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Beta Wavelet Neural Network Based Load-Frequency Controller for an Interconnected Reheat Power system with Hydrogen Electrolyser

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ABSTRACT:

This paper investigates a renewable energy resource's application to the Load-Frequency Control of interconnected power system. The Proportional plus Integral(PI) controller gains of the two area interconnected thermal power system with the fast acting energy storage devices are designed based on Control Performance Standards (CPS) using conventional/Beta Wavelet Neural Network(BWNN) approaches. The energy storing device Hydrogen generative Aqua Electrolizer (HAE) with fuel cell can efficiently damp out the 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 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 are obtained. The comparison of frequency deviations and tie-line power deviations of the two area interconnected thermal power system with HAE designed with BWNN Controller are found to be superior than that of output response obtained using PI Controller.

Keywords:

Load Frequency Control, Integral Square Error Criterion, Control Performance Standard (CPS), Hydrogen Generative Aqua Electrolyzer, Fuel Cell, Beta Wavelet Neural Network

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1. INTRODUCTION

Load-Frequency Control (LFC) is a very essential control stratergy in electric power system design to ensure reliable operation. It is well known that the main objectives of LFC 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 the permissible limit [1-3]. Designing load frequency controllers has received great attention of researchers in recent years and many control strategies have been developed. The Proportional plus Integral controller was one of control strategy, which is still widely used now a day 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 [4-7]. 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 also 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 Hydrogen generative Aqua Electrolyzer with Fuel cell in the interconnected power system is to enhance a quality and reliable power supply. The Hydrogen generative Aqua Electrolyzer (HAE) with Fuel cell is found to be superior over the other energy storing devices because of its easy operability. The renewable energy resources with different energy storage systems can resolve natural gas or water into hydrogen and oxygen using aqua electrolyzers (HAE). The generated hydrogen can then be compressed, stored, and transported to the FC through pipelines [15]. HAE had found to exhibit a fast active response to resume the system to normal in a faster manner when experience with disturbances. It is easy to increase the capacity and free from degradation due to fast charging and discharging action [15-16].

2. TWO-AREA INTERCONNECTED REHEAT POWER SYSTEM WITH HAE UNITS

2.1. Problem formulation

The system state space representation of a two-area interconnected power system can be expressed as

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

$$Y = Cx \quad (2.2)$$

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

System Control input vector $u = \begin{bmatrix} u_1 \\ u_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{c1} \\ \Delta P_{c2} \end{bmatrix}$ (2.3)

Disturbance vector $d = \begin{bmatrix} d_1 \\ d_2 \end{bmatrix} = \begin{bmatrix} \Delta P_{D1} \\ \Delta P_{D2} \end{bmatrix}$ (2.4)

Where,

Augmented System matrix $\overline{A} = \begin{bmatrix} 0 & C \\ 0 & A \end{bmatrix}$ (2.5)

Augmented Control input matrix $\overline{B} = \begin{bmatrix} 0 & B \end{bmatrix}$ (2.6)

Augmented Disturbance matrix $\overline{\Gamma} = \begin{bmatrix} 0 & \Gamma \end{bmatrix}$ (2.7)

Augmented Output matrix $\overline{C} = \begin{bmatrix} 0 & C \end{bmatrix}$ (2.8)

Two state vectors $\int ACE_1$ and $\int ACE_2$ are included in the augmented state matrix and eleven state variables are presented in this augmented form.

$$\int ACE = \int_0^\infty [(\beta_1 \Delta F_1)^2 + (\beta_2 \Delta F_2)^2 + (\Delta Ptie_{1,2})^2]dt \quad (2.9)$$

Substituting the equation we get,

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$$\begin{bmatrix}\bar{Y}\\ \dot{\bar{X}}\end{bmatrix} = \begin{bmatrix}0 & C\\ 0 & A\end{bmatrix}\begin{bmatrix}\int ACE.dt\\ \bar{X}\end{bmatrix} + \begin{bmatrix}0\\ B\end{bmatrix}U \qquad (2.10)$$

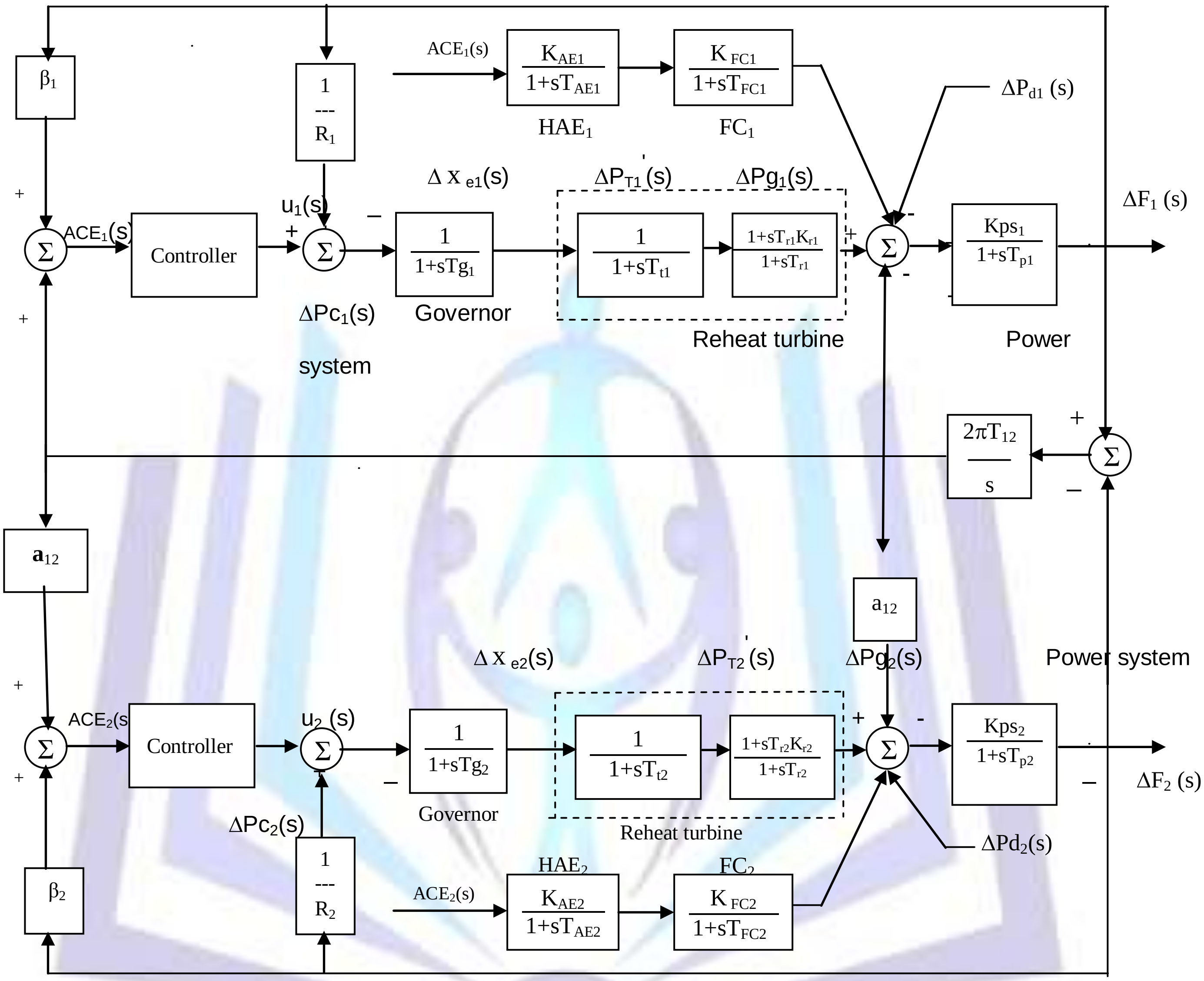


Fig-1 Block diagram of a Two – Area Interconnected power system with Hydrogen Generative Aqua Eectrolyser (HAE) and Fuel Cell

2.2. 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 or cost function (J) of the optimization of the performance of the system [16] is given in equation (2.11).

$$J = \int_0^{\infty} [(\beta_1 \Delta F_1)^2 + (\beta_2 \Delta F_2)^2 + (\Delta Ptie_{1,2})^2]dt \qquad (2.11)$$

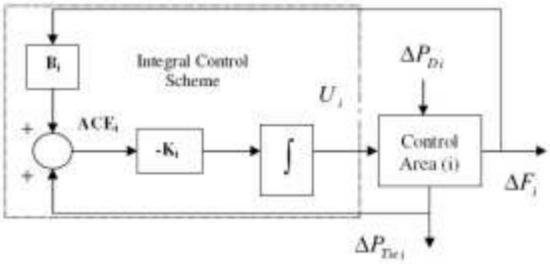


Fig.2. Conventional PI control scheme on i[th] area

3. HYDROGEN ENERGY STORAGE.

Hydrogen is one of the promising alternatives that can be used as an energy carrier. The universality of hydrogen implies that it can replace other fuels for stationary generating units for power generation in various industries. Having all the advantages of fossil fuels, hydrogen is free of harmful emissions when used with dosed amount of oxygen, thus reducing the green house effect [15]. Essential elements of a hydrogen energy storage system comprise an electrolyzer unit which converts electrical energy input into hydrogen by decomposing water molecules, the hydrogen storage system itself and a hydrogen energy conversion system which converts the stored chemical energy in the hydrogen back to electrical energy in Fig 3. The major application of the stored hydrogen is the electricity production by help of fuel cells. Water to hydrogen conversion efficiency is averaged at 65 % and fuel cell conversion efficiency is 65 – 70 % which ends up to 20 – 40 % overall system efficiency [16]. It must be kept in mind that in terms of storage, hydrogen is not used as a fuel, but as an energy carrier in a wider sense. The energy exchange process of the Hydrogen generated Aqua Electrolyzer based storage is shown in the fig 3.

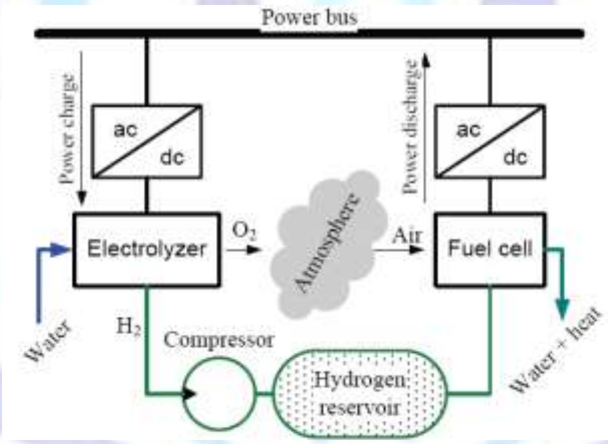


Fig.3. Energy exchange processes of the hydrogen based energy Storage

3.1 Aqua-electrolyzer for production of hydrogen

Aqua-electrolyzer, 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]. The Transfer Function of the Aqua Electrolyser can be expressed as

$$G_{AE}(S) = \frac{K_{AE}}{1 + sT_{AE}} \quad (3.1)$$

3.2 Fuel-Cell (FC) power generation

Fuel cells are static energy conversion device which converts the chemical energy of fuel (hydrogen) directly into electrical energy. They are considered to be an important resource in distributed power system due to the advantages like high efficiency, low pollution etc. The Transfer Function of FC can be given by a simple linear equation as

$$G_{FC}(S) = \frac{K_{FC}}{1 + sT_{FC}} \quad (3.2)$$

4.0 CONTROLLER DESIGN CRITERIAN

4.1 Control Performance Standards (CPS)

CPS_1 assesses the impact of ACE on frequency over a certain period window or horizon and it is defined as follows: over a sliding period, the average of the "clock-minute averages" of a control area's ACE divided by "10 times its area frequency bias" times the corresponding "clock-minute averages of the interconnection of frequency error" shall be less than the square of a given constant, E_1, representing a target frequency bound. These strategies lead to the conclusion that ACE should satisfy a decreasing function of T.

$$RMS\ \{AVG_T\ \{ACE\}\} = \varphi\ (T) \quad (4.0)$$

Where φ (T) is the root-mean-square (RMS) of all the T minute average ACE values over the past 12 months. It is shown in [5] that if ACE were a random signal, φ (T) would be proportional to 1/T. Of course ACE itself cannot be made to meet this condition because its next data cycle value is far more likely to be close to the present value than to be random. However, a good control algorithm can make AVG_T {ACE} nearly random for T >TC. Moreover, this can be accomplished with far less generation maneuvering than that of many present AGC schemes.

4.1.1 CPS2

Since the equation CPS_1 = 100(2-AVG {CF1}) allows areas to benefit from a large \ACE\ when ACE x ΔF is negative, a second performance standard, CPS_2, is applied to ten minute average ACE. This standard is derived from an interconnection objective:

$$RMS\ \{\Delta F_{10}\} \le E_{10} \quad (4.1)$$

Where ΔF_{10} is the ten minute average of F, and 10 is a target bound for the 12 month RMS often minute average interconnection frequency error. This standard is similar to the Ai criterion, but with a technically defensible L_d like A2, it is a rolling 12 month condition to be met 90% of the time. The CPS_2 standard is based on the dimensionless compliance factor:

$$CF_2=1/L_{10*}|ACE_{10}| \quad (4.2)$$

Where L_{10} is the 10 minute average

$$L_{10} = 1.65\ E_{10} \quad (4.3)$$

The number L_{10} is the area's average B over the ten minute interval reassessment! The multiplier 1.65 is the statistical conversion factor from a 68.3% confidence limit (1 standard deviation) to a 90% confidence limit. The parameter v relates the size of the area to that of the interconnection.

A derivation of v based on fair considerations for electric interconnection is given in (2.10). If all areas use constant B, then v = B/B_3. Thus, if all B values are constant, it is simplifies to:

$$L_{10}=1.65E_{10}\sqrt{\ (-10B_i)*(-10B_i)} \quad (4.4)$$

For most areas, L_{10} values given by (4.4), using NERC's recommended 10 target for each of the NERC Interconnections, are larger than those used in the A2 criterion. They are much larger for many areas, these limits as well as all other control area parameters related to CPS_1 and CPS_2.
To measure compliance with CPS_2, one first computes the ratio of ten minute interval counts:

$$CPS_2=100(1-R) \quad (4.5)$$

The interval counts in 6 per hour are over one month for reporting purposes, and over rolling twelve month durations for compliance measure. An area fails compliance if CPS_2 is less than 90%. It should be noted that CPS_2 is insensitive to ACE non-randomness or its coincidence with other ACEs. Hence, the chosen L_{10} values are appropriate only if the coincidence among ACEs does not significantly increase.

5. BETA WAVELET NEURAL NETWORK CONTROLLER (BWNN)

The structure of a four layer Beta wavelet neural network (BWNN) controller [13,14] is shown in Fig 4.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 means, 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,

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

(5.0)

where, $x_c = \frac{px_1 + qx_0}{p+q}$ (5.1)

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:

$$\Psi_n(x) = \frac{d^{n+1}\beta(x)}{dx^{n+1}}$$ (5.2)

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

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

$$+ \quad \frac{(n-i)!q}{(x_1-x)^{n+1-i}}]P_1(x)\beta(x)$$

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.

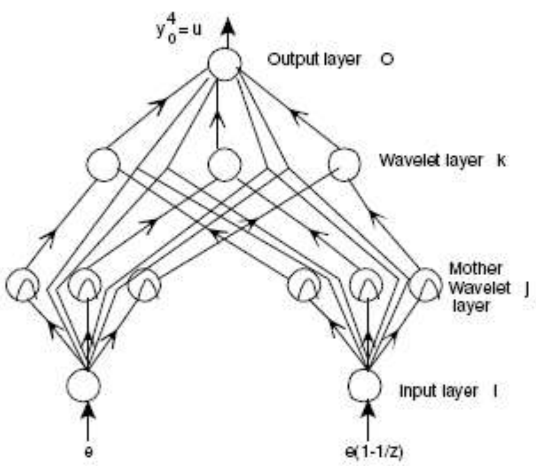


Fig 4. Four layer Beta Wavelet Neural Network structure

4. SIMULATION RESULTS AND OBSERVATIONS

The Proportional plus Integral controllers are designed and implemented in the two area interconnected power system with HAE unit using CPS criterion also Beta Wavelet Neural Network based controllers are designed and implemented in the interconnected reheat power system scenario is also applied. The simulation studies of the two-area interconnected thermal power system were performed with the PI controller and BWNN Controller for a step load disturbance of (0.01pu MW and 0.05 pu MW) in area-1 and the corresponding frequency deviations and tie-line power deviations are plotted for easy comparison and are presented in figures 5 to 10. It is observed from the output responses that, the HAE with Beta Wavelet Neural Network Controller when incorporated with two area interconnected power system has not only improved the transient response of the system but also has reduced the settling time.

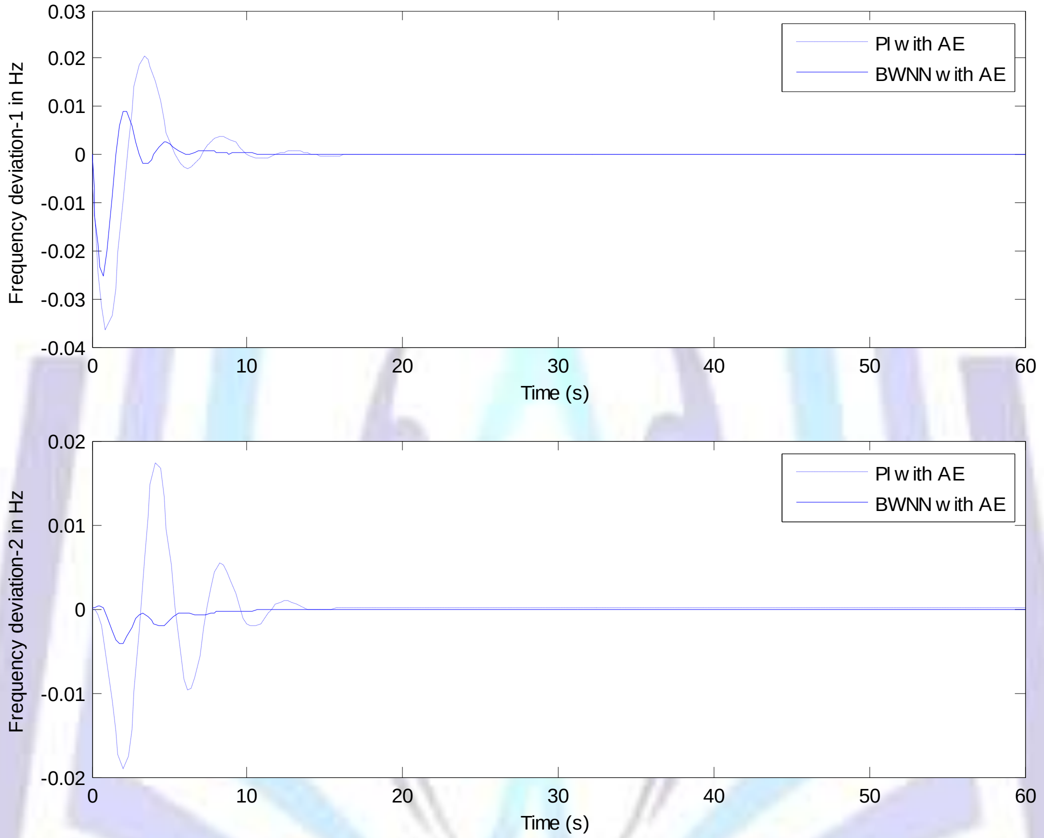
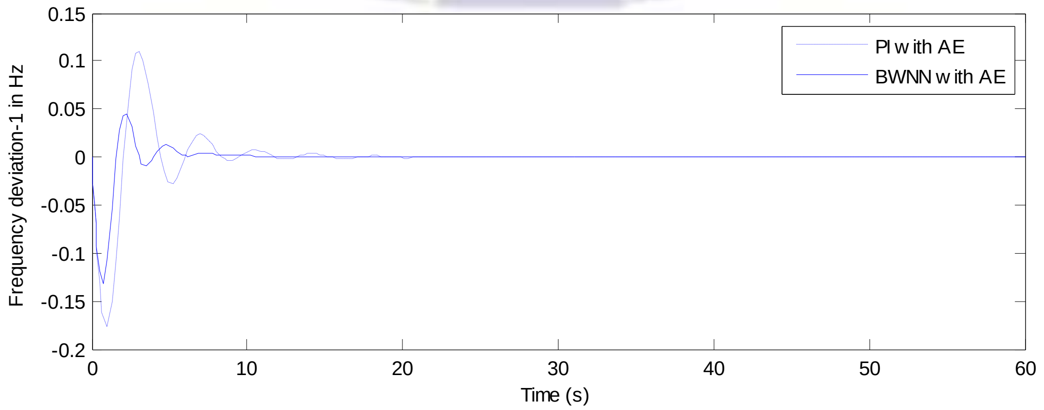


Fig5: Frequency Deviations of area 1 and area 2 in a two area interconnected thermal reheat power system considering AE with PI Controller and BWNN Controller for 1% step load disturbance in area 1



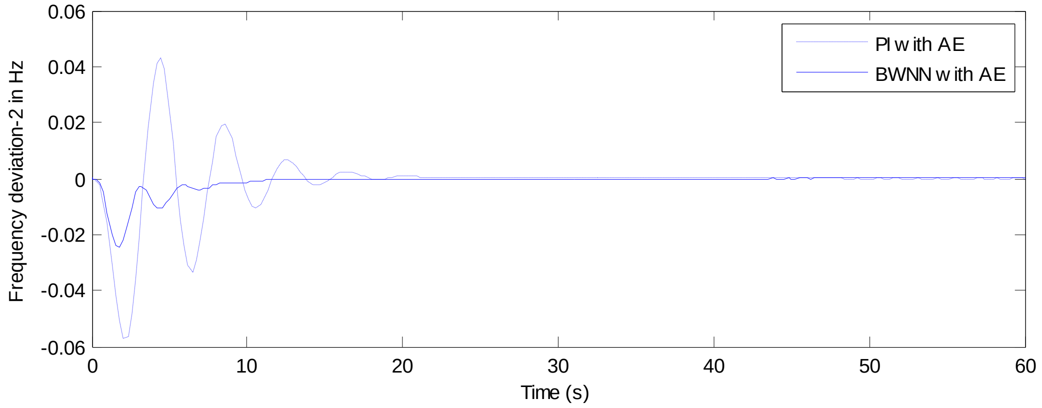


Fig6: Frequency Deviations of area 1 and area 2 in a two area interconnected thermal reheat power system considering AE with PI Controller and BWNN Controller for 5% step load disturbance in area 1

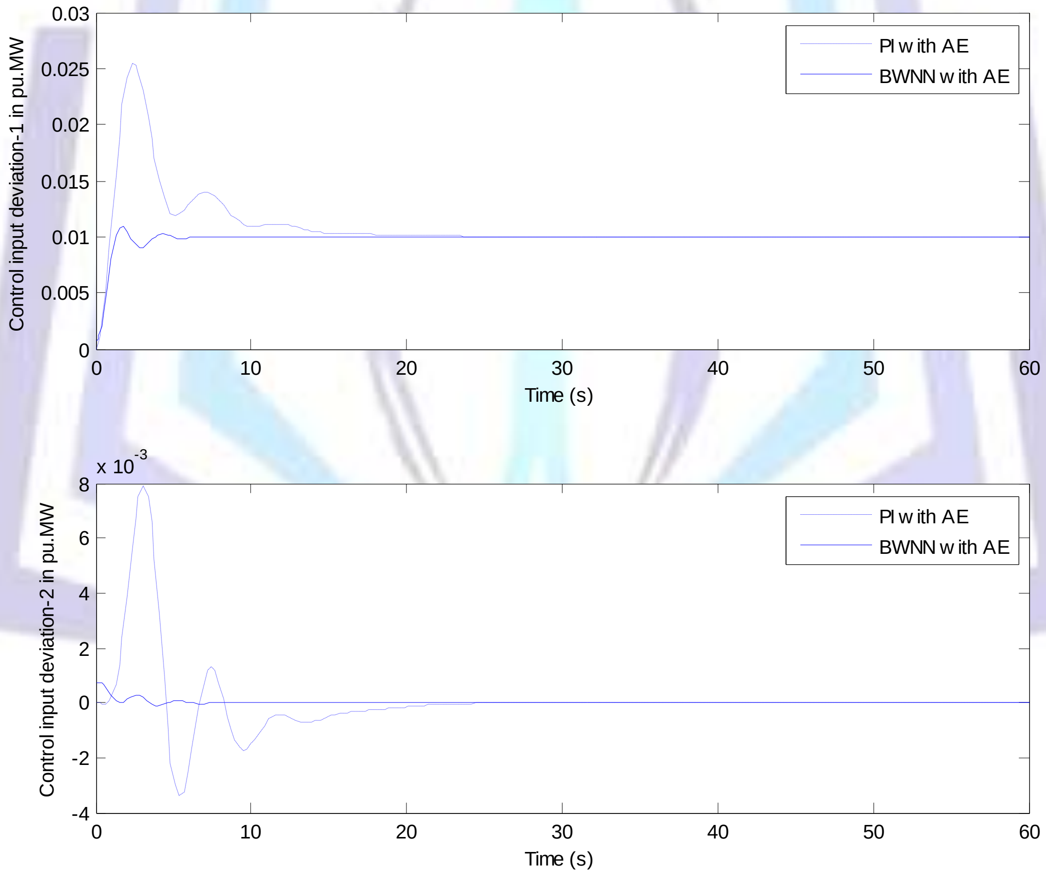


Fig7: Control input deviations of area 1 and area 2 in a two area interconnected thermal reheat power system considering AE with PI Controller and BWNN Controller for 1% step load disturbance in area 1

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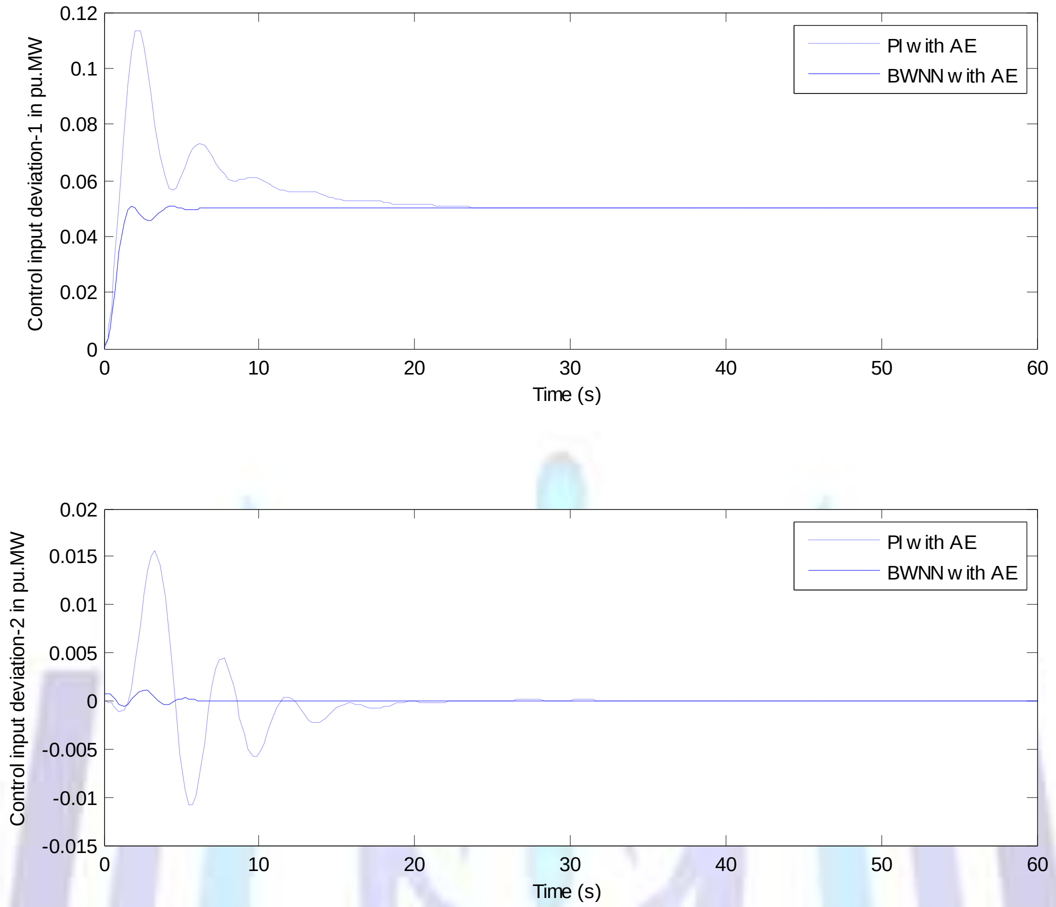

Fig8: Control input deviations of area 1 and area 2 in a two area interconnected thermal reheat power system considering AE with PI Controller and BWNN Controller for 5% step load disturbance in area 1

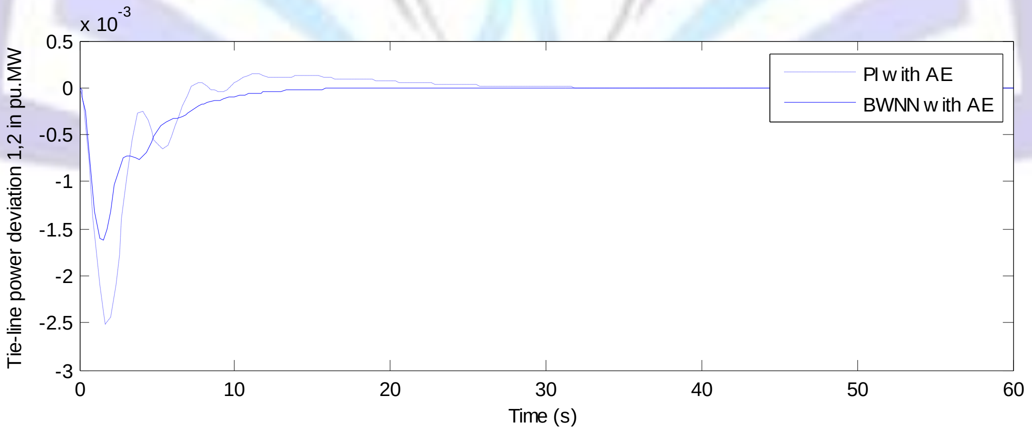

Fig 9: Tie-line power deviations in a two area interconnected thermal reheat power system considering AE with PI Controller and BWNN Controller with AE for 1% step load disturbance in area 1

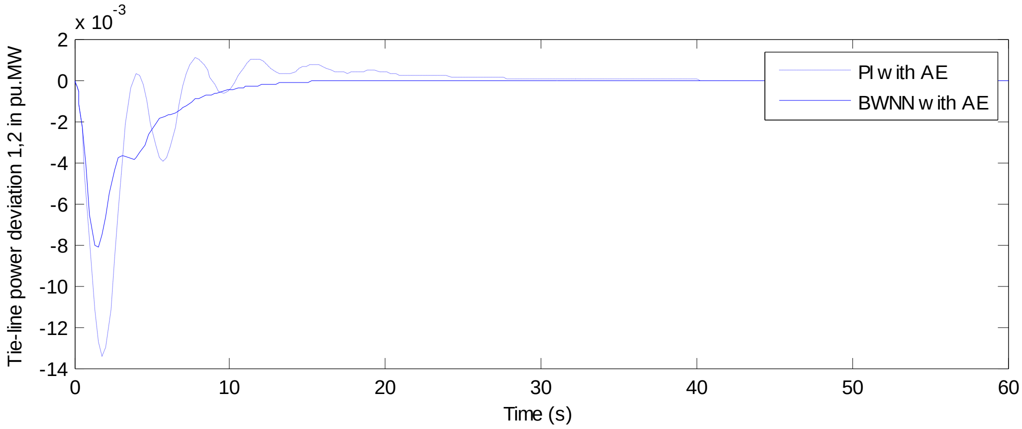

Fig 10: Tie-line power deviations in a two area interconnected thermal reheat power system considering AE with PI Controller and BWNN Controller for 5% step load disturbance in area 1

5. CONCLUSIONS

Two types of Load-Frequency Controllers for a two area interconnected power system with Hydrogen generative Aqua Electrolyser (HAE) were designed using Control Performance Standards (CPS) criterion. The first type of controller is Proportional plus Integral (PI) Controller and the second one is the Beta Wavelet Neural Network (BWNN) Controller. The PI and BWNN Controllers are designed using Integral Square Error (ISE) Criterion. The proposed BWNN controller is implemented in a two area interconnected power system ensures an improved transient response of the system than that of the response obtained with PI Controller.

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References

[1] 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.

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

[3] O.P.Malik, A.Kumar, G.S.Hope. “A load frequency control algorithm based on a generalized approach”. IEEE Transaction on Power System, Vol.3 (2), pp.375–82, 1988.

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

[5] 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.

[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), Nagerkovil, pp 200-205, 2011.

[8] M.J.Yao, R.R.Shoults and R.Kelm , “AGC Logic Based on NERC’s New Control Performance Standard and Disturbance Control Standard,” *IEEE Trans. on Power Systems*,, 2000, Vol. 15, no. 2, pp. 852–857.

[9] George Gross, Jeong Woo Lee, “Analysis of Load Frequency Control Performance Assessment Criteria”, IEEE Transactions on Power Systems, Vol.16, No. 3, pp. 520-525, 2001.

[10] M.Thuillard, “A review of wavelet networks, wavenets, fuzzy wavenets and their applications”, Conference - ESIT 2000 Aachen, Germany, pp 5–16, 2000.

[11] C. Aouiti, M.A Alimi, 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.

[12] Wajdi Bellil, Chokri Ben Amar, 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.

[13]Ben Amar, M. Zaied, 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.

[14] P. F. Ribeiro, B. K. Johnson, M. L. Crow, A. Arsoy, Y. Liu, “Energy storage systems for advanced power applications,” Proceedings of IEEE,Vol. 89, no. 12, pp. 1744–1756, Dec. 2001.

[15] S.Yu, T. J Mays, R. W. Dunn. **“**A New Methodology for Designing Hydrogen Energy Storage in Wind Power Systems to Balance Generation and Demand // Proceedings of the IEEE, 2009.

[16] M. Little, M. Thomson, I. Infield, “Electrical integration of renewable energy into stand-alone power supplies incorporating hydrogen storage, *International Journal of Hydrogen Energy*,Vol.32,no.10-11, pp.1582-1588, 2007.

Appendix-1

Data for the interconnected two area thermal power system [4],[15].

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Rating of each area=2000 MW
Base power=2000 MVA
f = 60 Hz
R_1=R_2= 2.4 Hz/p.u 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/p.u MW
B_1 =B_2= 0.425 p.u MW/Hz
T_{12} = 0.545 MW/Hz
ΔP_{d1}=0.01p.u MW/HZ
a_{12} = -1
K_{AE}=0.002
Td_{AE} = 0.5 sec
K_{FC}=0.01
$T_{FC=}$ 4 sec

Appendix-2

List of symbols:

f Frequency
K_{ps} Power system gain
K_r Reheat thermal power system gains
K_P Proportional gain
K_I Integral gain
T_r Reheat time constants
T_t Time constant of turbine
T_{AE} Time constant of AE
X_e Governor Valve position
T_g Time constant of governor
P_g Turbine output power
R Regulation parameter
T_{ij} Synchronizing power coefficient
a_{ij} Operator
T_p Power system time constant
P_{ref} The output of ACE
Δf_i Frequency deviation of area i (i = 1, 2)
ΔXE_i Governor Valve position deviation of area I (i = 1, 2)
ΔPtie 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
HAE Hydrogen generative Aqua Electrolyser
AE Aqua Electrolyser
FC Fuel Cell
BWNN Beta Wavelet Neural Network

Biographies

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