Enhancement Of Small Signal Stability Caused By Sub Synchronous Resonance In Seris Compensated AC Transmission Network

Major Project Report

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By

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I dedicate this thesis to........

The Almighty

&

My Family

Certificate

This is to certify that **Mrs. Kinjal J Bhatt (Roll No: 12MEEE02)** of semester-IV M.Tech Electrical (E.P.S) towards the partial fulfillment of the requirements for Semester-IV of Master of Technology (Electrical Engineering) in the field of Electrical Power System of Nirma University is the record of work carried out by him under our supervision and guidance. The work submitted has in our opinion reached a level required for being accepted for examination. The results embodied in this major project work to the best of our knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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Undertaking for Originality of the Work

I, **Kinjal J Bhatt (Roll No:12MEEE02)**, give undertaking that the Major Project entitled"**Enhancement Of Small Signal Stability Caused By Sub Synchronous Resonance In Seris Compensated AC Transmission Network** " submitted by me, towards the partial fulfillment of the requirement for the degree of Master of Technology in Electrical Power System, Electrical Engineering,under Institute of Technology, Nirma University, Ahmedabad is the original work carried out by me and I give assurance that no attempt of plagiarism has been made.I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere, it will result in severe disciplinary action.

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Abstract

In a series compensated transmission a.c network Sub Synchronous Resonance is accrues. This Sub Synchronous Resonance accurse because of energy exchange between electrical system and mechanical system also its frequency is less than the power frequency. Before 1971 the phenomena of sub synchronous resonance was not known. In 1970 at Mohave power plant in southern Nevada shaft breakdown accrued and 1971 the same phenomena accrued again in power system so power system engineers deeply analyze dynamic analysis and finalize this shaft is breaks because of Sub Synchronous Resonance[1].

In this theses we have used series compensated a.c network and IEEE 2nd benchmark 9 bus system. With the help of MATLAB software Eigen value and frequency analysis is done. And sub synchronous resonance is mitigating with the help of VSC based back to back system used supplementary controller.

Acknowledgement

It's my pleasure in submitting the report on Enhancement of Small Signal Stability Caused by Sub synchronous Resonance in a Series-Compensated AC Transmission Network I am grateful to my Project Guide for Prof. Shankar Godwal allowing me to work on this project and his constant support and also he offered valuable advice when i needed it. I acknowledge with thanks to Prof.Dr.S.C.Vora for his great encouragement. They have been very generous in extending their cooperation and help and this has enabled me to carry out this study properly. I would also like to thank the other faculty members of my group as well as the rest of the faculty for their selfless motivation. At last, I thank my friends and family for their support and encouragement.

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Chapter 1

Introduction

1.1 Introduction

Series compensation is used in long ac transmission network to enhance power transmission capability of the transmission line. Because of the series compensation in the a.c transmission network the capacitive reactance is increased in the transmission line and it compensate the inductive reactance of the system. Thus stability limit is increased. When capacitor is connected in series with the transmission network it introduces adverse effect at the turbine shaft. This adverse effect is introduced if any resonance frequency of the electrical system is match with mechanical natural frequency sub synchronous resonance is accrued.[1][2]

Sub synchronous resonance condition is very serious problem in the power sector so power system engineers find out different method to mitigate this sun synchronous resonance in the power system. Small signal stability caused by Sub Synchronous Resonance is analyzed by Frequency analysis and Eigen value analysis.

There are number of different methods to mitigate Sub Synchronous Resonance. The main controller which is used to mitigate the sub synchronous resonance is the Static Compensator (STATCOM), the Static Synchronous Series Compensator (SSSC) , the Unified Power Flow Controller (UPFC) , and the Voltage Source Converter High-Voltage Direct-Current (VSC HVDC)[3]

1.2 Literature Survey

1. stability and control by prabha kundur gives classic introduction of sub synchronous resonance and different analytical methods and its mitigation methods

2. In power system dynamics stability and control by k .r. padiyar and operational p.s. murty information that series capacitor can cause self excitation oscillation at low frequency and sub synchronous frequency due to induction generator effect and the problem of self excited torsional oscillation due to torsional interaction.

3. Supplemental Control of Voltage Sourced Converter-Based Back-to-Back for Damping Subsynchronous Resonance S.O. Faried, Senior Member, IEEE, G. Tang, Member, IEEE and A. Edris, Senior Member[3], IEEE this papes gives IEEE bus system and theory of sub synchronous resonance phenomena and its effect. It also gives the excellent sub synchronous resonance mitigation method and discuss the supplementary control .

4. Analysis of sub synchronous resonance in a multi-machine power system using series compensation Oriane M. Neto a, Donald C. Macdonald [4] in this paper explained the sub synchronous resonance phenomena and its effects in IEEE 14 bus system. this sub synchronous resonance investigates with the help of eigen value analysis . it also give the introduction about dynamics of shaft and power system.

5. Effective method of sub synchronous resonance detection and its limitations Maciej Orman a, Przemysaw Balcerek b, Micha Orkisz .[5]This paper present excellent novel approach to find out sub synchronous resonance in series compensated transmission network. It explain demodulation, modulation and analysis procedure and find out resonance frequency with minimum time and increase the stability limit.

6. Determination of reduced order model for torsional interaction investigate Using selective modal analysis part 1[6] present IEEE 1ST benchmark model analysis. With the help of QR algorithm sub synchronous resonance analysis is done. it gives the fast result and find out different modes in the system it different levels of compensation.

7. Series compensation scheme reduce the potential scheme for sub synchronous resonance[7] this paper investigate IEEE 2nd benchmark system . with the help of L and C different combination at phase wise reduce the potential of resonance .and also done the frequency analysis and sub synchronous resonance is mitigate.

8. Sub synchronous resonance counter measure using phase imbalance.[8]. This paper is investigate IEEE 2nd benchmark model. Series and parallel resonance circuit is inserted with the help of different combination of C and L parameter and sub synchronous resonance is mitigate. This program is done in the EMTP .

9. Sub-synchronous Resonance Damping in Interconnected Power System Nadia Yousif, Majid Al-Dabbagh [9]this paper present IEEE 2nd bench mark system to investigate sub- synchronous resonance in series compensated transmission network with the help of frequency and Eigen value analysis and find out this analysis at different compensation level. In this paper also investigate that particular one compensation level the resonance frequency is within the range of natural frequency or not and reduce the chances of sub synchronous resonance phenomena accurance.

10. Analysis of sub synchronous resonance in series compensated line with booster transformer G.V.Rajshekhr [10] gives the excellent introduction about frequency

analysis and eigen value analysisat different compensation level and it gives the different modes in the system.

11. Sub synchronous resonance in power system by P.M. Anderson, B.L.Agrawal Published under the sponsorship of the IEEE Power Engineering Society[11]. This book is intended to provide the engineer with technical information on sub synchronous resonance (SSR), and to show how the computation of eigen values for the study of SSR in an interconnected power system can be accomplished. It is primarily a book on mathematical modelling. It describes and explains the differential equations of the power system that are required for the study of SSR. However, the objective of modelling is analysis.. The goal here is to examine the small disturbance behaviour of a system in which SSR oscillations may exist.

12. Power electronics devices and control by P.S.Bhimbra[12] this book gives excellent introduction of voltage source converter and its principal operation.

13. voltage source converter in power system modelling , controlling and application byYazdani, Reza iravni[13] this paper gives the excellent introduction about voltage source converter and its controlling modes in the system. And also explain analysis part of that system. It gives theory based onVarious function and its requirement in the power system.

1.3 Objective of Dissertation

There is a number of methods are employed to mitigate the sub synchronous resonance. The main objective of this model is the enhance the small signal stability cause by the sub synchronous resonance oscillation in series compensated transmission system. For this simulation model (IEEE 9 bus system) of series compensated ac transmission network is build in Matlab software. Small signal stability analyse by the Eigen value analysis and Several excellent methods exist for mitigating the effects of SSR, including:

SSR blocking filters

Supplemental exciter damping controls (SEDC)

Thyristor-controlled series capacitor (TCSC)

Switching of series capacitor segments

With the help of another method we mitigate the sub synchronous resonance torsional relays are used and protect shaft of turbine from damage in the event that mitigations fail or detect Sub Synchronous Resonance in delay. As primly configuration we use one of the best method to mitigate the Sub Synchronous Resonance. Here VSC based back to back supplementary control scheme is use to mitigation of SSR[3]

Chapter 2

SubSynchronous Resonance Phenomena

2.1 Basics Of SSR

In a series compensated transmission network sub synchronous resonance condition is arise and its frequency is less than the nominal frequency. In the power system current component consider in two part one is the nominal frequency component and second is depends on entired inter connected power system. The current equation of R-L-C network is given by

$$\text{K}[\text{Asin}(\omega_1 t + \psi_1)\text{+B}e^{-\zeta\omega_2 t} sin(\omega_2 t + \psi_2)]$$

For the dynamic analysis above expression is described mathematically by parks theorem. In the steady state condition ,transformation present nominal frequency component but current in frequency w2 contain two frequency (w1+w2) which is considered as super synchronous frequency and (w1-w2) which gives considered as sub synchronous resonance frequency. Turbine generator shaft is damage because turbine shaft having its own natural frequency oscillation and because of resonance frequency due to entire electrical system introduce resonance frequency math with the any natural frequency at that time shaft oscillation is high . This condition is known sub synchronous resonance and cause this SSR shaft of turbine failure.[1][3]

Single series compensated transmission line is shown in figure 2.1. This shows turbine generator spring mass system. Turbine system having its own damping system and generator system having its own damping system and this masses are connected by spring mass system. our electrical system are interconnected system so there are numbers of masses are connected in the system so electrical resonance frequency is fer1, fer2, fer3..........etc. same as due to mechanical system several masses is connected with each other and its natural frequency is fn1,fn2,fn3.......etc. so when resonance frequency match with the any resonance frequency at that time sub synchronous resonance condition is accured.[3]

In the electrical power system if any fault is accrued. Fault current flow in the generator at fer frequency and its rotating magnetic field induce. Due to positive sequence its frequency is 2fer. The relative speed of the rotating magnetic field and the speed of rotor current are induce in the rotor winding. Torsional interaction is

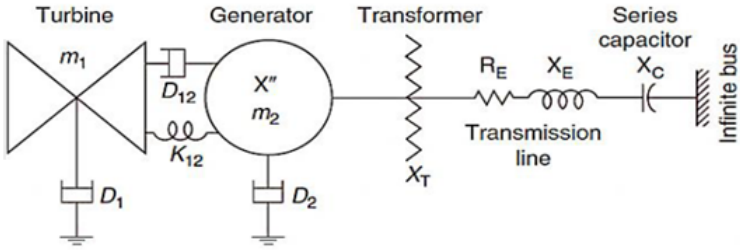

Figure 2.1: Turbine Generator Model

develop due to frequency of fo-fer . fer frequency is produced due to armature rotating magnetic field.fo frequency is produce due to rotor d.c field and torque component is produced. Due to this torque component torsional interaction is accrued and this interaction is known as sub synchronous resonance and simply we can say this accurse in compensated transmission network.

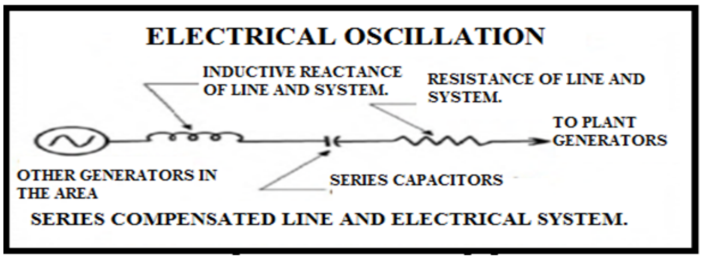

Figure 2.2: Electrical System

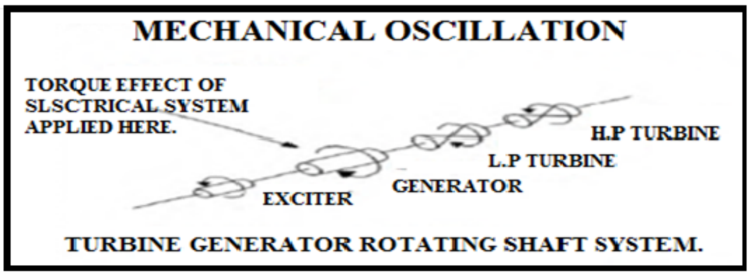

Figure 2.3: Mechanical System

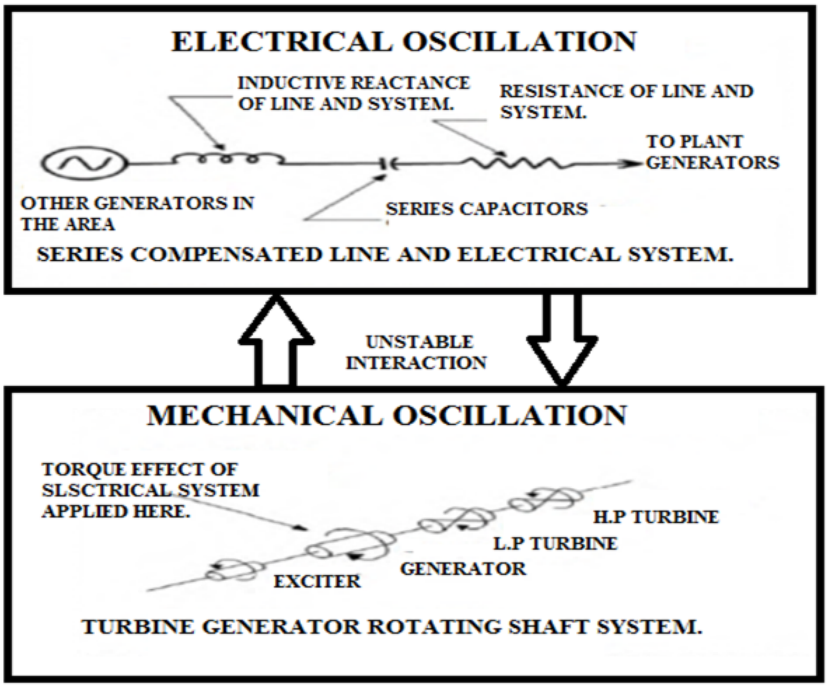

Figure 2.4: Unbalance between Elect. & Mech. System

2.2 Characteristic Of Seris Compensated Transmission Line

First of all we discuss about an uncompensated transmission system if any fault or any other disturbance accuure in the transmission line it will introduce dc offset component in the generator stator windings. In air gap torque at the slip frequency of 60 Hz. In case of unbalance fault, the negative phase sequence component of stator current in a 120 Hz component of air-gap torque. Therefore, it is necessary to avoid having any of the torsional frequency very near either 60 Hz or 120 Hz.

Now we are discuss about series capacitor compensated transmission system, this situation can be very different. Consider simple radial system in figure In this case dc component of fault current plus the offset transient current is also present and ac frequency ωn of the circuit inductance and capacitance .[2]

The sub synchronous frequency that may interact with one of the natural torsional modes of the turbine-generator shaft, at the time of exchange of energy at a sub synchronous frequency, with possible torsional fatigue damage to the turbine-generator shaft. And rotor current of slip frequency (60- fn) Hz. A series compensated transmission network can cause negatively damped sub synchronous oscillation by two distinctive mechanisms

$$f_n = fo \times \sqrt{\frac{X_l}{X_c}}$$

Generator stator current component of frequency fn induce rotor current of slip frequency (60- fn) Hz.

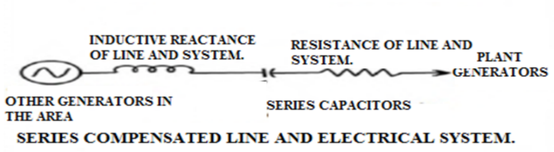

Figure 2.5: Series Compensated Transmission Line

1. Self excitation due to induction generator effect
2. Interaction with torsional oscillation

Table shows the natural and slip frequency as a function of the degree of compensation.[2]

(XC/XL)*100 (%)	*Natural frequency(fn)*	Slip frequency(60-*fn*)
10	18	42
25	30	30
30	32.6	27.4
40	38	22
50	42.4	17.4

Figure 2.6: Natural and slip frequency as a function of the degree of compensation.

Above table[2.6] shows that when the degree of compensation is increased ,its natural frequency also increases but slip frequency is decreased .it means when degree of compensation is increased, the chances of occurrence of the SSR decreases.

Chapter 3

Effects Produced Due To SSR & Its Mitigation Methods

3.1 Self Exication Due To Induction Generator Effect

Rotor lumped single circuit represented in below with a resistance Rr and leakage reactance Xr .the power frequency quantities have been omitted and only sub synchronous frequency effects are considered.

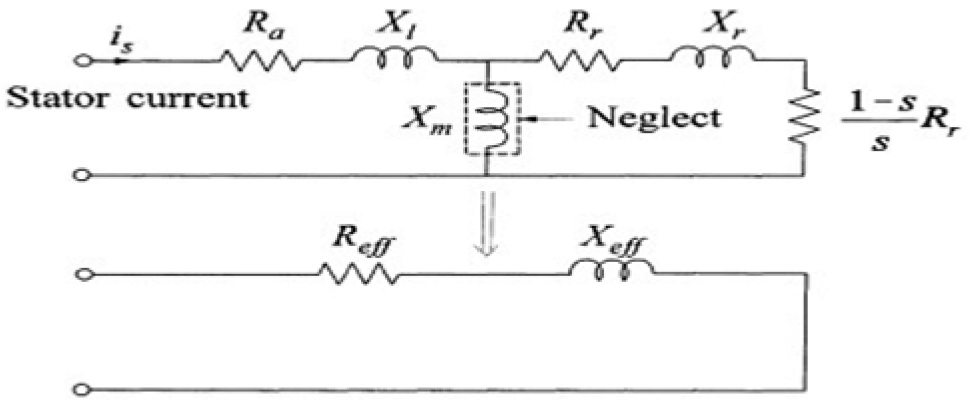

Figure 3.1: Equivelent Model Induction Generator

Above circuit is consider simple R-L-C circuit , when this circuit is excited at that time if R=0 then oscillation is sustain , when R= positive oscillation is damp out or decay and if R= negative then oscillation is grow.so at the time of SSR condition fn is less than fo, the slip is negative, and the rotor behaves like that of an induction machine running above synchronous speed. Depending on fn the effective resistance Re can be negative. And oscillation is increase at the degree of compensation this apparent negative resistance. Such a condition will result in self excitation causing electrical oscillation in tolerable levels. This sub synchronous resonance instability is decrease by increasing the network resistance and by decrease the resistance of generator rotor circuit.[2]

3.2 Torosional Interaction Resulting In SSR

If the natural frequency of the system is match with any torsional frequency in compensated electrical power system at that time torsional interaction is happen. This condition is considered as Sub Synchronous Resonance and due to this condition electromagnetic torque component is introduce and shaft oscillation is growing.[4][5]

3.3 Mitigation Methods Of SSR

There are many different method to counter measurement of SSR[3]

1. Static filter This can take the form of a blocking filter in series with the generator or damping circuit with the generator , or damping circuit in parallel with the series capacitors.

2. Dynamic filter This is an active device placed in series with the generator it pick up a signal derived from motion and produces a voltage in phase opposition so as to compensate for or even exceed the sub synchronous voltage generated in the armature.

3. Dynamic stabilizer this consist of thyristor modulated shunt reactor connected to generator terminal. Control of SSR is achieved by modulating the thyristor switch firing angle using derived from the shaft speed.

4. Excitation system damper- Generator excitation control is modulated by using a signal derived from the shaft speed so as to provide increased damping of torsional oscillation.

5. Protective relay The SSR condition is detected by a relay and the affected units are tripped motion by sensing rotor speed or detection of SSR condition by sensing the armature current.

6. NGH scheme- NGH scheme is thyrister control scheme it gives Sub synchronous resonance mitigation method when it detect the resonance it decrease the voltage across capacitor with the help of resister discharge.[1]

In this theses we used supplementary controller with voltage source converter HVDC back to back system to mitigate all the SSR taking place in the system.[3]

Chapter 4

VSC based HVDC Back To Back System

4.1 Voltage Source Converter

Recently by use of VSC topology in power system to mitigate Sub Synchronous Resonance . They are used to minimise the operating frequency of the diodes used and improve the power quality of output waveform .Here we have used IGBT switching , two switches placed on each lag and is connected in anti parallel with each other.[3]

The current VSC switching strategies aimed at utility application may be classified into two main categories :

1.Fundamental frequency switching:Here each switch having only one turn on and one turn off power cycle. The output waveform may be quassi square and having high harmoniec content .

2.Pulse-Width-Modulation (PWM):In this method the switches are to be turned on and off at very high rate then the fundamental frequency modulated. The the harmonics in output is shifted to higher frequency , so filtering is easy . this is most simple and effective method for usage .[12][13]

Here both the technique have main disadvantages , the switching frequency has complex arrangement and PWM technique has higher switching loss.

4.2 Principle of Voltage Source Converter Operation

Here an a.c system is connected to the VSC converter through a lossless inductor. The a.c reference voltage lx is the reactance of the inductor. Let δ be the phase angle between a.c source and VSC.[3][12][13]

The active power flow between the AC source and the VSC is controlled by the phase angle δ . The active power flows into the AC source from the VSC for $\delta > 0$, and flows out of the AC source from the VSC for $\delta < 0$.

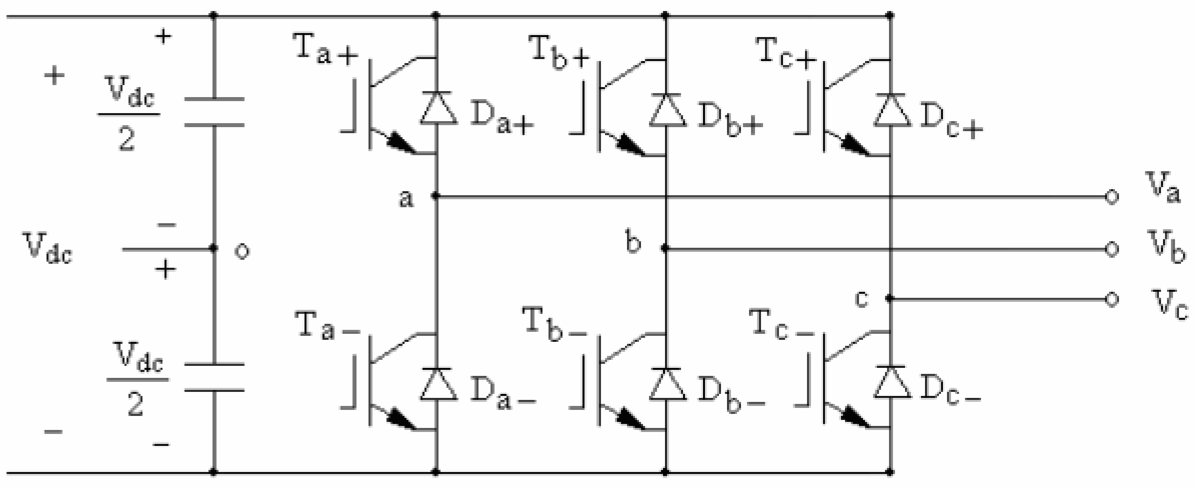

Figure 4.1: Voltage Source Converter model

4.3 Voltage Source Converter-Based High-Voltage Direct-Current

In this hvdc system two back to back converter are used one is rectifier type and other is inverter type and connected with each other through d.c cable . the schematic diagram is shown in figure 4.2 .here m and δ are the modulation ratio and phase angle of system.[3]

The VSC HVDC has several main advantages which is given below:

1. Active and reactive power can be controlled at the converter ststion
2. Do not required harmonic filter.
3. Power quality and stability can be improved.
4. Do not required local power generation.

4.4 Model of HVDC Back to Back System

Series compensation is very effective to increase the power transfer capability of the transmission network. Main problem of the series compensation is that SSR is introducedin the system due this reason shaft can be damage fact controller are very effective to control the active and reactive power improve stability of system. The VSC based HVDC back to back system can be used to mitigate the SSR produced in the series compensated ac network.[3]

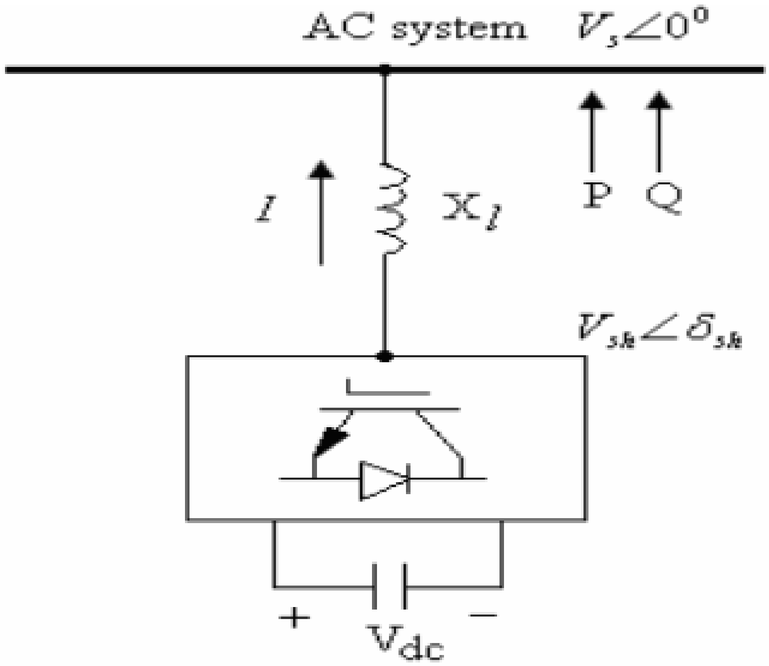

Figure 4.2: VSC connected to AC system

4.4.1 System Under Study

The VSC connected to a.c system is as shown in figure 4.4 . system 1 is weak and system 2 is strong. This system is three mass system having high-pressure turbine (HP), an intermediate-pressure turbine (IP), low-pressure turbines(LP), the generator rotor and a rotating exciter (EXC).[5][8]

4.4.2 Steady - State Model of VSC based Back- to- Back system.

Here is the fundamental frequency analysis of the back to bac system Vsh is the source voltage , Zsh is the transformer impedance . here shunt impedance is the purely inductive. The active power flow take place between the two stations . this loss less system is considered and no power injection is take place[12][13].

This constraint that must be satisfied by the VSC-based BtB system at steady-state is expressed mathematically as:

ReV Esh *I Esh +V Bsh* I Bsh= 0

4.4.3 Dynamic Model of VSC system

In this dynamic model the VSC -In the dynamic model the VSC HVDC is able to control both active and reactive power by regulating the amplitude and phase angle

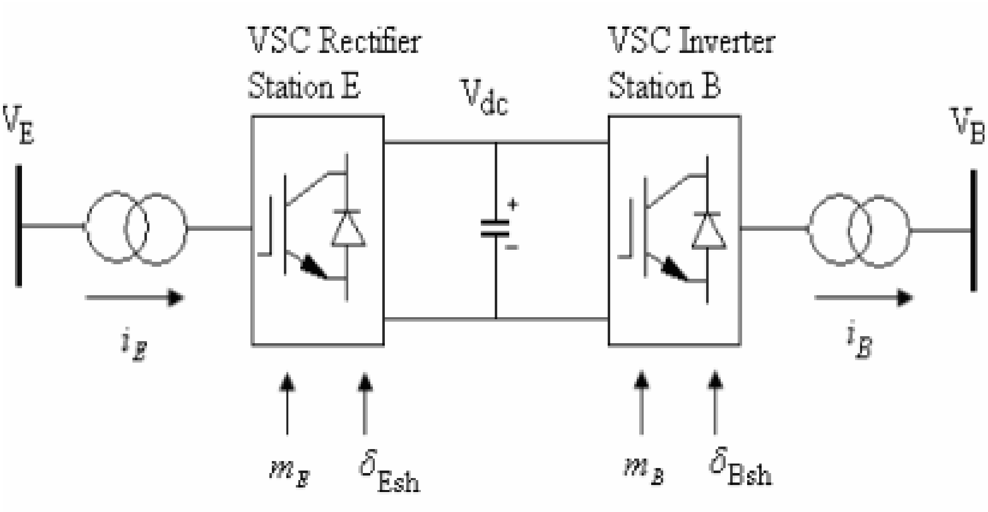

Figure 4.3: VSC HVDC back to back system

of output voltage. Phase angle method is use to control power and output voltage to control the reactive power. Here one converter station control d.c side voltage and other one control real power. This real power flow control is maintained. Here the supplementary controller used to damp SSR produced in the system. Figure shows PI controller of supplementary control [12][13]

Where K is a constant that relates the ac and dc voltages and m is the magnitude of modulation ratio.

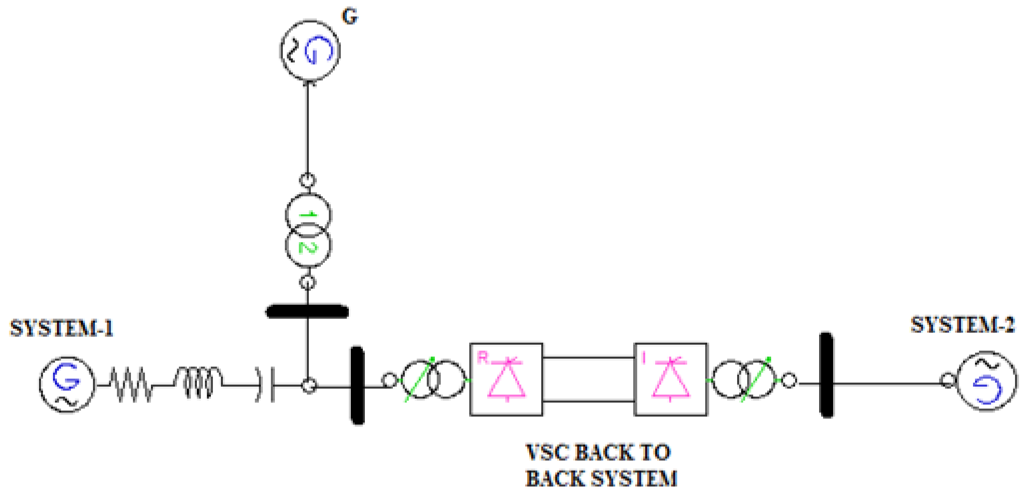

Figure 4.4: System under Study

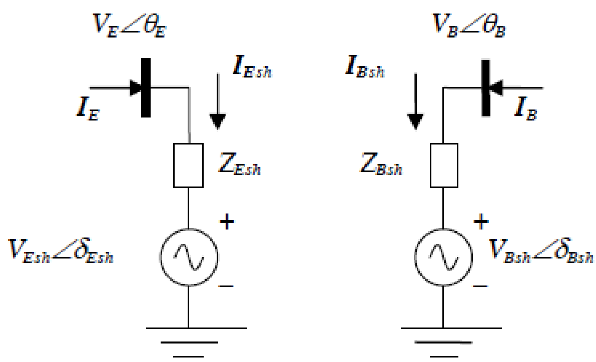

Figure 4.5: Equivalent circuit of VSC back to back System

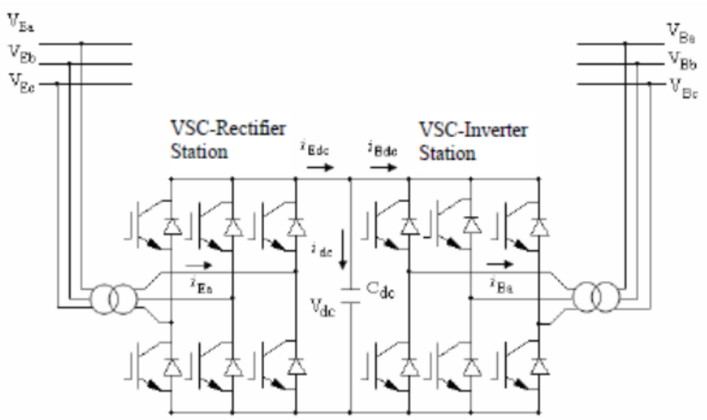

Figure 4.6: Dynamic model of VSC back to back System

Chapter 5

Modelling of Series Compensated Transmission Line

5.1 Introduction

The line diagram of IEEE 2nd bench mark model is given in figure5.1 . and IEEE 2nd benchmark system is shows in figure 5.2. Three generators of different rating are connected to infinite busbar. Three phase fault is created in series compensated transmission network then shows the torque output of low pressure turbine(LP), High pressure turbine (HP) and generator , and angle deviation[10]

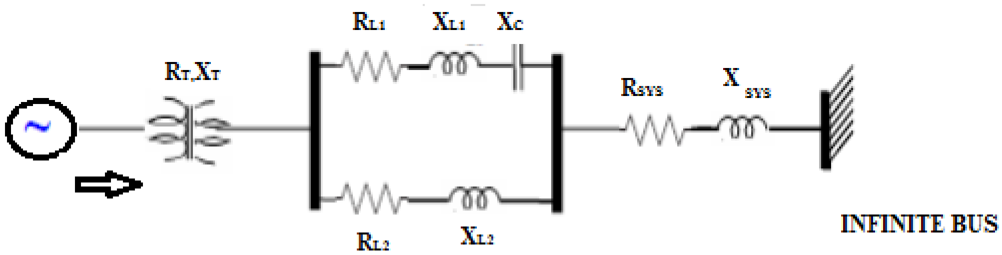

Figure 5.1: IEEE Benchmark Model

5.2 Methods to Analyse SSR

There are five methods to analyse SSR

1. Scanning frequency of system
2. Frequency domain analysis
3. Analysis of eigen value

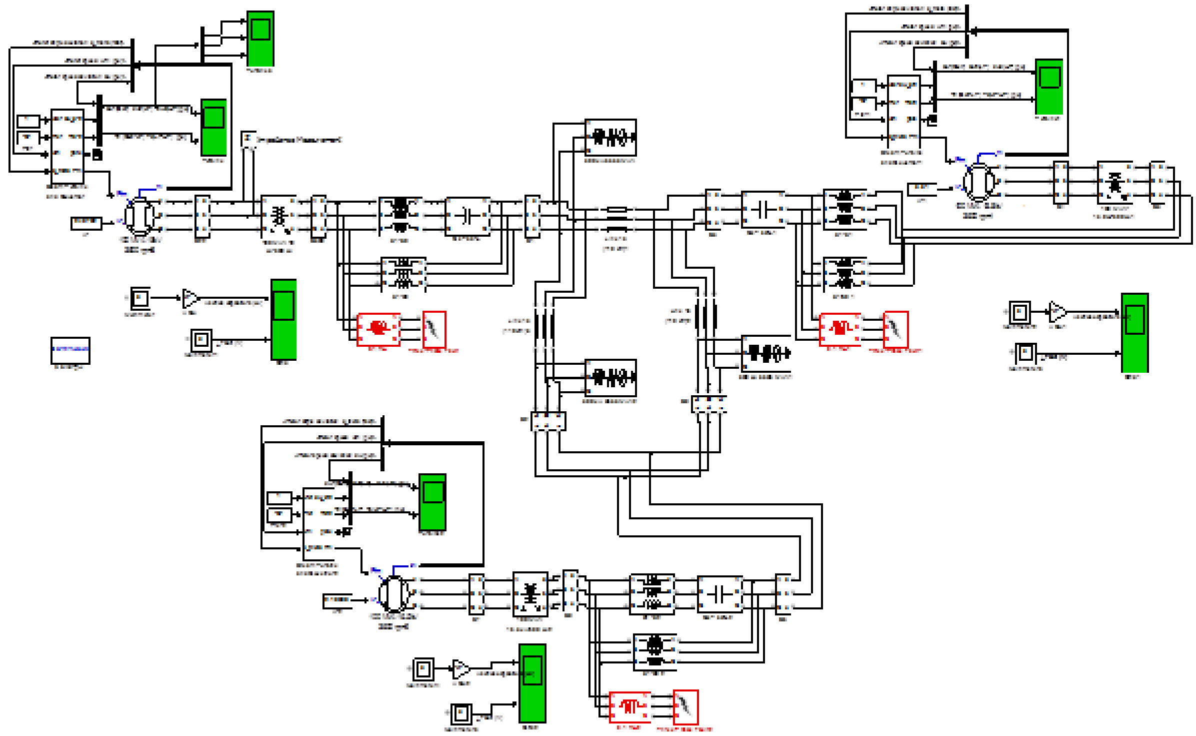

Figure 5.2: IEEE 2 benchmark 9 bus system

4. Frequency responce analysis of l system

5. Frequency domain analysis of the system.

Frequency scanning gives the induction generator effect and impedance of the buses connected to the generator. It also give the information about the natural frequency of the system.

Eigen value analysis gives out the frequency at wich SSR is produce and also gives damping of each frequency from the steady state model.

Time domain simulation can be done on different program such aas EMTP, it provides information about the stresses on the generator shaft at different compensation levels.[9][10]

5.3 Frequency Analysis

Here the SSR is produced in the system when the compensation of55% is applied on the line. The frequency spectrum is shown in figure 5.7. all this analysis can be done with the help of frequency analysis[10]

The resonant frequency occurs at 37.5 Hz. The natural frequencies (fer) due to parallel resonance are clearly identified for a particular compensation. The practical upper limit for series compensation of long transmission lines is up to 70%. Using

Figure 5.3: Color code of Graphs

the given value of capacitance, the resonant frequency of the transmission line is computed as follows

The zero sequence impedances are not required for the computations. This corresponds to a frequency of f = 37.07 Hz. which is clearly in the range of frequencies that may give rise to a sub synchronous resonance with the turbine-generator shaft.

5.4 Eigen Value Analysis

Here, We used MATLAB control system tool box [PSAT] to do the eigen value analysis and result are shown in simulation the result shows the effect of series compensation and SSR is produced. It gives the more information of system stability. Here linear system of differential equation is used to model the transmission line and a.c network. It gives the oscillation of frequency and damping of each frequency[8][10]

$$\lambda = \sigma + j\omega$$

It contains information about the response of the system to a small perturbation. The eigenvalue can be real and/or complex. The complex values appear in conjugate pairs if A is real

Each eigenvalue represents a system mode and the relationship between this mode and the stability is given by Lyapunov,s first method

i. Stable system, then σ is lessthan zero

ii Unstable system, then σ is greater than zero

iii When is $\sigma = 0$, then nothing can be said in general

Below figure shows that all real parts are in left hand side means our system is stable but when 55% compensation is given real parts in the left hand side means system is unstable.

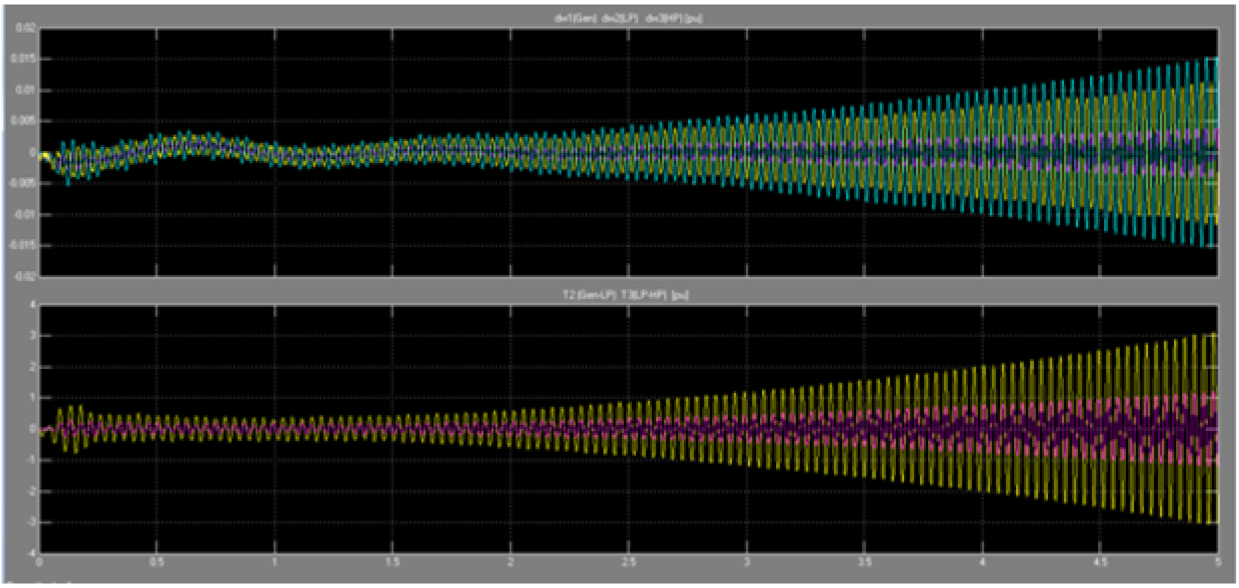

Figure 5.4: Outwaveform with seris comp. of Generator1

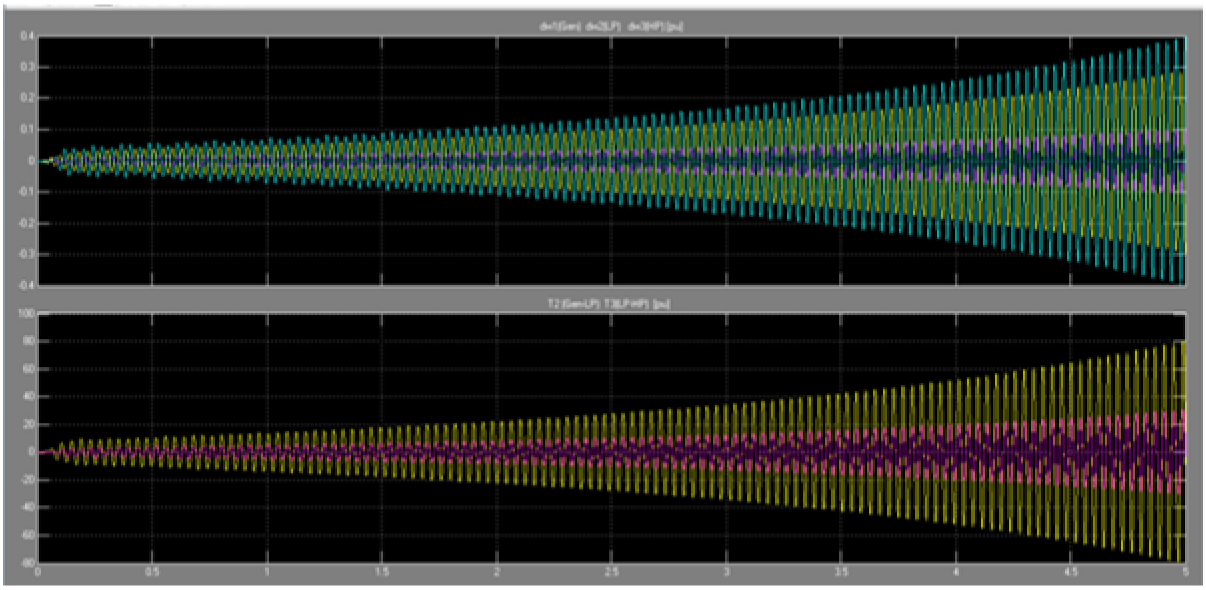

Figure 5.5: Outwaveform with seris comp. of Generator2

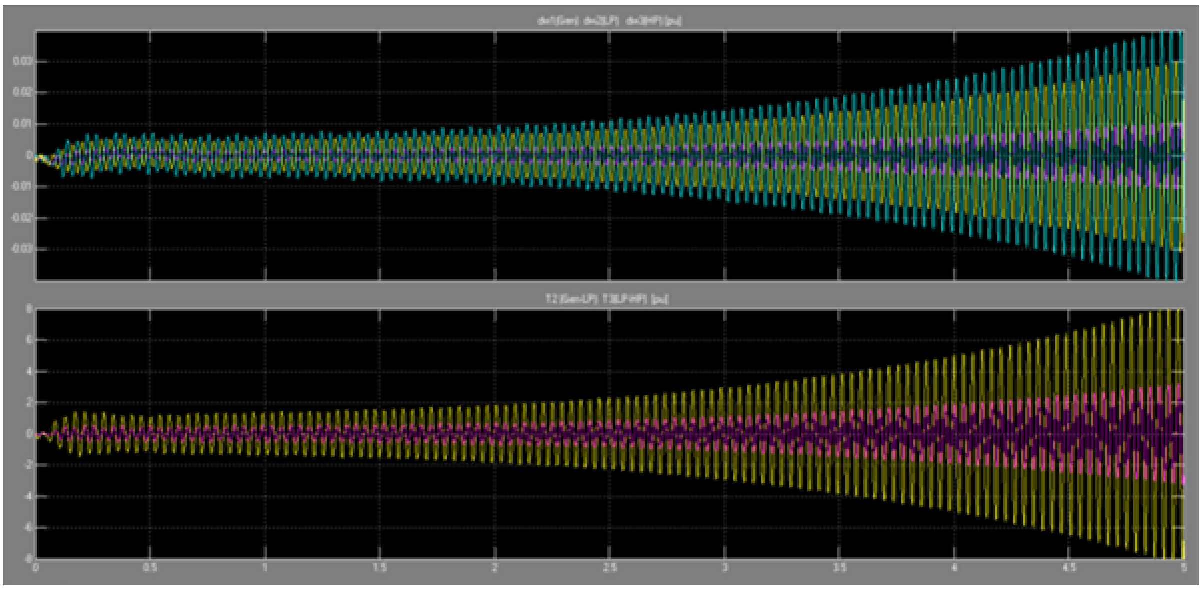

Figure 5.6: Outwaveform with seris comp. of Generator3

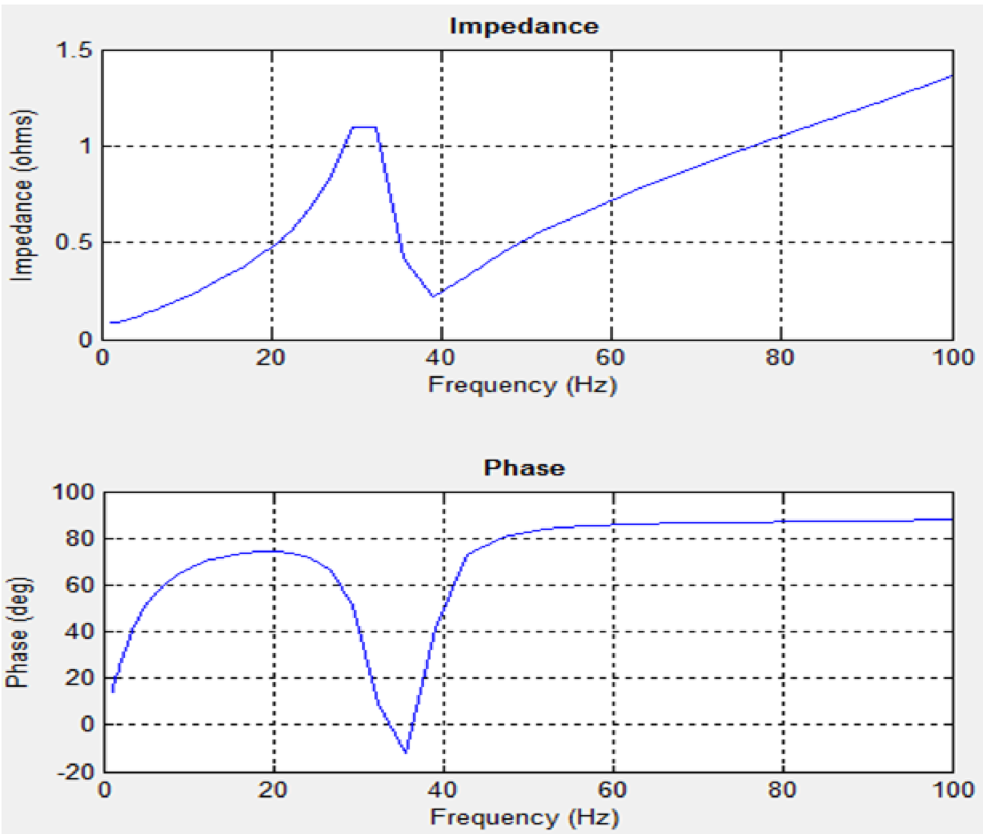

Figure 5.7: Impendence vs Frequncy Graph

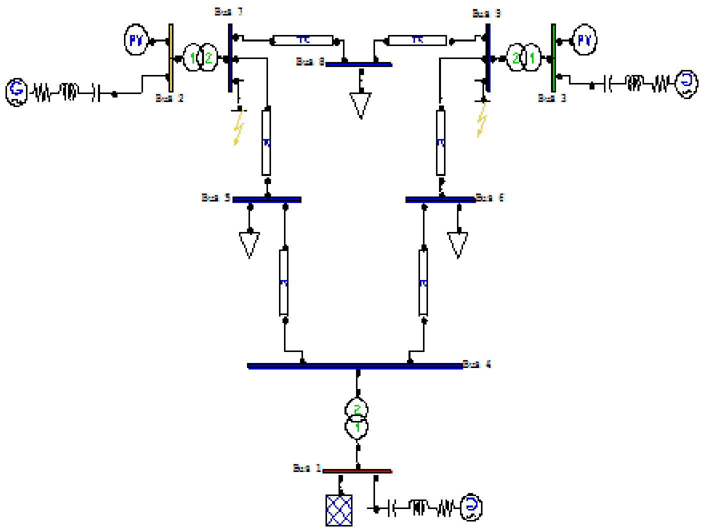

Figure 5.8: 9 bus model

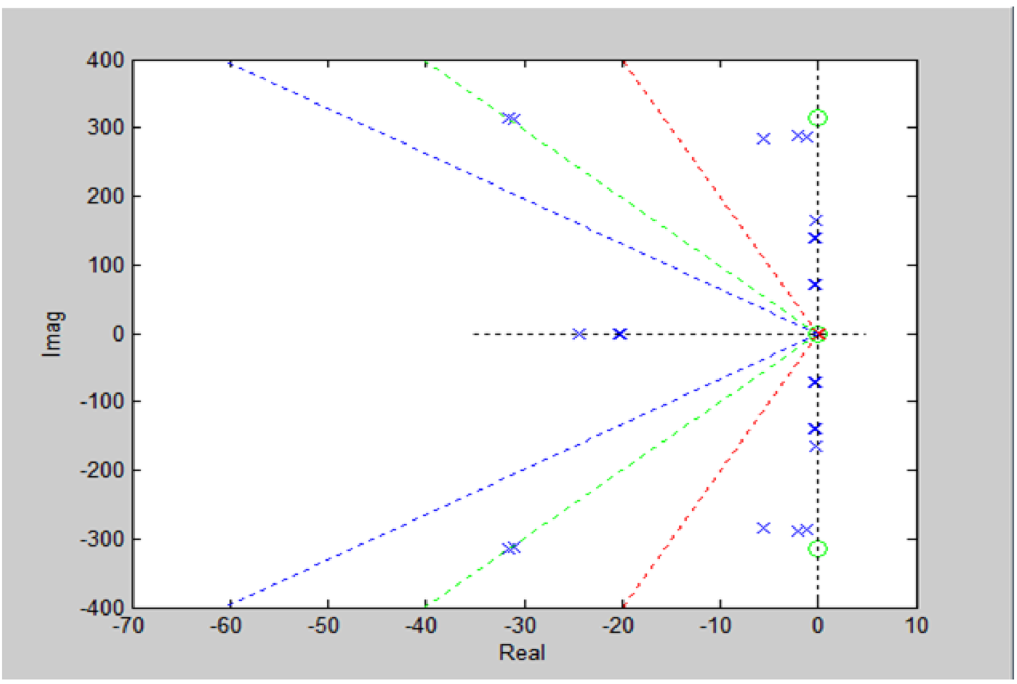

Figure 5.9: polezero model without compensation

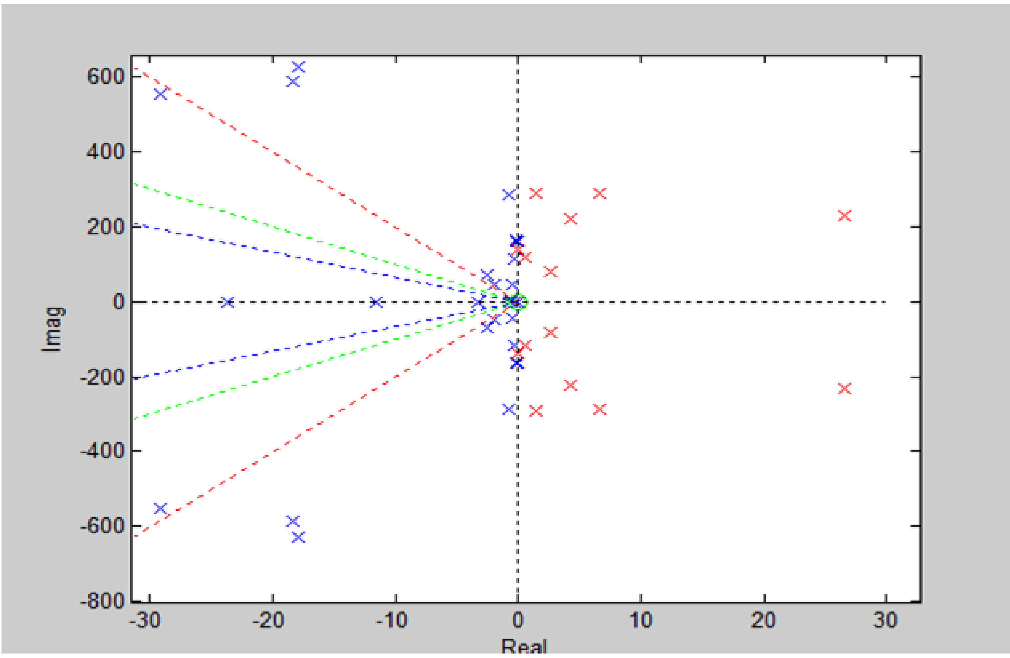

Figure 5.10: polezero model with compensation

Chapter 6

The VSC HVDC Back-to-Back Control strategy

6.1 Introduction

The schematic diagram of the VSC control systemis as shown in figure 6.1 the converters are identical and we can control separately. Both of this converters having two degree of freedom.

P and Q in station 1 (rectifier)

Ud and Q in station 2 (inverter).

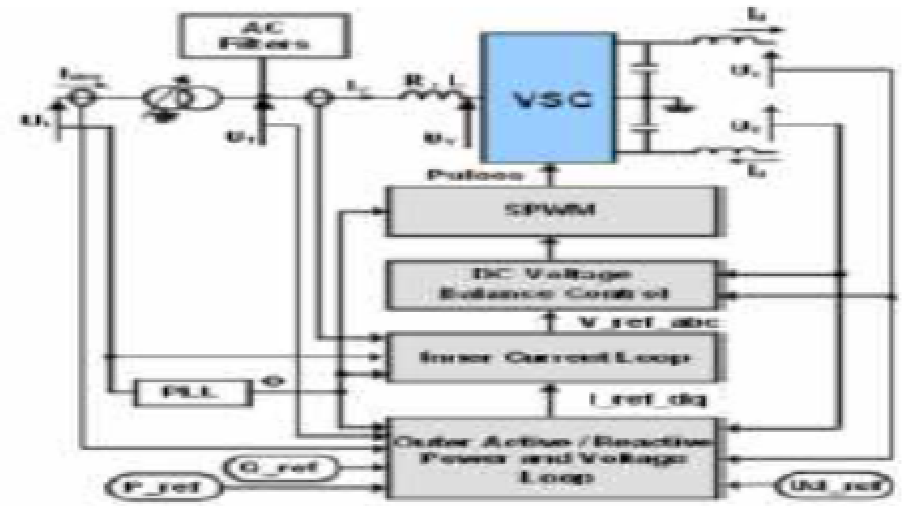

Figure 6.1: VSC control system overview diagram

6.1.1 The Phase Locked Loop

There PLL used to synchronised the converter control with line voltage and find out the transformation angle in d-q transformation. It means the function of PLL is system frequency and synchronous angle in d-q block. Here sinθ is in phase with fundamental component of the frequency.[3][13]

6.1.2 Outer active and reactive power and voltage loop

Here,If we controlling the [delta] directly control the active power and by the control of m control the reactive power. The real and reactive power can be present in term of d-q transformation.

In d-q theory ,the voltage quadrature component is very less as compared to the current the active and reactive power can be control by outer loop regulate active , reactive power and voltage loop.[3][13]

6.1.3 Characteristic of VSC used in HVDC and FACTS system

The major element of the converter are the valve bridge and converter transformer. The valve bridge is an array of high voltage switches or valves that sequentially connect the three phase alternating voltage to the dc terminals so that the desired conversion and control of power are achieved. The converter transformer provides the appropriate interface between the ac and dc systems. In this we will describe the structure and operation of practical converter circuit used in HVDC system.

6.1.4 Pulse-Width Modulation Control

The basic PWM switching scheme can be explained using the simple one-leg switch-mode inverter shown in Figure

A simple one leg switch mode inverter using PWM scheme is as shown in figure 6.2 .To produce a desired output voltage ,the input waveform is compare with the triangle waveform. The triangle waveform kept constant . this frequency is called carrier frequency . to remove the harmonics from the output waveform another high frequency is used it is called modulating frequency . if this not used we contain harmonics.[13]

In the inverter of Figure, the switches Ta+ and Ta- are controlled based on the comparison of Vcontrol and Vtri, and the following output voltage results, independent of the direction of the current

Vcontrol > Vtri Ta + is ON

Vcontrol < Vtri Ta - is ON

Since the two switches are never off simultaneously, the output voltage Vao fluctuates between two values. The voltage Vao and its fundamental frequency component (dashed curve)

6.1.5 The VSC HVDC Back-to-Back Supplementary Controller

The generator accelerating power and speed deviation are used to design the supplementary controller . Here the speed deviation is used to control the tortional modes of the system.[3] and enhance the power system stability.

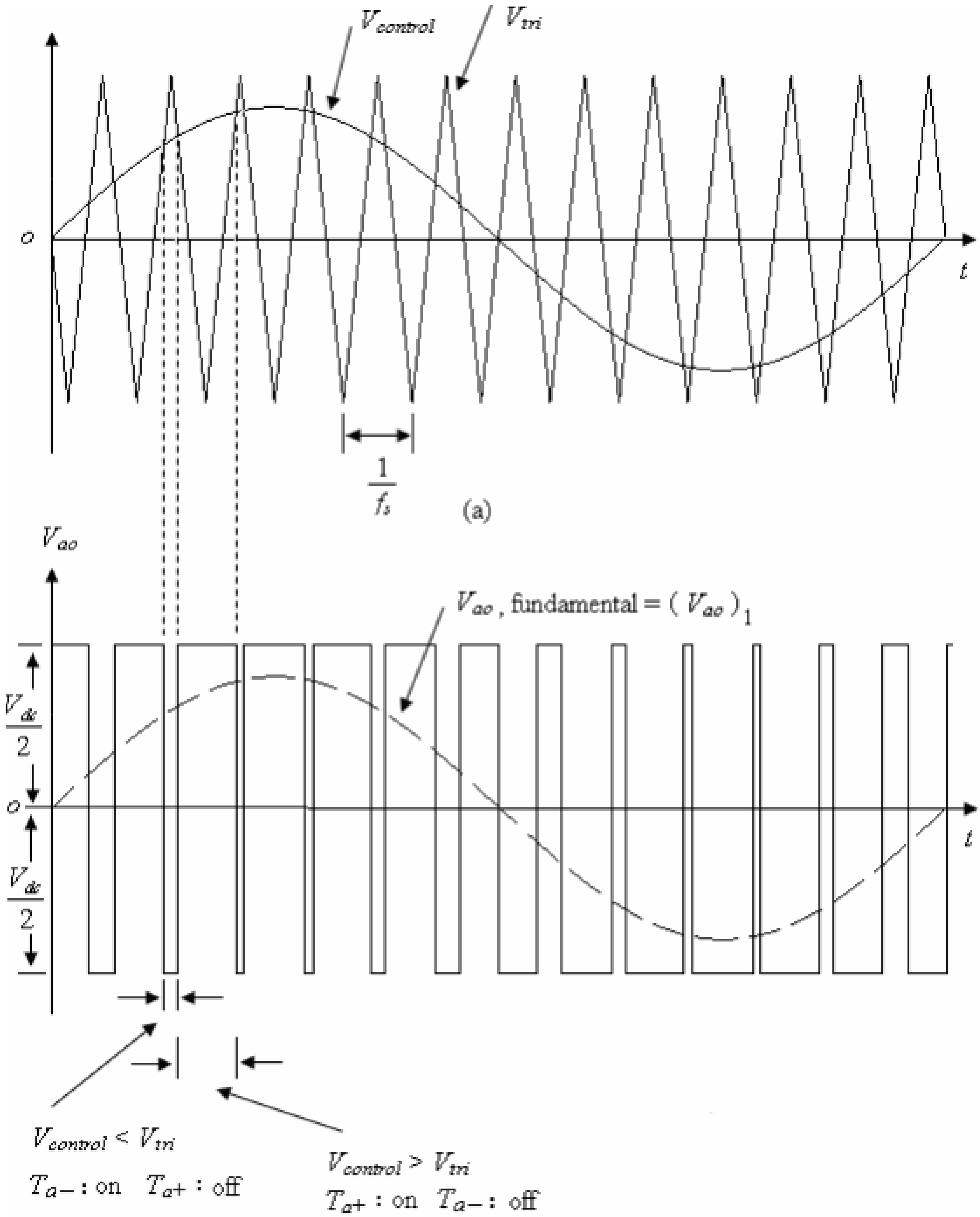

Figure 6.2: PWM control Scheme

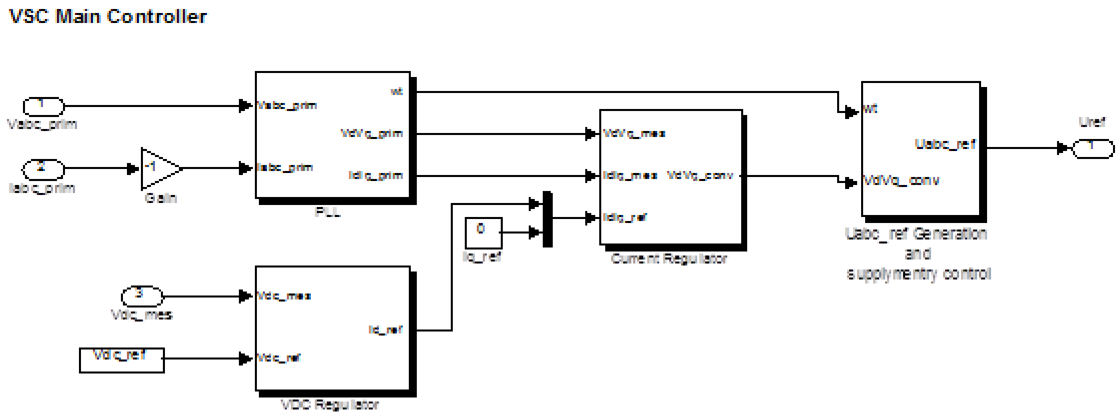

Figure 6.3: VSC main controller

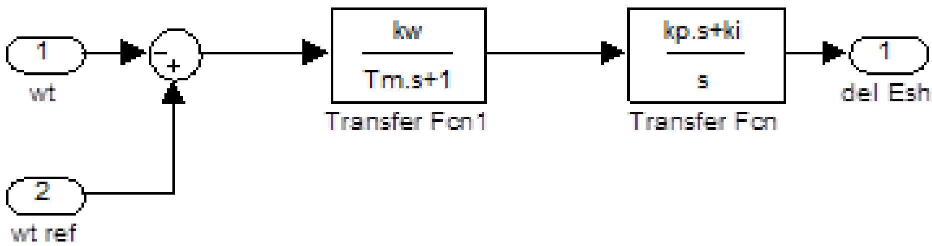

Figure 6.4: Transfer Function of supplementary Controller

Chapter 7

Mitigation of SSR using HVDC back to back scheme.

7.1 System Under Study

The VSC HVDC B2B system is connected to IEEE benchmark 9 bus system . The Turbine Generator electromagnetic & torsional responses due to fault at generator terminals is as shown in the fig. As it can be seen, the proposed controller effectively damps all the shaft torsional torques at this loading condition. It is worth noting here that simulation results. We mitigate SSR with rhe help of VSC HVDC back to back system.

VSC HVDC controller is used to mitigate the SSR taking place in the system. Here PI controller damp all the torsional torque at the generator shaft at loading condition . thus proposed controller mitigate the SSR produced in the system which is verify by simulation result[10]

7.2 Analysis of Sub Synchronous Resonance Under VSC Based HVDC Back to Back System.

After applying vsc hvdc back to back system clearly shows that all eigen values are left side and there is no positive eigen vaue means system is stable.

Before the vsc based hvdc back to back system is applyin the resonant frequency occurs at 37.5 Hz .And after we see this effectiveness of vsc hvdc back to back system its resonance frequency is 39Hz .

This corresponds to a frequency at 55% compensation f = 37.07 Hz. which is clearly in out of range of frequency vsc base HVDC back to back system is apply, means sub synchronous resonance mitigate in the turbine-generator shaft in series compensated transmission line. And enhance our system stability.[8]

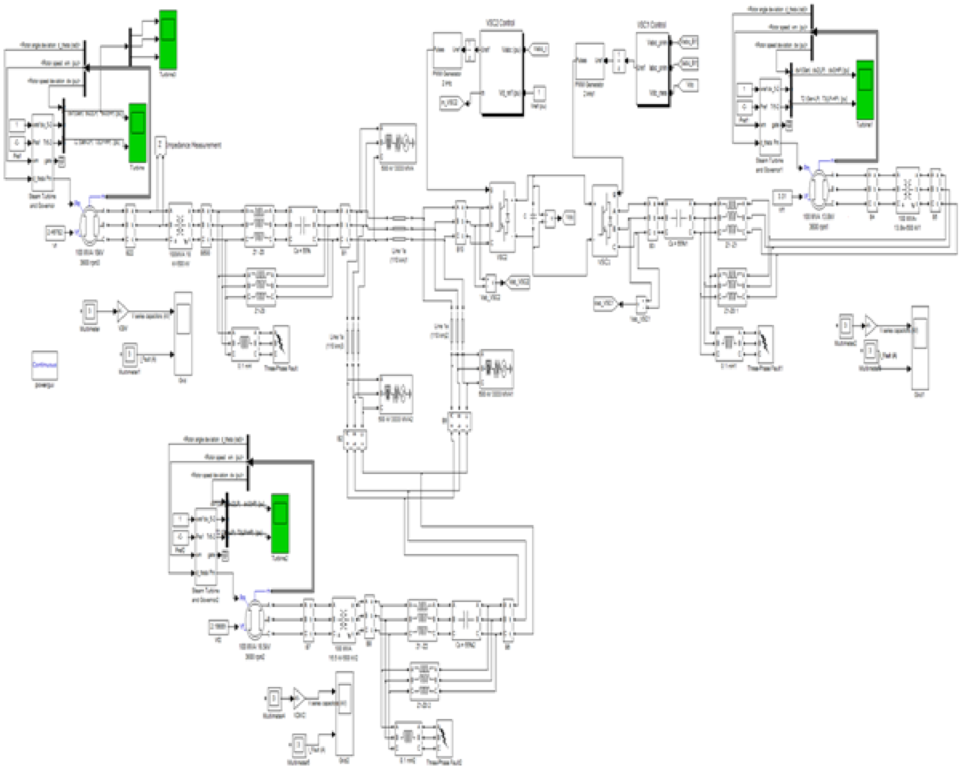

Figure 7.1: Case Study II, IEEE 9 bus system using VSC back to back system

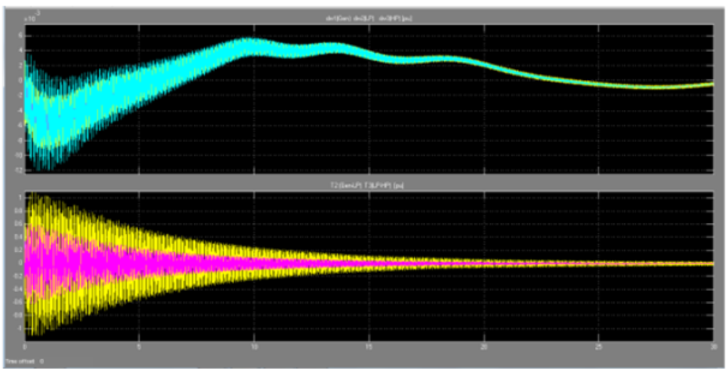

Figure 7.2: Rotor angle deviation & Torque o/p at Generator 1

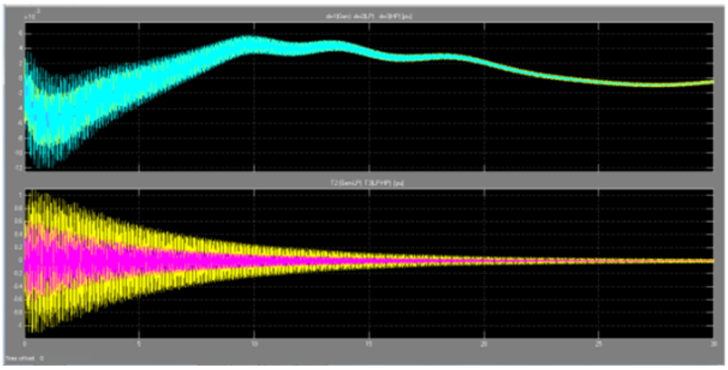

Figure 7.3: Rotor angle deviation & Torque o/p at Generator 2

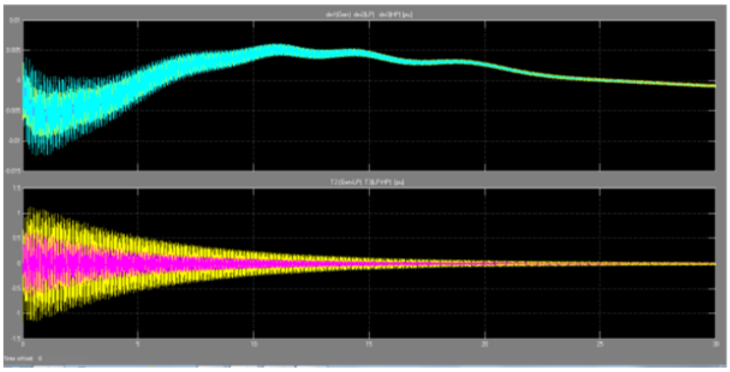

Figure 7.4: Rotor angle deviation & Torque o/p at Generator 3

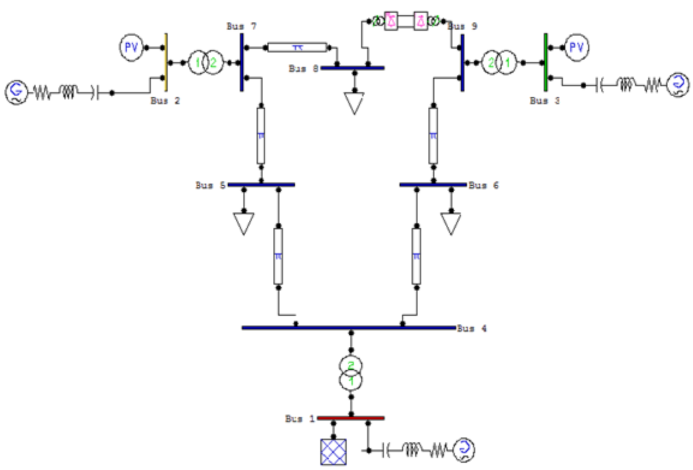

Figure 7.5: Eigen Value Analysis in PSAT

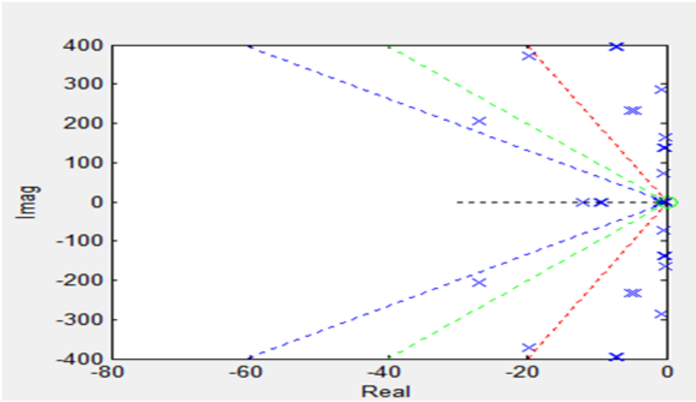

Figure 7.6: PoleZero Analysis

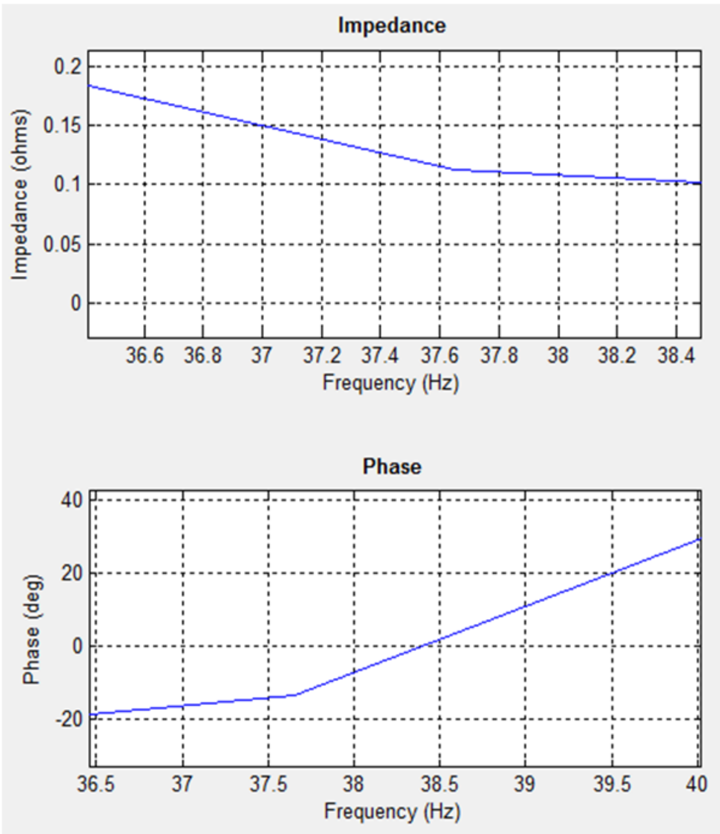

Figure 7.7: Frequncy Analysis w/o B-B system

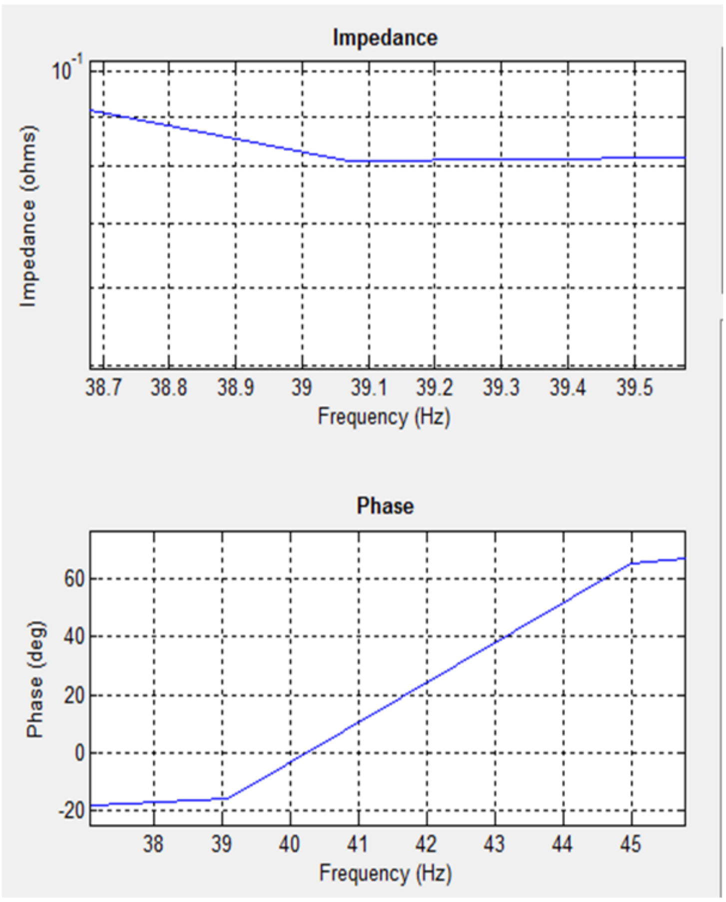

Figure 7.8: Frequncy Analysis with B-B system

Chapter 8

Conclusion

In this report we have shown 2nd benchmark IEEE 9 bus system. We have done Frequency Analysis & Eigen Value Analysis with VSC back to back system. The function of the proposed supplementary controller is designed to provide damping of sub synchronous torsional oscillations. From this analysis we can find out the system stability & SSR frequency and enhance the power transfer capability in series compensated transmission network without accurance of sub synchronous resonance in long transmission line.

Chapter 9

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Chapter 10

Appendix

Mechanical System Data

Mass	Shaft	Inertia *M* (seconds)	Damping *D* (p.u./p.u. speed)	Spring constant *K*(p.u./rad)
EXC		0.0684	0.0175	
	GEN-EXC			2.822
GEN		1.736	0.099	
	LPB-GEN			70.858
LP		1.768	0.100	
	LP-IP			52.038
IP		0.311	0.025	
	HP-IP			19.303
HP		0.1856	0.008	

Figure 10.1: Mech. Parameters of Generator 1

Mass	**Shaft**	**Inertia** M **(seconds)**	**Damping** D **(p.u./p.u. speed)**	**Spring constant** K**(p.u./rad)**
EXC		0.0683	0.0175	
	GEN-EXC			2.821
GEN		1.735	0.099	
	LPB-GEN			70.857
LP		1.767	0.100	
	LP-IP			52.037
IP		0.312	0.025	
	HP-IP			19.301
HP		0.1857	0.008	

Figure 10.2: Mech. Parameters of Generator 2

Mass	**Shaft**	**Inertia** M **(seconds)**	**Damping** D **(p.u./p.u. speed)**	**Spring constant** K**(p.u./rad)**
EXC		0.0685	0.0176	
	GEN-EXC			2.821
GEN		1.737	0.097	
	LPB-GEN			70.855
LP		1.767	0.100	
	LP-IP			52.035
IP		0.313	0.023	
	HP-IP			19.302
HP		0.1857	0.006	

Figure 10.3: Mech. Parameters of Generator 3

$K_g = 25$	$T_{ch} = 0.40$ sec.
T_{rh} =7.0sec.	$T_{co} = 0.60$ sec.
$T_g = 0.1$sec	$F_B = 0.22$
$F_I = 0.26$	$F_H = 0.30$
Cvclose = 4.0 p.u./sec.	Cvclose = 4.0 p.u./sec.

Figure 10.4: Parameters of Governor & Turbine System of Generator 1

$K_g = 23$	$T_{ch} = 0.40$ sec.
T_{rh} =7.0sec.	T_{co}= 0.60 sec.
$T_g = 0.05$sec	$F_B = 0.22$
$F_I = 0.25$	$F_H = 0.30$
Cvclose = 3.7 p.u./sec.	Cvclose = 3.7 p.u./sec.

Figure 10.5: Parameters of Governor & Turbine System of Generator 2

$K_g = 25$	$T_{ch} = 0.40$ sec.
T_{rh} =7.0sec.	T_{co}= 0.60 sec.
$T_g = 0.08$sec	$F_B = 0.22$
$F_I = 0.26$	$F_H = 0.30$
Cvclose = 3.9p.u./sec.	Cvclose = 3.9 p.u./sec.

Figure 10.6: Parameters of Governor & Turbine System of Generator 3

MVA=100	Frequency=60Hz	
KV=18		
R_a = 1e-7	R_{fd} = 0.0013	R_{1d} = 0.0297
R_{1q} = 0.0124		R_{2q} = 0.0182
X_{ad} = 1.66		X_{aq} = 1.58
X_d = 1.79	X_q = 1.71	X_{ffd} = 1.7335
X_{11d} = 1.7177	X_{11q} = 1.6319	X_{22q} = 1.9029

Figure 10.7: Elect. Parameters of Generator 1

MVA=100	Frequency=60Hz	
KV=13.8		
R_a = 1e-7	R_{fd} = 0.0013	R_{1d} = 0.0297
R_{1q} = 0.0122		R_{2q} = 0.0182
X_{ad} = 1.62		X_{aq} = 1.56
X_d = 1.71	X_q = 1.71	X_{ffd} = 1.7335
X_{11d} = 1.7177	X_{11q} = 1.6319	X_{22q} = 1.9029

Figure 10.8: Elect. Parameters of Generator 2

MVA=100	Frequency=60Hz	
KV=16.5		
R_a = 1e-7	R_{fd} = 0.0013	R_{1d} = 0.0297
R_{1q} = 0.0124		R_{2q} = 0.0182
X_{ad} = 1.66		X_{aq} = 1.53
X_d = 1.79	X_q = 1.70	X_{ffd} = 1.7635
X_{11d} = 1.7177	X_{11q} = 1.6319	X_{22q} = 1.8629

Figure 10.9: Elect. Parameters of Generator 3

Line 1	$XL1$ = 0.7
RL = 0.02	
Line 2	$XL2$ = 0.1
$RL2$ = 0.005	
Line 3	$XL3$ = 0.1
$RL3$ = 0.005	
Line 4	$XL4$ = 0.65
$RL4$ =0.049	
Line 5	$XL5$ = 0.1
$RL5$ =0.005	
Line 6	$XL6$ = 0.46
$RL6$ =0.045	

Figure 10.10: Parameters of Transmission Line

Kp	0.05
Ki	0.10
Kw	3.0
Ts	0.01 sec.

Figure 10.11: Parameters of Supplementary Controller

References