

Application of Optimal Non-Linear TSK in Power System's Load-Frequency Control with Production Limitation and Dead Band Governor

Mohsen Ebrahimian Baydokhti

Department of Electrical Engineering,
Islamic Azad University, Gonabad
Branch, Gonabad, Iran
Email: ebrahimian.mo@gmail.com

Mohsen Jafaei

Department of Electrical Engineering,
Islamic Azad University, Gonabad
Branch, Gonabad, Iran
Email: mohsen_jafaei@yahoo.com

Assef Zare

Department of Electrical Engineering,
Islamic Azad University, Gonabad
Branch, Gonabad, Iran
Email: assefzare@gmail.com

Abstract – Regulating frequency of power systems, so called load-frequency control, is an important control issue in design and application of power systems. maximum performance of a power system requires a balance of produced power with total of used power and loss of energy.

An event in the network brings about a change in the operation point of power system. Thus, there is a deviation in frequency and power appointed to each unit. Such deviations result in undesirable effects in the network. Load-frequency control, along with automatic production control, is one of the most important and challenging issues in design and use of power systems in order to obtain better performance and higher safety capabilities.

In this paper, the idea of non-linear TSK fuzzy controller (NTSK) for two-area load-frequency system with considering limitation of production rate and dead band of governor has been proposed. We have used Cuckoo optimization algorithm for optimization of output coefficients of controller has been used.

Next, TSK, Optimal TSK, and Optimal NTSK have been compared with each other according to RSM and ITSE criterions.

Keywords – Frequency-Load, Production Rate Limitation, Optimal NTSK, Optimization, Cuckoo Algorithm.

I. INTRODUCTION

The main purpose of power control system is creating electrical power in a continuous system in a potential and cost-effective way with a permissible voltage and frequency.

Active power must be created as necessary and since load consumption changes in different hours in a day, therefore power created by generator must be controlled. For this purpose, opening and closing steam valve or the water channel regulates the steam or water flow on the turbine and results in electrical power and active power of generator output control.

If load consumption power goes up, steam valve or water channel must be opened more in order to increase the production power of generator. On the other hand, if load consumption power decreases, steam valve or water channel must be closed as much to reduce the production power of generator and establish a balance of active power. However, opening and closing valves have their own limitations. Steam valve can be opened or closed up to a point and in radical frequency change situations, opening and closing of valves can not account for frequency

change. Thus, a complementary controller is always needed in load-frequency control issues.

Lack of power balance can be felt from its effect on speed or frequency. In the case of load decrease and extra amount of production, generator desires to increase its speed and frequency. In the same way, in the case of load increase and lack of production, speed and frequency of generator decreases.

Frequency deviation from its nominal value has been chosen as a signal to stimulate automatic control system. Active balance of active power means that system frequency is constant, which is of great importance in its own turn.

Active power is rotor angle and frequency deviations in a control channel, so called PF channel- power frequency or megawatt frequency. Related system is also called load automatic load-frequency control system, or LFC.

The aims of load-frequency control performance are the following [1]:

- 1) keeping frequency within permissible and acceptable limits
- 2) distribution of power between generators
- 3) control of power transmission programs within the communication line

Various methods have been presented for load-frequency control. Among such methods, classic methods are more common in industry. Some of the inefficiencies of such methods are high deviation of power and lack of resistance against non-linear elements, such as dead band of governor.

Because of the fact that coefficient of controllers are constant and parameters are changeable as it has clearly been shown in reference [2], classic controllers do not have an appropriate performance in comparison with other controllers. Also, the fact that load-frequency system is multi-variable and non-linear makes designing such controllers difficult.

Principles of optimal control in the structure of AGC was first used by Lured and Fousha. They did their researches on a two-area system including two similar power stations with steam turbines which resulted in a new formulation for the problem. Among the disadvantages of using optimal control include its impracticability due to need for information from all systems on the one hand and its linear structure on the other hand [3].

Estimators have been constantly used for identification of variables, such as loads and accidental and unclear deviations so as in recent years deviation estimation and

control methods have been used in load-frequency control problems[4-5].

Since digital control is precise and trustworthy and its use can precipitate system performance, such idea has been used in a number of research papers[6].

An optimal AGC, if only designe based on nominal papameters, might not have a safe performance capability in the case that system parameters face accidental deviations of load and disturbance.

Thus, it is necessary to do research studies on the sensitivity of system agains parameter changes, which has already resulted in use of controllers with non constant structures[7].

Also, In reference [8] Erschler was the first reearcher who concentrated on applying VSS for electrical systems and introduced ideas in relation with resistant control in load-frequency control system, which has been more payed attention to in recent years[9-11].

First studies on AGC problem focused on the shape of control and most of such studies are classified according to type of deviation. However, the main limitation of such studies is the need for a large amount of information and data, which makes the size of calcultions and control more complicated[9].

In other papers, no limitations have been considered for turbin or governor, which turns the results into mere stimulation.

In a number of papers, load-frequency control has been done by fuzzy controller. One of the advantages of fuzzy controller is that there is no need to dynamic models for satisfactory designing[13-14].

Other advantages of fuzzy controller include extensive consideration of devation range of system parameter, considering non-linear elements, such as dead band of governor and no need to conversion function. On the other hand, considering the numer of input and output in the power system, controlling load-frequency is actually a control problem with multiple variables which further complicates the system and thus make the act of regulating the coefficient of classic controller more difficult. Considering the above issues makes the need to use fuzzy controller in load-frequency control problem evident and necessary[1-2].

II. TENDENCY CONTROL OF COMMUNICATION LINE

In load-frequency control systems equipped with control loop, power change in one area will be compensated wita production increase in both two areas and with current power change in the communication line and decrease in the frequency. In normal performance conditions, power system is exploited in a way to prepare for demand of all areas in the nominal frequency.

A simple control strategy for normal conditions is as follows[15]:

- a. keeping frequency close to nominal amount
- b. keeping current power in the communication line within the programmed limit

c. absorption of power change in each area within the same area

The usual load-frequency control system according to tendency control of communication linemeans that each area desires to decrease control error of area 1 (ACE) as much as zero. Control error for each area is a linear combination of frequency error and power change in the communication line.

Tendency coefficient of area K_i determines the amount of mutual effect between contagious areas in disturbance situations. Generally, satisfactory performance results when K_i tendency coefficient frequency coefficient area

that is, $B_i = \frac{1}{R_i} + D_i$ is chosen.

$$ACE_1 = \sum_{j=1}^n \Delta P_{12} + B_1 \Delta \omega_1 \tag{2}$$

$$ACE_2 = \sum_{j=1}^n \Delta P_{21} + B_2 \Delta \omega_2 \tag{3}$$

In which ΔP_{12} and ΔP_{21} are the difference between amount of transmissionof programmed powers with amount of transmission of current existing powers. The errors of area control have been used as stimulation signls for activating changes in reference's power regulation points, thus when obtaining stable condition, the amount as well as $\Delta \omega$ will become zero. Integral constant quotience must be as low as not to result in area getting the shape of chasing[1,12].

III. DESCRIBING TIMULATED POWER SYSTEM

In most systems a group of generators have cose affinity to each other and thus change with each oterr. On the other hand, generator's turbins desire to have similar response characteristics, which are called identical generators[16,17]. Such factor result in formation of a multiple area system. For descriptions and stimulations pirposes, a two area power system with a considarton of production rate limitation with amount of saturation surface [0.2 to -0.2] have been used.

Figure (1) show production limitation and dead band governor and Figure (2) indicates a simulated system.

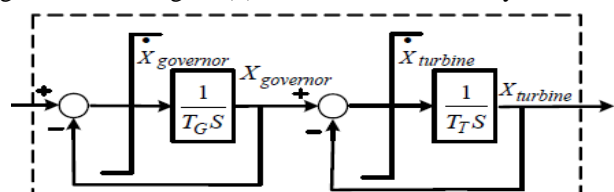


Fig1. Turbine governor model and taking into account the constraints

Figure (2) has the following properties:

- Tti: timeconstant of turbine
- Tpi: time constant of power system
- Kpi: efficiency of power system model
- Tgi: time constant of governor
- Ri: multiple of regulation of area i
- ΔFi: frequency deviation of area i

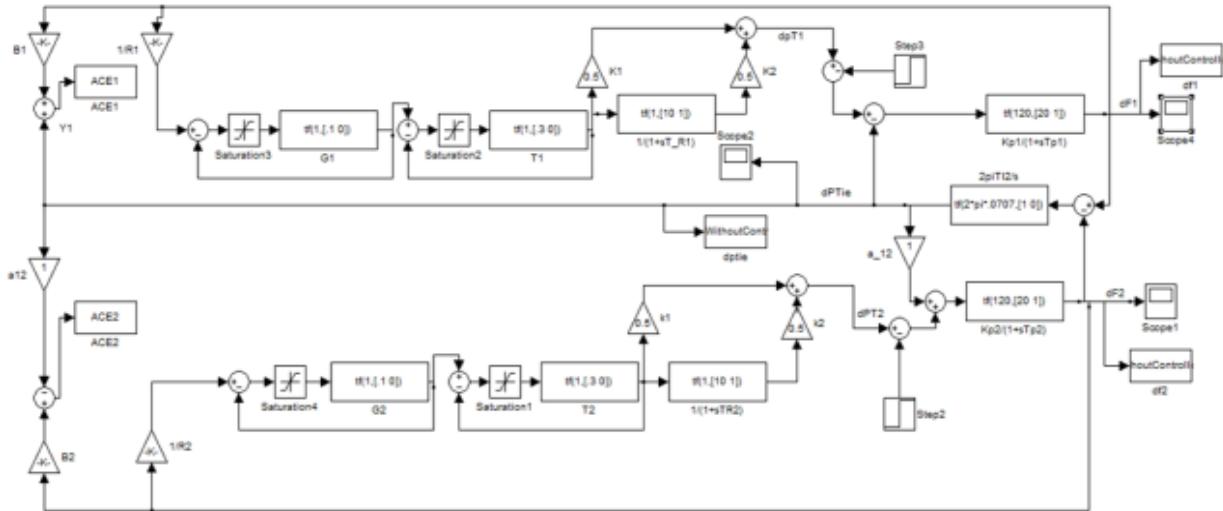


Fig.2. Simulation of two-area load-frequency system

In this section, simulation on the two area system by considering limitation in production of dead band of governor according to the characteristics in table(1) have been presented. The state-space in figure (2) is defined as follows:

$$\dot{X}(t) = Ax(t) + Bu(t) + Fd(t) \quad (4)$$

$$Y(t) = Cx(t) \quad (5)$$

$$x = [\Delta P_{c1} \Delta X_{G1} \Delta P_{T1} \Delta F_1 \Delta P_{c2} \Delta X_{G2} \Delta P_{T2} \Delta F_2]^T \quad (6)$$

$$U = [\Delta P_{c1} \Delta P_{c2}]^T \quad (7)$$

$$Y = [ACE_1, ACE_2]^T \quad (8)$$

$$ACE_i = \Delta P_{net_i} + B_i \Delta F_i \quad (9)$$

Where A, B, F, C matrices of the state, input, and output are disturbing. $d(t)$, $u(t)$, $x(t)$ the state vector and control of turbulence.

Table 1: System characteristics

Coefficients	Zone 1	Zone 2
Tg	0.1	0.1
Tt	0.3	0.3
Tr	10	10
Tp	20	20
K1	0.5	0.5
K2	0.5	0.5
B	0.425	0.425
R	2.4	2.4

$a_{12}=1 \quad T_{12}=2.2727$

IV. DESIGNING CONTROLLERS

Load-frequency system is formed in way in which only ACE signal can be used for control. As a result, in this paper, all controllers contain three inputs of ACE, ΔACE , and $\int ACE$ which are controller inputs of proportional, derivative, and integral quotiences respectively. The defined range for each input is $[2, -2]$ and functions are triangular.

The output of TSK fuzzy controller is a combination of controller inputs, because TSK fuzzy controller contains 3

inputs (X_1 -ACE, X_2 - ΔACE , and X_3 -IACE). The output of TSK fuzzy controller has been shown in equation (8)

$$Y = a_1 X_1 + a_2 X_2 + a_3 X_3 + a_4 \quad (10)$$

Equation (10) shows that TSK fuzzy output is a linear equation of inputs.

In this paper, in order to be able to estimate a greaterrange of function by each regulation, NTSK has been used. In fact, non-linearization of output of each regulation help in beter estimation and decrease in the number of regulations, because the number of selected conditions for fuzzy collections in input (X_1, X_2, X_3) can be decrease.

Thus, we have a fuzzy system with higher speed. Such higher speed is particularly evident in problems of greater size. The output of this controller is as follows:

$$Y = a_1 X_1 + a_2 X_2 + a_3 X_3 + a_4 X_1 X_2 + a_5 X_1 X_3 + a_6 X_2 X_3 + a_7 X_1^2 + a_8 X_2^2 + a_9 X_3^2 + a_{10} \quad (11)$$

In both equations above, a_i s are constans which have been used. In NTSK fuzzy output, there are coefficients of multiplication 2 of output variable or their squares which makes fuzzy system control system better and easier. On the other hand, the number of output variables are more than the normal conditions. Therefore, there are more parameters for control.

Each normal TSK control input contains 5 membership function and each putput contains 7 membershipfunctions Therefore, controller contains $5^3 = 125$ regulations. The surfise of designed regulations ar as shown in figure (3):

NTSK has been designed in such a way in which 3 membershipfunction have been considered for each input and 5 membershipfunction for each output. As a result, in this condition, fuzzy controller contains $3^3 = 27$ regulations.

Cuckoo optimization algorithm has been used for optimization of NTSK output coefficient in which optimization rate according to ITSE criterion is shown in figure (4).

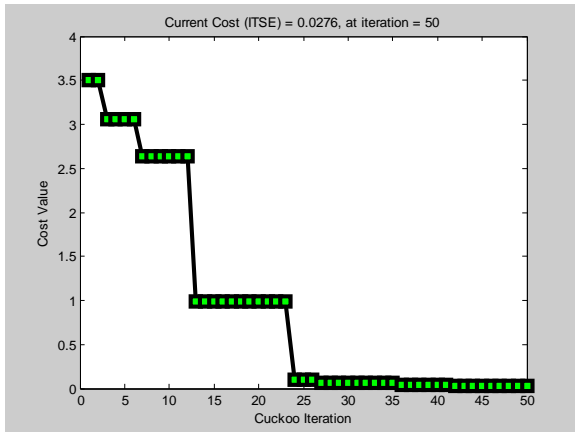


Fig.4. optimization rate of optimization algorithm

V. COMPARING CONTROLLERS' PERFORMANCE

In order to compare controllers' performance, the results of simulations according to 2 criterions of ITSE and RMS (equations 12 and 13) will be investigated.

$$ITSE = t^* \int_0^{30} [ACE_1(t)^2 + ACE_2(t)^2] dt \quad (12)$$

$$RMSE = \sqrt{[ACE_1(t)^2 + ACE_2(t)^2] / N} \quad (13)$$

In order to determine the performance of controllers, the following conditions have been considered for stimulations:

- a. load disturbance 8 and 5 percent for areas 1 and 2
- b. load disturbance of 10 and 8 percent for areas 1 and 2

Figures 5 and 9 shows respectively the frequency deviations in areas one and two in condition A and B in the system without controller.

Figures 6, 7 , and 8 show frequency deviations in area 1, frequency deviation in area two and transmission power deviations in condition A respectively.

Also, figures 10, 11, and 12 show frequency deviations in area 1, frequency deviation in area two and transmission power deviations in condition B respectively.

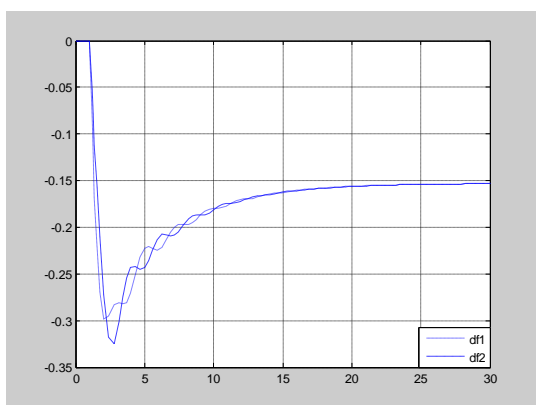


Fig.5. frequency deviations in area 1 and 2 in system without controller in condition A

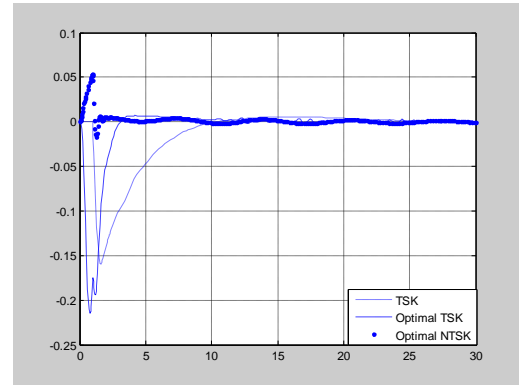


Fig.6. frequency deviations in area 1 with fuzzy controllers in condition A

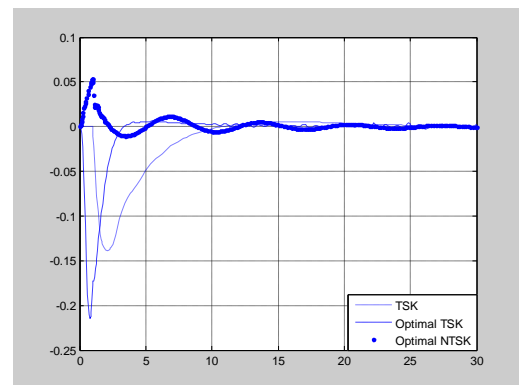


Fig.7. frequency deviations in area 2 with fuzzy controllers in condition A

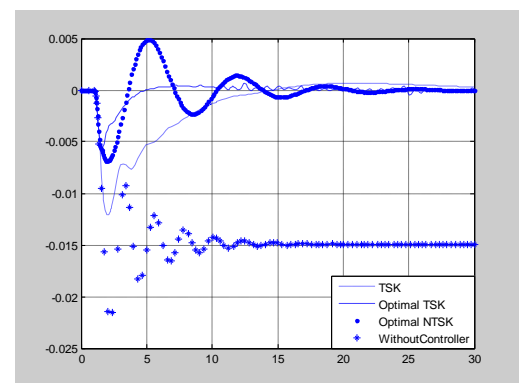


Fig.8. power transmission deviations between lines in condition A

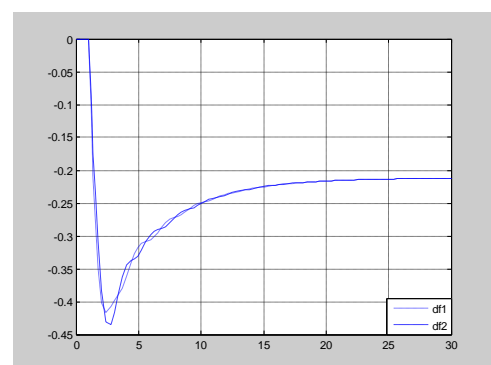


Fig.9. frequency deviations in area 1 and 2 in system without controller in condition B

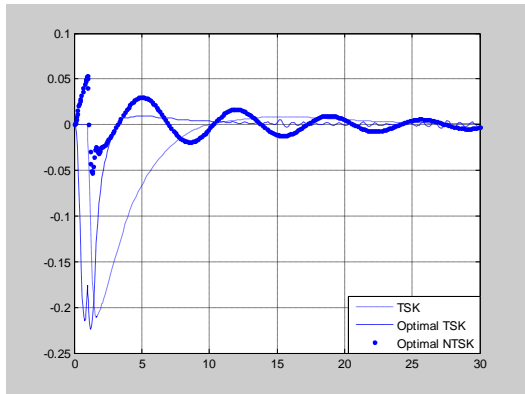


Fig.10. frequency deviations in area 1 with fuzzy controllers in condition B

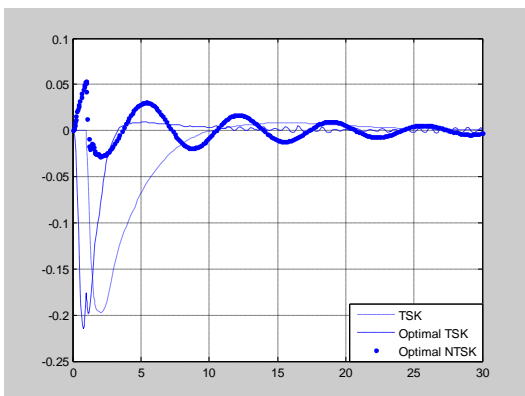


Fig.11. frequency deviations in area 2 with fuzzy controllers in condition B

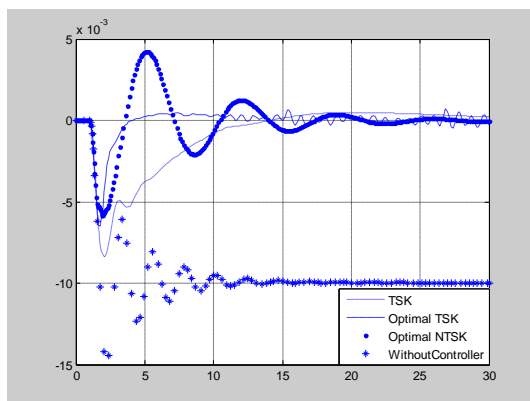


Fig.12. transmission power deviation between lines in condition B

As it can be seen in figures above, in both conditions A and B in system without controller, frequency deviations are in a way that the first control loop is unable to turn frequency deviations an transmission power into zero. However, in stimulation experiments with TSK, Ptimal TSK, and Optiman NTSK fuzzy controllers, frequency deviations and transmission power has become zero within a short time. Thus, the only difference of the above controllers are in their speed and their performance method.

Accordingly, in order to be able to compare the above controllers better, the results will be examined according to ITSE and RMS criterion as shown in tables 2 to 5.

Table 2: Comparison of ITSE criterion in condition A

Controller	ITSE criterion
Without Controller	14.8362
TSK	0.4750
Optimal TSK	0.2608
OptimalNTSK	0.0276

Table 3: Comparison of ITSE criterion in condition B

Controller	ITSE criterion
Without Controller	27.4747
TSK	0.9835
Optimal TSK	0.3160
Optimal NTSK	0.1190

Table 4: Comparison of RMSE criterion in condition A

Controller	RMSE criterion
Without Controller	0.1492
TSK	0.0395
Optimal TSK	0.0296
Optimal NTSK	0.0104

Table 5: Comparison of RMSE criterion in condition A

Controller	RMSE criterion
Without Controller	0.2065
TSK	0.0608
Optimal TSK	0.0471
Optimal NTSK	0.0151

In table 2 simulation results according to ITSE criterion in condition A has been shown. In this table, Optimal NTSK controller has better performance compared with other controllers. Yet, other controllers have had an acceptable performance, satisfying system's load-frequency expectations. On the other hand, in addition to improved performance, Optimal NTSK has been able to reduce the number of simulation regulation as much as 78.4% because of its non-linear characteristics.

Table 4 presents the simulation results from condition A according to RMSE criterion. In this table, the suggested controller has a better performance as much as 64.86 % compared with Optimal TSK controller and 73.67 % compared with TSK controller.

Tables 3 and for show simulation results in condition B. according to ITSE and RMSE criterion respectively. As in condition A, the suggested controller has the best performance.

VI. CONCLUSION

In this paper, load-frequency control of a two-area power system by considering production rate limitation and dead band of governor by using Optimal NTSk has been suggested. Instead of pessising only a linear equation of inputs, Optimal NTSK fuzzy output contains a non linear equation of inputs. As a result, instead of designing a controller with 125 regulations, a controller with only 27 regulations can be designed. In this study, Cuckoo algorithm has been used for optimization of controller's output coefficients.

The performance of suggested controller has been compared with TSK, Optimal TSK and Optimal NTSK according to RMSE and ITSE criterion. According to the simulation experiments, Optimal NTSK controller, Optimal TSK and TSK rank in the best performance respectively.

REFERENCES

- [1] M. Shiroei, M.R.Toulabi, A.M.Ranjbar, " Robust multivariable predictive based load frequency control considering generation rate constraint" *Electrical Power and Energy Systems* 46 (2013) 405–413. www.elsevier.com/locate/ijepes.
- [2] Ebrahimian.Baydokhty.Mohsen, Zare.Assef, Ebrahimian. Baydokhty. Mohammad, Farshad. Mohsen, Mirzade.Majid "Controlling frequency load in fuzzy systems with non-linear power model," 4th Iranian Conference on Electrical and Electronics Engineering (ICEEE2012).
- [3] C. E. Fosha and O. I. Elgerd, "The Megawatt Frequency Control Problem: A New Approach via Optimal Control Theory", *IEEE Trans. on Power Apparatus and Systems*, Vol. PAS-89, No. 4, pp. 563–577, Apr 1970.
- [4] Vrdoljak, Kresimir; Peric, Nedjeljko; Petrovic, Ivan, "Estimation and Prediction in Load frequency Control", *International Conference on Power Engineering, Energy and Electrical Drives, (POWERENG 2007)*, pp. 785 - 790, Apr 2007.
- [5] Kong, Lianfang; Xiao, Lei Miniesy, "A New Model Predictive Control Scheme-Based Load-Frequency Control", *IEEE International Conference on Control and Automation (ICCA2007)*, pp. 2514–2518, May 2007.
- [6] A.Bensenouci and A.M. Abdel Ghany, " Optimal Discrete-Time Output Feedback Control for Multi-Area Load Frequency Control Using Evolutionary Programming ", *IEEE International Symposium on Industrial Electronics, (ISIE 2005)*, pp. 95-100, June 2005.
- [7] A.Bensenouci and A.M. Abdel Ghany, "Step-Wise Optimum Adaptive Variable-Structure Load-Frequency Control Design Using Simulated Annealing" , *IEEE International Symposium on Industrial Electronics (ISIE2007)*, pp. 318 – 323, June 2007.
- [8] J. Erschler, F. Roubeliat and J. P. Vernhes, "Automation of A Hydroelectric Power Station using Variable-Structure Control Systems", *Automatica*, No. 10, pp. 31–36, 1974.
- [9] M, H, Kazemi, M. Karrari and M. B. Menhaj , "Decentralized Robust Adaptive-Output Feedback Controller for Power System Load Frequency Control", *Journal of Electrical Engineering, Springer-Verlag*, Vol. 84, No. 2, pp. 75–83, 2002.
- [10] Bensenouci, Ahmed; Ghany, A.M. Abdel, "Mixed H_∞/H_2 with Pole-Placement Design of Robust LMI-Based Output Feedback Controllers for Multi-Area Load Frequency Control", *International Conference on "Computer as a Tool"*, pp. 1561 – 1566, Sept 2007.
- [11] M. Aldeen and R. Sharma, "Robust Detection of Faults in Frequency Control Loops", *IEEE Trans. on Power Systems*, Vol. 22, No. 1, pp. 413 – 422, Feb 2007 .
- [12] Ebrahimian.M.B, Zare.A and Balochian.S "Load frequency control with Hierarchical fuzzy systems in non-linear power model" *International Journal Of Advanced Electrical Engineering Research (IJAER)*, Vol. 1, Issue. 1, pp. 18-31, 2013
- [13] Z. Ai-Hamouz, Y. Abdel-Magid, "Variable-structure load-frequency controllers for multi area powersystems," *Electric Power Energy System*, vol. 15, pp. 23–29, 1993
- [14] C. C. Lee, "Fuzzy Logic in Control System: Fuzzy Logic Controller - Part 1 and 2," *IEEE Trans. on Systems, Man, and Cybernetics*, Vol.20, No. 2, March/April 1990, pp. 404 - 435.
- [15] Hassan Bevrani, Pourya Ranjbar Daneshmand, " Fuzzy Logic-Based Load-Frequency Control Concerning High Penetration of Wind Turbines" *IEEE SYSTEMS JOURNAL*, VOL. 6, NO. 1, MARCH 2012.
- [16] M.Rahmani, N.Sadati "Hierarchical optimal robust load-frequency control for power systems," *The Institution of Engineering and Technology* 2012, *IET Gener. Transm. Distrib.*, 2012, Vol. 6, Iss. 4, pp. 303–312
- [17] H. Kondo, Y. Suzuki, and Sh. Iwamoto, "A Load Frequency Control Design using the Sliding mode Control Theory with a VSSObserver," *International Journal of Computer Applications* (0975 – 8887) Volume 46– No.15, May 2012.
- [18] Nilay.N.Shah, Aditya.D.Chafekar, Dwij.N.Mehta, Anant.R.Suthar, "Automatic Load Frequency Control Of Two Area Power System With Conventional And Fuzzy Logic Control," *Ijret* , Available, Volume: 1 Issue: 3, Nov 2012, ISSN: 2319 – 1163.
- [19] Z.Namadchian, A.Zare and A. Namadchian, " Stability Analysis of Nonlinear Dynamic Systems by Nonlinear Takagi–Sugeno–Kang FuzzySystems"