ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

Load Frequency Control for an Interconnected Reheat Thermal Power Systems with Redox Flow Batteries using Beta Wavelet Neural Network Controller

R.Francis, Dr. I. A. Chidambaram

Abstract: This paper presents optimization of Proportional Integral controller gains of the two area interconnected thermal power system with the fast acting energy storaging devices. The energy storing device especially Redox Flow Batteries (RFB) can efficiently damp out electromechanical oscillations in the power system because of their efficient storage capacity in addition to the kinetic energy of the generator rotor, which can share the sudden changes in power requirements. The proposed controller is designed with the feasibility of applying a Beta Wavelet Neural Network (BWNN) approach for the automatic generation control and implemented in a two area interconnected thermal power system without and with RFB. The system was simulated and the frequency deviations in area 1 and area 2 and tie-line power deviations for 1% and 5% step-load disturbance in area 1 were obtained. The comparison of frequency deviations and tie-line power deviations for the two area interconnected thermal power system without and with RFB reveals that the system with RFB enhances a better stability than that of system without RFB.

Keywords: **Load Frequency Control, Integral Square Error Criterion, Redox Flow Batteries, Beta Wavelet Neural Network.**

I. INTRODUCTION

Automatic generation control is a very important criterion in electric power system design and operation. It is well known that the main objectives of AGC in multi-area power systems are to keep the tie-line power flows in a prescribed tolerance and to fix the frequency of each area within limits. Designing efficient load frequency controllers has received great attention of researchers in recent years, and many control strategies have been developed [1-5]. The Proportional plus integral controller was one of control strategy, which is still widely used now a days in industry. Several adaptive control techniques have also been suggested to overcome these shortcomings of the conventional techniques. The attempt of such control is to extend the stability margin of the power systems [7]. The artificial intelligence neural network and fuzzy logic control approaches have been applied successfully to the controllers used in load frequency control. Such intelligent control systems [8-12] are independent of the power system mathematical model parameters, but they can work with the available system time responses. The wavelet neural network approach has been applied successfully to the two area interconnected thermal power systems. The proposed Beta wavelet neural network (BWNN) load frequency controller has a very good and fast tracking control performance relative to that of the conventional neural network technique without prior knowledge of the controlled plant [13-14]. The proposed controller provided very fast response relative to that of the fixed gain controllers. The stabilization of frequency oscillations in an interconnected power system became challenging when implemented in future competitive environment. The major advantage of incorporating the Redox Flow Batteries in the interconnected power system is to enhance a quality and reliable power supply. The Redox Flow Batteries (RFB) are found to be superior over the other energy storing devised because of its easy operability at normal temperature, very very small loss during stand by and have a long service life, Flexibility in layout, easy to increase the capacity and free from degradation due to fast charging and discharging action[15-16].

II. TWO AREA INTERCONNECTED REHEAT POWER SYSTEM WITH RFB UNITS

A. *Problem formulation*

The system state space equations are developed as

$$\dot{X} = Ax + Bu + \Gamma d \qquad (2.1)$$

Where, x, u and d are the state, control and disturbance vectors. The control and disturbance vectors are given by

System Control input vector $u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{c1} \\ \Delta P_{c2} \end{bmatrix}$ (2.2)

Disturbance vector $d = \begin{bmatrix} d_1 \\ d_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{D1} \\ \Delta P_{D2} \end{bmatrix}$ (2.3)

Where ,

Augmented system matrix $\overline{A} = \begin{bmatrix} 0 & C \\ 0 & A \end{bmatrix}$ (2.4)

Augmented control input matrix $\overline{B} = \begin{bmatrix} 0 & B \end{bmatrix}$ (2.5)

Augmented disturbance matrix $\overline{\Gamma} = \begin{bmatrix} 0 & \Gamma \end{bmatrix}$ (2.6)

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

Augmented output matrix $\bar{C} = [0 \quad C]$ (2.7)

Two state vectors ∫ ACE_1 and ∫ ACE_2 are in clouded in the augmented state matrix and eleven state variables are presented in this augmented form.

$$\int ACE = \int_0^\infty [(\beta_1 \Delta F_1)^2 + (\beta_2 \Delta F_2)^2 + (\Delta Ptie_{1,2})^2] dt \quad (2.8)$$

Substituting the value we get,

$$\begin{bmatrix} \bar{Y} \\ \dot{\bar{X}} \end{bmatrix} = \begin{bmatrix} 0 & C \\ 0 & A \end{bmatrix} \begin{bmatrix} \int ACE.dt \\ \bar{X} \end{bmatrix} + \begin{bmatrix} 0 \\ B \end{bmatrix} U \quad (2.9)$$

B.PI Controller gain optimization

The fixed gain controllers which are designed at nominal operating conditions and fail to provide best control performance over a wide range of operating conditions. But it is desirable to keep system performance near its optimum. Thus, the objective function of the optimization of the performance of the system [3] is given in equation (2.10).

$$C = \int_0^\infty [(\beta_1 \Delta F_1)^2 + (\beta_2 \Delta F_2)^2 + (\Delta Ptie_{1,2})^2] dt \quad (2.10)$$

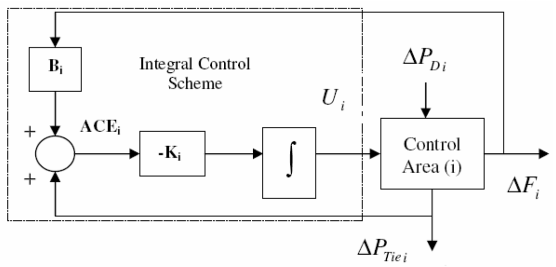


Fig.1. Conventional PI Control Scheme on I[th] Area

C.1.Configuration and Operation of RFB Battery

The configuration of Redox Flow Battery is shown in figure 2. A sulfuric acid solution containing vanadium ions is used as the positive and negative electrolytes, which are stored in respective tanks and circulated to battery cell. The reactions that occur in the battery cell during charging and discharging can be expressed simply with the following equations [15].

$$\text{Positive Electrode: } V^{4+} \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{5+} + e^- \quad (2.11)$$

$$\text{Negative Electrode: } V^{3+} + e^- \underset{\text{Discharge}}{\overset{\text{Charge}}{\rightleftharpoons}} V^{2+} \quad (2.12)$$

The Redox Flow Batteries offer the following features, and are suitable for high capacity systems that differ from conventional power storage batteries.

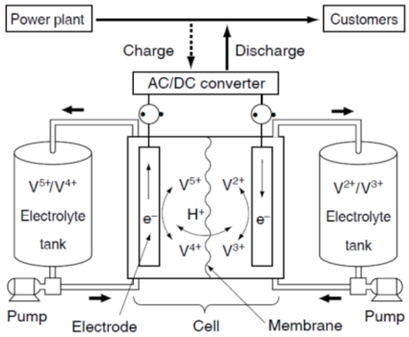


Fig 2.Configuration of Redox Flow Battery

The battery reaction only involves a change in the valence of a vanadium ion in the electrolyte. There are none of the factors which reduce the battery service life seen in other batteries that use a solid active substance, such as loss are electro depositions of the active substance. Further more, operation at normal temperatures ensure less deterioration of the battery materials due to temperature. The charged electrolyte is stored in separate positive and negative tanks when the battery has been charged, therefore no self-discharge occurs during prolonged stoppage nor is auxiliary power required during stoppage. Furthermore, start-up after prolonged stoppage requires only starting of the pump, thus making start-up possible in only a few minutes. The electrolyte (i.e., the active substance) is sent to the each battery cell from the same tank, therefore the charging state of each battery cell is the same, eliminating the need for special operation such as uniform charging. so that, maintenance is also easy because the electrolyte is relatively safe and the operating are at normal temperature and assures superior environmental safety. Waste vanadium from generating stations can be used so it can be superior recyclability. Furthermore, the vanadium in the electrolyte can be uses permanently. The RFB systems are incorporated in the power system to suppress the load frequency control problem and to ensure an improved power quality. In particular, these are essential for reusable energy generation units, such as wind power and photovoltaic generator units, which need measures for absorption of changes in output and to control flicker and momentary voltage drop. With the excellent short-time overload output and response characteristics possessed by RFB in particular [15], the effects of generation control and of the absorption of power fluctuation needed for power quality maintenance are expected. The set value of the RFB has to be restored at the earliest, after a load disturbance so that the RFB unit is ready to act for the next load disturbance. The RFB are capable of very fast response and therefore, hunting due to a delay in response does not occur. For this reason, the ΔFi was used directly as the command value for LFC to control the output of RFB as shown in Figure 2.

IJEIT
ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

C.2 Characteristics of RF batteries

RF batteries have the following characteristics and can be used in various applications.

(1) The battery reaction principle is simply the change in valence of the metal ions in the electrolyte, realizing a long charge/discharge cycle service life.

(2) The output section (cells) and capacity section (tanks) are independent of each other and can be optimally designed according to application needs.

(3) Maintenance is easy mainly because the same electrolyte is supplied to individual cells and therefore the state of charge (SOC) in each cell does not need to be monitored, and because heat can be controlled easily based on the flowing electrolyte. Since the SOC can be easily monitored by measuring the potential of the electrolyte, the SOC can be monitored continually during operation.

(4) The electrolyte is stored in the positive and negative tanks separately, so that no self-discharge occurs during stand-by and stoppage, except in the cell section.

(5) RF batteries are useful to absorb irregular, short cycle output fluctuations, such as in natural energy generation, because they have the characteristic of instantaneous response in an order of milliseconds and can charge and discharge at an output rate a few times larger than the designed rating for a short period of time.

(6) The electrolyte is friendly to the environment, because it scarcely changes during normal operation except for Changes in ion valance and it can be used virtually permanently and reused [16].

C.3 RFB UNITS in LFC

Redox flow battery, in addition to load leveling, a function commonly assigned to them, have range of allocations such as Load Frequency Control (LFC) and power quality maintenance for decentralized power supplies [15].

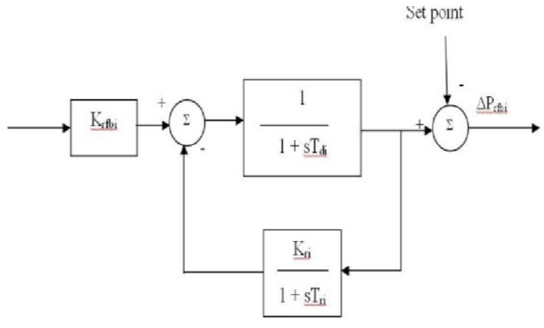


Fig 3 Redox Flow Batteries Model the RFB modeling equations are

$$\Delta P_{rfbi} = \frac{Kc_i}{1+sTd_i}\Delta Pc_i \qquad (2.13)$$

$$\Delta P_{rfbi} = Kci.\Delta Pc_i \qquad (2.14)$$

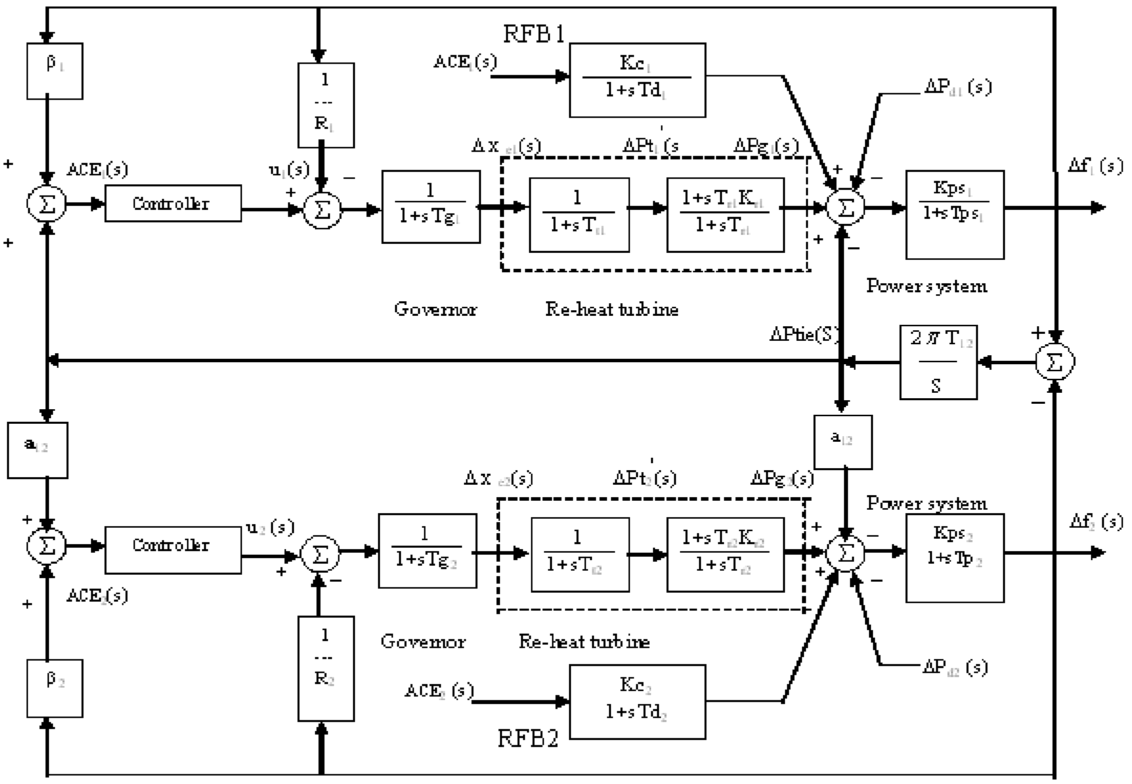


Fig-4 Block Diagram of A Two – Area Interconnected Power System with Redox Flow Batteries

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

III. NEURAL NETWORK CONTROLLER

The NN controller architecture employed here is a Model Reference Neural Network, which is shown in Fig.5. In this technique, the Model Reference Adaptive Control configuration uses two neural networks, a controller network and a model network. The Model network can be trained off-line using historical plant measurements. The controller is adaptively trained to force the plant output to track a reference model output. The model network is used to predict the effect of controller changes on plant output, which allows the updating of controller parameters. In the study, the frequency deviations, tie-line power deviation and load perturbations of the area are chosen as the neural network controller inputs. The outputs of the neural network are the control signals, which are applied to the governors in the areas. The data required for the ANN controller training is obtained from the designing the Reference Model Neural Network and applying it to the power system with step response load disturbance. It is a three-layer perceptron with five inputs, 13 neurons in the hidden layer, and one output in the ANN controller. Also, in the ANN Plant model, it is a three-layer perceptron with four inputs, 10 neurons in the hidden layer.

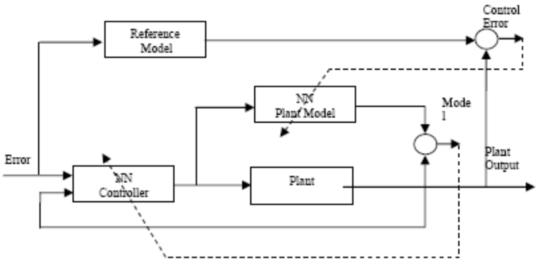


Fig. 5.Neural Network System Architecture

IV. BETA WAVELET NEURAL NETWORK CONTROLLER

The structure of a four layer Beta wavelet neural network (BWNN) controller is shown in Fig 7. The objective of the control problem is to track the frequency deviation to zero in the case of a load disturbance. To achieve this control, the frequency deviation is taken as a tracking error, e. The input of the WNN consists of the error e and e $(1 - z^{-1})$, where z^{-1} is the time delay, and the output of the WNN is the control input signal U, which represents Up1, Up2.

The Beta function [13, 14] is defined as: if p>0, q>0,

$$\beta(x) = \begin{cases} \left(\frac{x-x_0}{x_c-x_0}\right)^p \left(\frac{x_1-x}{x_1-x_c}\right)^q & if \;\; x \in [x_0, x_1] \\ 0 & else \end{cases} \quad \text{--- (4.0)}$$

$$\text{where, } x_c = \frac{p x_1 + q x_0}{p+q} \quad \text{--- (4.1)}$$

p represents the center of membership function

q Represents the width and the shape of membership function The general form of the n^{th} derivative of Beta function is:

$$\Psi_n(x) = \frac{d^{n+1}\beta(x)}{dx^{n+1}} \quad \text{---(4.2)}$$

$$= [(-1)^n \frac{n!p}{(x-x_0)^{n+1}} + \frac{n!q}{(x_1-x)^{n+1}}]\beta(x)$$
$$+ P_n(x)P_1(x)\beta(x) + \sum_{i=1}^{n} C_n^i [(-1)^n \frac{(n-i)!p}{(x-x_0)^{n+1-i}}$$
$$+ \frac{(n-i)!q}{(x_1-x)^{n+1-i}}]P_1(x)\beta(x)$$

Where,

$$P_1(x) = \frac{p}{x-x_0} - \frac{q}{x_1-x}$$

$$P_n(x) = (-1)^n \frac{n!p}{(x-x_0)^{n+1}} - \frac{n!q}{(x_1-x)^{n+1}}$$

If p=q, for all n € N, 0<n<p, the functions $\Psi_n(x) = \frac{d^{n+1}\beta(x)}{dx^{n+1}}$ are wavelets. The first, second and third derivatives of beta wavelets are shown below the Fig 6.

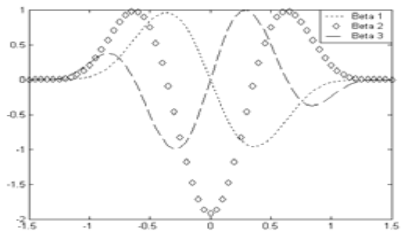


Fig 6 Beta Wavelets

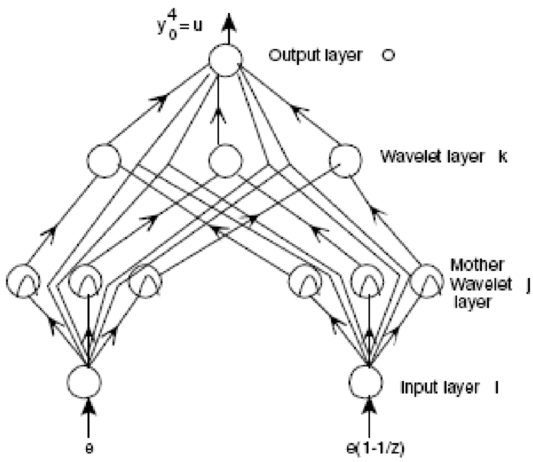


Fig. 7 Four Layer Wavelet Neural Network Structure

V. SIMULATION RESULTS AND OBSERVATIONS

The Proportional integral controllers are designed and implemented in the two area interconnected power

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

system with and without RFB unit and Beta Wavelet Neural Network in the interconnected reheat power system is also applied. The simulation studies were performed with these controllers for a step load disturbance of (0.01pu MW / 0.05 pu Mw) in area-1 and the corresponding frequency deviation and tie – line power deviations are obtained for easy comparison, the frequency and tie-line power deviations of the two – area interconnected power system without and with RFB and Beta wavelet neural network approaches are presented in figures 8 to 13. It is observed from the output responses that, the RFB with Beta Wavelet Neural Network when incorporated has not only improves the transient response of the system but also has reduced the settling time.

VI. CONCLUSION

Controller Based on Beta Wavelet Neural Network (BWNN) is designed to control the frequency deviation and tie-line power flow deviation of the two-area interconnected thermal–reheat power systems. The proposed BWNN controller is implemented in a two area interconnected power systems and design implementation of the controller is found that the frequency and tie-line power deviations of the interconnected power systems considering RFB unit with BWNN controller ensures improved transient response of the system.

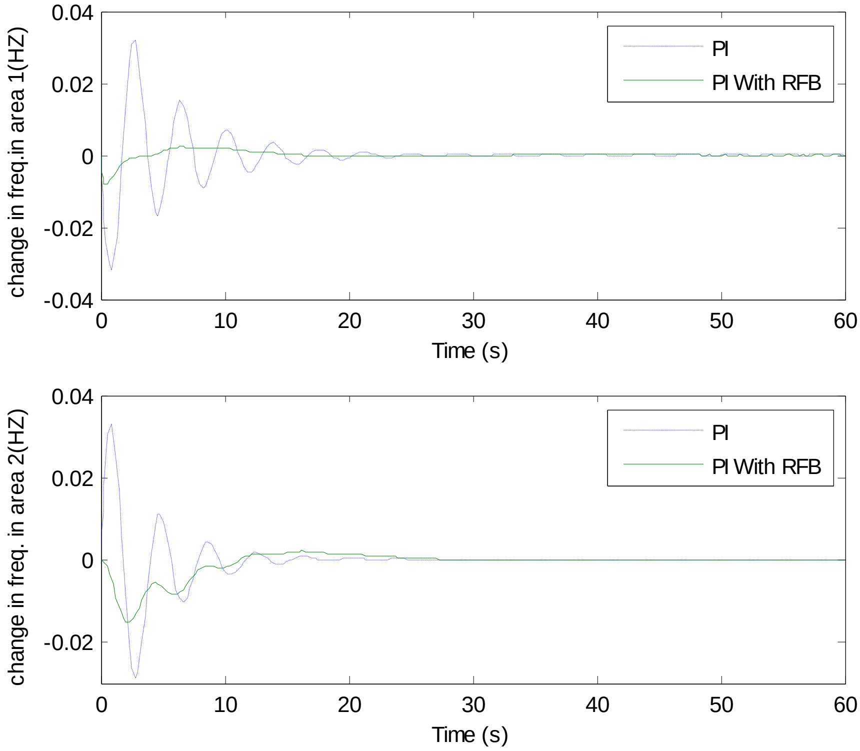
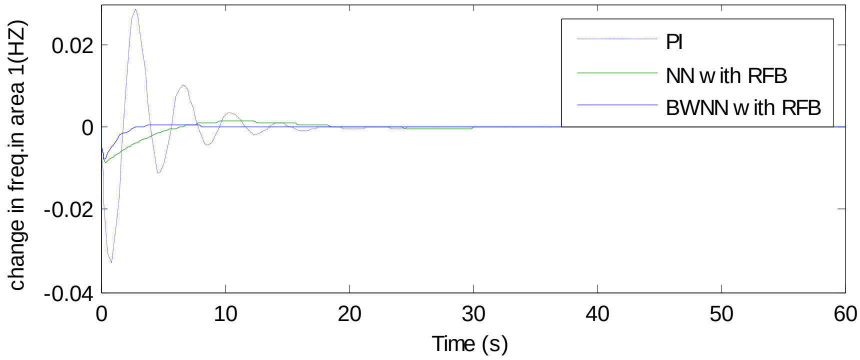


Fig8: Frequency Deviation Of Area 1 and Area 2 in A Two Area Interconnected Thermal Reheat Power System With PI Controller and PI With RFB Controller For 1% Step Load Disturbance in Area 1



ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

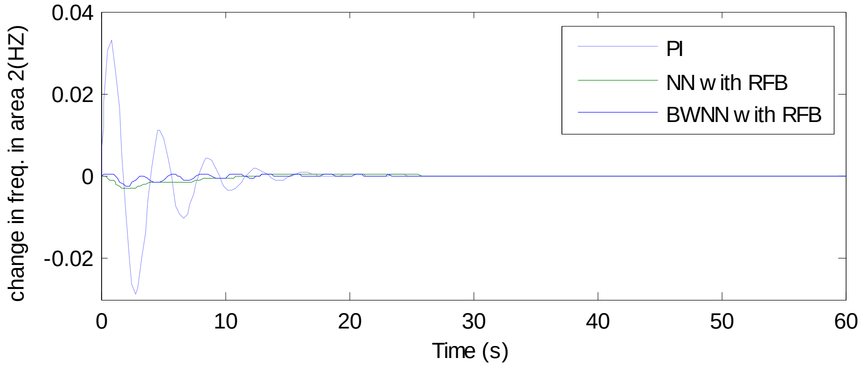


Fig 9: Frequency Deviation of area 1 and area 2 in a two area interconnected thermal reheat power system with PI Controller, Neural Network Controller and BWNN controller for 1% step load disturbance in area 1

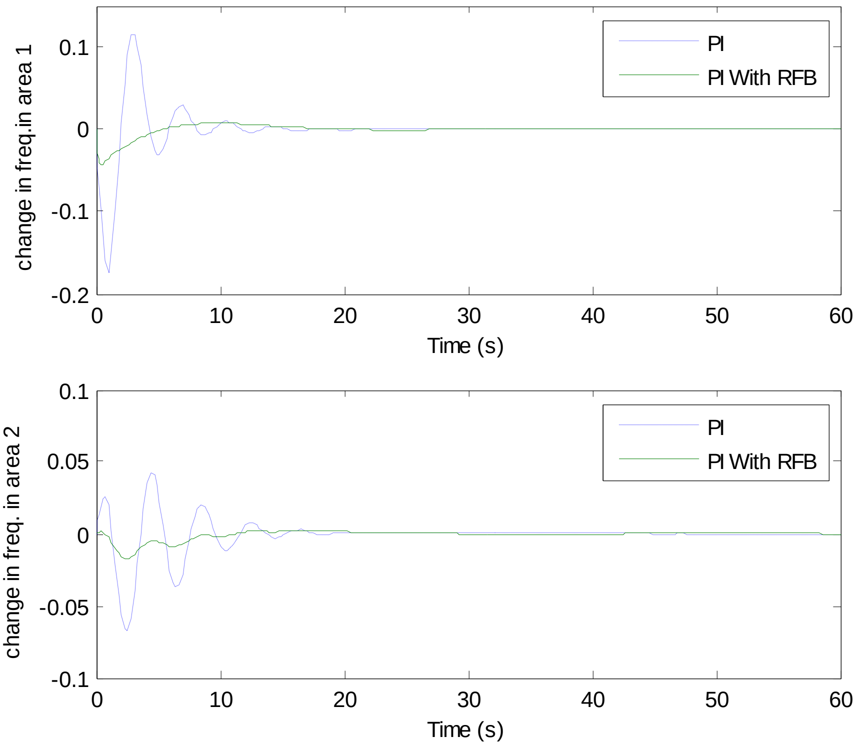
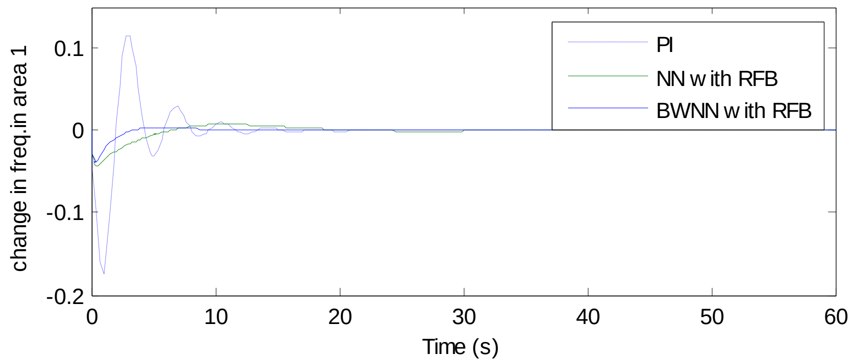


Fig10: Frequency Deviation of area 1 and area 2 in a two area interconnected thermal reheat power system with PI Controller and PI with RFB controller for 5% step load disturbance in area 1



ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

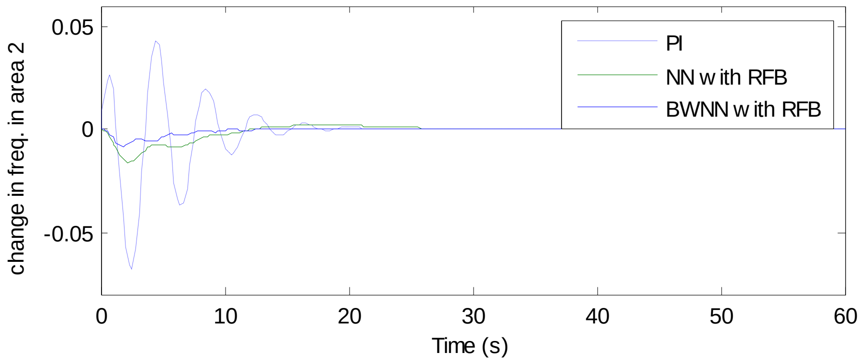


Fig11: Frequency Deviation of area 1 and area 2 in a two area interconnected thermal reheat power system with PI Controller, Neural Network Controller and BWNN controller for 5% step load disturbance in area 1

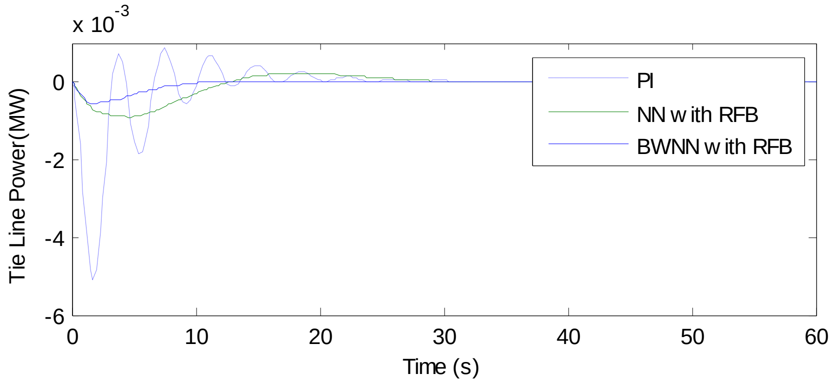


Fig12: Tie-line power Deviations in a two area interconnected thermal reheat power system with PI Controller, Neural Network Controller and BWNN controller for 1% step load disturbance in area 1

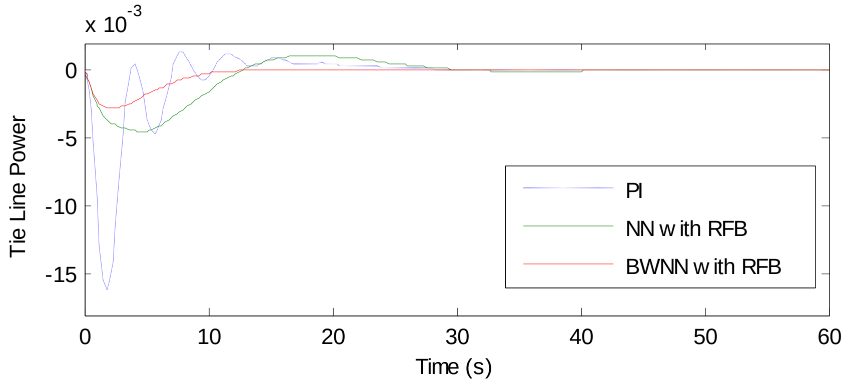


Fig13: Tie-line power Deviations in a two area interconnected thermal reheat power system with PI Controller, Neural Network Controller and BWNN controller for 5% step load disturbance in area 1

APPENDIX-1

Data for the interconnected two area thermal power system [4].

Rating of each area=2000 MW

Base power=2000 MVA

f = 60 Hz

R_1=R_2= 2.4 Hz/Pu MW

T_{g1} = T_{g2}=0.08 sec

T_{t1} = T_{t2}=0.3 sec.

T_{p1} =T_{p2}= 20 sec

K_{p1} = $K_{p\,2}$=120 Hz/Pu MW

B_1 =B_2= 0.425 Pu MW/Hz

T_{12} = 0.545 MW/Hz

ΔP_{d1}=0.01pu MW/HZ

a_{12} = -1.

*K*ri = 0

Tdi = 0

Tri = 0

APPENDIX-2

List of symbols:

f Frequency

K_p Power system gain

K_r Reheat thermal power system gains

T_r Reheat time constants

T_t Time constant of turbine

T_d Time delay of RFB

T_t Time constant of RFB

ISSN: 2277-3754
ISO 9001:2008 Certified
International Journal of Engineering and Innovative Technology (IJEIT)
Volume 2, Issue 9, March 2013

X_e Governor Valve position
T_g Time constant of governor
P_g Turbine output power
R Regulation parameter
T_{ij} Tie-line synchronizing coefficient
a_{ij} Operator
T_p Power system time constant
P_{ref} The output of ACE
X State vector
A, B State matrices
Δf_i Frequency deviation of area i (i = 1, 2)
ΔPG_i Generation deviation of area i (i = 1, 2)
ΔXE_i Governor Valve position deviation of area i (i = 1, 2)
ΔP_{tie} Tie line power deviation of area i (i = 1, 2)
ΔP_{di} Step load input of area i (i = 1, 2)
ΔP_{ri} Rotor position deviation of area i (i = 1, 2)
ΔUp_i Controller signal deviation of area i (i = 1, 2)
ACE Area control error
RFB Redox Flow Batteries
NN Neural Network
WNN Wavelet Neural Network
BWNN Beta Wavelet Neural Network

ACKNOWLEDGMENT

The authors wish to thank the authorities of Annamalai University, Annamalainagar, Tamilnadu, India for the facilities provided to prepare this paper.

REFERENCES

[1] I.P. Kumar, D.P.Kothari, "Recent philosophies of automatic generation control strategies in power systems" IEEE Transactions on Power System, Vol.20, No.1, pp. 346-357, 2005.

[2] Shayeghi.H, Shayanfar.H.A, Jalili.A,"Load frequency control strategies state of the art survey for the researcher", Energy Conservation and Management. Vol. 50(2), pp.344-353, 2009.

[3] Malik OP, Kumar A, Hope GS. "A load frequency control algorithm based on a generalized approach". IEEE Transaction on Power System, Vol.3 (2), pp.375–82, 1988.

[4] Velusami.S, Chidambaram.IA,"Decentralized biased dual mode controller for LFC of interconnected power systems", Electric Power Component and Systems, Vol.34 (10), pp.1691-1702, 2007.

[5] N.Jaleeli.N, Vanslyen.LS, Ewart.DN, .Fink LH,"Understanding automatic generation control", IEEE Transaction on Power Systems. Vol.7 (3), pp.1106–1122, 1999.

[6] Pan CT, Liaw CM." An adaptive controller for power system load frequency control". IEEE Transaction on Power Systems, Vol.4 (1), pp.122–128, 2001.

[7] I.A.Chidambaram, R.Francis,"Automatic Generation Control of two area interconnected power system based on cps using fuzzy neural network", IEEE International Conference (ICETECT 2011), Nagarkovil, pp 200-205, 2011.

[8] M. Thuillard, "A review of wavelet networks, wavenets, fuzzy wavenets and their applications", ESIT 2000 Aachen, Germany, pp 5–16, 2000.

[9] Senjyu T, Tamaki Y, Takara H, Uezato K."Next day load forecasting using wavelet analysis with neural network". Electrical Power Component System, Vol.30, pp.1167–78, 2002.

[10] Wai RJ, Chang JM."Intelligent control of induction servo motor drive via wavelet neural network". Electric Power System Research, Vol.61, pp.67–76, 2002

[11] Wai RJ, Duan RY, Lee JD, Chang HH. "Wavelet neural network control for induction motor drive using sliding mode design technique". IEEE Transaction Industrial Electronics, Vol.50 (4), pp.733–48, 2003.

[12] C. Aouiti, M.A Alimi, and A. Maalej, "Genetic Designed Beta Basis Function Neural Networks for Multivariable Functions Approximation, Systems Analysis, Modeling, and Simulation", Special Issue on Advances in Control and Computer Engineering, Vol. 42(7), pp. 975-1005, 2002.

[13] Wajdi Bellil, Chokri Ben Amar, and Adel M. Alimi," Comparison between Beta Wavelets Neural Networks, RBF Neural Networks and Polynomial Approximation for 1D, 2D Functions Approximation", Proceedings of World Academy of science , engineering and Technology, Vol.13, pp. 102-107, 2006.

[14] Ben Amar, M. Zaied and M. A. Alimi, "Beta wavelets. Synthesis and application to lossy image compression", Journal of Advances in Engineering Software, Elsevier Edition, Vol. 36(7), pp. 459 - 474. 2005.

[15] N.Tokuda, "Development of a Redox Flow Battery System", Engineering conference, IECEC-98-1074, August, 1998.

[16] Enomoto K, Sasaki T, Shigematsu T, Deguchi H,"Evaluation study about Redox flow battery response and its modeling". IEEE Transaction on Power System Engg, Vol.122-B (4), pp.554–560, 2002.

BIOGRAPHIES

R.Francis (1977) received Bachelor of Engineering in Electrical and Electronics Engineering (1999), Master of Engineering in Power System Engineering (2001) from Annamalai University, Annamalainagar. From 2002 he is working as Assistant professor in the Department of Electrical Engineering, Annamalai University. He is a member of ISTE. His research interests are in Power Systems and Electrical Measurements and Controls. (Electrical Machines Laboratory, Department of Electrical Engineering, Annamalai University, Annamalainagar – 608002, Tamilnadu, India)

I.A.Chidambaram (1966) received Bachelor of Engineering in Electrical and Electronics Engineering (1987), Master of Engineering in Power System Engineering (1992) and PhD in Electrical Engineering (2007) from Annamalai University, Annamalainagar. During 1988 - 1993 he was working as Lecturer in the Department of Electrical Engineering, Annamalai University and from 2007 he is working as Professor in the Department of Electrical Engineering, Annamalai University, Annamalainagar. He is a member of ISTE and ISC. His research interests are in Power Systems, Electrical Measurements and Controls. (Electrical Measurements Laboratory, Department of Electrical Engineering, Annamalai University, Annamalainagar – 608002, Tamilnadu, India, Tel: - 91-04144-238501, Fax: -91-04144-238275) driacdm@yahoo.com.