Course No: EEE 306

Analysis of HVDC system

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Abstract:

The massive transmission of electricity in the form of DC over long distances by means of submarine cables or overhead transmission line is the high voltage direct current transmission. This type of transmission is preferred over HVAC transmission for very long distance when considering the cost, losses and many other factors. The names Electrical superhighway or Power superhighway are often used for HVDC**.** AC power is generated in the generating station. This should first be converted into DC. The conversion is done with the help of rectifier. The DC power will flow through the overhead lines. At the user end, this DC has to be converted into AC. For that purpose, an inverter is placed at the receiving end.

Thus, there will be a rectifier terminal in one end of HVDC substation and an inverter terminal in the other end. The power of the sending end and user end will be always equal. The following project illustrates the Simulink modelling of a High Voltage DC Transmission link using 12-pulse based convertors between a 500kV, 5000MVA, 60Hz, system to a 345kV, 10000MVA, 50Hz system over a 1000MW(500kV, 2kV) DC interconnections. Through this model, we will analyze –

1) Real time response/ Transient and Steady state response
2) Frequency response of the AC system
3) Comparison between Distributed line parameter and Pi section line parameter through Real time and frequency response.
4) DC line fault
5) AC line to ground fault

MAIN COMPONENTS IN HVDC

1. Thyristor valves: The thyristor valves make the conversion from AC into DC and thus are the central component of any HVDC converter station. The thyristor valves are of the indoor type and air-insulated.

2. Convertor Transformer: The converter transformers transform the voltage of the AC busbar to the required entry voltage of the converter. The 12-pulse converter requires two 3-phase systems which are spaced apart from each other by 30 or 50 electrical degrees. At the same time, they ensure the voltage insulation necessary in order to make it possible to connect converter bridges in series on the DC side, as is necessary for HVDC technology.

3. Smoothing reactors: Functions of the Smoothing Reactor • Prevention of intermittent current. • Limitation of the DC fault currents. • Prevention of resonance in the DC circuit.

4. Harmonic filters: The filter arrangements on the AC side of an HVDC converter station have two main duties:

• to absorb harmonic currents generated by the HVDC converter and thus to reduce the impact of the harmonics on the connected AC systems, like AC voltage distortion and telephone interference

• to supply reactive power for compensating the demand of the converter station.

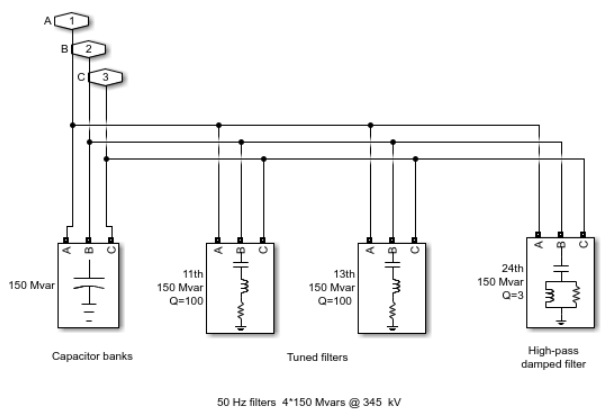

Figure 1 AC filter Design

5. Surge Arrestors: The main task of an arrester is to protect the equipment from the effects of over voltages. During normal operation, it should have no negative effect on the power system. Moreover, the arrester must be able to withstand typical surges without incurring any damage.

6. DC Transmission line

7. Control and Protection

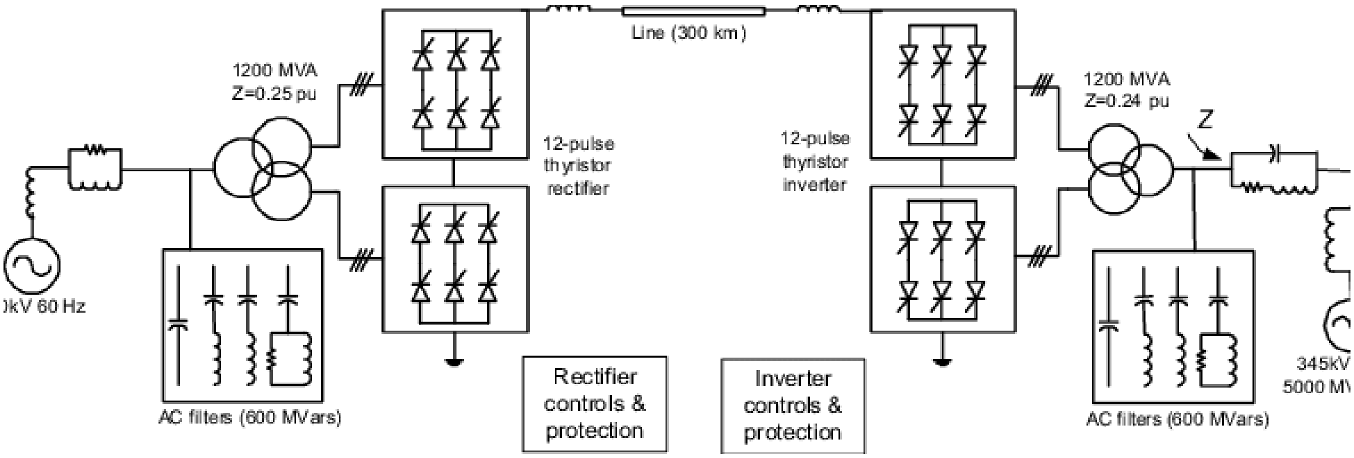

Figure 2: 12 pulse HVDC system

Main objectives for the implementation of the HVDC control system are reliable energy transmission which operates highly efficient and flexible energy flow that responds to sudden changes in demand thus contributing to network stability.

ANALYSIS OF THE MODEL Description Of HVDC Transmission System

The section illustrates modelling of a high-voltage direct current (HVDC) transmission link using 12pulse thyristor converters. Perturbations are applied to examine the system performance. A 1000 MW (500 kV, 2 kA) DC interconnection is used to transmit power from a 500 kV, 5000 MVA, 60 Hz system to a 345 kV, 10000 MVA, 50 Hz system. The AC systems are represented by damped L-R equivalents with an angle of 80 degrees at fundamental frequency (60 Hz or 50 Hz) and at the third harmonic. The rectifier and the inverter are 12-pulse converters using two Universal Bridge blocks connected in series. The converters are interconnected through a 300-km line and 0.5 H smoothing reactors. The converter transformers (Wye grounded/Wye/Delta) are modelled with Three-Phase Transformer blocks. From the AC point of view, an HVDC converter acts as a source of harmonic currents. From the DC point of view, it is a source of harmonic voltages. The order n of these characteristic harmonics is related to the pulse number p of the converter configuration: $n = kp \pm 1$ for the AC current and $n = kp$ for the direct voltage, k being any integer. In the example, $p = 12$, so that injected harmonics on the AC side are 11, 13, 23, 25, and on the DC side are 12, 24. AC filters are used to prevent the odd harmonic currents from spreading out on the AC system. The filters are grouped in two subsystems. These filters also appear as large capacitors at fundamental frequency, thus providing reactive power compensation for the rectifier consumption due to the firing angle α. For α = 30 degrees, the converter reactive power demand is approximately 60% of the power transmitted at full load. Inside the AC filters subsystem, the high Q (100) tuned filters at the 11th and 13th harmonics and the low Q (3), or damped filter, used to eliminate the higher order harmonics, e.g., 24th and up. Extra reactive power is also provided by capacitor banks.

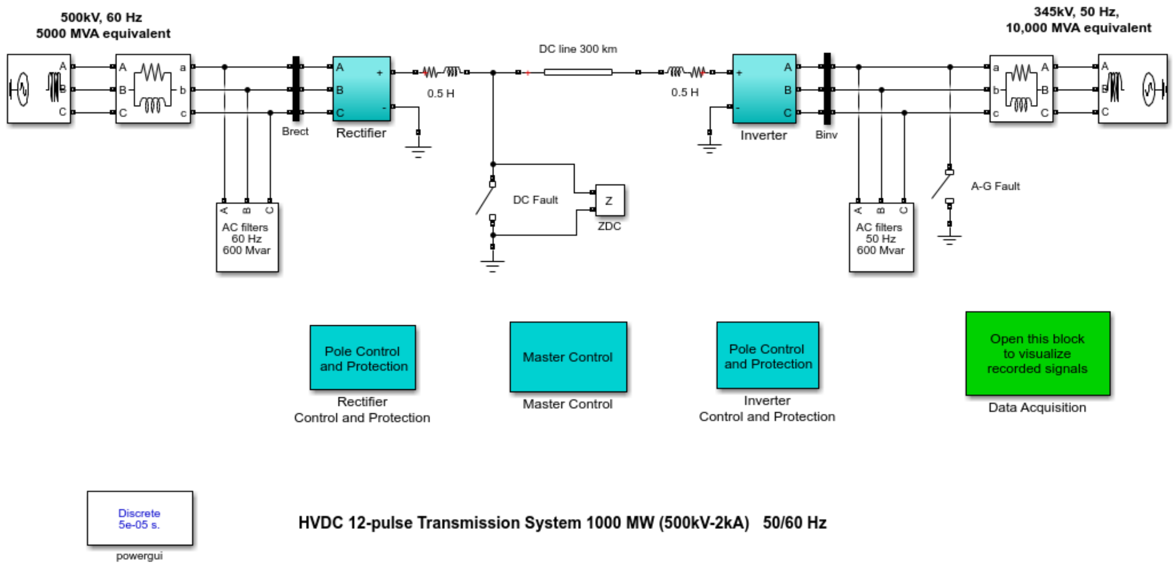

Figure 3: HVDC 12-pulse Transmission System 1000 MW (500kV-2kA)   50/60 Hz Simulink model

System Real time response- Steady-State and Step response:

The system is discretized, using sample time Ts = 50e-6 s. The system is programmed to start and reach a steady state. Then a step is applied first to the reference current and later to the voltage reference so you can observe the dynamic response of the regulators. Finally, a stop sequence is initiated to bring the power transmission smoothly down before blocking the converters. Notice in the Converter Controller that after reception of the Stop signal a Forced_alpha is ordered for 0.150 s, and then 0.1 s later the blocking of the pulses is ordered.

In the Master Control, the converters are deblocked and started by ramping the rectifier and inverter reference current. At t = 0.02 s (i.e. when the converters at deblocked), the reference current is ramped to reach the minimum value of 0.1 pu in 0.3 s (0.33 pu/s). At the end of this first ramp (t = 0.32 s) the DC line is charged at its nominal voltage and DC voltage reaches steady-state. At t= 0.4 s, the reference current is ramped from 0.1 pu to 1 pu (2kA) in 0.18 s (5 pu/s). At the end of this starting sequence (t=0.58 s) , the DC current reaches steady state. The RECTIFIER then controls the current and the INVERTER controls the voltage. In steady-state, the alpha firing angles (trace 3) are 16.5 degrees and 143 degrees respectively on the RECTIFIER and INVERTER sides. The extinction angle gamma (minimum value) is measured at the INVERTER and shown in trace 4. In steady-state, the minimum value is between 22 and 24 degrees.

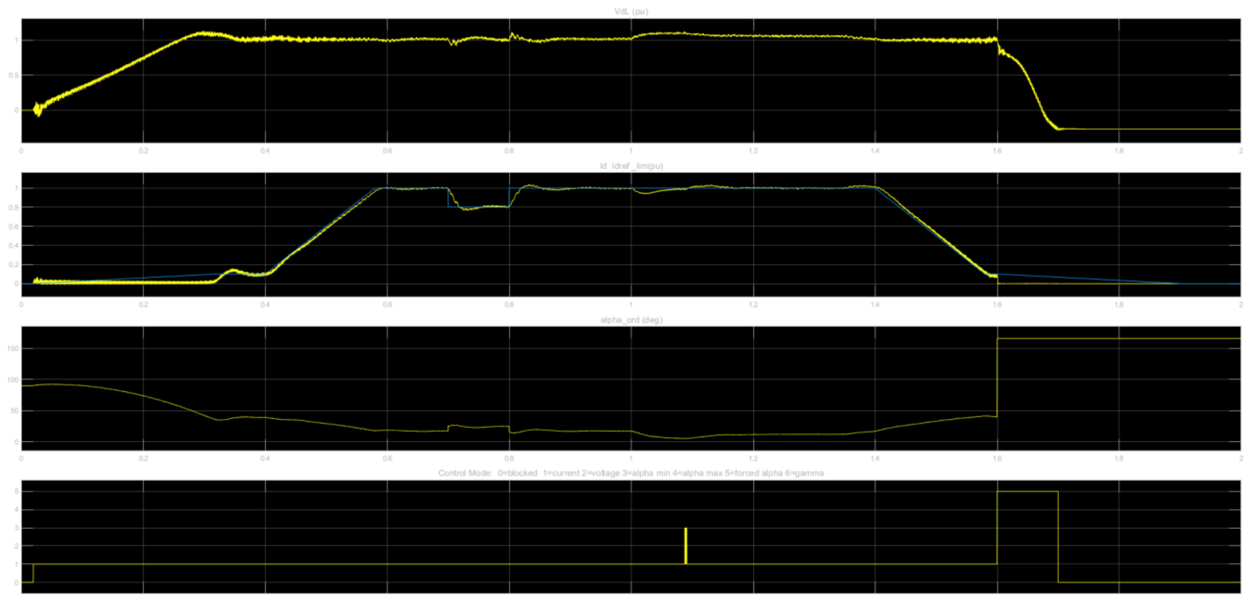

Figure 4: Real time response Rectifier Side

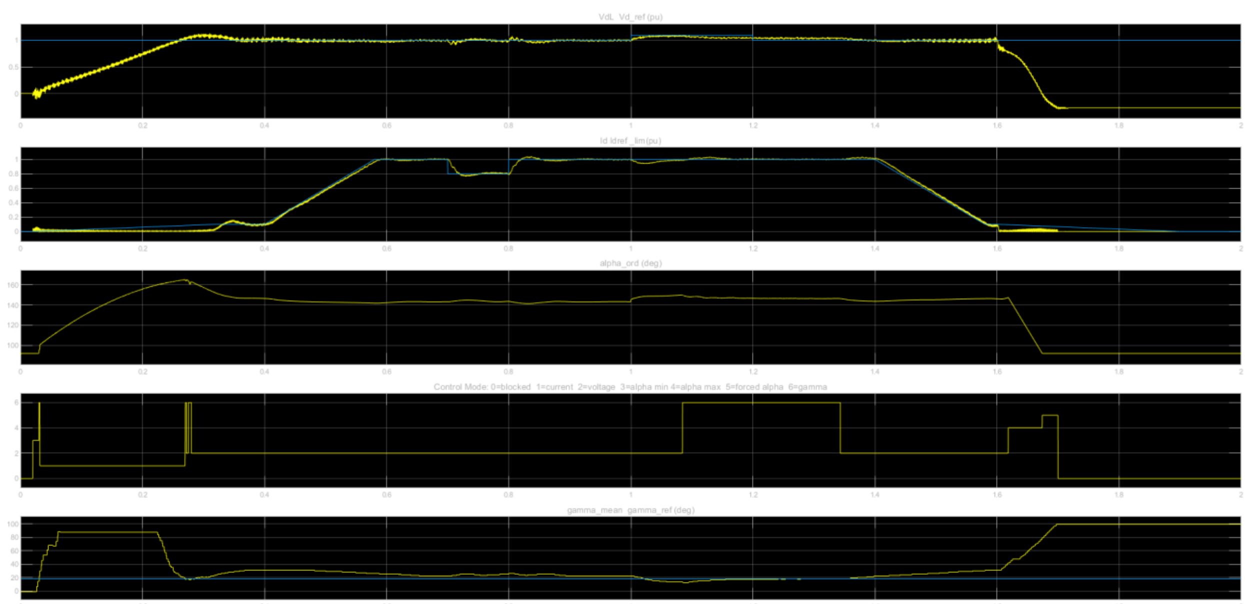

Figure 5: Real time response Inverter Side

Frequency Response of AC and DC system:

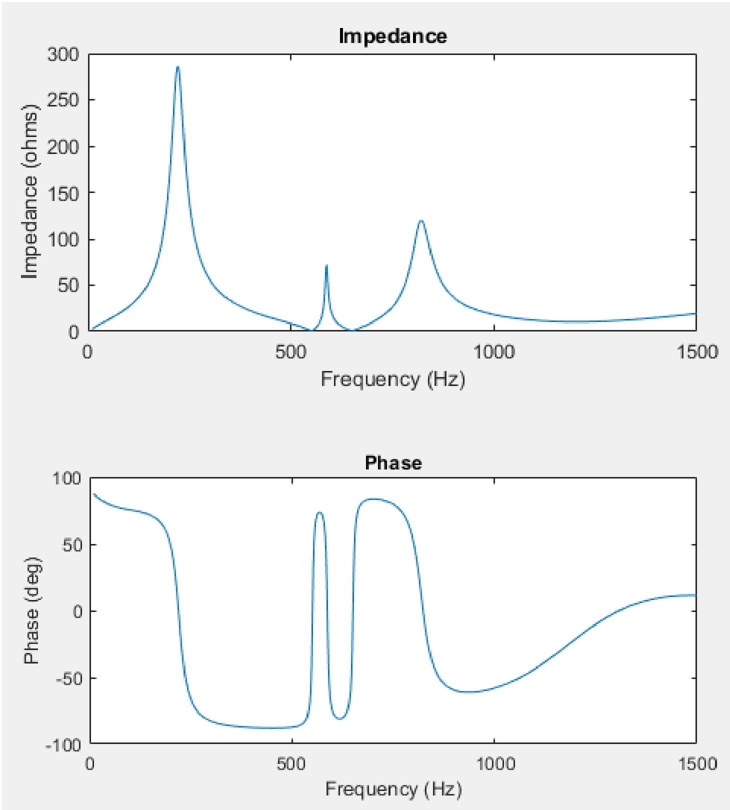

Figure 6: Frequency response of Zinv

Inverter Side: Peak Impedance of 286.7ohms at 222Hz due to 600Mvar capacitive filters. Resonance at 550Hz and 650Hz due to the 11th and 13th harmonic filters.

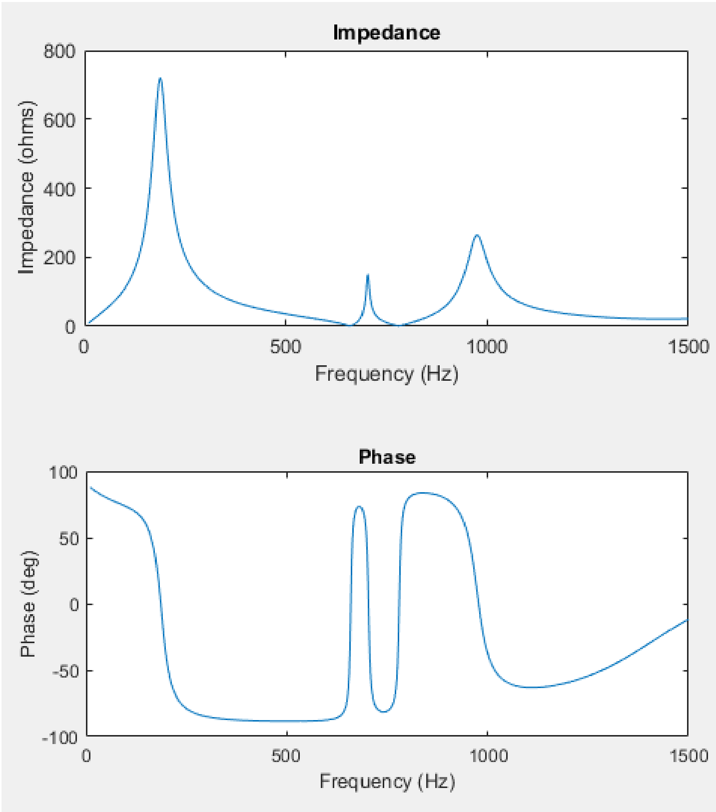

Figure 7: Frequncy response of Zrec

Rectifier Side: Peak Impedance of 730 ohms. Resonance at 660Hz and 780Hz due to the 11th and 13th harmonic filters.

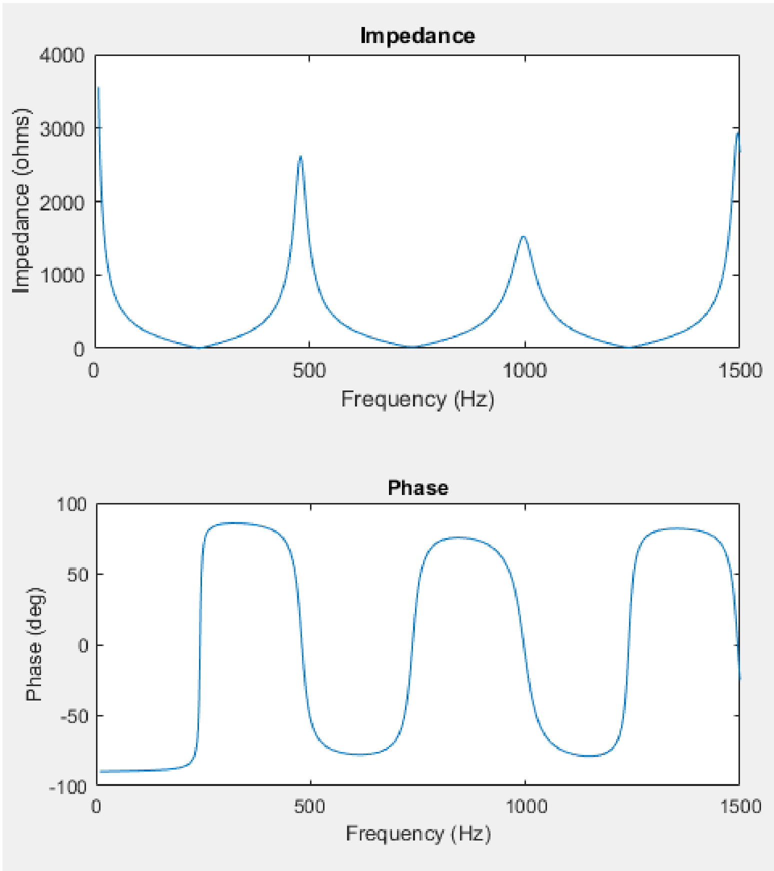

Figure 8: Frequncy response of Zdc for 300 km line

DC side: For the DC line, note the series resonance at 240 Hz, which corresponds to the main mode likely to be excited on the DC side, under large disturbances.

Comparison between Pi Section and Distributed Line Parameter:

The simulation is performed with two different line models.

1. π sections line

2. Distributed parameters line

For a transmission line, the resistance, inductance and capacitance are uniformly distributed along the line. An approximate model of the distributed parameters line is obtained by cascading several identical π sections as shown in the figure 2.

Unlike the distributed parameters line block, which has an infinite number of states, the π sections linear model has a finite number of states that permits to compute a linear state-space model.

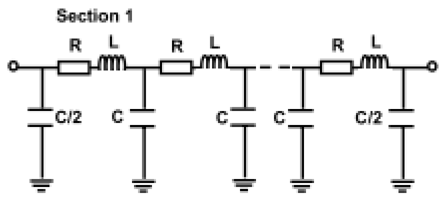

Figure 9: pi sections line

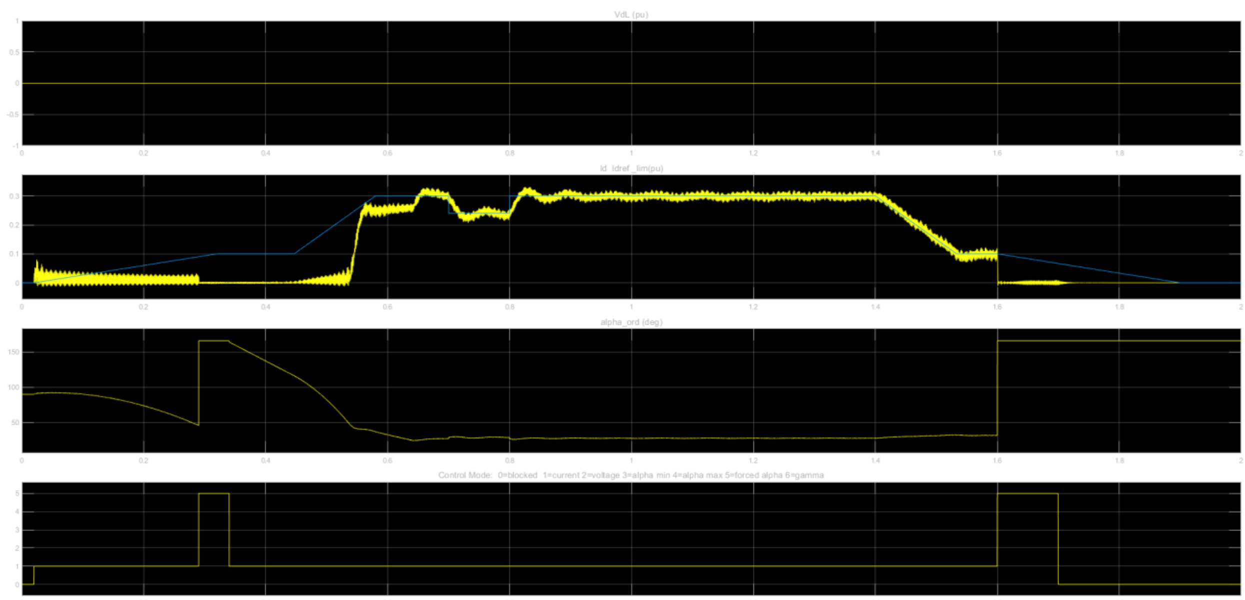

Figure 10: Real time response Rectifier side (for pi-section line)

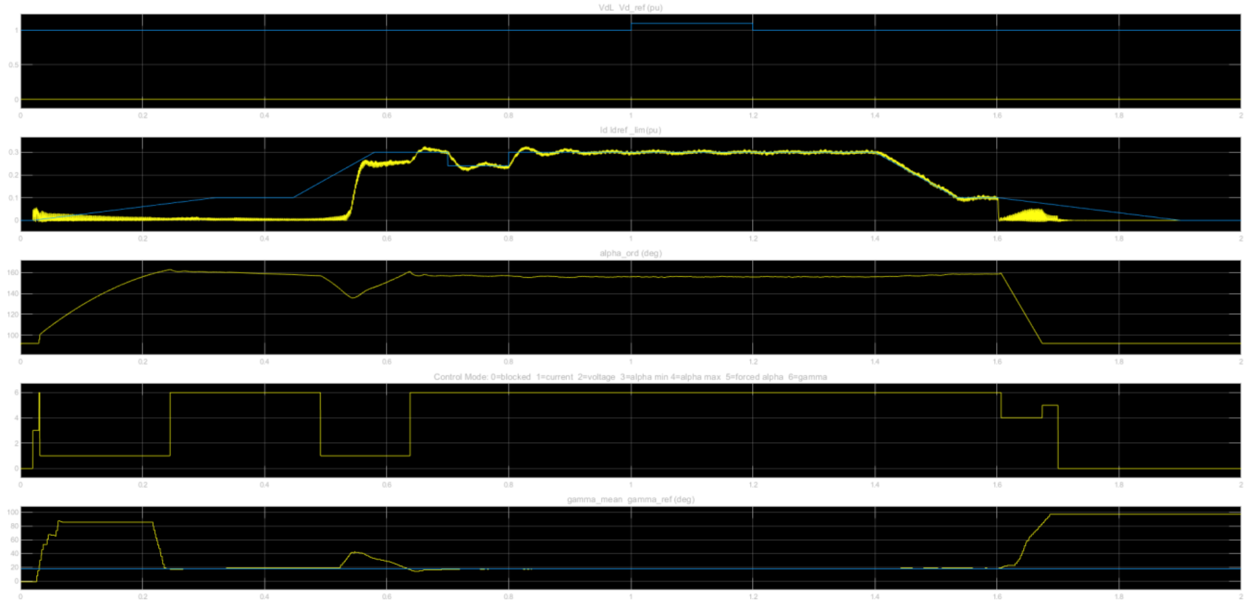

Figure 11: Real time response of Inverter side (pi-section line)

Frequency response of the DC system:

The magnitude of the impedance as a function of frequency of the DC system, as seen from the rectifier. It is composed by the two smoothing reactors and the DC line (300 km), represented by two π sections, or distributed parameters line (the two impedances are displayed on the same graph). The distributed parameters line shows a succession of poles and zeros equally spaced, every 492 Hz. The first pole occurs at

246 Hz, corresponding to

Frequency: f =1/4 τ

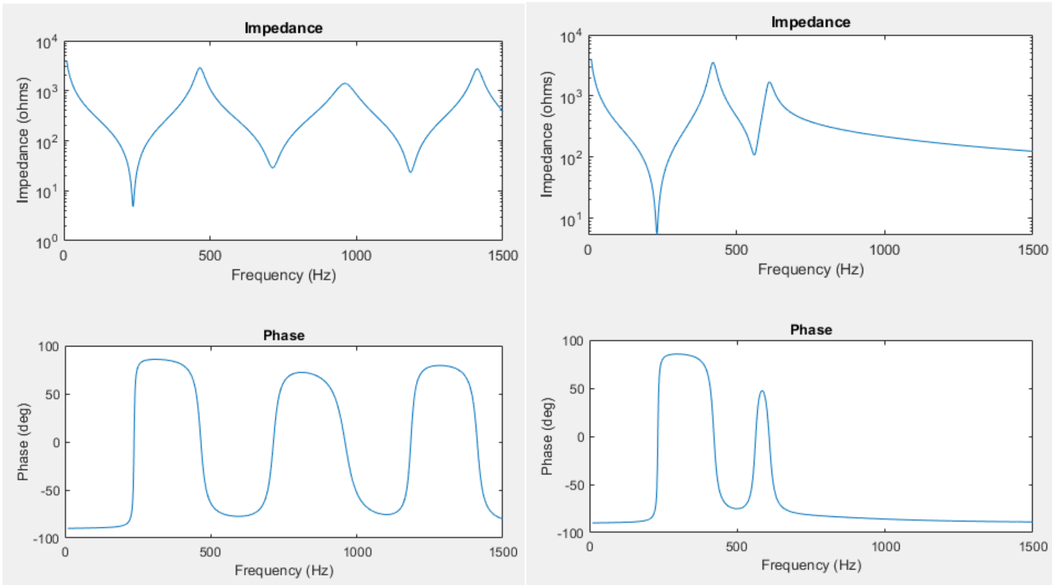

Fig12: Comparative graph of Zdc for Distributed parameter line and for 2-pi sections line

The π sections line only shows two poles because it consists of two π sections. Impedance comparison shows that a two π sections line gives a good approximation of the distributed line for the 0-247 Hz frequency range. In transient studies with π sections, it is important to consider whether a line should be represented by one or several sections. This is dependent upon:

1. The travelling time (τ).
2. The frequency of response simulation model.
3. The length of the line (l).

If we use 10 pi-sections instead of 2 pi-sections, we will get an accurate result as we have got from the distributed parameter line.

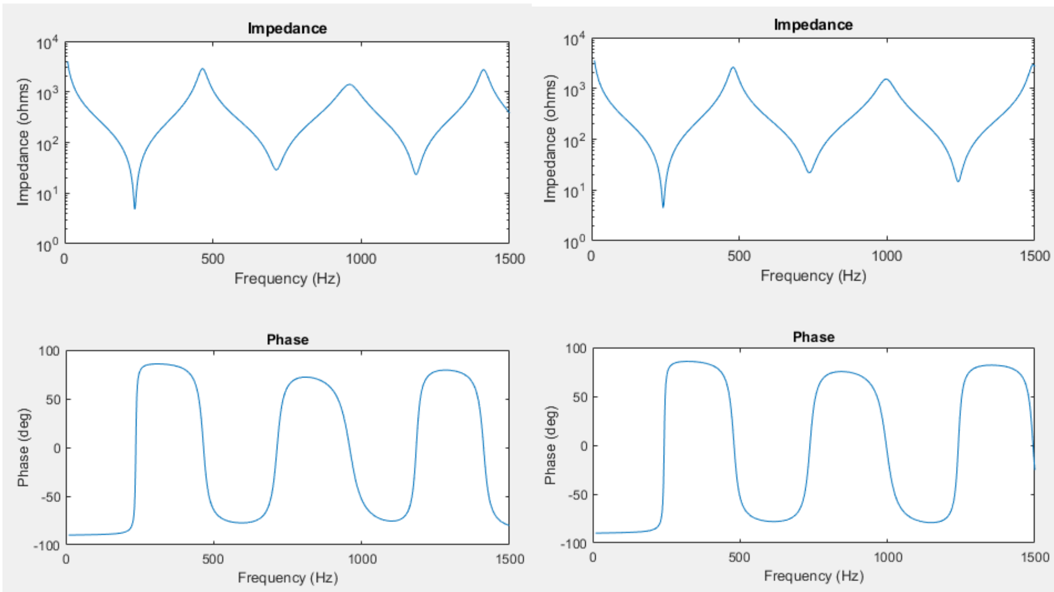

Fig 13: Comparative graph of Zdc for Distributed parameter line and for 10-pi sections line

<u>For a 15km DC transmission line,</u>

At light speed, a wave may travel 15 km over 50ms. If the length of the transmission line is less than 15 km when (Δ t = 50ms), then one π section is adequate to represent the line. If the line is longer than 15 km, two or more π sections should be cascaded in series.

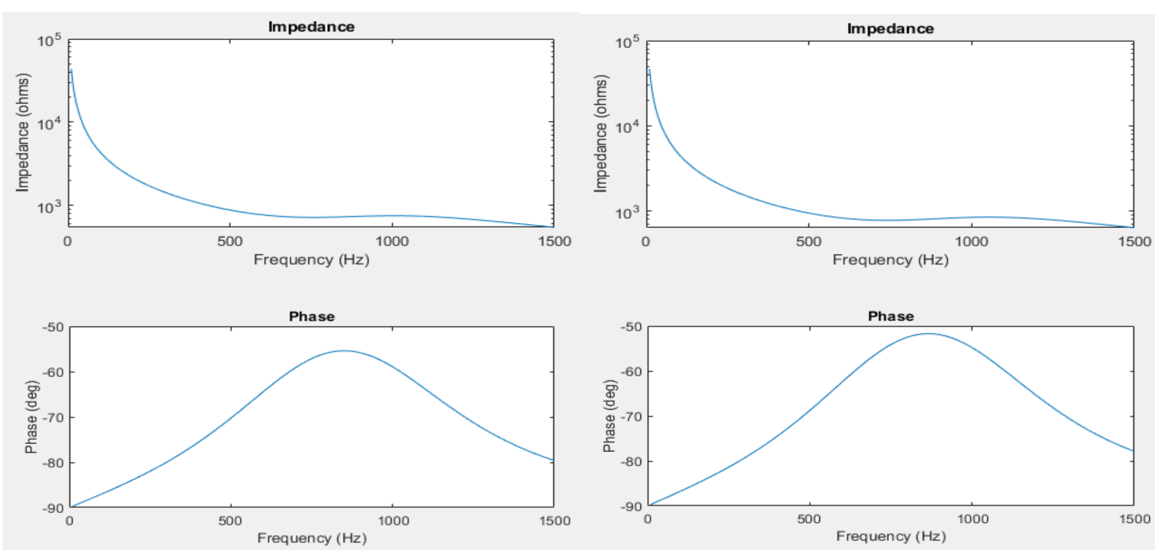

Fig 14: Comparative graph of Zdc for Distributed parameter line and for 2-pi sections line for a 15 km line

AC/DC FAULTS AND THEIR IMPACTS

Large oscillations are generated in the HVDC transmission system, during a fault due to a sudden disturbance caused by lightning strikes, switching faults. The decrease in voltage occurring in the grid results in lowering of active power transfer through the DC link. In DC transmission system, the impact of environmental factors is considerably lower than that of the AC-transmission system. The environment factors which affects the performance of the transmission system are categorized into four major types namely, noise, electric field, radio interference and visual impact. Treatment of noise in a transmission system is more cumbersome in case of a DC system than an AC system. The main contributor to noise signals is the transformer. Other noise adding components are smoothing reactors, filters and cooling towers. The low-noise components can be preferred during installation to reduce the noise level but it will be more expensive when enclosures or noise damping covers or walls are used.

The problems or faults occurring because of the electric field under a transmission line are due to space charges produced by corona and the electric discharges DC transmission faces problems of less severity in nature, in comparison to AC and however DC transmission requires less-space and shorter tower for transmission. The harmonics resulting in the operation of the HVDC converters and commutation processes give rise to disturbances in the kHz and MHz frequency range. These can be mitigated by shielding. The radio waves do not affect the HVDC as it does for AC system for semiconductor devices, due to advancement, it is now possible to achieve high power AC/DC conversion in the GW power range.

DC Line fault:

In the DC Fault block, change to 1 the 100 multiplication factor in the Switching times so that a fault is now applied at t = 0.7 s. The DC Fault protection (DCPROT) in the rectifier is activated by default.

We have to position the switch in lower control at master control and inverter control and protection. At fault application the DC current quickly increases to 2.3 pu and the DC voltage falls to zero at the rectifier. This DC voltages drop is seen by the Voltage Dependent Current Order Limiter (VDCOL) which reduces the reference current to 0.3 pu at the rectifier. A DC current still continues to circulate in the fault. Then, at t = 0.77 s, the rectifier alpha firing angle is forced to 166 degrees by the DC protection because a DC voltage drop is detected (VdL< 0.5 pu for more than 70 ms). The rectifier now operates in inverter mode. The DC line voltage becomes negative and the energy stored in the line is returned to the AC network, causing rapid extinction of the fault current at its next zero-crossing.

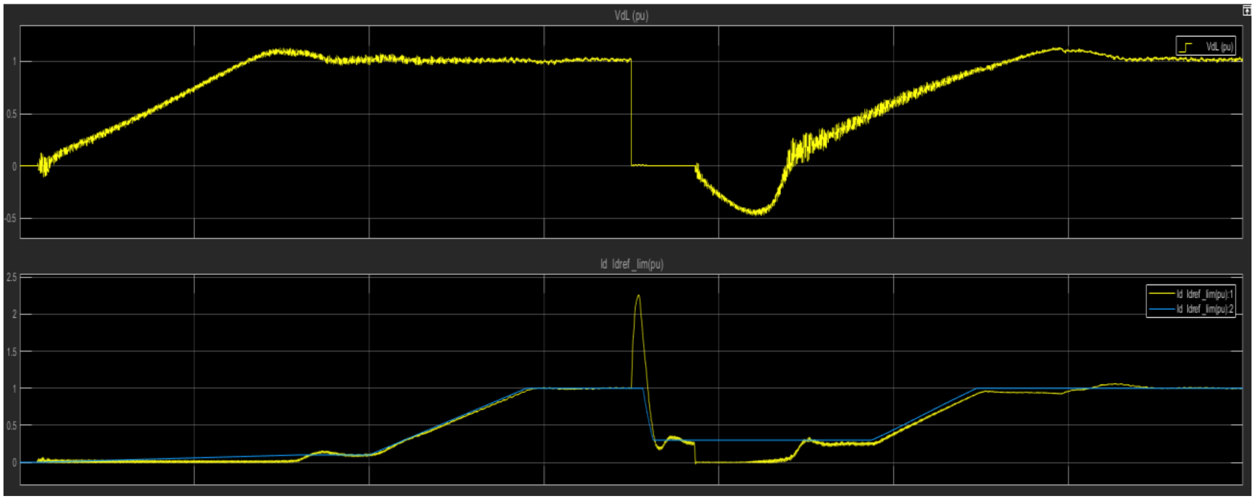

fig 15: DC line fault on Rectifier side

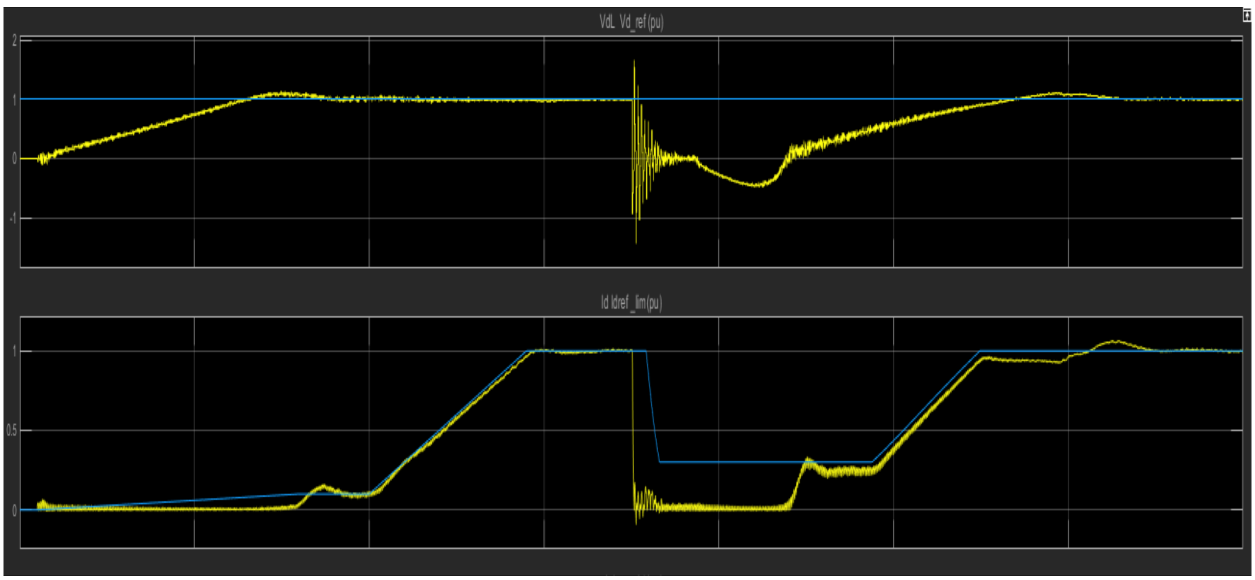

Fig 16: DC line fault on Inverter side

AC line to ground fault:

Modifying the fault timing in the DC block, changing the multiplication of Zdc to 100, we eliminate DC fault. Changing switching time to 1 in AG fault block, we induce a six cycle line to ground fault at t= 0.7 s. Now the simulation becomes –

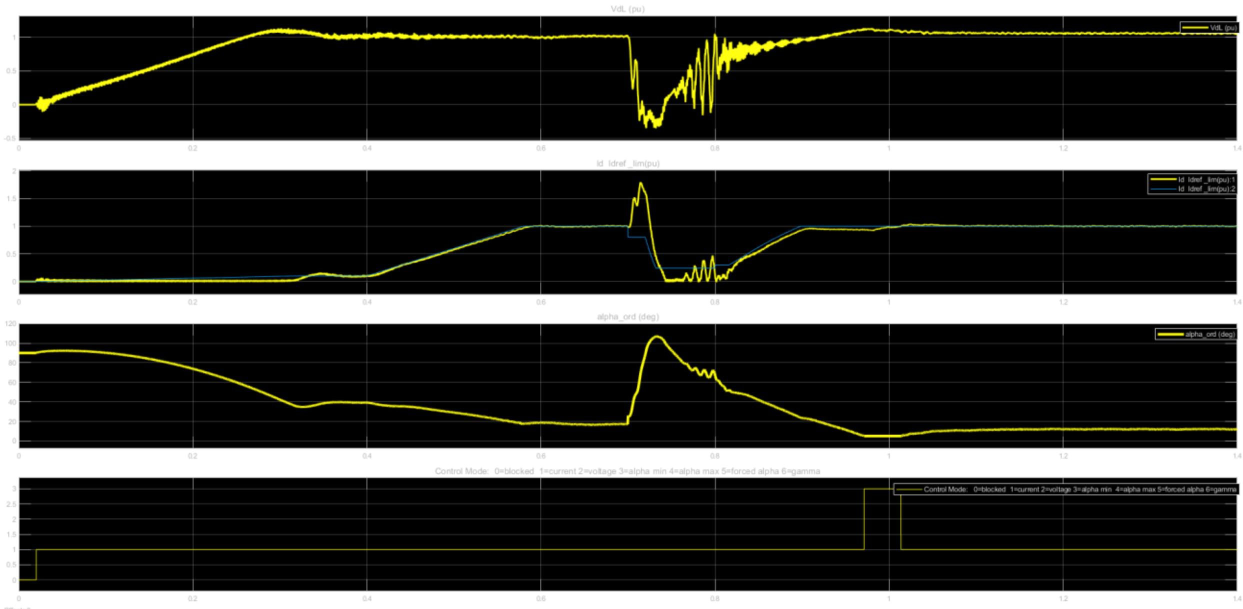

Fig 17: AC line to ground fault on Rectifier Side

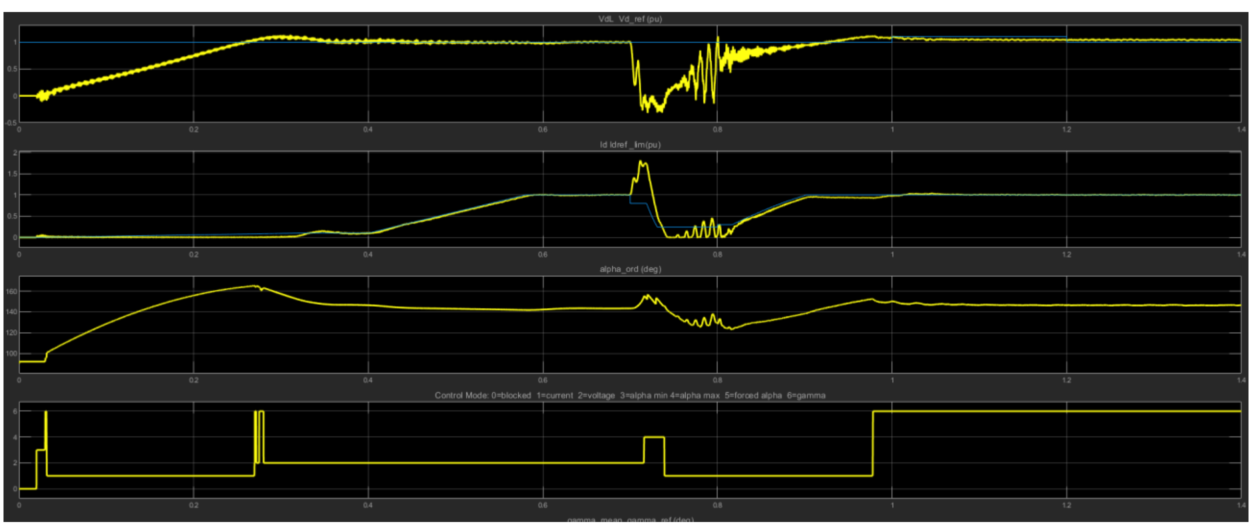

Fig 18: AC line to ground fault on Inverter side

Because of commutator fault, DC current has been increased to 2pu. Commutator failure is the failure of the incoming valve to take over the direct current before commutation voltage reverses its polarity. So VDCOL brings down the reference current to 0.3pu to start working.

CONCLUSION:

This paper provides some general guidelines regarding the areas of applicability and the limitations of HVDC model in Simulink.

In Real time response, we have seen how we can change the reference current and how the other components change with it.

A simple π section model cannot give the correct impedance at higher frequencies; it is suitable for very short lines where the travelling wave models cannot be used. The π sections models are generally not the best choice for transient solutions, because travelling wave solutions are faster and usually more accurate.

The AC/DC faults and their impact system have been discussed. The enhancement of the AC system performance used in HVDC transmission to damp oscillations causing disturbance during the operation and the control signals used to suppress oscillation and improve the transient stability of the system have been presented in detail.

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