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# Load Frequency Control Using Intelligent Techniques

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**Abstract:** In this paper a brain emotional learning based on intelligent controller (BELBIC) and fuzzy logic with Mamdani and Sugeno type fuzzy inference has been suggested for two area hydro electrical power system and compared with PI controller for elimination of the problems load frequency control such as frequency deviations and power flow control in transient condition. The Proposed controllers are substituted instead of conventional PI controller. Intelligent controllers have some parameters when tuned better response can be achieved. These controllers are flexible and robust against change in system parameters, loads, generation rate constraints and other nonlinear factors in a power system. These controllers are used for two-area hydro electrical power system and simulation results have confirmed the superiority of intelligent controllers over conventional controllers. The Application and performance of these controllers have been verified in linear and nonlinear systems. The Simulation has been done in matlab simulink software.

**Keywords:** Load Frequency Control, Brain Emotional, Fuzzy Logic.

## I. INTRODUCTION

In recent years, the formation of power system has become more complicated, and its construction is made of nonlinear elements. Many parts of industries depend on power quality. Since power systems are constructed of interconnected parts, if a fault occurs in a subsystem, the subsequent perturbation can affect in the power system quality. Any unbalancing between production and demand can cause frequency deviation. The frequency of a system depends on balancing the active power. Since the frequency is the common factor in the whole system, the change in the demand of active power in a district of power system can be affected in overall power system. At interconnected system with two or more independent control areas, beside frequency control, generation control is crucial to kept interchange power at a programmed level. Controlling production and frequency is referred as "Load Frequency Control" (LFC) and is a very important factor for power system quality. The dynamic operation of many industries and factories is very affected by perturbation of the changes of the action point and function of the power system. The initial aim of LFC is to have a constant frequency during changes of the load. In a multi-areas interconnected power system, control areas are connected together through lines and load increasing lead to frequency decrease. It is necessary to have a control strategy to achieve the following goals [1]:

- Keep frequency at a nominal value.
- Load changing in one area should be responded at the same area.

Finally LFC should be sensitive to load frequency changing, so designing the controller for LFC is very important. PI controller is one of the conventional controllers for LFC. This controller has a constant gain that is designed based on nominal work point, so the utilization of this controller is very simple but frequency deviations are high. When system parameters and load suddenly change, this controller cannot respond well and it has deviations in transient conditions. To overcome this problem intelligent methods and algorithms such as genetic algorithm[2], particle swarm optimization[3],artificial neural network[4] and nonlinear controllers such as sliding mode control[5], adaptive controller[6] are proposed for LFC for two-area system in recent years.

Due to the complicated construction of large power systems and the difficulty of simulating and analyzing such systems, in this paper a two area power system is considered to study and simulate.

## II. TWO AREA POWER SYSTEM

Two area power system structure depicted in Fig1 [7].

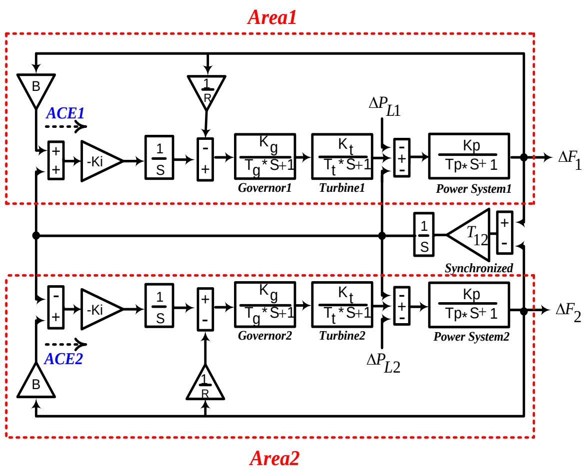


Fig.1. Two area power system block diagram

Transfer function and turbine-governor model of a power system are shown in Fig.1 while Kt, Kg, H, R, B, K, Δfi

are turbine transfer function gain, governor transfer function gain, generator inertia constant, speed regulation coefficient, bias frequency coefficient, controller gain and frequency error at $i_{th}$ area, respectively.
The State variables area is as follows:

$$X^{\bullet} = Ax(t) + Bu(t) + Ld(t) \qquad 1$$

While A is the state matrix of the system, B is the input of the system and L is the input's disturbance. In (1) the state vector(x) is equal to:

$$x = \left[ \Delta F_1, \Delta P_{g1}, \Delta P_{t1}, \Delta P_{tie}, \Delta F_2, \Delta P_{g2}, \Delta P_{t2} \right]$$

While $\Delta P_{tie}, \Delta P_{ti}, \Delta Pgi \;, \Delta F_i$ are synchronization coefficient, mechanical power changes, input fluid changes and frequency error of $i_{th}$ area respectively. $u = [u_1, u_2]^T$ While $U_i$ is the output of controller in $i_{th}$ area and $d = [\Delta PL_1, \Delta PL_2]^T$ while $\Delta P_i$ is load disturbance in $i_{th}$ area.
In two area power system, area control error ($ACE_i$) is a linear combination of $\Delta f_i$ and $\Delta P_{tie\,(ij)}$ and should be equal to zero. For a two area power system, ACE in each area control is defined as equations 2 , 3:

$$ACE_1 = \Delta P_{12} + B_1 \Delta F_1 \qquad 2$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta F_2 \qquad 3$$

So the output of controller in each area is as follows:

$$out_1 = -KI_1 \int ACE_1 dt \qquad 4$$

$$out_2 = -KI_2 \int ACE_2 dt \qquad 5$$

And to determine the system response in steady state, must:

$$\Delta P_{12} + B_1 \Delta F_1 = 0 \qquad 6$$

$$\Delta P_{21} + B_2 \Delta F_2 = 0 \qquad 7$$

These equations are true in the following condition:

$$\Delta F_i = \Delta P_{ij} = 0$$

## III. INTELLIGENT SYSTEMS

Conventional control methods are based on identification and system modeling and conventional controllers are designed according to predefined objectives. Identifying the complex system is difficult and sometimes impossible. On the other side due to change in system parameters, it is crucial to redesign the controllers which is very difficult and intricate. One of the new control methods in engineering sciences is the use of intelligent controllers which are independent to the system model. In this method there is a strong tendency to get inspired by natural systems. In this method there is a strong tendency to get inspired by natural systems. Designing intelligent controllers has been the focus of research in recent years.
Artificial intelligence is referred to systems which can do some humanlike reactions such as: perceiving complicated conditions, intellectual process simulation, human reasoning methods and responding them well, learning capability and reasoning to solve problems. Artificial intelligence was impossible before inventing computers and it is a part of computer sciences. Today's artificial intelligence is one of the important topics in engineering, basic, medical and management sciences. Some branches of artificial intelligence are as follows:
Computational Intelligence, evolutionary intelligence, swarm intelligence, artificial neural network, fuzzy system and brain emotional controller [8].

### III- A. Fuzzy Logic

Fuzzy logic was first introduced by Prof Lotfizadeh at 1965 as fuzzy sets [9]. Fuzzy logic is a new method to simplify the conventional methods to design and modeling systems there is a need for complex and advanced mathematic
Fuzzy logic algorithm usually includes a set of reasoning rules where can spot it as a nonmathematical and adaptable algorithm based on verbal process in contrast to conventional algorithms.
Today fuzzy systems are used in many sciences such as: control, signal processing, communications, integrated circuits, medicine and business [10-11].
An important application of fuzzy logic is in control systems. The main structure of the fuzzy algorithm is shown as a block diagram in Fig.2.

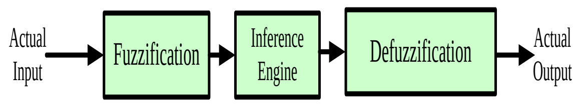


Fig.2. Fuzzy logic algorithm structure

Where fuzzification step is defined as fuzzy sets for input-output variables. To define fuzzy sets, there should be the primary knowledge of the variation domain of each variable. At inference step fuzzy rules are made. These rules determine the value of control signals with regard to inputs. Finally at defuzzification stage the real value of outputs is determined with regard to inference step level.

### III- B. Intelligent Control Based on Brain Emotional Learning

Brain emotional learning algorithm is based on the existence of antibiotics and is a member of intelligent system family whose application is widespread Nowadays intelligence computational is successfully used for solving complex problems.
The main difference between intelligent system and classic system is learning and education issues. A common feature of the learning progress is the capability of adaptation to parameters variations and environmental conditions. One of the necessities of the learning algorithm is circumstance evolutionary. Brain emotional learning is one of the newest of these methods and is based on brain emotional evolutionary. This progress was made in a part of the brain of mammals called "limbic system"[12]. Moren and Balkenius offer a method inspired by amygdala computational and orbitofrontal cortex model in limbic system [13] and with respect to this model they offer brain emotional learning based on intelligent controller (BELBIC) [14]. Proposed model is adapted for complex system [15]. BELBIC can supersede conventional controllers such as PID controller. Simulation results show


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BELBIC's responses are faster, with lower overshoot or undershoot and are robust against the variations of the system parameters and disturbances compared with conventional PID controller.

In real time control systems due to simplification, low computations and fast educating, emotional learning is a very powerful method [16].

Recently BELBIC controller is proposed for systems such as: power systems [17], electrical machines control [18] and nonlinear systems [19].All of the studies show robustness and good operation of BELBIC.

III-C.limbic system structure

Limbic system is a part of mammal brain and its task is processing emotional signals. It is composed of Amygdala, orbit frontal cortex, thalamus, hypothalamus, sensory cortex etc. Fig 3 shows limbic system structure [20].

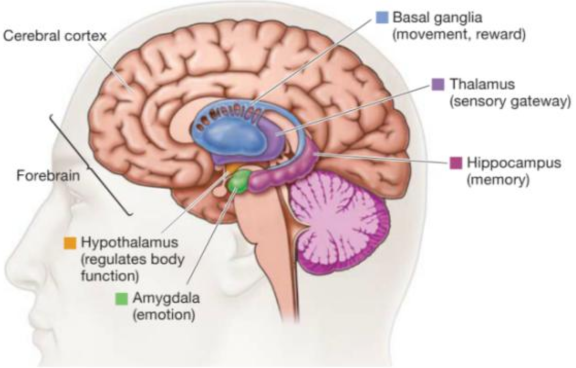


Fig.3. limbic system structure

The relationship between amygdala and other limbic system element is shown in fig.4 [20].

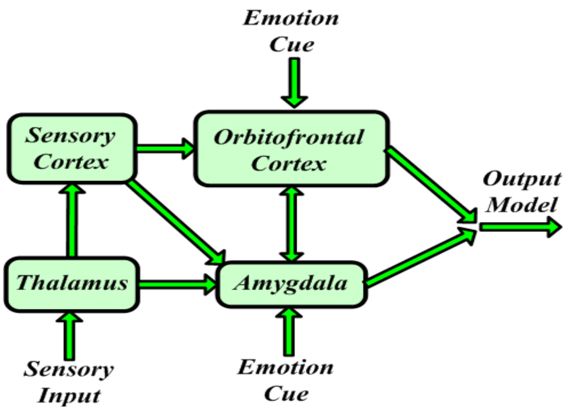


Fig.4. Amygdala relationships in limbic system.

III- C. Amygdala computational model

Block diagram of amygdale computational model is shown in fig. 5 [20].

Based on new theories, amygdala system and orbitofrontal complete the learning progress in two steps. Actuation internal signals are first evaluated and then used for reinforcement coefficients in affected actuation response. These signals actuate amygdala and a amygdala's response is used for learning continuously. Besides orbitofrontal cortex acts as a reformer for the inappropriate amygdala's responses and reactions. In computational model amygdale and orbitofrontal cortex have lattice structures where there is a node for sensitive inputs in each. One node is thalamus's input in amygdale and its value is equal to maximum value of sensitive inputs. The output of nodes in amygdale and orbitofrontal cortex is computed based on the following equations respectively:

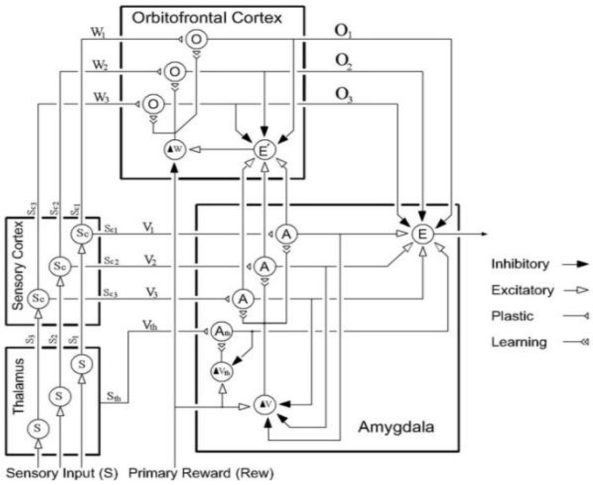


Fig.5 .Amygdala computational model block diagram

$$A_i = S_i V_i \quad (8)$$

$$O_i = S_i W_i \quad (9)$$

Where $A_i$, $O_i$ are nod's output in amygdale lattice and orbitofrontal cortex respectively. V and W are nod's weight and $S_i$ is sensory inputs.

V and W changes are computed through following equations:

$$\Delta V_i = \alpha \left( S_i \max\left(0, R - \sum_j A_j\right)\right) \quad (10)$$

$$\Delta W_i = \beta S_i \left( \sum_j A_j - \sum_j O_j - R \right) \quad (11)$$

Finally the output of the model is computated as follows:

$$E = \sum_j A_j - \sum_j O_j \quad (12)$$

## IV. LFC USING FUZZY LOGIC

LFC block diagram with fuzzy logic is shown in Fig.6.

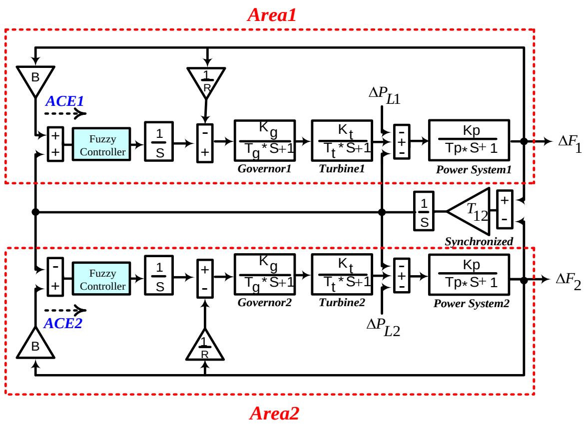


Fig.6 .LFC system using Fuzzy Logic


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The only difference between fuzzy and conventional control is that fuzzy controller is a substitute for integrator gain.

IV-A.Mamdani TypeInference System

This method was proposed first by Mamdani in 1975[21]. This method was applied based on the combination of verbal control rules with human experiences. In this method all of the input and output variables are defined as fuzzy membership function. In this paper turbine time constant (TP), bias frequency coefficient (B) and synchronization coefficient (T12) are the inputs of fuzzy controller and ki is the output. Input and Output membership function is shown in Fig.7.

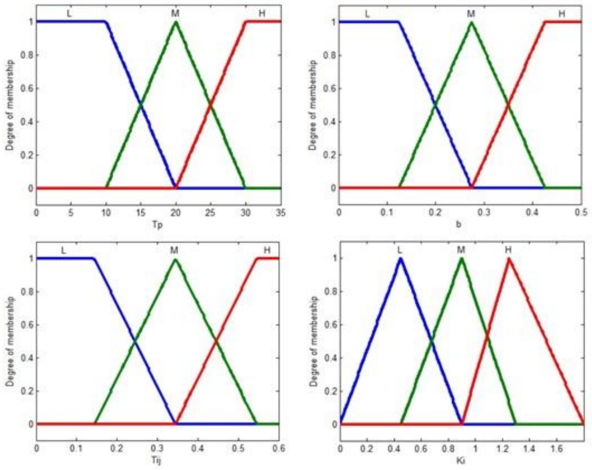

Fig.7. Input - Output Membership Functions

Input level control based on output is shown in Fig.8.

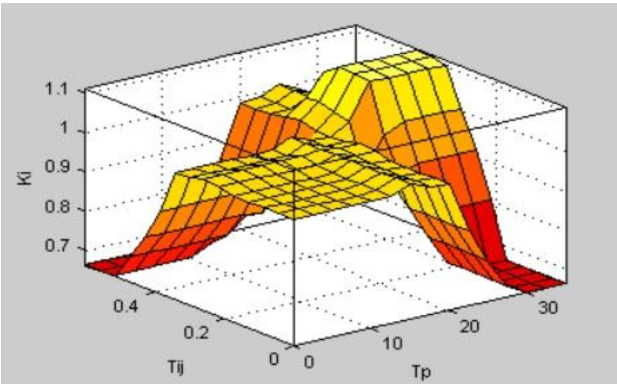

Fig.8. level control

IV- B. Sugeno Type Inference System

Sugeno Inference method was first proposed by Takagi–Sugeno– Kang in 1985[22].This method is similar to Mamdani inference method in many aspects such as: input fuzzification and utilizing logic operators. The only difference is the output membership function of Sugeno method is a linear combination of inputs or constant. Fuzzy rules for Mamdani and Sugeno inference system are shown in table1. These rules are designed based on primary knowledge of conventional PI controller in LFC.

Table I. Fuzzy rules for Mamdani and Sugeno inference system.

| | $T_p$ | $T_{ij}$ | b | $K_i$ (Mam) | $K_i$ (Sug) | | $T_p$ | $T_{ij}$ | b | $K_i$ (Mam) | $K_i$ (Sug) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | L | L | L | H | 1.48 | 15 | M | M | H | L | 0.58 |
| 2 | L | L | M | M | 0.7 | 16 | M | H | L | H | 1.24 |
| 3 | L | L | H | L | 0.49 | 17 | M | H | M | M | 0.78 |
| 4 | L | M | L | H | 1.46 | 18 | M | H | H | L | 0.55 |
| 5 | L | M | M | M | 0.69 | 19 | H | L | L | H | 1.14 |
| 6 | L | M | H | L | 0.36 | 20 | H | L | M | L | 0.71 |
| 7 | L | H | L | H | 1.17 | 21 | H | L | H | L | 0.56 |
| 8 | L | H | M | L | 0.49 | 22 | H | L | L | H | 1.12 |
| 9 | L | H | H | L | 0.38 | 23 | H | M | M | H | 0.77 |
| 10 | M | L | L | H | 1.28 | 24 | H | M | M | M | 0.63 |
| 11 | M | L | M | M | 0.77 | 25 | H | M | H | M | 1.07 |
| 12 | M | L | H | L | 0.57 | 26 | H | H | M | M | 0.73 |
| 13 | M | M | L | H | 1.43 | 27 | H | H | H | L | 0.44 |
| 14 | M | M | M | M | 0.72 | | | | | | |

## V. LFC USING BELBIC

BELBIC structure is shown in Fig 9. BELBIC replaces conventional PI controller specifically.

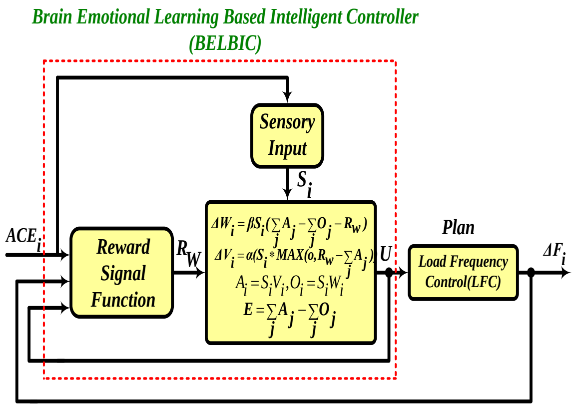


Fig.9. BELBIC'S Structure

Sensory input (Si) is a function based on $ACE_i$ and is designed as follows:

$$S_i = K_{1s} ACE_i + K_{2s} \frac{d}{dt} ACE_i + K_{3s} \int ACE_i dt \quad 13$$

Besides emotional signal is designed as follows:

$$R_w = K_{1r} \left|ACE_i\right| + K_{2r} \left|ACE_i \times \Delta F_i\right| + K_{3r} \left|u\right| \quad 14$$

We can have proper response with tuning $K_{1r}$, $K_{2r}$, $K_{3r}$ and $K_{1s}$, $K_{2s}$, $K_{3s}$ and select α and β adequately.

## VI. SIMULATIONS RESULTS

Comparison between BELBIC and fuzzy logic with conventional PI controllers are shown in Fig9 to Fig16. The simulations time is 15 second and Simulations are done in matlab simulink software with continuous integrator.

Frequency deviation in area 1 and area 2 in normal conditions are shown in Fig9 and Fig10. Tie line power deviation is shown in Fig11. Frequency deviation in area 1 and area 2 and tie line power deviation in abnormal condition such as change in disturbance load, bias coefficient frequency, synchronize coefficient, time constant turbine in two areas are shown in Fig 12 to Fig 14 respectively. Finally, deviation in power mechanical in two areas is shown in Fig 15 and Fig16.

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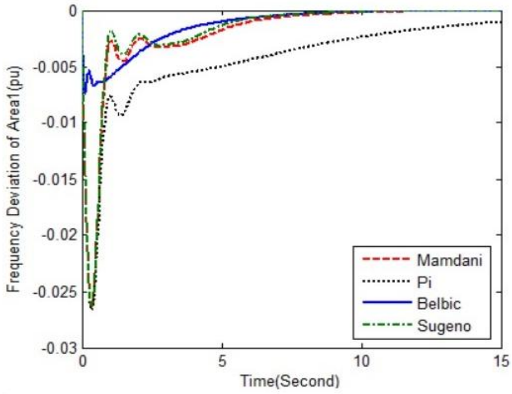


Fig.9. Frequency deviations in area 1

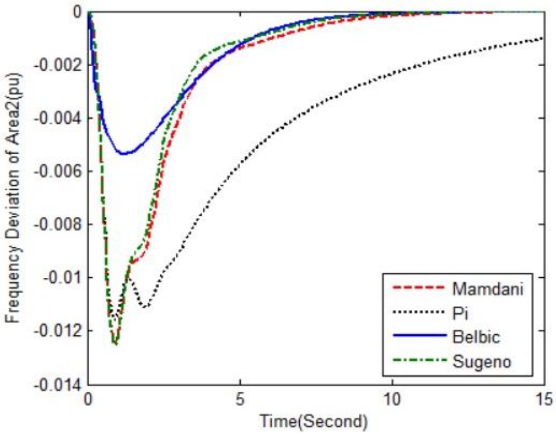


Fig.10. Frequency deviations in area 2

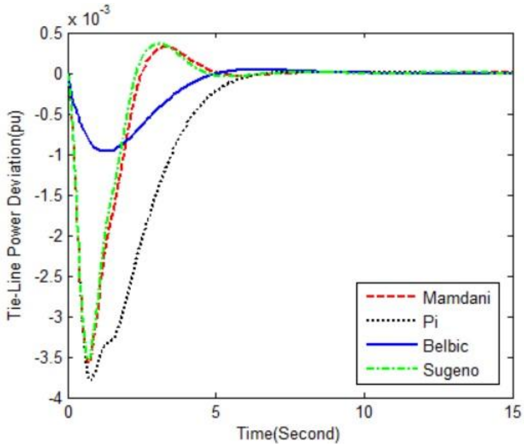


Fig11. Tie Line power deviations

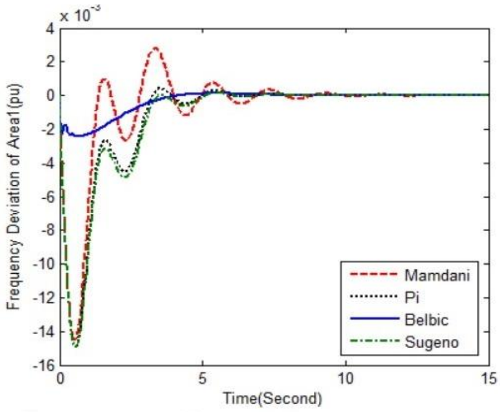


Fig12**.** Frequency deviations in area 1 with abnormal conditions

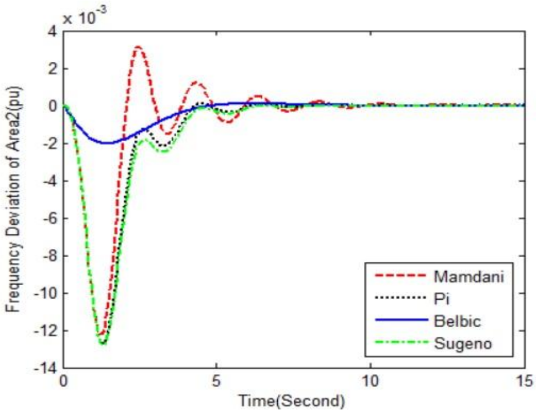


Fig13. Frequency deviations in area 2 with abnormal conditions

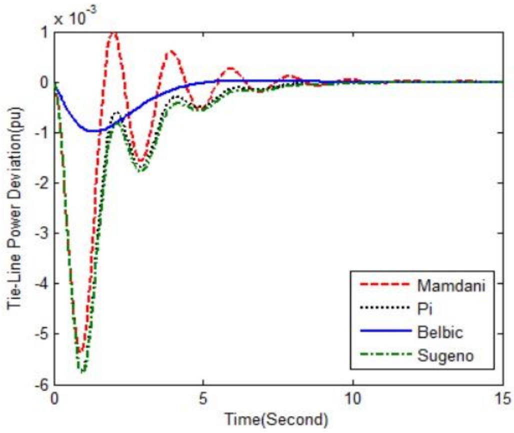


Fig14**.** Tie Line power deviations with abnormal conditions

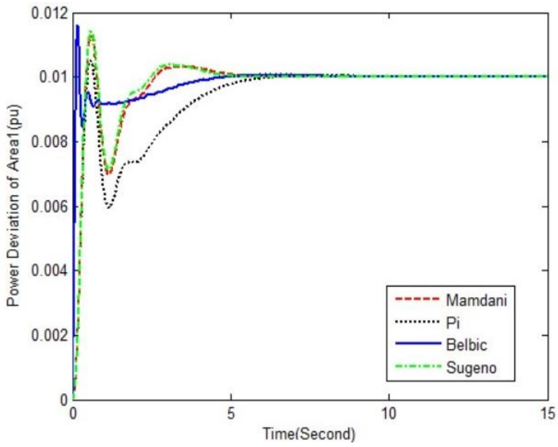


Fig15**.** Power deviations in Area1

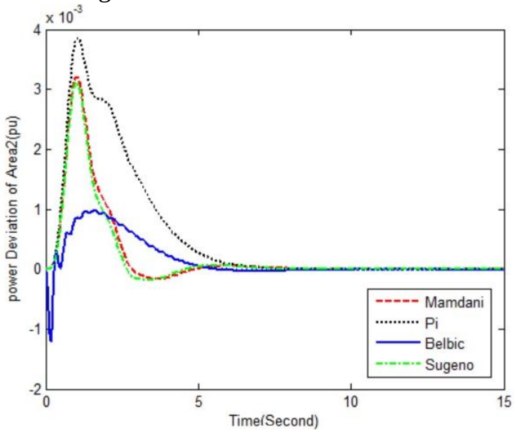


Fig16. Power deviations in Area2

## VII. CONCLUSIONS

The main aim of LFC is balancing between generation and consumption. Due to complexity and multi variable power system, in abnormal conditions conventional PI controller cannot have proper response, so robust and intelligent controllers such as BELBIC and fuzzy logic are used. To evaluate the PI, BELBIC and fuzzy logic controllers in normal and abnormal system conditions, criterions such as: Lower integral error (IE), lower over shoot, better transient response, zero steady state error and higher velocity in response are considered.
Simulation results show superiority and robustness of intelligent controllers.

### Appendix:

Two area power system parameters

| | | | |
|---|---|---|---|
| $K_1$=0.54 | R=2.4 | $T_g$=0.08 | B=0.125 |
| $T_t$=0.1 | $T_{ij} = 0.345$ | H=5 | $\Delta P_{L1} = 0.01$ |
| $K_p$=120 | $T_p$=10 | D=0.6 | $\Delta P_{L2} = 0$ |

BELBIC parameters controller

| | |
|---|---|
| | K1s=0.01 Coefficient in sensory input(Si) |
| V=1.3 Amygdalas Weight | K2s=0.009 Coefficient in sensory input(Si) |
| W=230 Orbitofrontals Weight | K3s=0.009 Coefficient in sensory input(Si) |
| Vi=170 Input Signal of Sensory | K1r=0.001 Coefficient in emotional signal(Rw) |
| Alfa=20e-5 Coefficient in $\Delta V_i$ | K2r=0.09 Coefficient in emotional signal(Rw) |
| Beta=20e-5 Coefficient in $\Delta W_i$ | K3r=0.001 Coefficient in emotional signal(Rw) |

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**Babak Mahmoodi** was born in Izeh, iran. He received B.SC in Islamic Azad University, Dezful branch, Iran in 2008 And M.sc electrical engineering from the same place at 2011. His main research interest is power system dynamic and control, Facts devices And Intelligent systems; he has worked in Islamic Azad University, Izeh branch as a teacher, Izeh, Iran since 2009.