STABILZATION OF FREQUENCY OSCILLATIONS USING POWER MODULATION CONTROLLER OF HVDC LINK IN A PARALLEL AC-DC INTERCONNECTED SYSTEM

DISSERTATION/THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS
FOR THE AWARD OF THE DEGREE
OF

MASTER OF TECHNOLOGY
IN
POWER SYSTEMS

Submitted by:

Manish Kumar Jha

2k12/PSY/06

Under the supervision of

Dr. Suman Bhowmick

DEPARTMENT OF ELECTRICAL ENGINEERING
DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

DECLARATION

I, hereby declare that the work being presented in this Project Report entitled **"Stabilization of Frequency Oscillations using Power Modulation Controller of HVDC Link in a parallel AC-DC interconnected System"** is an original piece of work and an authentic report of our own work carried out during the period of 4th Semester as a part of our major project.

The model developed and results presented in this report is an outcome of the work carried out during the above said period and is also compiled as thesis for my Major Project for completing the requirements of Master's Degree of Examination in Power System Engineering, as per Delhi Technological University curriculum.

Manish Kumar Jha

Roll no. 2k12/PSY/06

M.tech (Power Systems)

Department of Electrical Engineering

Delhi Technological University, New Delhi.

DEPARTMENT OF ELECTRICAL ENGINEERING

DELHI TECHNOLOGICAL UNIVERSITY
(Formerly Delhi College of Engineering)
Bawana Road, Delhi-110042

CERTIFICATE

I, Manish kumar jha, Roll No. 2k12/PSY/06 student of M. Tech. (Power System), hereby declare that the dissertation/project titled "Stabilization of Frequency Oscillations using Power Modulation Controller of HVDC Link in a parallel AC-DC interconnected System" under the supervision of Dr.Suman Bhowmick of Electrical Engineering Department , Delhi Technological University in partial fulfillment of the requirement for the award of the degree of Master of Technology has not been submitted elsewhere for the award of any Degree.

Place: New Delhi **Manish Kumar Jha**
Date: **(NAME OF THE STUDENT)**

Dr. Suman Bhowmick
(NAME OF SUPERVISOR)

Academic Designation

ACKNOWLEDGEMENT

I would like to express my gratitude to my supervisor Dr Suman Bhowmick whose valuable guidance and support has helped me to steer through all the challenges I faced during my research. I would like to express my gratitude towards Prof. Madhusudan Singh, Head of Department of electrical engineering and Prof Narendra kumar Ex- Head of Department for their encouragement during the conduct of project work. I would also like to thank other faculty members of Electrical Department for giving me excellent understanding of courses like Power Systems, Renewable Energy Systems and Optimization. I would also like to thank all non teaching staff of Electrical engineering Department for their fullest cooperation

.

I would like to thank my friends and fellow .This thesis would not have been possible without the countless number of discussions and knowledge sharing sessions with them. I would like to thank my parents and my brother for their love, support and encouragement throughout my career. Many thanks to all those who made this possible.

Manish Kumar Jha (2k12/PSY/06)
M Tech (Power System)

ABSTRACT

Power systems have many control areas which are interconnected to each other .In such a system if any sudden change of load occurs in any area this will lead to change of system frequency of all area and also tie line powers. By the implementation of Automatic Generation Control (AGC) we can maintain nominal frequency and keep tie line power at scheduled value even after the step load is subjected to any area. To implement this Automatic generation control it takes help of Area Control Error signal. This signal is fed to integral controller for achieving desired response of frequency.

Though system described above attained nominal frequency with help Area Control error signal but still before frequency reached its nominal value after disturbance its response is oscillatory with large overshoot and settling time. With the objective of stabilizing such frequency oscillation and simultaneously reducing both overshoot and settling time. In this project we are using a interconnection of HVDC in parallel to AC tie line. As gain of closed loop system plays an important role in its dynamic performance so gain is optimized to obtain best response. To attain the above objective a power modulation controller is designed to damp out inter-area oscillation. Simulation study response corroborates significant outcome of the designed control.

INDEX

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

1.1 AUTOMATIC GENERATION CONTROL PROBLEM

In a power system having many control areas are interconnected with each other by transmission. Control area is described as a system in which all the generators accelerate or decelerated together that is swing together. System will always attempt to maintain nominal frequency and scheduled power in an interconnected transmission line. In such a system any abrupt and small load change in any of the areas will lead to variation of frequency in all the area and in line between them.

The objectives of Automatic Generation Control (AGC) are

I. To maintain the scheduled active power output and the nominal frequency of an interconnected power system.

II. To maintain the net interchange of active power among control areas at scheduled values.

Addition of sudden load increase in any area which is operating at nominal power frequency will lead to power mismatch between generation and demand. As governor cannot operate immediately so extra power required is met by decrease in kinetic energy and this frequency of system will reduce. As the frequency decreases, the power taken by load also goes on decreasing. In large power systems, the equilibrium may be obtained by themselves at a point when the new load is compensated by the reduction in power consumed by old load and the power corresponding to kinetic energy extraction from the system. This equilibrium is attained at the cost of a reduction in frequency. This equilibrium is managed by the system itself and it does not require any governor action. The frequency reduction under such a system is quite large.

However, in case of large mismatch, the governors start operating and the output power of generators increases. Now the balance is attained at a point where the new load is matched with the reduction in the power taken by old load and the increased power generation because of governor action. So, amount of kinetic energy drawn from the system is decreased by greater extent, but not totally. Hence for such type of equilibrium, the decrease in frequency still occurs, but in this case deviation in frequency is quite smaller than the previous case. Such equilibrium is normally attained in 10-12 seconds after the change of load. The action of governors is thus called primary control. Despite the governor action the frequency is still different from the nominal frequency, it is further required to bring the frequency back to nominal frequency by another control technique. This is done by using Integral Controllers. This is called secondary control (which will operate after the primary control act).It brings back the frequency to nominal frequency or very close to nominal frequency. But, the conventional integral controllers are slow in action.

So as per general rule in an interconnected power systems which have two or more than two areas each area will supply load to their respective area and in case any sudden load change to allow less deviation of frequency other will be supplying fraction of increased load through tie line. So, a load change in any of the areas will also affects frequency of other areas as well as the power flow in tie lines.

As there is change in frequency in all the connected areas so we will be needing signal corresponding to this change of each area apart from this we will also be needing any change in tie line powers between those areas. This information are combined together to generate signal Area Control Error .This Area Control error signal will be different for each area. This signal will be fed to integral controller with proper gain to reduce achieve nominal frequency.

Thus AGC schematics will help to obtain nominal frequency maintaining tie line power at scheduled values after any step load change.

1.2 INTERCONNECTED POWER SYSTEMS

As per actual scenarion, the frequency control of power system having many areas having tie line connection between those areas are more important than single isolated area. However, for understanding this theory and concept of an interconnected area system, the knowledge of single area is also desired.

Today all power systems area are connected with neighboring areas and the issue of automatic generation control becomes a joint phenomena. Following are the basic operating principles of an interconnection of power systems.

I. In case of normal operation each area will meet it own load requirement except for that portion which are already scheduled to be met by other areas as per mutual contract

II. Each and every area must agree to adopt, regulate and control strategies and equipment that are beneficial for all in case of both normal and abnormal condition.

Advantages of interconnection:

I. Effect of size: This is one of the major advantages for the total interconnected system. As soon as a block of load is added, during the first moments, the required energy is borrowed temporarily from the kinetic energy of the system. Obviously, the larger the system is, the more is the energy available. Hence the static frequency drop is comparatively less. However, the same amount of change in load may cause a higher frequency drop in an isolated or small power system, which may even make the entire system unstable.

II. Reduced need of reserve capacity: Since the peak demands can occur at various hours of the day in various areas, the ratio between peak and average load for a large system is smaller than that of smaller systems. It is therefore obvious that, all the interconnected areas can benefit from a reduced need of reserve capacity by a scheduled arrangement of energy interchange.

1.3 TWO AREA INTERCONNECTED POWER SYSTEM

As two area interconnected power system connected through a tie line is shown in Fig. 1 Each area feeds its control area and tie line allows electric power to flow between the areas.

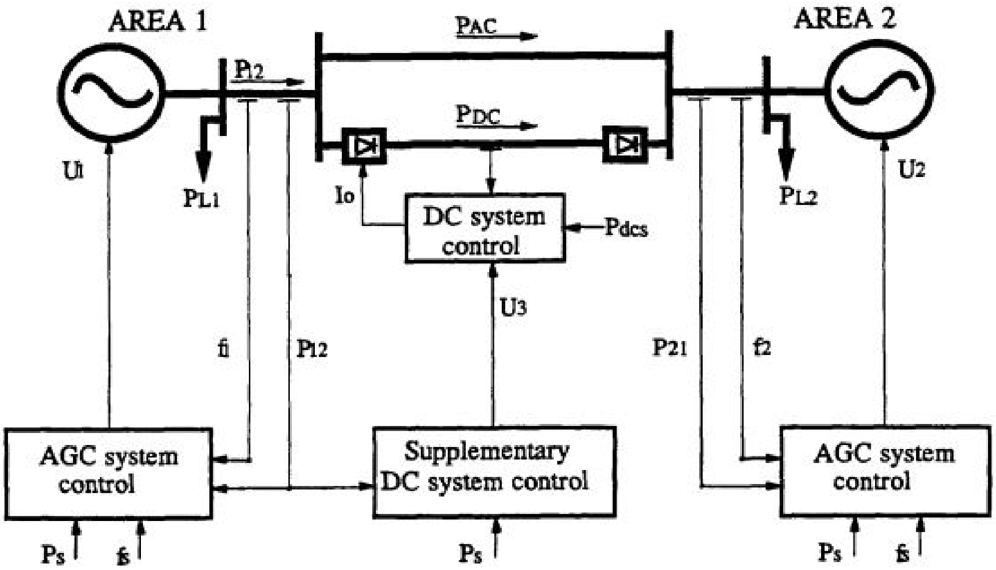

Figure1: AC-DC parallel interconnection of two area

A single control area is characterized by the same frequency throughout. In other words, the area network is ‘rigid’ or ‘strong’. In the case of a two area system, it is assumed that each area is individually ‘strong’ and the two areas are connected by a ‘weak’ tie line. An interconnected power system may consist of any number of subsystems or areas.

CHAPTER 2

LITERATURE REVIEW

Many valuable research is done in area of frequency control using automatic generation control like AGC regulator design circuit considering various parameter variation and uncertainties, governor control, automatic load frequency control, secondary loop control that is using integral controller and in parallel AC/DC link etc.

Till now majority of work done so far consist of liberalized model for single area and multi area systems. Afterwards Generation Rate Constant effect has been taken into account for similar type of studies in both continuous and discrete power system models. But because of presence of non linearity associated with power system and considering linear model for such system was not justifiable so cannot ensure system stability. Hence so focus shifted towards nonlinearities associated with system like destabilization tendency associated with governor dead band which can produce oscillations in frequency and tie line active power. To operate any system successfully require matching of generation with load demand and all the associated losses. Whenever power generation and load changes there is deviation in frequency and hence oscillation in frequency and also change in power transmission tie line. Which is not a desired phenomena .Two variables of observance is frequency and tie line power exchange which should not change ideally.

The above mentioned two variables are considered together to obtain one variable known as area control error (ACE). Because of this variable control philosophy to stabilize frequency oscillation and overall dynamic performance improved. The critical review of literature about a wide range of methodologies of AGC regulator designs with their salient features is described next.

The definitions for AGC in electrical power systems model were approved by the IEEE STANDARDS Committee in 1968 [1]. After that that transient model for load frequency control were studied by IEEE PES working groups [2-3]. This concept of Automatic Generation control philosophy and ACE definition is revised continuously as per actual implementation and power system development. [4, 5, 6, 7].

R. K. Green [6] presented a new formulation of the principles of AGC. He suggested the concept of transformed AGC, by use of which we can eliminate fixed setting that is bias setting and hence able to maintain or achieve nominal frequency as per set point for each area separately.

Stankovic [7] has addressed design issue of load frequency control along with its analysis keeping two important goal in vision that is to for examining principle behind heuristic method guideline and to synthesize methodology for its control. They forwarded an effective method for closed loop control.

Till now in most of load frequency control studies it is assumed that power nd frequency are independent from reactive power and voltage so they are analyzed separately but this assumption is valid only when speed of excitation system is fast enough that is faster as compared to Load frequency control system. But in practicality this is not true in case of dynamic system and hence there is interaction between voltage/Reactive power closed loop and frequency/Active power control loop [8].

Elgard and Fosha [10] has proposed a unique feedback with loop gain method to remove unwanted disturbances from power system. They considered disturbance in system due to load as deterministic. They forwarded method of proportional controller without considering point of requirement of steady state and also load disturbance compensation. In case of work considered under Automatic Generation control study main limitation was that in this signals are need to be exchanged among different areas which are spread widely and distantly along with increased computational complexities. To handle such complexities in order to concept of decentralized AGC was used in power system which simplifies control effectively.

These days a new and innovative concept of HVDC technology is used for transmission of power. This HVDC technology has many advantage both technology wise and economic wise for transmitting large volume of water and for considerably large distance. In addition to this making an additional HVDC link in parallel to existing AC line has other advantages like transferring higher power and stabilizing system etc. Added advantage of this DC system interconnected between has potential of damping any frequency or power disturbance. A detailed work has been done by Kumar and Ibrahim [9] and proposed a optimal automatic generation control regulator for two area system in case of parallel AC line and DC line. Such type of interconnected power system was studied and analyzed with designed optimal regulator by taking into account of incremental DC link power flow as an additional state of variable control. This investigation has expressed that system dynamic performance has improved as compared to system performance without DC link that is through AC link only.

CHAPTER 3

MODELLING OF POWER SYSTEM FOR AGC WITH SUPPLEMENTARY CONTROL

3.1 Modeling of various component

3.1.1 Prime mover model (Non reheat turbine)

Considering control area concept each area has many generator each having multiple valves for controlling steam flow into the steam turbine. The prime mover shaft of this turbine has some time constant yo respond to any change in steam flow. Corresponding model shown in Figure 2. T_{CH} is time constant to respond to any change in steam flow . ΔP_{Valve} represents valve position change in pu. ΔP_{Mech} represents mechanical output power change in put.

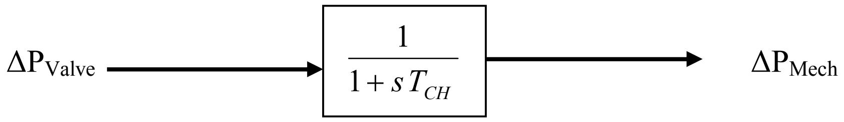

Figure 2: Prime mover model

3.1.2 generator-load model

I. Generator Model

Small load change analysis of the swing equation of the synchronous machine is given by,

$$\frac{2H}{\omega_S}\frac{d^2\Delta\delta}{dt^2} = \Delta Pm - \Delta Pe \qquad (3.1)$$

When expressed as small change in angular velocity

$$\frac{d\Delta\frac{\omega}{\omega_S}}{dt} = \frac{1}{2H}\left(\Delta P_m - \Delta P_e\right) \qquad (3.2)$$

Where speed is in pu, we have

$$\frac{d\Delta\omega}{dt} = \frac{1}{2H}\left(\Delta P_m - \Delta P_e\right) \qquad (3.3)$$

Using Laplace transformation, we obtain

$$\Delta\omega(s) = \frac{1}{2Hs}\left[\Delta Pm(s) - \Delta Pe(s)\right] \qquad (3.4)$$

The above relation is depicted in block diagram

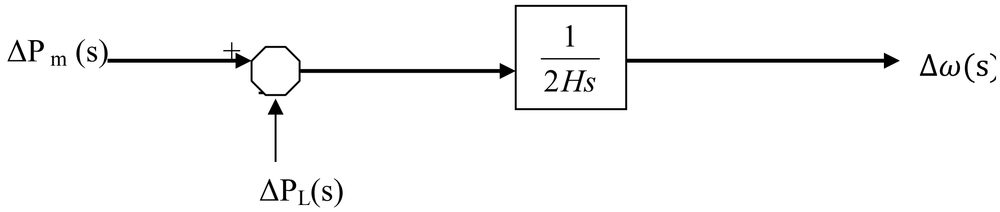

Figure 3: Generator block diagram

II. Load model

In an power system there are many types of load connected to grid. Some loads are independent of frequency like lighting load ,heating load and many other resistive load while many other loads are dependent on frequency like motor loads. In case of motor load requirement depends on frequency of system. The frequency dependency of load depends on the speed load characteristics of electrical device.

The frequency dependent load can be expressed by equation.

$$\Delta P_e = \Delta P_L + D\,\Delta\omega \tag{3.5}$$

Where, ΔP_L is frequency independent portion of load variation.

$D\,\Delta\omega$ is Frequency dependent portion of load variation.

D is given by percentage change in load divided by percentage change in frequency. Generator block diagram including the load model, results in the block diagram.

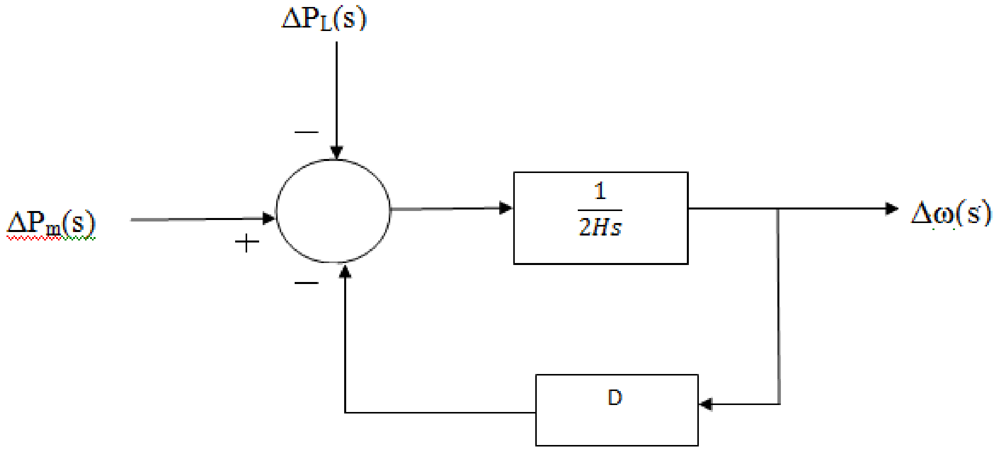

Figure 4: Generator and load block diagram_1

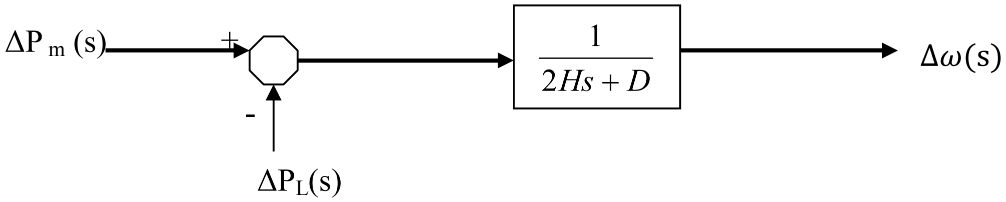

Figure 5: Generator and load block diagram_2

While the turbine output power is mechanical and generator output power is electrical that is generator converts mechanical power into electrical. In case of any change in demand of electrical power prime mover power should also change accordingly to make up difference. As input steam power is constant till now so turbine will slow down losing its kinetic energy this ultimately leads to reduction in generator frequency. The transfer function model is shown in Fig. 5.

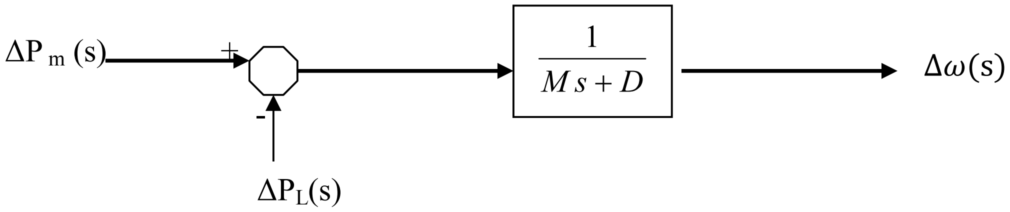

Figure 6: Generator-load block diagram_3

M is the angular momentum. D is the percentage variation in load divided by the percentage variation in frequency. D is defined by the equation below.

$$D = \frac{\Delta P_{L(freq)}}{\Delta f} \tag{3.6}$$

3.1.3 Block diagram for the governor

Prime mover that is turbine has governor control to control steam flow into it. Governor increases or decreases steam flow to maintain rotating speed of prime mover at fixed rated speed and hence frequency of system is maintained. Governor control is achieved by a comparator which compares output frequency with fixed biased frequency (50Hz) and thus increase or decrease rate of steam flow in it to maintain desired speed of prime mover and output frequency. As all turbine are not similar so different turbine has different droop characteristic which keep different output power of each turbine at same speed. This droop characteristic is determined by following equation.

$$R = \frac{\Delta\omega}{\Delta P} \, per\ unit \qquad (3.7)$$

The model for the governor is shown in Figure 7.

Governors also have governor time constant T_G. The governor model is biased by the load reference set point. This set point is determined so each unit can maintain its load dispatch.

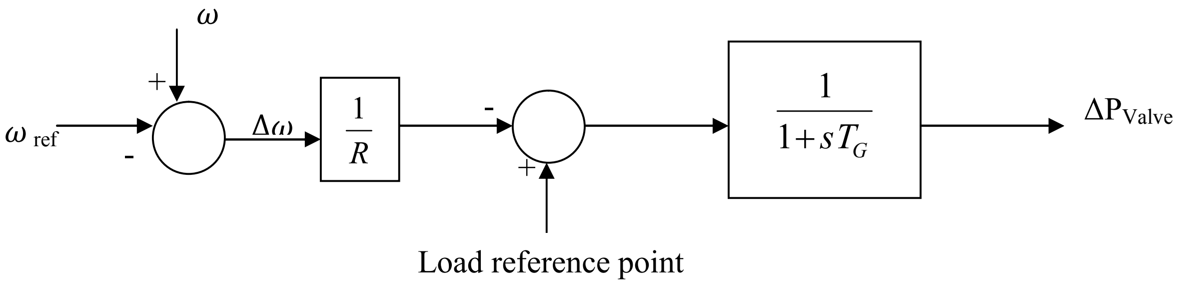

Figure 7: Governor model

3.1.4 Tie-line model

Power flow in a tie line is given by the synchronizing coefficient of the tie-line multiplied by the difference in phasor angles between two areas. Expressed as below.

$$P_{tie} = T_{12}(\Theta_1 - \Theta_2) \qquad (3.8)$$

As we need change in tie line power, so

$$\Delta P_{tie} = T_{12}\left(\Delta\Theta_1 - \Delta\Theta_2\right) \tag{3.9}$$

In terms of angular frequency, equation can be expressed as,

$$\Delta P_{tie} = \frac{T}{s}\left(\Delta w_1 - \Delta w_2\right) \tag{3.10}$$

$$\Delta P_{tie}(S) = \frac{T_{12}}{s}\left(\Delta F_1(S) - \Delta F_2(S)\right) \tag{3.11}$$

$$T_{12} = \frac{V_1 V_2}{X_{12}}\left(COS\left(\Theta_1{}^0 - \Theta_2{}^0\right)\right) \tag{3.12}$$

Here, T_{12} is considered the tie-line stiffness constant.

Area Capacity Ratio- If two area have different base values ,And as we are dealing in per unit system we have to make necessary arrangement.

Now,

$$\Delta P_{12} = -\Delta P_{21} \tag{3.13}$$

$$(\Delta P_{21})pu = -(\Delta P_{12})\frac{1}{P_{B2}} \tag{3.14}$$

$$(\Delta P_{21})pu = -(\Delta P_{12})pu\,\frac{P_{B1}}{P_{B2}} \tag{3.15}$$

$$a_{12} = -\frac{P_{B1}}{P_{B2}} \quad \text{[Area capacity ratio]} \tag{3.16}$$

So, by combining above theory complete model for Automatic Generation Control is given by block diagram shown in Figure 8.

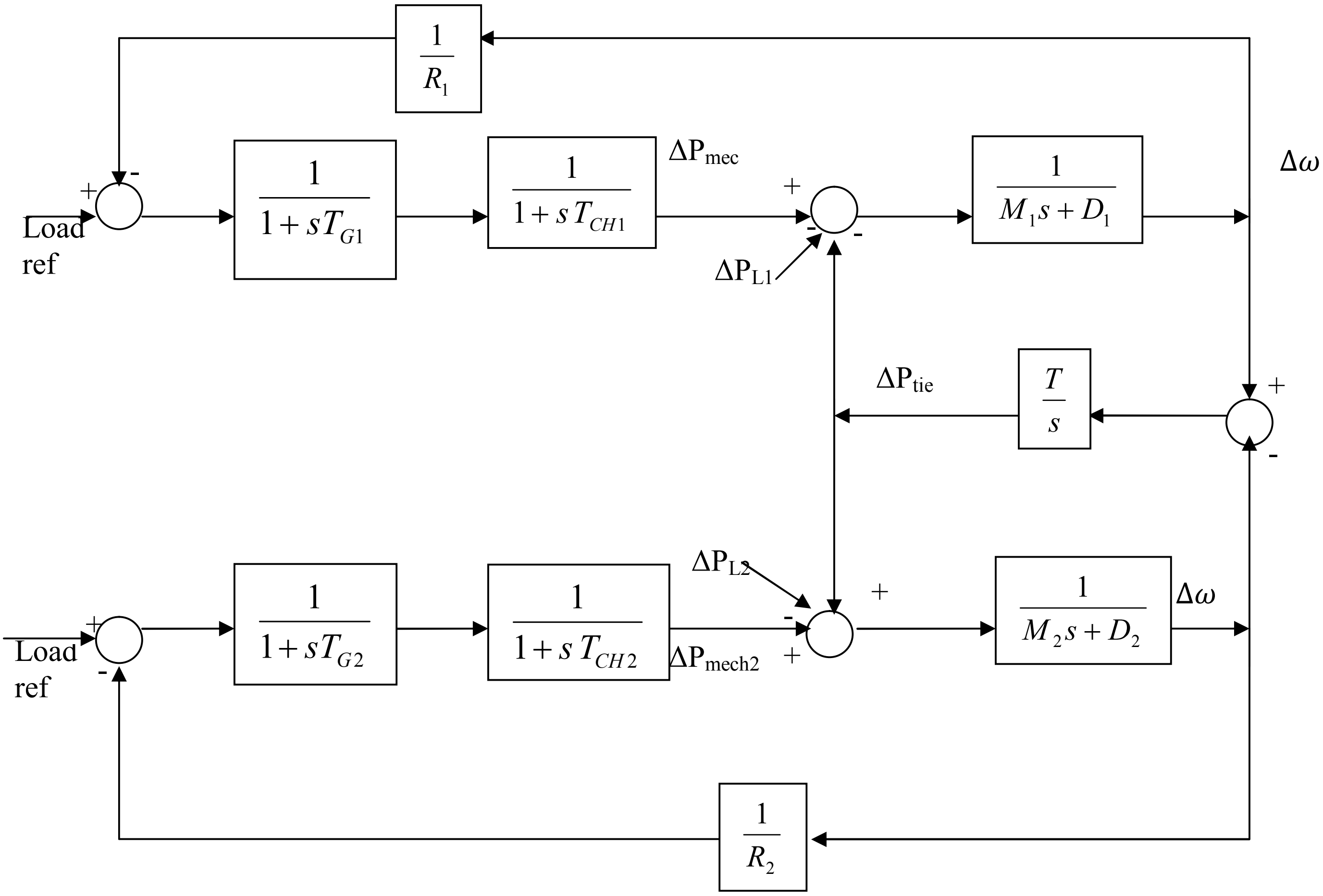

Figure 8: Governor, prime mover, generator-load, and tie line model combined

Following equations are deuced from above model.

$$\Delta\omega = \frac{-\Delta P_{L1}}{\frac{1}{R_1} + \frac{1}{R_2} + D_1 + D_2} \tag{3.17}$$

$$\Delta P_{tie} = \frac{-\Delta P_{L1}\left(\frac{1}{R_2} + D_2\right)}{\frac{1}{R_1} + \frac{!}{R_2} + D_1 + D_2} , \qquad (3.18)$$

The load reference point indicated in Fig 8 act as a supplementary control , it makes frequency deviation to zero and hence attaining nominal frequency..

As in case of interconnected power system change in demand in any single area will change generation of all area so a control schematics must be designed which will make return of tie line power to previous value. This is type of arrangement is required as whatever exchange of power take place between different areas should be according to contract of sell and buy of power any deviation from contract will have extra cost implication or penalty. So to avoid this area control error (ACE) signal is generated and applied. The ACE is defined below.

$$ACE = -\Delta P_{tie} - B\Delta\omega \qquad (3.19)$$

B represents frequency bias factor

$$B = \frac{1}{R} + D \qquad (3.20)$$

Complete Automatic Generation control schematic is shown in Figure 9.

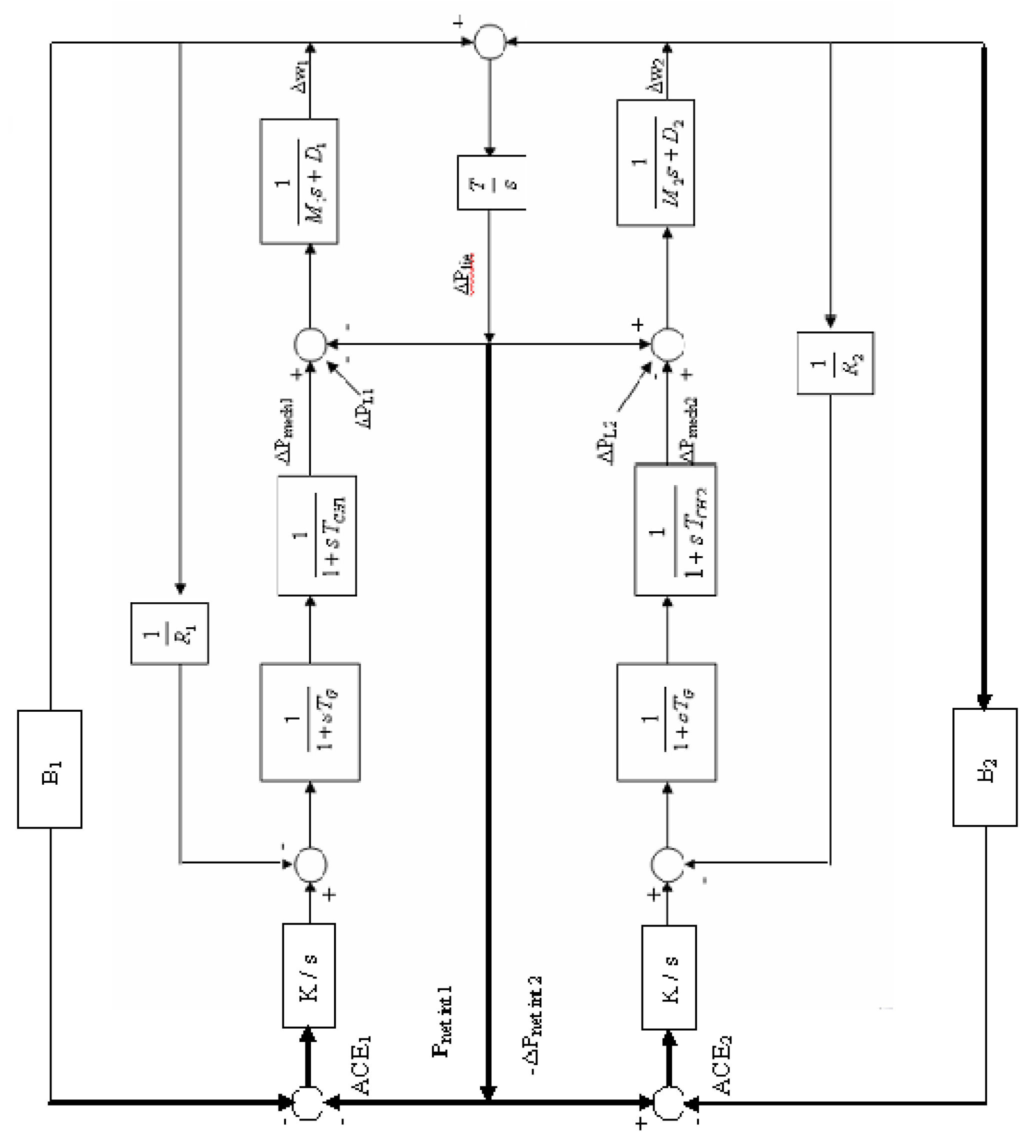

Figure 9: Complete AGC model

CHAPTER 4

ROLE OF HVDC IN FRQUENCY STABILZATION OF POWER SYSTEM WITH AGC CONTROL

4.1 Introduction

It is well known that when transferring large amount of power from one area to another area HVAC-lines or HVDC-links can be used. Using HVAC-lines, the transmitted active power is affected by phase angle difference between the line terminals and total reactance of the line. In order to increase the total transmitted power and at the same time make it possible to increase the line length, most of the long HVAC lines have the total series inductances usually decreased by installation of series capacitors. However, with HVDC-lines, the maximum power to be transferred is only limited to thermal characteristic of the line conductor. This gives a significant advantage of the HVDC transmission over the HVAC transmission, especially when a load center requires a large amount of power to be transferred from different remote ac networks. Response of power system will depend on its characteristic property of power system.

HVDC network is equipped with converter and inverter this is seen as another load in power system on which loading depends on voltage and angle. The controllability of the HVDC converters makes it possible to improve the performance of the converters and the performance of the power system as a whole.

This paper proposes how HVDC Link can be used to damp out Frequency oscillations of power system.

In case of power system having many areas disturbace in one area will also lead to disturbance in other that is change in frequency causing severe problem in the entire power system network. With the help of ALFC we can automatically matches our generation with load .So it's a very important to maintain a quality power in. now generally power systems are not designed with intention of power trading to mach load variation so if any load change in area it will disrupt our initial planning of our network. Most of the grids are already close to their limits. If the transmission of large power blocks through the interconnected system is needed, the problem can be solved by the interconnection of HVDC transmission system with an AC system and it can additionally enhance the system stability. For the system study, we have considered example of two control area having both AC and DC link.

In this system the power demand is rapidly increased due to sudden change of load such as arc furnace, steel mills, etc., in one area.These large load changes may lead to situation of frequency oscillation in that area. Generally the capacity of frequency control of that area governor is not sufficient. The power exchange in the neighboring areas can be achieved by the interconnection. Connecting long HVDC transmission line in parallel with AC line between Area1 and Area 2 having enough capacity to make up the demand in area-1. The interconnections of AC and DC line, the DC tie line power modulation is capable to stabilize the frequency oscillation of associated AC networks and it can additionally enhance the system stability, especially when the connected AC line is weak. The scheme discussed is capable to offer the service for stabilizing frequency oscillations in the power system network ,under the different load disturbance in any area.

4.2 Design of Power Modulation Controller by HVDC Link

Simultaneous control of HVDC Link and Governors

To make frequency deviation zero and to damp out frequency variation this concept of simultaneous control HVDC link and Governor is used. The HVDC link has far more superior performance compared to governor which is traditionally used to control frequency of system as HVDC link because being thyristor based has very fast response and quick to react and response if any type of change is detected in system. So simultaneous control of HVDC link and governors is used which is explained as below .

When there is sudden load change in any area HVDC link whose firing angle control is modulated with frequency deviation senses that and hence vary its inverter and converter firing angle accordingly to compensate that load increase or decrease and hence able to decrease peak value transient frequency and thus damps out frequency oscillation. Later governor adjust steam input to match entire demand as per schedule and thus in steady state it redces frequency deviation to zero.

Control Design

The linearized model of HVDC link can be precisely represented as below. Here governor dynamics of all are is neglected as time constant for governor control is quite high compared to HVDC power modulation controller tome constant. Here power modulation controller is modeled as a proportional controller of active power. In this type of power modulation controller ΔP_{DC} effect will be polarity wise opposite on two areas between which these are operating on one area it will produce positive effect on another it will produce negative. The time constant T_{DC} is set equal to 0.05 seconds in the transfer function model which is based on as per actual conditions.

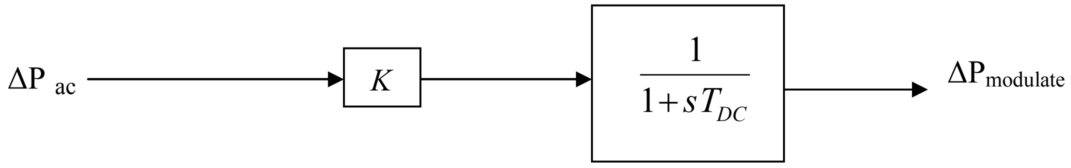

Figure 10: Transfer Function model of HVDC Link

CHAPTER 5

RESULTS AND DISCUSSIONS

5.1 System Data

Description	Area 1	Area2
Capacity[MW]	2000	400
Inertia Constant ,[p.u.MW.s/Hz]	0.2	0.167
Damping Coefficient ,D[p.u.MWlHz]	0.00833	0.00833
Turbine Time Constant [sec]	0.30	0.30
Governor Time Constant [sec]	0.20	0.20
Bias Coefficient ,B [p.u.MW/Hz]	0.2	0.2
Area Capacity Ratio ,a12	0.2	0.2
Synchronizing Power Coefficient (parallel AC-AC lines) T12 [MW/rad]	0.02	
Synchronizing Power Coefficient (parallel AC-DC lines) T12 [MW/rad]	0.01	
Load change in both unit (pu)	0.01	

5.2 Generator Load Model (Without Governor)

Addition of sudden load increase in any area which is operating at nominal power frequency will lead to power mismatch between generation and demand. As governor cannot operate immediately so extra power required is met by decrease in kinetic energy and this frequency of system will reduce. As the frequency goes on decreasing, the power taken by old load also goes on decreasing. Thus the equilibrium may be obtained by the reduction in power taken by old load plus the power corresponding to kinetic energy extracted from the system. Obviously this equilibrium is obtained at the cost of a reduction in frequency. This equilibrium is self managed by the system and it does not require any governor action. The frequency decline under such a condition is quite large.

Generator load can be modeled as in Fig.11 with increase in step load of 0.01pu at t=1sec .Frequency change here will be quite large as per response characteristic in Fig.12

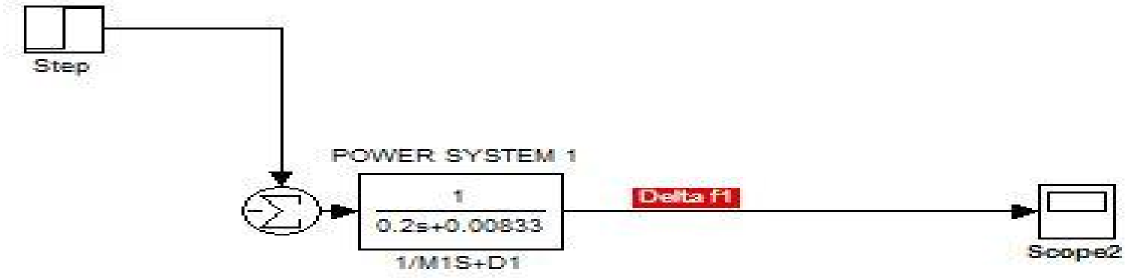

Figure 11: Generator-Load Model

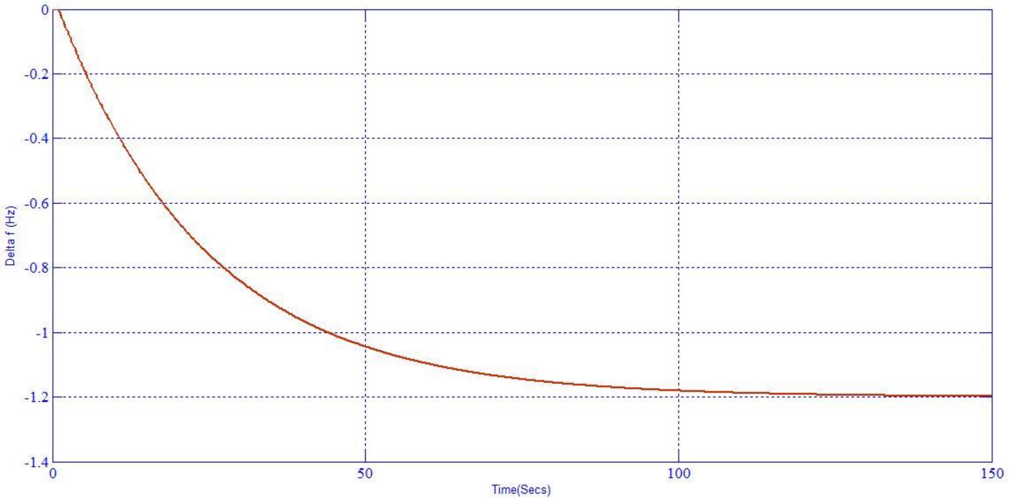

Figure 12: Frequency change in case of no Governor

5.3 Generator Load Governor Model

Figure 13 represent system with governor which will reduce frequency deviation to very small value but it still has steady state error because of damping and regulation constant of system. Its frequency deviation response will be as per Figure 14

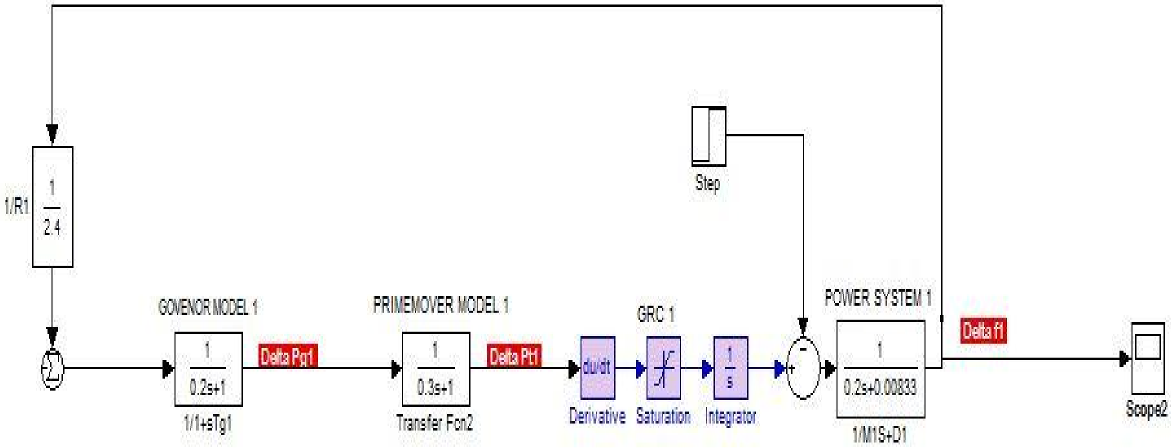

Figure 13: Generator Load Governor Model

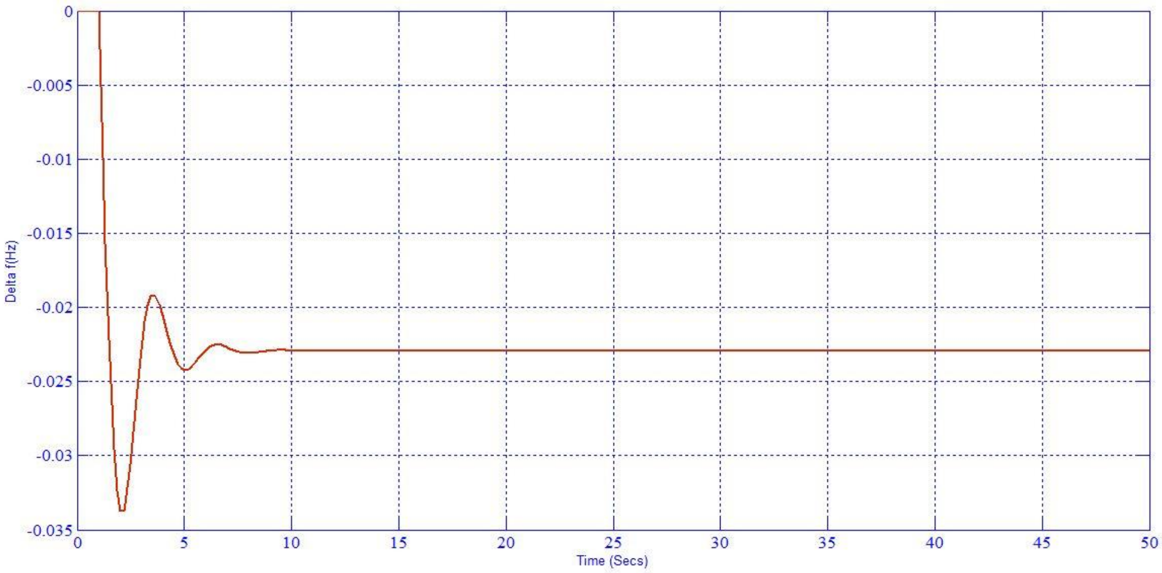

Figure 14: Frequency change in case of Governor

5.4 Modelling of Single Area with integral controller

Since governor cannot bring frequency to nominal value another precise control integral controller is used. This reduces steady state error to zero. Modeling of single area with integral controller is shown in Figure 15 and its frequency deviation response shown in Figure 16

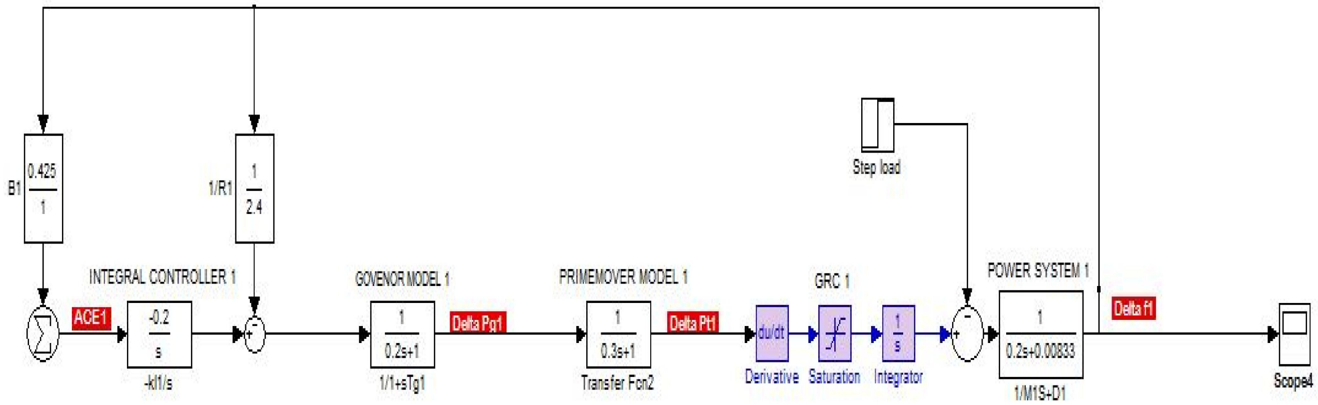

Figure 15: Single Area Model with Integral Controller

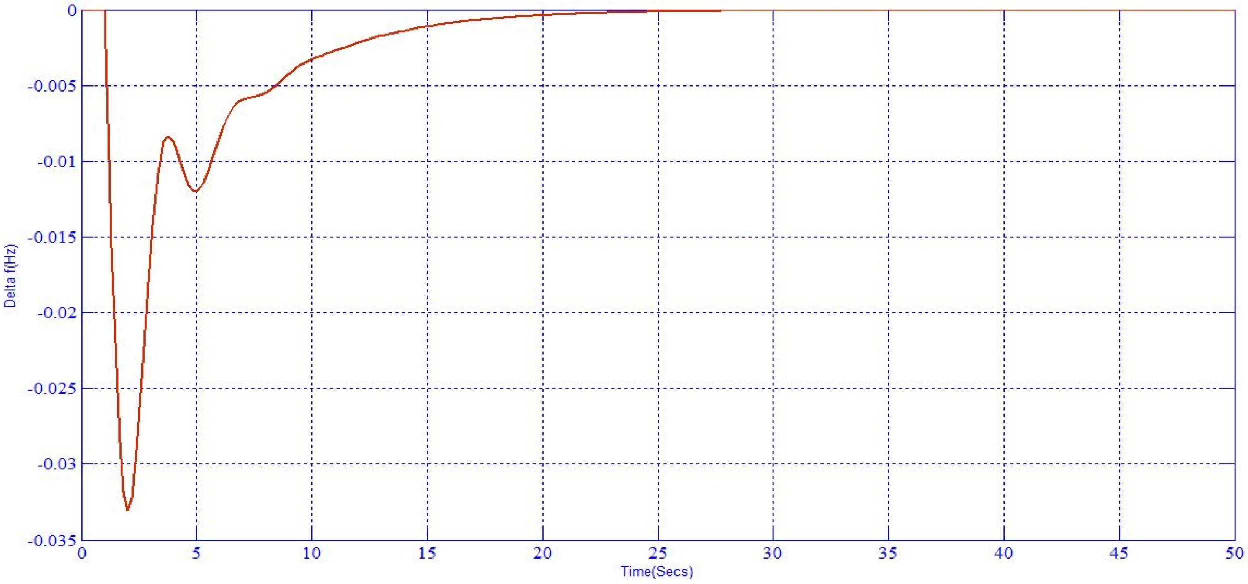

Figure 16: Frequency change in Area 1 (Integral control ,Gain = -0.2**)**

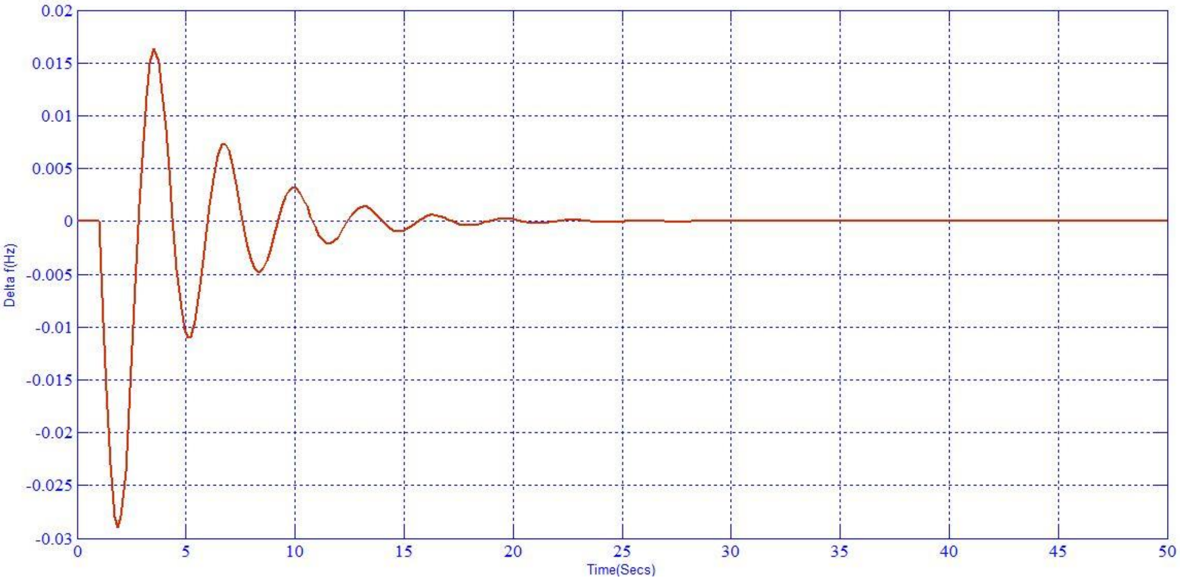

Figure 17: Frequency change in Area 1 (Integral control ,Gain = -1)

5.5 Two Area control of Frequency Deviation

Advantages of interconnection:

Effect of size: As a block of load is added, initially the required energy is extracted from the kinetic energy of the system. Obviously, the larger the system is, the more is the energy available. Hence the static frequency drop is comparatively less.

Reduced need of reserve capacity: Since the peak demands can occur at various hours of the day in various areas, the ratio between peak and average load for a large system is smaller than that of smaller systems

In case of power system having two or more areas connected to each other through AC tie lines, each area will meet its own load except for the portion of load which are already scheduled to met by other area as per mutual contract. But if any sudden load change occurs in any area will affect frequency of all area as well as power flow between them.

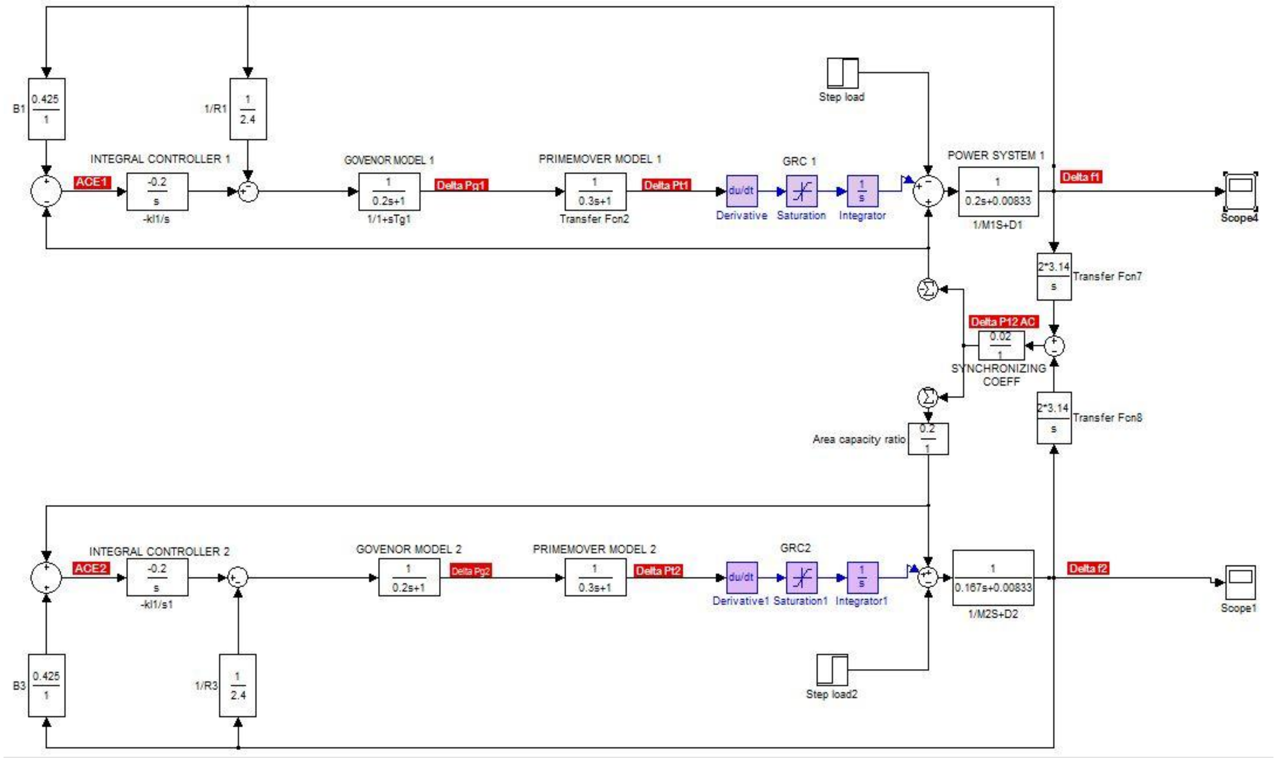

Figure 18: Two area frequency control model

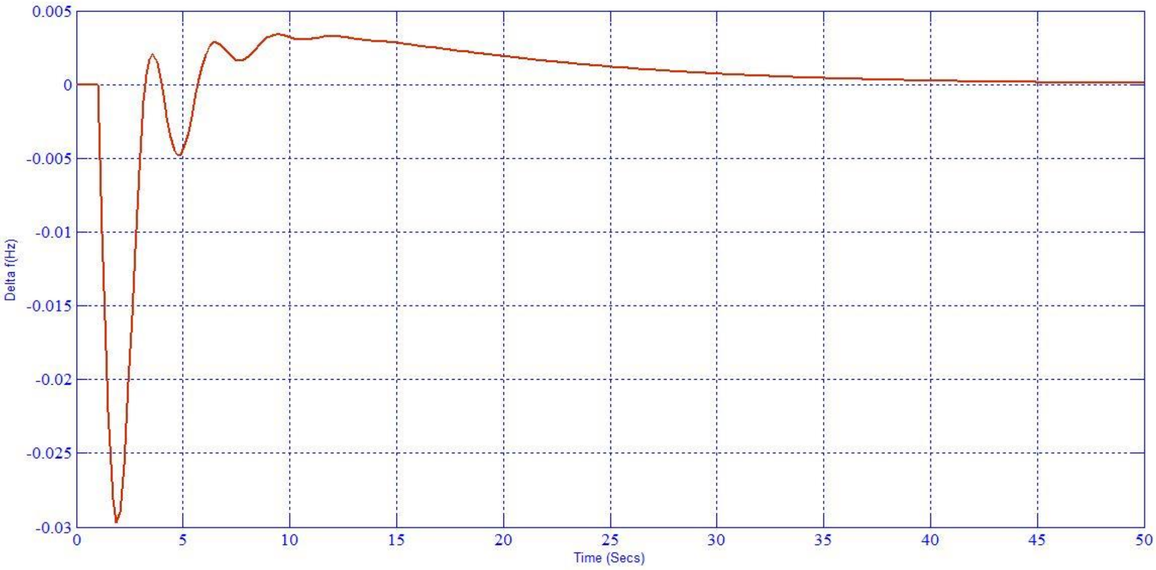

Figure 19: Frequency change in Area 1 (Two Area Model)

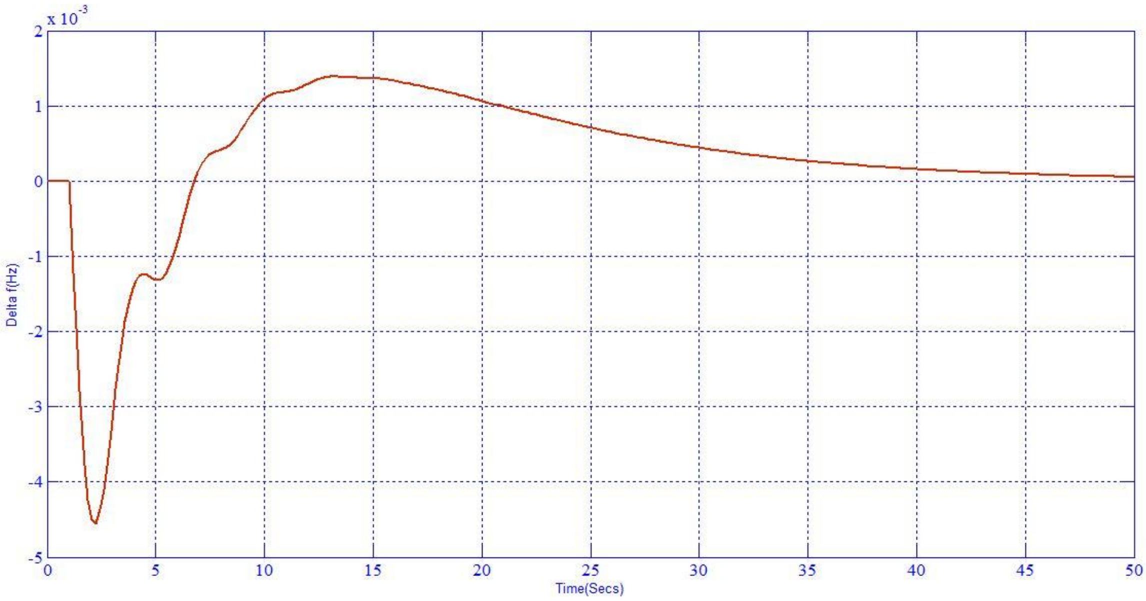

Figure 20: Frequency change in Area 2 (Two Area Model)

5.6 Power Modulation Controller of HVDC Link in Two Area system with Governor ACE signal

Here HVDC link is used in parallel with AC system to damp frequency oscillation after sudden load disturbance.

Power modulation controller of HVDC link is shown by First order transfer function having Time constant which represent delay in establishing DC current after step change.

Figure 21 represent model of Power Modulation Controller of HVDC Link in Two Area system. Figure 22-35 represent frequency deviation characteristic with varying K(Delta f) gain.

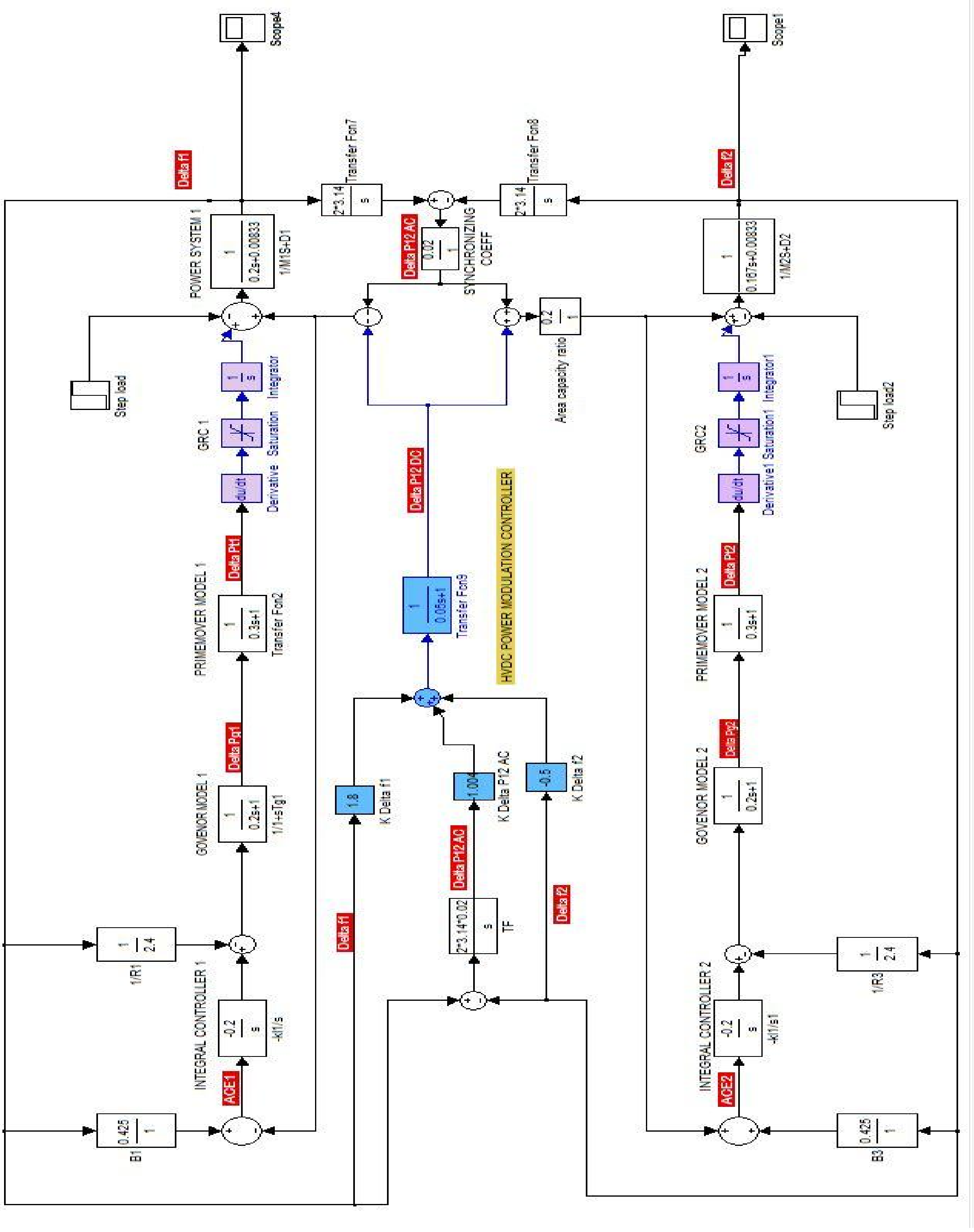

Figure 21: Two area AC system with HVDC link

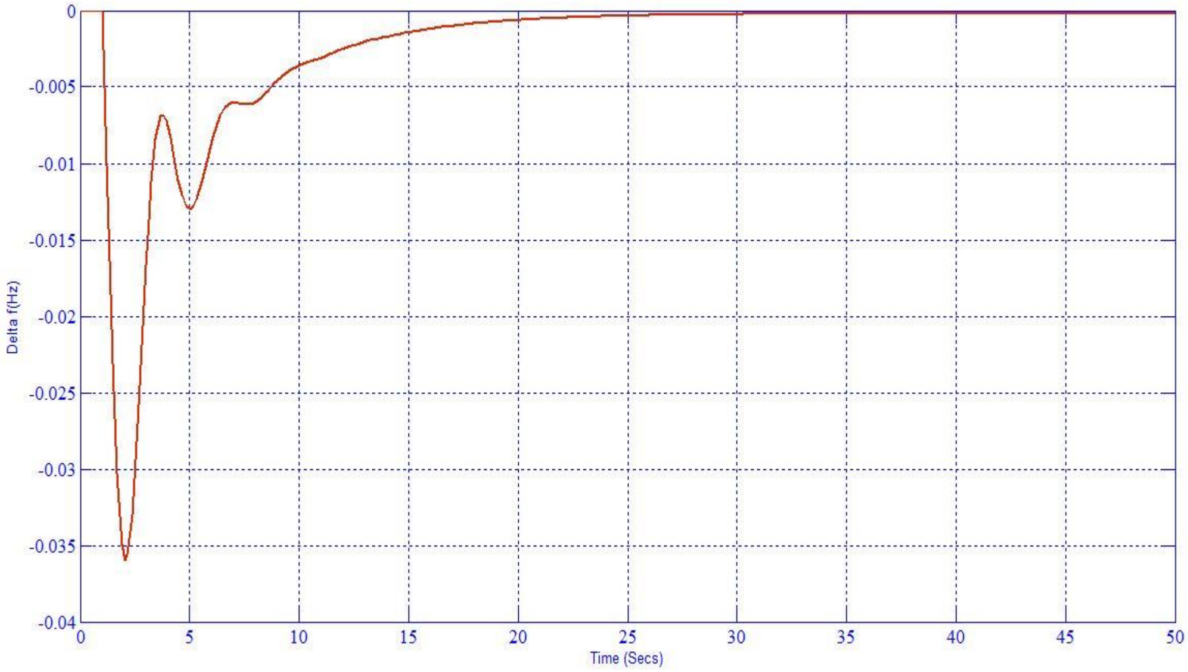

Figure 22: Frequency change in Area 1 with HVDC link

K(Delta f1)= 0.01

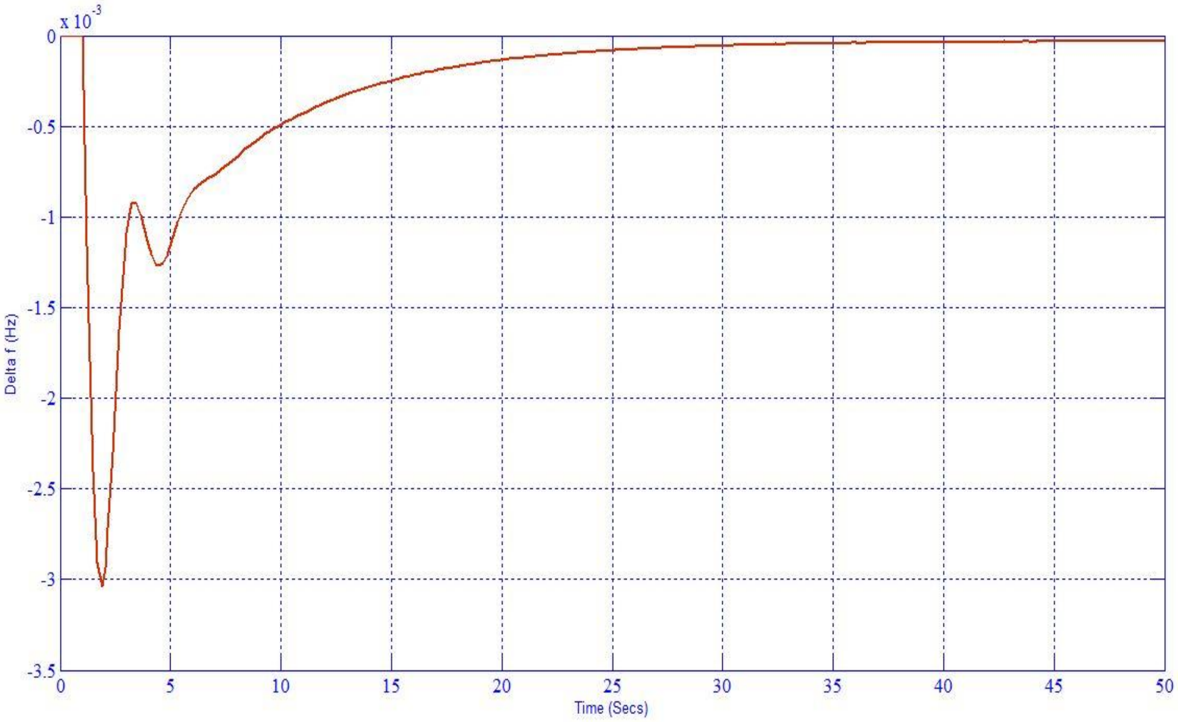

Figure 23: Frequency change in Area 2 with HVDC link

K(Delta f1)= 0.01

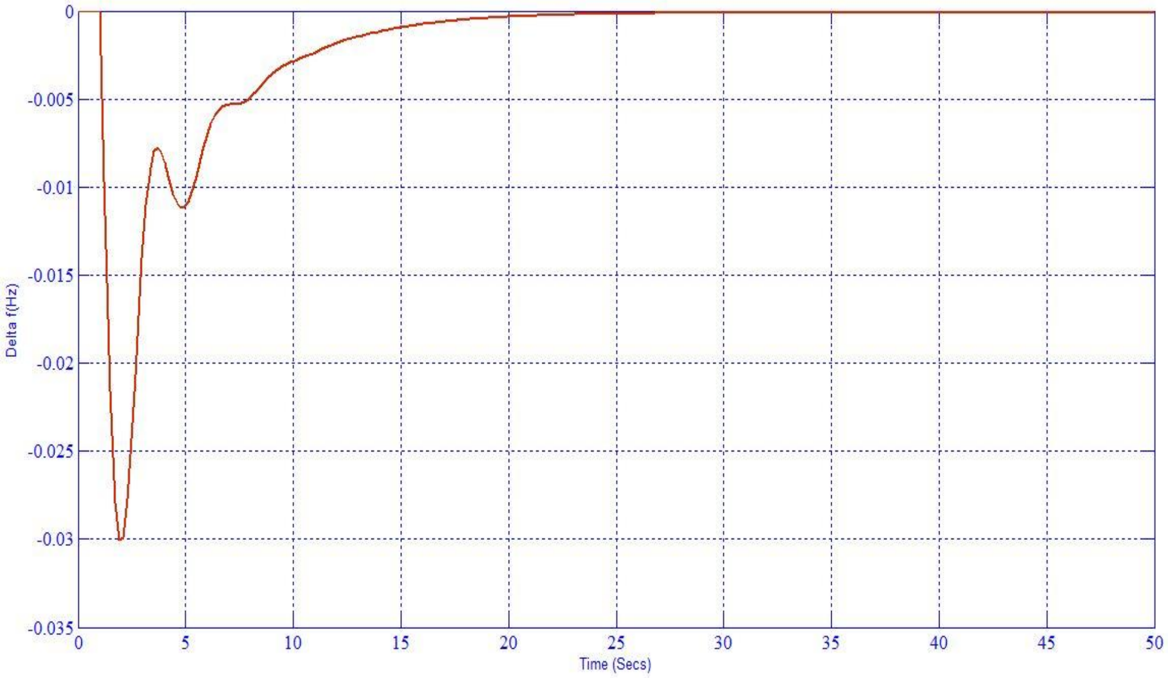

Figure.24: Frequency change in Area 1 with HVDC link

K(Delta f1)= 0.1

-

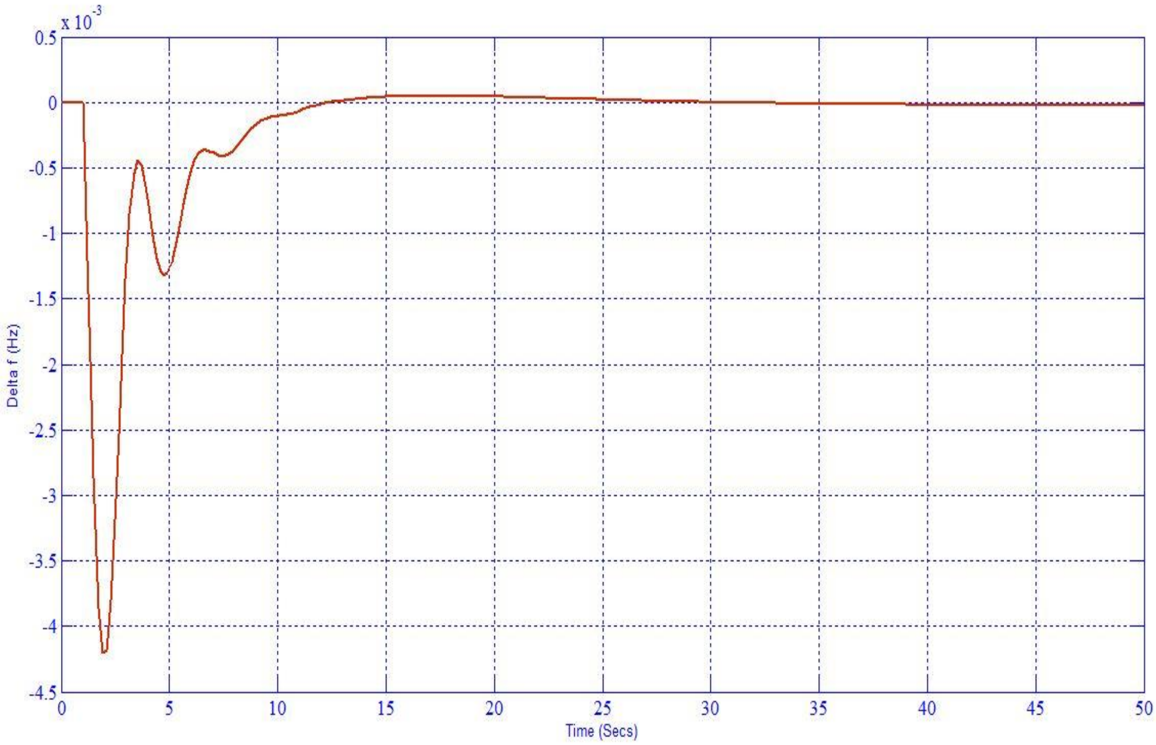

Figure.25: Frequency change in Area 2 with HVDC link

K(Delta f1)= 0.1

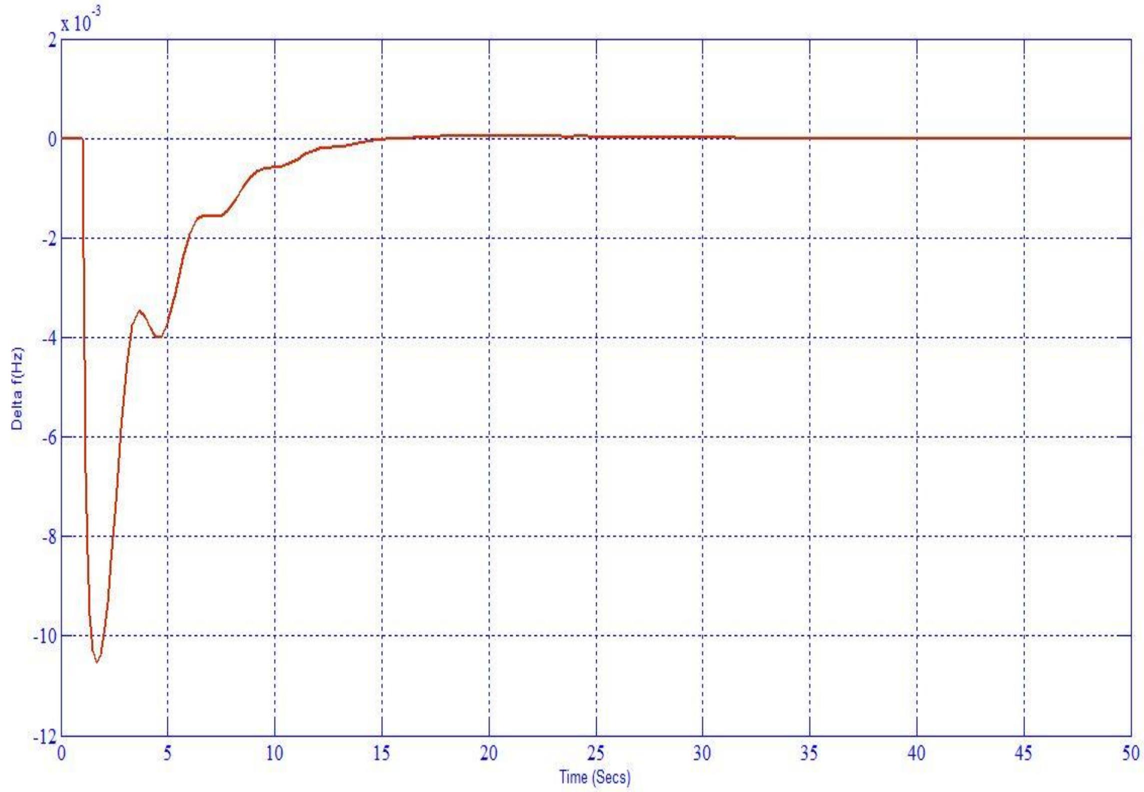

Figure 26: Frequency change in Area 1 with HVDC link

K(Delta f1)= 1

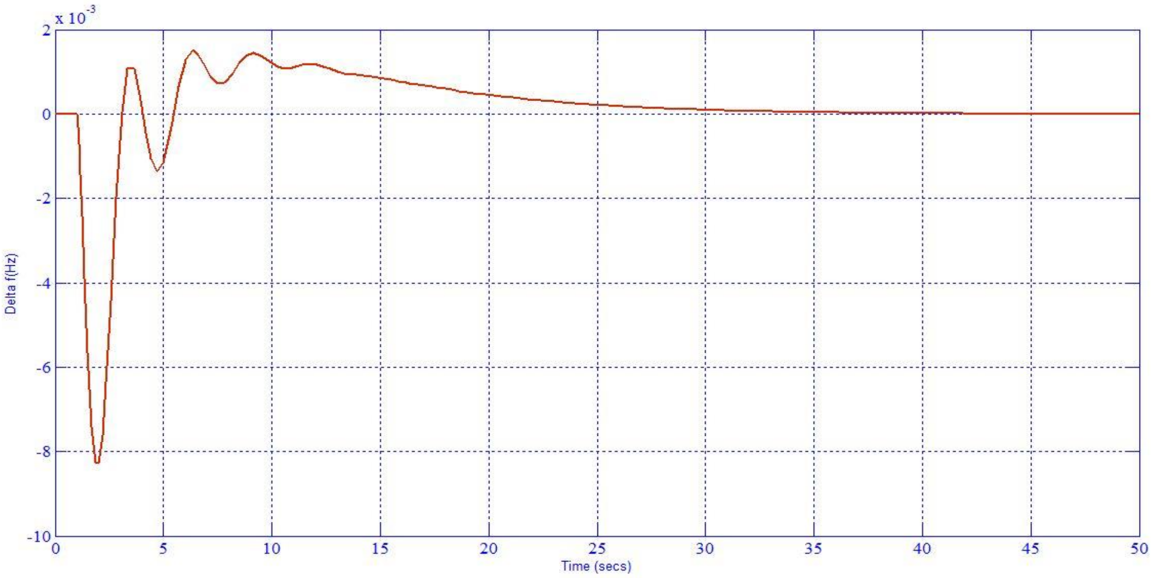

Figure 27: Frequency change in Area 2 with HVDC link

K(Delta f1)= 1

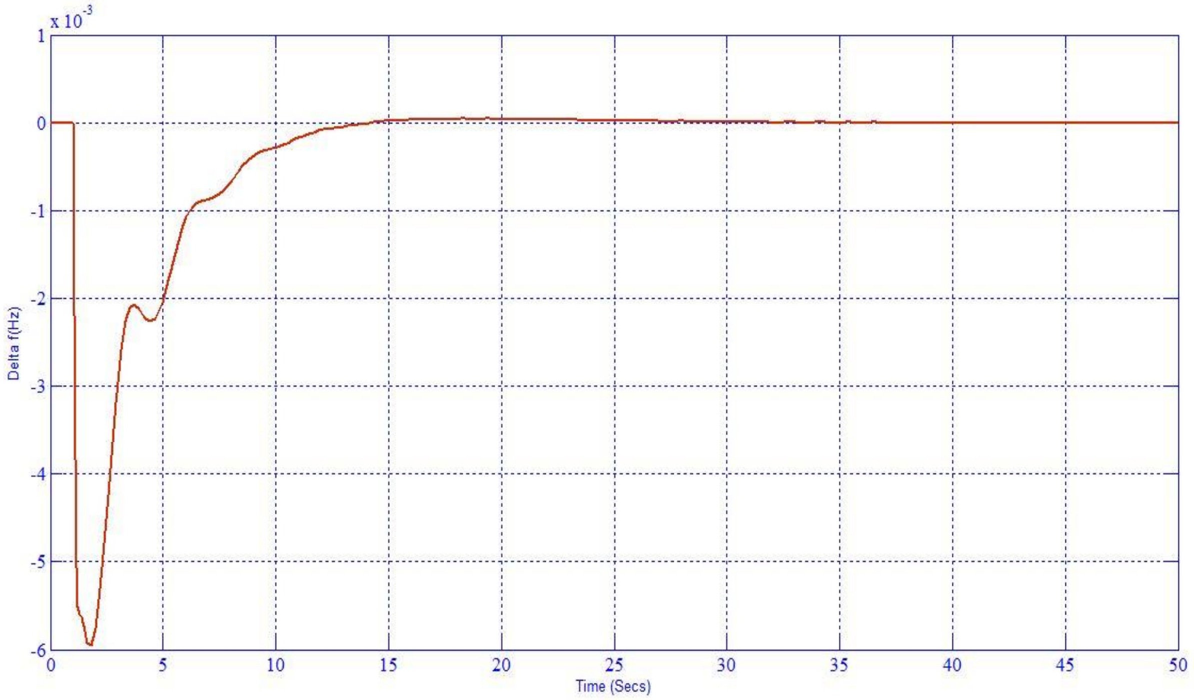

Figure 28: Frequency change in Area 1 with HVDC link

K(Delta f1)= 2

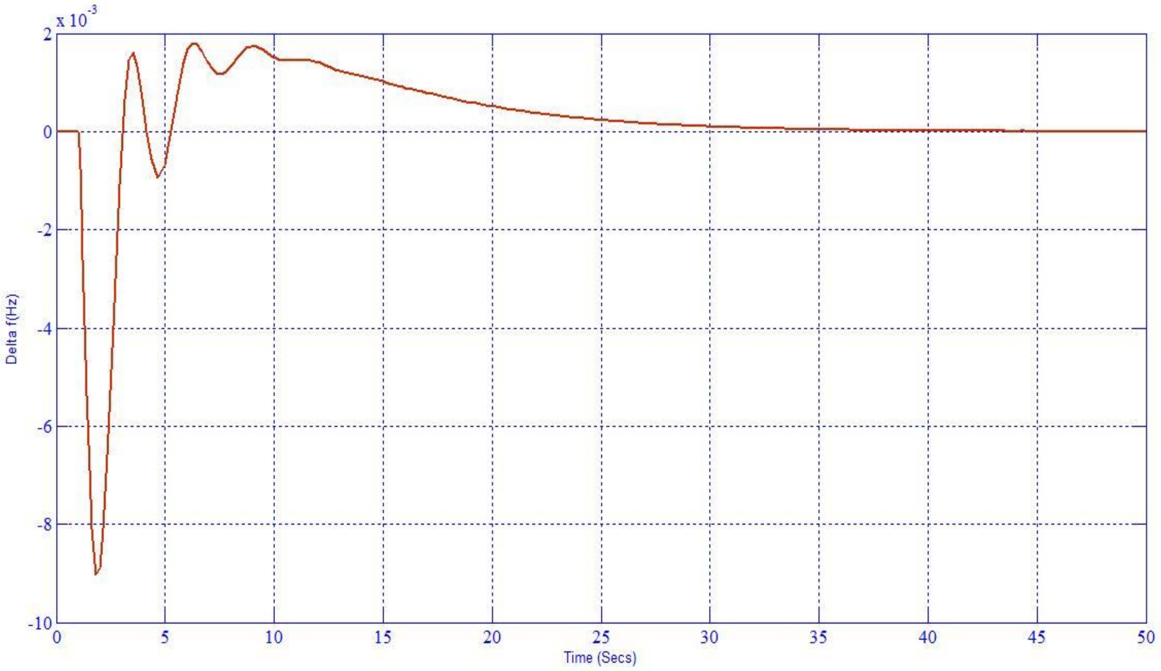

Figure 29: Frequency change in Area 2 with HVDC link

K(Delta f1)= 2

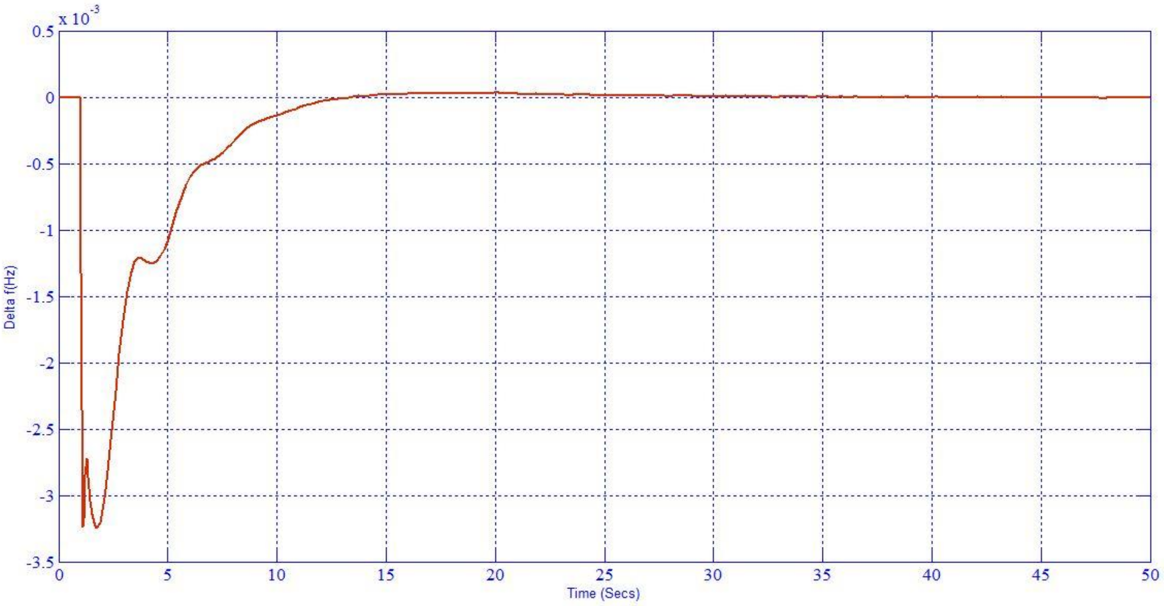

Figure 30: Frequency change in Area 1 with HVDC link

K(Delta f1)= 4

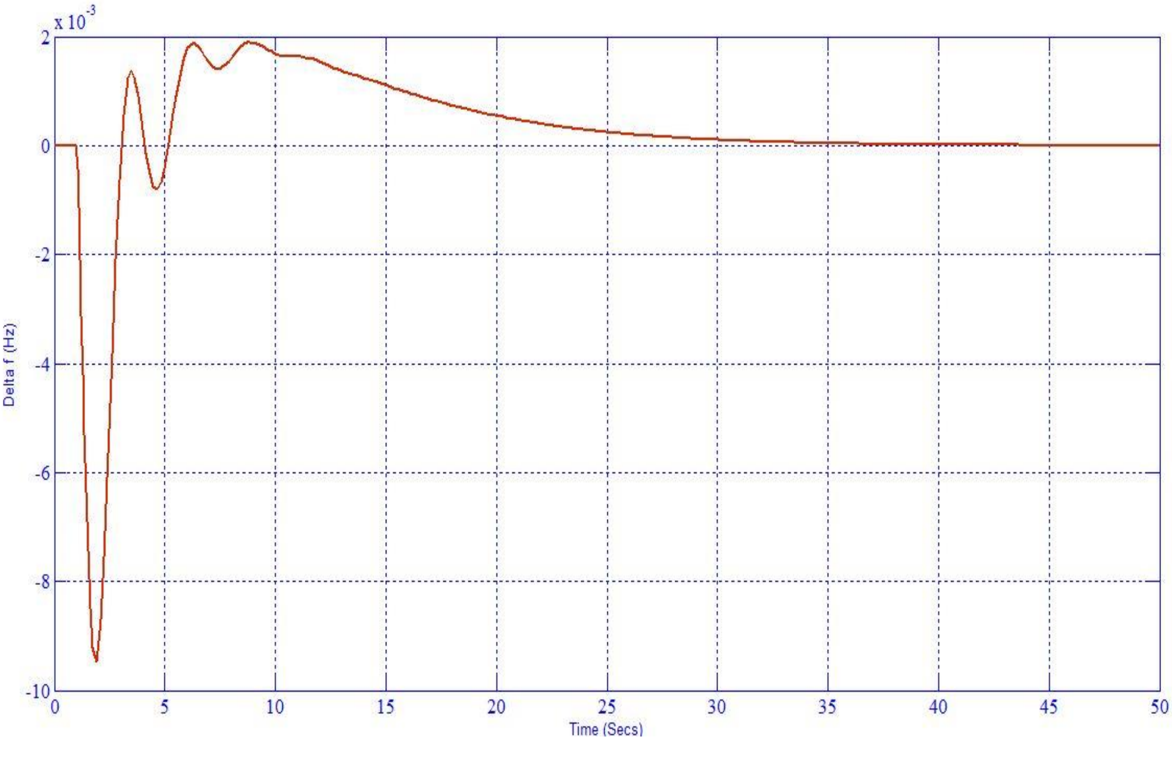

Figure 31: Frequency change in Area 2 with HVDC link

K(Delta f1)= 4

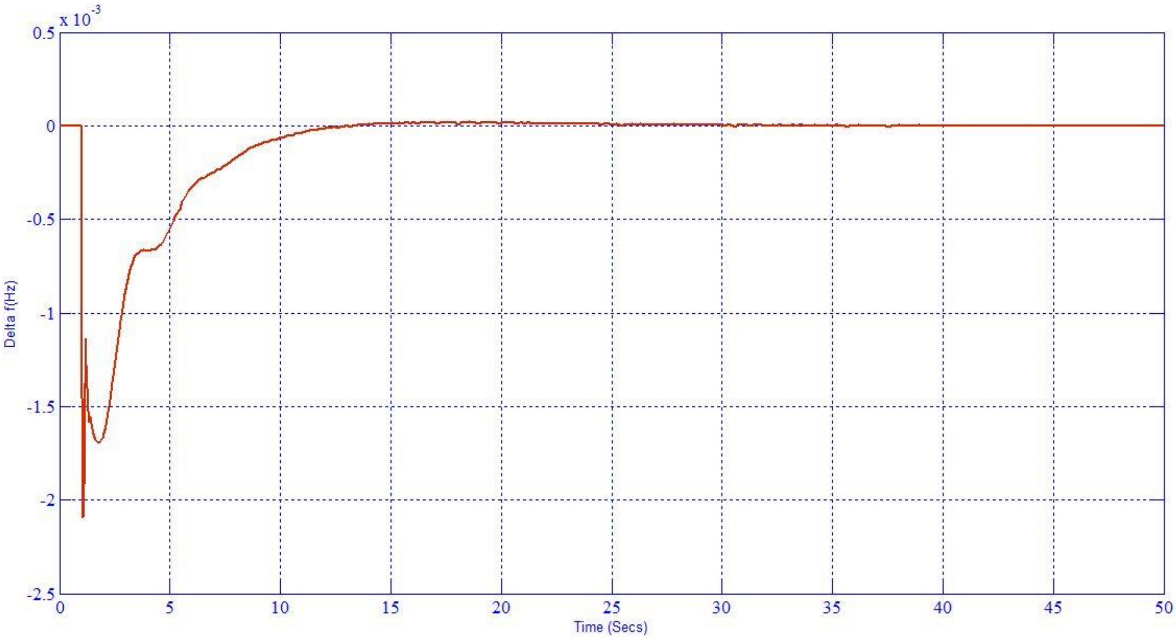

Figure 32: Frequency change in Area 1 with HVDC link

K(Delta f1)= 8

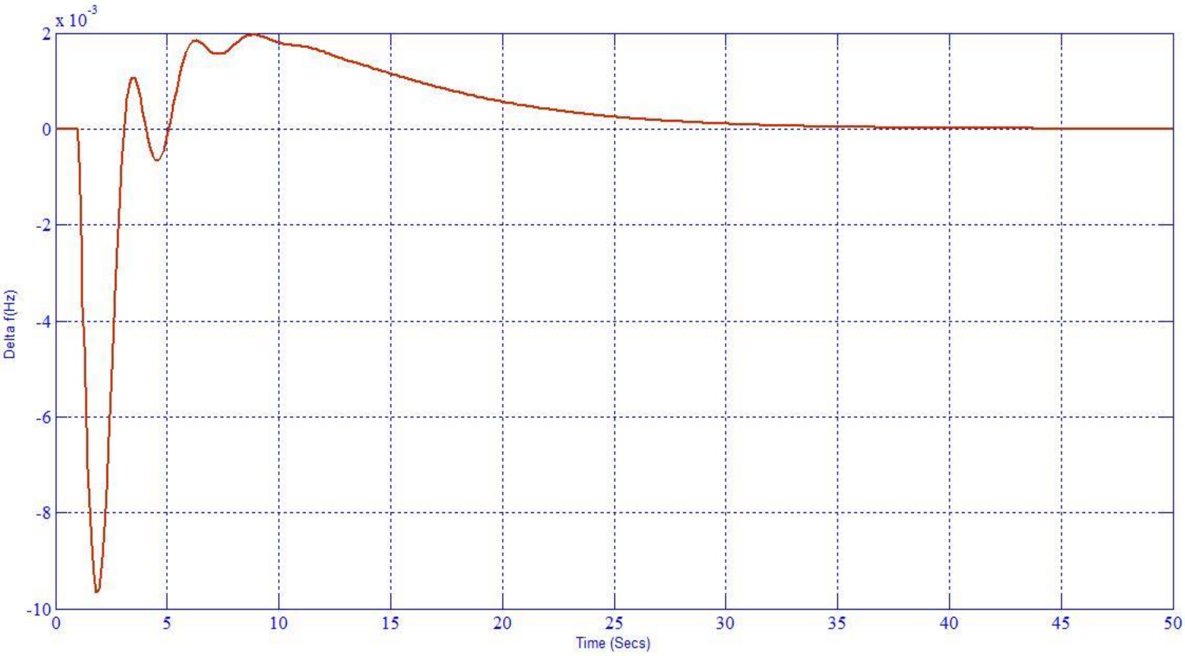

Figure 33: Frequency change in Area 2 with HVDC link

K(Delta f1)= 8

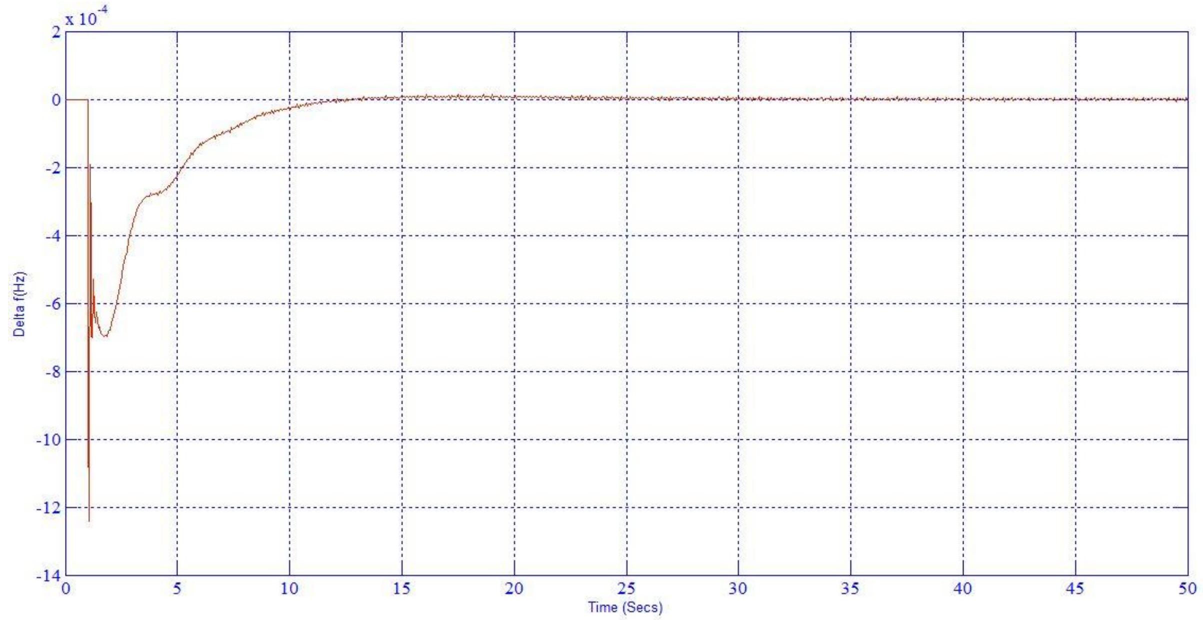

Figure 34: Frequency change in Area 1 with HVDC link K(Delta f1)= 20

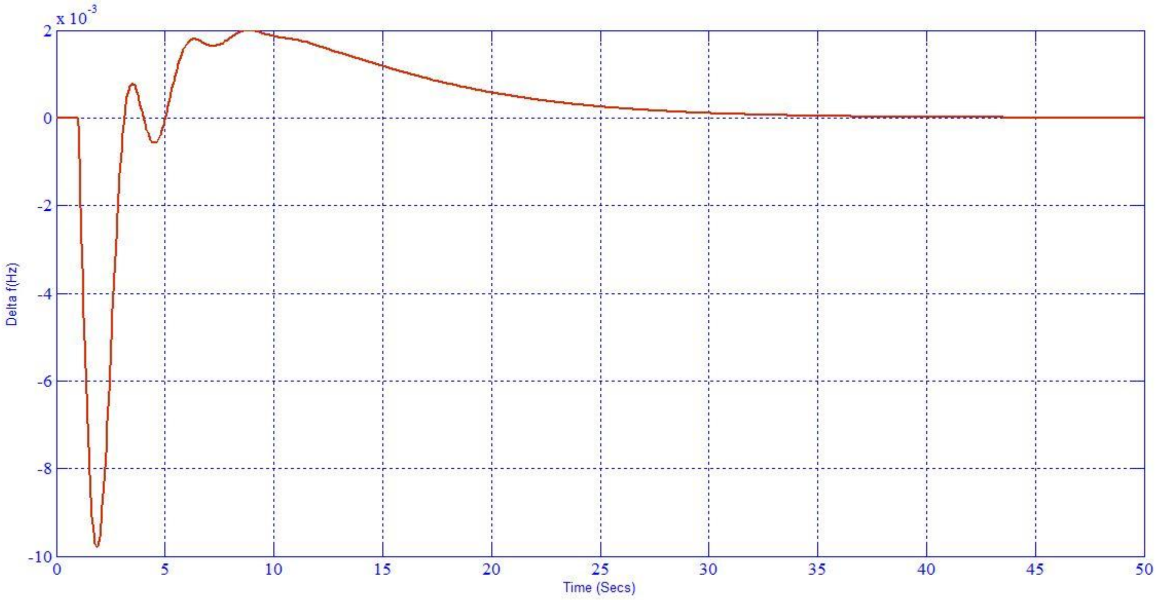

Figure 35: Frequency change in Area 2 with HVDC link K(Delta f1)= 20

From various response it can be concluded that best response is for K(Delta f1)= 0.1

CONCLUSIONS

I. Governor control reduces frequency deviation, when sudden load change occurs in system.

II. Supplementary control reduces steady state frequency deviation to zero, when sudden load change occurs in system.

III. Models of interconnected power systems having different area characteristics have been developed for integral control strategies. The models have also been tested for system stability. It has been also shown that how load is shared between two areas on sudden load change and thus reduces net frequency deviation. And finally all load change is taken by same area in which load change occurred.

IV. HVDC link is used in parallel with AC system to stabilize frequency oscillation and reduce dynamic frequency deviation after sudden load disturbance.

V. Gain of HVDC controller was varied to attain optimal response.

VI. Overshoot and settling time reduce satisfactorily.

VII. System with HVDC controller gave satisfactory performance under simultaneous load perturbations in both the interconnected areas .

VIII. Nonlinearities like Generation Rate Constraint (GRC) have been considered.

SCOPE FOR FURTHER WORK

i. This work considers load disturbances are of deterministic nature. The work can be extended to dynamic (time varying) load disturbances.

ii. This work considers the system parameter values are constant throughout the period of control action. However they may change due to aging effect, imperfection of components, wear & tear, temperature variations, environmental changes etc. The variations in parameters from their nominal values during control action may be taken into consideration while designing the controllers. The controllers so designed will be robust and insensitive to parameter variations.

iii. This work considers only one generating unit is considered in one area but in actual there are many generating unit and any load change in that area is distributed as per economic load dispatch. This can be further be analyzed.

iv. In multiarea system it can shown that frequency deviation in any area can be damped using single HVDC link. This can be further be analyzed.

REFERENCES

[1] IEEE Committee Report, IEEE Trans. Power App. Syst., vol. PAS-89, Jul./Aug. 1970. 'Standard definitions of terms for automatic generation control on electric power systems.'

[2] IEEE PES Committee Report, IEEE Trans. Power App. Syst., vol. PAS-92, Nov. 1973. 'Dynamic models for steam and hydro-turbines in power system studies.'

[3] IEEE PES Working Group, 'Hydraulic turbine and turbine control models for system dynamic Studies,' IEEE Trans. Power Syst., vol. PWRS-7, no. 1, pp. 167–174, Feb. 1992.

[4] IEEE PES Committee Report, IEEE Trans. Power App. Syst., vol. PAS-98, Jan./Feb. 1979. 'Current operating problems associated with automatic generation control.'

[5] N. Jaleeli, L. S. Vanslyck, D. N. Ewart, L. H. Fink, and A. G. Hoffmann, 'Understanding automatic generation control,' IEEE Trans. Power App.Syst., vol. PAS-7, no. 3, pp. 1106–1122, Aug. 1992.

[6] R. K. Green, 'Transformed automatic generation control,' IEEE Trans.Power Syst., vol. 11, no. 4, pp. 1799–1804, Nov. 1996.

[7] A. M. Stankovic, G. Tadmor, and T. A. Sakharuk, 'On robust control analysis and design for load frequency regulation,' IEEE Trans. Power Syst., vol. 13, no. 2, pp. 449–455, May 1998

[8] S. C. Tripathy, T. S. Bhatti, C. S. Jha, O. P. Malik, and G. S. Hope, 'Sampled data automatic generation control analysis with reheat steam

turbines and governor dead band effects,' IEEE Trans. Power App. Syst., vol. PAS-103, no. 5, pp. 1045–1051, May 1984.

[9] P. Kumar and Ibraheem, 'Dynamic performance evaluation of 2-area interconnected power systems: A comparative study', J. Inst. Eng., vol. 78, pp. 199–208, 1998

[10]Fosha C.E., and Elgerd O.L.(1970) The megawatt- frequency control problem: a new approach via optimal control theory. IEEE Transactions on PAS