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RESEARCH ARTICLE

DEREGULATED POWER SYSTEM BASED STUDY OF AGC USING PID AND FUZZY LOGIC CONTROLLER

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Abstract

In this paper automatic generation control for deregulated power systems equipped different controllers are studied using PID and fuzzy logic controller. Initially a two-area reheat thermal power system is considered and the controller parameters are optimized TLBO algorithm. Three different controllers namely conventional PID, cascade PD-PI & fuzzy-PI controllers are used to analyze the transient performance of the power system. It is verified that fuzzy-PI controller yields its dominance over the other two. Integral time absolute error (ITAE) is used as objective function to optimize the controller gains. Further the sensitivity analysis is carried out varying the load conditions and step load perturbations. In both the power system model Fuzzy-PID controller proves to be performing better in terms of undershoot, overshoot & settling time which is further extended to a non-linear three-area thermal power system model by considering the effect of generation rate constraints. This novel controller is proved to be ensuring better dynamic performance compared to the others.

Introduction

A. Automatic Generation Control

For large scale power systems which consists of inter-connected control areas, load frequency then it is important to keep the frequency and inter area tie power near to the scheduled values. The input mechanical power is used to control the frequency of the generators and the change in the frequency and tie-line power are sensed, which is a measure of the change in rotor angle. A well designed power system should be able to provide the acceptable levels of power quality by keeping the frequency and voltage magnitude within tolerable limits. Changes in the power system load affects mainly the system frequency, while the reactive power is less sensitive to changes in frequency and is mainly dependent on fluctuations of voltage magnitude. So the control of the real and reactive power in the power system is dealt separately. The load frequency control mainly deals with the control of the system frequency and real power whereas the automatic Voltage regulator loop regulates the changes in the reactive power and voltage magnitude. Load frequency control is the basis of many advanced concepts of the large scale control of the power system.

Mathematically

$$P = \frac{EV}{X}\sin\delta \qquad (1)$$

$$Q = \frac{EV}{X}\cos\delta - \frac{V^2}{X} \qquad (2)$$

$$\frac{d^2\delta}{dt^2} = \prod f(P_m - P_e) \qquad (3)$$

In an interconnected power system, if a load demand changes randomly, both frequency and tie line power varies. The main aim of load frequency control is to minimize the transient variations in these variables and also to make sure that their steady state errors is zero. Many modern control techniques are used to implement a reliable controller. The objective of these control techniques is to produce and deliver power reliably by maintaining both voltage and frequency within permissible range. We can therefore state that the load frequency control (LFC) has the following two objectives:

- Hold the frequency constant ($\Delta f = 0$) against any load change. Each area must contribute to absorb any load change such that frequency does not deviate.
- Each area must maintain the tie-line power flow to its pre-specified value.

B. Load Frequency Control

The operation objectives of the LFC are to maintain reasonably uniform frequency, to divide the load between generators, and to control the tie-line interchange schedules. The change in frequency and tie-line real power are sensed, which is a measure of the change in rotor angle δ, i.e., the error Δδ to be corrected. The error signal, i.e., Δf and ΔPtie, are amplified, mixed, and transformed into a real power command signal ΔPv, which is sent to the prime mover to call for an increment in the torque. The prime mover, therefore, brings change in the generator output of an amount ΔP_g which will change the values of Δf and ΔPtie within the specified tolerance. Proper assumptions and approximations are made to linearize the mathematical equations describing the system, and a transfer function model is obtained for the following components.

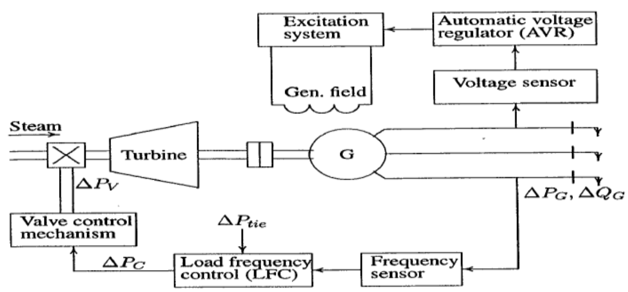

Fig.1. Schematic diagram of LFC and AVR of a synchronous generator

AGC in deregulated environment

A. Restructured Power system

In the competitive environment of power system, the vertically integrated utility (VIU) no longer exists. Deregulated system will consist of GENCOs, DISCOs, and transmission companies (TRANSCOs) and independent system operator (ISO). However, the common AGC goals, i.e. restoring the frequency and the net interchanges to their desired values for each control area, still remain. The power system is assumed to contain two areas and each area includes two GENCOs and also two DISCOs as shown in Fig. 2.3. As there are several GENCOs and DISCOs in the deregulated structure, a DISCO has the freedom to have a contract with any GENCO for transaction of power. A DISCO may have a contract with a GENCO in another control area. Such transactions are called “bilateral transactions.” All the transactions have to be cleared through an impartial entity called an independent system operator (ISO). The ISO has to control a number of so-called “ancillary services,” one of which is AGC.

Here, we introduce the information signals which were absent in the traditional scenario. The demands are specified by cpfs (elements of DPM) and the pu MW load of a DISCO. These signals carry information as to which GENCO has to follow a load demanded by which DISCO. The scheduled steady state power flow on the tie line is given as

$\Delta P_{tie1-2,scheduled} =$ (Demand of DISCOs in area II from GENCOs in area I)-(demand of DISCOs in area I from GENCOs in area II)

$$\Delta P_{tie1-2,scheduled} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \sum_{i=3}^{4}\sum_{j=1}^{4} cpf_{ij}\Delta P_{Lj} \quad (4)$$

$$\Delta P_{tie1-2,actual} = \frac{2\prod T_{12}}{s}(\Delta f_1 - \Delta f_2)$$

At any given time, the tie line power error $\Delta P_{tie1-2,error}$ is defined as

$$\Delta P_{tie1-2,error} = \Delta P_{tie1-2,actual} - \Delta P_{tie1-2,scheduled} \quad (5)$$

$\Delta P_{tie1-2,error}$ vanishes in the steady state as the actual tie line power flow reaches the scheduled power flow. This error signal is used to generate the respective ACE signals as in the traditional scenario.

$$ACE_1 = B_1\Delta f_1 + \Delta P_{tie1-2,error}$$

$$ACE_2 = B_2\Delta f_2 + \Delta P_{tie2-1,error}$$

$$\Delta P_{tie12,error} = a_{12}\Delta P_{tie21,error}$$

$$a_{12} = -\frac{P_{r1}}{P_{r2}}$$

Where P_{r1} and P_{r2} are the rated powers of areas I and II, respectively

The local loads in areas I and II are denoted by $\Delta P_{L1,loc}$ and $\Delta P_{L2,loc}$, respectively

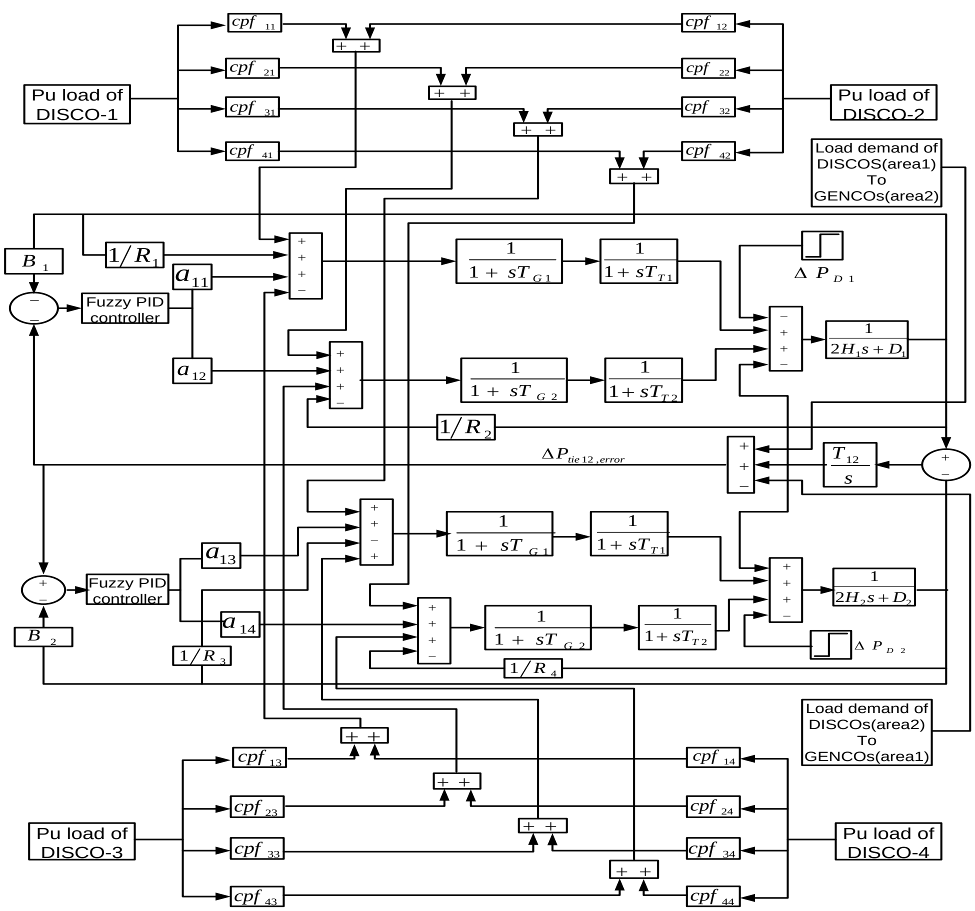

Fig.2. An interconnected power system model with multi-source power generation in deregulated power environment

Teaching-Learning based Optimization (TLBO):-

TLBO is population based method. In this optimization algorithm a group of learners is considered as population and different design variables are considered as different subjects offered to the learners and learners' result is analogous to the 'fitness' value of the optimization problem. In the entire population the best solution is considered as the teacher. The working of TLBO is divided into two parts, 'Teacher phase' and 'Learner phase'. Working of both the phases is explained below.

Following are the notations used for describing the TLBO:

N: number of learners in a class i.e. "class size";

D: number of courses offered to the learners;

MAXIT: maximum number of allowable iterations.

The population X is randomly initialized by a search space bounded by matrix of N rows and D columns. The jth parameter of the it learner is assigned values randomly using the equation (6).

$$x_{(i,j)}^{0} = x_j^{\min} + rand \times (x_j^{\max} - x_j^{\min}) \qquad (6)$$

Where rand represents a uniformly distributed random variable within the range (0,1), $x_j^{\min}$ and $x_j^{\max}$ represent the minimum and maximum value for jth parameter. The parameters of learner for the generation g are given by

$$x_{(i)}^{g} = [x_{(i,1)}^{g}, x_{(i,2)}^{g}, x_{(i,3)}^{g}, ..., x_{(i,j)}^{g}, ..., x_{(i,D)}^{g}] \qquad (7)$$

A. Teacher phase

The mean parameter M^g of each subject of the learners in the class at generation *g* is given as

$$M^{g} = [m_1^{g}, m_2^{g}, ..., m_j^{g}, ..., m_D^{g}] \qquad (8)$$

To obtain a new set of improved learners a random weighted differential vector is formed from the current mean and the desired mean parameters and added to the existing population of learners.

$$Xnew_{(i)}^{g} = X_{(i)}^{g} + rand \times (X_{Teacher}^{g} - T_F M^{g}) \qquad (9)$$

Where T_F is not a parameter of the TLBO algorithm. The value of T_F is not given as an input to the algorithm and its value is randomly decided by the algorithm as in equation (10). After conducting a number of experiments on many benchmark functions it is concluded that the algorithm performs better if the value of T_F is between 1 and 2. However, the algorithm is found to perform much better if the value of T_F is either 1 or 2 and hence to simplify the algorithm, the teaching factor is suggested to take either 1 or 2 depending on the rounding up criteria.

$$T_F = round[1 + rand(0,1)\{2-1\}] \qquad (10)$$

If $Xnew_{(i)}^{g}$ is found to be a superior learner than $X_{(i)}^{g}$ in generation g, than it replaces inferior learner $X_{(i)}^{g}$ in the matrix.

B. Learner phase

In this phase the interaction of learners with one another takes place. The process of mutual interaction tends to increase the knowledge of the learner. The random interaction among learners improves his or her knowledge. The ith parameter of the matrix Xnew in the learner phase is given as

$$Xnew_{(i)}^{g} = X_{(i)}^{g} + rand \times (X_{(i)}^{g} - X_{(r)}^{g}) \text{ if } f(X_{(i)}^{g}) < f(X_{(r)}^{g})$$

$$= X_{(i)}^{g} + rand \times (X_{(r)}^{g} - X_{(i)}^{g}) \text{ otherwise} \qquad (11)$$

Conventional PID controller

PID controller has all the necessary dynamics: fast reaction on change of the controller input (D mode), increase in control signal to lead error towards zero (I mode) and suitable action inside control error area to eliminate oscillations (P mode). As shown in the figure no. 3, by varying the gain parameters of the controller we can control the stability, overshoot and steady state error, speed of response and accuracy of the system. In this paper TLBO (Teaching Learning Based Optimization) algorithm is used to tune the parameters.

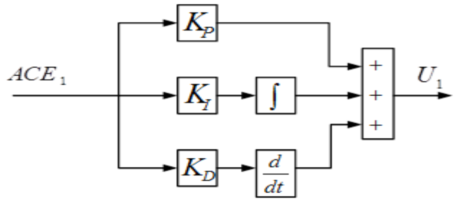

Fig 3. Block diagram of PID controller

Mathematically

$$c(t)=K_p e(t)+K_I \int e(t)\,dt+K_d \frac{d}{dt} e(t) \qquad (12)$$

In this paper the optimum goal is to minimize the frequency deviation and tie line power deviation, which are added together and passes through the tuned PID controller to make the power system stable.

Fuzzy logic controller

The output of a fuzzy controller is derived from fuzzifications of both inputs and outputs using the associated membership functions. A crisp input will be converted to the different members of the associated membership functions based on its value. From this point of view, the output of a fuzzy logic controller is based on its memberships of the different membership functions, which can be considered as a range of inputs.

If X is a collection of objects denoted generically by x, then a fuzzy set A in X is defined as a set of ordered pairs:

$$A = \{ (x, \mu A(x)) \,|\, x \,\varepsilon X\}$$

Where μA(x) is called the membership function for the fuzzy set A. The membership function maps each element of X (the universe of discourse) to a membership grade between 0 and 1. The main objective of fuzzy logic is to represent and reason with some particular form of knowledge expressed in a linguistic form.

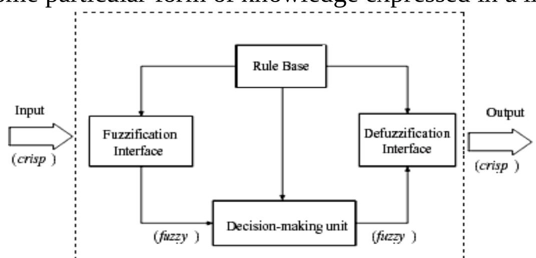

Fig.4. Block diagram of fuzzy logic controller

To implement fuzzy logic technique to a real application requires the following three steps:

a. Fuzzification – convert classical data or crisp data into fuzzy data or Membership Functions (MFs).
b. Fuzzy Inference Process – combine membership functions with the control rules to derive the fuzzy output.
c. Defuzzification – use different methods to calculate each associated output and put them into a table: the lookup table. Pick up the output from the lookup table based on the current input during an application.

Fuzzy PID controller

However, it has been known that conventional PID controllers generally do not work well for nonlinear systems, higher order and time-delayed linear systems, and particularly complex and vague systems that have no precise mathematical models. To overcome these difficulties, fuzzy PID controller is introduced in this paper as shown in Fig.4.6.

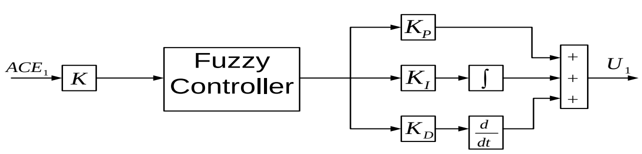

Fig.5. Block diagram of fuzzy PID controller

Simulation Results

This paper deals with three case studies in deregulated power system model to observe the transiency of frequency deviation and tie line power deviation with PID and Fuzzy PID controllers.

A. Case 1: Base case results

As shown in fig. 2.3. a step load disturbance of 10% is provided in area 1 and 0% in area 2 to observe the transiency of the system by using PID and Fuzzy PID controller individually in each area.

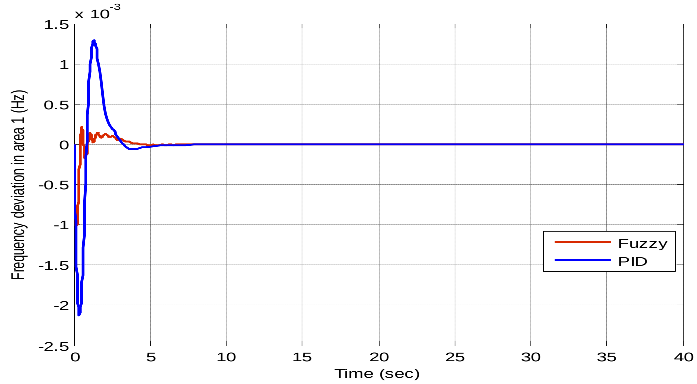

Fig.6. comparison between PID and Fuzzy PID controller for area 1 frequency deviation in deregulated power system

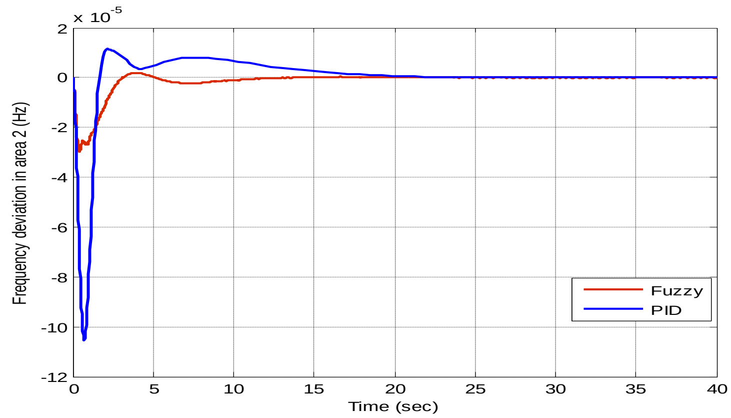

Fig.7. comparison between PID and Fuzzy PID controller for area 2 frequency deviation in deregulated power system

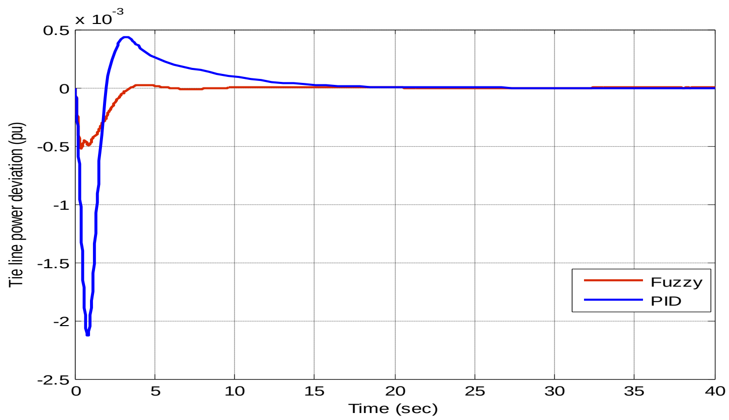

Fig.8. Comparison between PID and Fuzzy PID controller for tie line power deviation in deregulated power system

B. Case 2: Bilateral Transactions results

In this case a step load disturbance of 10% is provided in both area 1 and area 2 to observe the transiency of the system by using PID and Fuzzy PID controller individually in each area.

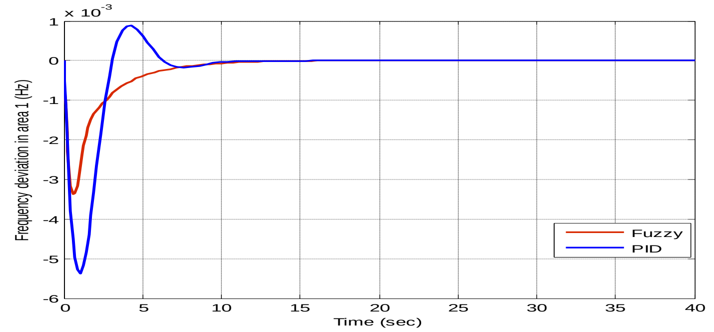

Fig.9. comparison between PID and Fuzzy PID controller for area 1 frequency deviation in deregulated power system

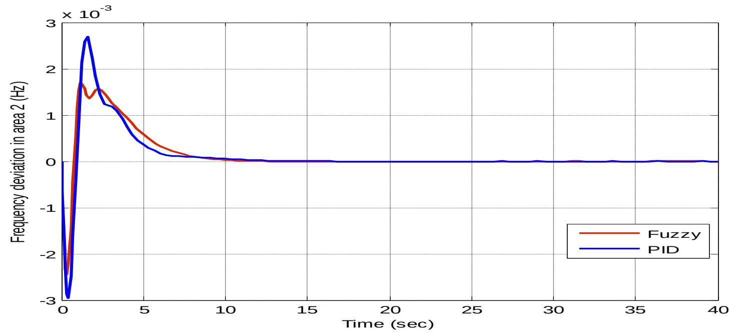

Fig.10. comparison between PID and Fuzzy PID controller for area 2 frequency deviation in deregulated power system

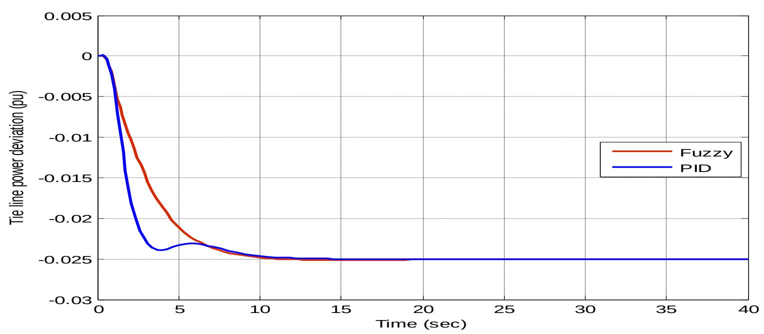

Fig.11. comparison between PID and Fuzzy PID controller tie line power deviation in deregulated power system

C. Case 3: Contract violation results

In this case a step load disturbance of 11% is provided in area 1 and 0% to area 2 to observe the transiency of the system by using PID and Fuzzy PID controller individually in each area.

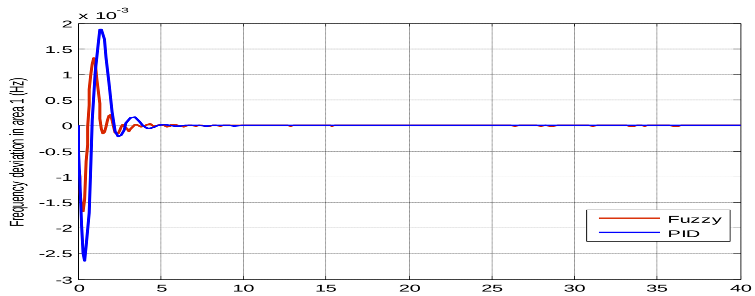

Fig.12. comparison between PID and Fuzzy PID controller for area 1 frequency deviation in deregulated power system

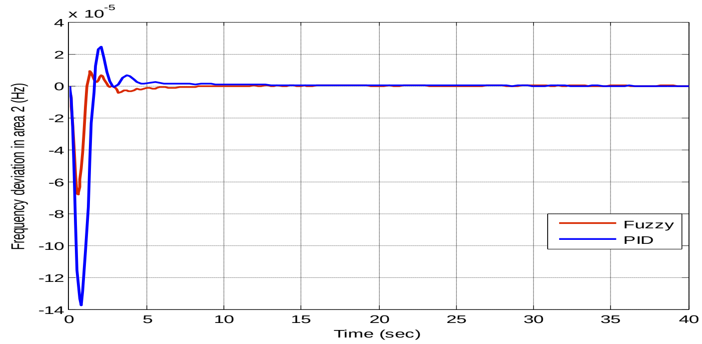

Fig.13. comparison between PID and Fuzzy PID controller for area 2 frequency deviation in deregulated power system

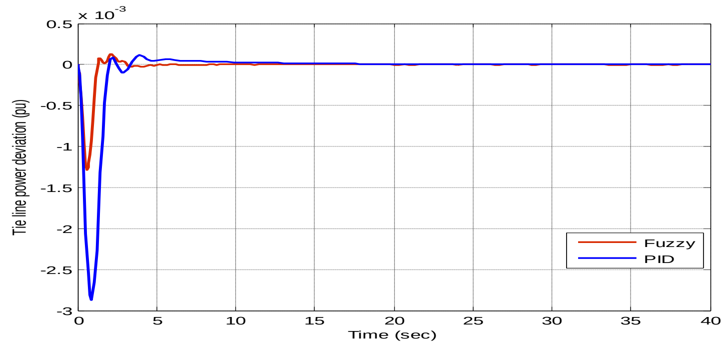

Fig.14. Comparison between PID and Fuzzy PID controller for tie line power deviation in deregulated power system

Table 1 Output response for both Fuzzy PID and PID controller of deregulated power system in order of 10^{-4}

Controller type		**F_1_min**	**F_2_min**	**P_{tie}_min**	**F_1_max**	**F_2_max**	**P_{tie}_max**
Fuzzy PID	Case 1	-10.0620	-0.2969	-5.2015	2.0805	0.0190	0.2595
	Case 2	-33.7592	-24.4319	-1.4378	0.0167	16.8793	250.8405
	Case 3	-16.7313	-0.6833	-12.8860	13.1582	0.0925	1.3110
PID	Case 1	-21.2825	-1.0528	-21.2986	12.8958	0.1142	4.3612
	Case 2	-53.7246	-29.5297	-0.1856	8.7927	26.9566	251.0194
	Case 3	-26.4741	-1.3789	-28.7347	18.8265	0.2445	1.1402

Conclusion

This paper presents TLBO algorithm is applied to multi area multi source like gas plant in both conventional and restructured power system for tuning the PID and Fuzzy PID controller parameters and their performance. TLBO searches for an optimum through each learner trying to achieve the experience of the teacher, which is treated as the most learned person in the society, thereby obtaining the optimum results, rather than through learners undergoing genetic operations like selection, crossover and mutation. Due to its high efficiency and simplicity, it becomes a promising and effective algorithm to solve the problem.

In deregulated environment both PID and Fuzzy PID controller is applied. Due to some advantages of Fuzzy PID over Simple PID controller, Fuzzy PID controller is found more effectively eliminate the oscillations and provides smooth operation. From the simulation results by comparing the PID with Fuzzy PID controller only, the former has the advantages of better control performance in terms of less overshoot, undershoot and settling time in both environments.

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