ONLINE TUNING OF GENETIC BASED PID CONTROLLER IN LFC SYSTEMS USING RBF NEURAL NETWORK AND VSTLF TECHNIQUE

*Mohammad Monfared, Abbas Molavi Daryani, Mehrdad Abedi**

Abstract: In this paper, a novel control strategy for the load frequency control (LFC) system is proposed. The developed method includes a genetic algorithm (GA) based self-tuned PID controller for online application. The new method is presented in order to regulate PID controller coefficients by a radial basis function neural network (RBFN). Furthermore, a very short time load forecasting (VSTLF) scheme is also employed as a novel approach for the system load variations to be considered in the LFC system. For validation of the proposed method, several comparative case studies are presented. The simulation results indicate that the proposed strategy improves the system dynamics remarkably.

Key words: *Load frequency control (LFC), real coded genetic algorithm (RCGA), radial basis function neural network (RBFN), very short time load forecasting (VSTLF)*

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1. Introduction

Load Frequency Control (LFC) systems ensure the balance between the generation and load in order to maintain the desired nominal frequency and tie-line power exchanges in interconnected power systems. Presently, most LFC systems are equipped with fixed gain integral controllers. The most common and fundamental method for designing such a controller is based on a trial and error procedure in order to improve the transient and dynamic response of the frequency and interchanged power [1–3]. However, in the past years, with the aid of precise and standard models available for generation units, power networks and two well known indices such as ISE (Integral of the Square Error) and ITAE (Integral of

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Time multiplied Absolute value of Error), the desired parameters of integral controllers could be specified more accurately and efficiently. These indices can be defined as [1, 4], and [5]: $ISE = \int_0^\infty E(t)^2\, dt$,$ITAE = \int_0^\infty t\,|E(t)|\, dt$, where $E(t)$ is the area control error (ACE) of LFC system. In current industrial applications, fixed gain integral controllers are mostly used. They are designed for a nominal operating condition and may fail to operate appropriately during abnormal situations [3, 6]. Furthermore, due to the non-linearity of power systems and unpredictability of load variations, the operating point varies remarkably. Thus, to provide an appropriate and efficient controller for the LFC system, several efforts have been made, including its designing State feedback and adaptive optimal control strategy is reported in [7–10]. In [11, 12] the variable structure control strategy is presented, while the robust controller is also introduced in [13, 14]. These controllers require the full data related to the system states, whose measurement or estimation is not simple or might be impossible. Uncertainty and parameter variations decrease the reliability of the above-mentioned methods. In addition, intelligent techniques such as artificial neural network (ANN), fuzzy and genetic algorithm (GA) can be seen in [15–21]. In these reports, authors tried to ensure the insensitivity of the controller to the system parameters and the variations of the operating point with respect to the nominal condition. The neural networks ability to deal with inherent uncertainty of power system and their learning feature as well as their fast response provide a useful implementation of ANNs to the LFC systems [14–17]. However, the main drawbacks of commonly used multi-layer perceptron ANN based controllers can be classified as:

a) the large size of the network,

b) remarkable long learning time,

c) requirement of a large number of parameters and input data, mostly dependent on inaccessible states.

This paper presents a genetic algorithm based self-tuned PID controller for the LFC system in a multi-area interconnected power system. *In fact, in the proposed control scheme, PID coefficients are not constants and an ANN is used for online tuning of PID coefficients, which ensures optimum performance under different disturbances and operating conditions. The PID controller parameters are optimized offline by GA at all possible operating conditions. Then this input-output data pairs generated by the GA are used to train the ANN, which is also performed in the offline situation. In this work, a newly implemented ANN named RBFN (Radial Basis Function Network) is used to regulate the PID coefficients online.* The application of RBFN reduces the size of ANN as well as the long learning time. To overcome the third problem, we used a scheme called VSTLF, which had not previously been used in the LFC application; it was only recently employed for very short time load forecasting [22–24]. In the present report, VSTLF associated with RBFN is used to overcome the disadvantages of the conventional multi-layer perceptron applied to PID control in the LFC systems. In fact, this approach, which has not been seen previously in the LFC systems, is the main objective of this paper. *As mentioned before,* GA is used to obtain the optimum values for the

PID controller for all possible operating conditions and power system load variations in order to provide an input data pair for the RBFN training process in the offline condition. In this paper, we also present a newly proposed performance index, whose minimum value ensures zero steady-state error, minimum overshoot and minimum settling time related to the dynamic response of the LFC system. Thus, the trained RBFN associated with the VSTLF scheme can be used for online application and automatic tuning of the proposed PID controller. The efficiency of the proposed controller is verified by simulation of a two-area power system.

2. Power System Model

In this paper, two similar interconnected power networks including steam turbines and reheats are employed to apply the proposed method and simulation studies. Two-area sample system has been used only for approving the performance of the suggested method, while the same approach can be implemented accurately and efficiently for the multi-area power system connected via tie-lines [25]. Fig. 1 depicts the block diagram of the employed two-area power system, whose *variables and* parameters are given in *Appendices 1 and 2*. It can be seen that non-linear factors, such as generator power rate constraint (GRC) and governor dead-band, have been included. These non-linearities increase the overshoot and settling time of the system response due to disturbances. In [12] it is shown that the elimination of these non-linearities in the controller design process may cause the system to become unstable in real life applications. *In the block diagram of Fig. 1,* ΔP_{D1}, *and* ΔP_{D2} *are load changes in areas 1 and 2, and* $\Delta f_1, \Delta f_2$, *and* ΔP_{12} *are variations in the frequency in areas 1 and 2 and variations in the tie-line power from their desired values, respectively. The goal of control system is to damp these variations to zero as fast and smooth as possible, following a change in* ΔP_{D1}, *and* ΔP_{D2} *values.* ΔP_{Ci} *is the controller output and is applied to the governor of each generator to provide a closed loop control system.*

3. Proposed Control Scheme

Similarly to the most currently utilized methods, the input of the proposed controller for each area, according to Eq. 1, is ACE (Area Control Error), *the parameters of which are defined in Appendix 1* [1].

$$ACE_i = \Delta P_{ij} + B_i \Delta f_i \quad i = 1,2 \tag{1}$$

$$B_i = D_i + \frac{1}{R_i} \quad i = 1,2 \tag{2}$$

Fig. 2 shows the structure of the proposed controller, whose input is ACE_i and the output is ΔP_{Ci} ; which can be applied to the governor of each generator. ACE is defined by Eq. (1), and K_P, K_I and K_D are PID controller parameters.

Current controllers are generally based on constant gain integrators. Although the PID controllers require a more complex procedure to be designed, they can improve the transient response compared to the simple integral controllers [19].

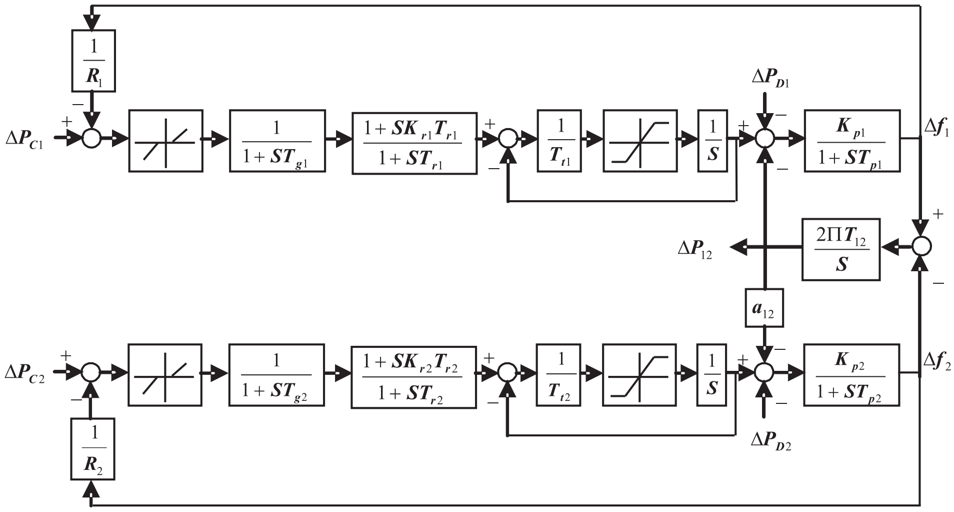

Fig. 1 *The sample two-area power system block diagram.*

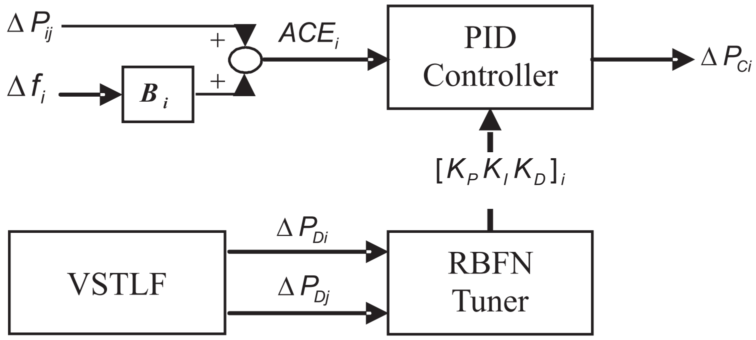

Fig. 2 *The proposed controller block diagram.*

The input-output data pairs required for the offline training of the RBFN used in the proposed controller, shown in Fig. 2, can be obtained by simulation of the studied system (i.e. Fig. 1) under all possible operating conditions and load variations using Matlab/Simulink software. At each operating point, GA is used to obtain the optimal PID controller constants. The recent procedure is shown in Fig. 3.

Using GA, an appropriate performance index (J) whose minimum value ensures zero steady-state error, minimum overshoot and minimum settling time has been developed. *This step is performed offline, and in each operating condition, the GA is used to optimize the PID controller parameters in order to minimize the performance index. Hereby, optimum values for* K_P, K_I*, and* K_D *coefficients for any possible* ΔP_{Di} *will be obtained. This procedure is shown in Fig. 3 and will*

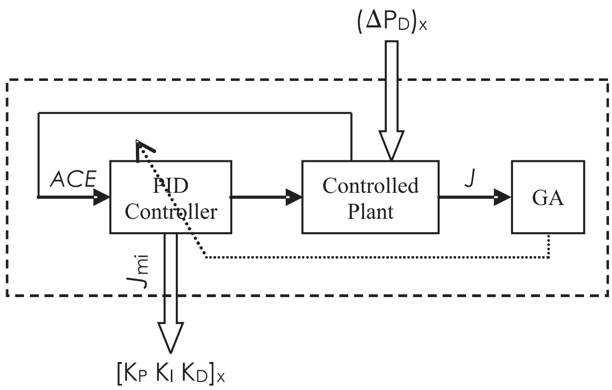

Fig. 3 *The offline application of GA in order to obtain the optimum PID constants.*

be discussed later clearly. The obtained data pairs are used to train the RBFN. After the RBFN training procedure, they can be used for online tuning of the PID controller. As seen before, the input data for the offline training of RBFN are power system load variations. These input data can be provided in the online operation by several techniques developed with high accuracy, called very short-time load forecasting (VSTLF). It is also possible to measure the load on each bus directly. So in the following subsections, the VSTLF techniques as well as GA and RBFN are briefly described.

A. VSTLF

Many techniques have been developed for precise load forecasting for the next minutes as well as next few days. These methods are called short-time load forecasting. One of the most recent and advanced group of these techniques is called VSTLF (very short-time load forecasting) or RTLF (real-time load forecasting), and it is able to estimate the network load variations in the next or several minutes precisely. There are many successful efforts in the field of VSTLF, reported in [22, 23], and [24]. In [23] VSTLF is suggested for the LFC system, however, the full application of this method in the real LFC system has not been discussed. In this paper, VSTLF has been employed for practical applications in the LFC system, which has not been reported yet.

B. GA (Genetic Algorithm)

For the past 25 years, GA has been employed in optimization problems extensively. GA is an effective algorithm which provides reasonable results even if it has not been used appropriately. Although GA is based on a stochastic procedure, it has been proved to be a robust method, providing universal optimums [26]. GA includes reproduction, crossover and mutation operators. The reproduction operator creates a new generation of population by selecting the most fitted individuals in the current population. Crossover is the most dominant operator in GA, in which new offspring are produced by selecting two strings and exchanging some portions of their structures. The mutation operator alters the value of a random position in a string.

Real Coded Genetic Algorithm (RCGA)

GA is classified into two main categories: binary genetic algorithm (BGA) and real coded genetic algorithm (RCGA), which is often referred to as a continuous parameter genetic algorithm. In specific problems including continuous search space, the binary representation causes large dimensions [26, 27]. Furthermore, since the BGA precision is limited by the binary representation of the values, using real numbers will easily provide the required system precision. In addition, RCGA can be easily implemented in Matlab/Simulink [27].

Computational process of the Genetic Algorithm

RCGA algorithm for obtaining the optimal PID constants can be presented as follows:

1. The first generation is formed randomly.
2. The performance index is computed by simulation in Matlab/Simulink (Eq. 3).

$$\begin{array}{l} J = \int_0^T t\,(|\Delta P_{tie}| + B_1\,|\Delta f_1| + B_2\,|\Delta f_2|)dt \\ B_i = D_i + \frac{1}{R_i} \end{array} \qquad (3)$$

   With this definition for J, its minimum value ensures the minimum overshoot and minimum settling time for frequency and tie-line power fluctuations. The steady-state error is also always zero.

3. A new generation is formed using reproduction, crossover, and mutation operators.
4. Performance index is computed for the members of new generation.
5. If the population converges or the number of generations reaches a certain limit, the search will stop, otherwise we will go to step 3.

Fig. 4 shows the flowchart of this process. The GA is executed for 100 generations, and the population size has been chosen to be 50. The probabilities of crossover and mutation have been selected as scattered and Gaussian functions, respectively. Fig. 3 shows how the GA is used offline in order to obtain the optimum PID constants.

C. RBFN (Radial Basis Function Network)

In spite of most of the sophisticated controllers presented so far for the LFC system, the neural network is very fast due to its parallel processing nature; thus it can be implemented in real-time applications. Like most other feed-forward networks, RBFN also has three layers called input, hidden and output layers. Fig. 5 shows a

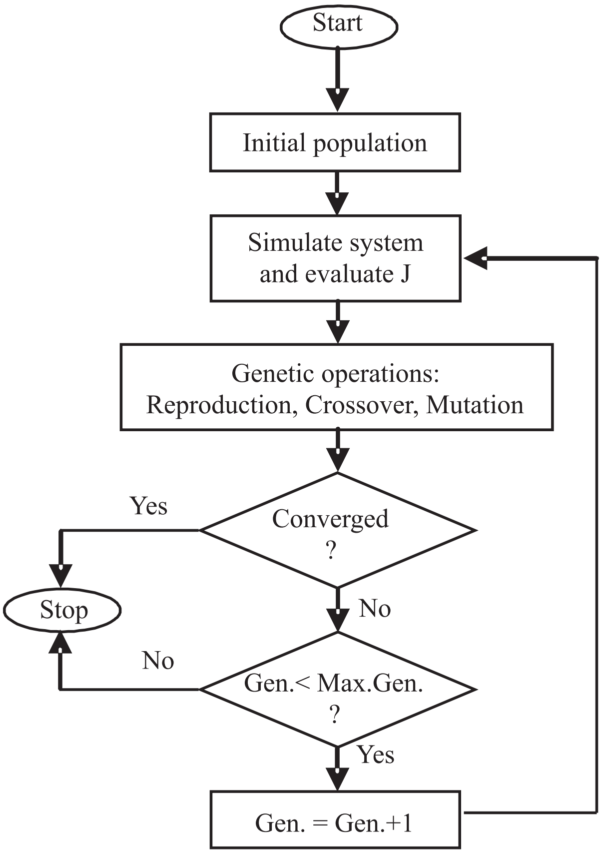

Fig. 4 *GA computational flowchart.*

schematic diagram of the employed RBFN, which has two inputs and three outputs. The hidden layer nodes are RBF units. Each node in this layer has a parameter vector called a center. Each node computes the Euclidean distance between the center and the input vector and passes the result through a nonlinear function (.). The output layer is a set of linear combiners. Generally, for a RFBN, which has n inputs and m outputs, the output y_i due to input vector $x, [x_1 \ldots x_n]^T$ is computed as:

$$y_i = \theta_{0i} + \sum_{j=1}^{M} \theta_{ji} \Phi \left(\|x - c_j\| , \sigma_j \right). \quad (4)$$

M is the number of hidden units and c_j and σ_j are the center and the width of the jth hidden unit. θ_{ji} is the weight between jth hidden unit and ith output unit; and θ_{0i} is the bias term related to the ith output unit. As seen in Eq. 5, in this work, the Gaussian activation function is used for (.); and also the orthogonal least square method has been employed for a training purpose.

$$\Phi \left(z, \sigma \right) = \exp \left(-z^2 / 2\sigma^2 \right). \quad (5)$$

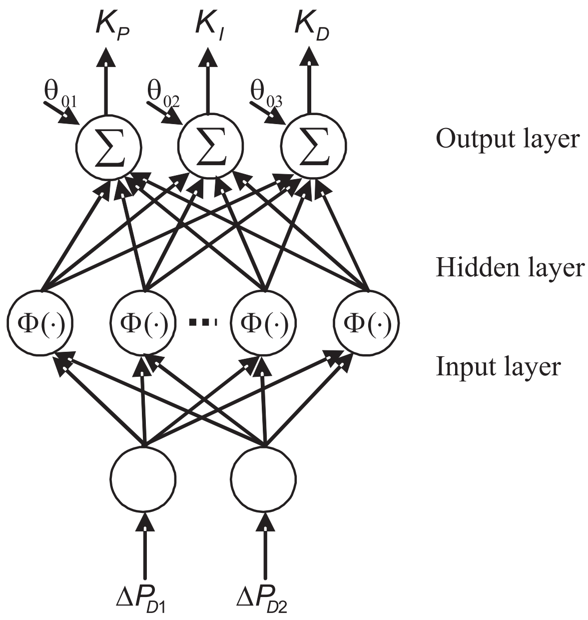

Fig. 5 *The schematic diagram of the used RBFN.*

4. Simulation Results

As shown in Fig. 1, the employed sample system for simulation studies includes reheat turbines and generator power rate constraint (GRC), which is more realistically compared to the linear model for a non-reheat turbine. The GRC value is assumed to be 0.2 p.u./min for each generation unit [21]. Moreover, another non-linearity effect such as turbine governor dead-band, which is assumed to be 0.06% for each area [21], is included for simulation purposes. For comparative studies, we also used a conventional fixed gain integral controller (i.e. K_I/s, $K_I = 0.125$) for each area. K_I is determined by a commonly used method employing ITAE criteria. Tab. I summarizes three case studies under our investigation. Figs. 6 to 8 illustrate the dynamic responses related to the sample power system using the fixed gain integral controller as well as the proposed controller employed for each area for all cases mentioned in Tab. I. According to cases 1 and 2, Figs. 6 and 7 show that the system equipped with the proposed controller provides remarkable performance compared to the conventional fixed gain integral controller. It is clear that the system, using the proposed controller, experiences fewer oscillations with smaller peaks, which vanish more rapidly; and also, *in both the cases, the settling time is reduced drastically. Although, with both controllers, steady-state errors are in acceptable limits, the proposed controller provides a better steady-state performance.* Fig. 8 shows that the variation of load in the both areas (case 3) is the worst case, in which the fixed gain integral controller is not capable to maintain the frequency in acceptable limits and the system is completely unstable. However, it can be seen that *in such a sever condition,* the proposed controller maintains the stability with remarkable dynamic behavior. *Fig. 8 also shows that with the proposed controller, the frequency and tie-line power deviations are driven to zero successfully in a very short time, while with the fixed gain integral controller, the control variables deviations cannot be driven back to zero at all. This study shows that the proposed controller is not only fast and accurate, but also robust.* In addition, for more validation we use ITAE criteria for both the fixed gain integral and proposed controllers in all cases given in Tab. I. The results of these comparative studies are summarized in Tab. II; we can see that the proposed controller acts remarkably.

case 3	case 2	case 1	step load change
1%	3%	1%	ΔP_{D1}
3%	0	0	ΔP_{D2}

Tab. I *Summary of case studies.*

case 3	case 2	case 1	controller type
unstable	21.13	1.067	fixed gain integral controller
9.279	3.775	0.1898	proposed controller

Tab. II *The comparison of ITAE value for three case studies.*

5. Conclusions

In this paper, a genetic algorithm based self-tuned PID controller for the LFC system, whose coefficients are regulated online by a newly implemented artificial neural network, RBFN, is proposed. In this novel approach, the VSTLF technique is employed for very short time load forecasting. The efficiency of the proposed controller is verified by simulation studies of two-area interconnected power system in three different scenarios. In comparison with the conventional fixed gain integral controller, the major advantages of proposed strategy can be classified as:

1. The input signal of the proposed controller is the same as that of the conventional controller (i.e. ACE), while the output can be applied to the governor.
2. VSTLF provides more accurate load forecasting and eliminates the measurement and estimation of system states. Therefore, the VSTLF scheme simplifies the design and implementation of the proposed controller for the LFC system. Also the stability and optimal control in a wide range of load variations could be achieved.
3. The learning feature of RBFN and the ability of GA to find the optimal values of coefficients in the proposed controller in all possible operating points with inherent uncertainty of system states provide a more flexible and robust controller.

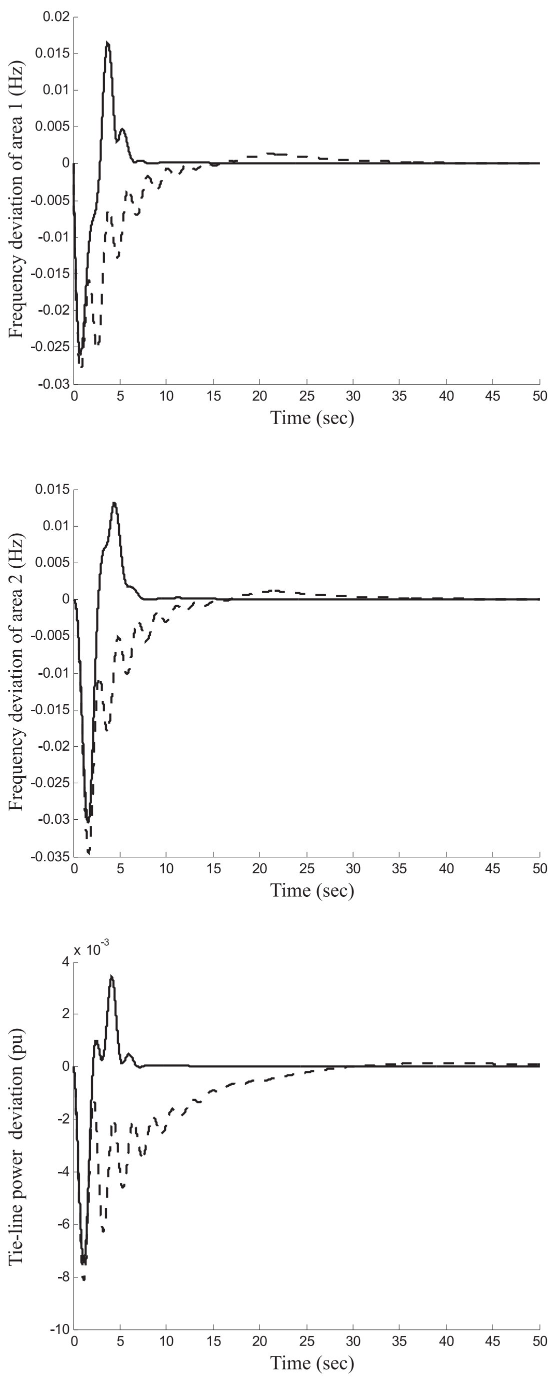

Fig. 6 *Dynamic responses for two different control strategies for case 1:* $\Delta P_{D1} =$ 1%, ΔP_{D2}= 0. *Fixed gain integral controller (- - -); Proposed controller (—).*

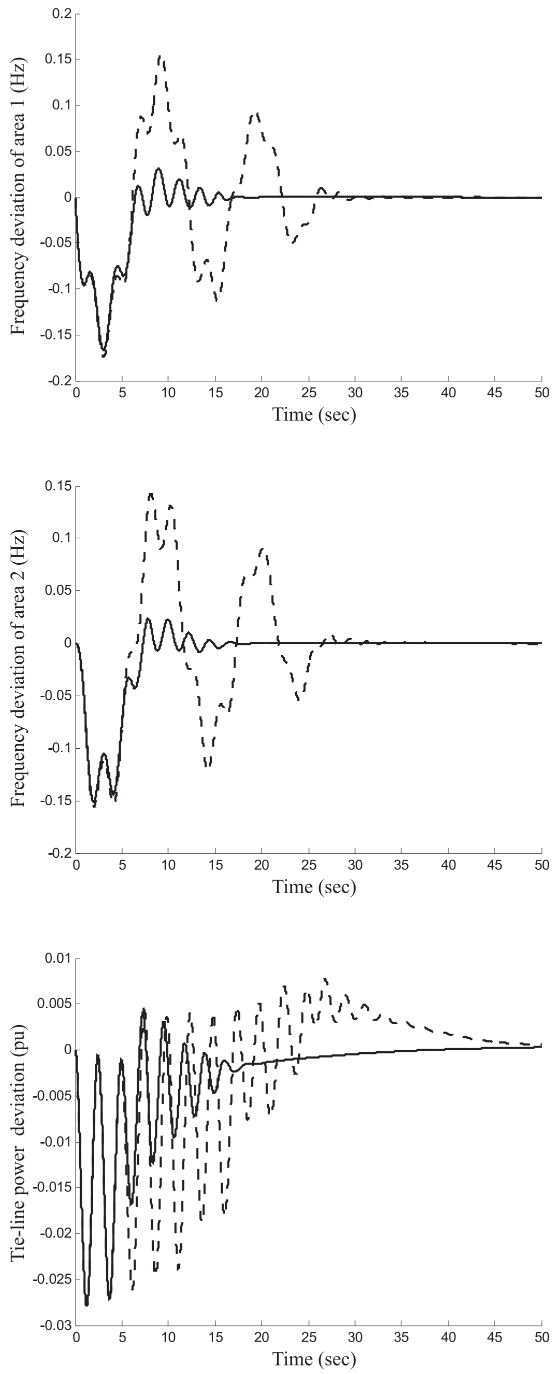

Fig. 7 *Dynamic responses for two different control strategies for case 2:* $\Delta P_{D1}=$ *3%,* $\Delta P_{D2}=$ *0. Fixed gain integral controller (- - -); Proposed controller (—).*

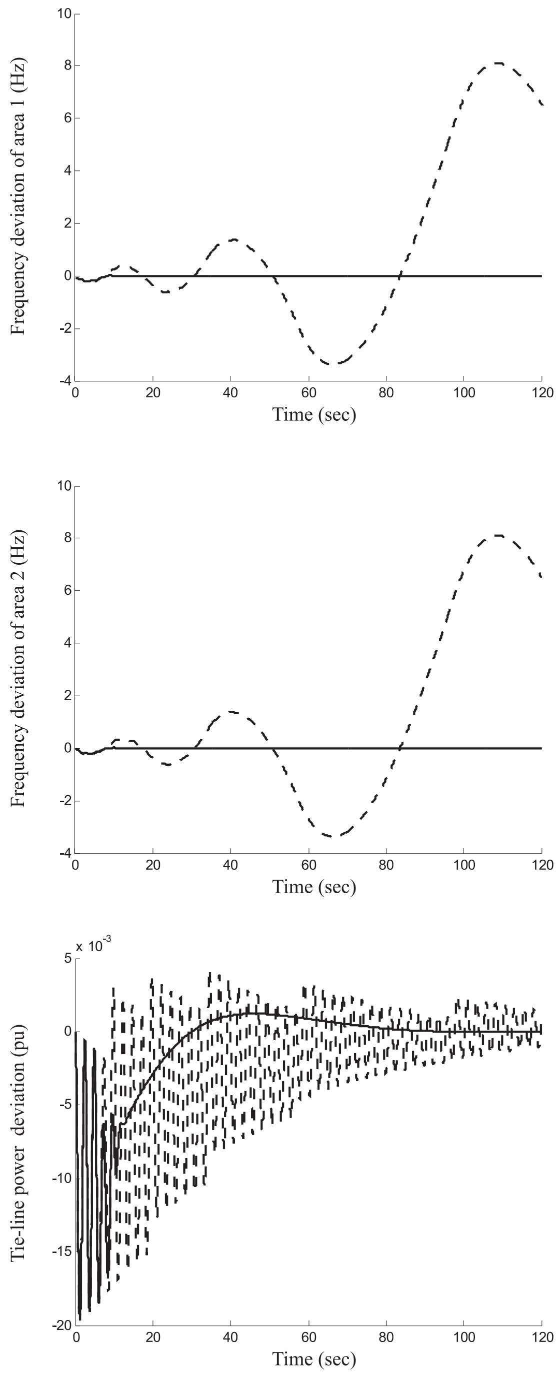

Fig. 8 *Dynamic responses for two different control strategies for case 3:* $\Delta P_{D1}=$ *1%,* $\Delta P_{D2}=$ *3%. Fixed gain integral controller (- - -); Proposed controller (—).*

4. The design of the proposed controller is achieved in the offline environment, while in the online operation the coefficients of suggested controller can be regulated through the RBFN with a high speed response and minimum complexity, appropriate for real time application.

5. Due to the VSTLF scheme, the control strategy can be expanded to include economical dispatch of the power systems.

Appendix 1

Block diagram model parameters and variables shown in Fig. 1 ($i = 1, 2$):

f:	System frequency (Hz)
Δf_i:	Change in frequency in area i
ΔP_{Di}:	Load change in area i ($p.u.$)
$\Delta P_{12}/\Delta P_{tie}$:	Change in tie-line power interchange between areas 1 and 2 ($p.u.$)
B_i:	Frequency bias constant of area i ($p.u./Hz$)
D_i:	Load governing characteristic of area i ($p.u./Hz$)
R_i:	Speed governor regulation of area i ($Hz/p.u.$)
T_g:	Time constant of speed governors (s)
T_r:	Reheat time constant of reheat turbines (s)
K_r:	Reheat parameter
T_t:	Turbine time constant (s)
T_p:	Time constant of power system (s)
K_p:	Power system parameter ($Hz/p.u.$)
T_{12}:	Tie-line synchronizing power coefficient between area 1 and area 2 ($p.u.$)

Appendix 2

Nominal parameters of the studied system:

$$D = 8.33 \times 10^{-3}\, p.u.MW/Hz\,,\ R = 2.4\, Hz/p.u.MW$$
$$P_r = 2000\, MW\ (area\, rated\, capacity)$$
$$P_{tie,r} = 200\, MW\ (tie\text{-}line\ \ capacity)$$
$$T_{12}^0 = \frac{P_{tie,r}}{P_r}\cos 30°,\ T_g = 0.08\, s,\ T_t = 0.3\, s$$
$$T_r = 10\, s, K_r = 0.5, T_p = 20\, s, K_p = 120\, Hz/p.u.MW$$

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