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Study of PID Controllers to Load Frequency Control Systems with Various Turbine Models

Abdul Shariq*, Shanti Bayyavarapu**
*(Department of Electrical Engineering, A.U.College of Engineering, Andhra University, Visakhapatnam)
** (Department of Electrical Engineering, A.U.College of Engineering, Andhra University, Visakhapatnam)

ABSTRACT
This paper studies the load frequency control problem for various systems under various controller design methods. Frequency should remain nearly constant for satisfactory operation of a power system because frequency deviations can directly impact on a power system operation, system stability, reliability and efficiency. 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 system to original set point values or very nearer to set point values effectively after any load change. This can be achieved by the use of conventional and modern controllers. In this proposed paper PID controller has been applied for LFC power systems. The parameters of the PID controller are tuned by different methods names as Ziegler-Nichols (Z-N) Method, and IMC method for better results. We use various tuning formulae in Z-N method and certain model approximation methods and the responses of LFC with model approximation are studied. It is seen that the results obtained are as good as the conventional controller.

Keywords – Integral Model Controller(IMC), Load Frequency Control(LFC), PID controllers, Zielger-Nichols Method

I. INTRODUCTION

THE problem of controlling the real power output of generating units in response to changes in system frequency and tie-line power interchange within specified limits is known as load frequency control (LFC).

The Objectives of LFC are to provide zero steady-state errors of frequency and tie-line exchange variations, high damping of frequency oscillations and decreasing overshoot of the disturbance so that the system is not too far from the stability. 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

Due to the increased complexity of modern power systems, advanced control methods were proposed in LFC, e.g., optimal control; variable structure control; adaptive and self-tuning control; intelligent control; and robust control. Recently, LFC under new deregulation market, LFC with communication delay, and LFC with new energy systems received much attention. Improved performance might be expected from the advanced control methods, however, these methods require either information on the system states or an efficient online identifier thus may be difficult to apply in practice.

Here, PID controllers for LFC were studied due to their simplicity in execution. Certain papers suggested fuzzy PI controllers for load frequency control of power systems; proposed a derivative structure which can achieve better noise-reduction than a conventional practical differentiator thus load frequency controller of PID type can be used in LFC; proposed a PID load frequency controller tuning method for a single-machine infinite-bus (SMIB) system based on the PID tuning method proposed and the method is extended to two-area case. It is shown that the resulted PID setting needs to be modified to achieve desired performance. In this paper, methods to design and tune PID load frequency controller for power systems with non-reheat, reheat and hydro turbines using Revised Zielger-Nichols(RZ-N) tuning and Integral Model Controller (IMC) will be discussed. The methods are flexible in that the performance and robustness of the closed-loop systems are related to single tuning parameter in IMC and two tuning parameters in RZ-N. These methods can also be extended to multi-area power systems.

Tuning Methods

A thorough study of papers based on PID controller tuning methods and stabilization of LFC using PID Controllers has been carried out.

The basics of PID controllers have been studied using references [1] –[2]. The various tuning methods used in PID controllers like Ziegler-Nichols Tuning Formula, revised and Modified Z-N tuning formulae are used thoroughly studied and algorithms and programs were developed to use them for various systems. Approaches for identifying the equivalent first-order plus dead time model, which is essential in some of the PID controller design algorithms, will be presented. A modified Ziegler–Nichols algorithm is also given. Some other simple PID setting formulae such as the Chien–Hrones–Reswick formula, Cohen–Coon formula, refined Ziegler–Nichols tuning, Wang–Juang–Chan formula and Zhuang–Atherton optimum PID controller will be presented.

The study of Model approximation methods, to approximate a given plant to First Order Plus Dead Time (FOPDT) or First Order Integral Plus Dead Time (FOIPDT) formulae for FOIPDT (first- order lag and integrator plus dead time) and IPDT (integrator plus dead time) plant models, rather than the FOPDT (first-order plus dead time) model, will be given in sections .

IMC controller with Single Degree of Freedom and Two degree of Freedom are studied using and their methods of implementations are presented.
Load Frequency Controller Operation, the derivation of various transfer functions in LFC, the importance of stabilization are studied and presented. The implementation designs of PID Controllers on LFC under various systems like non-reheated, reheated, hydrothermal systems with and without drooping characteristics are studied.

II. LFC-PID DESIGN

We consider the case of a single generator supplying power to a single service area, and consider three types of turbine used in generation. We are interested in tuning PID controllers to improve the

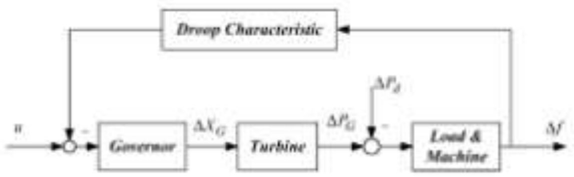

Fig. 2.1.Linear model of a single-area power system.

performance of load frequency control system, i.e., $u=-K(s)\Delta f$ find a control law , where K(s) takes the form

$$K(s)=K_p\left(1+\frac{1}{T_i s}+T_d s\right) \tag{2.1}$$

In practice, to reduce the effect of noise, the PID controller should be implemented as a practical one

$$K(s)=K_P\left(1+\frac{1}{T_i s}+\frac{T_d s}{Ns+1}\right) \tag{2.2}$$

Where N is the filter constant

$$K(s)=K_p\left(1+\frac{1}{T_i s}+\frac{T_d(1-e^{-Ts})}{T}\right) \tag{2.3}$$

where T is a small sampling rate.

Since for the load-frequency control problem the power system under consideration is expressed only to relatively small changes in load, it can be adequately represented by the linear model. (obtained by linearizing the plant around the operating point).
The droop characteristic is a feedback gain to improve the damping properties of the power system, and it is generally set to 1/R before load frequency control design. So there are two alternatives for LFC design, i.e.,

1) Design controller $\tilde{K}(s)$ for the power system without droop characteristic, and then subtract 1/R from $\tilde{K}(s)$,i.e., the final controller will be

$$K(s)=\tilde{K}(s)-1/R \tag{2.4}$$

If $\tilde{K}(s)$ is of PID type, then the final proportional gain of the PID controller just needs to be decreased by 1/R.

Design controller K(s) directly for the power system with droop characteristic.
The model dynamics for the two cases are different so the final result might be different if the tuning parameters are not carefully chosen. We will discuss the two alternatives in detail.

2.1 LFC Design Without Droop Characteristic
2.1.1 Non-Reheated Turbine:

The plant for a power system with a non-reheated turbine consists of three parts:

• Governor with dynamics:

$$G_g(s)=\frac{1}{T_G s+1} \tag{2.5}$$

• Turbine with dynamics:

$$G_t(s)=\frac{1}{T_T s+1} \tag{2.6}$$

• Load and machine with dynamics:

$$G_p(s)=\frac{K_P}{T_P s+1} \tag{2.7}$$

Now the open-loop transfer function without droop characteristic for load frequency control is

$$\tilde{P}(s)=G_pG_tG_g=\frac{K_P}{(T_P s+1)(T_T s+1)(T_G s+1)} \tag{2.8}$$

From the TDF-IMC-PID design procedure, since $\tilde{P}$ is minimum-phase, the set point-tracking IMC controller takes the form

$$Q(s) = \tilde{P}^{-1}(s)\frac{1}{(\lambda_s + 1)^3} = \frac{(T_P s+1)(T_T s+1)(T_G s+1)}{K_P(\lambda s+1)^3} \quad (2.9)$$

To improve the disturbance response another degree of freedom Qd(s) is used. We observe that the load demand $\Delta P_d(s)$ must pass through $K_P/(T_P s+1)$ to affect the frequency deviation $\Delta f(s)$, in order to have a fast disturbance rejection; we choose Qd to cancel the pole s=-(1/Tp) .

S.no	Parameter	Power System
1	Speed Regulation due to governor action R (Hz/p.u.MW)	2.4
2	Electric System Gain(Kp)(s)	120
3	Electric System Time Constant(Tp)(s)	20
4	Turbine Time Constant(Tt)(s)	0.4
5	Governor Time Constant (Tg)(s)	0.08

Let $Q_d = \frac{\alpha_1 s+1}{\lambda_d s+1}$ then α_1 should satisfy

$$(1-\tilde{P}(s)Q(s)Q_d(s))|_{s=\frac{1}{T_P}} \quad (2.10)$$

that is,

$$\alpha_1 = T_P\left(1-\left(1-\frac{\lambda}{T_P}\right)^3\left(1-\frac{\lambda_d}{T_P}\right)\right) \quad (2.11)$$

By choosing suitable parameters λ and λ_d, TDF-IMC controllers Q(s) and Qd(s) can be obtained and the corresponding PID controller can be obtained by the procedure described in the previous section.

2.1.2 Reheated Turbine:

For reheated turbines, the turbine dynamics becomes

$$G_t(s) = \frac{cT_r+1}{(T_r s+1)(T_T s+1)} \quad (2.12)$$

where Tr is a constant and is the portion (percentage) of the power generated by the reheat process in the total generated power. In such case the open-loop transfer function without droop characteristic becomes

$$\tilde{P}(s) = G_p G_t G_g = \frac{K_P(cT_r s+1)}{(T_P s+1)(T_T s+1)(T_r s+1)(T_G s+1)} \quad (2.13)$$

and the set point-tracking IMC takes the form

$$Q(s) = \frac{(T_P s+1)(T_T s+1)(T_r s+1)(T_G s+1)}{K_P(cT_r s+1)(\lambda s+1)^3} \quad (2.14)$$

The disturbance-rejecting IMC Qd has the same structure as the non-reheat turbine case, and α_1 can be computed in the same way as in .

2.1.3 Hydro Turbine:

For hydro turbines, the turbine dynamics is

Table : 3.1 Non Reheated Turbine System Parameters.

$$G_t(s) = \frac{1-T_\omega s}{1+0.5T_\omega s} \quad (2.15)$$

where is a constant. In this case the open-loop transfer function without droop characteristic becomes

$$\tilde{P}(s) = G_p G_t G_g = \frac{K_P(1-T_\omega s)}{(T_P s+1)(0.5T_\omega s+1)(T_G s+1)} \quad (2.16)$$

the transfer function contains a right-half-plane zero, so the setpoint-tracking IMC takes the form

$$Q(s) = \left(\frac{(T_P s+1)(0.5T_\omega s+1)(T_G s+1)}{K_P(1-T_\omega s)(\lambda s+1)^2}\right) \quad (2.17)$$

The disturbance-rejecting IMC has the same structure as the non-reheat turbine case, however, in this case the parameter α_1 must satisfy

$$\alpha_1 = T_P\left(1-\left(1-\frac{\lambda}{T_P}\right)^2\left(1-\frac{\lambda_d}{T_P}\right)/\left(1+\frac{T_\omega}{T_P}\right)\right) \quad (2.18)$$

2.2 LFC Design With Droop Characteristic

In this case the plant model used in LFC design is

$$P(s) = \frac{G_g G_t G_p}{1+G_g G_t G_P/R} \quad (2.19)$$

Where Gg is the governor dynamics ,Gp is the load and machine dynamics, and Gt is the turbine dynamics for non-reheated turbines, for reheated turbines, and for hydro turbines.

Unlike $\tilde{P}(s)$ discussed in the previous subsection, which has a non-oscillatory step response for all kinds of turbines, the step response of P(s) is generally oscillatory, even unstable in some cases for hydro turbines, so the LFC design is more complicated. It was shown that for LFC tuning purpose, the transfer function of the power systems can be approximated with a second-order oscillatory model, and a PID tuning procedure can be done based on the TDF-IMC method. We note that the approximation to a second-order model is not necessary, and the process only works well for power systems with non-reheated turbine.

Here we can directly apply the TDF-IMC design method to the plant model. To achieve good disturbance rejection performance, we need to use Qd to cancel the undesirable poles of P(s) . MATLAB-based programs for general TDF-IMC design and PID reduction are available for such purpose and good measure of robustness of the PID controllers.

III. NUMERICAL STUDIES

3.1 Non-Reheated Turbine

Consider a power system with a non-reheated turbine. The model parameters are given by

The plant model without droop characteristic is

$$\frac{120}{(0.08s+1)(0.3s+1)(20s+1)} \qquad \text{------3.1}$$

By the LFC-PID design procedure discussed, we get the following

3.1.1 Non-Reheated Turbine without droop

PID controller:

Modified Zielger-Nichols Tuning

For $\phi_b = 45^o$, $r_b = 0.45$

$$0.8557+\frac{1.155}{s}+0.1586s \qquad \text{. ....3.2}$$

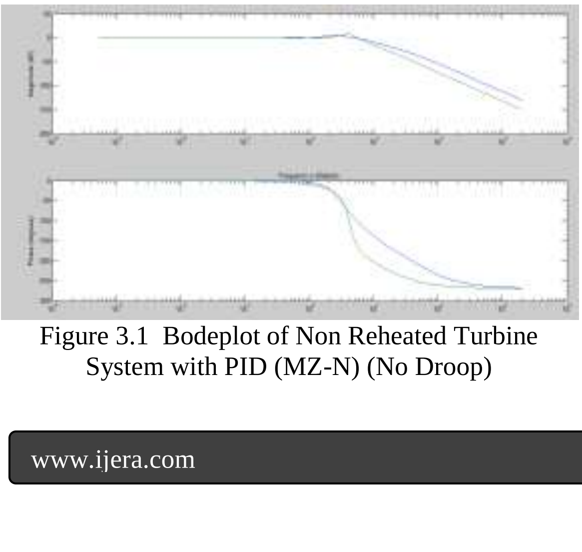

Figure 3.1 Bodeplot of Non Reheated Turbine System with PID (MZ-N) (No Droop)

3.1.2 Integral Model Controller

Tf = 10

$$0.1037+\frac{0.014}{s}+0.028s \qquad \text{............3.3}$$

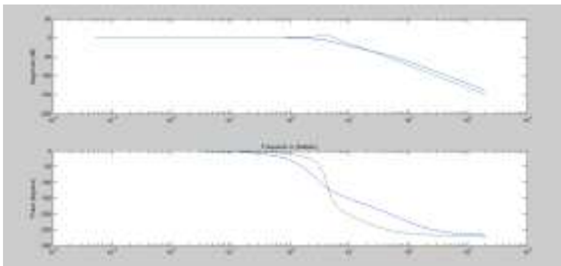

Figure 3.2 Bodeplot of Non Reheated Turbine System with PID (IMC) (no droop)

3.1.2 Non Reheated With Droop

LFC-PID can also be tuned for the plant model with droop characteristic, which is

$$\frac{250}{s^3+15.88s^2+42.46s+106.2} \qquad \text{............ 3.4}$$

The model has a pair of complex poles at with damping ratio 0.459. So the response is oscillatory. We get the following PID controller:

The plant model without droop characteristic is

PID controller:

Modified Zielger-Nichols Tuning

For $\phi_b = 45^o$, $r_b = 0.45$

$$0.732+\frac{0.987}{s}+0.136s \qquad \text{.......................... 3.5}$$

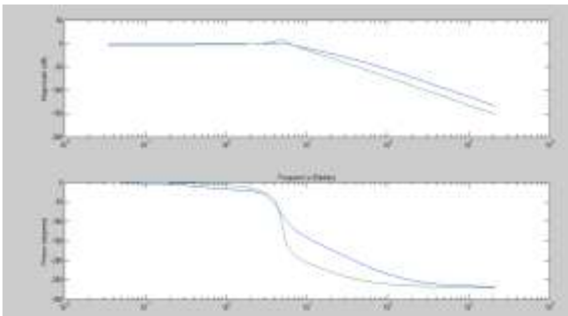

Figure 3.3 Bodeplot of Non Reheated Turbine System with PID (MZ-N) droop

Integral Model Controller

Tf = 10

$$1.081+\frac{1.14}{s}+0.125 \qquad \text{……........... 3.6}$$

S.no	Parameter	Power System
1	Speed Regulation due to governor action R (Hz/p.u.MW)	2.4
2	Electric System Gain(Kp) (s)	120
3	Electric System Time Constant(Tp) (s)	20
4	Turbine Time Constant (Tt)(s)	0.4
5	Governor Time Constant (Tg)(s)	0.08
6	Constant of Reheat Turbine (Tr) (s)	4.2
7	Pecentage of power generated in Reheat Portion (c)	0.35

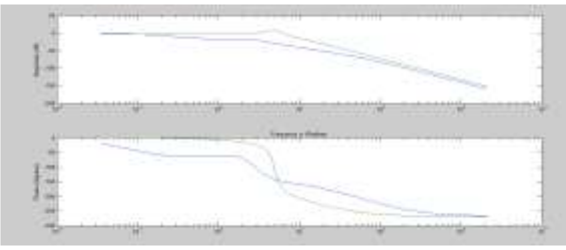

Figure 3.4 Bodeplot of Non Reheated Turbine System with PID (IMC) droop

They are very small which mean that the closed-loop systems with the tuned PID controllers are quite robust.

Both guarantee stability and performance of the closed-loop system under parameter variations.

3.2 Reheated Turbine

Consider a power system with a reheated turbine. The model Parameters are given by

3.2.1 REHEATED TURBINE WITHOUT DROOPING

The plant model without droop characteristic is

$$\frac{120(1.47s+1)}{(0.08s+1)(0.3s+1)(20s+1)(4.2s+1)} \quad ....3.7$$

By the LFC-PID design procedure discussed,
we get the following PID controller:

Modified Zielger-Nichols Tuning

For $\phi_b = 45^o$
$r_b = 0.45$

$$0.3983 + \frac{0.13}{s} + 0.303s \quad ....3.8$$

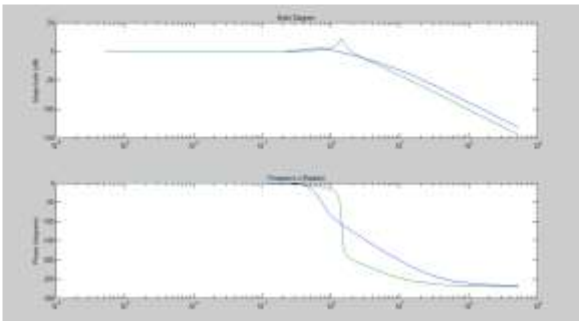

Figure 3.5 Bodeplot of Reheated Turbine System with PID (MZ-N) Without droop

Integral Model Controller
Tf = 10

$$0.7249 + \frac{0.076}{s} + 0.36 \quad ....3.9$$

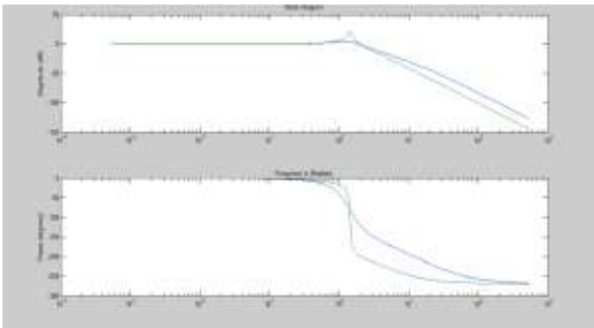

Figure 3.6 Bodeplot of Reheated Turbine System with PID (IMC)

3.2.2 REHEATED TURBINE WITH DROOP

LFC-PID can also be tuned for the plant model with droop characteristic, which is

$$\frac{87.5s + 59.52}{s^4 + 16.12s^3 + 46.24s^2 + 48.65s + 25.3} \quad ....3.10$$

By the LFC-PID design procedure discussed,
we get the following PID controller:

Modified Zielger-Nichols Tuning

For

$$1.904 + \frac{2.349}{s} + 0.385s \quad ....3.11$$

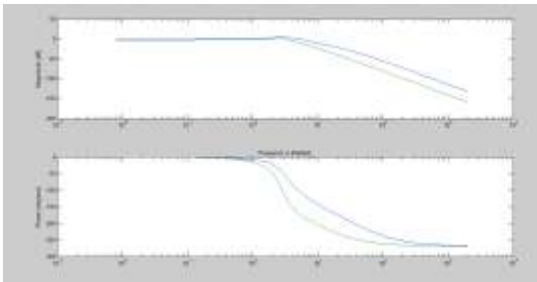

Figure3.7 Bodeplot of Reheated Turbine System with PID (MZ-N) With droop

Integral Model Controller

Tf = 10

$$2.823+\frac{1.132}{s}+0.37s \quad ....3.12$$

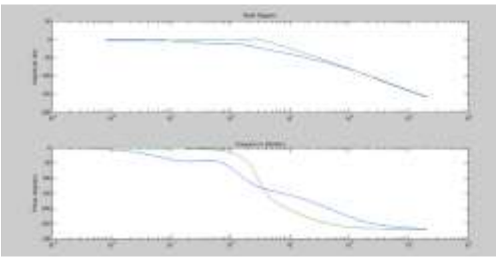

Figure3.8 Bodeplot of Reheated Turbine System with PID (IMC) With droop

3.3 Hydro Turbine

Consider a hydro-turbine power system with the following parameters

Table 3.3 Hydro Turbine System Parameters.

S.no	Parameter	Power System
1	Speed Regulation due to governor action R (Hz/p.u.MW)	0.05
2	Electric System Gain(Kp)(s)	1
3	Electric System Time Constant(Tp)(s)	6
4	Hydro Turbine Time Constant(Tw)(s)	0.4
5	Governor Time Constant (Tg)(s)	0.5

3.3.1 Hydro Turbine without droop

The plant model without droop characteristic is

$$\frac{1-4s}{2.4s^3+13.6s^2+8.2s+1} \quad ....3.13$$

Modified Zielger-Nichols Tuning

For $\phi_b = 45^o$

$r_b = 0.45$

$$-0.6113+\frac{0.059}{s}+1.59s \quad ....3.14$$

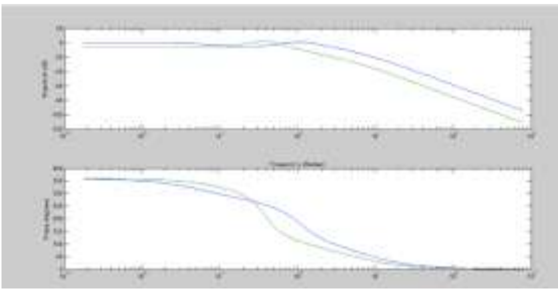

Figure 3.9 Bodeplot of hydro Turbine System with PID (MZ-N) Without droop

Integral Model Controller

Tf = 10

$$-0.3997+\frac{0.068}{s}+0.555s \quad ....3.15$$

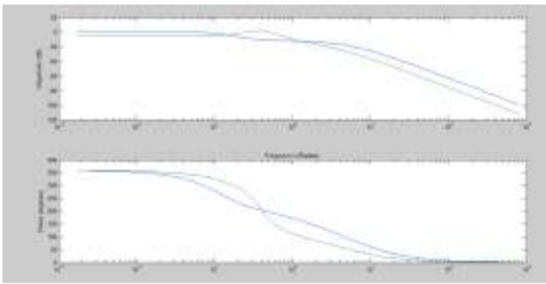

Figure3.10 Bodeplot of hydro Turbine System with PID (IMC) Without droop

3.3.2 Hydro Turbine with droop

LFC-PID can also be tuned for the plant model with droop Characteristic

The model has two unstable poles at 0.312 and 3.09. We get the following PID controller:

The plant model with droop

Characteristic is basically unstable and requires two degree freedom IMC for stabilizing the plant then designing the parameters.

IV. CONCLUSION

The two tuned PID controllers achieve comparable performance with a manual re-tuning. For the tuned PID setting, the robustness measure of the closed-loop systems with the tuned PID controllers is less, which guarantees that the closed-loop systems are reasonably robust. Stability and performance of the closed-loop system under parameter variation are guaranteed.\

The individual use of controller can be extended to multi-Area systems and stability and range of application can be increased by application of two degree freedom method IMC Design which can stabilize an unstable system.

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