Load Frequency Control on A Multi Area power System under Deregulated Environment by Using Fractional Order PI Controller

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Abstract— Electrical industry under deregulated environment, the LFC and AGC system has been considered by taking the effect of bilateral contracts taken into an account i.e., any DISCO has liberty to have agreements with GENCOs in other areas also. The aim is to enhance system parameters such as line transmitted power, frequency deviation error and area control error using FOPI Controller. This paper presents Load Frequency Control (LFC) of interconnected two equal area Thermal-Hydal systems in deregulated environment by using FOPI Controller that compared with classical integer order PI controller. The simulation in MATLAB/SIMULINK of the LFC with FOPI Controller shows better responses.

Keywords- Load Frequency Control (LFC), Deregulated Environment, FOPI Controller and Integer Order PI Controller.

1. Introduction

Electrical Energy is a significant factor in the industrial advancement in any country. In underdeveloped countries the master topics have been an eminent demand maturation linked to ineffective system direction and irrational tariff policies. In such condition many utility services forced to restructure their power sectors under distress from irrational backing agencies. The goal of deregulation is to meliorate contention and take consumers worn options and economic interest. Under deregulation, the early vertical integrated utility which officiate entire roles implied in power system i.e., generation, transmission, distribution and retail sales is segregated into freestanding bodies dedicated to each service.

In interconnected power system any incongruity among generation and load crushes large frequency changes. The frequency of generating stations is relocated to expected values by assigned load transfer among dissimilar areas this kind of frequency control is described as secondary frequency control. It is located along with primary frequency control (Governor Control).

In the prior late decades abundant examinations and attempts have been logged out to sketch an excellent automated generation controller to embellish stability and safety of the structure. A literature assessment on the LFC of Power System has been submitted with several controls features considering LFC question have been spotlighted. Dynamic functioning of all the conventional, classical integer order controllers such as integral (I), Proportional Integral (PI), Proportional Integral Derivative (PID) controllers in the areas of LFC have been studied in the past investigations.

2. Deregulation

In the restructured power environment, vertical integrated utility models not any more continued they emerged as various bodies namely generating companies (GENCOs), transmission companies (TRANSCO), distribution companies (DISCOs). In bilateral model, any DISCO have the independence to pick the GENCO for power transactions. A DISCO may choose dealings with GENCOs in other control areas also but in case of pool co model GENCOs co-operate of in LFC of respective control area only[1,2]. Whole activities have to be done by a fair minded entity called as independent system operator (ISO). There can be several aggregations of pool co based and bilateral commitments among GENCOs and DISCOs can be handily envisioned by the approach of a DISCO participation matrix (DPM) [1].

\[ DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \]

In DPM No. of columns and rows are equivalent to the NO. of discoms and gencos accordingly. Every element in a DPM resembles to a contracted load by a discom, it must be supplied from the respective genco implicated in the contract. The cpf\text{mn} is contract participation factor among m\text{th} Genco and n\text{th} Discom. The cpf\text{mn} coincide with the total load power contracted by the discom-m from a gencos [1]. The sum of whole elements in the column is unity in DPM Matrix, \[ \sum_{m} cpf_{mn} = 1 \]

Where cpf\text{mn} = Contract Participation Matrix of m\text{th} denco in providing the load of n\text{th} dicom.

In this work is having two gencos and two discoms. Let genco1 and genco2, discom1 and discom2 are in control area1. Genco3 and genco4, discom3 and discom4 are in control area2. In any occasion change in load occurred in this restricted system. Only a specific genco essential to take up the change in load required by a specific discom.

In this manner, information signals essential to run out from the DISCOs to the GENCOs to designate equivalent demands. These information signals are acquired by the way of “transaction tags”, in OASIS system of the US. These signals accomplish information regarding “which GENCO has to act in accordance with load required by which DISCO”. Further, for those DISCOs having a agreement with GENCOs not present in their area, load demand signals has to adapt the required flow on the tie-lines.
The anticipated steady state power run out on the tie lines
\( \Delta P_{\text{tie-1, scheduled}} = \text{(Demand of DISCOs in Area-II from GENCOs in Area-I) - (Demand of DISCOs in Area-I from GENCOs in Area-II)} \)

The variation in tie-line power is described as

\[ \Delta P_{\text{tie-1, error}} = \Delta P_{\text{tie-1, actual}} - \Delta P_{\text{tie-1, scheduled}} \]

\( \Delta P_{\text{tie-1, error}} \) faded out in the steady state when the actual tie line power flow attains the scheduled tie line power flow. The variation in scheduled power flow introduces error in tie-line power which helps to derive ACEs for the respective control areas implicated in the action [3, 4].

The area control errors given as

\[ ACE_i = B_i \Delta F_1 + P_{\text{tie-1, error}}^{\text{D}} \]

\[ ACE_2 = B_2 \Delta F_2 + P_{\text{tie-1, error}}^{\text{D}} \]

ACE signals have to be distributed among the two GENCOs in each area in proportion to GENCOs participation in the LFC. Elements that share ACE to GENCOs are denoted as “ACE participation factor (apfs)”.

2. Fractional Order PI Controller

Fractional Calculus:

To learn the fractional order controllers, the beginning detail is naturally the fractional order differential equations exploiting fractional calculus. A usually exploited definition of the fractional order PI is the Riemann-Liouville definition:

\[ a^{D_{a}^\alpha} f(x) = \frac{1}{\Gamma(n-a)} \int_x^D (t-x)^{n-a-1} f(t) \, dt, \quad (n-1 < \alpha < n) \]

Where \( 0 < \alpha < 1 \), and \( a \) is the initial time instance, often assumed to be zero, i.e., \( a = 0 \).

The differentiation is then termed as \( a^{D_{a}^\alpha} f(x) \). The Riemann–Liouville definition is the most widely used definition in fractional order calculus. The subscripts on both sides of \( D \) represent, respectively, the lower and upper bounds in the integration. Such a definition can also be extended to fractional-order differentiations when the order satisfies \( n-1 < \beta \leq n \). The fractional-order differentiation is then defined as

\[ a^{D_{a}^\beta} f(t) = s^{\beta} F(s) - \sum_{k=0}^{n-1} \frac{\alpha^{\beta-k} n!}{\beta} (t-a)^{\beta-k-1} f(t) \]

It can be shown that for a class of real functions, the fractional-order differentiations from the Grunwald-Letnikov and Riemann–Liouville definitions are identical.

It can be seen that the Grunwald-Letnikov definition gives a very good fitting to the fractional-order derivatives for given functions. However, in control system analysis and design, the definition is not useful, since the samples of the function should be known. Online real-time fractional-order differentiation may be required in control systems. Using filters is one of the best ways to solve the problems.

Assume that the frequency range to be outlined as \((\omega_h, \omega_l)\). Within the specified frequency range, the fractional-order operator \( s^\alpha \) can be approximated by the fractional-order transfer function as

\[ K(s) = \left( \frac{1+bs}{1+b\omega_b s} \right)^{\lambda} ; \quad 0 < \lambda \leq 1 \]

Truncating the Taylor series leads to

\[ K(s) = \left( \frac{bs}{d\omega_b} \right)^{\lambda} \]

Thus, the fractional-order differentiator is defined as

\[ k(s) = \lim_{n \to \infty} \prod_{k=-N}^{N} \left( 1 + \frac{s/\omega_k^\prime}{1 + s/\omega_k} \right) \]

Above expression is stable if and only if all the poles lies on the left-hand side of the \( s \)-plane. The above expression has three poles: One of the poles is located at \( -b\omega_b/d \), which is a negative real pole since \( \omega_h > 0, b > 0, d > 0 \); the two other poles are the roots of the equation

\[ d(1-\alpha)s^2 + a\omega_h s + d\alpha = 0 \]

Whose real parts are negative since \( 0 < \alpha < 1 \). Thus, all the poles are stable within the frequency range \((\omega_h, \omega_l)\). The irrational fractional-order part of approximated by the continuous-time rational model

\[ s^\lambda \approx \left( \frac{d\omega_b}{b} \right)^{\lambda} \left( \frac{ds^2 + b\omega_h s}{d(1-\alpha)s^2 + b\omega_h s + d\alpha} \right) \]

According to the recursive distribution of real zeros and poles, the zero and pole of rank \( k \) can be written as

\[ \omega'_k = \left( \frac{d\omega_b}{b} \right)^{\frac{\alpha-2k}{2\lambda+1}}, \omega_b = \left( \frac{\omega_h}{d} \right)^{\frac{\alpha+2k}{2\lambda+1}} \]

Thus, the continuous rational transfer function model can be obtained [14-15] as

\[ s^\lambda \approx \left( \frac{d\omega_b}{b} \right)^{\lambda} \left( \frac{ds^2 + b\omega_h s}{d(1-\alpha)s^2 + b\omega_h s + d\alpha} \right) \prod_{k=-N}^{N} \left( \frac{s + \omega'_k}{s + \omega_k} \right) \]

Through the approximation method, the fractional-order system may be approximated as the very high integer-order system.

3. Fractional-Order PID Controller

Fractional-Order PID controller is an elongation to conventional PID controller and it represented as \( \text{PI}^\lambda D^\mu \) where \( \lambda, \mu \) are the non integer order of integrator and differentiator they can be any real numbers.

The integral-differential equation defining the control action of Fractional Order PID controller is given by
By applying Laplace transform theory the transfer function of the FOPID controller will be

\[ E(s) \quad \frac{1}{s^\mu} \quad \frac{K_p}{s^\lambda} \quad K_i \quad K_d \quad \sum \quad U(s) \]

If \( \lambda = 0 \) and \( \mu = 0 \), a P Controller is obtained.
If \( \lambda = 1 \) and \( \mu = 0 \), a PI controller is obtained.
If \( \lambda = 1 \) and \( \mu = 1 \), a PID controller is obtained.

![Diagram of FOPID control space](image)

4. Simulation Results

The acknowledgement of the LFC in the absence of controller presents improper long living perturbations with massive overshoots and immense steady state error. From the results, the steady state error is substantially minimized from the LFC when armed with the IOPI controller still the changing nature presents in the system even the IOPI controller has been installed.

By determining the proper optimization issues, optimum IOPI controller of the interconnected system with following transfer functions

Area I: \( G_{C1}(s) = \frac{2.6}{s} \)
Area II: \( G_{C2}(s) = \frac{0.72}{s} \)

Fluctuations in the area frequency deviation responses as shown in figure 1 and 2 and tie-line power deviation response of the system with IOPI controller as shown in figure 3. Placing optimal FOPI controller in place of IOPI Controller can effectively enhance steady state and transient nature of the system with the following transfer functions

Area I: \( G_{C1}(s) = \frac{1+1}{s^{1.1}} \)
Area II: \( G_{C2}(s) = \frac{1+1}{s^{1.1}} \)

Fluctuations in the area frequency deviation responses as shown in figure 1 and 2 and tie-line power deviation response of the system with FOPI controller as shown in figure 3.
5. Conclusion

To demonstrate the deregulated environment, the system is combination of Thermal and Hydel systems in each area. The FOPI controller setting time and peak time are lower than the other conventional controllers. It further may be extended to FO Fuzzy PI controller.

References


