CONTROL OF LOAD FREQUENCY IN INTERCONNECTED POWER SYSTEMS: A COMPARATIVE ANALYSIS OF PID AND PI CONTROLLERS

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ABSTRACT

This paper presents load frequency control of two area interconnected power system using PID controller and PI controller. The main target of load frequency control is to maintain good tracking of load demand and zero steady state errors for frequency deviation in a multi-area power system. This help to maintain a balance of energy and frequency of power generation system and enable proper power exchange for better trading. In the paper, a single area power generation system was first modeled to ensure that the right working condition of a power system is mimicked. Thereafter, the model single area is extended to a two-area generation system. The PID and PI controllers were applied for frequency control independently. Results analysis showed that, the PID has a better performance over the PI controller in terms of overshoot and settling time

1. INTRODUCTION

The electric power system contributes to the welfare, growth and technological advancement of humanity. The growth of electrical energy consumption in the world has been phenomenal [1]. An electric power system is defined as a network of electrical components used to supply, transfer, and consume electric power. The supply is done through some form of generation (e.g., a power plant), the transfer is done through a transmission (via a transmission line) and distribution system, and the consumption can be through residential applications such as powering the lights or air conditioning in your home, or via industrial applications such as the operation of large motors.

The power system starts with generation, by which electrical energy is produced in the power plant and then transformed in the power station to high-voltage electrical energy that is more suitable for efficient long-distance transportation. The power plants transform other sources of energy in the process of producing electrical energy. For example, heat, mechanical, hydraulic, chemical, solar, wind, geothermal, nuclear, and other energy sources are used in the production of electrical energy. High-voltage (HV) power lines in the transmission portion of the electric power system efficiently transport electrical energy over long distances to the consumption locations. Finally, substations transform this HV electrical energy into lowervoltage energy that is transmitted over distribution power lines that are more suitable for the distribution of electrical energy to its destination, where it is again transformed for residential, commercial, and industrial consumption [2].

Load Frequency Control (LFC), is a technique used to restore the balance between load and generation in a control area by means of speed control. Load frequency control (or frequency control) is the **system by which the frequency of the grid is kept or brought back to its nominal value after the demand-generation gap**. The frequency control of the whole power system is done by generating units. The power systems could be an interconnection of more than one control area through tie lines. The generators in a control area always vary their speed together (speed up or slow down) for maintenance of frequency and the relative power angles to the predefined values in both static and dynamic conditions [3]. If there any sudden load change occurs in a control area of an interconnected power system then there will be frequency deviation as well as tie line power deviation [3]. Two main objective of Load Frequency Control (LFC) are; to maintain the real frequency and the desired power output in the interconnected power system and to control the change in tie line power between control areas [4].

A proportional-integral-derivative controller (PID controller) is a control loop feedback mechanism (controller) widely used in industrial control systems. A PID controller calculates an error value as the difference between a measured process variable and a desired set point [5, 6]. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable. The PID controller-based Load Frequency Control is a technique by which the balance between generation and load is restored efficiently and effectively using a PID controller. In an interconnected power system, the PID controller-based load frequency control helps to minimize the frequency deviations and tie line power deviations of each control area. These deviations may lead complications of the power system if not controlled.

2. LITERATURE REVIEW

The paper presented by M. Lokanatha and K. Vasu in ref [7] covers the scope of Load Frequency Control in a two-area power system. The PID controller gave optimal value for load frequency control in the two-area power system. The performance of the given proposed controller was more accurate than that of the conventional PI controller under different load conditions. Therefore, the proposed controller of two area power systems, the transient response was improved with less peak overshoot and settling time. The performance and robustness of proposed controller was analysed for different change in load disturbance. However, the project was limited to two area power system. The research presented by Siddhahast Mohapatra in ref [8] also covers the scope of load frequency control in a two-area power system. The project presents a case study of designing a controller that can bear desirable results in a two-area power system when the input parameters to the system is changed. Two methods of Load Frequency Control were studied taking an isolated power system into consideration. It was seen that the optimal controller design bore better results and achieved desired reliability under changes in the input parameter. Hence an attempt was made to extend the Optimal Control design to a two-area network. The assumptions taken under consideration strictly followed that the system operation was normal throughout and the simulations were obtained without the presence of the integral controllers. However, the project did was limited to only two area power system and did not put the PID controller into consideration. The project work presented by Niranjan Behara in ref [9] covers the scope of load frequency control in a two-area power system. Series of controllers were used and compared in order to know the controller with the best response. Ref [10] proposed an empirical tuning method for a new type of fractional controller known as Fractional Order Filter Proportional Integral Derivative (FOF-PID) controller. A procedure which was based on set point overshoot was employed to tune the controller. Simulation on various first order with time delay processes were carried out and correlations were derived to obtain the parameters of the controller. In [11], a universal fractional order linear phase lead compensation multirate repetitive controller for pulse width modulated inverters was proposed. The idea is to provide a flexible selection of sampling frequency, fundamental frequency of the reference signal and down-sampling ratio in order to enhance effectiveness in applications. Multirate Repetitive Control (MRC) and Fractional Order Multirate Repetitive Control (FOMRC) scheme to achieve the design objectives. The effectiveness of the design was tested on a series of application examples of programmable AC power supplies with high tracking accuracy, low total harmonic distortion and good transient response. In [8], a new practical tuning method for fractional order PID controller was proposed. Ref, [12] introduces a new optimal tuning rule for a fractional order PID controller using an indirect design approach – 1(IDA-1). In this approach, the plant to be controlled is shifted in the frequency domain using a variable shifting parameter which helps in the setting of the robustness and tuning of the transient response of the frequency shifted process. The tuning rules are then designed for the new process and for accuracy, a valid range of the shifting parameter is proposed. The propose work is validated with some examples of stable and unstable processes. A practical experimental set up is also considered to test the effectiveness of the method. In [13] presented a FOPID controller to minimize the deviation in frequency of a single-area power system. Three types of turbines (non-reheat, hydro and reheat) were considered in the designed power system.

The robustness of the designed method was verified via parameter variation. The optimum values of the FOPID controller gain were obtained on the integral error criterion where the value of either one of kp, ki or kd is arbitrary chosen and the other two were calculated. Results obtained reveal that the designed FOPID controller minimizes frequency deviation even in the presence of parameter variation. However, the design method minimized frequency deviation even for parameter uncertainties on a single area non-reheat turbine. For the reheat and hydro turbine, the transfer function has some unstable poles, as such; the designed method is only effective for non-reheat thermal system. The proposed method will be extended to multi-area network considering reheat turbine and physical constraints. Ref [14] proposed a FOPID controller for load frequency control of two-area non-reheat thermal power systems. Particle swarm optimization was used to implement a tuning procedure for the FOPID controller. A comparative analysis of the controller showed the superiority of these approach over other numerical based methods.

3. METHODOLOGY

This section presents the methods employed in implemented the proposed multi-area load frequency control of power system. The model of the system is also presented using block diagram sown fig 1.

3.1 Area Generation Control

The function of Area Generation Control (AGC) is to restore frequency to specified nominal value in the event of deviation due to load imbalance. This restoration action can be achieved by introducing the integral controller to act on the load reference setting and change the speed set-point. The integral controller gain must be properly selected in order to attain satisfactory transient performances of the system can be computed as:

$$\frac{\Delta\Omega(s)}{-P_L(s)} = \frac{s(1+\tau_g s)(1+\tau_T s)}{s(2Hs+D)(1+\tau_g s)(1+\tau_T s)+K_1+\dfrac{s}{R}} \quad (1)$$

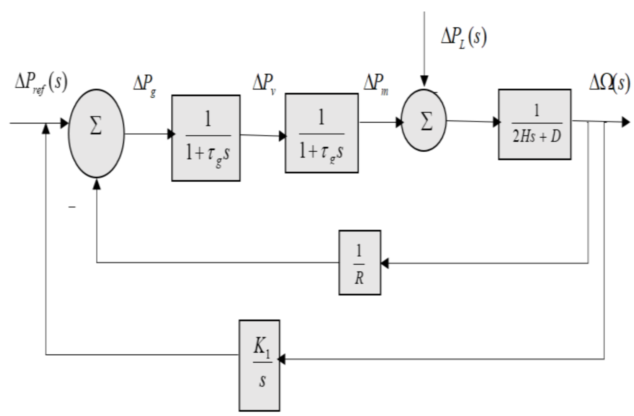


Fig. 1: Mathematical modelling of AGC in a single area power system

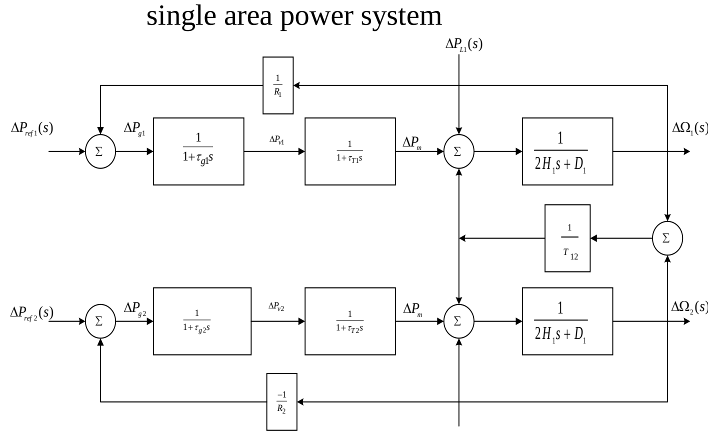


Fig. 2: Two area system with primary loop Load Frequency Control

3.2 Multi-Area Power System

Neighbouring power stations or companies are interconnected by one or more transmission lines called tie lines. The objective is to buy or sell power with neighbouring systems whose operating costs make such transactions profitable. Also, even if no power is being transmitted over ties, if one system has sudden loss of a generating unit, the units through all the interconnection will experience a frequency change and can help in restoring frequency and avoid total system collapse. The power networks are distributed by tie lines into various regular areas. Generators are required to maintain synchronism with the tie lines and connected areas [15]. In many cases a group of generators are closely coupled internally and swing in unison. Furthermore, the generator turbines tend to have the same response characteristics. Such a group of generators are said to be coherent in nature. Then it is possible to let the Load Frequency Control (LFC) loop represent the whole system and the group is called the control group. For a two-area system, during normal operation the real power transferred over the tie line is given by:

$$P_{12} = \frac{|E_1||E_2|}{X_{12}} \sin \partial \quad (2)$$

Where: X_{12} is the impedance of the two area and tie line given by:

$$X_{12} = X_1 + X_2 + X_{TIE}$$

And

$$\delta_{12} = \delta_1 + \delta_2$$

For a small deviation in the tie line power flow:

$$\Delta P_{12} = \frac{dP_{12}}{d\partial_{12}}\Big|_{12} = P_s \Delta\partial_{12} \quad (3)$$

The tie line power deviation then takes on the form:

$$\Delta P_{12} = P_s (\Delta\partial_1 - \Delta\partial_2) \quad (4)$$

P_{12} = power exchanged from area 1 towards area 2 via the tie line.

δ_1 and δ_2 are the power angles of end voltages V1 and V2.

$$\delta_{12} = \delta_1 - \delta_2$$

The simplified representation of this two area power systems is given in the following figure.

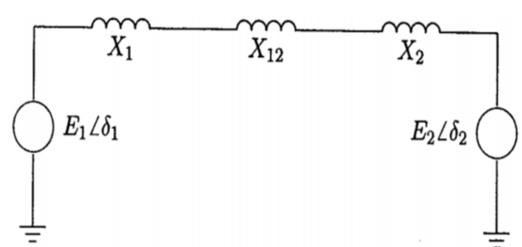


Fig. 3: Equivalent network of two-area power system

Assume that we have a two-area system, consider a load change in area 1. Both areas will have a steady-state frequency deviation.

In normal operating state, the system operating condition is derived as:

$$\Delta w = \Delta w_1 = \Delta w_2 \quad (5)$$

$$\Delta P_{m1} - \Delta P_{12} - \Delta P_{L1} = \Delta w D_1 \quad (6)$$

$$\Delta P_{m2} + \Delta P_{12} = \Delta w D_1 \quad (7)$$

$$\Delta P_{m1} = \frac{-\Delta w}{R_1} \quad (8)$$

$$\Delta P_{m2} = \frac{-\Delta w}{R_2} \quad (9)$$

$\Delta \boldsymbol{w}$ Is then given by:

$$\Delta w = -\frac{P_{L1}}{(\frac{1}{R_1} + D_1) + (\frac{1}{R_2} + D_2)} \quad (10)$$

$$\Delta w = -\frac{P_{L1}}{B_1 + B_2} \quad (11)$$

Where:

$$B_1 = (\frac{1}{R_1} + D_1) \quad (12)$$

$$B_2 = (\frac{1}{R_2} + D_2) \quad (13)$$

Where: B_1 and B_2 are known as frequency bias factors.

The change in tie-line power is given by

$$\Delta P_{12} = -\frac{(\frac{1}{R_2} + D_2)\Delta P_{L1}}{(\frac{1}{R_2} + D_2) + (\frac{1}{R_1} + D_1)} \quad (14)$$

Hence:

$$\Delta P_{12} = \frac{B_2}{B_1 + B_2}(-\Delta P_{L1}) \quad (15)$$

A change of power in area 1 should be met by the increase in generation in both areas and a reduction in frequency. A simple control strategy in the normal state is to maintain the tie-line flow at about schedule, each area should absorb it is own load change and keep the frequency approximately at the nominal value.

In a two-area system each area tends to reduce its area control error (ACE) to zero, the ACE can be calculated by the equation:

$$ACE_i = \sum_{j=1}^{n} \Delta P_{ij} + K_i \Delta_w \quad (16)$$

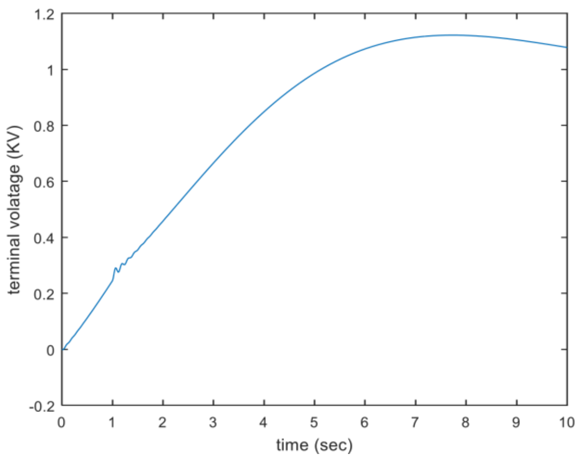
Where K_i is the area bias determines the amount of interaction during a disturbance in the neighbouring areas. The satisfactory performance is achieved when K_i is selected equal to the frequency bias factor of that area, the ACE's for two areas are [16]:

4. RESULTS DISCUSSION

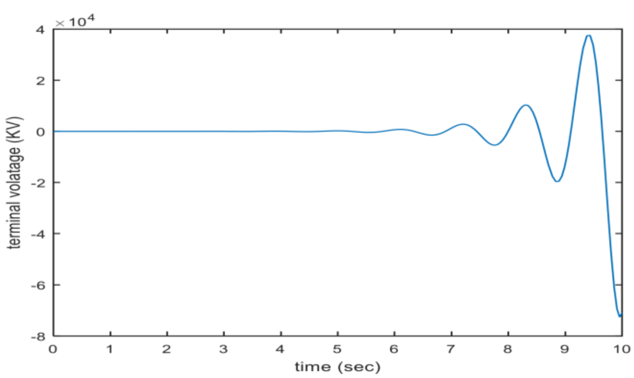
In this section, the results are presented and analyzed. The result presentation includes the frequency status of the system and the tie line power connecting the two area generation stations.

a. Analysis of the Single Area Power System

After the model design; the graph of the terminal voltage and speed deviations following a step increase of 0.01 p.u in the reference voltage for a single area network before concatenation is obtained. The response of the terminal voltage and speed are given in fig 4.



a. Terminal Voltage with Stabilization Loop



b. Terminal Voltage without Stabilization Loop

Fig. 4: Terminal Voltage for Single Area

From Fig, 5 a. it can be observed that the area generating station maintain a relatively constant speed just after 2 seconds where unstable speed was observed. In the case of the system without a stabilization loop, the response of the system shows a very unstable system. In fact, the system remains in the idle state until after 6 seconds before reacting to the step input voltage. This indicates the relevance of

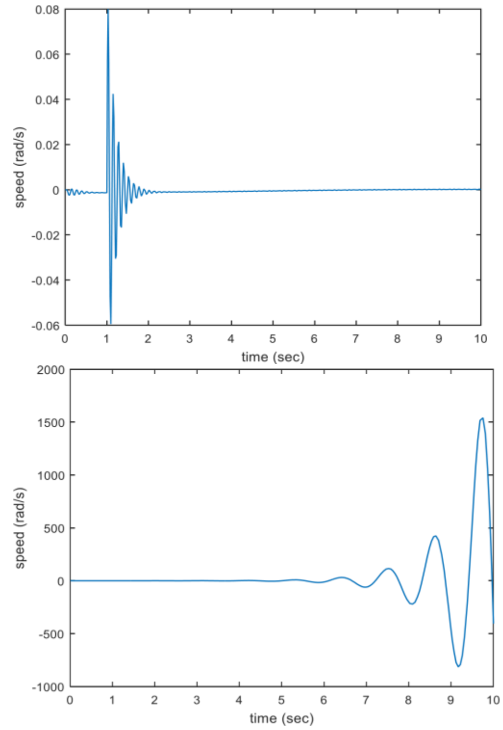


Fig. 5: Single area system with presence of stabilization loop

stabilization loop in the design of load frequency control power system.

Comparing the responses obtained with and without the presence of the stabilizing loop, it was observed that the presence of the stabilizing loop gave the system a better response; lesser overshoot and lesser settling time compared to the response of the system without the stabilizing loop thus, implying a more stable power system. In the case of the system with the stabilizing loop, the voltage deviation was about *1.1 unit* while the speed deviation was about *0.08 units* whereas in the case of the system without the stabilizing loop, the voltage deviation was about *400 units* and the speed deviation was about *12.5 units*. In addition to this, in the case of the system with the stabilizing loop, the settling time was approximately *10 seconds* whereas in the case of the system without the stabilizing loop, the settling time was more than *10 seconds.*

b. Analysis of Two Area Power System

After the construction of the Simulink model, the graphs of the tie line power deviations of each interconnected area and the graph of the frequency deviation of each area was obtained and analysed for both the PID and the PI controllers. Fig. 6 showed the frequency deviation obtained for both PID and PI controller for area one.

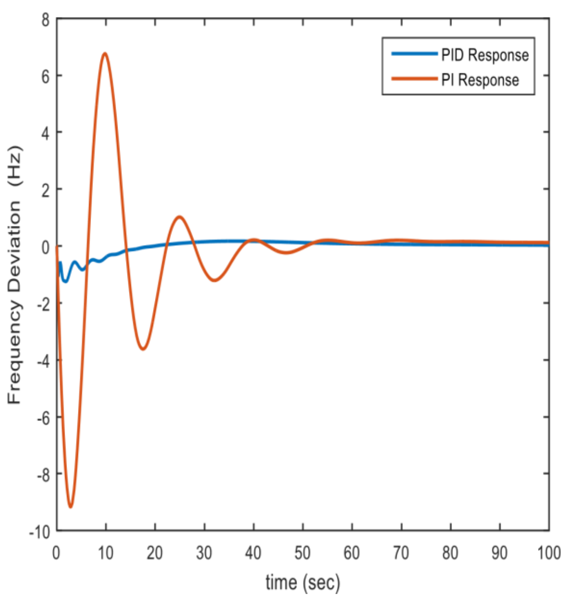


Fig. 6: Frequency Deviation Response for Area One

From the graph, the PID controller provided a clearly better response compared to the PI controller. The overshoot obtained with the PID controller was slightly greater than zero and the settling time is about 40 seconds. However, with the PI controller the overshoot is about 7 Hz and the settling time is about 80 seconds. Fig. *7* below shows the graph of frequency deviation against time for area two.

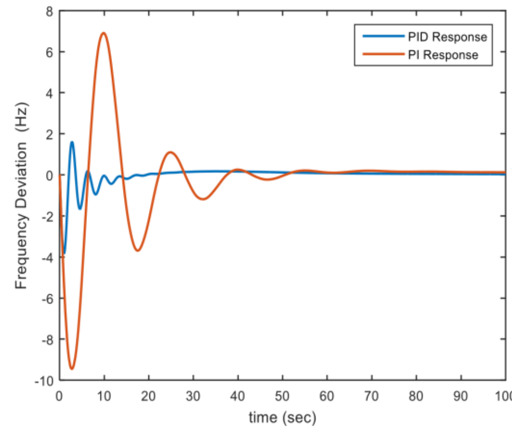


Fig. 7: Frequency Deviation for Area Two

From *Fig. 7*, it is observed that the PID controller provided a better response compared to that of the PI controller. For the PID controller's response, the overshoot was about 2Hz and the settling time was about 40 seconds. However, for the PI controller, the overshoot was about 7 Hz with a settling time of about 80 seconds.

The result of tie line power deviation of the power line connecting areas one and two for both the PID and PI controllers is shown in Fig. 8.

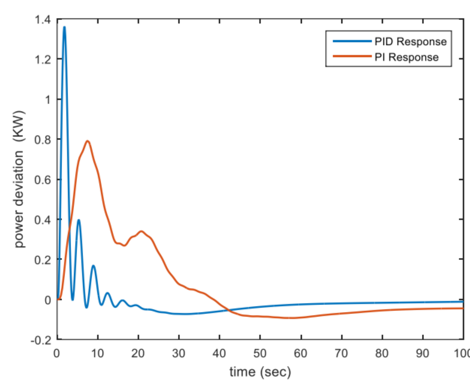


Fig. 8: Tie Line Power Between Area and Two

from Fig. 8, it can be observed that PID based tie line power settles faster than the power obtained by the PI controller. An overshoot value of about 1.38 KW and the settling time of about 50 seconds was obtained when PID controller was implemented. However, for the PI controller, the overshoot obtained was about 0.8 KW and a settling time of about 80 seconds was also obtained. Hence for practical application, the PID controller is preferable since stability is attained at a shorter time and the overshoot is still within specified limits.

5. CONCLUSION

The model of a single area power system was built after which the model of the load frequency control in a two area powers was built using MATLAB/SIMULINK environment. This is to ensure stability in the frequency and tie line power in a Two-area interconnected power system. The PID controller was included in the model to improve the general response and stability of the system. A comparison between the PI and PID controller was made and it was discovered that the system with the PID controller provided a better response. The LFC is built to maintain the frequency of the power system constant (within a specified range of deviation at least).

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