PID based Automatic Load Frequency Controller for Multiple Control Area

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Abstract— *In India, the Power grid is divided into 5 major regions or parts. As we all know that in India, the power system is established to work on 50Hz frequency among all major power grid. Frequency is interrelated with the load so as the load among various region changes it tends to the change in frequency of the system which is not permissible for the smooth operation of power system. In this research paper we have simulated a multiple control area where frequency is controlled by a PID controller in order to ensure that if load of certain control area(s) changes then the frequency remains within controlled permissible limits of the frequency. Here the variation in frequency and its controlling in ALFC is shown with graphical representation with and without help of controller.*

Keywords— Control Area, ALFC, PID Controller, Tuning, Simulation

I. INTRODUCTION

The frequency is a major factor which is related to real power for the purpose of balance in a overall network. While considering normal operation condition we find that generator that run synchronously generates the power which is being drawn by all kind of loads and also the real transmission losses. Although the amount of power lost in transmission is only a few percent of total transmitted power but it includes various factors for its existence such as i) ohmic losses in various transmission component ii) core losses in transformer and generator iii) corona loss on conductor.

In a overall view the rate of production of electric energy must be equal to rate at electric energy get consumed at load at every particular moment of time. If we fail to create this synchronism the power get imbalance and difference created would enter into kinetic energy storage. As we know the kinetic energy depends upon generator's speed, thus a power imbalance will get translated into frequency/ speed deviation. As the system load changes, it is compulsory to change the generation level so that power in balance can be easily minimized and with the change in load the level of frequency can be maintained within the prescribed limit.

II. AUTOMATIC GENERATION CONTROL (AGC)

To understand the variation of frequency in a power system, we can consider a single machine connected to an isolated load, as shown in the figure below.

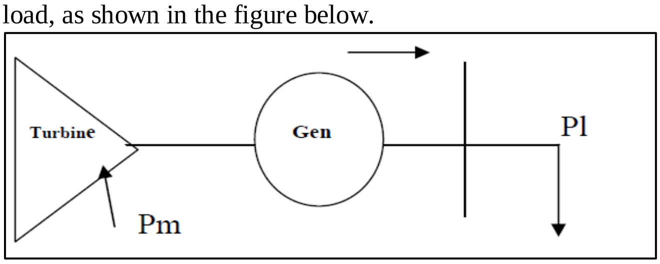

Fig. 1: Single Turbine Generator with Load

Normally, the turbine mechanical power (P_m) and the electrical load power (P_i) are equal. Whenever there is a change in load, with mechanical power remaining the same the speed (ω) of the turbine generator changes as decided by the rotating inertia (M) of the rotor system, as given by the following differential equation,

$$P_m - P_i = M[d\omega/dt] \qquad \text{eq. (1)}$$

The governing system senses this change in speed and adjusts steam control valve so that mechanical power (P_m) matches with the changed load (P_i). Speed variation stops but at a different steady value. The change in frequency (Δω) at steady state can be described using the following equation in terms of change in load (ΔP_i) and a factor R called 'speed regulation or 'droop'.

$$\Delta\omega = -[\Delta P_i](R) \qquad \text{eq. (2)}$$

Automatic Generation Control (AGC) usually implemented in Energy Management system (EMS) of Energy Control centers (ECC) consists of:

- Load frequency control
- Economic Dispatch
- Interchange scheduling

If the load on the system is increased suddenly then the turbine speed drops before the governor can adjust the input of the steam to the new load. As the change in the value of speed diminishes the error signal becomes smaller and the positions of the governor and not of the fly balls get closer to the point required to maintain the constant speed. One way to restore the speed or frequency to its nominal value is to add an integrator on the way. The integrator will unit shall monitor the average error over a period of time and will overcome the offset. Thus as the load of the system changes continuously the generation is adjusted automatically to restore the frequency to the nominal value. This scheme is known as automatic generation control. In an interconnected system consisting of several pools, the role of the AGC is to divide the load among the system, stations and generators so as to achieve maximum economy and reasonably uniform frequency.

III. LOAD FREQUENCY CONTROLLER

The speed/ frequency variation concept can be extended from a single turbine- generator system to a power system comprising several turbine- generators as shown in Fig.6. Now the mismatch between the total power generated and the total electrical load causes the frequency change as dictated by the combined system inertia. The governors of all the machines sense the frequency and the mechanical power outputs will be changed automatically to match the combined generation with the new combined load. This action is called primary regulation.

But frequency remains at a new value and set points must be adjusted, just as in single machine case for frequency restoration. This job is done by the Automatic Load Frequency controller (ALFC) as shown in Fig. This process of set point adjustment is called secondary regulation.

When load change occurs frequency varies and the regulation initially for the first few seconds is due to the action of the governors of all generating units and subsequently the Load frequency control system prevails.

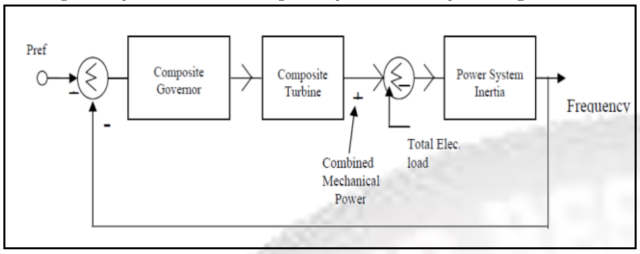

Fig. 2: Block Diagram Showing Power System Frequency Variation

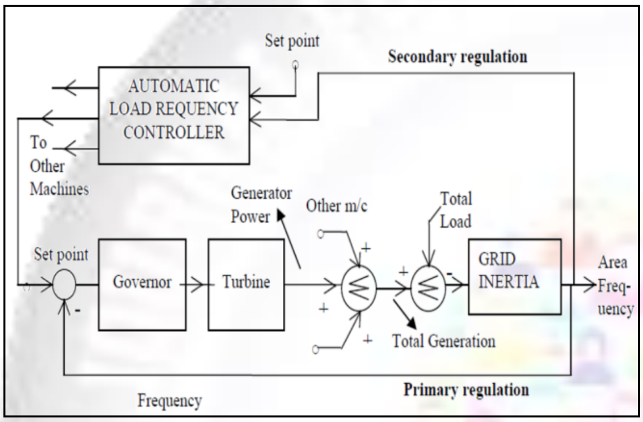

Fig. 3: Automatic Load Frequency Control System

Load-frequency control (LFC) is a type of integral control that restores the system frequency and power flows to adjacent areas back to their values before a change in load.

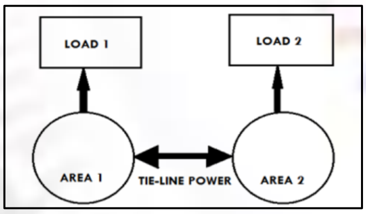

Fig. 4: Interconnected Power Systems with two Independent Loads

IV. MATHEMATICAL MODELING

Applying the swing equation [6] of a synchronous machine to small perturbation, we have

$$:\frac{2H}{\omega}\frac{d^2\Delta\delta}{dt^2} = \Delta P_m - \Delta P_e \qquad \text{eq. (3)}$$

Or in terms of small deviation in speed,

$$\frac{d\Delta\frac{\omega}{\omega_s}}{dt} = \frac{1}{2H}(\Delta P_m - \Delta P_e) \qquad \text{eq. (4)}$$

Taking Laplace Transform, we obtain

$$\Delta\Omega(s) = \frac{1}{2H_s}[\Delta P_m(s) - \Delta P_e(s)] \qquad \text{eq. (5)}$$

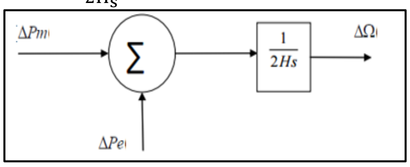

Fig. 5: Mathematical Model of Generator

A. Modeling of Load

The load on power system consists of a variety of electrical drives. The equipments used for lighting purposes are basically resistive in nature and the rotating devices are basically a composite of the resistive and inductive components. [6]

The speed-load characteristic of the composite load is given by:

$$\Delta P_e = \Delta P_L + D\Delta\omega \qquad \text{eq. (6)}$$

Where ΔP_L is the non-frequency- sensitive load change,
$D\Delta\omega$ is the frequency sensitive load change.

D is expressed as percent change in load by percent change in frequency.

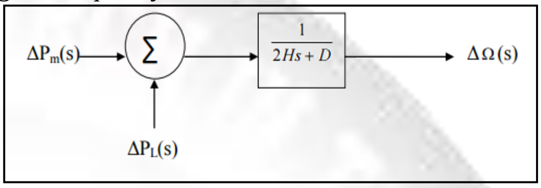

Fig. 6: Mathematical Model of Load

B. Modeling for Governor

Governor is a device used to control the speed of a prime mover. A governor protects the prime mover from over speed and keeps the prime mover speed at or near the desired revolutions per minute. When a prime mover drives an alternator supplying electrical power at a given frequency, a governor must be used to hold the prime mover at a speed that will yield this frequency. An unloaded diesel engine will fly to pieces unless it is under governor control.

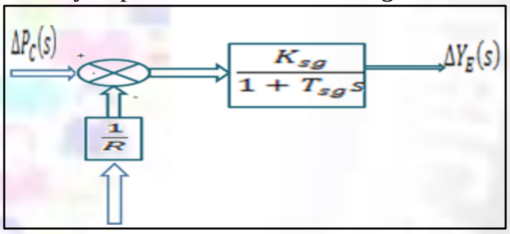

Fig. 7: Governor Model

Mathematical model of governor is shown in above figure. We can write its transfer function as,

$$\boxed{\Delta Y_E(s) = \left[\Delta P_C(s) - \frac{1}{R}\Delta F(s)\right] \times \left[\frac{K_{sg}}{1+T_{sg}s}\right]} \qquad \text{eq. (7)}$$

Combining all the block diagrams from earlier block diagrams for a single are system we get the following:

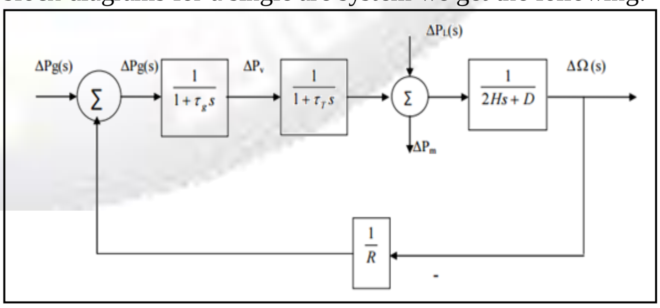

Fig 8: Model of Single System having Governor, Generator, Prime Mover and Load

C. Modeling of Turbine

Figure shown below represents mathematical model for turbine:

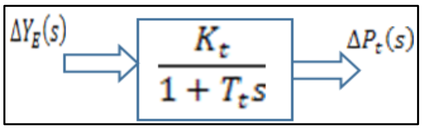

Fig. 9: Turbine Model

The transfer function of turbine is given by,

$$\Delta P_t(s) = \Delta Y_E(s)\frac{K_t}{1+K_t s} \qquad \text{eq. (8)}$$

V. VARIOUS TYPES OF TUNING

There are several methods for tuning a PID loop. The most effective methods generally involve the development of some form of process model, and then choosing P, I, and D based on the dynamic model parameters. Manual tuning methods can be relatively inefficient, particularly if the loops have response times on the order of minutes or longer. The choice of method will depend largely on whether or not the loop can be taken "offline" for tuning, and on the response time of the system. If the system can be taken offline, the best tuning method often involves subjecting the system to a step change in input, measuring the output as a function of time, and using this response to determine the control parameters.

A. Manual Tuning

If the system must remain online, one tuning method is to first set K_i and K_d values to zero. Increase the K_p until the output of the loop oscillates, and then the K_p should be set to approximately half of that value for a "quarter amplitude decay" type response. Then increase K_i until any offset is corrected in sufficient time for the process. However, too much K_i will cause instability. Finally, increase K_d, if required, until the loop is acceptably quick to reach its reference after a load disturbance. However, too much K_d will cause excessive response and overshoot. A fast PID loop tuning usually overshoots slightly to reach the set point more quickly; however, some systems cannot accept overshoot, in which case an over-damped closed-loop system is required, which will require a K_p setting significantly less than half that of the K_p setting that was causing oscillation.

B. Ziegler–Nichols Method

Another tuning method is formally known as the Ziegler Nichols method, introduced by John G. Ziegler and Nathaniel B. Nichols in the 1940s. As in the method above, the K_i and K_d gains are first set to zero. The proportional gain is increased until it reaches the ultimate gain, K_u, at which the output of the loop starts to oscillate. K_u and the oscillation period P_u are used to set the gains.

C. PID Tuning Software

Most modern industrial facilities no longer tune loops using the manual calculation methods shown above. Instead, PID tuning and loop optimization software are used to ensure consistent results. These software packages will gather the data, develop process models, and suggest optimal tuning. Some software packages can even develop tuning by gathering data from reference changes. Mathematical PID loop tuning induces an impulse in the system, and then uses the controlled system's frequency response to design the PID loop values. In loops with response times of several minutes, mathematical loop tuning is recommended, because trial and error can take days just to find a stable set of loop values. Optimal values are harder to find. Some digital loop controllers offer a self-tuning feature in which very small set point changes are sent to the process, allowing the controller itself to calculate optimal tuning values**.** Other formulas are available to tune the loop according to different performance criteria. Many patented formulas are now embedded within PID tuning software and hardware modules.

D. NCD Optimization Method

NCD uses optimization algorithms to find parameter values that allow a feasible solution to the given constraints. NCD automatically converts the constraint bound data and tunable variable information into a constrained optimization problem. Basically, the NCD Block set attempts to minimize the maximum constraint error. The NCD Block set generates constraint errors at equally spaced time points beginning at the simulation start time and ending at the simulation stop time. For upper bound constraints, it is defined the constraint error as the difference between the simulated output and the constraint boundary. For lower bound constraints, it is defined the constraint error as the difference between the constraint boundary and the simulated output.

VI. SIMULATION MODEL AND PARAMETERS

In the simplified model, there are two control areas. One has two thermal generators and another have only one hydro generator. PID controllers are attached there, then we analysis the dynamic response of the system by using both two tuning methods. In model-1 controller has been applied to a two area power system having the following data:-

The values of controllers obtained from Zeigler Nichols method are as follows:-

Parameters	Area1	Area2
K_g	1	1
T_g	0.08	0.072
K_t	1	1
T_t	0.3	0.33
Parameters	Area1	Area2
K_{ps}	120	112.5
T_{ps}	20	25
B	0.425	0.425
R	2.4	2.7

Table 1: Simplified Model, there are two control areas

$K_u = 11 \quad T_u = 10$

VII. SIMULATION RESULTS

Two area interconnected power system is represented using new state variables namely frequency deviation and its derivative as state variables in both the areas without integral control of frequency in each case. The static errors of the frequency deviations and tie line power deviations are increasing with increase in load changes without PID controller.

The case study with PID controllers in both the areas for a load change in area 1 indicates that the responses are oscillatory. However the magnitudes of the overshoots are less compared to that of the integral controller case. It is also observed that the values of the maximum overshoots are increasing with increase in load changes. The settling times for frequency deviations and tie line power deviations are less with this scheme

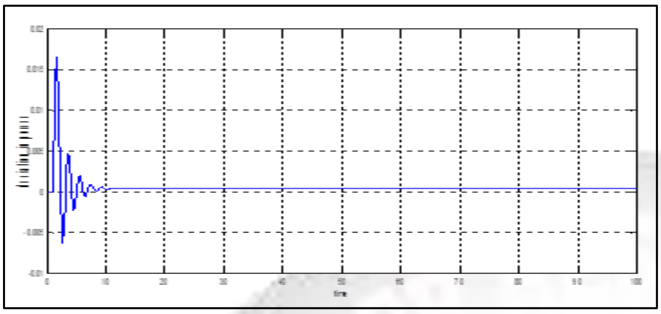

Fig. 10: Change in Power for Model-1

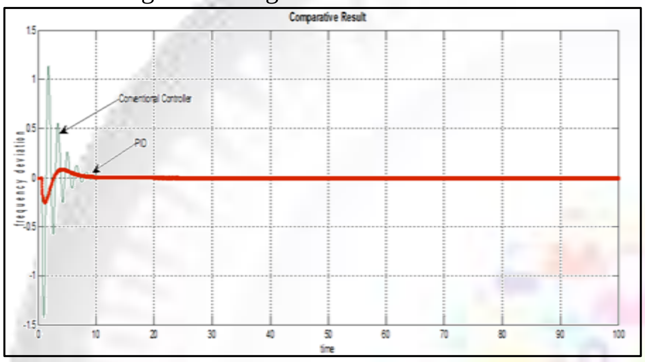

Fig. 11: Comparative Results of Deviation in Frequency of Control Area-1

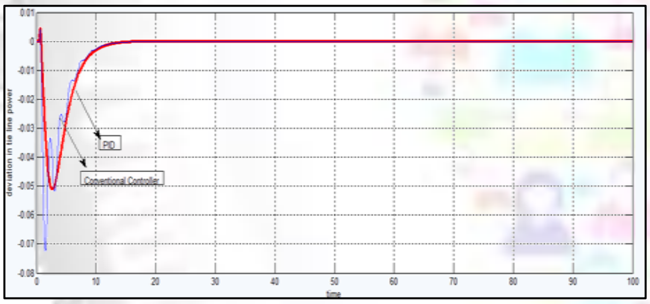

Fig. 12: Comparative Results of Deviation of Tie Line Power

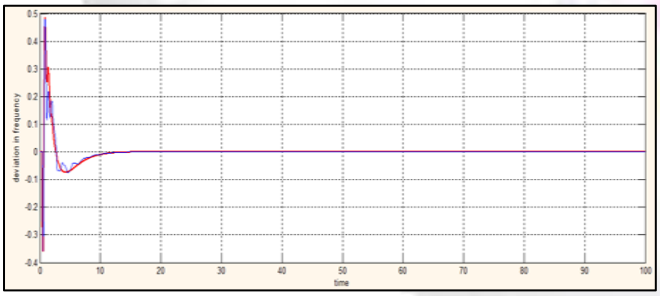

Fig. 13: Comparative Results of Deviation in Frequency of Control Area-2

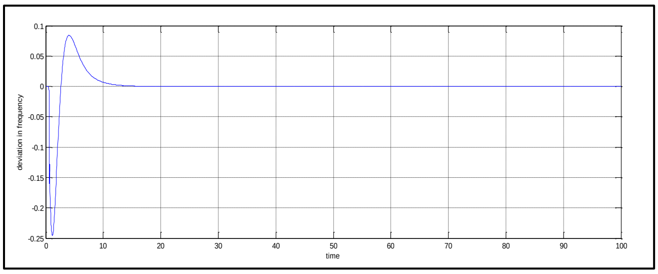

Fig 14: Deviation of Power of Control Area-1

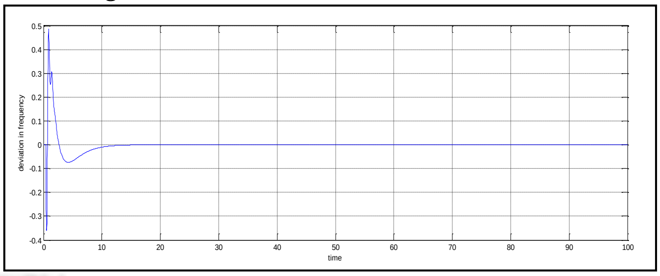

Fig15 : Deviation of Power of Control Area-2

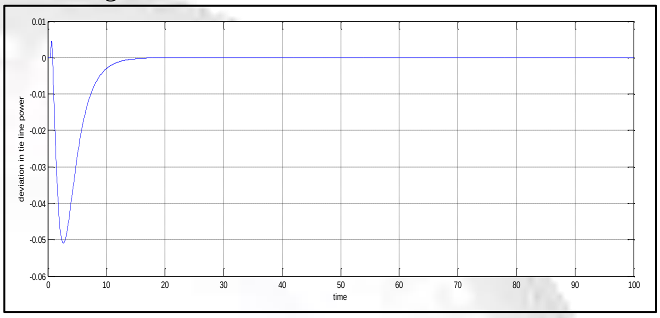

Fig. 16: Deviation of Tie Line Power

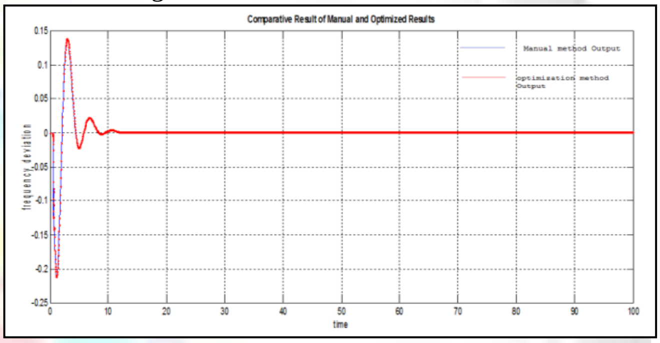

Fig. 17: Comparative Results of Zeigler Nichols & Optimized Method

These results show that the structure of PID controller is more effective than the conventional integral controller.

VIII. CONCLUSION

From the given simulations it is clear that the Figure 13 which depicts the deviation in frequency of the isolated system has more ripples and its counterpart in Figure 15 and has fewer ripples. It is clear from the graphical representation of the step response that the settling time is more while integral controllers. When we have a look into the step response in the PID Controller design then it is observed that the settling time is comparatively less. The system reaches equilibrium faster than that for the conventional controllers. In general there are two situations where the tuning is required. The first case is when the system is unstable. The second case is when the system is stable but the settling time is more. The comparison between both two tuning Technique shows that result obtained from Zeigler Nichols method are optimum and quite similar with results of NCD block set method. Hence NCD block set method is nothing but use only to optimize the results within the prescribed limit.

Controllers	Settling time	Peak time
Conventional(Integral)	5.4534	7.2948
PID	2.5910	4.0672

Table 1: Comparison between different controllers

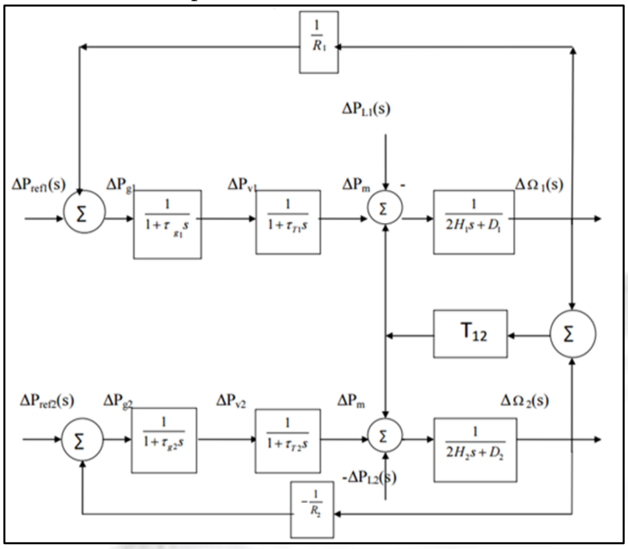

Fig. 18: Mathematical Model of AGC for a Multi Area Power System

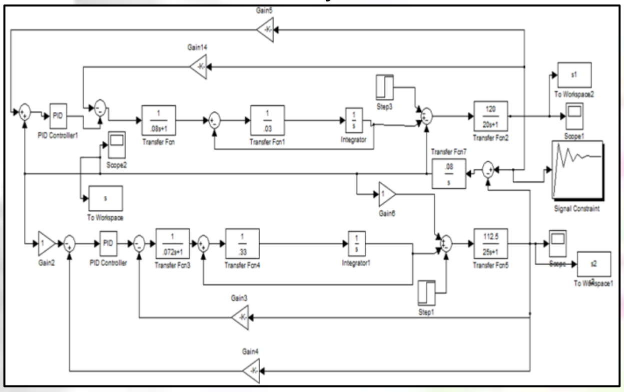

Fig. 19: Simplified Simulink model of Two Area System

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