Load Frequency Control of Hydro-Hydro System with Fuzzy Logic Controller Considering DC Link

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Abstract: This paper describes the dynamic performance of two area interconnected hydro-hydro power systems when subjected to 1% step load perturbation. For this present study, the system is incorporated with conventional Proportional-Integral (PI) controller and Fuzzy Logic Controller (FLC). The dc link is used as system interconnection in parallel with ac tie-lines. The dc link is considered to be operating in constant current control mode and the power flow deviation through dc link is modeled based on frequency deviation at rectifier end. To investigate system performance, optimum PI controller gains are obtained using integral square error (ISE) technique. The responses with these controllers are sluggish. To overcome this drawback FLC is proposed. Time domain simulation is used to compare the dynamic performance. Finally, simulation results shows that FLC has better dynamic control performance than PI controller.

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Nomenclature

Δ	Deviation
i	Subscript referred to area (1, 2)
F	Nominal system frequency
K_{pi}	Gain constant of generator
T_{pi}	Time constant of a generator
P_{ri}	Rated area power
T_1,T_3	Time constants of hydro governor
T_2	Mechanical governor reset time constant
T_w	Water starting time
K_{dc}	Gain associated with dc link
T_{dc}	Time constant of dc link
T_{12}	Synchronizing coefficient
P_{tie}	Tie line power
P_{di}	Load disturbance
R_i	Governor speed regulation parameter
B_i	Frequency bias constant
K_P	Proportional controller gain
K_i	Integral controller gain
a_{12}	-Pr1/Pr2
ACE	Area Control Error
LFC	Load Frequency Control
J	Cost index
T	Sampling time period

Introduction

Load frequency control or Automatic Generation Control (AGC) is a very important factor in power system operation and control for supplying sufficient and reliable electrical power to consumer with good quality. Moreover, the works reported in literature on LFC using optimum control pertain to either thermal-thermal interconnection or hydro-thermal interconnections (Elgerd, 1982). There is no work on hydro-hydro interconnection using optimum control. The main function of AGC is to satisfy the basic requirements such as, tie-line power exchanges and frequency deviation errors must be zero and all generators should satisfy optimum dispatch conditions. Based on linear control theory more control strategies are available in the literature. Because of the continuous load changing characteristics the operating point of the power system changes continuously (Fosha and Elgerd, 1970). That is the system parameter may change abrupt in the boundaries, which gives unsatisfactory results. Therefore fixed gain controller is not suitable for dynamic load characteristics.

HVDC has made a significant impact in the technical and commercial aspects of electric power transmission in developing countries. The entrenched HVDC technology has got appealing characteristics that has made it more suitable than AC transmission for certain applications like long distance power transmission, long submarine cable links and interconnection of asynchronous systems (Kumar and Ibraheem, 1993). Moreover HVDC system provides an efficient and reliable solution, for the major technical challenges faced by traditional AC solutions such as high capacitive cable currents and necessity of keeping the wind farm frequency same as that of grid frequency (Mathur, H.V. Manjunath, 2007). The attractive features of HVDC transmission lines include quick controllability of line power by means of converter control, improvement of transient stability in HVAC lines, and economical benefits. In the AC system interface, decline of effective short-circuit ratio (ESCR) increases the disturbance sensitivity of

AC/DC interaction which makes it much more difficult to get good overall performance by correctly adjusting the control constants (Ali Zarei et al 2012). With the objective of providing a coordinated control of the HVDC link transmitted power, the off-shore grid ac voltage and HVDC inverter controllers were designed. An adequate regulation of both HVDC voltage and current is provided by the coordinated control system. In this view, a fuzzy based load frequency control for hydro-hydro power system is proposed in this paper.

System Studied

An interconnected power system is considered as being divided into control areas which are connected by tie lines. In each control area, all generators are assumed to form a coherent group (Das et al, 1990). The power system investigated in this study contains two area hydro power system interconnected by tie line as shown in the Figure 1. The nominal parameters of the system are given in appendix. Matlab version 7.1 has been used to obtain dynamic response of change in frequencies ΔF_1, ΔF_2 and $\Delta Ptie$ for 1% step load perturbation. (Prakash et al, 2012). The system has been designed for nominal frequency. Proper assumptions and approximations are made to linearize the mathematical equations which describe the system and transfer function model.

DC Link

Many problems have been identified with EHVAC interconnection between the power systems particularly using for long distance transmission. The major problems associated with these lines are: the presence of large power oscillations which can lead to frequent tripping, increase in fault current level and transmission of disturbances from one system to the other deteriorating the overall system dynamic performance. To circumvent these problems effectively, high voltage dc transmission systems emerged on power scenario (Ibraheem, Kumar, 2004). Many HVDC transmission lines are commissioned all over the world and several HVDC projects are envisaged in ensuing years. One of the major applications of HVDC transmission is operating a HVDC link in parallel with an EHVAC link interconnecting two control areas. With these developments, the power utilities are capable to fulfill the requirements of good quality of electric power supply to consumers to some extent but on the other hand the operational and control aspects of these systems are subjected for their review.

The HVDC transmission has emerged on a power scenario, due to its numerous technical and economic advantages, for a large chunk of power transfer over large distances (Srujana and Jayaram Kumar, 2010). Besides other applications, the commissioning of an HVDC link in parallel with existing ac links has shown beneficial effects from the point of view of stabilization of the system. Considerable attention has been paid to consider the damping effect of the dc system as an area interconnection between ac systems. As far as the system frequency control of power systems interconnected via a dc link is concerned, very few publications have appeared on this topic.

The advantages of the conventional HVDC systems over three-phase AC transmission systems are. Firstly, transmission line cost and operating cost are lower for HVDC systems. Secondly, synchronous operation of HVDC is not necessary between the two AC systems it connects. Thirdly, controlling and adjusting power flow are easier, etc. Conversion, switching and control are the disadvantages of HVDC systems. Though static converters are expensive, even for short distances static converters may be preferable because of the reduced losses associated with it compared to static inverters for AC transmission. Operating HVDC link in parallel with an EHVAC link for interconnecting two control areas is one of its major applications. Power transmission capability can be increased and system stability problems can be avoided by operating a bipolar high-voltage direct-current (HVDC) power transmission system in parallel with a 400-kV AC power transmission system. In two area power systems the length of transmission lines in the transmission links are regarded as long and are greater than the break even lengths of AC and HVDC transmission lines.

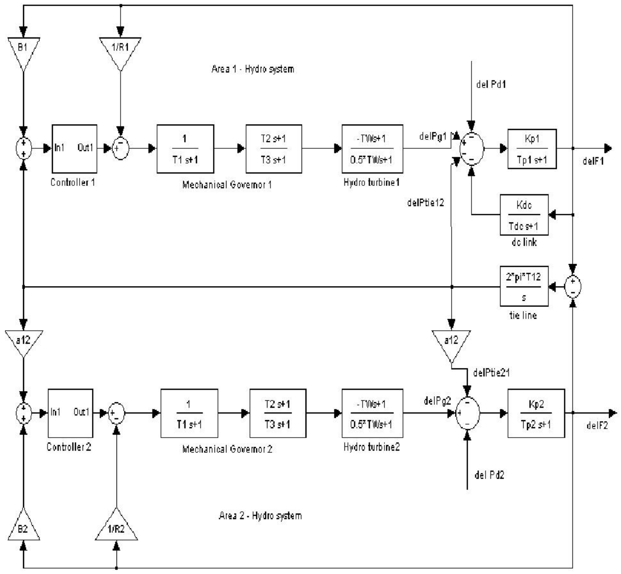

Figure 1. Transfer Function Model of Two Area Hydro-Hydro Interconnected System.

The three basic parts of HVDC Transmission systems are: 1) AC to DC converter station 2) transmission line and 3) DC to AC converter station.

The interconnected power systems were investigated with the implementation of designed optimal regulators by considering the incremental dc link power flow as an additional state as well as control variable. The investigations reveal that the system dynamic system performance has improved appreciably with the inclusion of incremental dc link power flow as an additional state variable as compared to that obtained when system interconnection is through the ac link only.

Conventional PI controller

The proportional-integral (PI) controller has received a great deal of attention in the process control areas. It is used as a feedback controller which drives the plant to be controlled with a weighted sum of the error and the integral of that value.

$$u_1 = -K_p \cdot ACE_1 - K_i \int ACE_1 dt \qquad (1)$$

$$u_2 = -K_p \cdot ACE_2 - K_i \int ACE_2 dt \qquad (2)$$

Where, K_p and K_i are proportional and integral gains respectively, ACE is area control error which defines "a quantity reflecting the deficiency or excess of power within a control area" (IEEE Report, 1991) and u1, u2 are controlled output of the respective areas.

The relative simplicity of this controller is a successful approach towards zero steady state error in the frequency of the system. When the integral term is combined with proportional controller it accelerates the movement of the process towards set-point and eliminates the residual steady state error (Tushir et al, 2012). The conventional control strategy for the LFC problem is to take the error as the control signal. For conventional PI controller the gain K_p and K_i has been determined using Integral Square Error (ISE) criterion. The objective function used for this technique is

$$J = \int_0^t (\Delta F_1^2 + \Delta F_2^2 + \Delta P_{tie}^2)\, dt \qquad (3)$$

where,

ΔF = change in frequency and

ΔP_{tie}= change in tie line power

On the basis of performance index curve as shown in the Figure 2 feedback gains should be determined to achieve the optimality of system performance. The main goal of LFC in interconnected power system is to protect the balance between generation and consumption. Because of the complexity and multi variable condition of the power system, a conventional model may not give satisfactory solution.

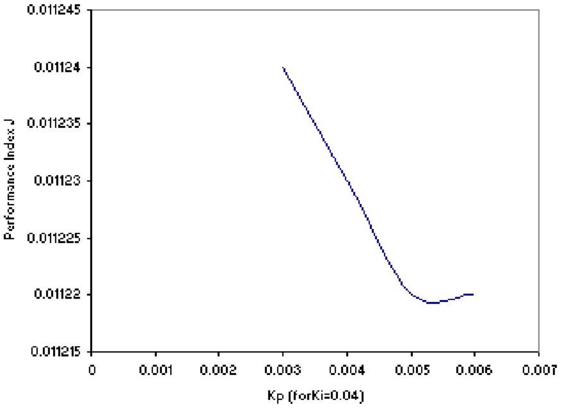

Figure 2. Performance Index Curve

From the above performance index curve, integral controller gain and proportional controller gain are found to be 0.04 and 0.005 respectively.

Fuzzy Logic Controller

Fuzzy logic control is based on a logical system called fuzzy logic which is much closer in spirit to human thinking and natural language than classical logical system (Reza Sharifian Dastjerdi et al 2012). Now –a-days, fuzzy logic is used in almost all sectors of industry and science. The main goal of load frequency control in interconnected power system is to maintain the balance between production and consumption. Because of the complexity and multi variable conditions of the power system, conventional control methods may not give satisfactory solutions (Ibraheem et al, 2004). On the other hand, their robustness' and reliability make fuzzy controllers useful in solving a wide range of control problems. Artificial intelligence based gain scheduling is an alternative technique commonly used in designing controllers for non-linear systems. The fuzzy logic controller is comprised of four main components; the fuzzification, the inference engine, the rule base and the defuzzification as shown in the Figure 3. The fuzzification transforms the numeric/crisp value into fuzzy sets so that the operation is called fuzzification (Gayadhar Panda et al., 2009).

The first step in designing a fuzzy controller is to decide which state variables represent the system dynamic performance must be taken as the input signal to the controller. Fuzzy logic uses linguistic variables instead of numerical variables. The process of converting a numerical variable (real number or crisp variables) into a linguistic variable (fuzzy number) is called Fuzzification. System variables, which are usually used as the fuzzy controller inputs includes states error, state error derivative, state error integral or etc. In power system, based on previous experience, Area Control Error (ACE) and its derivative (d(ACE)/dt) are chosen to be the input signals of fuzzy AGC. The membership function is a graphical representation of the magnitude of participation of each input. There are different memberships functions associated with each input and output response. In this study, we use the triangular membership function for input and output variables (Nanda et al 2004). The number of membership function determines the quality of control which can be achieved using fuzzy controller. As the number of membership function increases, the quality of control improves. As the number of linguistic variables increases, the computational time and required memory increases. Therefore, a compromise between the quality of control and computational time is needed to choose the number of linguistic variables.

Fuzzy system transforms a human knowledge into mathematical formula. Therefore, fuzzy set theory based approach in recent years, has emerged as a complement tool to mathematical approaches for solving power system problems. Fuzzy set theory and fuzzy logic establish the rules of a non-linear mapping. These rules are obtained based on experiments of the process step response, error signal and its time derivative. Fuzzy logic controller is shown in the Figure 3 it has two input signals namely ACE and dACE. And its output signal (ΔP ref) is used for controlling the load frequency control in the interconnected power system.

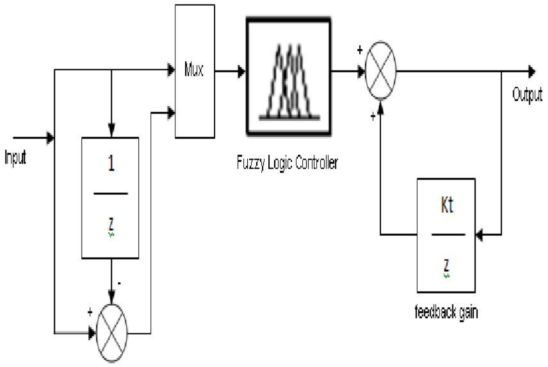

Figure 3. Block Diagram of Fuzzy Logic Controller

The main component of the FLC is the inference engine which performs all logic manipulations. The rule base consists of membership functions and control rules (Talaq and Al-Basri, 1999). For the proposed study, Mamdani fuzzy inference engine was selected and the centroid method is used in defuzzification process. In this study seven triangular membership functions is taken. Therefore 49 control rules are used in the proposed study. The ranges of the membership functions are chosen from simulation results. For the determination of the control rules it can be more complicated than membership functions which depend on the designer experience and actual physical system. The control rules build from the If – then statement.

In a fuzzy scale, each membership functions of seven linguistic states of triangular type are mapped into the values of Negative Large (NL), Negative Small (NS), Negative Medium (NM), Zero Error (ZE), Positive Small (PS), Positive Medium (PS) and Positive Large (PL).

Simulation Results and Discussions

Simulations were performed using conventional PI and fuzzy logic controller which is applied to two area interconnected hydro-hydro power system.

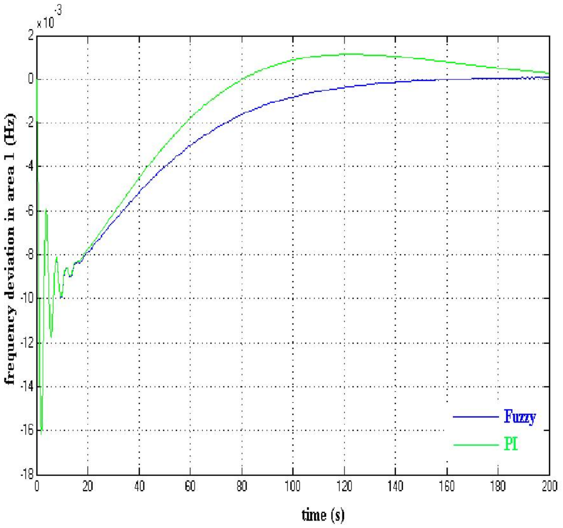

Figure 4. Frequency deviation in area 1

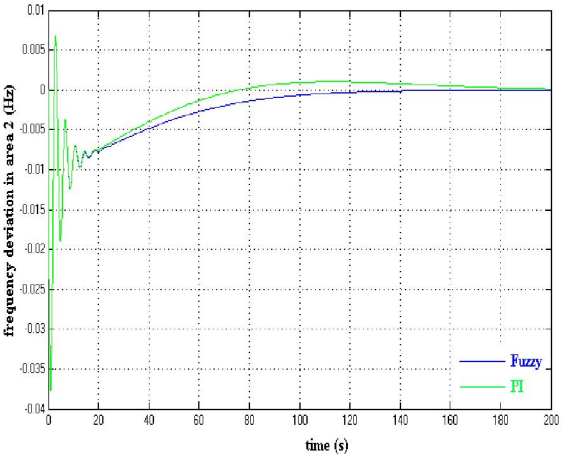

Figure 5. Frequency deviation in area 2

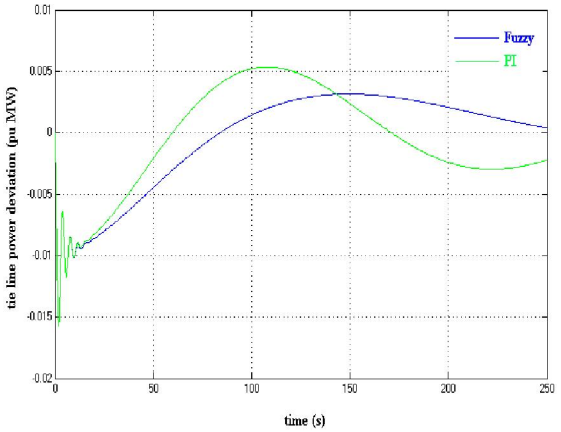

Figure 6. Change in tie line power

Performance criteria like settling time and overshoots were considered in the simulation for the system dynamic parameter, frequency deviation in both the area and the tie line power deviations. The system is simulated with 1% step load disturbance in either area of the system. Frequency deviation in area 1 and 2 with conventional PI and FLC are shown in the Figure 4 and Figure 5 respectively. Also the tie line power deviation is shown in the Figure 6.

By examine these results, conventional PI controller does not provide good control performance also it takes more settling time to settle down the steady state error, due to the fixed value of PI gains irrespective of the changing errors. But fuzzy logic controller provides satisfactory control performance over conventional PI controller. Referring tie line waveform, FLC yields very good performance where as PI controller has high oscillations nearer to set point.

Conclusions

In this study the fuzzy logic controller is employed for load frequency control. The proposed controller can handle two area hydro power systems and also yields adequate control performance. The effectiveness of the proposed controller in increasing the damping of load and inter area modes of oscillations is demonstrated in two area interconnected power system.

The simulation results are compared with a conventional PI controller and shows that the proposed intelligent controller is having improved dynamic response. Presence of FLC in both areas and small step perturbation in either area provides better dynamic response than with conventional PI controller. New model consisting of a fuzzy logic controller along with a HVDC link connected parallel to ac tie-line. Simulation results presented justify the incorporation of HVDC link to supply consumers reliable and quality power.

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Appendix

T_{t1} =0.3s
T_{g1}=0.2s
K_{p1}=120 Hz/pu MW
T_{p1}=20s
T_{12}=0.0707 MW/rad
R_1=R_2 =2.4 Hz/ pu MW
K_{p2}=80 Hz/pu MW
T_{p2}=13s
T_1=48.7s
T_2=0.513s
T_3=10s
T_w=1s
f=60 Hz

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