

IMC and GA Based Fractional Order Controller Design for Load Frequency Control Problem

M. V. Maheswaramma, P. Sujatha, P. Bharath kumar

Abstract: This paper proposes a genetic algorithm based fractional order proportional integral derivative controller for load frequency control (LFC) problem. Genetic algorithm used for tuning the proposed controller. Initially the proposed controller is applied to single area power system after that it is applied to two area power system. The turbines known as non reheated and hydro turbine, and all other physical parameters of turbine, governor are validating in practical system. The simulation test in the presence of uncertainties and constraints in the plant parameters, shows improved disturbance rejection, reducing peak overshoots and settling time.

Key words: Fractional order proportional integral derivative controller, Genetic algorithm, Load Frequency control.

I. INTRODUCTION

Power system control is most toughest task, since the power generated should balance the total demand in presence of electrical equipment such as generators, protective devices, transmission lines. If the generated power should not match the total load demand, it causes some performance disturbances such as frequency fluctuations caused by sudden change of load, voltage instability, rotor angle instability, and operating limits. These perturbations need to be removed for better power system performance. Now a day's power system is interconnected network, so the regulating of power output and frequency variations is most challenging task.

In power system among various control strategies, Load Frequency Control deals with the controlling of frequency deviations i.e., in the interconnected power system frequency should be maintain constant. The LFC manages the power deviation in tie-line and variations in frequency against the change in load and maintain within the predefined values as possible. The main objectives of LFC are: 1) by maintaining steady state error is zero against the frequency fluctuations and power deviations in tie line, 2) rejection of sudden load changes, 3) perform optimal transient behavior under recommended settling time, overshoot and error tolerance, 4) provide robust performance in presence of modelling uncertainty and non-linearity. 5) settling higher safety margins for the power system and less computing power. LFC is one of the largest, robust and optimization issue in the engineering from control perspective.

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For the LFC different control methods have been developed over the past decades with optimal, stable, adaptive and intelligent control prospectives. At earlier days PI controller was proposed by some authors for LFC. PI controller provides better performance in noisy environment so it can be used in power system. After that PID controller was introduced for LFC problem. The PID controller tuned by using internal model control, fuzzy networks and genetic algorithm results which gives better results than original PID. But in these days fraction order (FO) systems are more popular than PID control method. Because FO method provides better control performance, particularly for the systems operating in an uncertain environment, system with no linearities and accurate modeling of complex systems. It makes the FO-PID even stronger than the PID.

Alomoush suggested the first FO-PID approach, in which LFC was considered a constrained problem of optimization for two area power system. IMC technology is the control strategy used over the last few decades. The IMC technology's characteristics are simplicity, robustness, inadequacy and applicability in wide range. Because of these characteristics IMC technique is more familiar in control strategy. The FO-PID has got a new way through the introduction of IMC technique for its synthesis and analysis. In present day's intelligent algorithms and artificial intelligence getting greater attention among various control strategies. Genetic algorithm (GA) is a meta-heuristic algorithm that is motivated by natural selection process and belongs to a broader evolutionary class. Genetic algorithms are generally used by relying on bio-inspired operators such as mutation, crossover and selection to generate high quality solutions for optimization and research problems.

II. LFC MODEL DESCRIPTION

Electric power systems are complex nonlinear dynamic systems due to existing of more generators and loads. Nevertheless, all generators were lumped into a single equivalent generator for modeling purposes as well as for loads. The system can be satisfactorily represented by its linear model, since power systems are exposed to minor load changes.

$$\frac{d}{dt} \Delta f(t) = -\frac{1}{T_P} \Delta f(t) + \frac{K_P}{T_P} (\Delta P_G(t) - \Delta P_D(t)) \quad (1)$$

$$\frac{d}{dt} \Delta P_G(t) = -\frac{1}{T_T} \Delta P_G(t) + \frac{1}{T_T} \Delta X_G(t) \quad (2)$$

$$\frac{d}{dt} \Delta X_G(t) = -\frac{1}{RT_G} \Delta f(t) - \frac{1}{T_G} \Delta X_G(t) + \frac{1}{T_G} u(t) \quad (3)$$

In terms of the model of transfer function the governor is

$$P_G(s) = \frac{1}{T_G s + 1} \quad (4)$$

The non-reheated turbine is

$$P_T(s) = \frac{1}{T_T s + 1} \quad (5)$$

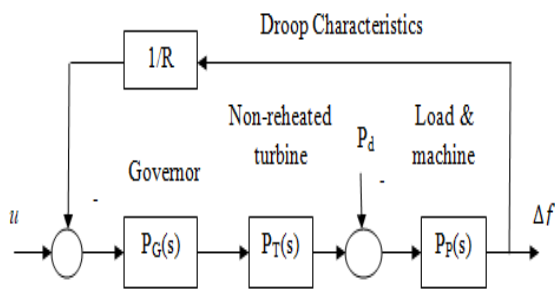


Fig. 1. LFC Block diagram of single area power system

And the load and machine is

$$P_p(s) = \frac{K_p}{T_p s + 1} \quad (6)$$

Now using (4)-(6), the whole plant can be written as

$$\frac{\Delta f(s)}{u(s)} = P(s) = \frac{P_G(s)P_T(s)P_P(s)}{1 + P_G(s)P_T(s)P_P(s)/R} = \frac{K_p}{a_3 s^3 + a_2 s^2 + a_1 s + a_0} \quad (7)$$

$$a_3 = T_G T_T T_P, \quad a_2 = T_G T_T + T_p T_T + T_p T_G, \quad a_1 = T_G + T_T + T_p, \quad a_0 = 1 + \frac{K_p}{R} \quad (8)$$

Since LFC is a problem of disturbance rejection, so our aim

is to find control law: $u(s) = C(s)\Delta f(s)$

Such that $\lim_{t \rightarrow \infty} \Delta f(t) = 0$, for all ΔP_d .

III. DESIGNING TOOLS

Here, FO operators and their characteristics are provided a short exposure. Fractional calculus is in fact the generalization of differentiation and integration of IO into any arbitrary real number. FO calculus is an ancient concept in mathematics but extraordinary progress from the last one decade in control engineering after implementation of FO controllers. Now we are introducing the concept of generalized FO operator of order $\alpha \in \mathbb{R}$ (often denoted by D_t^α , where x and t denotes the limits of operation) is defined as

$${}_x D_t^\alpha = \begin{cases} \frac{d^x}{dt^x} & \alpha > 0 \\ 1 & \alpha = 0 \\ \int_x^1 (dT)^{-\alpha} & \alpha < 0 \end{cases} \quad (9)$$

We define the FO system in this paper using the form differential equation

$$\sum_{i=1}^m a_i D_i^{v_i} u(t)$$

Where $\mu_m > \mu_{m-1} > \dots > \mu_1 > 0$ and $v_l > v_{l-1} > \dots > v_1 > 0$ are purely real positive numbers and $(a_i, b_i) \in \mathbb{R}^2$. The transfer function can be achieved when this question is interpreted in the popular sense Caputo (definition 1) and when the transformation of Laplace is applied to zero initial condition as

$$G(s) = \frac{\sum_{i=1}^l b_i s^{v_i}}{\sum_{i=1}^m a_i s^{\mu_i}} \quad (10)$$

Where $a_m \neq 0$ and $\mu_m > v_i$ is assumed so that $G(s)$ is strictly proper.

Definition1: Definition of the FO derivative order α of a continuous function $f: \mathbb{R}^+ \rightarrow \mathbb{R}$ is defined as

$$D_t^\alpha f(t) = \frac{1}{\Gamma(n - \alpha)} \int_a^t \frac{f^{(n)}(\tau)}{(t - \tau)^{\alpha - n + 1}} d\tau$$

$$\forall n - 1 < \alpha < n \quad (11)$$

Where $f^{(n)}(t)$ is the derivative of $f(t)$ with respect to t with n^{th} order, $n \in \mathbb{N}$ and $\Gamma(\cdot)$ is Gamma function. The derivative laplace transform is given by

$$\int_0^t e^{-st} {}_a D_t^\alpha f(t) dt = s^\alpha F(s) \sum_{k=0}^n s^{x-k-1} f^{(k)}(0) \quad (12)$$

Remark: when $\alpha = n \in \mathbb{N}$ then $D_t^\alpha f(t) = \frac{d^n}{dt^n} f(t)$.

Remark: Different fractional calculus definitions are presented in literature but Caputo definitions are very popular in engineering. Under Caputo definition, the initial conditions are of integer (*i.e.*, derivative of constant is zero) which make it easier to understand because the IO derivatives of the variables are physically well established and are easy to obtain through experimental methods. Like IO system, where integrators and differentiators are the building blocks of the system, the FO system also includes FO integration and differentiation as their basic elements.

Definition 2. The FO integrator transfer function is defined as

$$G(s) = \frac{1}{s^p}, \quad p \in (0,1). \quad (13)$$

$G(s)$ is a pure integrator for $p = 1$. As p tends towards 0, the integration operation effect eliminates because $s^0 = 1$.

Remark: In control theory it delays the response speed by adding pure integration but in this case this limit is eased by the FO integration.

The spectral transfer function is achieved as if $s = j\omega$ is inserted

$$G(j\omega) = \frac{1}{\omega^p \left[\cos\left(\frac{p\pi}{2}\right) + j \sin\left(\frac{p\pi}{2}\right) \right]} \quad (14)$$

Whose magnitude $A(\omega) = \frac{1}{\omega^p}$ is given in dB by

$$M(\omega) = -20p \log(\omega) \quad (15)$$

and the phase is

$$\Phi(\omega) = \arg \left[\frac{1}{\omega^p} j^{-p} \right] = -\frac{p\pi}{2} \quad (16)$$

From eq...(15) and eq...(16), it is evident that in the frequency domain, the magnitude of FO integrator decreases at a rate of 20p dB/dec and its phase is $-\pi/2$ throughout the domain. The IO integrator provides a constant drop in magnitude rate of -20 dB/dec and $-\pi/2$ in phase response. This may interfere with the stability and strength of the closed-loop system. The FO integrator therefore introduces new levels of versatility which simplify the design of high performance control unit.

IV. GENETIC ALGORITHM

The genetic algorithm is an optimizing research tool. GA based on the principles of evolutionary and natural selection. The GA enables a population consisting of many individuals to evolve to a state that maximizes the “fitness” (*i.e.*, minimizes the cost function) under specified selection rules, many versions of evolutionary programming have been tested with varying degrees of success. Some of the advantages of GA include



- Continuous or discrete variables optimization.
- No derivative information is required.
- Searches for a broad cost surface sample at the same time.
- Optimization of extremely complex surface variables (they can jump out of a local minimum)
- Can encode the variables so that encode variables are optimized.
- Works with the data generated numerically, experimental data or analytical functions.

Genetic algorithms have many variations, but the basic form is simple genetic algorithm (SGA). This algorithm defined as strings, with a population collection of candidate solution. The first population consists of individuals randomly generated. The fitness of each individual in current population is calculated in each iteration of the algorithm. The population is then changed into stages in order to produce a new current population. The genetic operators are usually applied in three phases: 1) selection, 2) crossover and 3) mutation. The selector operator is used as many times as there are people in the population during the first phase. At this stage, each individual is replicated with a probability commensurate with his relative fitness in the population. The cross over operator will be applied in the next stage. Two new individuals are produced by combining two parent individuals. The combination takes place by selecting at random a cutting point where each parent is separated into two parts, which are replaced by the parents in the population. In the final step, the mutation operator changes the value in an individuals randomly selected location. Following a fixed number iterations, the algorithm ends with the best individual generated during running.

V. DESIGN OF GA BASED FO-PID CONTROLLER FOR LFC

The new controller is now implemented for both single area and two area power systems. Simulations are performed in the MATLAB and simulink to implement the controlling system proposed for single area and two area systems. Power system plant nominal parameters are taken as $K_P = 120, T_P = 20, T_T = 0.3, T_G = 0.08, R = 2.4$ (17)

A. Designing of LFC for single-area system

By replacing the aforementioned values in eq...(8) the original plant in eq...(7) is given

$$P(s) = \frac{250}{s^3 + 15.88s^2 + 42.46s + 106.2}$$

In order to demonstrate the proposed controller performance, a step load $\Delta P_D = 0.01$ p.u at $t=1$ s, and $\pm 50\%$ uncertainty in all power plant parameters is also added to observe the controllers robustness, that is to say, $K_P = [60, 170], T_P = [10, 40], T_G = [0.04, 0.1], R = [1.2, 3.6]$ (18)

For nominal, lower and upper bands the proposed controller performance in rejecting disturbance is obtained. The principal advantage with the proposed controller is that, even if the system parameters are varied. The frequency variations for the time compared with the other scheme is IMC based FO-PID to determine the performance of the

proposed controller. The proposed controller reduces the rapid fluctuations, peak over shoots with less time to settle. The proposed scheme is applied to single area system. The resultant graphs are as shown in Fig.2 the performance parameters are compared in the table1.

For single area system the disturbance is given in the form of step input at the instant of one. After the application step input the resultant graph is shown in fig.2. nominal case. In that figure we compared two methods proposed method that is GA based FOPID and IMC based FOPID. The graph shows frequency variation with respect to time. So from the graph is peak overshoot, rise time and settling time are better values than the other one in the graph.

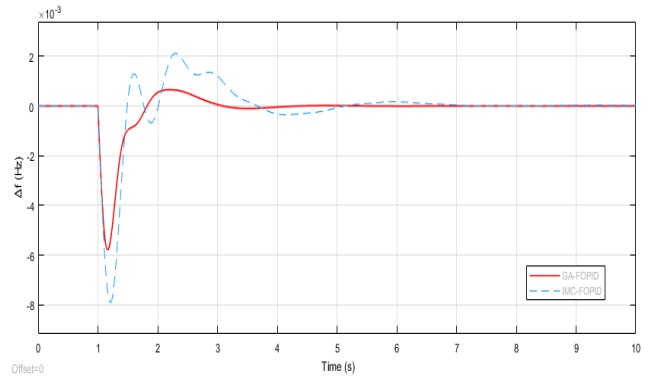


Fig.2. In nominal case frequency deviation for single area system

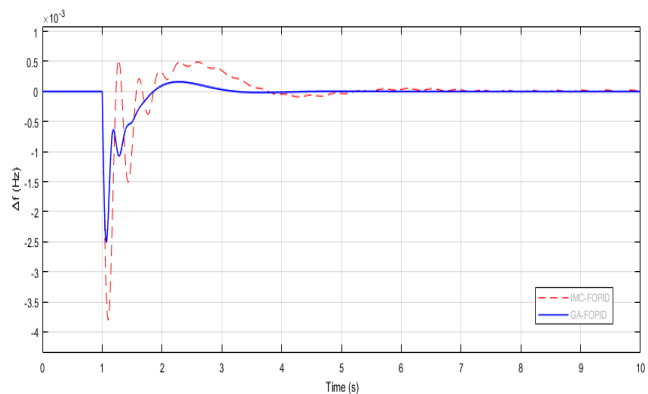


Fig.3. In lower case frequency deviation for single area system

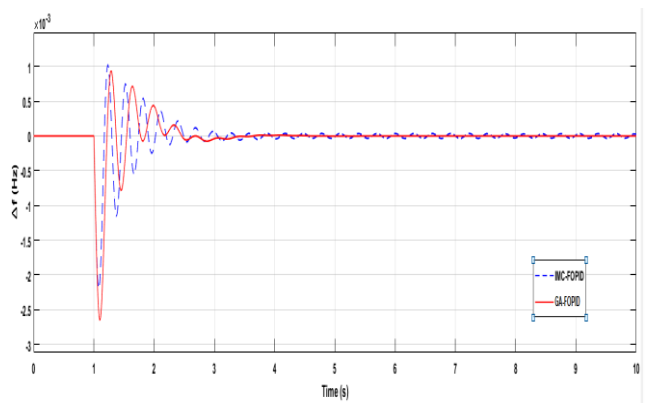


Fig.4. In upper case frequency deviation for single area system

IMC and GA Based Fractional Order Controller Design for Load Frequency Control Problem

By substituting the eq...(18) values in single area system we will get lower frequency single area system. The resultant graph for lower case is shown in Fig.3. In the graph we observe that peak overshoot is reduced and also rise time reduced. Settling time is very less compared to the IMC based FOPID.

Similarly in eq...(18) the another set values i.e., upper values are substitute in place of nominal values. By simulating we get the resultant graph is as shown in fig.4 the graph shows the variation of frequency with respect to time for upper case. From graph we observe that peak over shoot is reduced compared to previous method. In proposed method the output settles very quickly compared to previous method.

Table1: Comparison of performance parameters

Existing & Proposed	Peak overshoot *10 ⁻³	Settling time(s)
Nominal	1.2	7.5
Lower	0.6	6.8
Upper	1.1	20
Nominal	0.6	4.2
Lower	0.2	4
Upper	0.8	10

We can see from the figures above that the peak overshoot is diminished and decreases rise time and settling time. Rise time and settling time also improved. Thus, settling time is reduced compared to current scheme so the response is quicker.

B. LFC design for two area system

With out loss of originality, the proposed system is expanded to two area power system. The tie-line power deviation also measurable parameter in two area power system with deviation in frequency.

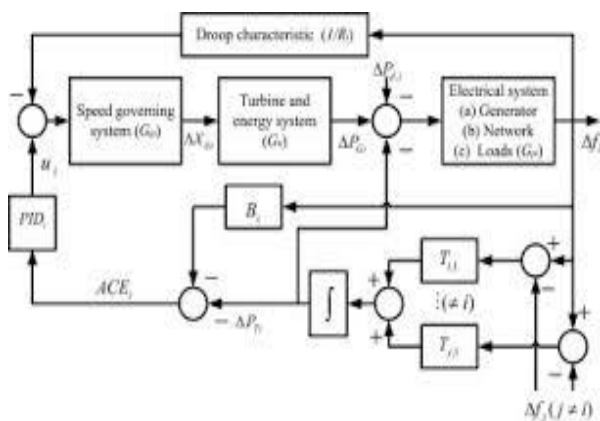


Fig.5. Two area power system functional block diagram

The proposed fractional order control system based on the genetic algorithm applied to two area system. The resultant graphs are shown in Fig.6, Fig.7, Fig.8. The parameters are compared in the table.2. for two area system.

In two area system and multi area system deviation in frequency and power deviation in tie line are very important. We are creating the disturbance in the form of step input. The proposed GA based FOPID controller is used to reduce rapid changes in frequency and tie-line power. The frequency deviation in areal regarding time shown in

fig.6.From the graph we can observe that peak overshoots are reduced compared to previous scheme. Compared with other method in the graph, the rise time and settling time are much less.

Two areas connected with a tie-line in two area power system. When disturbance occur in one area the other area also effected by that disturbance. The graph in fig.7. shows frequency deviation with respect to time in area2. The peak overshoot is reduces and settling time also very less in proposed scheme compared to other method in the graph.

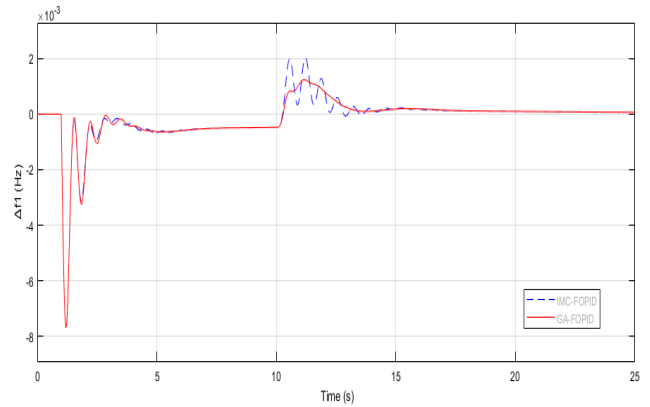


Fig.6. Deviation of frequency in area1

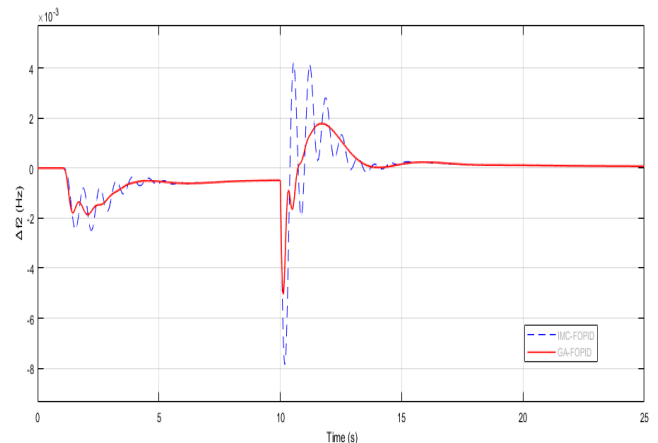


Fig.7. Deviation of frequency in area2

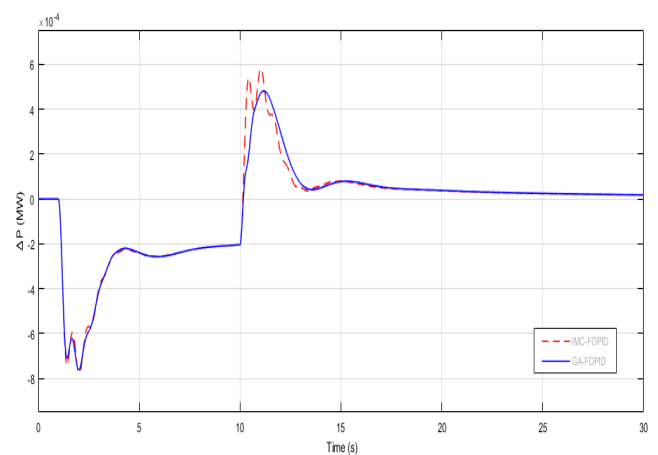


Fig.8. Power deviation in Tie-line

Tie-line power deviation has significance in multi area power system. The graph in fig.8. shows tie-line power deviation with time. From the graph we can observe that peak over shoot reduces and settling time also reduced compared to other method in the graph.

Table 2: Comparison of performance parameters

Existing& Proposed	Peak overshoot *10 ^{^-3}	Settling time (s)
Δf_1	2	17
Δf_2	4.2	20
ΔP	5.8	25
Δf_1	0.8	13
Δf_2	1.8	14
ΔP	4.2	18

VI. CONCLUSION AND FUTURE SCOPE

From the complete analysis of graphs and tables by using different time domain specifications like rise time and peak overshoot, we can conclude that the graphs with IMC based FOPID controller gives more peak aver shoots, oscillations and also takes more settling time compared with GA based FOPID controller. Thus, we can say that GA based FOPID controller shows better dynamic performance than IMC based FOPID controller.

In this work we have applied the proposed controller for single area and two area power system, sofuture we can extend it to complex system. In future we can use various soft computing techniques in place of FOPID. Infuture we can extend it to complex system. In future we can use various soft computing techniques in place of FOPID.

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