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# Controller Design and Load Frequency Control for Single Area Power System with Model Order Reduction Technique

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***ABSTRACT***
The performance of power systems gets worsening due to the presence of sudden load changes, uncertainties of parameters etc. Therefore the design of load frequency control is very important in the modern power systems. This paper presents LFC control technique to reject the typical disturbance as well as control the large-scale system problems. Parameter uncertainty and load disturbance approach has been proposed to LFC design on the purpose of rejection of typical disturbances. This paper presents the model order reduction technique of Transfer function of the single area power system by using Routh approximation. The Second-order reduced system model has proposed instead of full order system to effectively improve the performance of the closed loop system. This entire approach is simulated in MATLAB environment for a single –area power system. In addition to this the reduced order power system is converted into digital domain for digital implementation of load frequency controller.

***Index Terms***—Internal model control (IMC), load frequency control (LFC), model-order reduction, robustness, Digital domain.

## I. INTRODUCTION

The power system has become a very complex network due to the presence of modern electrical technology. Generally power systems consist of tie-lines which will interconnect the generation, distribution and transmission units. In case of interconnected power systems fluctuations are very frequent so the voltage levels and synchronism gets affected therefore it is essential to maintain stability even for any external disturbances [10]. It is very important to maintain the frequency and inter area tie power near to the operating values, in the case of modern power system because it is a very large scale power system which inter-connects various control areas. The change in frequency, the frequency of the generators and tie line power is controlled by the input mechanical power, which evaluates the change in rotor angle. In this paper the proposed power system can be provide with tolerable limits for frequency and voltage magnitude. Any change in load causes the change in frequency of the power system and change in voltage magnitude affects the change in reactive power. Therefore real and reactive power in the power system can be controlled separately. In general there are different control strategies viz. optimal control, adaptive and self tuning control, intelligent control, P/PI/PID control, IP control, discrete time sliding mode control and robust control. In this paper internal model control (IMC) scheme is proposed to control the load frequency strategies [1]. The parameter values of different power generating units like governor, turbine, generator etc. will varies with respect to time and depends upon the system and power flow conditions. Hence the load frequency control (LFC) [4]-[7] is the main criteria to analyze the parameter uncertainties and disturbance rejection of the system. In this paper model order reduction technique [8] is proposed in order to reduce the complexity of the power system and more over to reduce the size of the controllers, hence the cost reduces. In present research a new strategy for LFC proposed by using model order reduction technique and IMC filter design. This proposed controller brings robust and optimal performance, as well as faster disturbance rejection.

## II. MODEL ORDER REDUCTION OF PLANT

By using MOR we are converting large scale system (higher order or full order) into small scale system (lower order or reduced system) without losing behavior of the original system. The main objective of the MOR technique is to maintain dominant poles while rejecting the non-dominant poles. Model order reduction (MOR) is basically a technique in which the original system is reduced to a lower order model without changing the dominant characteristics of the given original system [9]-[10]. Mathematical model of the physical system required in order to develop MOR technique. There are several methods based on dynamic behavior of the system to reducing the order of the plant. There are several concepts to reduce the order which can be utilized for

SISO/MIMO systems to get the lower order system and further it is used to design specific controller. There are two methods for reducing the order viz. i) Routh and ii) pade approximations. Shamash introduced pade approximation (PA) to reduce the order of transfer function. This method provides correct steady state response but initial transient response is not good. Even the original system is stable, the stability of the model is may not be guaranteed [10]. Hutton and Fried land introduced Routh approximation technique; it preserves the high frequency characteristics and deals with the transient response of the model [13]. In this present study we deal with Routh approximation [10]-[11].

## III. LFC FOR SINGLE AREA POWER UNIT

A single-area power system is a system which supplying power from a single generator to a single service-area. Generally power systems having complex non linear dynamic, at operating point these non linear dynamics can be linearized. Here we considering a single generator through which power is transferred to a single area. This single area power unit consists of governor $G_g$ (s), turbine $G_t$ (s), load $G_p$(s) and Here 1/R is the droop characteristic, nothing but a feedback gain.

The dynamics of the subsystems are

$$G_g(s) = (T_{G^s} + 1)^{-1} \tag{1}$$

$$G_t(s) = (T_{T^s} + 1)^{-1} \tag{2}$$

$$G_P(s) = K_P(T_{P^s} + 1)^{-1} \tag{3}$$

The entire proposed system can be shown as

$$\Delta f(s) = G(s)u(s) + G_d(s)\Delta P_d(s) \tag{4}$$

$$G_d(s) = \frac{G_P(s)}{1 + G_g(s)G_t(s)G_P(s)/R} \tag{5}$$

$$G_d(s) = \frac{G_g(s)G_t(s)G_P(s)}{1 + G_g(s)G_t(s)G_P(s)/R} \tag{6}$$

$$= \frac{K_P}{(T_P T_T T_G)s^3 + (T_P T_T + T_T T_G + T_P T_T T_G)s^2 + (T_P + T_T + T_G)s + (1 + K_P/R)}$$

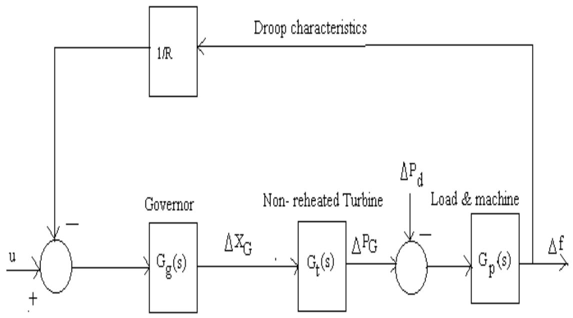


Fig.1. Basic block diagram of a single area power system:

## IV. MODEL ORDER REDUCTION OF PLANT

Even though by considering Single area power system by containing single generator still the order is in third- order, if we use this full order model the IMC controller design [12]-[13]will be in higher order, thereby converting this third order into second order reduced model of the single area- power system by using Routh approximation method.

This equation (6) can be written as

$$G(s) = \frac{K_P / A}{s^3 + (\frac{B}{A})s^2 + (\frac{C}{A})s + (\frac{D}{A})} \tag{7}$$

Where,

$$A = T_P T_T T_G \qquad B = T_P T_T + T_T T_G + T_P T_G$$

$$C = T_P + T_T + T_G \qquad D = 1 + (\frac{K_P}{R})$$

The coefficients of the power series expansion can be expressed as ,

$$G(s) = C_0 + C_1 s + C_2 s^2 + C_3 s^2 + .......... \tag{8}$$

Where,

$$C_0 = \frac{K_P}{D}, C_1 = -\frac{CK_P}{D^2}, C_2 = (\frac{C^2 - BD}{D^3})K_P, C_3 = (\frac{2BCD - AD^2 - C^3}{D^4})K_P$$

$$G(s) = \frac{K_P / A}{(\frac{D}{A}) + (\frac{C}{A})s + (\frac{B}{A})s^2 + s^3} \tag{9}$$

TABLE-1

$\alpha$ and $\beta$ table for Routh approximation method

| $\alpha$ table | $\beta$ table |
|---|---|
| $D$ $B$<br>$C$ $A$<br>$\alpha_1 = \frac{D}{C}$, | $K_P$ 0<br>0<br>$\beta_1 = \frac{K_P}{C}$ |
| $\alpha_1 = \frac{C^2}{BC - AD}$<br>$B - \frac{AD}{C}$ | $\beta_2 = 0$ |

## V. ROUTH APPROXIMATION METHOD

By resembling the coefficients from Routh table, the reduced order model can be obtained. By considering the reduced second-order model $G_{MR}^{Routh}(s)$ as $G_{MR}^{Routh}(s) = \frac{P_2(s)}{Q_2(s)}$, where $P_2(s)$ and $Q_2(s)$ are the numerator and the denominator respectively. By reciprocating $G_{MR}^{Routh}(s)$ using relation $\tilde{G}(s) = \frac{1}{S}G(\frac{1}{S})$, thus reciprocating model $G(s)$ become

$$\tilde{G}(s)=\frac{K_P s^2}{Ds^3+Cs^2+Bs+A}=\frac{P_i(s)}{Q_i(s)} \quad (10)$$

$$\tilde{G}(s)=\frac{P_i(s)}{Q_i(s)}=\sum_{t=1}^{n}\beta_t\prod_{j=1}^{i}F_j(s) \quad (11)$$

Where

$\beta_t$ (t=1,2 ) are constants $F_j(s)$(j=1,2) contains $\alpha_j$ terms . Then we need to calculate $\alpha$ and $\beta$ tables corresponding to $\tilde{G}(s)$ shown in above table I. The complete study and estimation of $\alpha$ and $\beta$ tables are given in [16]. These $\alpha$ and $\beta$ terms provides reciprocated numerator $\tilde{P}_2(s)$ and $\tilde{Q}_2(s)$ denominator for second-order reduced model are

$$\tilde{P}_2(s)=\beta_2+\alpha_2\beta_1 s \quad (12)$$

$$\tilde{Q}_2(s)=1+\alpha_2 s+\alpha_1\alpha_2 s^2 \quad (13)$$

By replacing the values of $\alpha$ and $\beta$ in $\tilde{P}_2(s)$ and $\tilde{Q}_2(s)$ ,we can obtain

$$\tilde{P}_2(s)=\frac{CK_P S}{(BC-AD)} \quad (14)$$

$$\tilde{Q}_2(s)=1+C^2 s/(BC-AD)+CDs^2/(BC-AD) \quad (15)$$

By reciprocating the above the equation we can get the required final reduced order

$$G_{MR}^{Routh}(s)=\frac{CK_P/(BC-AD)}{s^2+(\frac{C^2}{BC-AD})s+CD/(BC-AD)} \quad (16)$$

## VI. INTERNAL MODEL CONTROL THEORY

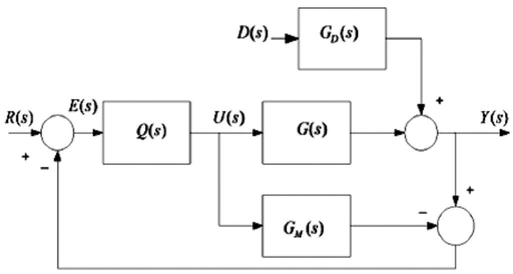


Fig. 2. Basic IMC structure.

In single-area power system, IMC based PID controller for load frequency control has proposed by Tan. Various control strategies are there to design a robust load frequency controller (LFC). However in those controlling strategies the power full directional controlling strategy called internal model control (IMC) gets an wide-ranging research in electrical engineering . This set of control method is known to demonstrate robustness, as well as it gives easy understandable approach. However, IMC has a disturbance rejection and also possible to optimize system performance for load disturbance rejection. As we know that the modern power system is a interconnected model therefore the order of the system and number of controllers are increased. In this particular instance the modern control of IMC plays an important role in order to reduce the order as well as the complexity of the modern power system. hence the size and cost of the system is reduced.

The basic IMC structure is illustrated in Fig. 2. The structure is distinguished by a real plant to be controlled G(s) the feedback controller Q(s), and an internal- model $G_M(s)$. The error has been produced based on the difference between the outputs of G(s) and $G_M(s)$.

Steps for designing IMC controller as follows:

**Step1:** model the Factor as

$$G_M(s)=G_{M+(S)}G_{M-(S)} \quad (17)$$

Where,

$G_{M+(S)}$ = non-minimum phase and

$G_{M-(S)}$ = minimum phase.

**Step2:** IMC controller defined as

$$Q(s)=G_{M-(S)}^{-1}F(s) \quad (18)$$

Where

$F(s)$= low-pass filter and is commonly defined as

$$F(s)=(1+\lambda_S)^{-n} \quad (19)$$

Here $\lambda$ is a tuning parameter, the speed of the closed-loop system adjusted and also plant/model mismatch is removed by this tuning parameter. Hence choosing the proper value of $\lambda$ makes the system robustness.

## VII. SIMULATION RESULTS

By considering the IEEE standard values of parameters for the single area power system can be taken as

$$K_P=120, T_P=20, T_T=0.3, T_G=0.08, R=2.4$$

therefore by using G(s) equation we get transfer function as below

$$G(s)=\frac{120}{0.48S^3+7.624S^2+20.38S+51}$$

This single area power system transfer function is in the form of third order under damped system without applying any control technique. Now, if we apply the model order reduction techniques to the above third order transfer function, it can be reduced into second order transfer function of the single area power system.

$$G_{MR}^{Routh}=\frac{18.68}{S^2+3.173S+7.94}$$

The step responses for both higher order and reduced order are compared as shown below, it is clear that the Response of the response of the original system is almost equal to the reduced order system. hence the response of Routh approximation is good.

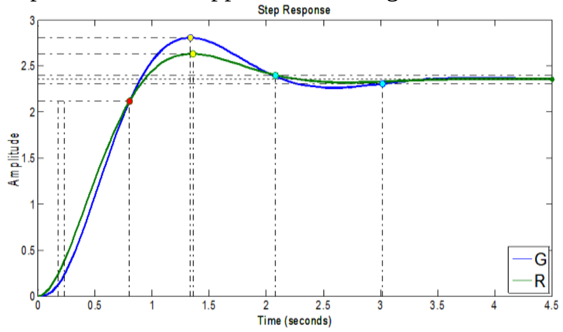


Fig.3. Comparing the step responses of both original and reduced order model. Without IMC

TABLE-2
Parameter Values of Higher Order and Reduced Order Without Controller

| | S | S-R |
|---|---|---|
| Peak amplitude | 1.18 | 1.18 |
| % over shoot(sec) | 18.4(0.9) | 18.4(0.7) |
| Settling time | 4.35 | 2.97 |
| Rise time | 0.428 | 0.356 |
| Phase margin(deg) | 41.4 | 62.1 |
| Delay margin(sec) | 0.15(4.6) | 0.2(5.24) |
| Peak gain(db) | 4.63 | 3.03 |

## VIII. MOR RESULTS WITH IMC CONTROLLER

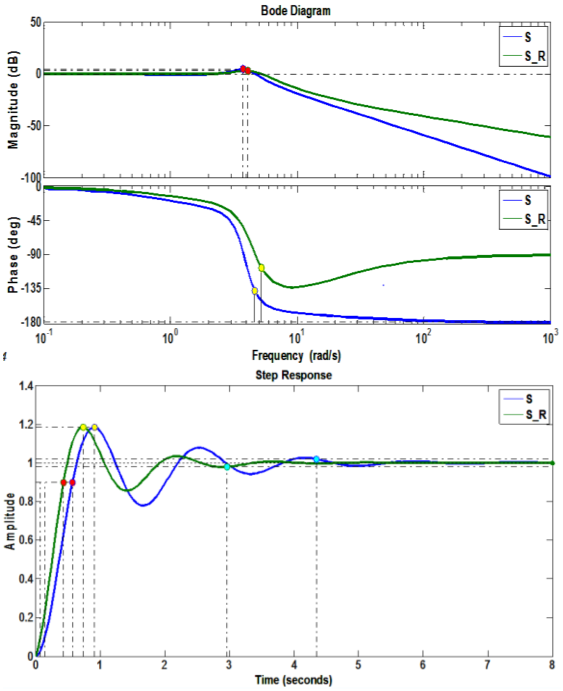


Fig.4. Comparing the step response and bode of both original and reduced order model. With IMC

TABLE -3
Parameter Values for Higher Order and Reduced Order With IMC

| | S | S-R |
|---|---|---|
| Peak amplitude | 1.18 | 1.18 |
| % over shoot(sec) | 18.4(0.9) | 18.4(0.7) |
| Settling time | 4.35 | 2.97 |
| Rise time | 0.428 | 0.356 |
| Phase margin(deg) | 41.4 | 62.1 |
| Delay margin(sec) | 0.15(4.6) | 0.2(5.24) |
| Peak gain(db) | 4.63 | 3.03 |
| Phase cross over frequ ency | 4.64 | 4.24 |

TABLE-4
Performance of Original and Reduced Order System with Different Types of Controllers

| Type | | Origional (S) | Reduced Order (S_R) |
|---|---|---|---|
| P | Rise Time | 0.329S | 0.291S |
| | Peak Amplitude | 0.767 | 0.85 |
| | % Peak Overshoot | 44.9 | 32.4 |
| | Settling Time | 4.2S | 2.35S |
| | Final Value | 1 | 1 |
| | Phase Margin | 120 | 102 |
| | Gain Margin | 11.4 | 11.4 |
| | Phase Crossover Frequency | 3.23 | 4.38 |
| | Gain Crossover Frequency | 6.52 | 6.52 |
| PI | Rise Time | 3.48 | 0.822 |
| | Peak Amplitude | 1 | 1.12 |
| | % Overshoot | 0 | 11.7 |
| | Settling Time | 4.39 | 4.39 |
| | Final Value | 1 | 1 |
| | Phase Margin | 120 | 120 |
| | Gain Margin | 11.2 | 8.55 |
| | Phase Crossover Frequency | 1.51 | 1.51 |
| | Gain Crossover Frequency | 2.59 | 3.57 |
| PID | Rise Time Peak Amplitude % Overshoot Settling Time Final Value Phase Margin Gain Margin Phase Crossover Frequency Gain Crossover | 0.357<br>1.08<br>8.47<br>2.061<br>114<br>3.84 | 0.357<br>1.22<br>22.4<br>3.41<br>60.6<br>4.99 |

| | | | |
|---|---|---|---|
| | Frequency | | |
| PID- | Rise Time Peak | 0.332 | 0.332 |
| 2 | Amplitude % Overshoot | 1.33 | 1.36 |
| | Settling Time Final | 32.6 | 35.6 |
| | Value Phase Margin | 7.11 | 4.631 |
| | Gain Margin Phase | 22.6 | 45.8 |
| | Crossover Frequency | | |
| | Gain Crossover | 4.53 | 5.37 |
| | Frequency | | |
| PID- | Rise Time Peak | 0.317 | 0.234 |
| 3 | Amplitude % Overshoot | 1.35 | 1.44 |
| | Settling Time Final | 34.7 | 44.3 |
| | Value Phase Margin | 5.21 | 4.2 |
| | Gain Margin Phase | 1 | 1 |
| | Crossover Frequency | 30.5 | 47.3 |
| | Gain Crossover | 5.65 | 7.12 |
| | Frequency | | |
| PID- | Rise Time Peak | 0.353 | 0.356 |
| 4 | Amplitude % Overshoot | 1.18 | 1.1818 |
| | Settling Time Final | 18 | 2.971 |
| | Value Phase Margin | 4.35 | 72.1 |
| | Gain Margin Phase | 1 | 5.24 |
| | Crossover Frequency | 41.4 | |
| | Gain Crossover | 4.64 | |
| | Frequency | | |
| PID- | Rise Time | 0.275 | 0.275 |
| 5 | Peak Amplitude | 1.367 | 1.14 |
| | % Overshoot | 37 | 14 |
| | Settling Time | 3.13 | 1.59 |
| | Final Value | 1 | 1 |
| | Phase Margin | 169 | 167 |
| | Gain Margin | | |
| | Phase Crossover | 1.81 | 1.99 |
| | Frequency | | |
| | Gain Crossover | | |
| | Frequency | | |
| PID- | Rise Time | 0.267 | 0.202 |
| 6 | Peak Amplitude | 1.43 | 1.48 |
| | % Overshoot | 43 | 48 |
| | Settling Time | 5.46 | 4.33 |
| | Final Value | 1 | 1 |
| | Phase Margin | 32.2 | 51.4 |
| | Gain Margin | | |
| | Phase Crossover | 6.29 | 7.9 |
| | Frequency | | |
| | Gain Crossover | | |
| | Frequency | | |
| IMC | Rise Time Peak | 0.609 | 0.349 |
| | Amplitude % Overshoot | 1 | 1 |
| | Settling Time Final | 0 | 0 |
| | Value Phase Margin | 1.22 | 0.607 |
| | Gain Margin Phase | 1 | 1 |
| | Crossover Frequency | | |
| | Gain Crossover | 18.9 | 18.9 |
| | Frequency | | |
| | | 11.6 | 11.6 |

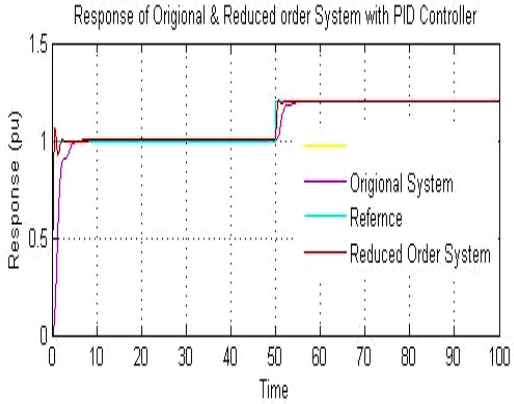


Fig 5. Response of original and reduced order system with PID controller

Similarly we can apply this method for any type of controllers as shown in above table, for example we consider PID controller

## IX. NOMENCLATURE OF POWER SYSTEM PARAMETERS

$\Delta P_d$ = *load disturbance (p.u.MW)*

$K_P$ = Electric system gain.

$T_P$ = Electric system time constant (s).

$T_T$ = Turbine time constant (s).

$T_G$ = Governor time constant (s).

R = Speed regulation due to governor action (Hz/p.u.MW).

$\Delta f(t)$ = Incremental frequency deviation (Hz).

$\Delta P_G(t)$ = Incremental change in generator output (p.u.MW).

$\Delta X_G(t)$ = Incremental change in governor valve position

## X. CONCLUSION

A Load Frequency Controller with Model Order Reduction Technique for Single Area Power System has been designed. The reduced model order has been obtained by resembling the coefficients from Routh table. The dynamic equations of the plant were formulated using system identification tools, and then after used in the design of the load frequency controller. The performance of the closed loop system has effectively improved with Second-order reduced system model instead of full order system. The Second-order reduced system model has proposed instead of full order system to effectively improve the performance of the closed loop system with different types of controllers (P, PI, PID and IMC) with different types of tuning techniques. Parameter values for higher order and reduced order with IMC has been compared and also IMC controller has been compared with P, PI, PID controllers and finally noticed that Rise Time, peak Amplitude, % Overshoot, Settling Time, etc are reduced effectively. The reduced order power system has been converted into digital domain for digital implementation of load frequency controller. Finally the entire approach has simulated in MATLAB environment for a single – area power system.

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