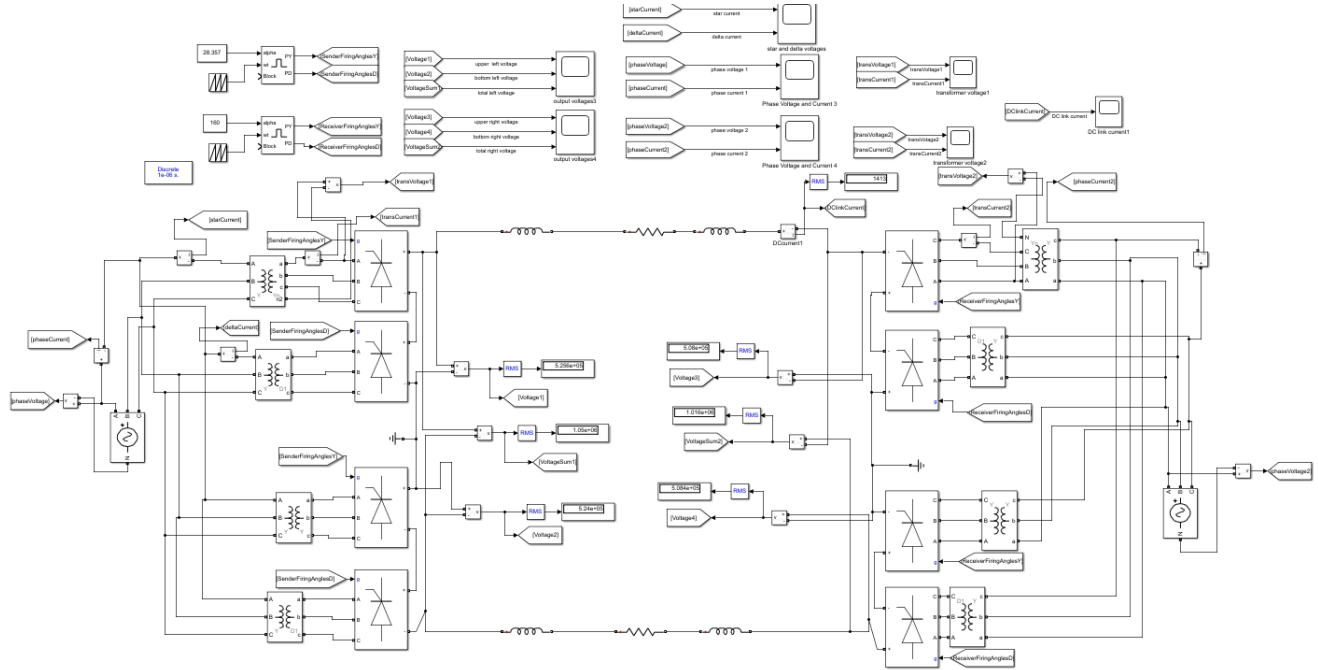
## DC current (L=0.1 Henry):



### 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:

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

$$800 = V_{dor} * I_{dc}$$

$$I_{dc} = \frac{V_{dor} - 507.61}{10}$$

$$\therefore 8000 = V_{dor}^2 - 507.61 * V_{dor}$$

$$\therefore V_{dor} = 522.909KV$$

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

$$\therefore \alpha = 28.357^\circ$$

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

- Since alpha ( $\alpha$ ) 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 ( $\alpha = 25.5 \text{ degrees}$ ).

$$V_{doi} = 507.61KV$$

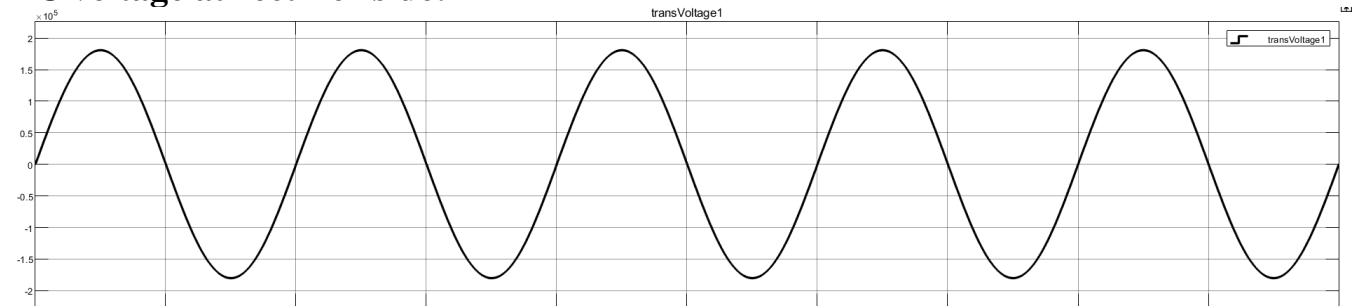
$$V_{dor} = 522.909KV$$

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

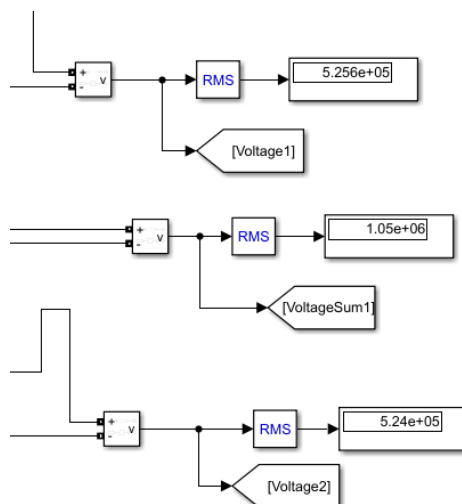
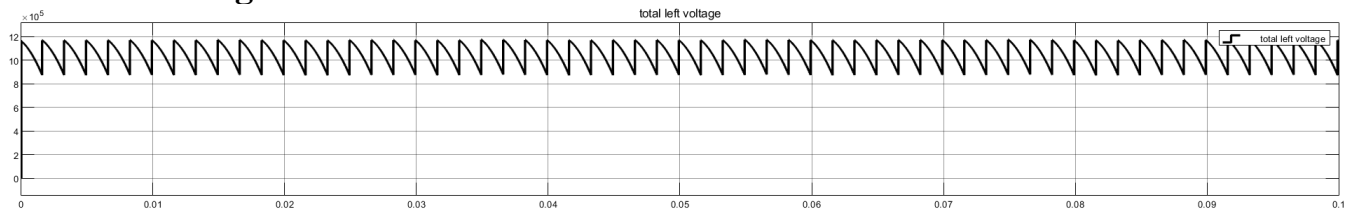
$$\therefore \alpha = 22.131^\circ$$

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

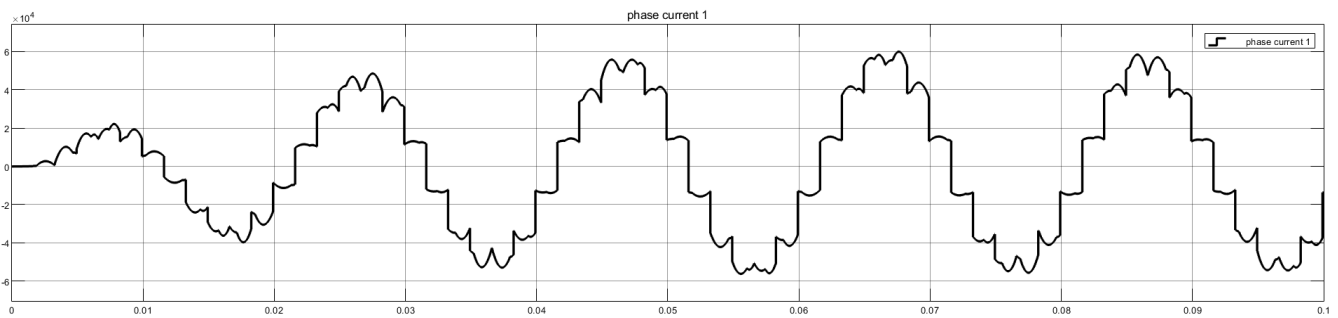
### AC voltage at rectifier side:



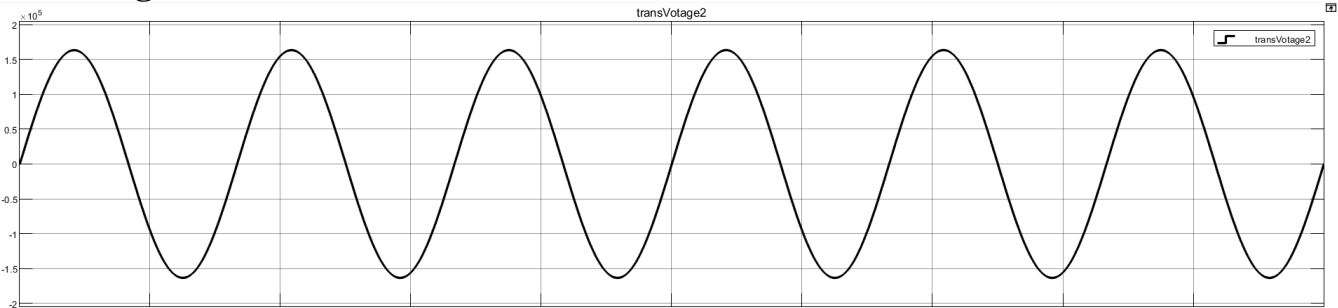
### $V_{dor}$ : DC voltage at rectifier side:



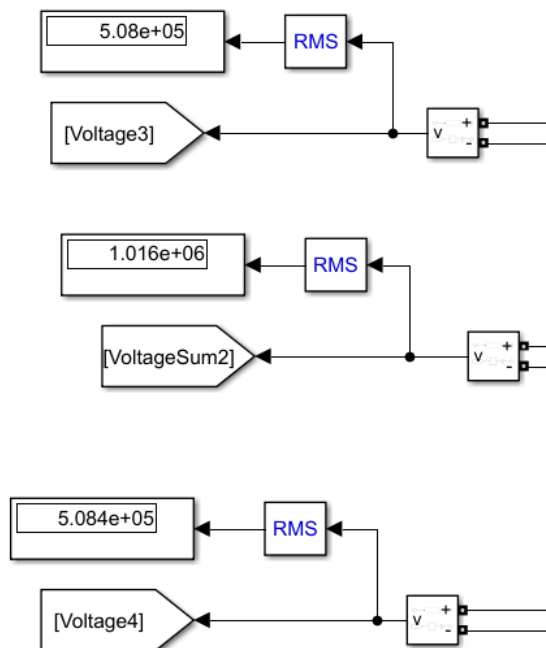
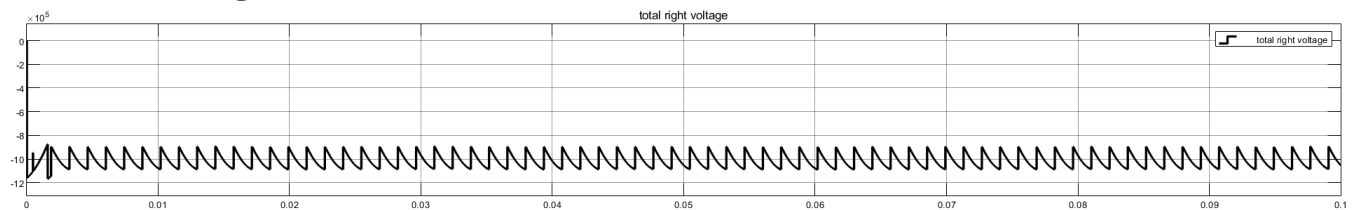
## Grid current at rectifier side:



## AC voltage at inverter side:

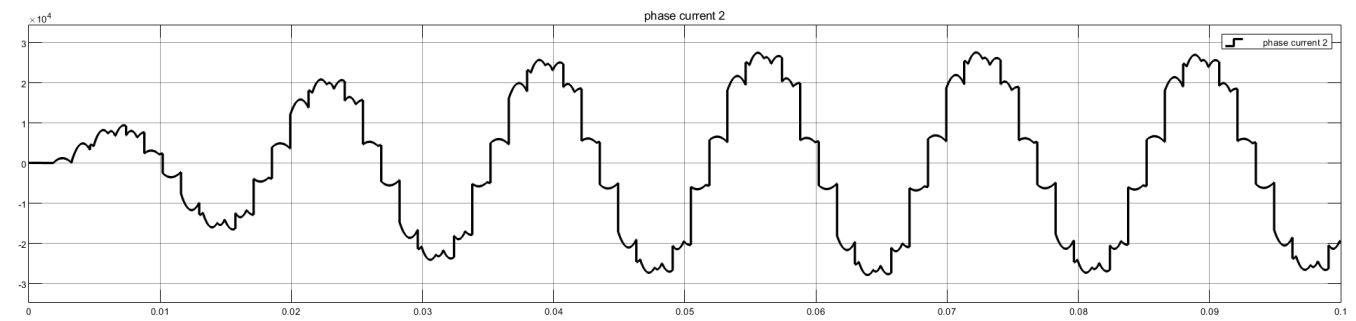


## $V_{doi}$ : DC voltage at inverter side:

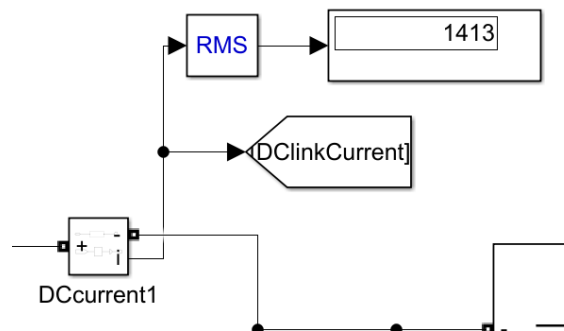
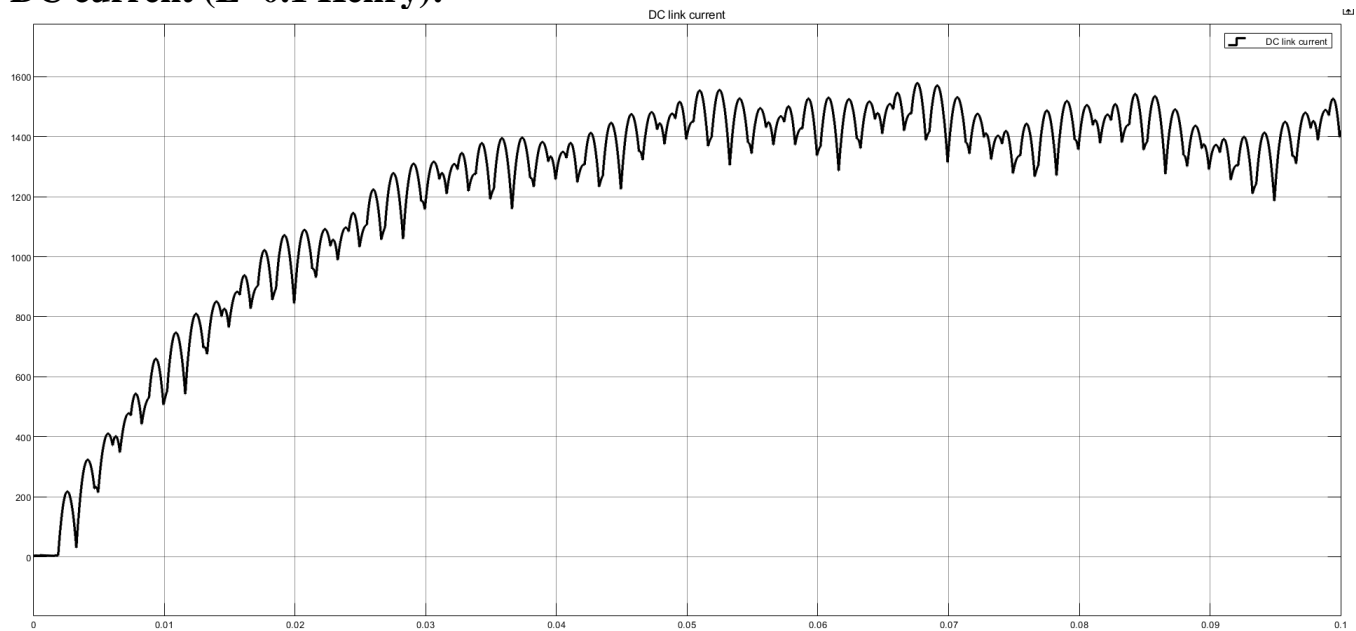




## Grid current at inverter side:



## 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:**

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

$$600 = V_{dor} * I_{dc}$$

$$I_{dc} = \frac{V_{dor} - 502.54}{10}$$

$$\therefore 6000 = V_{dor}^2 - 502.54 * V_{dor}$$

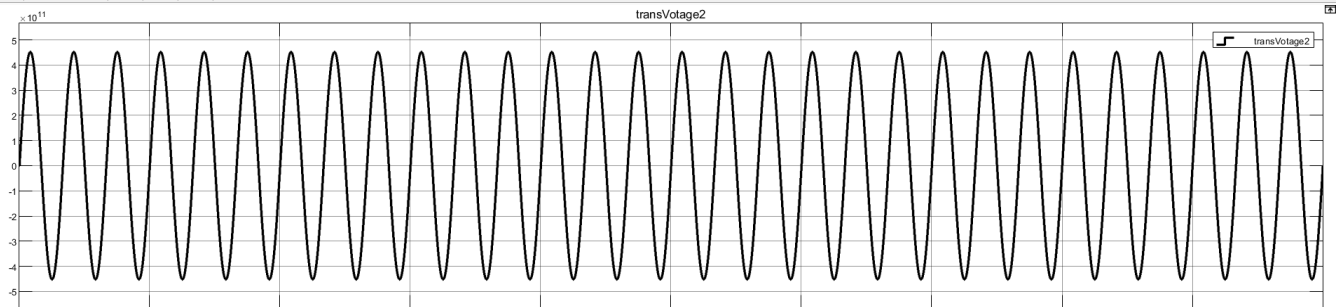
$$\therefore V_{dor} = 514.21KV$$

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

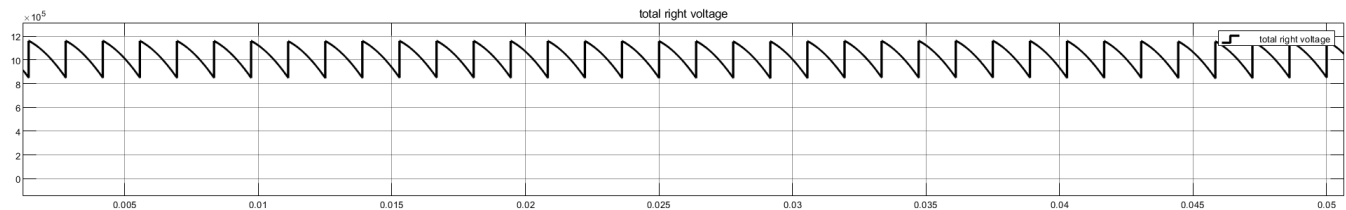
$\therefore \alpha = 30.08^\circ \rightarrow$  Higher than maximum limit but transformer tapping ratio is already modified I don't know...

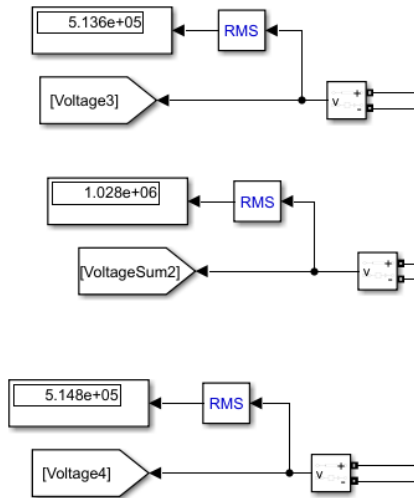
$$\therefore I_{dc} = \frac{514.21 - 502.54}{10} = 1.167KA$$

**AC voltage at rectifier side:**

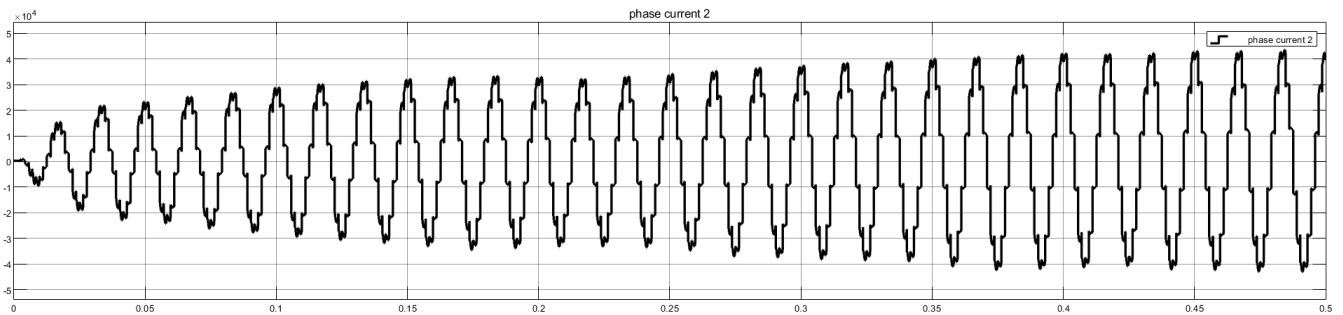


**$V_{dor}$ : DC voltage at rectifier side:**

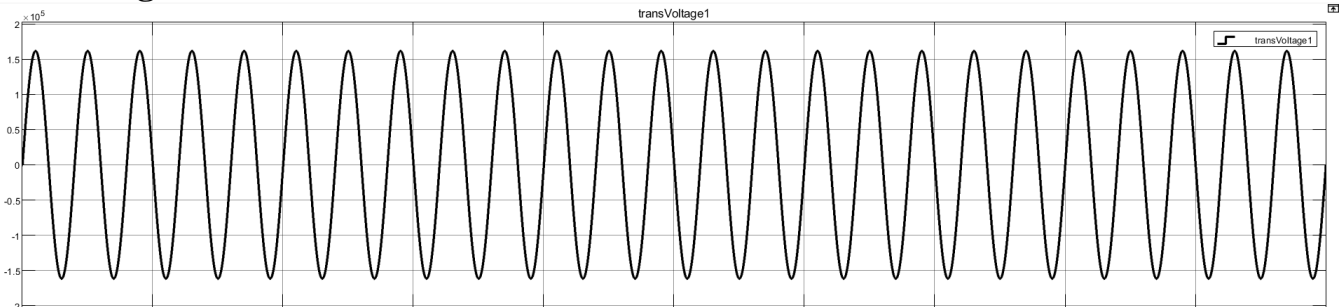




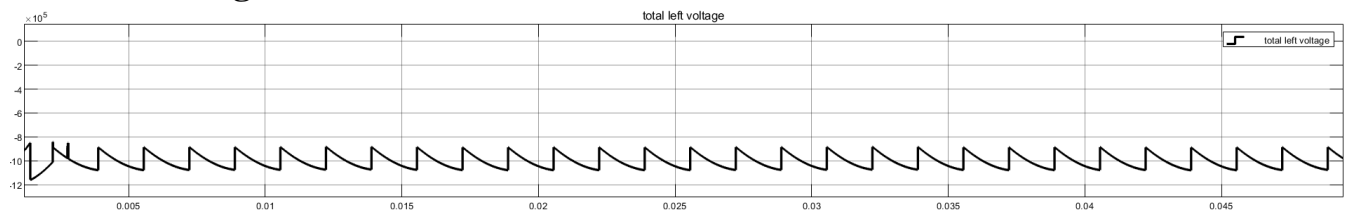
### Grid current at rectifier side:

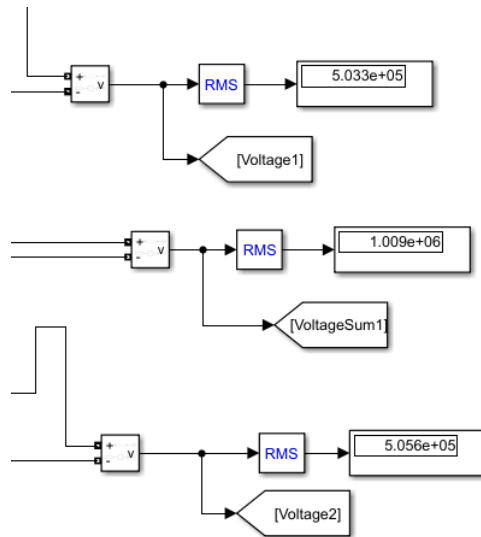


### AC voltage at inverter side:

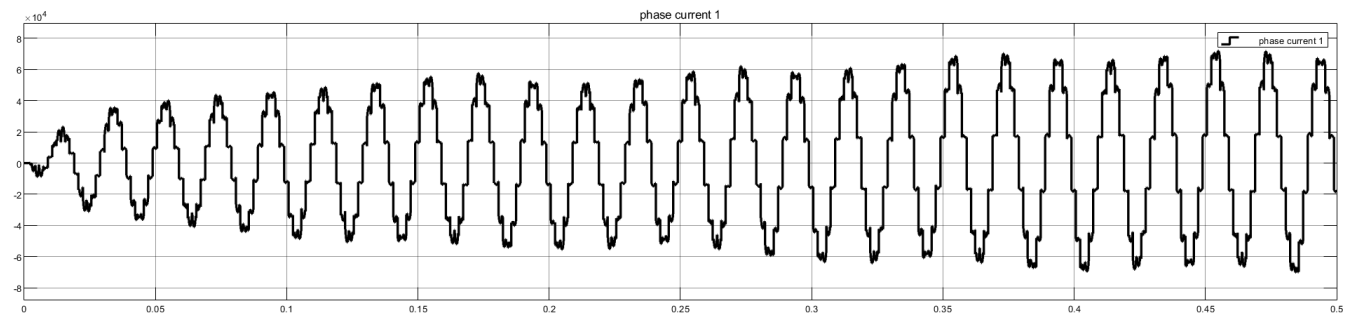


### $V_{doi}$ : DC voltage at inverter side:

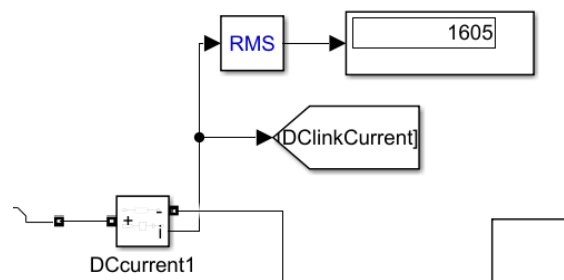
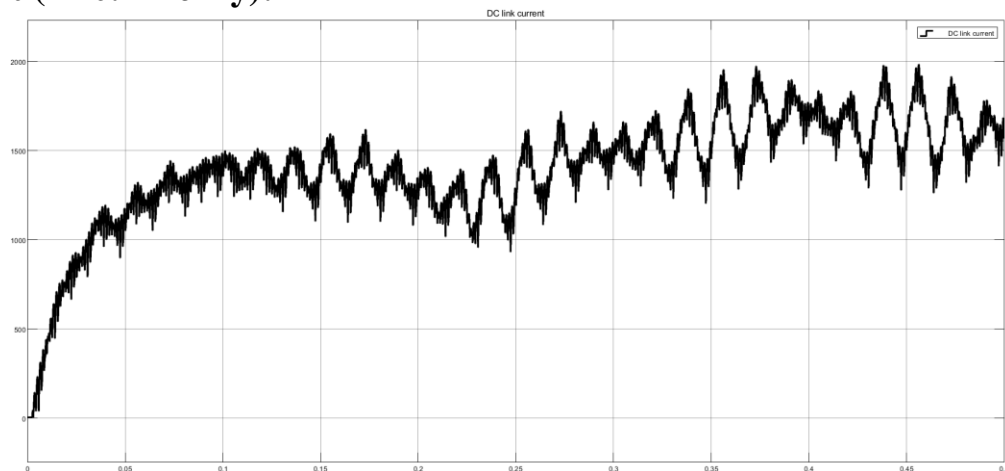




### Grid current at inverter side:



### 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:

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

$$800 = V_{dor} * I_{dc}$$

$$I_{dc} = \frac{V_{dor} - 507.61}{10}$$

$$\therefore 8000 = V_{dor}^2 - 507.61 * V_{dor}$$

$$\therefore V_{dor} = 522.909KV$$

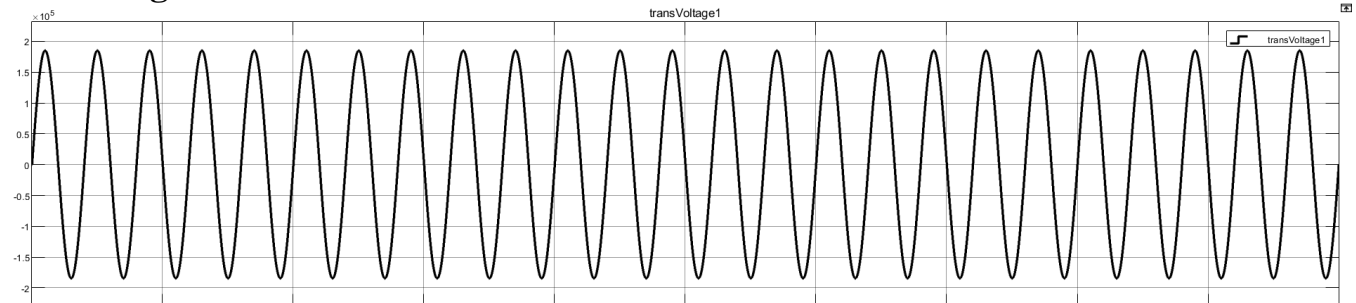
$$V_{dor} = \frac{2 * 3\sqrt{2} * 220 * 1.025}{\pi} \cos \alpha = 522.909KV$$

$$\therefore \alpha = 30.85^\circ$$

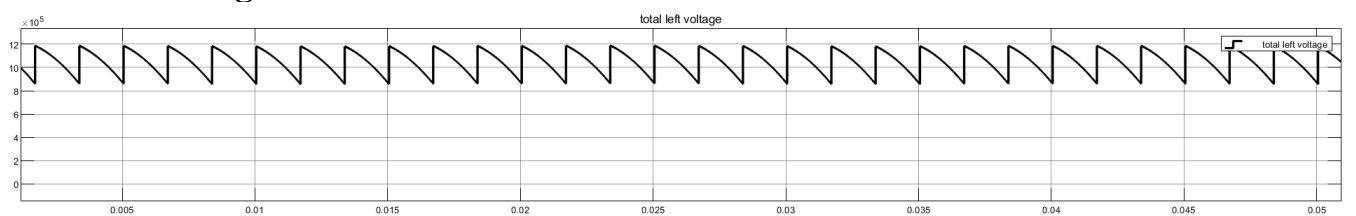
$$\therefore I_{dc} = \frac{522.909 - 507.61}{10} = 1.5299KA$$

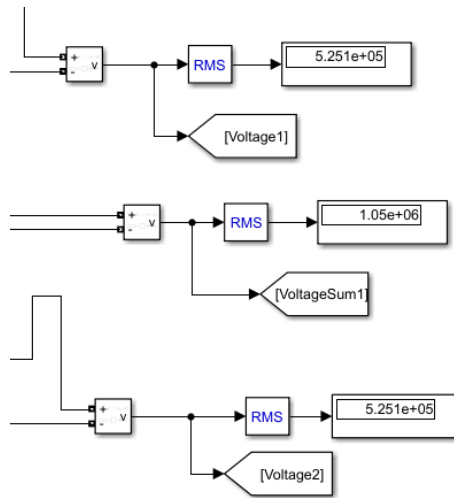
- Again, alpha exceeds the limit, but I will leave it for now...

#### AC voltage at rectifier side:

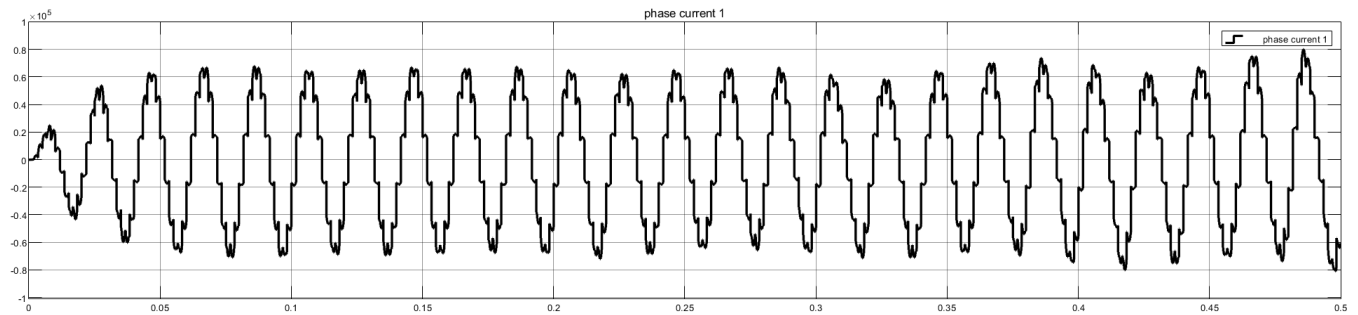


#### $V_{dor}$ : DC voltage at rectifier side:

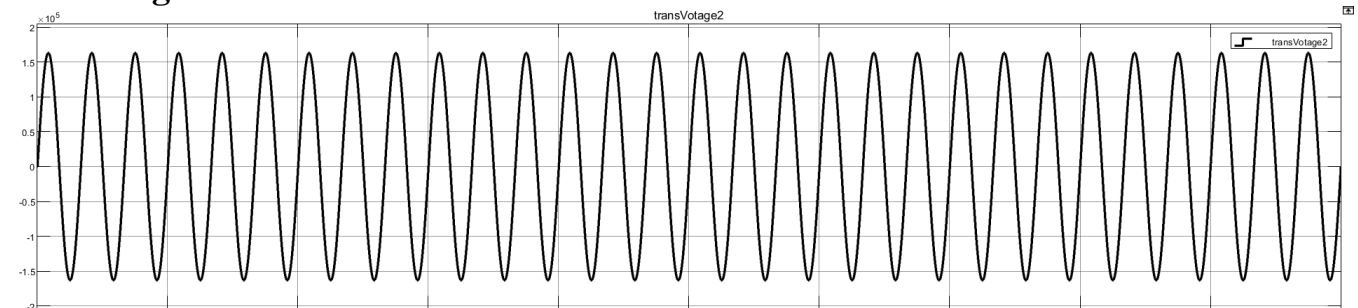




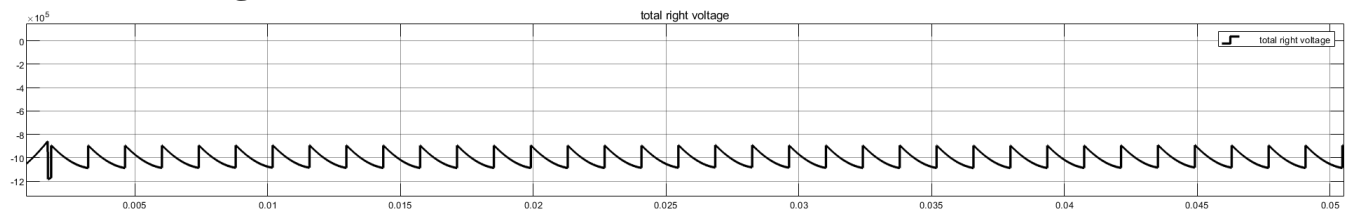
### Grid current at rectifier side:

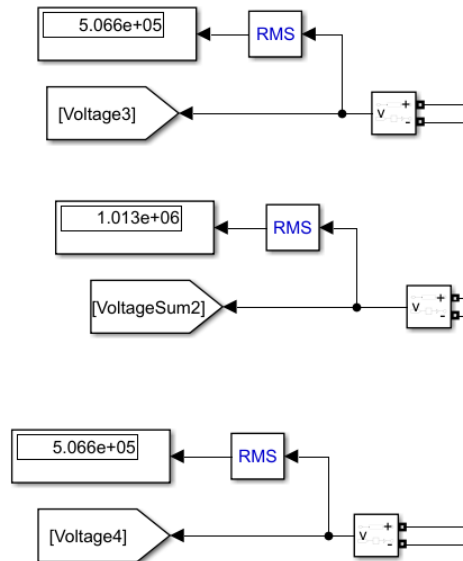


### AC voltage at inverter side:

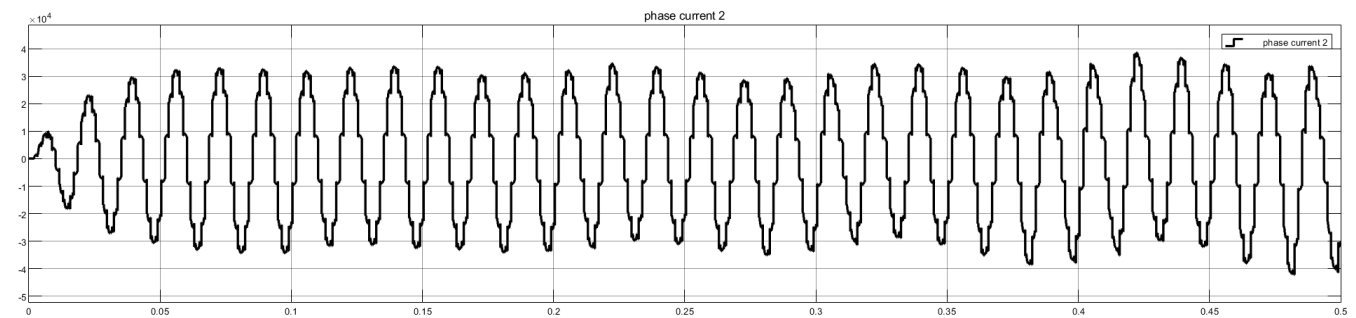


### $V_{doi}$ : DC voltage at inverter side:

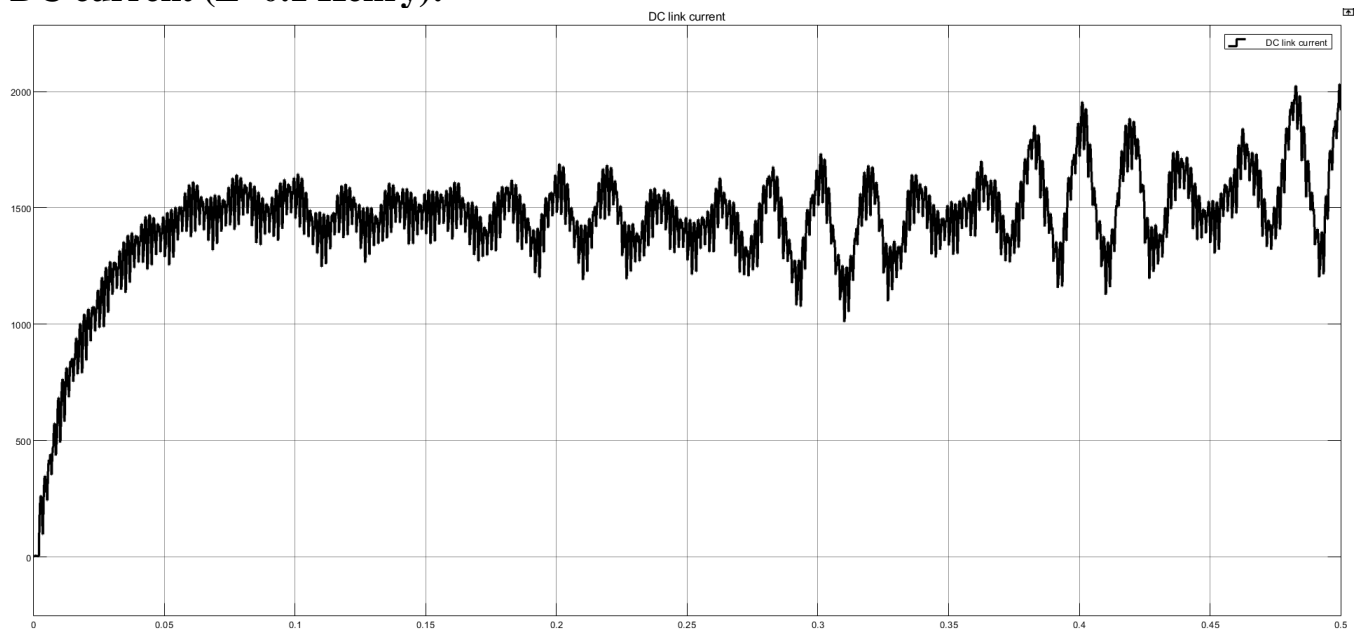


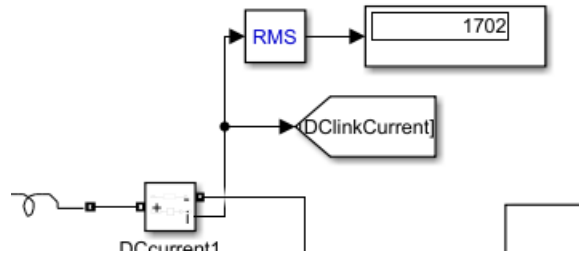


### Grid current at inverter side:



### DC current (L=0.1 Henry):



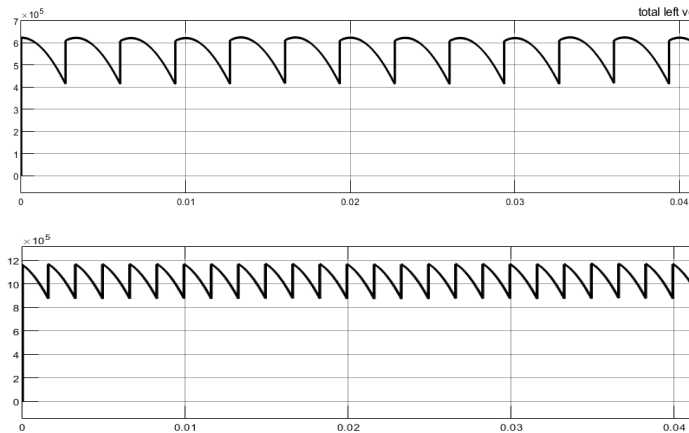


## IV. Comparison:

### Question (D):

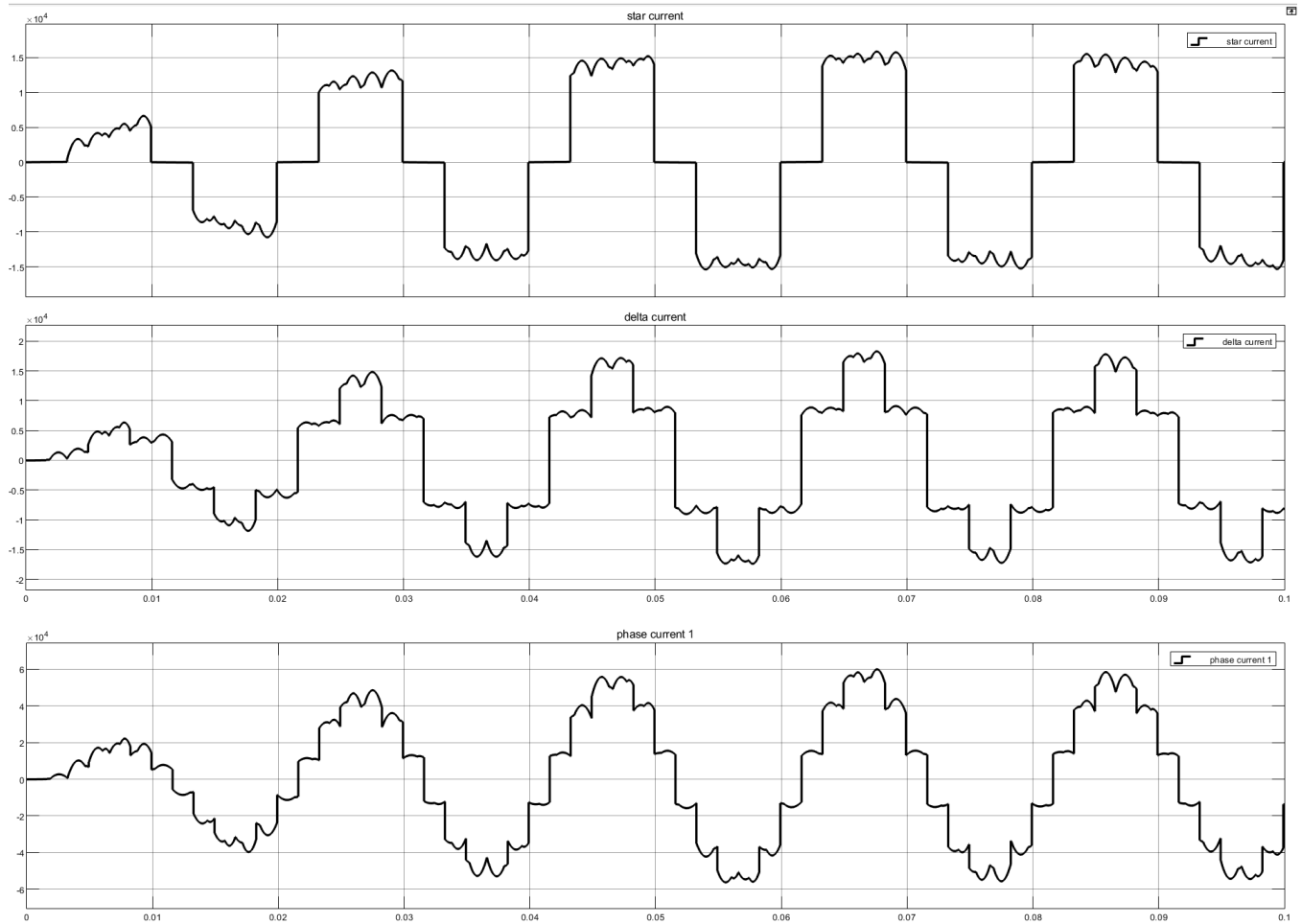
**Compare the performance of 6-pulse and 12-pulse converters. Comment.**

- 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.](#)