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Load Frequency Control of Integrated Nepal Power System

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Abstract

The frequency stability of a power system is concerned with the overall inertia of the system, effective droop coefficient, and governor/turbine time constants. The frequency sensitive loads like motor, transformers operates inefficiently for frequency unstable system which results poor output power. Variable frequency causes mechanical resonance which creates large amplitude stress in turbine blades. The speed of the motor depends on the system frequency. A stable system frequency should be maintained within specified limits for proper operation of power system equipment. The frequency related parameters change with the change in load and the type of generation integrated into the power system network. This research paper analyzes the Load Frequency Control of Integrated Nepal power system (INPS) which is responsible to maintain the frequency and power output in the interconnected power system. It keeps net power exchanges within control regions at predetermined levels, and keeps the distribution of power among units at the optimum economic levels. This paper studies three different scenarios which includes base case scenario, 50% reduction in droop and 50% reduction in inertia along with load change scenarios. This paper considers two area system; Area-1 as INPS and Area-2 as Indian Power System. The simulation result shows steady state deviation errors in each cases, the transients in frequency, and the changes in mechanical power response of the area that has undergone various modifications.

Keywords

Load Frequency Control, Two Area System, Tie-line Power, Inertia Constant, Damping Control

1. Introduction

In a power system, the active power flow and reactive power flow is independent of one another and is primarily influenced by different factors. Rotor angle, frequency, and active power are the parameters that changes during a power system operation [1]. The control of active power and reactive power flow is vital for the satisfactory performance of a power system. The quality of active power is governed by control of frequency. Frequency needs to be constant for a power system to operate adequately. Frequency stability of a power system is governed by the inertia,droop and turbine/governor time constants. The system inertia is achieved from the rotating mass of generators and induction motors which provides kinetic energy to interconnected grid or it absorbs from the interconnected grid in case of frequency deviation i.e it gives tendency to remain rotating.The overall grid frequency is linked with synchronous generators and thus to active power balance in the system. Hence, rotational inertia i.e inertia constant H suppresses the frequency deviation making the frequency dynamics of the system slower. This provides response time to the system to react the fault events such as large load change, power plant outages, line outages etc [2]. Frequency control maintains the induction motors, along with a number of other loads, and generating units operate at a constant speed. Induction motors and transformers may experience large magnetizing currents as a result of a substantial drop in frequency. A change in active power demand at one place is directly mirrored by a change in frequency across the system since the frequency of a system is a common factor. Therefore, governors are offered to the generators as a key means for speed regulation[3]. Thus,frequency stability is directly related to both inertia and drop. The drop of inertia due to large renewable energy source penetration displacing conventional generators into the power system can cause substantial increase in rms frequency deviation and decrease response time to react to fault events. Similarly, integration of RES into the system reduces inverse droop which causes larger frequency deviations[4]. The concept of virtual inertia and use of energy storage can be done for improving the system frequency dynamics parameters[4][5].

The requirements of the electric power system are satisfied by a large number of controllers. The load-frequency control (LFC) is a component of this hierarchical control system that works through the generators' speed control system to keep the tie-line load exchange, the system frequency, and their integrals as close to the set points as possible. In an interconnected system, in addition to controlling frequency, generation of each area must also be regulated in order to ensure scheduled power exchange. The control of generation and frequency is termed as load frequency control.

The given interconnected system is build into two areas mainly, Area-1 and Area-2. [6] displays LFC for two area that models the power stations and interconnected power systems for the design of load-frequency controller of Hungarian power system. Similarly, [7] simulated three area LFC model with non-identical capacity in MATLAB/Simulink. Similarly this model of INPS and Indian grid system is made considering two area system for each grid. The simulation done in MATLAB/Simulink is shown in Fig 1.

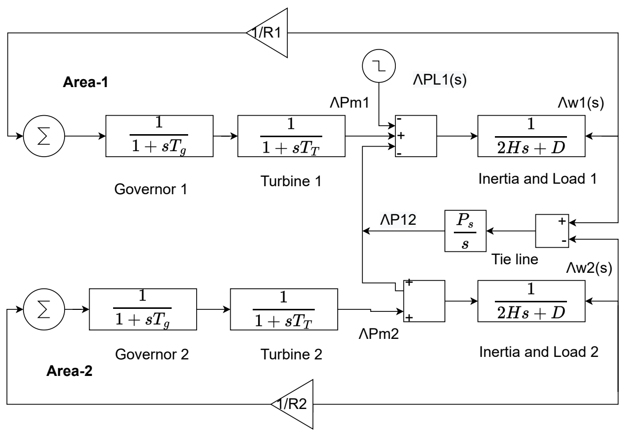

Figure 1: Block diagram of two area system for LFC

There are various types of loads connected in the system. Some are frequency dependent while others are frequency independent. For instance resistive loads are frequency independent. The motor loads are frequency dependent loads such that as the speed of the motor changes the electrical power changes with frequency. The frequency dependent property of a composite load can be stated as follows [8]

$$\Delta P_e = \Delta P_L + D\Delta\omega_r \tag{1}$$

A quick load change in any one of the two areas of a two-area power system will cause the tie line powers and all of the areas' frequencies to deviate. In these circumstances, automatic generation control (AGC), commonly referred to as load frequency control, is utilized with the primary goal of minimizing transient error deviations in both the frequency and the scheduled tie-line power and ensuring zero steady-state errors of these variables. In this system to prevent frequency variations, generation must be matched to load. Generator output is adjusted using governors in response to frequency variations brought on by generation and load mismatches. System inertia and load-frequency help the governors operate to maintain a constant system frequency. System inertia and load-frequency help the governors operate. Governor monitors for a single machine and AGC looks after all the generators in the system [9]. The units throughout the entire interconnection will sense a frequency change and can help in restoring frequency if one system suddenly loses a generating unit, even if no power is being delivered over ties to other systems. Maintaining frequency stability when the load changes is the key objective of the load frequency control. The two interconnected areas are connected through the tie-lines as shown in Fig. 1. In a given control area, generating plants constantly adjust their speeds in tandem to maintain the frequency and relative power angles at the predetermined levels under both static and dynamic conditions. Frequency deviation and tie line power deviation both occur when a sudden change in demand occurs in a control area of an interconnected power system. LFC regulates the frequency and expected power demand in a system and, holds the variation in tie-line power among the control areas.

The main contributions of this paper is a detailed simulation and analysis of LFC of two area system in MATLAB/Simulink for following three different cases; i) Analysis for the INPS with load change in Area-1 ii) Analysis for 50% reduction in inertia with load change in Area-1 iii) Analysis for 50% reduction in droop with load change in Area-1

2. Methodology

A two area power systems which delivers powers to its own area are connected through a tie-line as shown in Fig. 2. Generators in each area are coherent. The coherent generators swing in unison and are strongly connected internally such that LFC loop can represent the whole system termed as control area. The two areas are represented by an equivalent generating unit interconnected by a lossless tie-line having reactance X_tie. During normal condition the equivalent power through the tie-line is given by [10]

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin \delta_{12} \tag{2}$$

In a two-area power system the individual areas are strong but the tie-line which connects them is weak and the system is characterized by a single frequency. Depending on the direction of power flow, the tie line power flow occurs as an increase in load in one area and a drop in load in the other area. The phase angle difference determines the direction of power flow. Fig. 1 is a block diagram representation of a two-area power system. The control region is composed of three blocks, each containing a integral controller block. The three blocks are the power system block, which is actually the load block, the turbine block, and the governor block.

The steady state frequency deviation is given by

$$\Delta\omega = \frac{-\Delta P_{Area-1}}{(D_1 + \frac{1}{R_1}) + (D_2 + \frac{1}{R_2})} \tag{3}$$

The tie-line power flow is given by

$$\Delta P_{12} = \Delta\omega * [\frac{1}{R_2} + D_2] \tag{4}$$

For small change in angles the change in tie-line power flow is given by [11]

$$\Delta P_{12} = \frac{V_1 V_2}{X} (\cos \delta_1 - \delta_2)(\Delta\delta_1 - \Delta\delta_2) \tag{5}$$

$$\Delta P_{12} = T(\Delta\delta_1 - \Delta\delta_2) \tag{6}$$

In the steady state both areas will have the same steady state frequency deviation is given by

$$\Delta f = \Delta f_1 = \Delta f_2 \tag{7}$$

Change in mechanical power is given by

$$\Delta P_{m1} = -\frac{\Delta f}{R_1} \tag{8}$$

$$\Delta P_{m2} = -\frac{\Delta f}{R_2} \tag{9}$$

3. Result and Discussion

Here, three scenarios have been analysed.Base case scenario is the normal scenario with 50% load change in Area-1 and without no drop of inertia and droop. The remaining scenarios with 50% drop in inertia of Area-1 along with 50% load change in same area and 50% drop in droop of Area-1 along with 50% load change in same area.The parameters used for detailed simulation in MATLAB/Simulink are shown in Table 1.

Table 1: Parameter involved in the given system

Parameters	Units	Area-1	Area-2
Droop (R)	%	5	5
Frequency sensitive load (D)	%	1	1
Inertia constant (H)		5	5
Governor time constant (Tg)	sec.	0.2	0.2
Turbine time constant (Tt)	sec.	0.5	0.5
Base MVA	MVA	1500	100000
Synchronizing coefficient (Ps)	pu	0.053	0.053

3.1 Base Case Scenario

For Base case Scenario, load demand of Nepal which is 1481.85 MW is considered. Here if 50% of total present demand i.e., 740.9 MW load increases in Area-1, then frequency decreases. The both system attains 49.98 Hz which is less than the original frequency of 50 Hz with steady state frequency deviation of 0.0003643 p.u. as in Table 2. The load change get distributed into both areas.Area-l(Nepal) will increase its generation by 11.1 MW and Area-2 (India) by 728.8 MW. The total load change in generation is 739.9 MW met, which is 1 MW less than 740.9 MW and this is because of change in area loads due to the frequency drop. Thus, the tie-line power flows from Area-2 to Area-1 is 728.8 MW. The tie line power that flows from Area-2 to Area-1 is 729 MW as in Table 2.

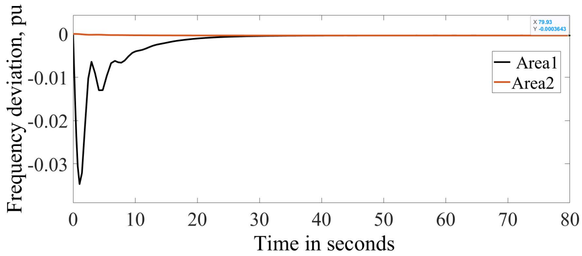

Figure 2: Actual frequency after load change

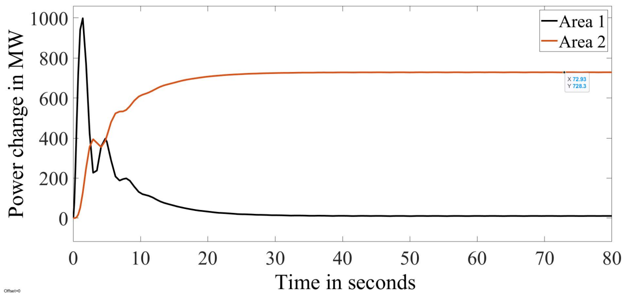

Figure 3: Mechanical power change in area-1 and area-2

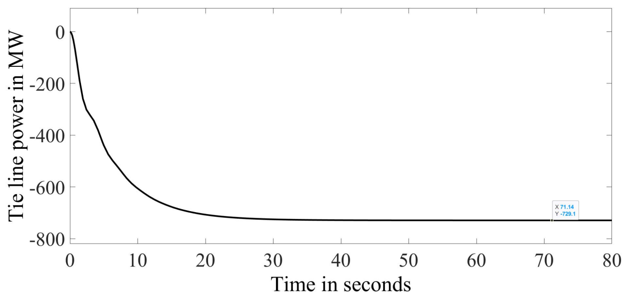

Figure 4: Tie-line power

3.2 Case-I: 50% Reduction in Inertia in Area-1

Here the load change is increased along with 50% reduction of system inertia in Area-1 which means when the existing system of Area-1 is integrated with renewable energy sources (RES) like solar PV, the inertia gets decreased due to the absence of rotating parts in RES. Here, from Fig. 5 we can observe that decrement in inertia leads to unstable frequency dynamics. Electrical transients can be visible in both Fig. 5 and Fig. 9 in comparison to base case scenario. The steady state deviation , power change and tie-line power is same as in base case which can be seen in Table 2. But both frequency and power change dynamics have amplified transients with respect to base case scenario. The frequency dynamics in Fig. 5 attains maximum value of 50.23 Hz and minimum of 47.71 Hz which violates the standard limits.

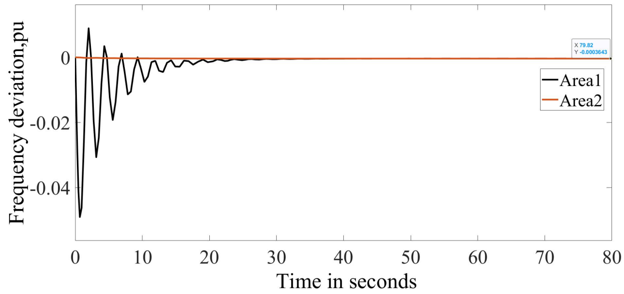

Figure 5: frequency after 50 percent drop in inertia

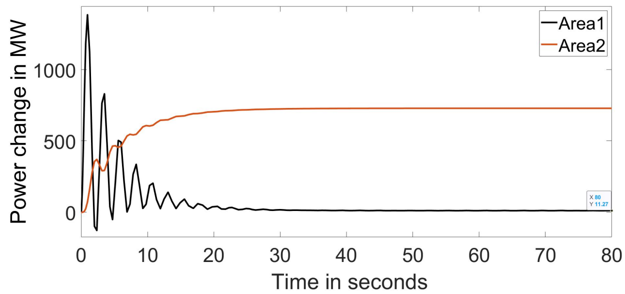

Figure 6: Mechanical power change in Area-1 and Area-2 after 50 percent drop in inertia

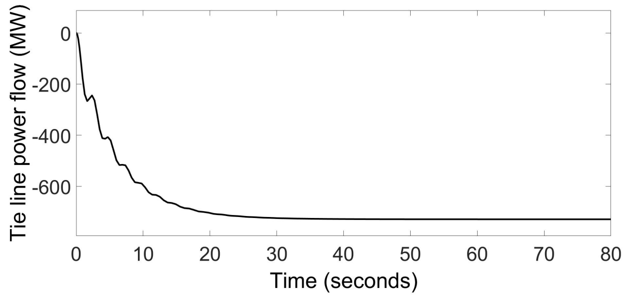

Figure 7: Tie-line power after 50 percent drop in inertia

3.3 Case-II: 50% Reduction in Droop in Area-1

In this case the load change is increased along with 50% reduction in droop of Area-1. The decrease in droop value results increment in steady state frequency deviation as in Fig. 8 in compare to steady state frequency deviation as shown in base case scenario in Fig. 2. The frequency value attains maximum value of 50.03 Hz and minimum value of 48.78 Hz and finally settles at 49.98 Hz. Fig. 8 depicts the amplified transients in frequency dynamics than in base case scenario. The decrement of droop value means the increment in power generation in Area-1 as shown in Fig. 9. The change in power generation in

Table 2: Parameter analysis at 50% increment in load, 50% reduction in inertia and 50% reduction in droop along with load change

Parameters	Units	Best Case Scenario	50% reduction in inertia (H)	50% reduction in droop (R)
Steady state frequency deviation	p.u.	0.0003643	0.0003643	0.0003587
Steady state frequency	Hz	49.9818	49.9818	49.9820
Change in generation in each area				
Area-1	MW	11.1	12.01	22.33
Area-2	MW	728.8	728.7	717.5
Tie-line power change	MW	-729	-729	-717.8

Area-1 increases to 22.33 MW as in Table 2, which is twice the value in base case scenario. The tie-line power flow slightly decreases.

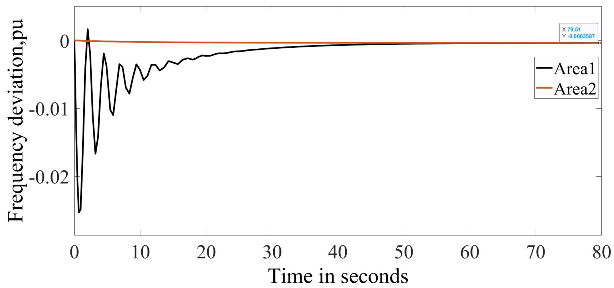

Figure 8: Actual frequency after 50 percent droop reduction

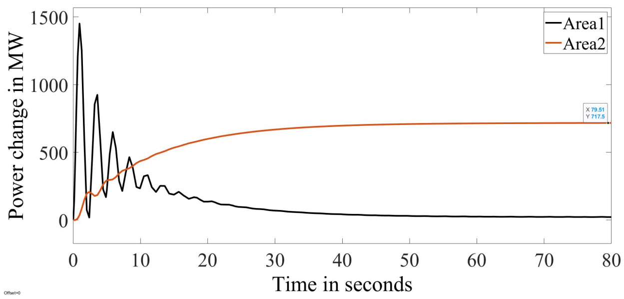

Figure 9: Mechanical power change in Area-1 and Area-2 after 50 percent droop reduction

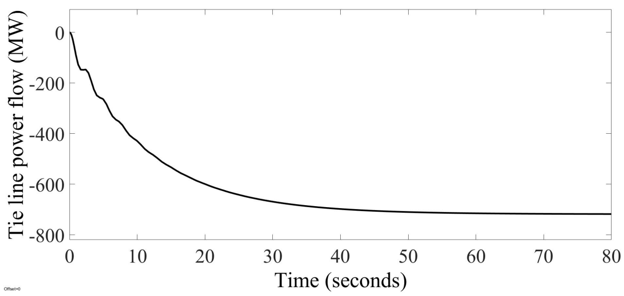

Figure 10: Tie-line power after 50 % droop reduction

4. Conclusion

This paper analysed that the load changes and penetration of inverter-connected power generation can have the significant impact on power system dynamics.The key contributions of this paper are;

i) The change in load in Area-1 along with change in droop and inertia respectively results the steady state deviation error. It is seen that there is slightly low steady state deviation in case-2 with respect to Base case.

ii) The change in power generation is greater in case-2 i.e., as load increases in Area-1 obviously it has to increase its generation resulting the slightly decrement in the power supply from Area-2 as compare to Base case and it remains same in case-1.

iii) There is a greater electrical transients and oscillations in both cases as compared to base case. The transients obtain higher maximum and minimum value i.e., 50.23 Hz and 47.71 Hz respectively when there is decrease in inertia which violets the standard limits of frequency.

Hence, it is observed from the aforementioned simulation and analysis that both generators have enhanced their generation to meet the increased load demand. Each area adapts to its own changes if there is a sudden change in load in any one area.Moreover, the transients observed in case-I and case-II can be the serious issue as they can give false triggering signal and unexpected trippings hence further disturbing the system stability.

5. Future Work

Since, Nepal has targets set for electrifying the transport sector, electric cooking etc. The further simulation and analysis can be performed with EV and electric cooking integration into the grid.

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