

Automatic Generation Control in Multi Area Interconnected Power System by using HVDC Links

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ABSTRACT

This paper investigates the effects of HVDC link in parallel with HVAC link on automatic generation control (AGC) problem for a multi area power system taking into consideration system parameter variations. A fuzzy logic controller is proposed for four area power system interconnected via parallel HVAC/HVDC transmission link which is also referred as asynchronous tie-lines. The linear model of HVAC/HVDC link is developed and the system responses to sudden load change are studied. The simulation studies are carried out for a four area interconnected thermal power system. Suitable solution for automatic generation control problem of four area electrical power system is obtained by means of improving the dynamic performance of power system under study. Robustness of controller is also checked by varying parameters. Simulation results indicate that the scheme works well. The dynamic analyses have been done with and without HVDC link using fuzzy logic controller in Matlab-Simulink. Further a comparison between the two is presented and it has been shown that the performance of the proposed scheme is superior in terms of overshoot and settling time.

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1. INTRODUCTION

The automatic generation control (AGC) is a technical requirement for the proper operation of an interconnected power system. Automatic generation control is very important in power system operation and control for supplying sufficient and reliable electric power with good quality, particularly for large scale electrical power systems that normally consist of interconnected control areas representing coherent groups of generators. In cases of area load changes and abnormal conditions, such as outages of generation and varying system parameters, mismatches in frequency and scheduled tie-line power flows between areas can be caused. These mismatches are corrected by controlling the frequency, which is defined as the regulation of the power output of generators within a prescribed area. Automatic generation control is the regulation of power output of controllable generators within a prescribed area in response to change in system frequency, tie-line loading, or a relation of these to each other, so as to maintain the scheduled system frequency and establish the interchange with other areas within predetermined limits [1]. To accomplish this, it becomes necessary to automatically regulate the operations of main steam valves or hydro gates in accordance with a suitable control strategy. Some intelligent controllers have been proposed to perform this act considering area interconnection with ac tie line [1]-[4]. Also fast-acting energy storage systems e.g. superconducting magnetic energy storage [5], battery energy storage [6], super-capacitor bank [7] etc., can effectively damp

electromechanical oscillations in a power system, because they provide storage capacity in addition to the kinetic energy of the generator rotors which can share sudden changes in power requirement. A little attention has been paid to use of HVDC transmission link as system interconnection. Majority of the work carried out earlier is centered on interconnected power systems considering the area interconnection with ac tie lines only. However, there has been a tremendous growth of the HVDC transmission system due to economic, environmental and performance advantages over the other alternatives. Hence it has been applied widely in operating a dc link in parallel with an HVAC link interconnecting control areas to get an improved system dynamic performance with greater stability margins under small disturbances in the system [8]-[12]. A favorable effect on system dynamic performance has been achieved considering such system interconnection. These studies are carried out considering the nominal system parameter values after linearization of the system about an operating condition. In practical cases, system parameters do not remain constant and continuously vary with changing operating conditions. To solve this problem various recent trend intelligent controllers are discussed in [13]-[14]. Because of the complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. On the other hand robustness and reliability makes fuzzy controllers useful in solving wide range of control problems including AGC of interconnected power system [15]-[21].

In the present paper a fuzzy logic based proportional integral (pi) controller is designed and implemented to analyze the dynamic performance of four area thermal power system, interconnected with HVAC/HVDC parallel link taking parameter uncertainties into account. The simulation results are presented to show the effectiveness of the scheme.

2. FOUR AREA POWER SYSTEM

The four area power system model identified in the present study has the following configuration;

- (i) It is a four area interconnected power system consisting of identical single stage reheat thermal turbines.
- (ii) The four areas are interconnected via HVAC tie line in parallel with HVDC link.

The single line diagram of the model under consideration for two areas is presented in Figure 1 and the transfer function model of four area interconnected power system with HVDC link is described in Figure 2. The transmission links are considered as long transmission lines specifically of length greater than break even distance length of HVAC and HVDC transmission lines [8].

Investigations have been carried out on a four unequal area interconnected thermal power system of area 1: 2000 MW, area 2: 4000 MW, area 3: 8000 MW and area 4: 10000 MW. Typical generation rate constraints (GRC) of the order of 10% per minute for thermal area and 4.5%/s (270%/minute) for raising and 6%/s (360%/minute) for lowering generation for hydro area has been considered as in the IEEE Committee Report on Power Plant Response [22]. The detailed transfer function models of speed governors and turbines are discussed and developed in the IEEE Committee Report on Dynamic Models for Steam and Hydro Turbines in Power System Studies [23]. An equal bias (B_i) setting is considered for both thermal and hydro areas. The step load perturbation of 1% of the nominal loading has been considered in either of the area for system analysis. The system parameters are taken from [8], [28] as given in the appendix.

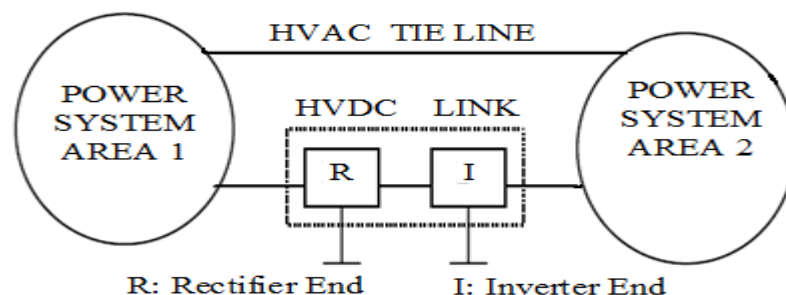


Figure 1. Single line diagram of two area power system with parallel HVAC/HVDC links

3. FUZZY LOGIC CONTROLLER

Because of inherent characteristics of the changing loads, complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. Artificial intelligence based gain scheduling is an alternative technique commonly used in designing controllers for non-linear systems. Fuzzy system transforms a human knowledge into mathematical formula. Therefore, fuzzy set

theory based approach 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 nonlinear mapping [24]. Fuzzy 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 systems. Nowadays fuzzy logic is used in almost all sectors of industry and science. One of them is automatic generation control. The main goal of AGC in interconnected power systems is to protect the balance between production and consumption. The fuzzy logic controller designed for the system analysis is shown in Figure 3.

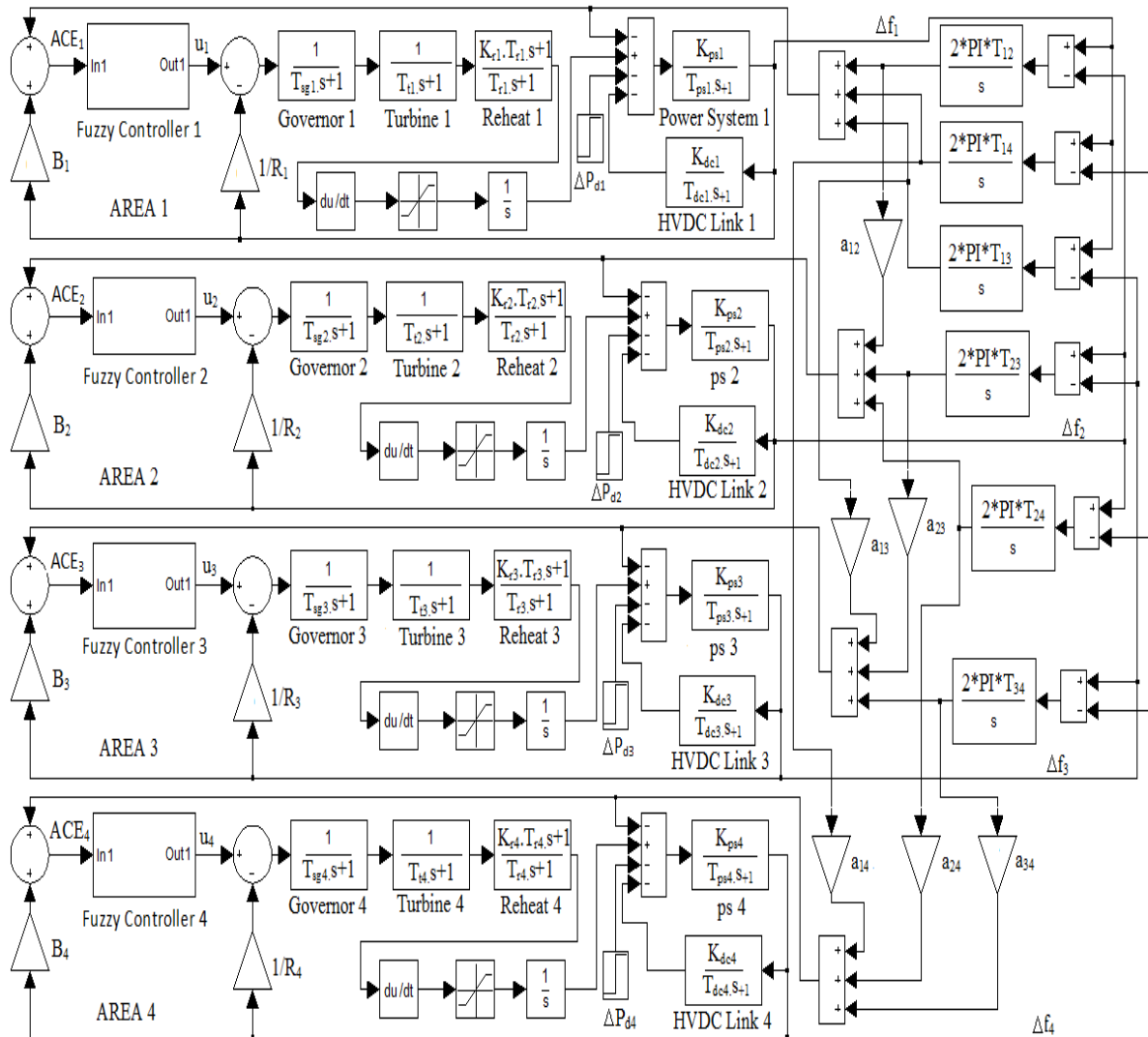


Figure 2. Transfer function model of four area interconnected power system

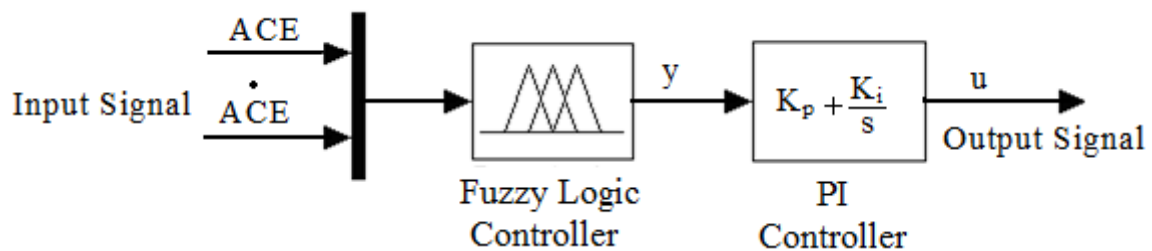


Figure 3. Structure of fuzzy logic controller

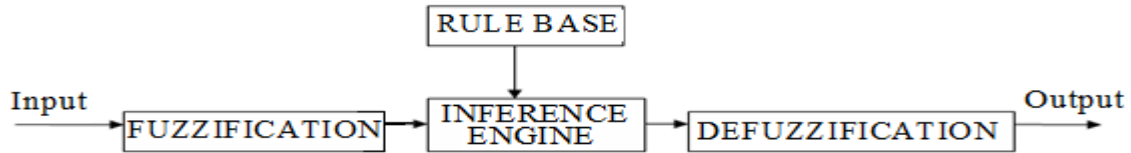


Figure 4. Components of a fuzzy controller

The fuzzy logic controller is comprised of four main components: the fuzzification, the inference engine, the rule base, and the defuzzification, as shown in Figure 4. The fuzzifier transforms the numeric/crisp value into fuzzy sets; therefore this operation is called fuzzification. The main component of the fuzzy logic controller is the inference engine, which performs all logic manipulations in a fuzzy logic controller. The rule base consists of membership functions and control rules. Lastly, the results of the inference process is an output represented by a fuzzy set, however, the output of the fuzzy logic controller should be a numeric/crisp value. Therefore, fuzzy set is transformed into a numeric value by using the defuzzifier. This operation is called defuzzification. The control signal is given by

$$u(t) = -(K_p y + \int K_i y dt) \quad (1)$$

K_p and K_i are the proportional and the integral gains respectively and taken equal to one. For the proposed study, Mamdani [25] fuzzy inference engine is selected and the centroid method is used in defuzzification process.

Table 1. Rules for the fuzzy logic controller

| | | A C E | | | | | | |
|-----|----|-------|----|----|----|----|----|----|
| ACE | LN | LP | LP | LP | MP | MP | SP | Z |
| | MN | LP | MP | MP | MP | SP | Z | SN |
| | SN | LP | MP | SP | SP | Z | SN | MN |
| | Z | MP | MP | SP | Z | SN | MN | MN |
| | SP | MP | SP | Z | SN | SN | MN | LN |
| | MP | SP | Z | SN | MN | MN | MN | LN |
| | LP | Z | SN | MN | MN | LN | LN | LN |

LN: large negative, MN: medium negative, SN: small negative, Z: zero, SP: small positive, MP: medium positive and LP: large positive

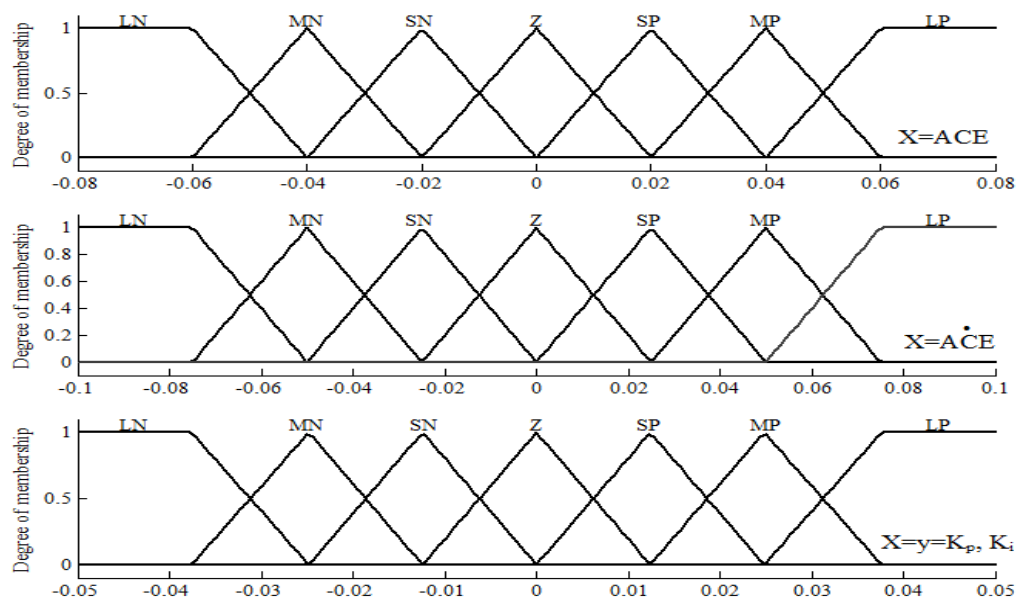


Figure 5. Membership functions used in the study

Fuzzy logic shows experience and preference through membership functions which have different shapes depending on the experience of system experts [26]. These rules are obtained based on experiments of the process step response, error signal, and its time derivative [27]. The membership functions of the fuzzy logic pi controller presented in Figure 5 consist of three membership functions (two-inputs and one-output). Each membership function has seven memberships comprising two trapezoidal and five triangular memberships. Seven numbers of rules have been taken in inference mechanism. Therefore, 49 control rules are used for this study. The range of X is selected from simulation results. All memberships are selected to describe the linguistic variables. These functions have different shapes depending on system experts' experience. For the determination of the control rules, it can be more complicated than membership functions, which depend on the designer experiences and actual physical system. The control rules are build from the if-then statement (i.e. if input 1 and input 2 then output 1). Table 1 taken from [28]-[29], indicates the appropriate rule base used in the study. Let us consider the fourth row and fifth column in Table 1 e.g. if ACE is Z and ACE is SP then y is SN.

4. SIMULATION RESULTS

In this paper, a fuzzy logic based proportional integral (pi) controller has been designed and applied to analyze the effect of HVDC link on the AGC of four area interconnected thermal power system. The implementation worked with Matlab-Simulink software. The simulations were run on a personal computer Intel Core2Duo CPU T5450 @ 1.66 GHZ, 982 MHZ, 2GB of RAM, under Window XP. The same values of system parameters given in appendix are used for all simulations to facilitate a comparative study.

The response plots for variables like frequency deviations in area 1 to area 4 and tie line power deviations for power system model with and without HVDC link, in the wake of load disturbance of 1% in area 1 are obtained with the implementation of fuzzy logic controller to analyze the system dynamic performance. Figure 6 shows the frequency deviation responses and Figure 7 shows some tie line power deviation responses with 1% load perturbation in area 1 of the four area interconnected system. Figure 8 shows the frequency deviation responses of area 1 to area 4 with 1% load perturbations in area 2 and area 4 simultaneously. The simulation results show that the settling time and peak overshoots are reduced considerably (as shown in Figure 6, Figure 7 and Figure 8) by the use of HVDC link in parallel of existing HVAC link. The simulation results of frequency deviations and tie line power deviation with fuzzy controller advocates, the HVDC link's suitability for AGC schemes.

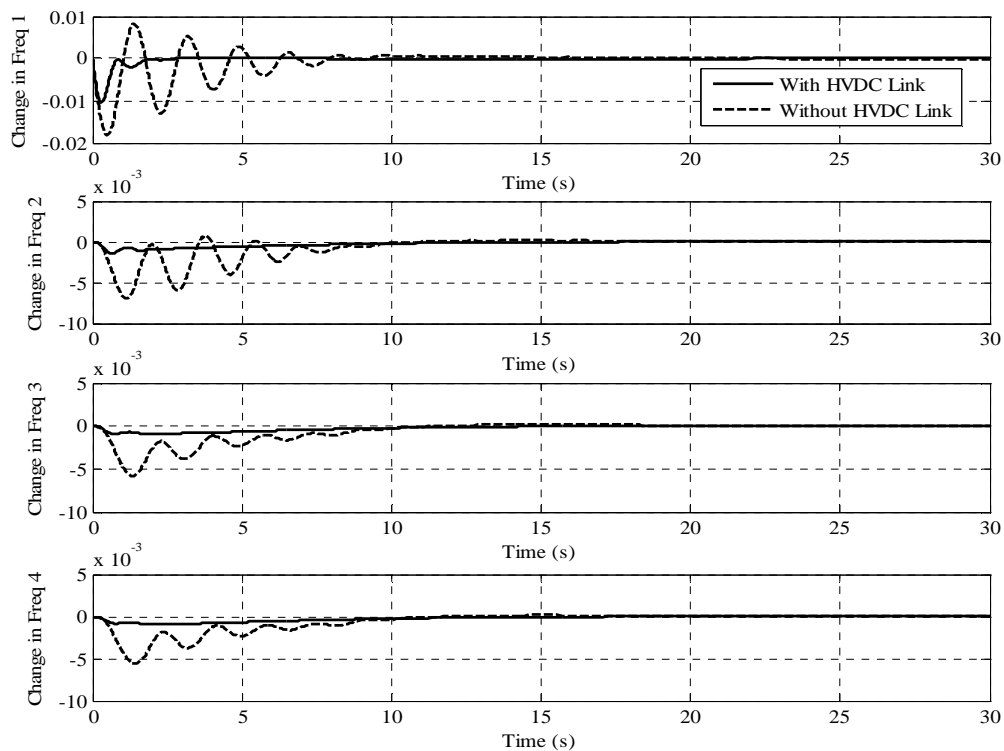


Figure 6. Frequency deviation of area 1 to area 4 with $\Delta P_{d1}=0.01$

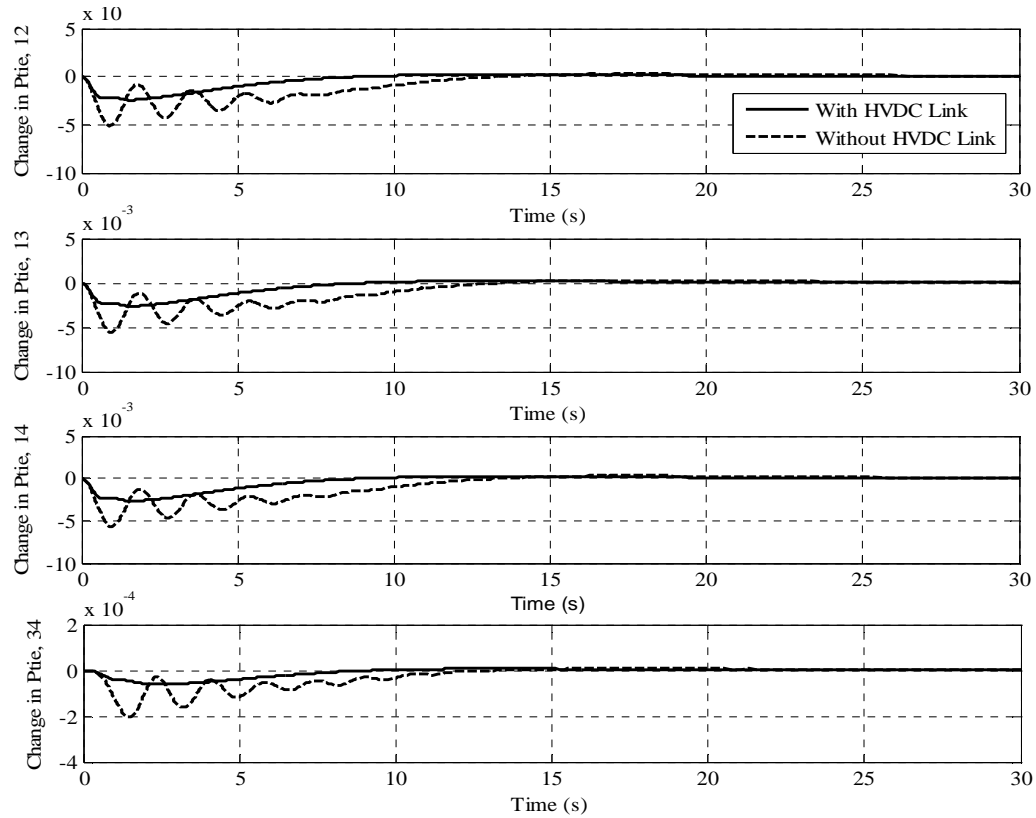


Figure 7. Tie line power deviations with $\Delta P_{d1}=0.01$

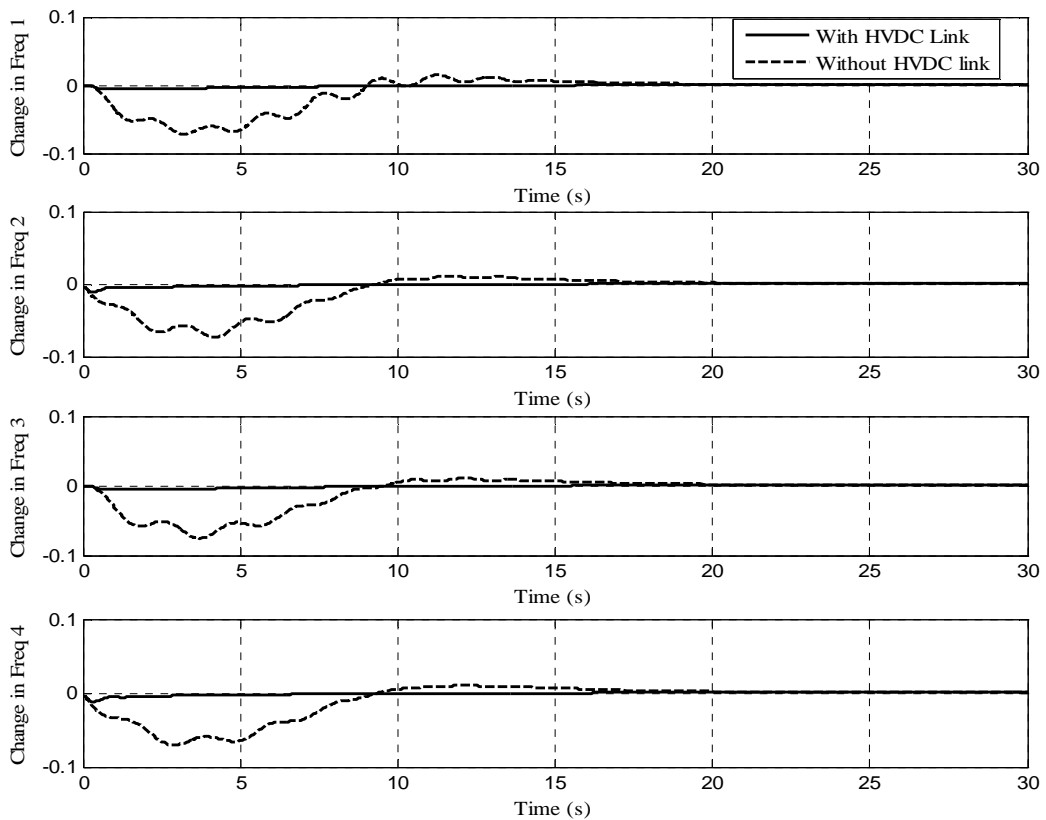


Figure 8. Frequency deviation of area 1 to area 4 with $\Delta P_{d2}=\Delta P_{d4}=0.01$

Automatic generation control problem is one of the major problems in present day power system scenario. The electrical utilities are also bound to supply quality and reliable power to its consumers in cut throat competition, therefore, in order to supply reliable and quality power, HVDC regulation controller connection is helpful to reduce sustained oscillations.

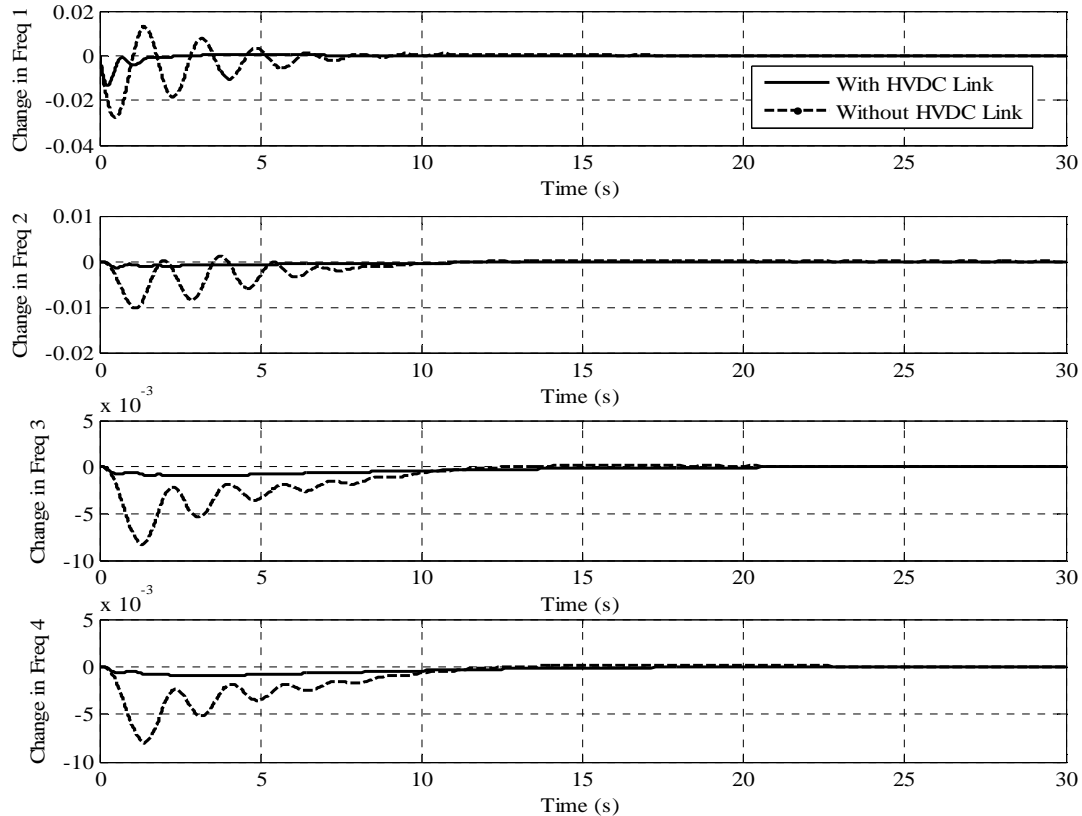


Figure 10. System frequency response with -35 % of nominal values of B_i , T_{psi} and T_{ij} with $\Delta P_{d1} = 0.01$

Other simulations in Figure 9 and Figure 10 are carried out for $\pm 35\%$ change in parameter values (mainly B_i , T_{ij} and T_{psi}) of the system. In Figure 9, the responses are shown with $+35\%$ change in system parameter values at 1% load perturbation in area 1. It indicates that the changes in frequency in area 1 to area 4 are getting settled down within reasonably good time. Similarly with same amount of disturbance in area 1, it is observed that the system settles down quite fast with -35% changes in system parameter values as shown in Figure 10. This justifies the robustness of the fuzzy logic pi controller which is capable to withstand the changes in dynamic parameters of the system. It also depicts the effectiveness of the HVDC link in parallel with HVAC tie line to suppress frequency and tie line power oscillations of interconnected power systems under load perturbations.

5. CONCLUSIONS

In this paper, a new power system model is proposed to improve the dynamic performance of interconnected four area thermal power system by the use of HVDC link in parallel with existing HVAC link. Four area power system consists of identical single stage thermal reheat turbines with GRC. The system dynamic performance in the wake of load disturbance in either area of interconnected power system has been investigated comprehensively. A fuzzy logic control strategy is designed and its feasibility is studied by varying system parameters. It has been observed that responses of the system with parallel HVDC link are better in terms of dynamic parameters such as peak overshoot and settling time. Simulation results presented justify the incorporation of HVDC transmission link to supply consumers reliable and quality power.

APPENDIX

Nominal parameters of the four area system investigated:

$$P_{r1}=2000 \text{ MW}; P_{r2}=4000 \text{ MW}; P_{r3}=8000 \text{ MW}; P_{r4}=10000 \text{ MW};$$

$$R_1=R_2=R_3=R_4=2.4 \text{ Hz/p.u.MW};$$

$$B_1=B_2=B_3=B_4=0.425 \text{ Hz/p.u.MW};$$

$$T_{sg1}=T_{sg2}=T_{sg3}=T_{sg4}=0.08 \text{ seconds};$$

$$T_{t1}=T_{t2}=T_{t3}=T_{t4}=0.3 \text{ seconds};$$

$$T_{ps1}=T_{ps2}=T_{ps3}=T_{ps4}=20 \text{ seconds};$$

$$K_{ps1}=K_{ps2}=K_{ps3}=K_{ps4}=120 \text{ Hz/p.u.MW};$$

$$T_{12}=T_{13}=T_{14}=T_{23}=T_{24}=T_{34}=0.086 \text{ p.u.MW/Radian};$$

$$a_{ij}=-P_{ri}/P_{rj};$$

$$T_{r1}=T_{r2}=T_{r3}=T_{r4}=10 \text{ seconds};$$

$$K_{r1}=K_{r2}=K_{r3}=K_{r4}=0.5;$$

$$P_{tie,max}=200 \text{ MW};$$

$$F=50 \text{ Hz}; K_{dc1}=K_{dc2}=K_{dc3}=K_{dc4}=1.0;$$

$$T_{dc1}=T_{dc2}=T_{dc3}=T_{dc4}=0.2 \text{ seconds};$$

$$\Delta P_{di}=0.01 \text{ p.u.MW}$$

REFERENCES

- [1] O.I. Elgerd, "Electric Energy Systems Theory: an introduction," *Tata Mc-Graw Hill Publishing Company Limited*, New Delhi, India, 2008.
- [2] C.E. Fosha and O.I. Elgerd, "The megawatt frequency control problem: A new approach via optimal control theory," *IEEE Transactions on Power Apparatus and Systems*, vol. PAS-89, no. 4, pp. 563-577, 1970.
- [3] H. Saadat, "Power system analysis," *Tata Mc-Graw Hill Publishing Company Limited*, New Delhi, India, 2000.
- [4] P. Kundur, "Power system stability and control," *McGraw-Hill*, New York, 1994.
- [5] R.J. Abraham, D. Das, A. Patra, "Automatic generation control of interconnected hydrothermal power system considering superconducting magnetic energy storage," *Electrical Power and Energy Systems*, vol. 29, no. 8, pp. 571-579, October 2007.
- [6] S.K. Aditya and D. Das, "Load frequency control of an interconnected hydro-thermal power system with new area control error considering battery energy storage facility," *International Journal of Energy Research*, vol. 24, no. 6, pp. 525-538, 2000.
- [7] M. Mufti, S. A. Lone, S. J. Iqbal, M. Ahmad and M. Ismail, "Super-capacitor based energy storage system for improved load frequency control," *Electric Power Systems Research*, vol. 79, no. 1, pp. 226-233, January 2009.
- [8] Ibraheem and P. Kumar, "Study of dynamic performance of power systems with asynchronous tie-lines considering parameter uncertainties," *Journal of Institution of Engineers (I)*, vol. 85, pp. 35-42, 2004.
- [9] Ibraheem and P. Kumar, "Dynamic performance enhancement of hydro-power systems with asynchronous tie-lines," *Journal of Institution of Engineers (I)*, vol. 85, pp. 23-34, 2004.
- [10] I. Ngamroo, "A Stabilization of frequency oscillation in a parallel ac-dc interconnected power system via an HVDC Link," *Science Asia*, vol. 28, pp. 173-180, 2002.
- [11] R. Thottungal, P. Anbalagan, T. Mohanaprakash, A. Sureshkumar and G.V. Prabhu, "Frequency stabilisation in multi area system using HVDC link," in *Proc. of IEEE International Conference on Industrial Technology*, 15-17, December, 2006, pp. 590-595.
- [12] H.D. Mathur and H.V. Manjunath, "Study of dynamic performance of thermal units with asynchronous tie-lines using fuzzy based controller," *Journal of Electrical System*, vol. 3, no. 3, pp. 124-130, 2007.
- [13] D.M.V. Kumar, "Intelligent controllers for automatic generation control," in *Proc. of IEEE region 10 International Conference on Global connectivity in Energy, Computer, Communication and Control*, Dec. 17-19, New Delhi, India, vol. 2, pp. 557-574.
- [14] H.D. Mathur and S. Ghosh, "A Comprehensive analysis of intelligent controllers for load frequency control," in *Proc. of IEEE Power India 2006 Conferenc*, April 10-12, Delhi, 2006.
- [15] H.D. Mathur and H.V. Manjunath, "A fuzzy based improved intelligent controller for automatic generation control," *International Journal of Engineering Simulation*, vol. 7, no. 3, pp. 29-35, 2006.
- [16] G.A. Chown and R.C. Hartman, "Design and Experience with a fuzzy logic controller for automatic generation control," *IEEE Transactions on power systems*, vol. 13, no. 3, pp. 965-970, 1998.
- [17] J. Talaq and F. Al-Basri, "Adaptive fuzzy gain scheduling for load frequency control," *IEEE Transactions on power systems*, vol. 14, no. 1, pp. 145-150, 1999.
- [18] C.S. Chang and W. Fu, "Area load frequency control using fuzzy gain scheduling of pi controllers," *Electrical Power System Research*, vol. 42, issue 2, pp. 145-152, August 1997.
- [19] Y.H. Song and A.T. Johns, "Application of fuzzy logic in power systems. I. General Introduction to fuzzy logic," *IEE power Engineering Journal*, vol. 11, no. 5, pp. 219-222, 1997.

- [20] Y.H. Song and A.T. Johns, "Application of fuzzy logic in power systems. II. Comparison and integration with expert systems, neural networks and genetic algorithms," *IEE power Engineering Journal*, vol. 12, no. 4, pp. 185-190, 1998.
- [21] Y.H. Song and A.T. Johns, "Application of fuzzy logic in power systems. III. Example applications," *IEE power Engineering Journal*, vol. 13, no. 2, pp. 97-103, 1999.
- [22] I.W. Group, "MW response of fossil fueled steam units," *IEEE Transaction on Power Apparatus and Systems*, vol. PAS-92, no. 2, pp. 455-463, 1973.
- [23] I.C. Report, "Dynamic models for steam and hydro turbines in power system studies," *IEEE Transaction on Power Apparatus and Systems*, vol. PAS-92, no. 6, pp. 1904-1915, 1973.
- [24] Z.A. Zadeh, "Fuzzy sets," *Information and Control*, vol. 8, issue 3, pp. 338-353, June 1965.
- [25] S.G. Cao, N.W. Rees and G. Feng, "Mamdani-type fuzzy controllers are universal fuzzy controllers," *Fuzzy Sets and Systems*, vol. 123, issue 3, pp. 359-367, 2001.
- [26] K. Tomsovic, "Chapter IV-Fuzzy systems applications to power systems," in *Proc. of International conference on intelligent system application to power systems*, Brazil: Rio de Janeiro, 1999, pp. 1-10.
- [27] I. Kocaarslan, G. Akalin and T. Erfidan, "Application of fuzzy reasoning to load frequency control in two area power system," in *Proc. of European Control Conference ECC'99*, 31 August-3 September, Karlsruhe, Germany, 1999, pp. 27-31.
- [28] I. Kocaarslan and E. Cam, "Fuzzy logic controller in interconnected electrical power systems for load frequency control," *Electrical Power and Energy Systems*, vol. 27, issue 8, pp. 542-549, 2005.
- [29] S. Pothiya, I. Ngamroo, S. Runggeratigul and P. Tantaswadi, "Design of optimal fuzzy logic based pi controller using multiple tabu search algorithm for load frequency control," *International Journal of Control, Automation, and Systems*, vol. 4, no. 2, pp. 155-164, April 2006.

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