Load Frequency Control using IMC based PID Controller

S. Jennathu Beevi*, R. Jayashree*, P. Anbumalar#
* Department of Electrical and Electronics Engineering,
# Department of Electronics & Instrumentation Engineering
B.S. Abdur Rahman University, Chennai - 600048

ABSTRACT — . In this paper the internal model control (IMC) based PID load frequency control for two area power system is presented. The Performance of IMC based PID and conventional PI controllers are compared for the same two area power system with non-reheat turbines. The damping of the two area power system is improved by an IMC based PID controller. The effectiveness of the proposed controller is compared by applying load disturbances. The dynamic response of the load frequency control problem is studied using MATLAB simulink package. The results indicate that the proposed IMC based PID controller exhibits better performance.

INDEX TERMS— area control error, internal model control, inter-connected two area system, load frequency control, proportional-integral-derivative, tie-line power deviation.

IJSER

1 INTRODUCTION

Load frequency control(LFC as a major function of Automatic Generation Control(AGC) is one of the important control problems in electric power system design and operation. It is becoming more significant today because of the increasing size, changing structure and complexity of power systems. A large frequency deviation can damage equipment, corrupt load performance and can interfere with system protection schemes, ultimately leading to an unstable condition for the electric power system. Maintaining frequency and power interchanges with neighboring control areas at the scheduled values are the two main primary objectives of a power system LFC[1]. Many control strategies for Load frequency control in electric power systems have been proposed by researchers over the past decades.

S.Jennathu Beevi is currently pursuingPh.D in power systems engineering in B.S.Abdur Rahman University, India, PH-04422751347. E-mail: jennathu.beevi@bsauniv.ac.in

R. Jayashree, has completed Ph.D in Congestion Management in Dergulated Environment and currently working as Professor in electrical engineering department in B.S.Abdur Rahman Universitty, India, PH-04422751347. E-mail : jaysubhashree@gmail.com

P.Anbumalar has completed her M.Tech in Instrumentation Engg and currently working as Assistant Professor in Electronics & Instrumentation Engg department in B.S.Abdur Rahman Universitty, India, PH-04422751347.
E-mail : anbumalarice@gmail.com

This extensive research is due to the fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specified limits. A unified tuning of PID controller for power systems via internal model control is proposed in this paper. In this simulation study, two area power system is chosen and load frequency control of this system is compared for conventional PI controller and IMC based PID controller.

2. OVERVIEW OF IMC

Here we adopt an internal model control (IMC) method for load frequency controller design.IMC is a popular control structure in process control . The IMC structure is shown in Fig. 1, where P is the plant to be controlled, $\tilde{P}$ is the plant model, and Q is the IMC controller to be designed.

ISSN 2229-5518

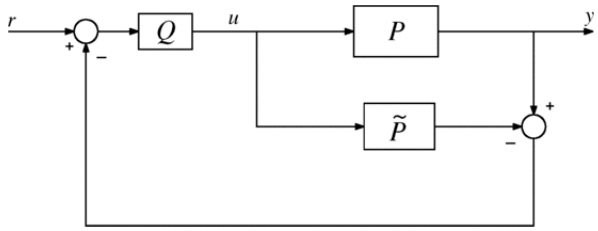


Fig. 1. IMC configuration.

The IMC design procedure goes as follows:

1) Decompose the plant model $\tilde{P}$ into two parts:

$$\tilde{P}(s) = P_M(s)P_A(s) \quad (1)$$

where $P_M(s)$ is the minimum-phase (invertible) part and $P_A(s)$ is the all pass (nonminimum-phase with unity magnitude) part.

2) Design a set point-tracking IMC controller

$$Q(s) = P_M^{-1}(s)\frac{1}{(\lambda s+1)^r} \quad (2)$$

where λ is a tuning parameter such that the desired set point response is $1 / (\lambda s+1)^r$, and r is the relative degree of $P_M(s)$.

It is shown that IMC control can achieve very good tracking performance. However, the load disturbance rejection performance sometimes is not satisfactory. So a second controller is added to improve the disturbance-rejection performance. The TDF-IMC structure is shown in Fig. 2, and the design of Q_d goes as follows:

Design a disturbance-rejecting IMC controller of the form

$$Q_d(s) = \frac{\alpha_m s^m + \cdots + \alpha_1 s + 1}{(\lambda_d s + 1)^m} \quad (3)$$

where λ_d is a tuning parameter for disturbance rejection, m is the number of poles of $\tilde{P}(s)$ such that the Q_d (s) needs to cancel. Suppose $p_1, \cdots, p_m$ are the poles to be canceled, $\alpha_1, \cdots, \alpha_m$ then should satisfy

$$\left(1 - \tilde{P}(s)Q(s)Q_d(s)\right)|_{s=p1\ldots pm} = 0 \quad (4)$$

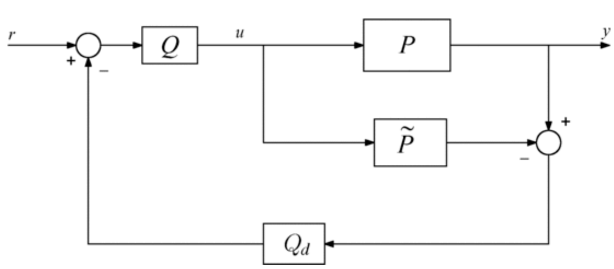


Fig. 2. TDF-IMC configuration.

It can be shown that the TDF-IMC structure is equivalent to the conventional TDF feedback structure shown in Fig. 3, where the feedback controller K equals

$$K = \frac{QQ_d}{1 - \tilde{P}QQ_d} \quad (5)$$

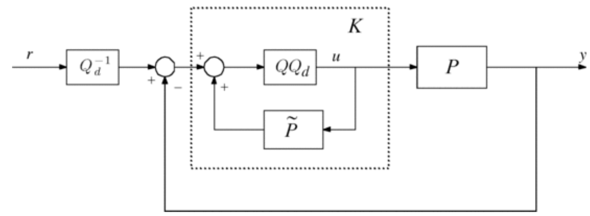


Fig. 3. Equivalent conventional feedback configuration.

3. LFC for Single Area Power Plant

A. Plant Description

The power systems are large-scale systems with complex nonlinear dynamics [1]. However, for relatively load disturbance, they can be linearized around the operating point. Here, a single-area power system supplying power to a single service-area through single generator is considered. This power plant for LFC design consists of governor $G_g(s)$, non-reheated turbine $G_t(s)$, load and machine $G_p(s)$, and 1/R is the droop characteristics, a kind of feedback gain to improve the damping properties of the power system. The linear model of plant is shown in Fig. 4. The dynamics of these subsystems are

$$G_g(s) = (T_G s + 1)^{-1}$$

$$G_t(s) = (T_T s + 1)^{-1}$$

$$G_t(s) = (T_T(s) + 1)^{-1} \quad (6)$$

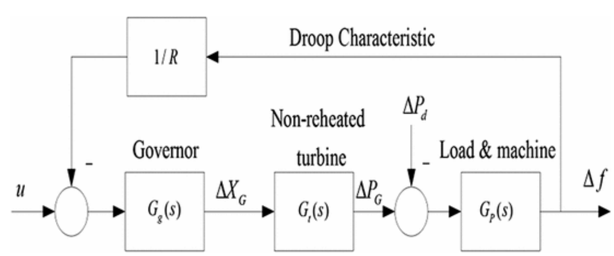


Fig. 4. Linear model of a single-area power system.

IJSER

ISSN 2229-5518

The whole system model can be illustrated by

$$\Delta f(s) = G(s)u(s) + G_d(s)\Delta P_d(s) \quad (7)$$

$$G_d(s) = \frac{G_p(s)}{1 + G_g(s)G_t(s)G_p(s)/R} \quad (8)$$

$$G(s) = \frac{G_g(s)G_t(s)G_p(s)}{1 + G_g(s)G_t(s)G_p(s)/R}$$

$$G(s) = \frac{K_p}{T_P T_T T_G s^3 + (T_P T_T + T_T T_G + T_P T_G)s^2 + (T_P + T_T + T_G)s + (1 + \frac{K_p}{R})} \quad (9)$$

From equation (7) we can understand that LFC is basically a regulatory problem which has the objective to evaluate the control law : u(s)= - K(s)Δf(s), where K(s) is IMC based compensator to control the power plant G(s) and minimize the effect on Δf(s) in the environment of small load disturbance $\Delta P_d(s)$.

IJSER

B. IMC based PID

It is clear from equation (9) that even the single area power system containing only one generator is of third order and thus IMC control design is obviously of higher order if the full order model is used. So, we obtain the first order plus dead time reduced model of the single area system using process reaction curve method or two point method.

The plant model used in LFC design is

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

where G_g is the governor dynamics , G_p is the load and machine dynamics and G_t is the turbine dynamics for non-reheated turbines.

Using process reaction curve method, the third order system is reduced to a FOPDT.

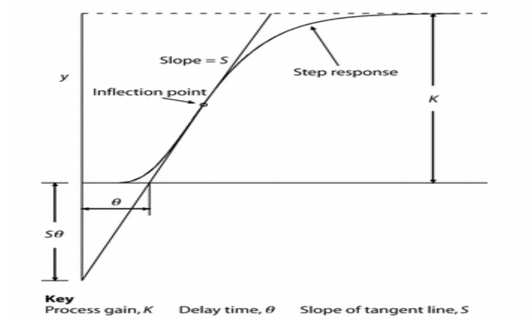


Fig. 5. Process reaction curve of a system.

From the process reaction curve the third order system is reduced to

$$P(s) = \frac{K_p}{\tau_p s + 1} e^{-\theta s} \quad (10)$$

C. IMC-Based PID Design for a First-Order + Deadtime Process

To find the PID controller which approximates IMC for a first-order + time-delay process, which is given by equation (10) , the following steps are followed.

Step1. Use a first-order Padé approximation for deadtime.

Step 2. Factor out the non-invertible elements (this time, do not make the "bad" part "all-pass")

Step 3. Form the idealized controller

Step 4. Add the filter - this time we will not make q(s) proper, because a PID controller will not result. We use the "derivative" option, where we allow the numerator of q(s) to be one order higher than the denominator. Now, find the PID equivalent.

We get the PID parameters as

$$k_c = \frac{(\tau_p + 0.5\theta)}{k_p(\lambda + 0.5\theta)}$$

$$\tau_I = \tau_p + 0.5\theta$$

$$\tau_D = \frac{\tau_p \theta}{2\tau_p + \theta} \quad (11)$$

The value of λ is chosen such a way that it's value is always less than $2\tau_p$ for IMC based PID with FOPDT.

F(s)= 1/(λs+1)

D.TWO AREA POWER SYSTEM

A two area power system connected through a power line each area feeds its user and tie line allows the electrical power flow between areas. For two area power system, During the normal operation the real power transferred over the line is given by

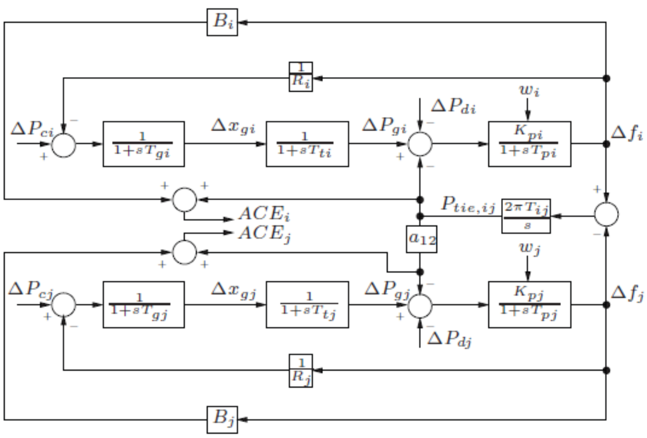


Fig.6. Two Area LFC

The uncontrolled two-area interconnected power system model is shown in shown in Fig. 6, where, for the subsystem area i:

- T_{pi} Power system time constant(s)
- K_{pi} Steady-state gain of power subsystem (Hz/ p.u. MW)
- a_{ij} Tie line coupling coeff. between areas i and j
- T_{gi} Governor time constant(s)
- R_i Frequency droop sensitivity due to governor action (Hz/ p.u. MW)
- T_{ti} Time constant of non-reheat type steam turbine(s)
- T_{ij} Tie line synchronizing coefficient(s)
- Δf_i Frequency deviation(Hz)
- Δx_{gi} Change in governor valve position (p.u.)
- ΔP_{gi} Change in real power generated (p.u. MW)
- $\Delta P_{tie,ij}$ Change in tie line real power between areas i and j (p.u. MW)
- ΔP_{ci} Change in real power command at speed governor (p.u. MW)
- ΔP_{di} Change in real power demand (p.u. MW)
- B_i Frequency bias factor(p.u. MW/ Hz)

Similar notation applies for other areas. The Area Control Error (ACE) of area i can be expressed as

$$ACE_i = \Delta P_{tie,ij} + B_i \Delta f_i \quad (12)$$

By setting the appropriate power commands at the governors, it is required to regulate the frequency and tie-line power deviations so that each ACE is driven to zero.

4. NUMERICAL STUDIES

Consider a power system with a non-reheated turbine.
K_p=120, T_P=20, T_T=0.3, T_G=0.08, R=2.4

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

$$P(s) = \frac{250}{s^3 + 15.883s^2 + 42.4583s + 102.0833} \quad (13)$$

From the process reaction curve the first order reduced model is derived as

$$P(s) = \frac{2.47\, e^{-0.8s}}{0.7s + 1} \quad (14)$$

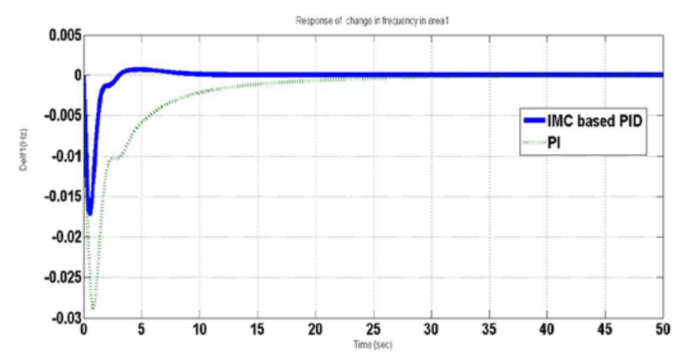
The filter function F(s) is computed as,

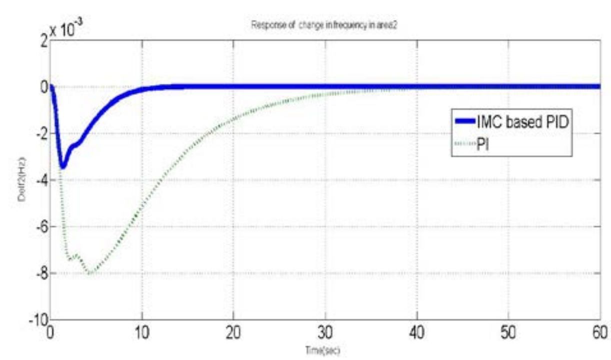
$$F(s) = \frac{1}{3.4s + 1} \quad (15)$$

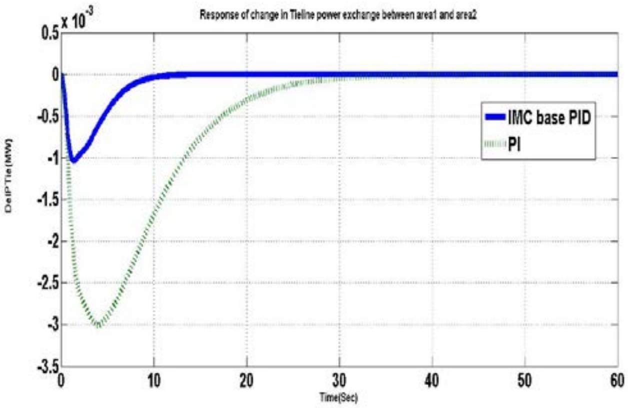
The values of k_c, τ_i, τ_d computed using the equations(11) are, k_c= 0.8906, τ_i= 1.1, τ_d= 0.2545.
We get the following IMC-based PID controller:

$$K(s) = 0.8906 + \frac{1.1}{s} + 0.2545s \quad (16)$$

The responses for IMC based PID controller and PI controller with a load demand ΔP_d=0.01 are compared. The IMC based PID is having good damping performance.







5. CONCLUSION

An IMC based PID design for load frequency control of power systems with non-reheat turbines in two area power system was studied. With the help of process reaction curve method, a reduced order model was derived. The IMC based PID was obtained. Simulation results for two area system showed that IMC based PID controller is easy to implement and damping is improved when compared with the conventional PI controller. Further research on decentralized PID tuning considering the tie-line interchange power is under progress.

ACKNOWLEDGMENT

Many sincere thanks go to Professor T.Thyagarajan, who has provided the motivation to undertake research related to IMC concepts.

REFERENCES

[1] O. I. Elgerd and C. Fosha, “Optimum megawatt-frequency control of multi area electric energy systems,” *IEEE Trans. Power Apparatus & Systems, vol. PAS-89, no. 4, pp. 556–563,* Apr. 1970

[2] P.Kundur, Power System Stability and Control. New York: McGraw-Hill, 1994.

[3] I. J. Nagrath, D. P. Kothari, Power System Engineering, TATA McGraw Hill, New York, 1994

[4] Bevrani. 2004 “Decentralized robust load-frequency control synthesis in restructured power systems”, PhD dissertation, Osaka University.

[5] Ignacio Egido, Fidel Fernández-Bernal, Luis Rouco, Eloisa Porras, and Ángel Sáiz- Chicharro, “Modeling of Thermal Generating Units for Automatic Generation Control Purposes”, *IEEE Trans. control systems technology, vol. 12, no. 1, Jan. 2004*

[6] Ibraheem, Prabhat Kumar, and Dwarka P. Kothari, “Recent Philosophies of Automatic Generation Control Strategies in Power Systems”, *IEEE Trans. Power App. Syst., vol. 20, no. 1,* Feb. 2005

[7] H. Shayeghi, H. A. Shayanfar, and A. Jalili, “Load frequency control strategies: A state-of-the-art survey for the researcher,” Energy Con- vers. Manage., vol. 50, no. 2, pp. 344–353, Feb. 2009.

[8] Wen Tan, “Unified tuning of PID load frequency controller for power system via IMC,” IEEE Trans. Power Systems, vol. 25, no. 1, pp. 341-350, 2010.

[9] Tavakoli-Kakhki, Mahsan, and Mohammad Haeri. "Fractional order model reduction approach based on retention of the dominant dynamics: Application in IMC based tuning of FOPI and FOPID controllers." *ISA transactions* 50.3 (2011): 432-442.

[10] Saxena, Sahaj, and Yogesh V. Hote. "Advances in internal model control technique: A review and future prospects." *IETE Technical Review* 29.6 (2012): 461.

[11] Toulabi, M. R., M. Shiroei, and A. M. Ranjbar. "Robust analysis and design of power system load frequency control using the Kharitonov's theorem."*International Journal of Electrical Power & Energy Systems* 55 (2014): 51-58

[12] Yesil, Engin. "Interval type-2 fuzzy PID load frequency controller using Big Bang–Big Crunch optimization." *Applied Soft Computing* 15 (2014): 100-112.

[13] Ali, Raheel, et al. "A new load frequency control approach in an isolated small power systems using coefficient diagram method." *International Journal of Electrical Power & Energy Systems* 56 (2014): 110-116.

IJSER