LOAD FREQUENCY CONTROL FOR THREE AREA SYSTEM WITH TIME DELAYS USING FUZZY LOGIC CONTROLLER

G.Karthikeyan[1], S.Ramya[2], Dr. S.Chandrasekar[3]

[1]*Asst. professor(Sr. G), EEE,Sona College of Technology,Tamil Nadu,India,* ***gkarthikeyan_78@yahoo.com.***
[2] *P.G Scholar, Sona College of Technology, Tamil Nadu, India,* ***sramyasct@yahoo.com.***
[3]*Principal, Gnanamani College of Engineering, Tamil Nadu, India.*

Abstract

The load-frequency control (LFC) is used to restore the balance between load and generation in each control area by means of speed control. The objective of LFC is to minimize the transient deviations and steady state error to zero in advance. This paper investigates LFC with time delays using proportional integral (PI) Controller and fuzzy logic controller for three area system using MATLAB/SIMLINK. In this proposed system Area 1 and 2, Area 2 and 3 are connected by frequency controllable High Voltage Direct Current transmission links and Area 2 and 3 is connected by normal AC tie-line. By using the system interconnections as the HVDC link, the tie-line power modulation of HVDC link through interconnections is possible. The advantage of incorporating time delays is important for satisfactory dynamical responses. The HVDC transmission link is to transfer power over long distance without any frequency deviation.

Index Terms: *K LFC, ACE, Time delay, HVDC tie line*.

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1. INTRODUCTION

Frequency changes in an interconnected power system are the direct result of imbalance between electrical load and the power supplied by generators connected to the systems [6]. The quality of power generating system is defined by three factors: constancy of frequency, constancy of voltage and level of reliability. In actual power system operations, the load is changing continuously and randomly, resulting in the deviations of load frequency and the tie-line power between any two areas from scheduled generation quantities. The aim of LFC is to regulate the frequency to the nominal value and to maintain the interchange power between control areas [9]. The network frequency is maintained constant in order to run power systems in parallel operation and also operating various motors at desired speed in the system.

LFC is a very important factor in power system operation and control for supplying sufficient and reliable electric power with good quality. The main advantage of HVDC link is the enhanced damping of AC transmission using power modulation via an HVDC link in a parallel AC-DC interconnected power system [11]. When an AC power system is subjected to a load disturbance the system frequency may deviate from normal operating frequency and it directly interrupt the operation of power and error system. To overcome this problem HVDC link is mostly preferred in parallel with AC transmission line.

Normally LFC systems use PI controllers. Since they are designed using a linear model, the non linearity's of the system are not considered [6] and these controllers are commonly tuned based on classical ,experience and trial and error approach, They are incapable of obtaining good dynamical performance in a multi area power system [1].

Now-a-days the LFC systems are faced by new uncertainties in the electrical market. To meet these uncertainties and to support the control process an open communication infra structure is important. In conventional LFC schemes dedicated communication channels are used for transmit the measurements to the control centre and then to the generator unit. The communication delays are considered as significant uncertainties in the LFC due to the complexity of the power system and cause the system instability. This also degrades the system performance.

Thus the analysis of LFC model in the presence of time delays is most important. Now-a-days many researchers concentrate on LFC modelling/synthesis in the presence of time delays [1]-[5]. They mainly focused on the network delay models and the communication network requirements.

In this paper, the power system with three areas having two reheat turbine and one non reheat turbine is considered in simulation study with time delays using PI controller and fuzzy logic controller. In the proposed structure Area 1 and 2, Area 1 and 3 area connected by frequency controllable HVDC transmission link and Area 2 and 3 is connected by normal tie-line. The advantage of using HVDC links is to reduce long distance transmission cost and power loss [7]. The purpose of using FLC is that it provides fast response, adequate disturbance rejection an also provides effective result for complex and non linear model. Finally the results of PI and FLC are considered as shown at simulation results. The controller improves effectively the damping of the oscillations after the load deviation in one of the areas in the interconnected system compared to conventional controllers.

2. PROPOSED CONTROL STRATEGY

2.1. Modelling of power generating units

2.1.1 Speed governing system model

When the generator electrical load exceeds, the electrical power exceeds the mechanical power input. This is compensated by the kinetic energy stored in the rotating system, this cause the generator frequency to fall. Speed governor model sense the machine speed and adjust the input valve to change the mechanical output and to restore frequency at nominal value.

$$\Delta P_v(s) = \frac{1}{1+\tau_g s}\Delta P_g(s)$$

A) *Turbine model*

The model for the turbine relates changes in mechanical power output (ΔP_g) to change in valve position (ΔP_v).

$$\Delta P_m(s) = \frac{1}{1+\tau_t s}\ \Delta p_v(s)$$

B) *Generator model*

The synchronous machine as an ac generator driven by a turbine is the device, which converts mechanical energy into electrical energy. In power system if there is any change in load cause change in frequency or speed of the generator unit in the system.

$$\Delta F(s) = \frac{1}{2Hs}(\Delta P_m(s) - \Delta p_e(s))$$

C) *Load model*

The load on a power system comprises of a variety of electrical devices. Some of them are purely resistive. Some are motor loads with variable power frequency characteristics, and others exhibit quite different characteristics. Since motor loads are a dominant part of the electrical load, there is a need to model the effect of a change in frequency on the net load drawn by the system. The relationship between the changes in load due to the change in frequency is given by

$$\Delta P_{L(freq)} = D\Delta\omega$$

2.2. Modelling of interconnected system

In an interconnected or multi area system load change in one area will affect the generation in all other interconnected areas. Tie line power flow should also be taken into account other than change in frequency.

2.2.1 Tie-line model and bias control

In an interconnected power system, different areas are connected with each other via tie-lines. When the frequencies in two areas are different, a power exchange occurs through the tie-line the two areas. In normal operation the power on the tie-line follows from equation.

$$P_{tieflow} = \frac{1}{X_{tie}}(\beta_1 - \beta_2)$$

This tie-line flow is a steady-state quantity. For purpose of analysis here, we will perturb the above equation to obtain deviations from nominal flow as a function of deviations in phase angle from nominal.

$$\Delta P_{tieflow} = \frac{1}{X_{tie}}[(\Delta\beta_1) - (\Delta\beta_2)]$$

Where β_1 *and* β_2 *are equal to* $\Delta\delta_1$ *and* $\Delta\delta_2$

The equation can be written as,

$$\Delta P_{tieflow} = \frac{T}{S}(\Delta\omega_1 - \omega_2)$$

Where T is the tie-line stiffness coefficient.

From the above discussion it is clear that the tie-line power error is the integral of the frequency difference between the two areas.

Suppose now that we have an interconnected power system broken into two areas each having one generator. The areas are connected by a single transmission line. The power flow over the transmission line will appear as a positive load to one area and an equal but negative load to the other, or vice versa, depending on the direction of flow. The direction of flow will be dictated by the relative phase angle between the areas, which is determined by the relative speed -deviations in the areas

Consider a three area system interconnected via the tie-line and hence at steady state the equation becomes,

$$\Delta\omega_1 = \Delta\omega_2 = \Delta\omega_3 = \Delta\omega$$

$$\frac{d(\Delta\omega_1)}{dt} = \frac{d(\Delta\omega_2)}{dt} = \frac{d(\Delta\omega_3)}{dt} = 0,$$

$$\Delta\omega = \frac{-\Delta P_{L1}}{\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + D_1 + D_2 + D_3}$$

If we consider the i^{th} control area, its net interchange equals the sum of the megawatts on all m outgoing tie lines. As the area control error ACE_i ought to be reflective of the total exchange of power it should thus be chosen of the form

$$ACE_i = \sum_{j=1} \Delta P_{ij} + B_i \Delta f_i$$

This error is added to the biased frequency error and the ACE. The ACE is communicated with all area generators that are participating in the secondary LFC.

2.2.2 Three Area LFC Model

In an interconnected power system a group of generators are closely coupled internally and swing in unison. The generator turbines tend to have the same response characteristics. Such a group of generators are said to be coherent. This is referred to as control area. The various control areas are generally interconnected using transmission lines called "tie lines" which allow the flow of active power from one area to another when required.

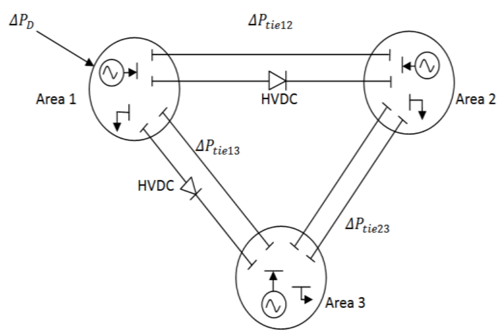

Fig 1: Three area system

When an interconnected AC power system is subjected to a load disturbance, system frequency may be considerably disturbed and becomes oscillatory. By utilizing the system interconnections as the control channels of HVDC link, the tie line power modulation of HVDC link through interconnections is applicable for stabilizing the frequency oscillation of AC system. The major advantages of HVDC link are long distance overhead bulk power transmission, transmission between unsynchronized AC transmission and marine cable transmission.

In this proposed model a HVDC transmission link is used to transfer power from one area to another over a long distance without any frequency deviation. Since it is frequency insensitive under the constant current control, Auxiliary frequency controllers are widely used along with HVDC transmission in order to improve the system performance. These HVDC links are then frequency sensitive and may pose some stability problems. A load frequency controller corrects any deviation of the power system after a change in load demand.

Here each area requires only its local measurements. The remote terminal measurements are avoided. The collection of these local frequency controllers is known as de-centralized load frequency controller. In the presence of frequency controllable HVDC links, frequency regulation of a receiving area will cause frequency deviations in its sending ends. All the local frequency controllers and affected AFC's are activated.

In this structure area 1 and 2 contain reheat type turbines and area 3 uses non-reheat turbine. Area 2 and 3 are interconnected through normal tie-line. It is assumed that both areas 2 and 3 may face large load changes that will cause a significant and unacceptable frequency deviation. They are therefore linked to area 1 via HVDC tie-lines for assistance in frequency regulation.

2.3. Modelling of time delays

In this paper control delay is considered on the control input and control output of the LFC system. The delays on the measured frequency and power tie-line flow from remote terminal units to the control centre is considered on the area control error(ACE) signal and the produced rise/lower signal from the control centre to individual generation units.

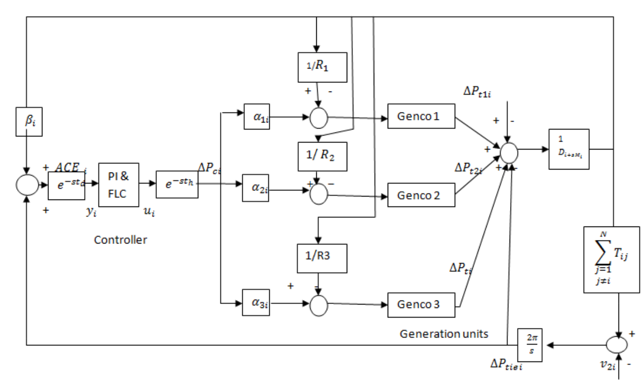

Fig 2: Three control area with time delays

The communication delay is expressed by an exponential function $e^{-s\tau}$ where τ gives the communication delay time following a load disturbance with in a control area. The frequency of the area experiences a transient change and the feedback mechanism comes into play and generates the appropriate control signal to make the generation readjust to meet the load demand. The balance between the connected control areas is achieved by detecting the frequency and tie-line power deviation via communication to generate the ACE signal by PI and FLC and this control signal is submitted to the participated generation companies via another communication link, based on their participation factor.

2.3.1 Dynamic model of LFC with time delay

For multi area LFC scheme, all generation units in each control area are simplified as an equivalent generation unit. The dynamic model of the multi-area power system including n control areas as follows,

$$\dot{x}(t) = Ax(t) + Bu(t) + F\Delta P_d$$
$$y(t) = cx(t)$$

Where,

$$x_i(t) = [\,\Delta f_i\ \Delta P_{mi}\ \Delta P_{vi}\ \int ACE_i\ \Delta P_{tiei}\,]^T,$$
$$y_i(t) = [\,ACE_i\ \int ACE_i\,]^T,$$
$$x(t) = [\,x_1(t)\ x_2(t)\ \cdots\ x_n(t)\,],$$
$$y(t) = [\,y_1(t)\ y_2(t)\ \cdots\ y_n(t)\,],$$
$$u(t) = [\,u_1(t)\ u_2(t)\ \cdots\ u_n(t)\,],$$
$$\Delta P_d(t) = [\,\Delta P_{d1}(t)\ \Delta P_{d2}(t) \cdots \Delta P_{dn}(t)]$$

Here

$\Delta f, \Delta P_m, \Delta P_v, \Delta P_d$ are the deviations of frequency, the generator mechanical output, valve position and load respectively.

ACE and $\int ACE$ are the area control error and its time integration respectively.

Using ACE as the input the design for PI controller is as follows,

$$u(t) = -K_P ACE - K_I \int ACE$$
$$= -Ky(t - d(t))$$
$$= -KCx(t - d(t))$$

Where $K = [K_P\ K_I]$,K_P, K_I are proportional and integral gains respectively, d(t) denotes the time varying delay.

Finally the equation is as follows,

$$\dot{x}(t) = Ax(t) + A_d x(t - d(t)) + F\Delta P_d$$

$$A = \begin{bmatrix} A_{11} & A_{12} & \dots & A_{1n} \\ A_{21} & A_{22} & \dots & A_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ A_{n1} & A_{n2} & \dots & A_{nn} \end{bmatrix},$$

$$B = \mathrm{diag}\,[B_1\ B_2\ \dots\ B_n],$$
$$C = \mathrm{diag}\,[C_1\ C_2\ \dots\ C_n],$$
$$F = \mathrm{diag}\,[F_1\ F_2\ \dots\ F_n],$$
$$B_i = [\,0\ 0\ \tfrac{1}{T_{gi}}\ 0\ 0\,]^T,$$
$$F_i = [-\tfrac{1}{M_i}\ 0\ 0\ 0\ 0\,]^T,$$
$$C_i = \begin{bmatrix} \beta_i & 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & 1 & 0 \end{bmatrix},$$

$$A_{ii} = \begin{bmatrix} -\frac{D_i}{M_i} & \frac{1}{M_i} & 0 & 0 & -\frac{1}{M_i} \\ 0 & -\frac{1}{T_{chi}} & \frac{1}{T_{chi}} & 0 & 0 \\ -\frac{1}{RT_{gi}} & 0 & -\frac{1}{T_{gi}} & 0 & 0 \\ \beta_i & 0 & 0 & 0 & 1 \\ 2\pi\sum_{j=1, j\neq i}^{n} T_{ij} & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$A_{ij} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ -2\pi T_{ij} & 0 & 0 & 0 & 0 \end{bmatrix},$$

$$T_{ij} = T_{ji}\,,$$

T_{ij} is the tie-line synchronizing co-efficient between i^{th} *and* j^{th} control areas.

The ACE signal in a multi area LFC scheme is defined as,

$$ACE_i = \beta_i \Delta f_i + \Delta P_{tiei}$$

The net exchange of tie-line power of the i^{th} control area is ΔP_{tiei}

For the multi-area system the net tie-line power exchange between each control area,

$$\textstyle\sum_{i=1}^{n} \Delta P_{tiei} = 0.$$

3. CONFIGURATION OF POWER SYSTEM BASED ON PI AND FUZZY LOGIC CONTROLLER

3.1 PI controller

The proportional plus integral controller produces an output signal consisting of two terms- one proportional to error signal and the other proportional to the integral error signal.

The control input's are,

$$U_i - K_i \int_0^\tau ACE_i dt = K_i \int_o^\tau \Delta P_{tie,1} + b_i \Delta f_i dt$$

Taking derivative,

$$u_i' - K_i(ACE_{i)} = K_i(\Delta P_{tie,1} + b_i \Delta f_i)$$

In matrix form,

$$U' = -K_i C_x$$

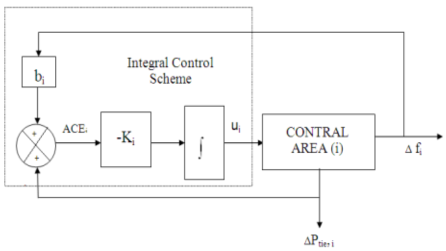

Fig 3: Block diagram of single area PI controller.

In PI controller, the proportional term provides control action equal to some multiple of the error and the integral term forces steady state error to zero.

3.2 Fuzzy Logic Controller

Fuzzy logic controller's (FLC) are knowledge based controllers usually derived from a knowledge acquisition process or automatically synthesized from self-organizing control architecture. It typically defines a non-linear mapping from the system's state space to the control space. The advantages of FLC's are,

1) Controller parameters can be changed very quickly by the system dynamics because no parameter estimation is required in designing controller for non-linear system.

2) It provides an efficient way of coping with imperfect information and offers flexibility in decision making process.

The basic configuration of fuzzy logic based LFC composes the following components:

1) A fuzzification interface.
2) A knowledge base
3) A decision making logic and
4) A defuzzification interface

A universal mamdani type fuzzy controller has been simulated for the LFC to damp out the oscillations due to instantaneous perturbation as fast as possible. The parameters that affect the system performance is considered as the inputs and they are

1) The frequency error
2) The change of frequency error

The output of the controller is the incremental control action i.e. incremental control output.

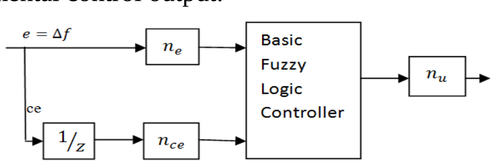

Fig 4: Fuzzy logic controller for LFC

Here n_e, n_{ce} are scaling gains of error and change of error and n_u ,z represent output control gain and maximum membership function respectively.

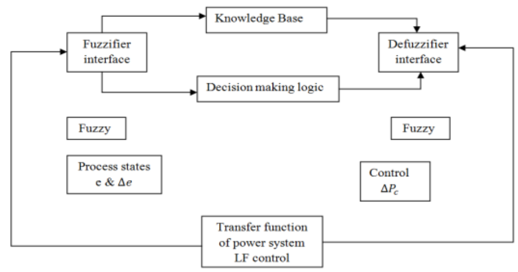

Fig 5: Fuzzy Logic Controller Installed in i^{th} Area

Figure 5 describes the function of fuzzy logic controller in power system. In this the tiangular membership function is taken due its flexibility and also measurement of values is accurate.

The next step is to fuzzifying the input.The universe of discourse of the inputs is divided into seven fuzzy sets of triangular. The first block inside the controller is Fuzzification, which converts each piece of input data to degrees of membership by a lookup in one or several membership functions. The fuzzification block thus matches the input data with the conditions of the rules to determine how well the condition of each rule matches that particular input instance. There is a degree of membership for each linguistic term that applies to that input variable.

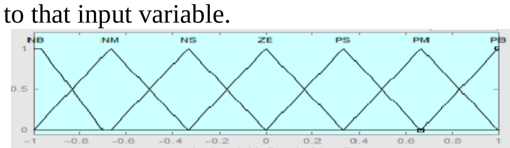

Fig 7: Output control signal

Then rules are implemented to fuzzify the linguistic variables. Fuzzy IF-THEN rules for LFC system is defined as follows,

If x is A_i and y is B_i then z is C_i . The rules are created based on mamdani type FLC. x is frequency error and y is change in frequency error.

	NB	NM	NS	Z	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	Z
NM	NB	NB	NM	NM	NS	Z	PS
NS	NB	NM	NM	NS	Z	PS	PM
Z	NM	NM	NS	Z	PS	PM	PM
PS	NM	NS	Z	PS	PM	PM	PB
PM	NS	Z	PS	PM	PM	PB	PB
PB	Z	PS	PM	PB	PB	PB	PB

Table.1: Fuzzy decision table

Finally defuzzification is done to get required crisp output. The reverse of fuzzification is called Defuzzification. The use of FLC produces required output in a linguistic variable. These linguistic variables have to be transformed to crisp output. The centre of area defuzzification method is used.

The crisp output value u is the abscissa under the centre of gravity of the fuzzy set,

$$u = \frac{\sum_i \forall\mu(x_i)x_i}{\sum_i \mu(x_i)}$$

Here x_i is a running point in a discrete universe, and $\mu(x_i)$ is its membership value in the membership function.

4. SIMULATION RESULTS

The simulation results of three area system area are shown below. In this six cases are considered based on the values used for LFC parameters.

Case 1:

In this case we consider the lowest parameters of three areas in proposed structure.

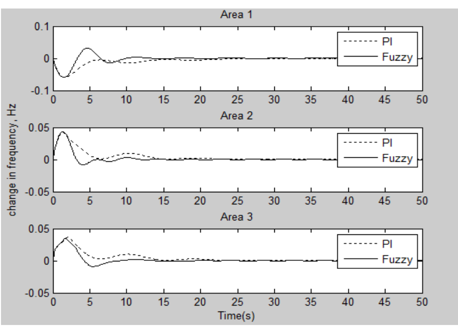

Fig 8: Frequency deviation of 3 area system-case 1

Case 2:

Here nominal parameter is assumed to three areas.

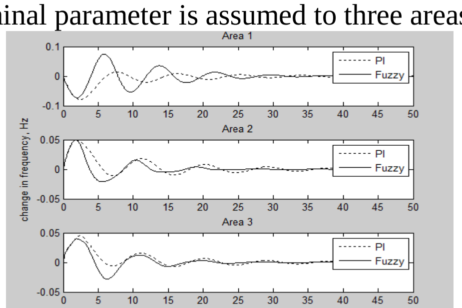

Fig 11: Frequency deviation of 3 area system-case 4

Case 3:

Highest parameters are assumed to all three areas.

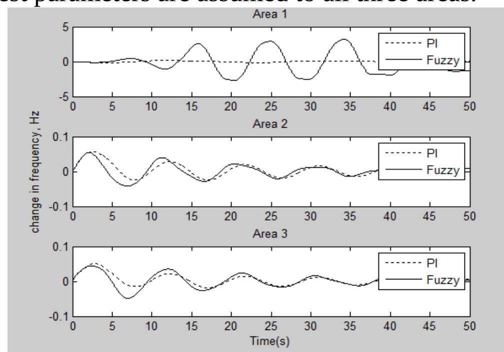

Fig 13: Frequency deviation of 3 area system-case 6

CONCLUSION

In this paper, three area load frequency control with time delays are analysed using PI and fuzzy logic controller in co-ordination with frequency controllable HVDC links. The results are shown that by using the time delay the dynamic response of the system will increase and the degradation in the system performance can be compensated effectively using HVDC link. By simulation study, the fuzzy logic controller is very effective in suppressing the frequency oscillations caused by rapid load disturbances and it will improve the system performance by effectively reduce the overshoot compared to PI controller.

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BIOGRAPHIES

G.Karthikeyan was born in India, in 1978. He received the B.E. degree in electrical and electronics engineering from Mailam Engineering College, Mailam in 2003 and M.E. degree in power systems engineering from Sona college of Technology, Salem in India, in 2006. Currently he is working as Asst. Professor (Sr.G) at Sona college of Technology in the department of Electrical and Electronics Engineering. His areas of research interest are power system automation and artificial intelligence techniques applications in electric power engineering.

S.Ramya was born in India, in 1989. She received the B.E. degree in electrical and electronics engineering from Sona College of Technology, Salem in 2010 .Currently she is pursuing M.E. degree in power systems engineering from Sona college of Technology, Salem in India.

Dr. S. Chandrasekar was born in India, in 1975. He received the B.E. degree in electrical and electronics engineering from Thiagarajar College Engineering Madurai in 1996 and the M.E degree in power system engineering from Coimbatore Institute of Technology, Coimbatore in India in 2001 and the Ph.D. degree from the Indian Institute of Technology Madras, India in 2005. He was a postdoctoral research fellow at the University of Bologna, Italy from 2005 to 2006. Currently, he is working as a Principal at Gnanamani College of Engineering. His research interests include condition monitoring of power apparatus and systems, insulation engineering, signal processing and artificial intelligence techniques applications in electric power engineering.