On Load Frequency Control for Two-area Power System

Project Report

Submitted by

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in partial fulfilment of the requirements for the award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRICAL AND ELECTRONICS ENGINEERING

DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

MANIPAL INSTUTUTE OF TECHNOLOGY

(A Constituent Unit of Manipal Academy of Higher Education)

MANIPAL-576104, KARNATAKA, INDIA

May 2020

MANIPAL INSTITUTE OF TECHNOLOGY
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DEPARTMENT OF ELECTRICAL AND ELECTRONICS ENGINEERING

Manipal
22 May 2020

CERTIFICATE

This is to certify that the project titled **On Load Frequency Control fro Two-area Power System** is a record of the bonafide work done by **Sheikh Zeeshan Basar** (*Reg. No. 160906432*) submitted in partial fulfilment of the requirements for the award of the Degree of Bachelor of Technology (B.Tech.) in **ELCTRICAL AND ELECTRONICS ENGINEERING** of Manipal Institute of Technology, Manipal, Karnataka, (A Constituent Institute of Manipal Academy of Higher Education), during the academic year 2019-2020.

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ACKNOWLEDGMENTS

I would like to take this oppurtunity to express my gratitude to Dr Srikanth Rao D, Director, MIT Manipal. I would also like to thank the HOD of Dept. of Eletrical and Electronics Engineering, Dr Chandrashekara S Adiga. Next I would like to thank the entire Dept. of Electrical and Electronics Engineering, MIT Manipal and more specifically to Mr Ganesh Kudva for taking me under his wing for my final project work. I thank him for mentoring me and guiding me in all aspects and not only during the project, and perhaps most importantly, thank you for believing in me even when I did not.

ABSTRACT

In a power system, when a load change occurs, the system frequency changes due to (de)acceleration of the generator. Without any corrective control, a significant load change may cause the frequency to rise or fall well beyond nominal limits. Load-frequency control is an integral type of control that is used to restore the system frequency to the nominal values that existed before a change in load. Load frequency control is widely used power systems to ensure the stability of the system.

The project aims to develop a controller to reduce the steady-state frequency deviation for a two-area power system. In the project, the author has developed the mathematical model and using that the frequency deviation is determined for uncompensated system. The results are compared with simulations. Further, the compensated system is develop and using the state-space matrices, the values of controller gains are determined that give the best performance. Finally, the response is determined for the compensated system, to a step change in load in one area, mathematically. The results are compared with the simulations.

By minimising the eigenvalues of the system matrix, the best performance in terms of settling time is achieved. The controller gains thus found are then plugged into the simulations and the results of the simulations and mathematical analysis match closely. The controller is successful in reducing the steady-state deviation to the zero.

The selected controller gains increse the settling time, due to introduction of new poles in the system, but provide an overall imporvement in the response. The presented mathematical model is a solid and robust base on which futher research can be conducted, such as using better and advanced optimisation algorithms and inclusion of power electronics based generating sources.

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1. INTRODUCTION

A tremendous amount of power is required to cater to the growing demands of a population of 7.58 billion people. Just in India with a population of more than 1.37 billion, an upwards of 370 thousand MW of power is generated. [1] The entire 370 thousand MW of power cannot be generated in one place, and hence are generated across the country by thermal and renewable sources. All the generating stations across the country are necessarily interconnected to improve the stability of the country's power system. Growing power demands and increased variability in the loads require a system to be in place to allow the transfer of power from one generating area to another. The transfer of power allows an underloaded area to share some of the loads from a neighbouring overloaded area. If an area is overloaded, its local grid frequency begins to fall. If the grid frequency falls below a threshold, the under-frequency relays trip the generators to protect them from any damage. A trip at the generating station could mean, in a best-case scenario, a power cut for a few hours if the generators are in a safe condition and power can be routed from other areas. In a worst-case situation, a trip in one area can cause a domino effect leading to a nation-wide blackout.

With generator speed control in action, a change in loads causes a deviation in the steady-state frequency of the system. The deviation depends on the droop characteristics of the governor. The steady-state value must be brought back to the nominal levels using some restorative process that adjusts the load reference point through the speed changer. According to the definition given by D. Das in Electrical Power Systems "..Automatic Generation Control (AGC).. to regulate the frequency to the nominal value and to maintain the interchange of power between control areas.. by adjusting the output of selected generators."[2]. Load Frequency Control (LFC) takes care of the frequency deviation using the integral action of a controller. In this project, the author aims to study the LFC for a two-area power system using computer simulations and mathematical studies. The author aims to determine the coefficient of integration to determine the system that reduced the frequency shift the fastest.

LFC and optimisation of its various parameters is an area of active research. Today, in industries, PID controllers are used to obtaining desired settling time and maximum overshoot of Δf. In a paper by Sondhi et al. (2014), a fractional order PID controller is discussed for non-reheated,

reheated and hydro turbines. It was shown that this controller has better robustness and disturbance rejection capabilities than existing techniques. [3] Use of fuzzy logic to determine parameters for LFC is also one of the commonly used methods, with the earliest literature dating back to 1999 (Kocaarslan et al.). [4] In the project, the author aims to gain a solid understanding of the power system control and the intricacies around it. The results of the computer simulations confirm the mathematical studies, proving the correctness of the power system model developed.

2. LITERATURE REVIEW

LFCs have been used historically to control the frequency drift by increasing the generation. Modern LFCs use microcontroller and microprocessors to adjust the load-reference point to adjust the frequency deviation. In this project, the author makes use of a simple integral controller to develop the LFC. Still, practically a PID controller is often used, as it gives a control over not just the speed at which the system deviations reaches zero but also because it allows the control of critical parameters such as maximum overshoot.

In a thesis by Ekka (2014), the details and various parameters of the LFC have been laid out. [5] The thesis explains in great detail the necessity of developing a robust and secure LFC and presents an optimisation study of various critical parameters of LFC using Bacteria Foraging Optimisation Algorithm (BFOA) in a three-area power system. It has been shown that the BFOA has fast convergence characteristics and serves to be useful when compared with the trial and error method. In a paper by Sondhi et al. (2014), a fractional order PID controller is discussed for non-reheated, reheated and hydro turbines. It was shown that this controller has better robustness and disturbance rejection capabilities than existing techniques. [3] Increasing penetration of renewable sources into the makes it necessary to include them in the stability studies. A novel study by Sonkar et al. (2016) demonstrates LFC for multi-area interconnected system integrated with DFIG-based wind power plants. [6] Based on simulation results, the tie-line power and steady-state frequency deviations show significant improvements.

Optimisation of controller gains and other critical parameters are a field of extensive research. Use of fuzzy logic to determine parameters for LFC is also one of the commonly used methods, with the earliest literature dating back to 1999 (Kocaarslan et al.). [4] In a study by Lal et al. (2018) fuzzy PID has proposed a frequency controller and its gains are tuned using a bio-inspired grasshopper optimisation algorithm (GOA). [7] The presented algorithm has shown to be superior in terms of fast convergence when compared with particle swarm optimisation (PSO), differential evolution (DE) and others. It was also shown that a fuzzy PID performed better when compared to a PID controller.

3. METHODOLOGY

In this chapter, the author aims to present in detail the process of modelling a two-area power system, the method used to determine the controller gain, the mathematics around that and the simulation process. The power system is modelled using state-space techniques and is written in MATLAB for mathematical study. Both compensated and uncompensated systems are modelled. The controller gain is determined by minimising the eigenvalues of the system matrix. The gain corresponding to the smallest eigenvalue of the system matrix will give the fastest response, as we do not want the addition of the pole to increase the time system takes to settle. The controller gain is then plugged into the compensated model, and the state-space equations are solved to determine the variation of output (frequency) w.r.t time for a step-change in the input (load) to one of the generating areas.

3.1.System Modelling: Uncompensated

Uncompensated system model forms a base on which the compensator can be added, and it is used to get the baseline values against which future values can be compared. The figure here shows a two-area uncompensated power system. Here x1 and x2 are the change in output (frequency), x3 is the tie-line power deviation, x4 and x5 are changes in generator input, and x6 and x7 are the net change in governer due to change in load.

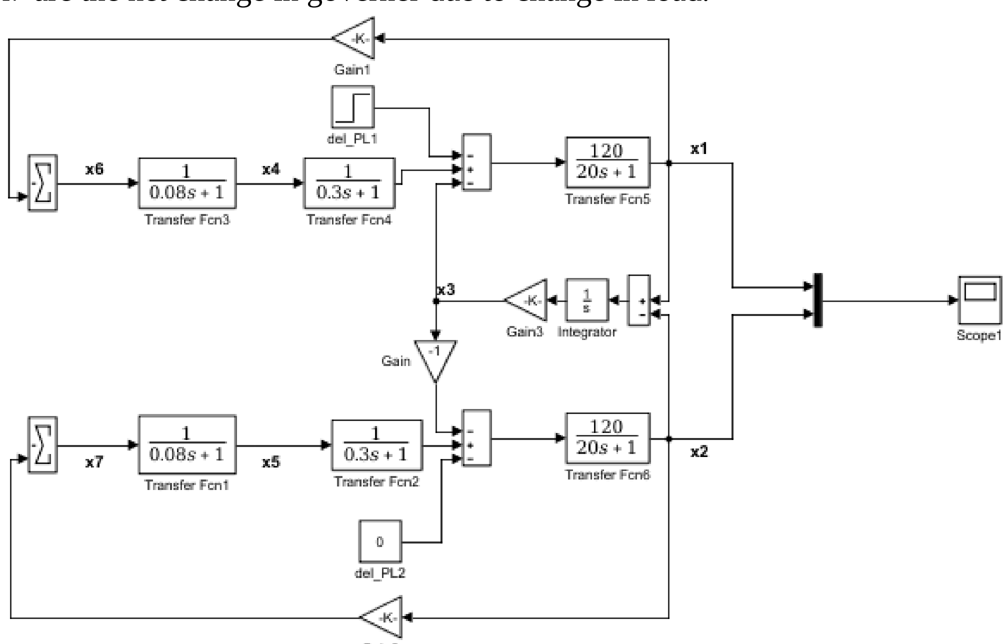

Fig. (1): Block diagram of two-area uncompensated system.

The system is then modelled using state-space techniques, and the state equations and output equations are as follows.

$$\begin{bmatrix}\dot{x1}\\ \dot{x2}\\ \dot{x3}\\ \dot{x4}\\ \dot{x5}\\ \dot{x6}\\ \dot{x7}\end{bmatrix}=\begin{bmatrix}\frac{-1}{Tp1} & 0 & \frac{-Kp1}{Tp1} & \frac{Kp1}{Tp1} & 0 & 0 & 0\\ 0 & \frac{-1}{Tp2} & \frac{-a12*Kp2}{Tp2} & 0 & \frac{-Kp2}{Tp2} & 0 & 0\\ 2\pi T12 & -2\pi T12 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & \frac{-1}{Tt1} & 0 & \frac{1}{Tt1} & 0\\ 0 & 0 & 0 & 0 & \frac{-1}{Tt2} & 0 & \frac{-1}{Tt2}\\ \frac{-1}{R1*Tg1} & 0 & 0 & 0 & 0 & \frac{-1}{Tg1} & 0\\ 0 & \frac{-1}{R2*Tg2} & 0 & 0 & 0 & 0 & \frac{-1}{Tg2}\end{bmatrix}\begin{bmatrix}x1\\ x2\\ x3\\ x4\\ x5\\ x6\\ x7\end{bmatrix}+\begin{bmatrix}\frac{-Kp1}{Tp1} & 0\\ 0 & \frac{-Kp2}{Tp2}\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\\ 0 & 0\end{bmatrix}\begin{bmatrix}\Delta P_{L1}\\ \Delta P_{L2}\end{bmatrix}$$

$$\begin{bmatrix}y1\\ y2\\ y3\\ y4\\ y5\\ y6\\ y7\end{bmatrix}=\begin{bmatrix}1 & 1 & 0 & 0 & 0 & 0 & 0\end{bmatrix}\begin{bmatrix}x1\\ x2\\ x3\\ x4\\ x5\\ x6\\ x7\end{bmatrix}$$

A mathematical analysis of the above equations gives the frequency deviation of both areas when a 10% load change occurs in area 1. The time-variation in the net frequency change is shown in the following figure.

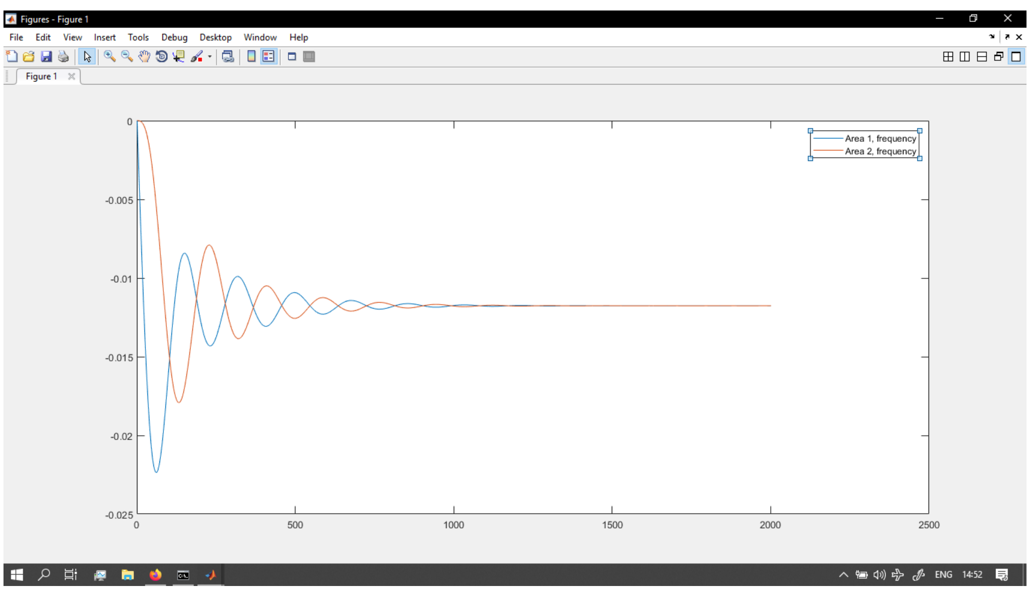

Fig. (2): Frequency deviation vs time plot for the uncompensated system.

It can be observed from the wavefrom that both area frequency deviations settle in about 9 seconds, area 1 has maximum overshoot of about 23%, area 2 has a maximum overshoot of about 18% and both area have a steady-state deviation of about 12%. The values are then confirmed using simulation in SIMULINK. The following figure shows the frequency deviation of both areas. From measurements, the change in frequency deviation is less than 0.01% w.r.t at approximately 9.055 seconds for both area, area 1 absolute maximum overshoot is 22.3%, area 2 absolute maximum overshoot is 17.9% and absolute steady-state deviation in both areas is 11.77%.

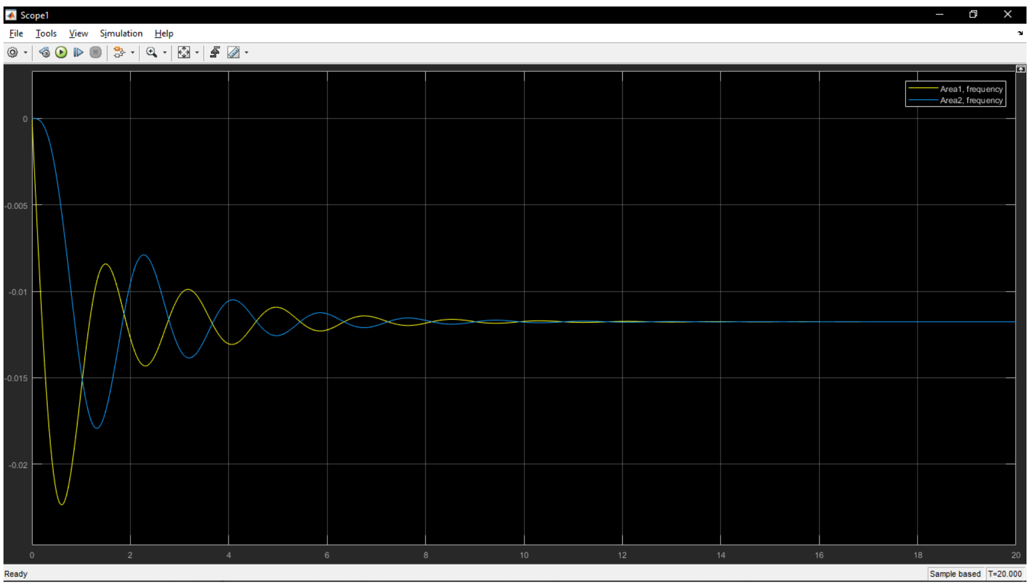

Fig. (3): Simulation result of uncompensated system.

3.2. System Modelling: Compensated

Presence of large deviation (about 12%) in steady-state frequency requires a controller action to correct the error. A compensated system is now developed. The controller presented here is of the integral-type. Integral controllers introduce a pole in the system which forces the steady-state deviation to zero. The following figure shows the block diagram of the compensated system.

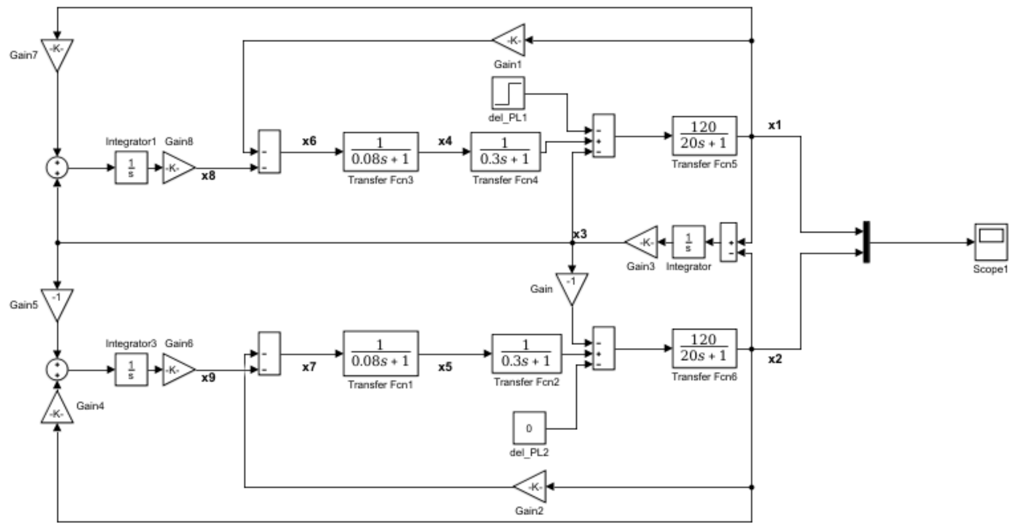

Fig. (4): Block diagram of two-area compensated system.

In the figure, state variables x1 through x7 remain the same as described in the above sections. The variables x8 and s9 are the regulator input to the governor. The following equations model the system mathematically.

$$\begin{bmatrix} \dot{x1} \\ \dot{x2} \\ \dot{x3} \\ \dot{x4} \\ \dot{x5} \\ \dot{x6} \\ \dot{x7} \\ \dot{x8} \\ \dot{x9} \end{bmatrix} = \begin{bmatrix} \frac{-1}{Tp1} & 0 & \frac{-Kp1}{Tp1} & \frac{Kp1}{Tp1} & 0 & 0 & 0 & 0 & 0 \\ 0 & \frac{-1}{Tp2} & \frac{-a12*Kp2}{Tp2} & 0 & \frac{-Kp2}{Tp2} & 0 & 0 & 0 & 0 \\ 2\pi T12 & -2\pi T12 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{-1}{Tt1} & 0 & \frac{1}{Tt1} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{-1}{Tt2} & 0 & \frac{-1}{Tt2} & 0 & 0 \\ \frac{-1}{R1*Tg1} & 0 & 0 & 0 & 0 & \frac{-1}{Tg1} & 0 & \frac{1}{Tg1} & 0 \\ 0 & \frac{-1}{R2*Tg2} & 0 & 0 & 0 & 0 & \frac{-1}{Tg2} & 0 & \frac{1}{Tg2} \\ -Ki1*B1 & 0 & -Ki1 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & -B2*Ki2 & -Ki2*a12 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \\ x6 \\ x7 \\ x8 \\ x9 \end{bmatrix}$$

$$+ \begin{bmatrix} \frac{-Kp1}{Tp1} & 0 \\ 0 & \frac{-Kp2}{Tp2} \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta P_{L1} \\ \Delta P_{L2} \end{bmatrix}$$

$$\begin{bmatrix} y1 \\ y2 \\ y3 \\ y4 \\ y5 \\ y6 \\ y7 \\ y8 \\ y9 \end{bmatrix} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} x1 \\ x2 \\ x3 \\ x4 \\ x5 \\ x6 \\ x7 \\ x8 \\ x9 \end{bmatrix}$$

3.3.Determination of controller gains

Stability and natural response of continuous-time LTI systems can be determined from the eigenvalues of the system matrix A. The denominator of the transfer function are equal to the characteristic polynomial found by:

$$\lambda(s) = |sI - A|$$

The roots of the characteristic polynomial are the poles of the system or the eigenvalues.

The eigenvalues of the system matrix, A of any system in state space form are the poles of the system. For a system to be stable, all the poles must be on the left-hand side of the jω axis, i.e. their real part must be negative. It can be approximated that, in an LTI system, the slowest part will dominate the response, and the faster parts can be ignored. For example, if a pole is at σ_1, any pole that lies beyond 5 or 10 times further away from σ_1 can be considered to be insignificant. The poles that lie farther from the $j\omega$ axis tend to have a much insignificant effect on the system as their response dies down quickly. Thus, the closer the pole is, the more dominant it will be.

Dominant poles have the most extended time constants. In the generating unit presented above, the power system time constant is the longest, Tp1 and Tp2 and thus power system transfer functions has the dominant pole. The aim here is to obtaining minimum settling time and reduce the steady-state deviation to zero. The integral action will reduce the steady-state deviation but for different values of Ki1 and Ki2, settling time changes.

To obtain the minimum settling time system matrix A is generated for each value of Ki2 between 0 and 1 with an interval of 0.001 and Ki1. Eigenvalues of A is determined, and the pole with the largest real part is selected; this is the dominant pole for a particular Ki1, Ki2 pair. The entire process is repeated for every value of Ki1 between 0 and 1 with in interval of 0.001. A 2x2 matrix is populated with the maximum real parts of eigenvalues and linear search is performed to determine the smallest values. The Ki1 and Ki2 corresponding to the smallest value gives the best settling time performance

4. RESULTS

The linear search for the minimum eigenvalue of the system matrix gives Ki1 = 0.34 and Ki2 = 0.342. The paarmeters used in the power system model are detailed in the annexures. A mathematical analysis using the selected values of controller gains gives the frequency deviation of both areas when a 10% load change occurs in area 1. The time-variation in the net frequency change is shown in the following figure.

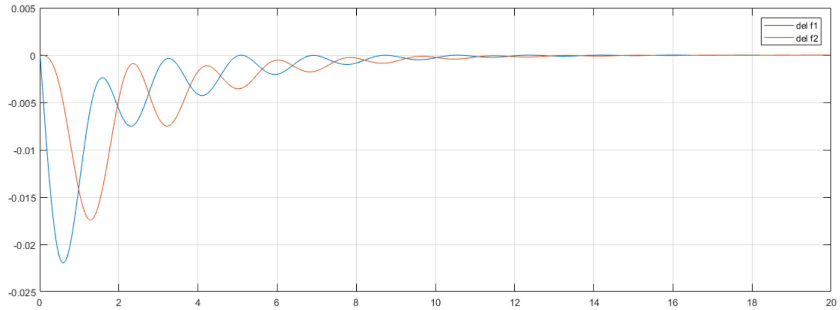

Fig. (5): Frequency deviation vs time plot for the compensated system

It can be observed from the wavefrom that both area frequency deviations settle in about 13 seconds, area 1 has maximum overshoot of about 23%, area 2 has a maximum overshoot of about 18% and both area have a steady-state deviation reduced down to zero. The values are then confirmed using simulation in SIMULINK. The following figure shows the frequency deviation of both areas. From measurements, the change in frequency deviation is less than 0.01% w.r.t at approximately 13.2 seconds for both area, area 1 absolute maximum overshoot is 22.1%, area 2 absolute maximum overshoot is 17.3% and absolute steady-state deviation in both areas is zero.

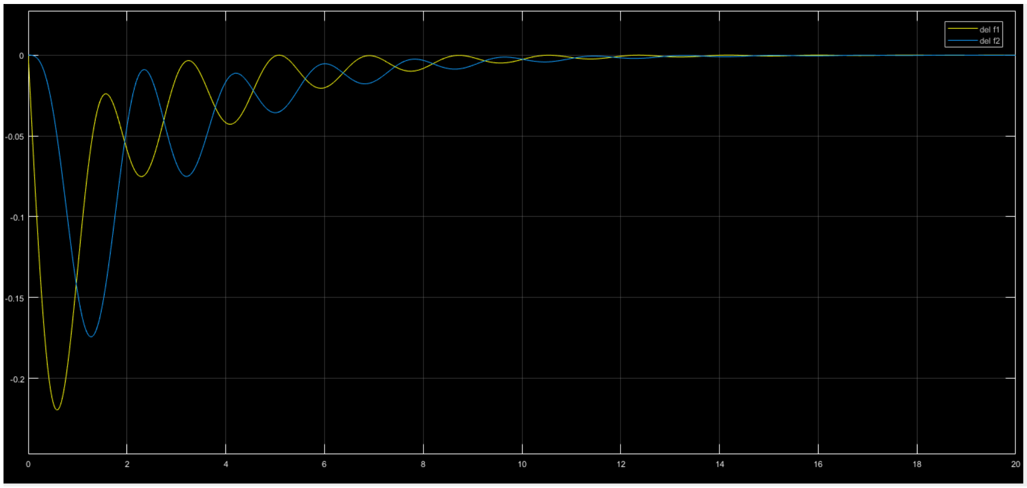

Fig. (6): Simulation result of compensated system.

5. CONCLUSIONS

The results of the simulations match closely with the mathematical analysis, proving the validity of the developed model. The maximum overshoot remained nearly the same as the maximum overshoot for both areas in uncompensated system. The controller forced the steady-state frequency deviation to zero for both the area. The settling time detoriated due to introduction of two new poles.

The studied model can be considered a robust model, opening further avenues to improve the controllers. The settling time and maximum overshoot can be further imporved by using better controllers such as PID. In future the controller gains can be determined using advanced optimisiation algorithms such as particle swarm or other bio-inspired algorithms. With increasing penetration of the renewable sources, further studies may also power electronics-based generating areas.

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ANNEXURE

Simulation parameters:

1. $Kp1 = Kp2 = 120$
2. $Tt1 = Tt2 = 0.3$
3. $R1 = R2 = 2.4$
4. $Tg1 = Tg2 = 0.08$
5. $Tp1 = Tp2 = 20$
6. $a12 = -1$
7. $Ki1 = 0.340$
8. $Ki2 = 0.342$
9. $B1 = \frac{1}{Kp1} + \frac{1}{R1}$
10. $B2 = \frac{1}{Kp2} + \frac{1}{R2}$
11. $\Delta P_{L1} = 0.01$

PROJECT DETAILS

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Project Duration	3 weeks	Date of reporting	13 May 2020
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