Advanced Research in Electrical and Electronic Engineering
p-ISSN: 2349-5804; e-ISSN: 2349-5812 Volume 2, Issue 14 October-December, 2015, pp. 1-7

http://www.krishisanskriti.org/Publication.html

Voltage Stability Assessment of Bipolar HVDC System with PSCAD/EMTDC Software and Enhancement with FACTS Controller

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Abstract—*This paper presents the study of voltage stability in Bipolar HVDC system. The system is designed in PSCAD/EMTDC environment. In Bipolar HVDC system by LG fault analysis we get the best location for placement of FACTS. As thyristor-controlled shunt compensation schemes have been introduced into high-voltage transmission since more than two decades, FACTS (Flexible AC Transmission Systems) devices are established as technical and economic means for improving the overall system performance of AC system .Simulation results represent enhanced voltage and power stability with application of STATCOM.*

Index Terms*: Bipolar HVDC, Fault analysis, FACTS, STATCOM.*

1. INTRODUCTION

In the power system operation and planning, voltage stability is one of the main issues, because it essentially deals with system reliability and security of the system, in the current environment the power transfer often results in high degree of vulnerability with respect to voltage stability. India is well known unreliable power system because of constant change in power demand, stress and contingencies, the problem of voltage stability caused several most severe blackouts recently on 30th and 31st July 2012 which have affected around 10 percent of world population and is the worst blackout ever so this voltage stability is major area of concern[1]. Usage of dc is widely accepted as the advantages of dc over ac like simper line construction, no skin effect, no corona effect; no charging current, no radio interference and it don't contribute to short-circuit current of ac system [1]. Here in this work bipolar HVDC link is considered which has two converters in series and the junction point of the converter is grounded .when there is fault on one of the conductor the other conductor can carry half of rated load current.

HVDC transmission systems transport very large amounts of electric power which can only be accomplished under very good controlled conditions. Precise control of rectifier and inverter operation affect the desired power flow Pd. Direct current and voltage are precisely controlled to affect the desired power transfer Pd. For the reliable and optimum operation it is necessary to measure system quantities continuously and precisely which at each converter bridge, the

DC current Id, the delay angle α for DC side voltage and extinction angle γ for an inverter. The circuit used is shown in fig. 1. The strength of the two AC systems connected by HVDC transmission has a significant impact on the AC/DC system interactions. It is well established that reactive compensation of transmission lines is done through rapidly variable solid state thyristor switches of the FACTS devices improve both the transient as well as dynamic performances of a power system [2].

This work investigates the effect of LG fault separately on both rectifier and inverter ac side in order to find out the best location to incorporate the STATCOM. It improves dynamic voltage stability, improves power transfer capability, reduced voltage variations, enhance steady-state voltage support, improve synchronous stability, increase transient stability, improved power system damping, damping of SSR, improves dynamic load balancing and it also improves power quality[3,10,11].

2. HVDC SYSTEM

The principles of HVDC control can be well described by the two-terminal monopolar HVDC link. The rectifier and the inverter incorporate 12 pulse converters using two 6 pulse thyristor bridges connected in series. Fig. 1 explains the basic HVDC scheme. The basic converter equations, for both rectifier and inverter operations, describing the relationship between the AC and DC variables can be written as follows [4]:

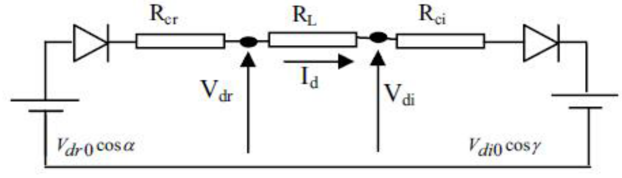

Fig. 1: Basic HVDC scheme

$Vdr = 2(Vdr0 \cos \alpha - Rcr\ Id)$
$Rcr = 3\ Xcr/\pi$
$Vdi = 2(Vdi0 \cos \gamma + Rci\ Id)$
$Rci = 3Xci/\pi$
$Vdr = Vdi + R_L Id$
$Pac = Pd = VdId$
$I_d = \frac{Vdr0 \cos \alpha - Vdi0 \cos \gamma}{Rcr + Rci - RL}$

Where Vd0r and Vd0i represent DC voltage of the rectifier and inverter converter transformer respectively at no load. Rcr and Rci are the commutation resistances of the rectifier and inverter respectively and Xcr and Xci are the commutation reactance of the converter transformer at the rectifier and inverter sides are respectively. The DC line resistance is denotes by RL. The firing angle for rectifier is α, the extinction angle for inverter is γ; the current of DC line is Id, the DC terminal voltage of the rectifier and the inverter ends are defined by Vdr and Vdi respectively. Although several control strategies are suggested for DC link operation, most DC transmission systems use constant current control at the rectifier end side and the concept of constant extinction angle control at the inverter side. The shift logic of these controllers is implemented by the current in DC line Id, which flows between rectifier and inverter. An HVDC system can be divided into several levels. The master control layer determines the reference current Id reference, which indeed decides the active power to be transmitted. The Voltage Dependent Current Order Limiter (VDCOL) limits the actual reference current Id reference used by the controllers, which is used to improve the fault recovery [5]. This control automatically reduces the reference current Id reference set point when Vd measured decreases (as, for example, during a DC line fault or a severe AC fault).

Reducing the Id reference, current also reduces the reactive power demand on the AC system, which is helpful to recover from the fault soon. The difference between both settings is the current margin I_{margin} and its value is normally fixed in the range of 10% to15% of the system rated current. Transition between the current control and voltage control is provided by current error I_{margin} which provides a way to facilitate control stabilization.

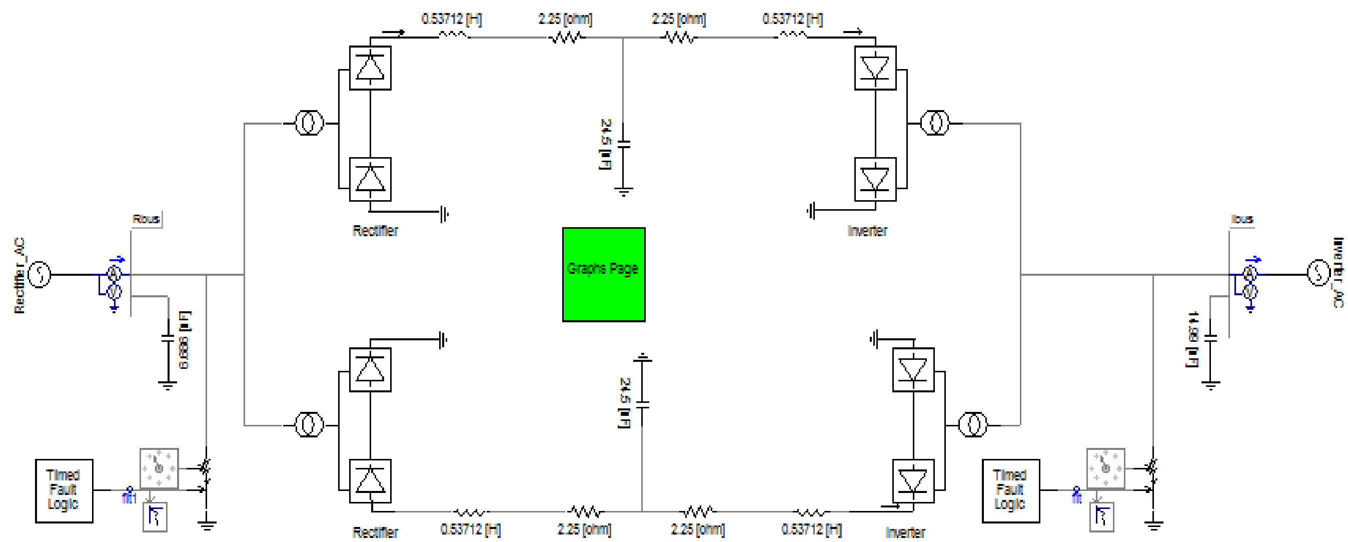

Fig. 2: Bipolar HVDC system with fault

The Pole control is the core of HVDC control and it activates the appropriate controller of the rectifier and inverter station according to the state of AC/DC systems. Then it produces the firing angle α for both rectifier and inverter stations.

Typical PI regulator is used to achieve constant current mode at the rectifier, which acts according to the error obtained from the measured and the desired current to keep the direct current constant. A constant current (CC) controller, PI controller and a constant extinction angle (CEA) controllers is incorporated under Pole control of the inverter station in order to maintain a constant voltage at the inverter end. Finally, the bridge or converter unit control determines the firing instants of the valves within a bridge.

3. LG FAULT AT RECTIFIER SIDE

Most of the fault is LG type. In case of LG fault one of the phases is grounded and in this type of fault all the positive I_{a1}, negative, I_{a2} and zero sequence I_{a0} current is equal and equal to one third of fault current.

$Ia1 = Ia2 = Ia0 = If/3$

The work investigates, single LG fault is simulated at rectifier side in PSCAD/EMTDC software shown in fig. 2. Blue color line represent AC volts rms value whose maximum value is 1.15840 p.u. and minimum value is 4.96865e-036 p.u at rectifier side where green color represent 3∅ instantaneous ac voltage at rectifier end in fig. 3. At the inverter side maximum value of ac voltage is 1.21989 p.u and the minimum value is 1.24046e-036 p.u where green color represents 3Ø instantaneous ac voltage at inverter end. Fig. 4 through 6 represents change in power flow variation with time at rectifier and inverter.

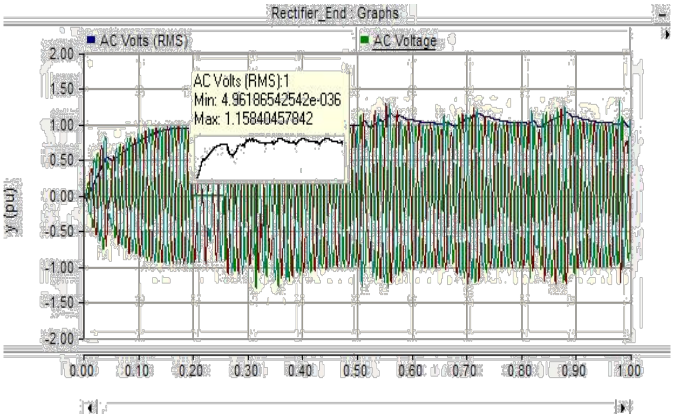

Fig. 3: Rectifier side AC Voltage with time (sec)

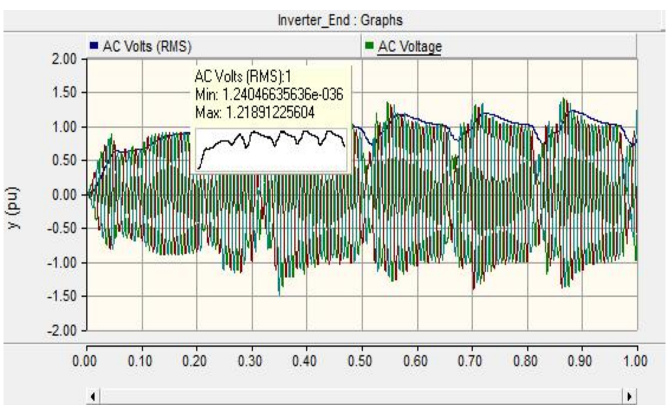

Fig. 4: Inverter side AC Voltage with time (sec)

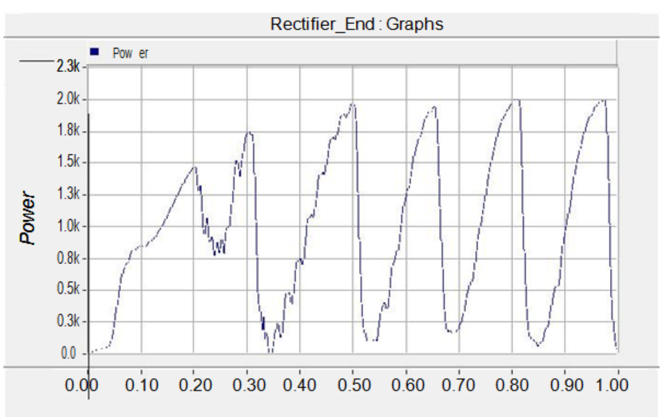

Fig. 5: Rectifier side Power (MW) with time (sec)

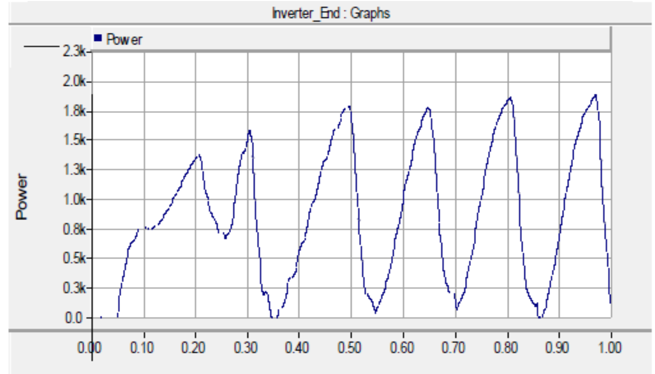

Fig. 6: Inverter side Power (MW) with time (sec)

4. LG FAULT AT INVERTER SIDE

Application of same single LG fault at inverter side is simulated in PSCAD/EMTDC software. Blue color line represent AC volts rms value whose maximum value is 1.16945 p.u. and minimum value is 4.96186e-036 p.u at rectifier side where green color represent 3Ø instantaneous ac voltage at rectifier end in Fig. 8. At the inverter side maximum value of ac voltage is 1.22007 p.u and the minimum value is 1.24046e-036 where green color represent 3Ø instantaneous ac voltage at inverter end in Fig9. Fig10 and Fig11 represent change in power flow with time at rectifier and inverter.

It has been noticed that on applying the same LG fault at both rectifier and inverter side, inverter side show more sensitivity to contingency as the variation of voltage is more at both rectifier and inverter side when fault is applied inverter side. From the above we may conclude that Static synchronous compensator should be applied at more vulnerable side in order to enhance voltage stability and overall performance of system [6].

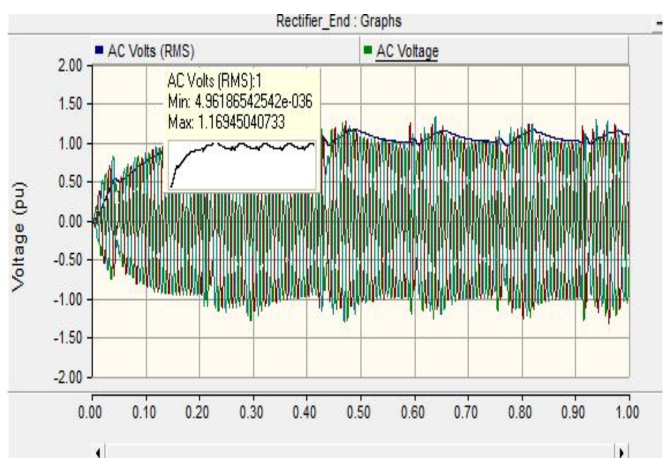

Fig. 7: Rectifier side AC Voltage with time (sec)

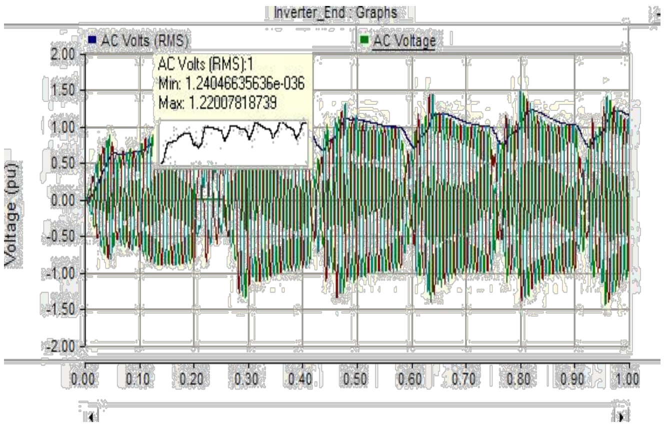

Fig. 8: Inverter side AC Voltage with time (sec)

5. SIMPLE BIPOLAR HVDC WITHOUT STATCOM

With the operation of simple bipolar dc link, the system response in term of voltage and power oscillations is obtained.

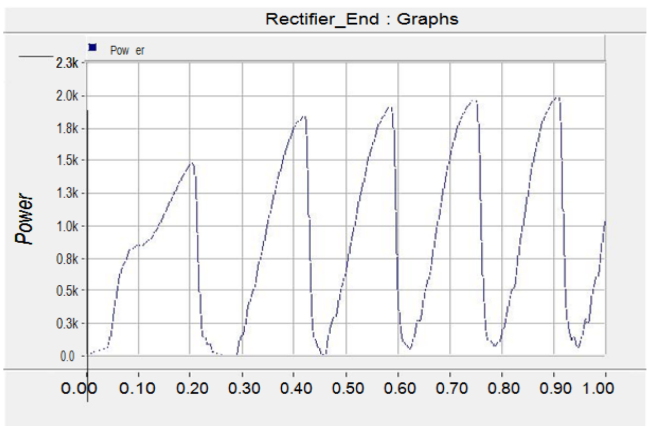

Fig. 9: Rectifier side Power (MW) with time (sec)

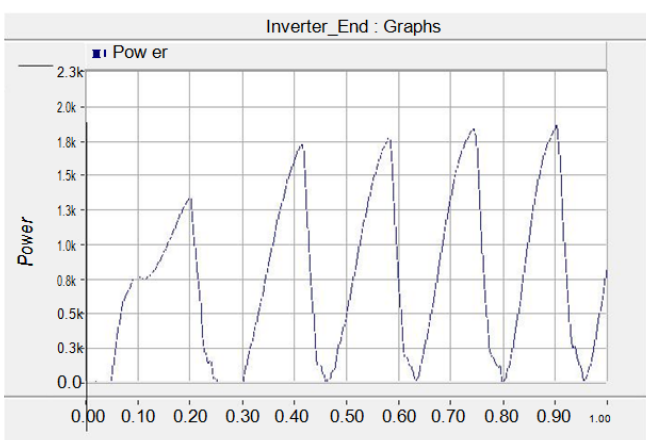

Fig. 10: Inverter side Power (MW) with time (sec)

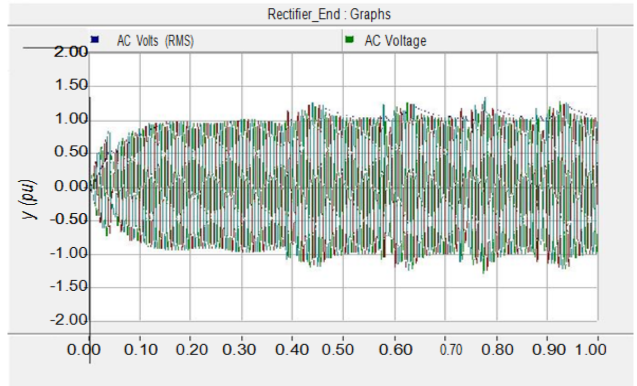

Fig. 11: Rectifier side AC Voltage with time (sec)

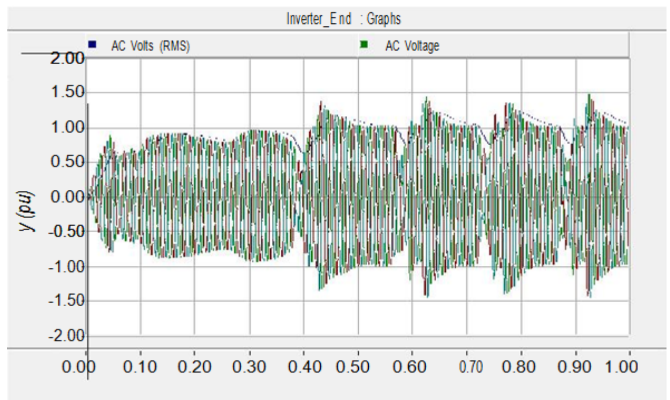

Fig. 12: Inverter side AC Voltage with time (sec)

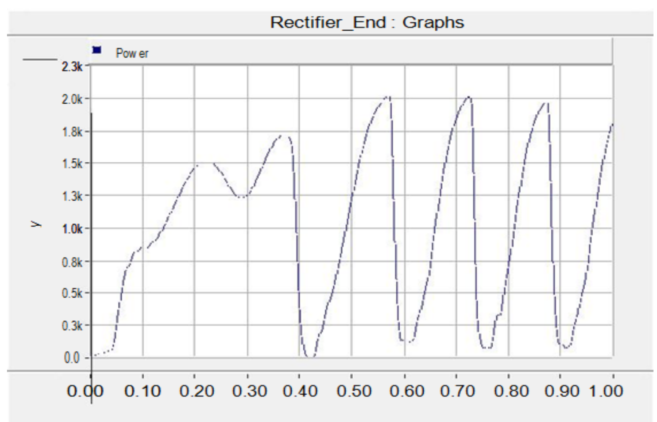

Fig. 13: Rectifier side Power (MW) with time (sec)

Voltage and power waveform is shown; from Fig. 11 to Fig. 14. It is clear that there are many oscillations in the system making system unstable. Maximum value of ac volts (rms) is1.78375 p.u and the minimum value is 1.65395 e-036 p.u at the rectifier side while maximum value of ac volts (rms) is 1.21479 p.u and the minimum value is 6.20233e-037 p.u at the inverter side.

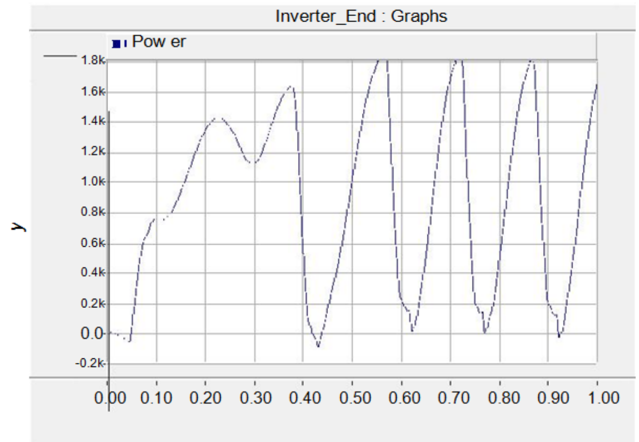

Fig. 14: Inverter side Power (MW) with time (sec)

6. BIPOLAR HVDC SYSTEM WITH STATCOM

The static compensator (STATCOM) provided shunt compensation in a similar way to the static var compensators (SVC) but utilizes a voltage source converter rather shunt capacitors and reactors [7]. It could inject or absorb the reactive power depending upon voltages of VSC Vi connected to capacitor and the voltage at the connected [8] bus is Vb. When Vb < Vi then it injects the reactive power and when Vb > Vi static compensator absorbs reactive power. Fig16 to19 represents that power and voltage oscillations is damped on application of STATCOM.

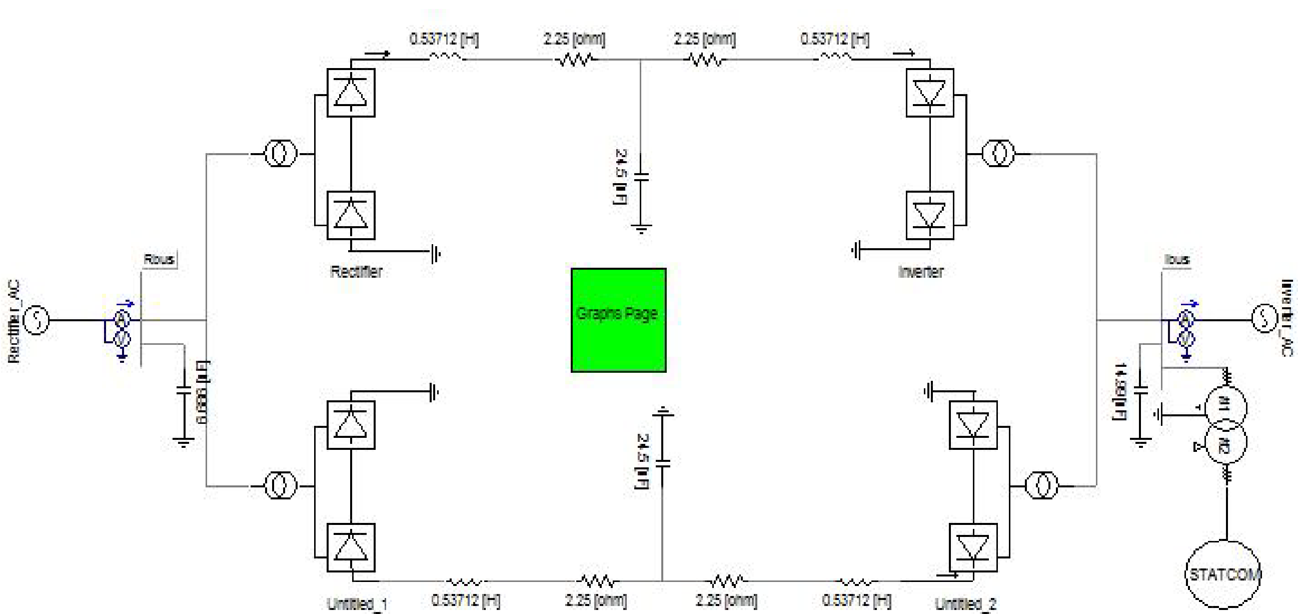

Fig. 15: Bipolar HVDC system with STATCOM

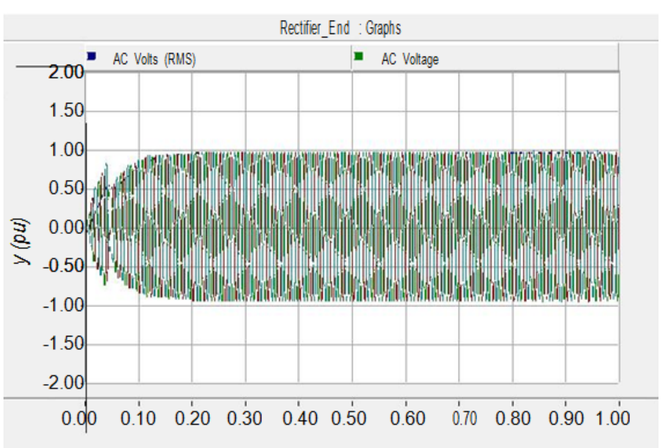

Fig. 16 Rectifier side AC Voltage with time (sec)

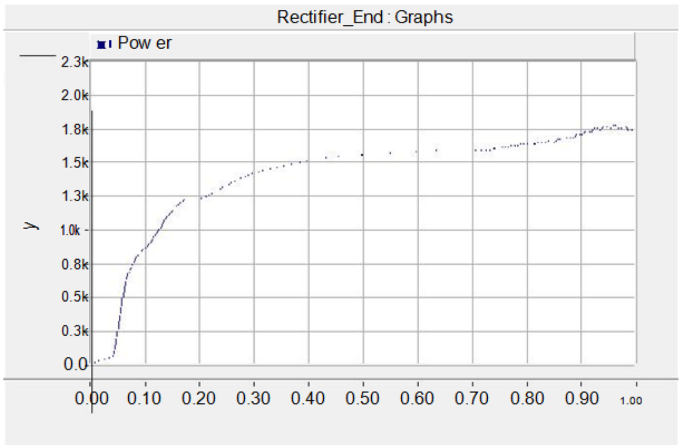

Fig. 17 Rectifier side Power (MW) with time (sec)

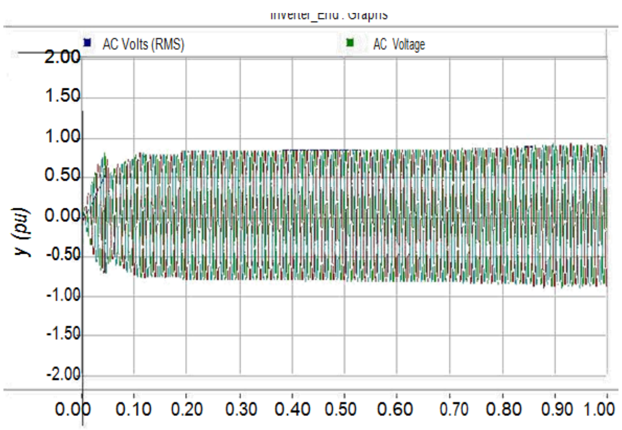

Fig. 18 Inverter side AC Voltage with time (sec)

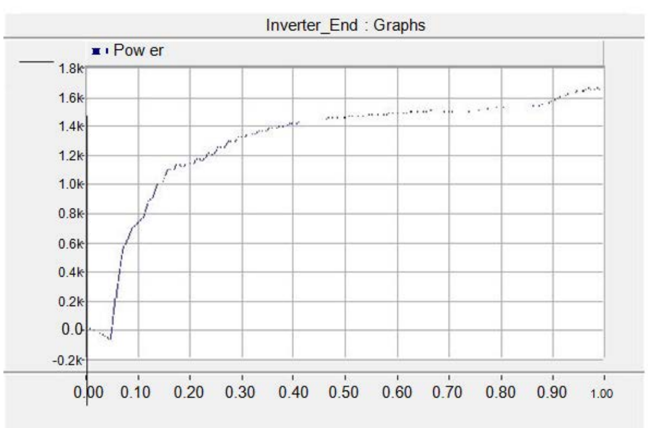

Fig. 19: Inverter side Power (MW) with time (sec)

Maximum value of ac volts (rms) is 0.96672 p.u and the minimum value is 3.30791 e-036 p.u at the rectifier side while maximum value of ac volts(rms) is 0.90034 p.u and the minimum value is 1.24046e-036 p.u at the inverter side. Variation between the maximum and the minimum value of rms voltage is reduced with STATCOM and overall system performance is improved.

7. CONCLUSION

This research work carries a comprehensive study of voltage stability in bipolar HVDC system. Study reveals that inverter side is the best location for FACTS application. With the application of STATCOM transients in voltage and power waveform is effectively damped out. Effective use of bipolar HVDC and STATCOM enhance grid security/reliability, reduces congestion, improves utilization of transmission assets, reduces losses and also prevent voltage collapse[9].Reactive power compensation effectively balance capacitive and inductive components of a power system to provide sufficient voltage support.

APPENDIX

System details for the developed HVDC model

AC voltage base:	345KV (Rectifier end) 230KV (Inverter end)
Base MVA	100 MVA on both Rectifier and Inverter ends
Voltage source:	1.088 ∠ 22.180 (Rectifier end) 0.935 ∠ -23.140 (Inverter end).
Nominal Angle:	α=150 degree , γ=150degree.minimum , γ=15degree
Voltage input time constant:	0.05 sec
Total reactive power supplied by the combination of Filters and shunt capacitor:	0.620 pu on both the Rectifier and Inverter ends.
DC line R, L:	4.5 Ω, 1.074 H
Rated Frequency:	50 Hz

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