LOAD FREQUENCY CONTROL IN CO-ORDINATION WITH FREQUENCY CONTROLLABLE HVDC LINKS USING FUZZY LOGIC CONTROLLER

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Abstract

In this paper decentralized load frequency control (LFC) for suppression of oscillations in multi-area power systems using fuzzy logic controller was studied. A three area system is considered in which areas 1 and 2 and areas 1 and 3 are connected by HVDC transmission links and areas 2 and 3 are connected by normal AC tie-line. The performance of the fuzzy logic controller is compared with the conventional PI controller and the simulation results shows that fuzzy logic controller is very effective enhancing better damping performance in non-linear conditions.

Keywords: *Load Frequency Control, High Voltage Direct Current transmission Link, Proportional Integral Controller, Fuzzy Logic Control.*

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1. INTRODUCTION

For the all-round development of any country and industrial development, Electrical energy is an essential ingredient. This is obtained by using a large-scale power interconnection system, which is intended to make the electrical energy generation and transmission more economical and reliable. Hence, in modern large interconnected system controllers are set for a particular operating condition and they take care of small changes in load demand without frequency and voltage exceeding the prescribed limits.

A power system consisting of number of areas are interconnected by means of AC tie-lines or HVDC transmission links.[1] It is necessary to maintain the frequency constant so that the power stations run satisfactorily in parallel and various motors operating in the system run at the desired speed. By achieving a balance between the generation and the connection of load, the frequency can be made constant to a major extent [2]. The frequency of a power system entirely depends upon the speed at which the generators are rotated by their prime movers. A constant speed is obtained by adjusting the gate or control valve opening of the speed governor. Power system operation at low frequency than that specified maximum permissible change in frequency ($\pm$ 0.5Hz) causes certain serious problems. When operating at frequencies below 49.5Hz, some types of steam turbines undergo excessive vibrations. In certain turbine rotor the effect causes resultant metal fatigue and blade failures. When the frequency falls below 49Hz, the turbine regulating devices fully open and the generating units becomes completely loaded. As the frequency decreases, the generator exciter loses their speed and generator emf falls and the voltage in the power system unit drop. This brings the danger of a “voltage avalanche” and disconnection of the consumers [3]. The main requirement of load frequency control is to ensure that the frequency of the various bus voltage and current are maintained at or near specified nominal value. Also to ensure that the tie-line power flows among the interconnection areas are maintained at specified levels[4,5]. Load frequency control made the operation of interconnected systems possible and today it is still the basic of any advanced concept for the guidance of large systems.

Power systems are generally non-linear. Controllers designed based on linear techniques like PI,PID etc. work satisfactorily on linear conditions only and a load frequency controllers designed on these techniques are not adequate for a power system[6]. Conventional PI control approach used in this project achieves zero steady state error in frequency but exhibits relatively poor dynamic performance by large overshoots and settling time. In recent year’s AI based approaches have attracted considerable attention for control strategies. First fuzzy logic based approach is used. A fuzzy logic controller uses fuzzy logic as a design methodology which can be applied, in developing linear and non-linear systems. In this paper, advantages of fuzzy logic controller [7-

9] have been employed to design a LFC to maintain desired megawatt output of generator unit and assist in controlling the frequency of three area power system and provide good damping over wide range of operating conditions.

2. SYSTEM MODELING

Modeling of physical system is an important task of the power system design procedure. The first step in the analysis of a dynamic system is to derive its mathematical model. Mathematical model may assume different forms. Once a mathematical model of a system is obtained various analytical and computer tools can be used for analysis and synthesis purposes.

2.1 Speed Governing System Model

If a generating unit is operated with fixed mechanical power output from the turbine, the result of any load change would be a speed change sufficient to cause the frequency sensitive load to exactly compensate for the load change. This condition would allow system frequency to drift for outside acceptable limits. This is overcome by adding a governing mechanism that senses the machine speed and adjusts the input valve to change the mechanical power output to compensate for load changes and to restore frequency to nominal value.

Equation of the speed governor model,

$$\Delta X(S) = \left[\Delta P_C(S) - \frac{1}{D}\Delta F(s) \right] * \frac{Kg}{1+sT_g} \qquad (1)$$

2.2Turbine Model

Prime-movers are devices which convert any form of energy into a mechanical energy. There is incremental increase in turbine power, due to the change in valve position that will result in an increased generator power.

$$G(s) = \frac{\Delta P_G(s)}{\Delta X(s)} = \frac{K_t}{1+sT_t}$$

2.3 Generator Load Model

The synchronous machine as an ac generator driven by a turbine is the device, which converts mechanical energy into electrical energy. An isolated generator is only supplying local load and is not supplying power to another area via tie line. Suppose there is a real load change ΔP_D, due to the action of turbine controllers, the generator increases its output by the amount ΔP_G.

$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)] \times \frac{K_P}{1+sT_P} \qquad (2)$$

2.4 Modeling the Tie-Line

Consider the system which has three areas as shown in fig..1.. These areas are interconnected by frequency-controllable HVDC links or normal tie-lines. Areas 1 and 2 and Areas 1 and 3 are interconnected by HVDC tie-lines and Areas 2 and 3 are interconnected by normal tie-line.

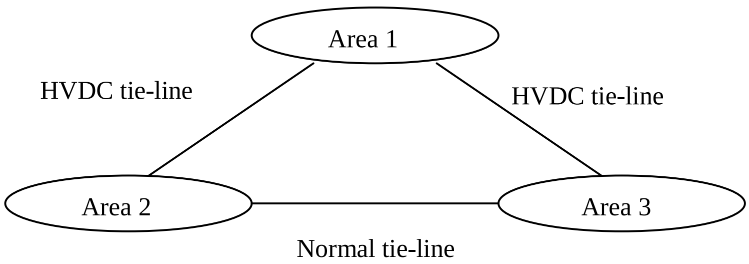

Fig1. Three Area Systems

The standard transfer function for a normal tie-line, which shows the incremental power flow from the ith area to the jth area, is given by

$$\Delta Ptieij = \frac{K_{Aij}}{s}(\Delta f_i - \Delta f_j) \qquad (3)$$

In considering the frequency controllable HVDC links, it is assumed that the deviation in the power system voltage, under the context of load-frequency control is negligible. Simple first-order AFC models, in the form of K_{Hij} /(sT_{Hij}+1), can therefore be used. The transfer functions of the HVDC links, in the presence of the AFCs, are given by

$$\Delta Ptie_{ij} = \frac{K_{Hij}}{sT_{Hij}+1}\Delta f_i \qquad (4)$$

$$\Delta Ptie_{ij} = \frac{-K_{Hij}}{sT_{Hij}+1}\Delta f_j \qquad (5)$$

A tie-line frequency bias control scheme is normally adopted in each area where the area control error (ACE) has to reach zero asymptotically.

ACE for the ith area is given by

ACEi (t) = KBi $\Delta f_i(t) + \Delta Ptie_i(t)$ (6)

2.5 Integral Control

The signal generated by the integral control must be of opposite sign to 'f(s)'. The steady state change in frequency has been reduced to zero by the addition of the integral controller. Change in frequency reaches steady state only when change in generated power equal to change in demand equal to constant. Because of the integrating action of controllers, this is only possible if change in frequency is equal to zero. In central load frequency control of a given control area, the change (error) in frequency is known as Area Control Error (ACE). By using the control strategy shown in fig 2., we can control the intolerable dynamic frequency changes with change in load.

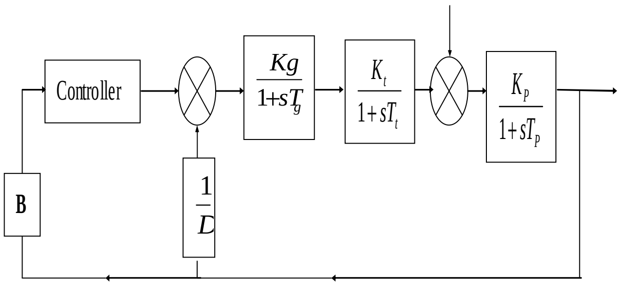

Fig2. Block diagram of Single Area Load Frequency Control

3. FUZZY LOGIC CONTROLLERS: A BRIEF OVERVIEW

Fuzzy logic is a novel approach that incorporates an alternate way of thinking which allows one to model complex systems using a higher level of abstraction. It is a very powerful method of reasoning when mathematical models are not available and input data are imprecise. It also finds extreme application wherever a logic in the spirit of human thinking can be introduced. In fuzzy logic, a particular object has a degree of membership in a given set which is in the range of 0 to 1. A Fuzzy Logic Controller (FLC) uses fuzzy logic as a design methodology which can be applied in developing linear and non-linear systems. FLC techniques have been found to be a good replacement for conventional control techniques, which require highly complicated mathematical models. The FLC comprises of four principal components.

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

The decision making logic is the kernel of an FLC. It has the capability of simulating human decision making based on fuzzy concepts and of inferring fuzzy control actions based on the defined rules

3.1 Fuzzification and Membership Functions

Fuzzification implies the process of transforming the crisp control values of the inputs to a controller, to fuzzy domain. Selection of the control variables relies on the nature of the system and its desired output. Seven linguistic variables for each input variables were used to get the desired performance. The linguistic variables are specified by Gaussian membership function.

Membership function forms a crucial part in a fuzzy rule base model because they only actually define the fuzziness a control variable or a process variable. A set of membership defined for seven linguistic variables are NB, NM, NS, ZE, PS, PM, PB respectively is shown in fig.3 and fig .4

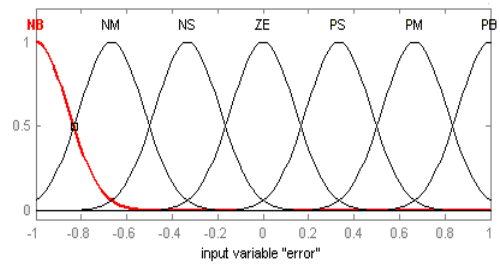

Fig3. Membership function for frequency deviation

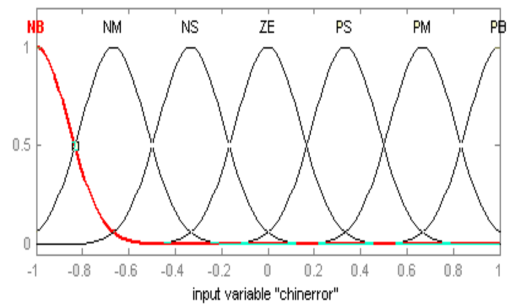

Fig 4. Membership function for integral of frequency deviation

3.2 Rules Creation and Inference

In general fuzzy systems map input fuzzy sets to output fuzzy sets. Fuzzy control rules provide a convenient way for expressing control policy and domain knowledge. The proper choice of process state variables and control variables are essential to the characterization of the operation of a fuzzy system. The modes of deriving fuzzy rules are based on trial and error method. Since each of the input variables contain seven linguistic variables, as a result of 49 rules are devised.

Table -1 Fuzzy Rule Base

$\int\Delta F$ \ ΔF	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NM	NM	NS	ZE	PS
NS	NB	NM	NM	NS	ZE	PS	PM
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NM	NS	ZE	PS	PM	PM	PB
PM	NS	ZE	PS	PM	PM	PB	PB
PB	ZE	PS	PM	PB	PB	PB	PB

The rule base contains the fuzzy IF-THEN rules of Mamdani type. An example of an i^{th} rules is,

If Δf is NB AND $\int\Delta f$ is ZE THEN ΔP_c is NB.

In the inference method, we wish to deduce or infer a conclusion, given a body of facts and knowledge. The modes of deriving fuzzy inference are based on the min- max method. The minimum of the two antecedent conjunct's value is chosen to be the consequent (w_i). For example if Δf belongs to NS with a membership of 0.5 and $\int\Delta f$ belongs to ZE with a membership of 0.9 then the rule consequent (w_i) will be 0.5.

3.3 Defuzzification

Defuzzification is the process of converting fuzzy quantity to a precise quantity. The output of the fuzzy process can be the logical union of two or more fuzzy membership functions defined on the "universe of discourse" of the output variable. The system has two inputs and a single output which implies two input gains K_1, K_2 and output gains K_3. In the present case, the output gain was set to give the maximum allowable control action while the other two parameters K_1&K_2 were used for tuning.

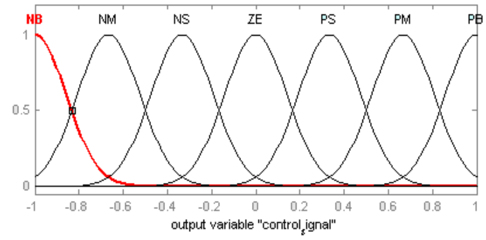

Fig5. Membership function for control signal

4 .SIMULATION RESULTS

In the three area system described in this paper, Areas 1 and 2 run on reheat type turbines; Area 3 uses non-reheat type turbine. Areas 2 and 3 are interconnected by a 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. Conventional PI controller anf fuzzy logic controller is used to control the intolerable dynamic frequency changes with change in load. Matlab software is used for simulation study.

The details of the test system are taken from [1] and consist of three areas. The first two areas uses reheat type turbines and the last one uses non-reheat type turbines. Area 1 assists in the frequency regulation for Areas 2 and 3 via HVDC links with AFCs. Areas 2 and 3 are connected with a normal tie-line.

Various disturbances under different operating conditions are applied to the test system.

Case Study 1

When a 0.05p.u step increase in torque reference is applied at 0sec to Area 1 and Area 2 of the Three Area Load Frequency Control System and also a -0.05p.u step increase in torque is applied at 0sec to Area 3 of the Three area Load Frequency Control System, the frequency response obtained is shown in figure 6.. In case study1 all the three areas are under lowest parameter condition.

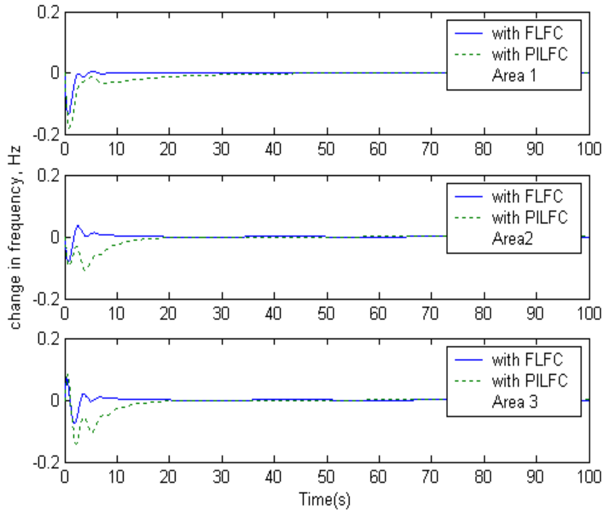

Fig6. Area responses for case study 1

Case Study 2

When a 0.05p.u step increase in torque reference is applied at 0sec to Area 1 and Area 2 of the Three Area Load Frequency Control System and also a -0.05p.u step increase in torque is applied at 0sec to Area 3 of the Three area Load Frequency Control System, the frequency response obtained is shown in figure 7. In case study 2 area 1 is under lowest parameter condition, area 2 is under highest parameter condition and area 3 is under nominal parameter condition.

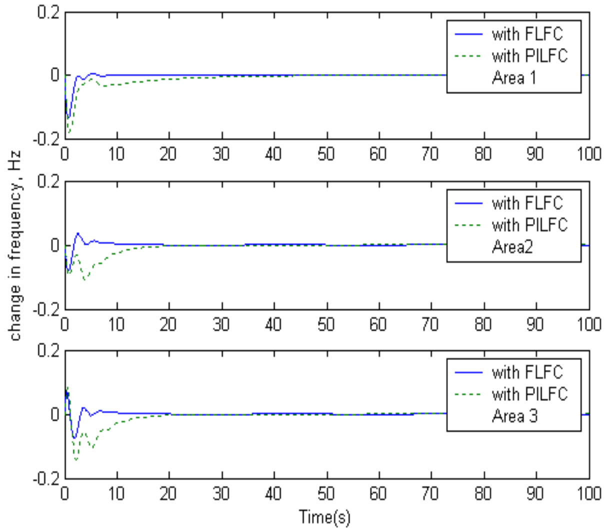

Fig7. Area responses for case study 2

Case Study 3

When a 0.05p.u step increase in torque reference is applied at 0sec to Area 1 and Area 2 of the Three Area Load Frequency Control System and also a -0.05p.u step increase in torque is applied at 0sec to Area 3 of the Three area Load Frequency Control System, the frequency response obtained is shown in figure 8.. Here area 1 is under nominal parameter condition, area 2 is under lowest parameter condition and area 3 is under highest parameter condition

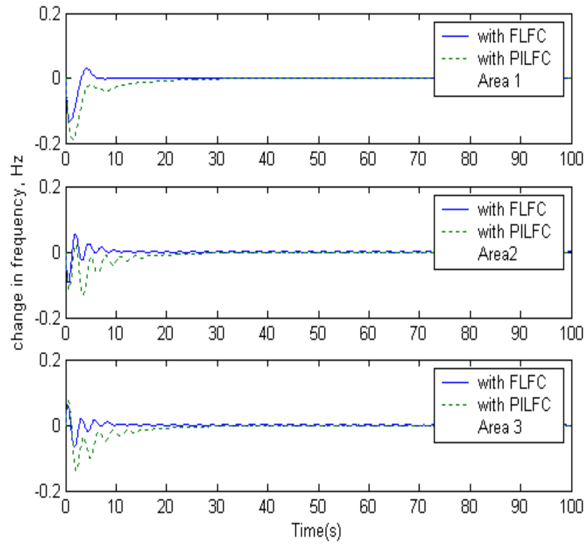

Fig8. Area responses for case study3

CONCLUSIONS

In this paper fuzzy logic is proposed to tune the parameters of PI controller. A three area power system is considered to demonstrate the proposed method… Use of HVDC links in the system reduces long distance transmission cost, also power loss is less. The simulation studies with fuzzy logic based LFC and PI controller based LFC under various disturbances shows that the fuzzy logic based LFC is very effective enhancing better damping performance in non-linear conditions.

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