

Comparative Analysis of Different Methods of Tuning the PID Controller Parameters for Load Frequency Control Problem

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ABSTRACT: This paper presents the analysis of tuning the parameters of PID controller applied to load frequency control problem. In case of an interconnected power system, any small sudden load change in any of the areas causes the fluctuation of the frequencies of each and every area and also there is fluctuation of power in tie line. For satisfactory operation of a power system, frequency should remain nearly constant. Frequency deviations can directly impact on a power system operation, system stability, reliability and efficiency. Large frequency deviations can damage equipments, degrade load performance, overload transmission lines and affect the performance of system protection schemes. These large-frequency deviation events can ultimately lead to a system collapse. A Load Frequency Control (LFC) scheme basically incorporates an appropriate control system for an interconnected power system, which is having the capability to bring the frequencies of each area and the tie line powers back to original set point values or very nearer to set point values effectively after the sudden load change. This can be achieved by the use of conventional and modern controllers. Modern controllers have a lot of advantages over conventional integral controller. They are much faster than integral controllers and also they give better stability response than integral controllers. In this proposed research work PID controller has been applied for LFC of two area power systems. The parameters of the PID controller are tuned by two different methods named as (1) Ziegler-Nichols (Z-N) Method and (2) Simplex Search Method for better results. It is seen that the results obtained are far better than the conventional controller.

KEYWORDS: Interconnected power system, LFC, PID controller, Tuning, Ziegler-Nichols.

I. INTRODUCTION

The interconnected power system is the interconnection of more than one control areas through tie line. The generators in a control area always vary their speed together either speed up or slow down for maintaining the frequency and the relative power angles to the predefined values with tolerance limit in both static and dynamic conditions. If there is any sudden change in load occurs in any control area of an interconnected power system then there will be frequency deviation as well as tie line power deviation.

Large size is one of the most important advantages for the whole interconnected power system. When a load block is added, at the initial time, the required energy is temporarily borrowed from the system kinetic energy. Generally the availability of energy is more for larger systems. So there is comparatively less static frequency drop, whereas for a single area power system, the frequency drop may be a bit higher for same amount in load change.

Some basic operating principles of an interconnected power system are written below:

1. The loads should strive to be carried by their own control areas under normal operating conditions, except the scheduled portion of the loads of other members, as mutually agreed upon.
2. Each area must have to agree upon adopting, regulating, control strategies and equipment which are beneficial for both normal and abnormal conditions.

For satisfactory operation of a power system, frequency should remain nearly constant. Frequency deviations can directly impact on a power system operation, system reliability and efficiency. Large frequency deviations can damage equipments, degrade load performance, overload transmission lines and affect the performance of system protection schemes. These large-frequency deviation events can ultimately lead to a system collapse. Variation in frequency adversely affects the operation and speed control of induction and synchronous motors. Considerable drop in frequency could result in high magnetizing currents in induction motors and transformers thereby increasing reactive power consumption. In domestic appliances, where refrigerator's efficiency goes down, television and air conditioners reactive power consumption increases considerably with reduction in power supply frequency.

Therefore it is very important to maintain the frequency within acceptable range. Due to the dynamic nature of the load, continuous load change cannot be avoided but the system frequency can be kept within sufficiently small tolerance levels by adjusting the generation continuously. This can be achieved using automatic generation control, which requires Load frequency control mechanism for its implementation.

Cohn [11] has done earlier works in the important area of LFC. Concordia et al [5] and Cohn [11] have described the basic importance of frequency and tie line power and tie line bias control in case of interconnected power system.

The revolutionary concept of optimal control for LFC of an interconnected power system was first started by Elgerd

[13]. There was a recommendation from the North American Power Systems Interconnection Committee (NAPSIC) that, each and every control area should have to set its frequency bias coefficient is equal to the Area Frequency Response Characteristics (AFRC). But Elgerd and Fosha [6,13] argued seriously on the basis of frequency bias and by the help of optimal control methods they presented that for lower bias settings, there is wider stability margin and better response. They have also proved that a state variable model on the basis of optimal control method can highly improve the stability margins and dynamic response of the load frequency control problem.

R. K. Green [15] discussed a new formulation of LFC principles. He has given a Concept of transformed LFC, which is heaving the capability to eliminate the requirement of bias setting by controlling directly the set point frequency of each unit.

R. K. Cavin et al [14] has considered the problem of LFC for an interconnected system from the theory of optimal stochastic system point of view. An algorithm based on control strategy was developed which gives improvised performance of power system for both small and large signal modes of operation. The special attractive feature of the control scheme proposed here was that it required the recently used variables. That are deviation in frequency and scheduled inter change deviations taken as input.

E. C. Tacker et al [8] has discussed the LFC of interconnected power system and investigated the formulation of LFC via linear control theory. A comparison between three relatives was made to the ability for motivation of the transient response of system variables.

II. LOAD FREQUENCY CONTROL PROBLEM

Load Frequency Control (LFC) can be defined as an ancillary service that is related to the short-term balance of energy and frequency of the power systems and acquires a principal role to enable power exchanges and to provide better conditions for electricity trading.

The main objectives of Load Frequency Control (LFC) are:

1. Ensuring zero steady-state error for frequency deviations.
2. Minimizing unscheduled tie line power flows between neighbouring control areas.
3. Getting good tracking for load demands and disturbances.
4. Maintaining acceptable overshoot and settling time on the frequency and tie line power deviations.

If there is a small change in load power in a single area power system operating at set value of frequency then it creates mismatch in power, both for generation and demand. This mismatch problem is initially solved by kinetic energy

extraction from the system, as a result declining of system frequency occurs. As the frequency gradually decreases, power consumed by the old load also decreases. In case of large power systems the equilibrium can be obtained by them at a single point when the newly added load is distracted by reducing the power consumed by the old load and power related to kinetic energy removed from the system. Definitely at a cost of frequency reduction this equilibrium is achieved. The system creates some control action to maintain this equilibrium and no governor action is required for this. The reduction in frequency under such condition is very large.

However, governor is introduced into action and generator output is increased for larger mismatch. Now here the equilibrium point is obtained when the newly added load is distracted by reducing the power consumed by the old load and the increased generation by the governor action. Thus, there is a reduction in amount of kinetic energy which is extracted from the system to a large extent, but not totally. So the frequency decline still exists for this category of equilibrium.

At the generation unit level, speed governor controls the speed of the prime mover as the load on the generator change. This is referred as primary speed control function. The setting of the governor can be modified as per the load to keep prime mover speed and hence frequency constant. In a single machine system, it is not a big deal to control the frequency. In the basic scheme of Load Frequency Control of single generating unit, the speed governor senses the change in speed (frequency) via the primary and supplementary control loops. A hydraulic amplifier provides the necessary mechanical forces to position the main valve against the high-steam (or hydro) pressure and the controller provides a steady-state power output setting for the turbine. For interconnected system the control is not as simple as for single unit. According to practical point of view, the load frequency control problem of interconnected power system is much more important than the isolated (single area) power systems.

Since after the introduction of governor action the system frequency is still different from its predefined value, different control strategies are needed to bring back the frequency to its predefined value with tolerance. Conventionally Integral Controllers are used for this purpose. This control is called as secondary control (which is operating after the primary control operation) which brings the system frequency to its predefined value or close to it. But the integral controllers are generally having many drawbacks.

The drawbacks can be given as follows:

1. They are very slow in operation.
2. There is some inherent nonlinearity of different power system components, which the integral controller does not care. Governor dead band effects, generation rate constraints and the use of reheat type turbines in thermal systems are some of the examples of inherent nonlinearities.
3. While there is continuously load changes occur during daily cycle, this changes the operating point accordingly. It is generally known as the inherent characteristic of power system. For good results the gain of the integrator should has to be changed repeatedly according to the change in operating point. Again it should also be ensure that, the value of the gain compromises the best between fast transient recovery and low overshoot in case of dynamic response. Practically to achieve this is very difficult. So basically an integral controller is known as a fixed type of controller. It is optimal in one condition but at another operating point it is unsuitable.

Thus the load frequency control of a multi area power system generally incorporates proper control system, by which the area frequencies could brought back to its predefined value or very nearer to its predefined value so as the tie line power, when the is sudden change in load occurs.

Implementation of modern control technique provides great help in LFC of power systems. Now days there are more complex power systems and required operation in less structured and uncertain environment. Similarly innovative and improved control is required for economic, secure and stable operation. Modern control techniques are having the ability to provide high adaption for changing conditions. They are having the ability for making quick decisions. Researchers are working in this area.

For the purposes of simulation, a two-area power system connected by a tie line is having the following parameters on a 1000 MVA common base taken as shown in table-1.

Table 1: Parameters of power system area-1 and area-2

S. No	Parameter	power system area-1	power system area-2
1	Speed Regulation due to governor action R (Hz/p.u.MW)	0.05	0.0625
2	Frequency sensitive load coefficient D	0.6	0.9
3	Inertia Constant H	5	4
4	Base Power (MVA)	1000	1000
5	Governor Time Constant T_G (T_g)	0.2 second	0.3 second
6	Turbine Time Constant T_T (T_t)	0.5 second	0.6 second
7	Electric System Gain $K_P = (1/D)$	1.67	1.11
8	Electric System Time Constant T_P	16.7	8.88

The basic block diagram of two area power system connected by tie line with ACE and PID controller is shown in fig.1.

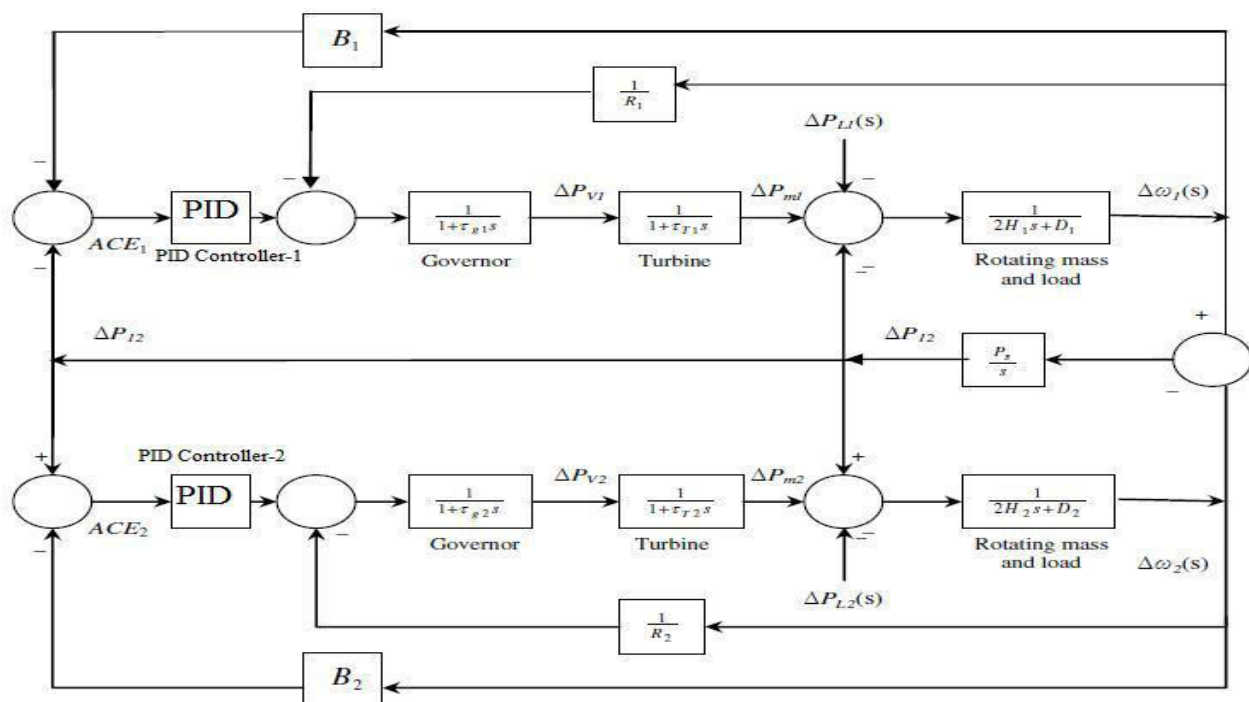


Fig.1 : LFC for a two-area power system with ACE loops and PID controller.

III. DESIGN OF CONTROLLER

Now days the use of conventional integral controllers is very rare in Load Frequency Control of power system as they produce very slow dynamic response for the system. With the wide development of control system, many different controllers have been invented which are much more effective than integral controllers.

PID controller is one of such controllers. The desired performance can be obtained by proper tuning of the PID controller parameters.

PID Controller: 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. The controller attempts to minimize the error by adjusting the process through use of a manipulated variable.

The PID controller involves three separate constant parameters and is accordingly sometimes called three-term control: the proportional, the integral and derivative values, denoted P, I, and D. Simply put, these values can be interpreted in terms of time: P depends on the present error, I on the accumulation of past errors, and D is a prediction of future errors, based on current rate of change.

Some applications may require using only one or two actions to provide the appropriate system control. This is achieved by setting the other parameters to zero. A PID controller will be called a PI, PD, P or I controller in the absence of the respective control actions. PI controllers are fairly common, since derivative action is sensitive to measurement noise, whereas the absence of an integral term may prevent the system from reaching its target value due to the control action.

PID controllers were subsequently developed in automatic ship steering. One of the earliest examples of a PID-type controller was developed by Elmer Sperry in 1911, while the first published theoretical analysis of a PID controller was by Russian American engineer Nicolas Minorsky.

The PID control scheme is named after its three correcting terms, whose sum constitutes the manipulated variable (MV). The proportional, integral, and derivative terms are summed to calculate the output of the PID controller. Defining $U(t)$ as the controller output, the final form of the PID controller is given in equation (1).

$$U(t) = MV(t) = K_p e(t) + K_i \int_0^t e(t) dt + K_d \frac{de(t)}{dt} \quad (1)$$

Proportional Term: The proportional term produces an output value that is proportional to the current error value. The proportional response can be adjusted by multiplying the error by a constant K_p , called the proportional gain constant. The proportional term is given in equation (2).

$$P_{out} = K_p e(t) \dots (2)$$

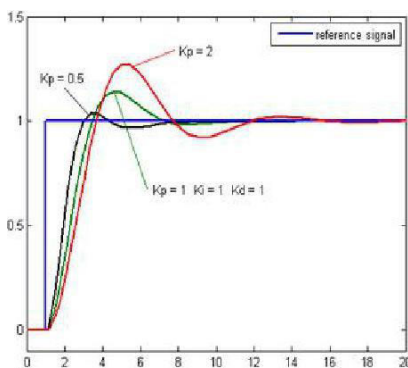


Fig. 2 : output vs time, for three values of K_p

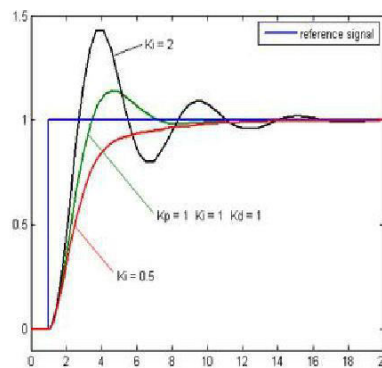


Fig.3 : output vs time, for three values of K_i

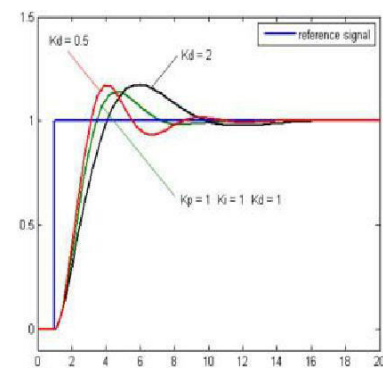


Fig. 4 :output vs time, for three values of K_d

Integral Term: The contribution from the integral term is proportional to both the magnitude of the error and the duration of the error. The integral in a PID controller is the sum of the instantaneous error over time and gives the accumulated offset that should have been corrected previously. The accumulated error is then multiplied by the integral gain K_i and added to the controller output. The integral term is given by equation (3).

$$I_{acc} = K_i \int_0^t e(t) dt \quad (3)$$

The integral term accelerates the movement of the process towards set point and eliminates the residual steady-state error that occurs with a pure proportional controller. However, since the integral term responds to accumulated errors from the past, it can cause the present value to overshoot the set point value. Fig.3 shows the effect of integral gain K_i .

Derivative term: The derivative of the process error is calculated by determining the slope of the error over the time and multiplying this rate of change by the derivative gain K_d . The magnitude of the contribution of the derivative term to the overall control action is termed the derivative gain, K_d . The derivative term is given by equation (4).

$$D_{out} = K_d \frac{d}{dt} e(t) \quad (4)$$

Derivative action predicts system behaviour and thus improves settling time and stability of the system. An ideal derivative is not causal, so that implementations of PID controllers include an additional low pass filtering for the derivative term to limit the high frequency gain and noise. Derivative action is seldom used in practice because of its variable impact on system stability in real-world applications. Fig. 4 shows the effect of derivative gain K_d .

Tuning: Tuning a control loop is the adjustment of its control parameters (proportional gain, integral gain and derivative gain) to the optimum values for the desired control response. Stability (no unbounded oscillation) is a basic requirement, but beyond that, different systems have different behaviour, different applications have different requirements and requirements may conflict with each other.

PID tuning is a difficult problem even though there are only three parameters and its principle is simple to describe, because it must satisfy complex criteria within the limitations of PID control. There are accordingly various methods for tuning and more sophisticated techniques are the subject of patents. This section describes some methods for tuning of controller parameters in PID controllers, that is, methods for finding proper values of K_p , K_i and K_d .

Designing and tuning a PID controller appears to be conceptually intuitive, but can be hard in practice, if multiple and often conflicting objectives such as short transient and high stability are to be achieved. PID controllers often provide acceptable control using default tunings, but performance can generally be improved by careful tuning and performance may be unacceptable with poor tuning. Usually, initial designs need to be adjusted repeatedly through computer simulations until the closed-loop system performs as desired.

Some processes have a degree of nonlinearity and so parameters that work well at full-load conditions don't work when the process is starting up from no-load. This can be corrected by gain scheduling (using different parameters in different operating regions).

Stability: If the PID controller parameters the gains of the proportional, integral and derivative terms are chosen incorrectly, the controlled process input can be unstable, i.e., its output diverges, with or without oscillation and is limited only by saturation or mechanical breakage. Instability is caused by excess gain, particularly in the presence of significant lag. Generally, stabilization of response is required and the process must not oscillate for any combination of process conditions and set points, though sometimes marginal stability or bounded oscillation is acceptable or desired.

Optimum Behaviour: The optimum behaviour on a process change or set point change varies depending on the application. Two basic requirements are regulation or disturbance rejection means staying at a given set point and command tracking or implementing set point changes, these refer to how well the controlled variable tracks the desired value. Specific criteria for command tracking include rise time and settling time. Some processes must not allow an overshoot of the process variable beyond the set point and other processes must minimize the energy expended in reaching a new set point.

IV.TUNING OF PID CONTROLLER BY ZIEGLER-NICHOLS (Z-N) METHOD

The Ziegler–Nichols tuning method is a heuristic method of tuning a PID controller. It was developed by John G.

Ziegler and Nathaniel B. Nichols.

Ziegler-Nichols Closed-Loop Tuning Method: The Ziegler-Nichols closed-loop tuning method allow to use the ultimate gain value K_u and the ultimate period of oscillation T_u , to calculate K_p . It is a simple method of tuning PID controllers and can be refined to give better approximations of the controller. The controller constants K_p , K_i and K_d can be obtained for a system with feedback. The Ziegler-Nichols closed-loop tuning method is limited to tuning processes that cannot run in an open-loop environment.

Determining the ultimate gain value K_u is accomplished by finding the value of the proportional gain that causes the control loop to oscillate indefinitely at steady state. This means that the gains from the I and D controller are set to zero so that the influence of P can be determined. It tests the robustness of the K_p value so that it is optimized for the controller. Another important value associated with this proportional control tuning method is the ultimate period (T_u). The ultimate period is the time required to complete one full oscillation while the system is at steady state. These two parameters, K_u and T_u , are used to find the loop-tuning constants of the controller (P, PI, or PID). To find the values of these parameters and to calculate the tuning constants, use the following procedure:

1. Remove integral and derivative action. Set integral gain (K_i) to zero value and set the derivative controller gain (K_d) to zero.
2. Create a small disturbance in the loop by changing the set point. Adjust the proportional, increasing and/or decreasing, the gain until the oscillations have constant amplitude.
3. Record the gain value (K_u) and period of oscillation (T_u).
4. Put these values into the Ziegler-Nichols closed loop equations and determine the necessary settings for the controller.

Table 2 : PID controller parameters using Ziegler–Nichols Method

Control Type	K_p	K_i	K_d
P	$0.5 K_u$	-	-
PI	$0.45 K_u$	$1.2 K_p / T_u$	-
PD	$0.8 K_u$	-	$K_p T_u / 8$
PID	$0.60 K_u$	$2 K_p / T_u$	$K_p T_u / 8$

For power system area-1

$K_u=1.1$ and $T_u=4s$, Therefore $K_p=0.6 K_u=0.66$, $K_i=2 K_p/T_u=0.33$ and $K_d=K_p T_u/8=0.33$

For power system area-2

$K_u=1.5$ and $T_u=4s$, Therefore $K_p=0.6 K_u=0.9$, $K_i=2 K_p/T_u=0.45$ and $K_d=K_p T_u/8=0.45$

Table 3 : PID controller parameters calculated using Ziegler–Nichols Method

Power System Area-1					Power System Area-2				
K_u	T_u	K_p	K_i	K_d	K_u	T_u	K_p	K_i	K_d
1.1	4s	0.66	0.33	0.33	1.5	4s	0.9	0.45	0.45

V. TUNING OF PID CONTROLLER BY SIMPLEX SEARCH METHOD

There are many methods available for tuning of PID controller. All these methods are used as initial guess for PID controller parameter setting. Later these settings are improved by fine tuning. Now a days simulation softwares are widely popular. MATLAB Simulink is one of them. Hence the advantage of simulation tools taken and used a method for tuning of PID controllers using simulation.

When a Simulink model is design to meet requirements for optimizing parameters, Simulink Design Optimization software automatically converts the requirements into a constrained optimization problem and then solves the problem using optimization techniques. The constrained optimization problem iteratively simulates the Simulink model,

compares the results of the simulations with the constraint objectives and uses optimization methods to adjust tuned parameters to better meet the objectives.

Simplex Search Method Problem Formulations: The Simplex Search method uses the Optimization Toolbox function `fminsearch` and `fminbnd` to optimize model parameters to meet design requirements. `fminbnd` is used if one scalar parameter is being optimized otherwise `fminsearch` is used. Parameter bounds cannot be used with `fminsearch`.

Several options for the optimization can be set. These options include the optimization methods and the tolerances the methods use. Both the Method and Algorithm options in the Optimization method area define the optimization method. The following results were obtained from Simplex tuning method as shown in table 4.

Table 4: PID controller parameters calculated using Simplex method

Power System Area-1			Power System Area-2		
K_p	K_i	K_d	K_p	K_i	K_d
0.4221	1.2113	0.3295	0.9	0.45	0.45

VI. RESULT AND DISCUSSION

In this section simulated two area power system connected by the tie line with (i) Only AGC loop (ii) AGC with ACE loop (integral control only) (iii) LFC with PID controller are shown. Also the PID controller whose parameters are tuned with different methods is applied and results are shown.

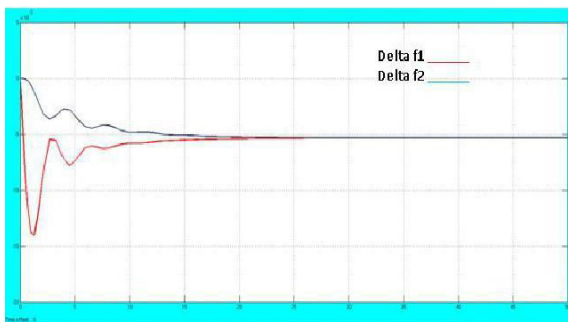


Fig 5. : Δf_1 and Δf_2 with AGC loop



Fig.6 : Δf_1 and Δf_2 with AGC-ACE loop

Fig. 5 shows the frequency deviation in area-1 and area-2 with only AGC loop. It is seen that there is always deviation in frequencies of both areas after the load change. Δf_1 and Δf_2 never set to zero. Fig. 6 shows the frequency deviation in area-1 and area-2 with AGC-ACE loop. It can be seen that there are number of oscillations and it take a large time to set Δf_1 and Δf_2 to zero or very near to zero.

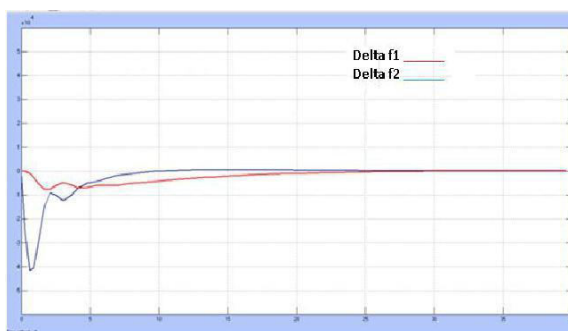


Fig.7 : Δf_1 and Δf_2 with PID controller tuned by Z-N method

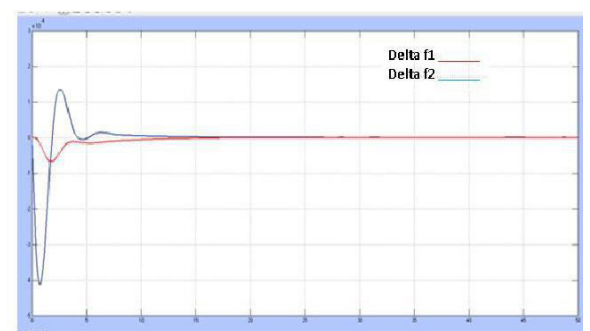


Fig.8: Δf_1 and Δf_2 with PID controller tuned by Simplex method

Fig. 7 and fig. 8 shows the frequency deviation in area-1 and area-2 with PID controller tuned by Z-N method and simplex method respectively. It is seen deviation in frequencies of both areas (Δf_1 and Δf_2) set to zero in very small time after the load change. Also there are very few oscillations. It means that both transient and steady state response improve.

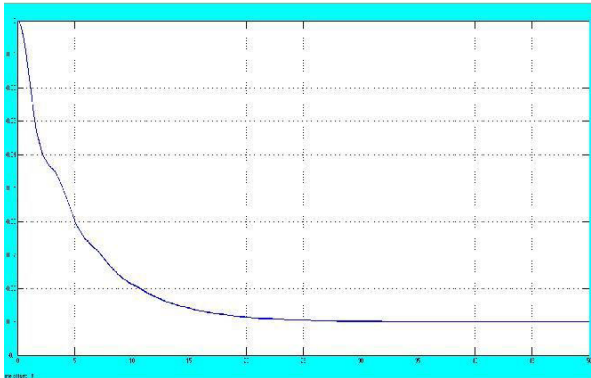
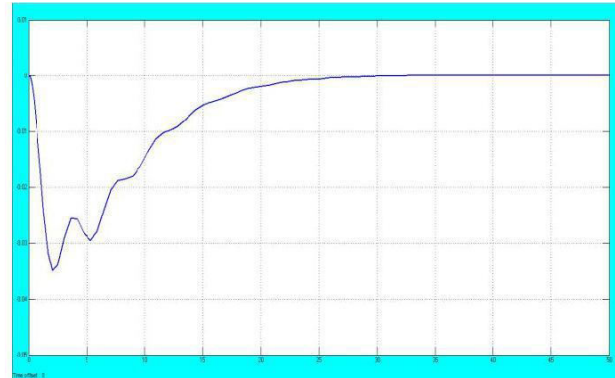

Fig.9: ΔP_{tie} with AGC loop

Fig.10: ΔP_{tie} with AGC-ACE loop

Fig. 9 shows Tie line power deviation with only AGC loop. It is seen that there is always deviation in tie line power of after the load change. ΔP_{tie} never set to pre set value. Fig. 10 shows the tie line power deviation with AGC-ACE loop. It can be seen that there are number of oscillations and it take a large time to set ΔP_{tie} to pre set value or very near to it.


Fig.11: ΔP_{tie} with PID controller tuned by Z-N method

Fig.12: ΔP_{tie} with PID controller tuned by Simplex method

Fig. 11 and fig. 12 shows ΔP_{tie} with PID controller tuned by Z-N method and simplex method respectively. It is seen deviation in tie line power (ΔP_{tie}) set to its pre defined value in very small time after the load change. Also there are very few oscillations. It means that both transient and steady state response improve.

Table 5 : Time response specifications for f1

S.No	Tuning Method	PID Controller -1			PID Controller -2			Mp	Tp	Tr	Ts	Response
		Kp	Ki	Kd	Kp	Ki	Kd					
1	Z-N	0.66	0.33	0.33	0.9	0.45	0.45	-0.8×10^{-4}	2s	27s	27s	Stable
2	Simplex	0.3295	1.2113	0.4221	0.45	0.45	0.9	-0.6×10^{-4}	2s	16s	16s	Stable

Here table 5 shows the comparative study of time response specifications for deviation in frequency of area-1(Δf_1) with PID controller whose parameters are tuned by Z-N method and simplex method.

Table 6 : Time response specifications for f_2

S.No	Tuning Method	PID Controller -1			PID Controller -2			Mp	Tp	Tr	Ts	Response
		Kp	Ki	Kd	Kp	Ki	Kd					
1	Z-N	0.66	0.33	0.33	0.9	0.45	0.45	-4.1×10^{-4}	1s	10s	10s	Stable
2	Simplex	0.3295	1.2113	0.4221	0.45	0.45	0.9	-4.1×10^{-4}	1s	2s	16s	Stable

The table 6 shows the comparative study of time response specifications for deviation in frequency of area-2(Δf_2) for load change with PID controller whose parameters are tuned by Z-N method and simplex method.

Table 7 : Time response specifications for T_{tie}

S.No	Tuning Method	PID Controller -1			PID Controller -2			Mp	Tp	Tr	Ts	Response
		Kp	Ki	Kd	Kp	Ki	Kd					
1	Z-N	0.66	0.33	0.33	0.9	0.45	0.45	-1.1×10^{-3}	4s	25s	25s	Stable
2	Simplex	0.3295	1.2113	0.4221	0.45	0.45	0.9	-0.8×10^{-3}	2s	20s	20s	Stable

The table 7 shows the comparative study of time response specifications for deviation in tie line power (ΔP_{tie}) with PID controller whose parameters are tuned by Z-N method and simplex method.

The change in load powers which are the input disturbances are taken as, $\Delta P_{L1} = 0.01$ pu, $\Delta P_{L2} = 0.00$ pu for all the cases.

VII. CONCLUSION

Model of a two area interconnected power system has been developed with different area characteristics for modern and conventional control strategies. In LFC systems it is important to keep the power system frequency and the inter area tie line power as close as possible to the scheduled values. It has been shown that the use of simple integral controller is incapable of obtaining good dynamic performance.

The PID controllers are well known and are widely used in power system and control systems to damp system oscillations, increase stability and reduce steady state error as they are simple to realize and easily tuned. It is seen that if the proper tuning of parameter of PID controller is done, the area frequencies could brought back to its predefined value or very nearer to its predefined value with acceptable tolerance so as the tie line power in minimum time, when the is sudden change in load occurs .

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