American Journal of Engineering Research (AJER)
e-ISSN : 2320-0847 p-ISSN : 2320-0936
Volume-03, Issue-04, pp-66-75
www.ajer.org

Research Paper Open Access

Power Improvement of Transmission Line Using High Voltage Direct Current (Hvdc) Transmission System

Lasisi, H., Olayemi, S.O
Department of Electrical/Electronic Engineering, Osun State University, P.M.B. 4494, Oke Baale, Osogbo, Nigeria

Abstract: - The use of long EHV (Extremely High Voltage) ac lines for the transmission of electrical energy increases the line reactance and susceptance which limits the thermal loadings on the line in order to keep sufficient margin against transient instability. With the scheme proposed in this paper, it is possible to load the lines very close to their limit with zero reactance and susceptance. The conductors are allowed to carry usual ac along with dc superimposed on it. The added dc power flow does not cause any transient instability.
The scheme comprises a twelve-pulse bridge rectifier, dc-links, pulse width modulated (PSW)-voltage sourced inverter (VSI) and converter transformers. The master current controller is used to implement the scheme which senses ac current and regulates the dc current orders for converters online such that conductor current never exceeds its thermal limit.
This paper gives the feasibility of converting a double circuit ac line into composite ac–dc power transmission line given the advantage of stability improvement, damping oscillations, voltage stabilization and reactive power compensation for ac weak buses.
Simulation and experimental studies using MATLAB (Matrix Laboratory) are carried out for the coordinated control as well as independent control of ac and dc power transmissions.

Keywords: - *Transmission System, Transient Stability, High Voltage Direct Current, Reactive Power, Damping Oscillation, Pulse Width Modulation, Voltage Source Inverter*

I. INTRODUCTION

Electric energy is the most popular form of energy, because it can be transported easily at high efficiency and reasonable cost (Saadat, 1999). The basic function of a transmission system is to transfer electrical power from one place to another or from one network to another network (Gupta, 2005). For transmitting power over very long distances it may be more economical to convert the EHV-ac to HVDC (High Voltage Direct Current), transmit the power over two lines, and invert it back to ac at the other end. Studies show that it is advantageous to consider dc lines when the transmission distance is 500km or more (Saadat, 1999). Dc lines have no reactance and are capable of transferring more power for the same conductor size than ac links. The dc transmission tie line acts as an asynchronous link between the two rigid system eliminating the instability problem inherent in the ac links (Saadat, 1999).

During the past two decades, utilities have been trying to compensate for the varying load conditions (Johnson et al., 1972 ; Gyugyi et al., 1976), enhance and control transmission lines power transfer capacity (Czech et al., 1980), improve power system transient and dynamic stabilities (Olgward et al., 1980; Sharaf et al., 1985; Xing et al., 1988) using voltage regulators, power factor correction capacitors and static reactive power compensators.

The limitations of a mono-polar dc transmission with ground as return path result to high amount of dc voltage which require more discs added to the insulator string to withstand the increased voltage.

In this paper, the feasibility study of conversion of double circuit ac line to composite ac –dc line without altering the original line conductors, tower structures, and insulator strings has been presented.

II. POWER IMPROVEMENT OF TRANSMISSION LINE USING HVDC TRANSMISSION

A. Configuration

The configuration shown in figure 1 consists of ac filters , transformer, converters, phase reactors, dc filters capacitor

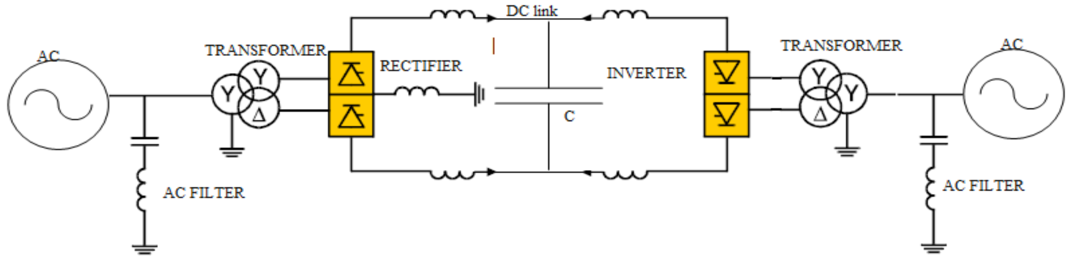

Figure 1: Configuration of the transmission using HVDC system

B. Components and its Operation

This scheme is based on the voltage source converter (VSC), where the valves are built by IGBT (Insulated Gate Bipolar Transistor) and PWM (Pulse Width Modulation) is used to create a desired waveform. The main function of the VSC-HVDC is to transmit constant dc power from the rectifier to the inverter.

i. Converters

The converter is a 12-pulse double bridge converter which consists of two 6-pulse bridge converters connected in series and employs IGBT power semiconductors, one operating as a rectifier and the other as inverter.

ii. Transformers

The converters are normally connected to the ac system via the transformers. The most important function is to transform ac voltage to a value suitable for the converter.

iii. Phase reactors

The phase reactors are used for controlling both the active and reactive power flow by regulating current through them. It can also function as ac filters to reduce harmonic contents as a result of switching.

iv. AC filters

The output of AC voltage contains harmonic components. These harmonics have to be removed to prevent them from being emitted into the ac system and causing equipment malfunctioning or radio and telecommunication interference. High –pass filters are installed to mitigate the harmonics.

v. DC capacitors

The objective of the dc capacitor is to provide a low inductive path for the turned off current and energy storage to be able to control the power flow. It also reduces the ripples on the dc side. The size of the capacitors depends on the required dc voltage.

vi. AC source

Ideally the ac source model can be developed by using the thevenin's equivalent circuit. However, for simplicity, the source was modelled using ideal symmetrical three-phase voltage. (Shri harsha et al., 2012)

III. CONTROL DESIGN OF DC TRANSMISSION

The current flowing in the dc transmission is determined by the dc voltage difference between the two converter stations.

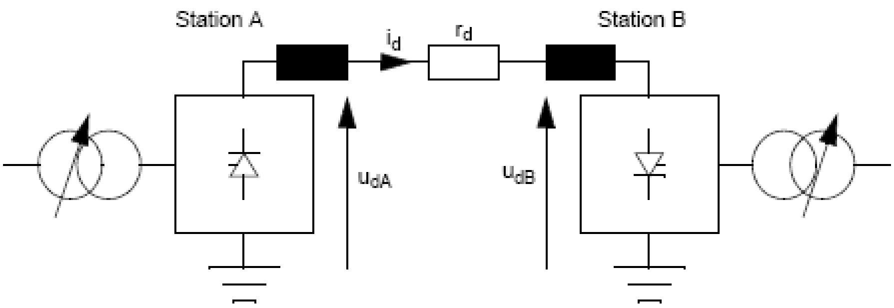

Figure 2: Control design of DC transmission

Using the notation shown in figure 2, where *rd* represents the total resistance of the line, we get for the DC current

$$i_d = \frac{u_{dA} - u_{dB}}{r_d} \qquad (i)$$

Where u_{dA} = dc voltage at station A
u_{dB} = dc voltage at station B

and the power transmitted into station B is

$$p_d = u_{dB} \cdot i_d = u_{dB} \cdot \frac{u_{dA} - u_{dB}}{r_d} \qquad (ii)$$

IV. MASTER CONTROL SYSTEM

The rectifier controls the dc voltage and the inverters controls the active power while the reactive power cannot be independently controlled. The PWM technology makes it possible to control the reactive power and the active power independently.

The master control, however, is usually designed with specification depending on the requirements of transmission. The control can be designed for constant current or constant power transmitted, or it can be designed to help stabilize the frequency in one of AC networks by varying the current of active power transmitted. The master control is only active in a station selected to act as the master station, which controls the current command. In order to synchronize the two converters and assume that they operate with the same current command, a telecommunication is required. The telecommunication system should be fault-free to avoid the current command to both converter station from been frozen. It is equipped with an IEEE type AC 4A excitation system of which block diagram is shown in Figure 3. Transmission lines are represented as the Bergeron model. It is based on a distributed LC parameter travelling wave line model, with lumped resistance. It represents the L and C elements of a PI section in a distributed manner.

A master current controller (MCC), shown in Figure 4, is used to control the current order for converters. It measures the conductor ac current, computes the permissible dc current, and produces dc current order for inverters and rectifiers.

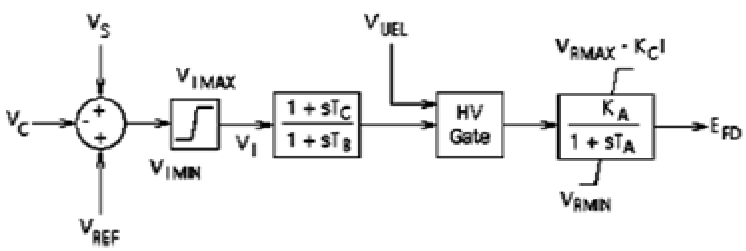

Figure 3: IEEE type AC4A excitation system

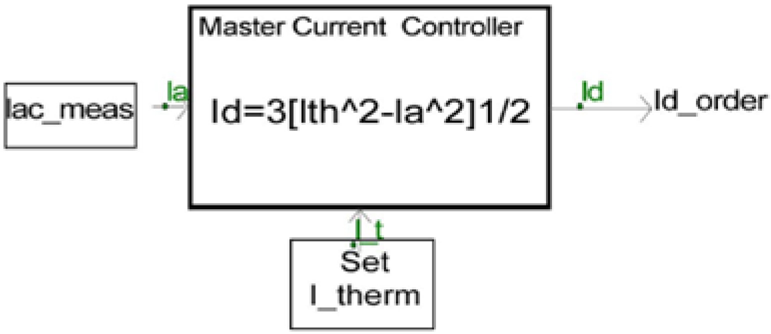

Figure 4: Master current controller

V. SIMULATION AND RESULTS

A. Simulink model

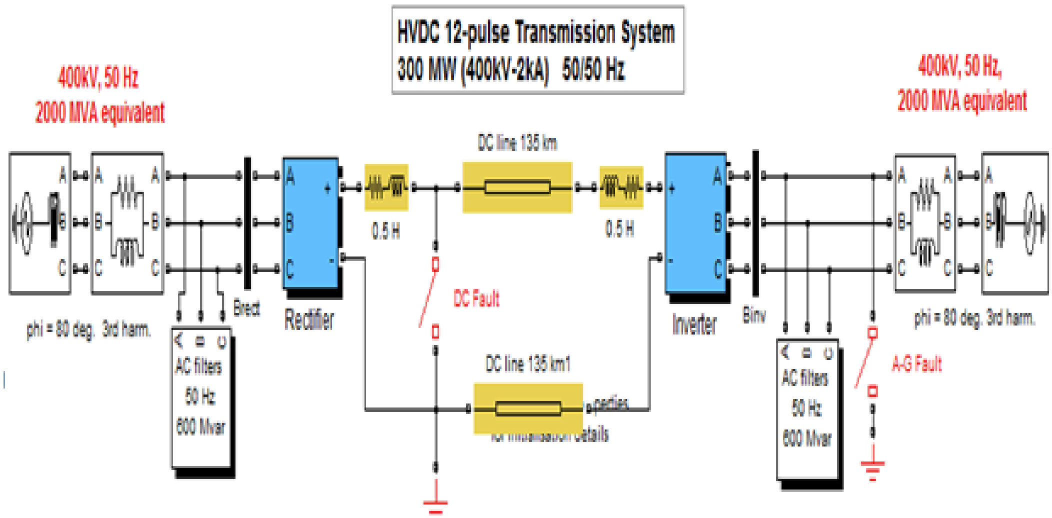

Figure 5: Simulink model of the scheme

B. System description

A 300MW (150kV) force commutated VSC is used to transmit dc power from a 400kV ,2000MVA, 50Hz system to another ac system. The rectifier and the inverter are connected through a 125km line (i.e. distributed parameter line) and two 8mH phase reactors. The sinusoidal pulse width modulation switching uses a frequency 27 times the fundamental frequency (1350Hz). A converter transformer (Y/D) is used to permit the optimal voltage transformation.

To meet ac system harmonic specifications, ac filters form an essential part of the scheme. They can either be connected on the ac system side or the converter side of the converter transformer.

C. Design procedure

The rectifier and inverter are the three level of VSC that use the IGBT/diode module available in the MATLAB/Simulink/ Simpower system. The design procedure is:

DC voltage rating: 150kV

System frequency: 50Hz

Source AC voltage: 400kV

$$\text{Rated DC current} = \frac{\text{Rated DC power}}{\text{Rated DC voltage}} = \frac{300\text{MW}}{150\text{kV}} = 2\text{kA} \qquad \text{(iii)}$$

D. AC system modelling

A simple three phase AC source is used to model the AC system with internal resistance and inductance that is calculated from short circuit level MVA calculations.

Source AC voltage: 400kV (phase to phase)

System frequency: 50Hz
Source inductance from MATLAB = 0.2546H

$$\frac{X}{R} = 10 \qquad \text{(iv)}$$

X = 2πfL = 2π x 50 x 0.2546 = 80Ω
R = 8Ω

E. Transformer design

A star/ delta transformer is used to permit the optimal voltage transformation. It also functions to block triplen harmonics produced by the converter.
The following data are used for the transformer:
Nominal power:
Nominal frequency:
Winding 1: Y connected
Nominal voltage: 400kV x 0.915 = 366kV
Resistance: 0.0025pu
Leakage reactance: 0.0075pu
Winding 2: D connected
Nominal voltage: 150kV
Resistance: 0.0025pu
Leakage reactance: 0.075pu
Magnetising losses: resistive = 500pu, inductive = 500pu

F. Filter design

The Three-Phase Harmonic Filter is built of RLC elements. The resistance, inductance, and capacitance values are determined from the filter type and from the following parameters: Reactive power at nominal voltage Tuning frequencies Quality factor. The quality factor is a measure of the sharpness of the tuning frequency. It is determined by the resistance value. The filter is made up of passive R, L, C components their values can be computed using specified nominal reactive power, tuning frequency and quality factor.
Nominal voltage: 150kV
Nominal frequency: 50Hz
Nominal reactive power: 25% of real power (300MW) 78.5MVar
Tuning frequency: 27 * 50 and 54 * 50
Quality factor: 15
(Shri harsha et al., 2012)

G. Simulation results

A. System's performance under Normal starting operation

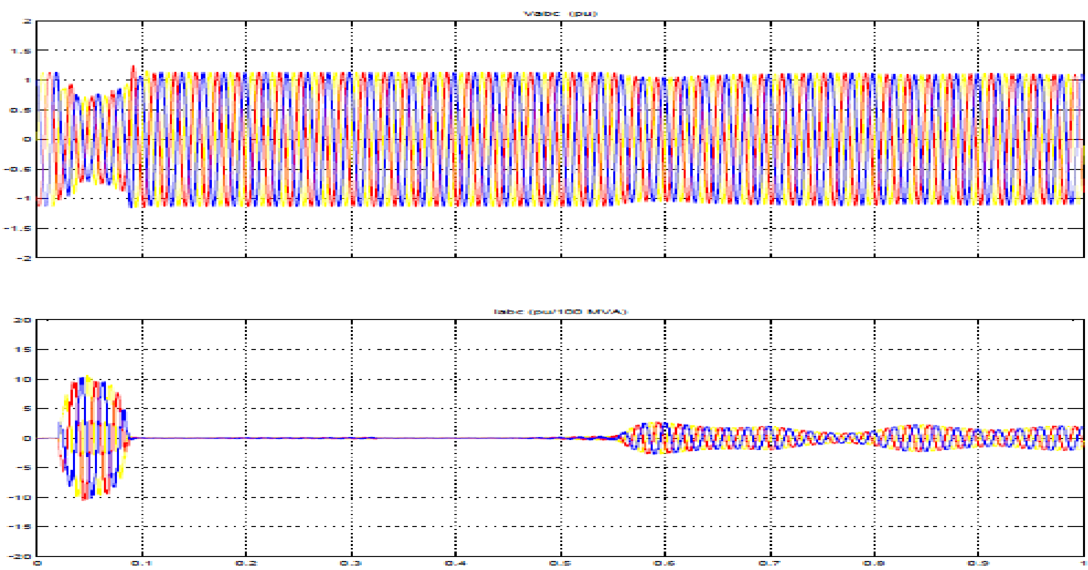

Figure 6. AC Rectifier terminal voltage and current under normal operating conditions.

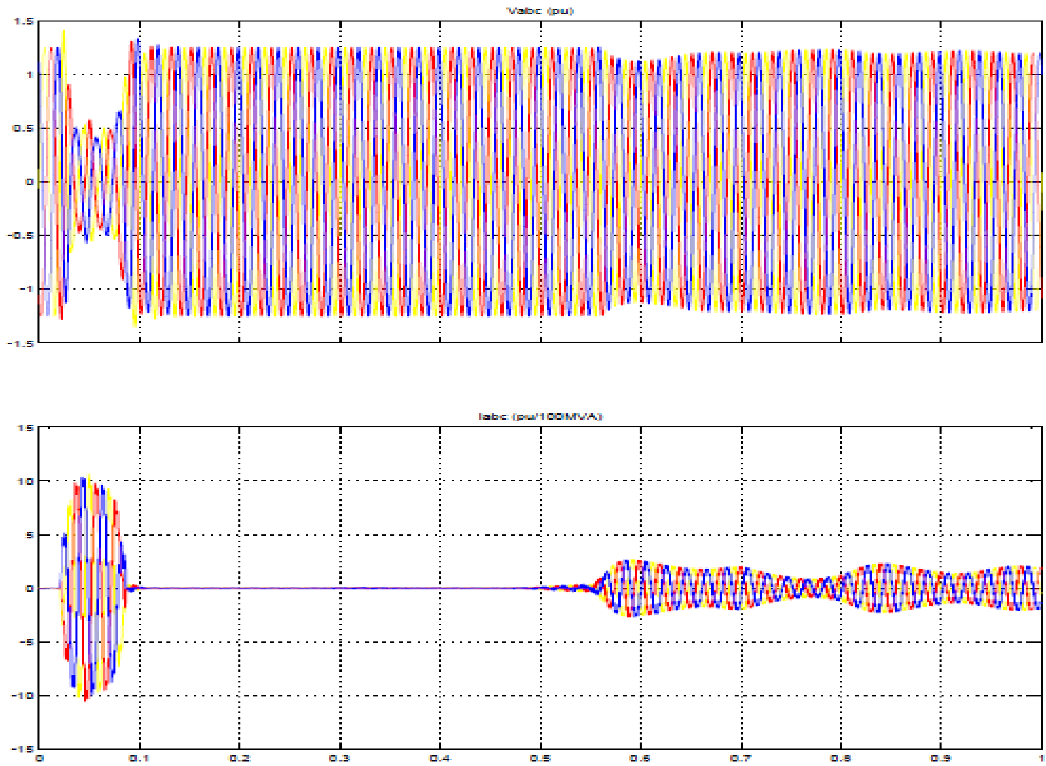

Figure 7: AC Inverter terminal voltage/current under normal operating conditions

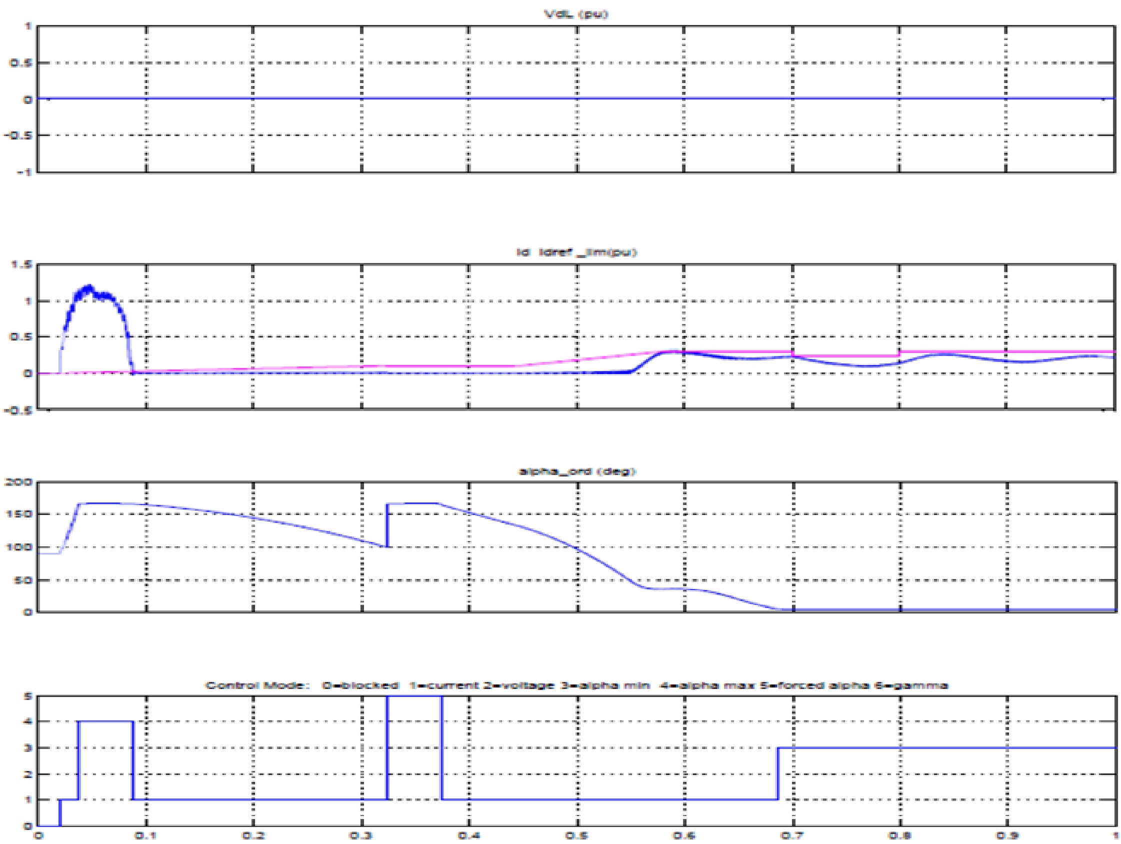

Figure 8: Rectifier current and voltage reference when steps is applied under normal operating conditions

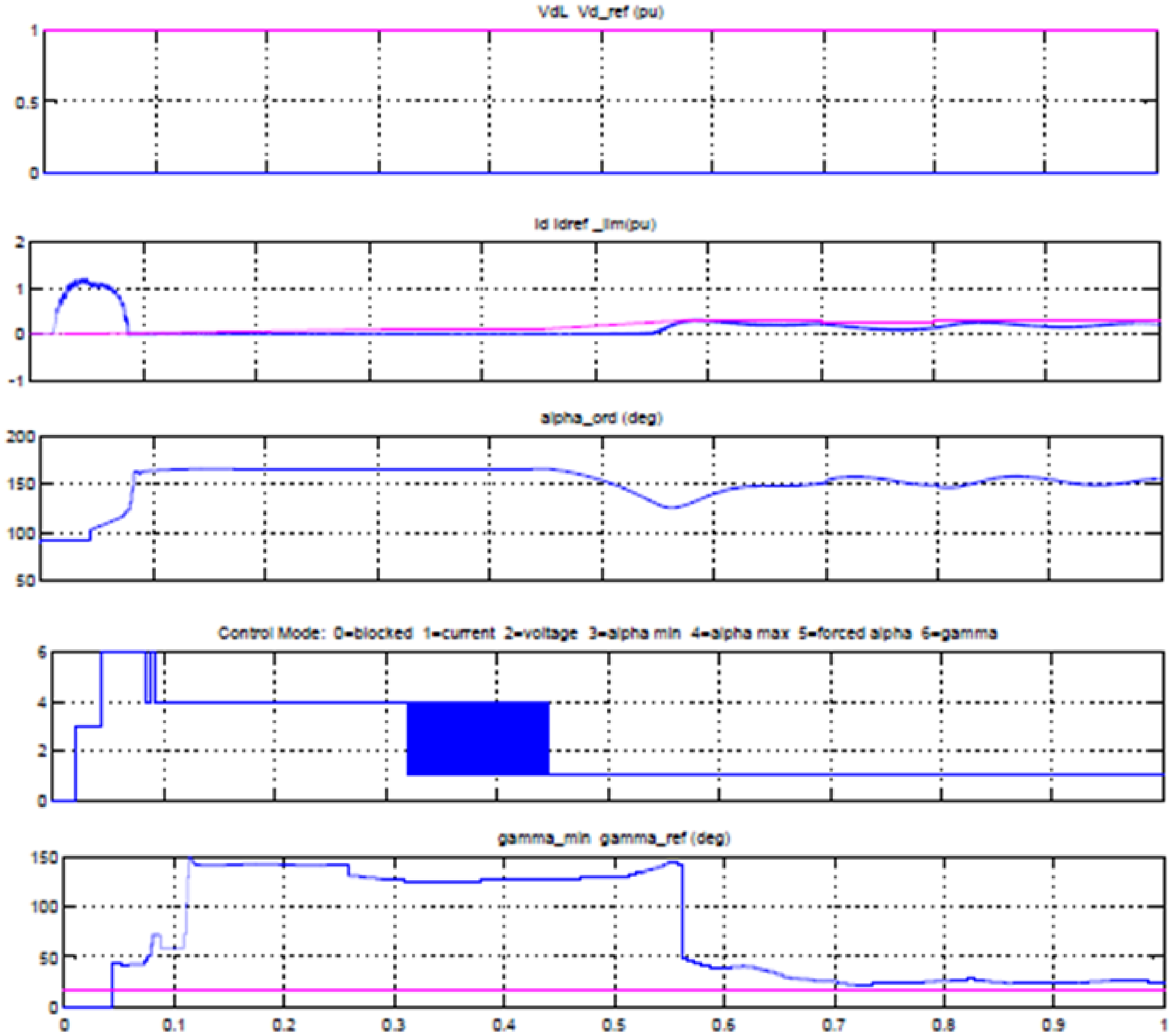

Figure 9: Inverter current and voltage reference when a step is applied under normal operating Conditions.

B. System performance under improvement

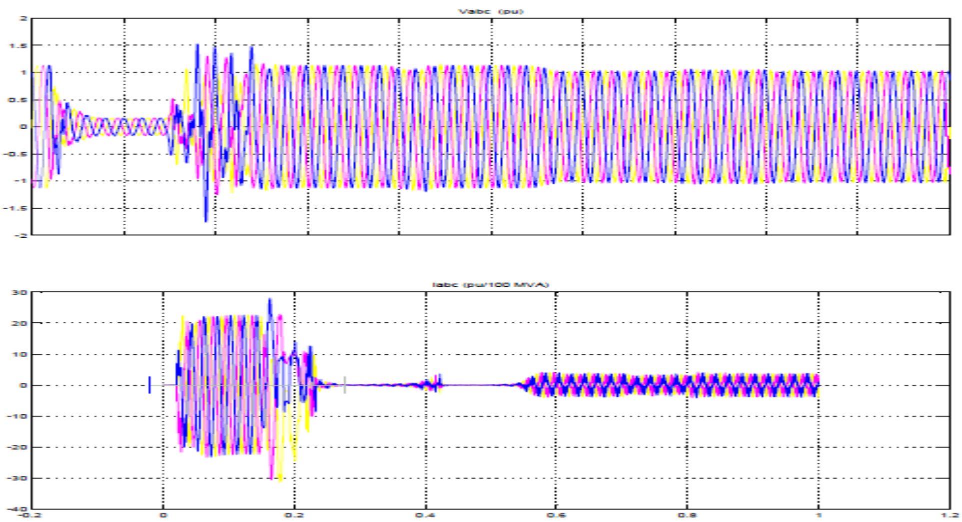

Figure 10: Rectifier voltage-current behaviour under improvement.

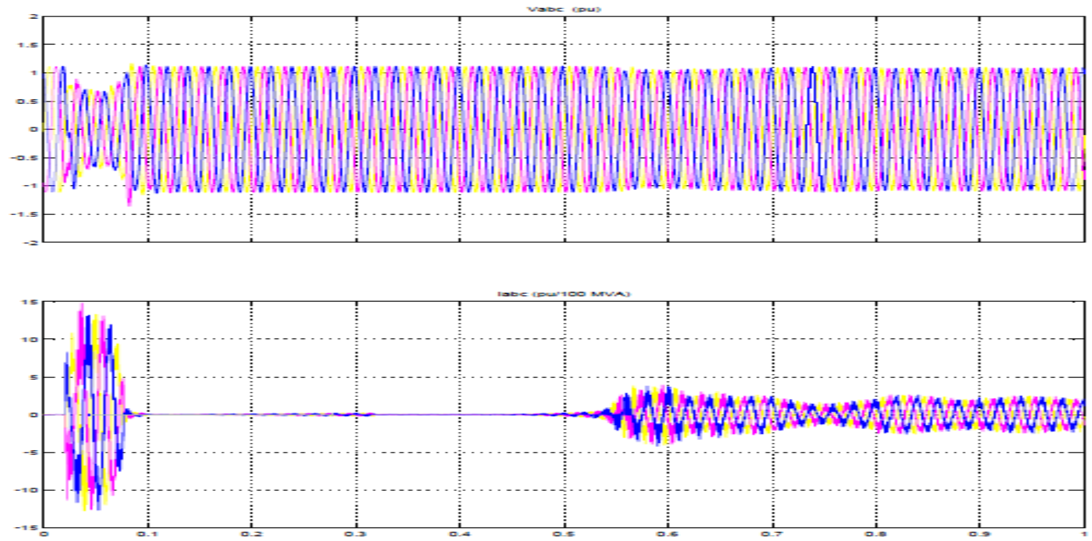

Figure 11: Inverter voltage-current behaviour under improvement

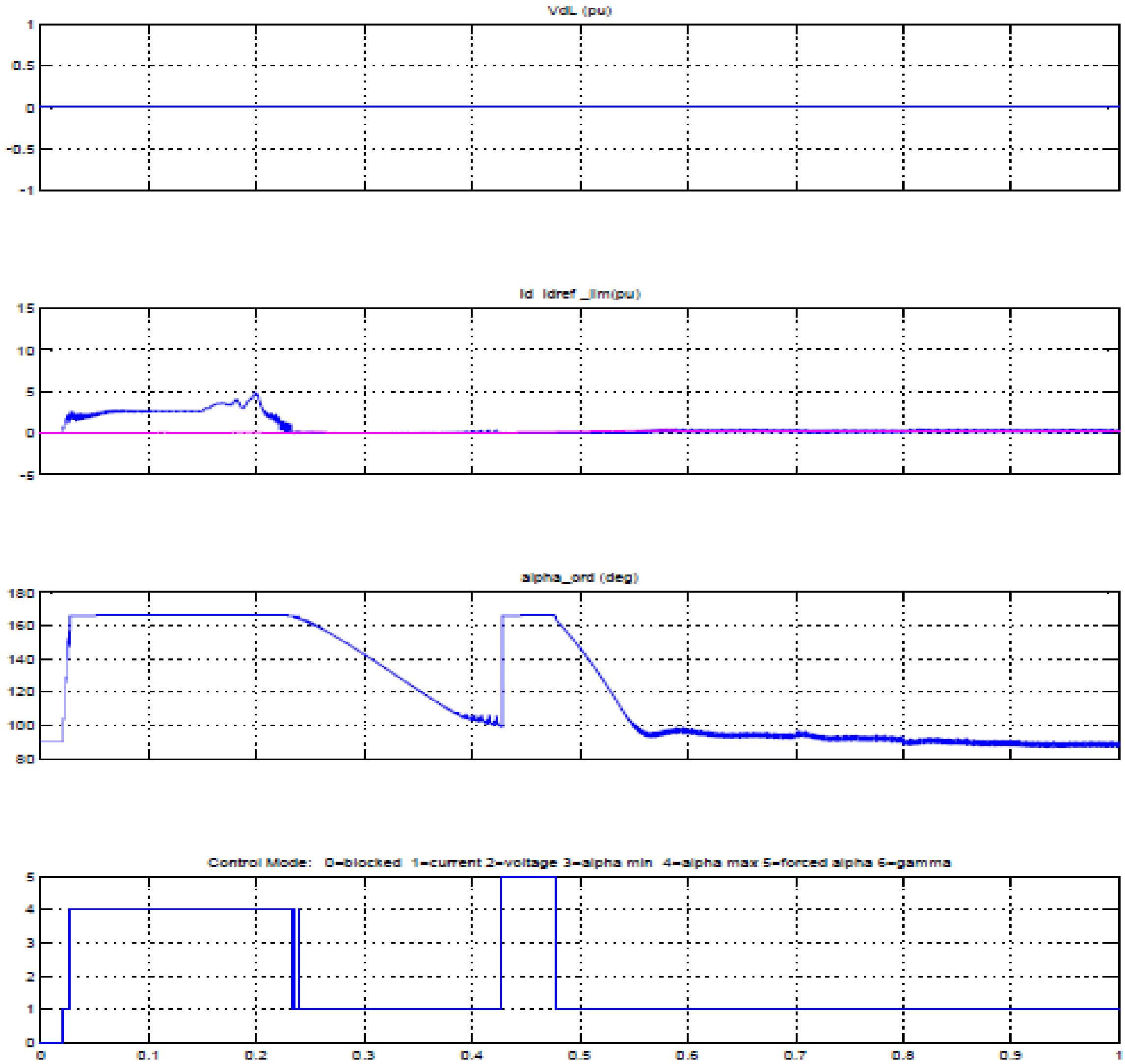

Figure 12: Rectifier current and voltage reference under improvement

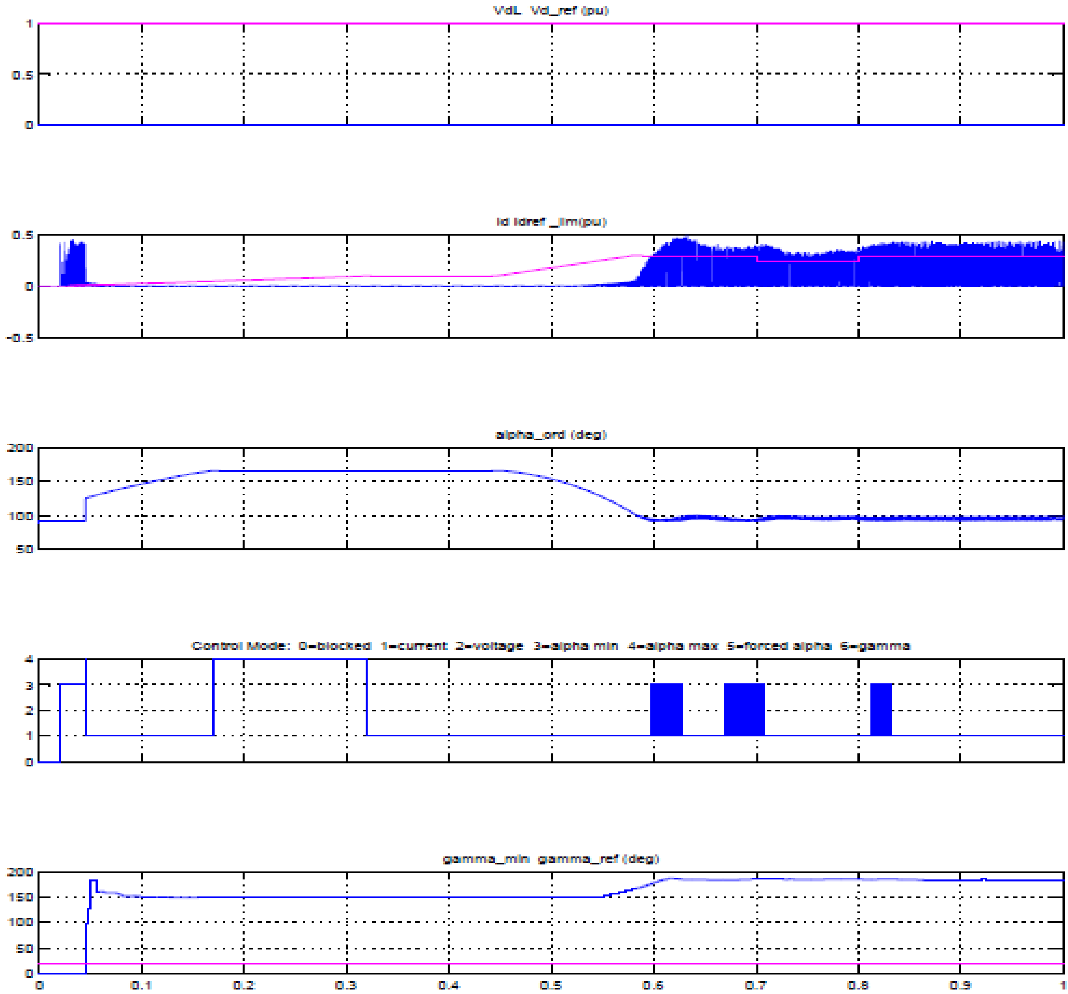

Figure 13: Inverter current and voltage reference under improvement

H. Result Discussion

A. Discussion of Result for normal operation

Under normal operating condition, figure 6 to figure 9 reveals the responses at different parts of the system. Figure 6 shows the p.u three phase voltage and current of the AC Rectifier while figure 7 indicates the three phase voltage and current of the AC inverter after completing the conversion process. The result shows a normal waveforms of a rectifier and inverter under normal operation condition without any conditioning.

When a step is applied first to the reference current and later to the voltage reference, the resulting waveform of the dynamic response of the regulators is shown in Figure 8 and figure 9. The rectifier controls the current and the inverter controls the voltage. Trace 1 of both Figure 8 and figure 9 shows the DC line voltage (1 pu = 330 kV). At the inverter, the voltage reference is also shown. Trace 2 shows the reference current and the measured Id current (1 pu = 2 kA). During the ramp, the inverter is actually controlling the current (Trace 4: Mode = 1) to the value of Id_ref_lim less the Current Margin (0.1 pu) and the rectifier tries to control the current at Id_ref_lim. At the inverter, the control mode changes from current control to gamma control (Mode = 6) before stabilizing to voltage control (Mode = 2) at t = 0.3 s. The rectifier becomes thereafter in control of the current. However, a control mode change will occur and alpha is limited to the minimum value of 5 degrees (Mode = 3) during an increase of the DC voltage initiated by a voltage reference increase at the inverter. At steady state, the α firing angles are around 16.5 degrees and 143 degrees respectively on the rectifier and inverter side. At the inverter, two Gamma Measurement blocks measure the extinction angle γ for each thyristor of the two six-pulse bridges by determining the elapsed time expressed in electrical degrees from the end of current conduction to the zero crossing of the commutating voltage. The mean value of the measured gamma for the last 12 extinctions (6 of the Delta converter and 6 of the Wye converter) is shown in traces 5 along with Gamma reference. In steady state, the mean γ is around 22.5 degrees.

B. Discussion of Result under improvement

The performance of the system is analysed under improvement when the lines are loaded beyond their thermal and the response of the system is given in figure 10 to figure 13. Figure 10 shows the voltage-current behaviour of the Rectifier under improvement and it shows the transient stability of the system has shifted from -0.2 and 0. 2 seconds under normal condition to 0.2 and 0.6 seconds when improved.

Figure 11 responses remain the same as when operating under normal operating condition but with a slight shift from 0 to 0.01 seconds indicating that when loaded beyond the thermal limit, the effect is minimal in the inverter station compared to the rectifier station.

Figure 12 and figure 13 shows the reference voltage and current when steps are applied under loading conditions. Figure 12 reveals that the rectifier at t = 0.24s, controls the current. The control mode change will occur and the alpha is limited to minimum value during the increase in DC voltage initiated by a voltage reference increased at the inverter. The control mode changes from current control to gamma control before stabilizing the voltage control at t = 0.05s. The extinction angle reaches the reference value and the gamma regulator takes control at t = 0.25s. At t = 0.55s the voltage regulator retakes control of the voltage as seen in figure 13.

It can also be observed that with the configuration used, the reactive power at the sending end was minimised while the receiving end voltage was maintained without any compensation.

VI. CONCLUSION

This paper presents a feasibility of a steady-state stability performance of dc Transmission and the system studied shows there is a substantial increase in the load ability of the line. The line is loaded to its thermal limit with the superimposed dc current. The dc power flow does not impose any stability problem. The advantage of parallel ac–dc transmission is obtained.

It can be concluded that the system response is fast; high quality ac voltages and ac currents can be obtained at the receiving station; the active and reactive power can be controlled independently. The scheme also ensures that the receiving voltage can be maintained without compensation.

This scheme can also be tailored to a multitude of applications depending on the control strategy selected. The knowledge obtained from this simulation can be used to predict the characteristic behaviour and the performance of the real system.

REFERENCES

[1] Czech, P., reichert, K., Schweickardt, H.E. and Holm, H.," Static VAR systems in power transmission-Principles, Solutions, Applications, Experiences with a 450 MVA unit in a 735 kV system," CIGRE' 28th Session, Working Group No. 32-05, 1980.

[2] Gupta, J.B., “A course in power systems", S.K Katarina publications. Tenth edition, 2005.

[3] Gyugyi, L. and Otto, R.A.," Static shunt compensation for voltage flicker reduction and power factor correction," Proc. of the American Power Conf., Vol. 38, pp. 1271-1286, 1976.

[4] Johnson, E.R., Hasler, P.S., Moran, RJ. and Titus, C.H.," Static high-speed VAR control for arc furnace flicker reduction, " Proc. of the American Power Conf., Vol. 34, pp. 1097-1105, 1972.

[5] MATLAB/Simulink /SimPowerSystems.

[6] Olwgard, A., Ahlgren, L. and Frank, H.," Thyristor-controlled shunt capacitors for improving system stability," CIGRE' 26^ Session, Working Group No. 32-20, 1976.

[7] Saadat, H., " Power System Analysis ", The Mc Graw- Hill Companies. 1999.

[8] Sharaf, A.M. and Sivakumar, S.," Stabilizing interconnected power systems using static phase shifters ", Electric Power Systems Research, 8(1984/85) 249-259.

[9] Shri harsha J, Shilpa G N, Ramesh.E, Dayananda L N, Nataraja.C., "Voltage source converter based HVDC Transmission", International Journal of Engineering Science and Innovative Technology (IJESIT) Volume 1, Issue 1, September 2012

[10] Xing, K. and Kusic, G.," Application of thyristor-controlled phase shifters to minimize real power losses and augment stability of power systems", IEEE Trans. Energy Conversion, Vol. 3, No. 4, Dec. 1988.