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Type-2 Fuzzy Controller based Load Frequency Control of Interconnected System with/without ACDC Link

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Abstract

Enchantment of a stable equilibrium between the increasing demand and load is the essential stipulation of the system. The interconnected power sources in modern power engineering, lead to the interchange of power between the tie lines by virtue of semiconductor devices. The dynamic nature of the load and power insist on a perfect equilibrium between both during disturbances. The frequency and the voltage of the generating system are the vital constraints that need to be maintained at their stated value for the favorable operation. This paper elucidate a powerful controller for frequency & tie line power of a two area three unit distinct energy established source with nonlinear thermal power (TPS), hydro power (HPP) and gas power (GPP) plant in the form of a new type-II fuzzy PID to diminish the local errors. To justify supremacy of proposed type-II fuzzy controller a comparative analysis with fuzzy type-I and PID controllers has been carried out. To obtain precious gain parameters for the above implemented controllers, a novel Grass Hopper Optimization has been proposed for the study.

Keywords: *Type 2 Fuzzy controller; Grass Hopper Optimization; Load Frequency Control.*

1. Introduction

In order to have scheduled and uninterrupted inter area energy transfer, systematic subdivision of power system into control areas are mandatory based upon the frequency [1]. The coordinated tie line power balance is important to maintain power quality. The power quality needs to be balanced for any load fluctuation in the form of generation outages and frequency decay by adopting Automatic Generation Control (AGC) or Load Frequency Control (LFC) design [2]. The power system is taking a constraint of change of weight and span of local factors, which is responsible for the change in the active power and also the frequency. For tolerable operation of a power system a constant frequency and active power balance is the main objective. The design of the suitable regulator, to mitigate the nonlinearity developed from physical constraints, the load variation and disturbance is mandatory to establish the said balance.

Fuzzy logic controllers (FLCs) are acknowledged for its robust behaviour to analyse and control of non-linear systems. It is motivated by its specialty of handling imperfection and nonlinearities of the load and source disturbance. The conventional fuzzy controller, in other word called Type-1 fuzzy, that can be called as Type-2 fuzzy by scaling the MFs (functions of membership) of the first type.

Type-2 fuzzy sets have a flexible membership function, which can be reflected in a cubic space. This has the advantage in giving an additional degree of freedom for disturbance approach, emphasizing the aforesaid attribute and a robust dispersed control scheme.

The intention of the article is to inspect the frequency, inter-area tie power and load control for any complication for an inter area power network reviewing the ambiguity of the system. A new type 2 Fuzzy PID controller is developed and compared with a fuzzy PID and conventional PID controller for a two area power network with number of sources in the Matlab Simulink platform.

A good amount of research is found with the advantages of Type 2 fuzzy (T2FLC) controllers as discussed

The design, utilization and analysis of a T2FLC as part of the AGC with the fuzzy controller to control the ACE calculation to determine the deficiency or surplus generation is explained [3].T2FLC is imported in [4] and the output processing is focused which is based on the nature of reduction to catch more information about rule changes and defuzzyfication. Paper [5] explains T2FLC for achieving adaptive noise abolition and the nullification of the interference of immeasurable interference. The adopted 2D fuzzy is defended and a comparative analysis of the controller in neural network is explained in [6] with GA as the optimization method. LFC problem is focused for load variation in multi-area system with PI, Type-1 and Type-2 fuzzy system in [7] with a comparision of the controller. The advantage of T2FLC is discussed for different said systems and for the rapid load and system parameter variations in [8, 9 and 10]. The paper [11] explains the feedback error learning (FEL) for LFC to enhance the controller. The postulated type-2 Fuzzy Logic System (GT2FLS) approach for parameter shift and design is presented in [12]. The efficiency justified and the optimal values of the changing parameters are done by the Bee Colony Optimization (BCO). In this article [13, 14], type-2 fuzzy-PID controller as a function of derivative filter (T2FPIDF & T2FPID), type-1 fuzzy-PID controller (T1FPID) and conventional PID controller are compared. A new auto tuned symbiotic organism search (ASOS) & symbiotic organism search (SOS) method is also discussed.

By using interval type-2 Takagi–Sugeno (T–S) fuzzy models, the nonlinear systems are designed in [15], which are compensated in a consolidated type-2 fuzzy network. In order to handle the parameter change in predesigned MFs, an auto adaptive system is developed to manage the time-variant weighs w.r.t the upper membership functions. A dual mode Fuzzy controller is proposed in [16] for stipulated load change and the results are compared with fuzzy PI used in a doubly fed induction generator wind integrated system. The proposed controller is suitable to improve the standard frequency profile for any deviation. In the paper [17, 18 and 19] the Interval type-2 fuzzy logic based on the Proportional Integral Derivative (IT2FL-PID) controller for AGC of multi area is formed. This method is able to improve the stability for the wide changes in system parameters. A control method based on neuro system for LFC is given in [20, 21 and 22]. The proposed type-2 fuzzy controller with error back-propagation and gradient change is also mentioned. The multilayer perceptron (MLP) structure and Jacobian of the system is extracted to determine system model in transient. The proposed online controller is compared with the PI, PID, N-PID, fuzzy-PI and neural network controllers as a study. A Type-2 Fuzzy Rule-Based System in which the membership functions is established a direct state feedback control with reference tracking to generate the nonlinear control action using parallel distributed compensation techniques is explained in [23].This strategy is applied to a synchronous generator and also to a magnetic levitation system. A new MPC method is derived to reimburse the voltage-frequency variation for an ac shipboard micro grid (MG) is in [24]. A single input interval type-2 fuzzy logic controller with a big bang big crunch (BBBC) optimization and PSO are applied for the parameter selection of TAKAGI-SUGENO-KANG (TSK) type IT2FNNs in [25]. The paper [26] deals with the design of Fuzzy Self-Tuning Type-1 (FSTT1), Fuzzy Self-Tuning Interval Type-2 (FSTIT2), and Optimum Proportional-Integral-Derivative (OPID) controllers under the influence of parameter uncertainties, noise, and external load disturbances. A comparative analysis between the mentioned three controllers is carried out for LFC. The article [27, 28] addresses robust control of a two area six unit diverse energy power network. AGC aims in maintaining a proper balance by a robust type-II fuzzy PID controller to diminish all error signals defined in local region with a novel hybridized Grey Wolf Optimization and Sine Cosine algorithm (hyGWO-SCA).

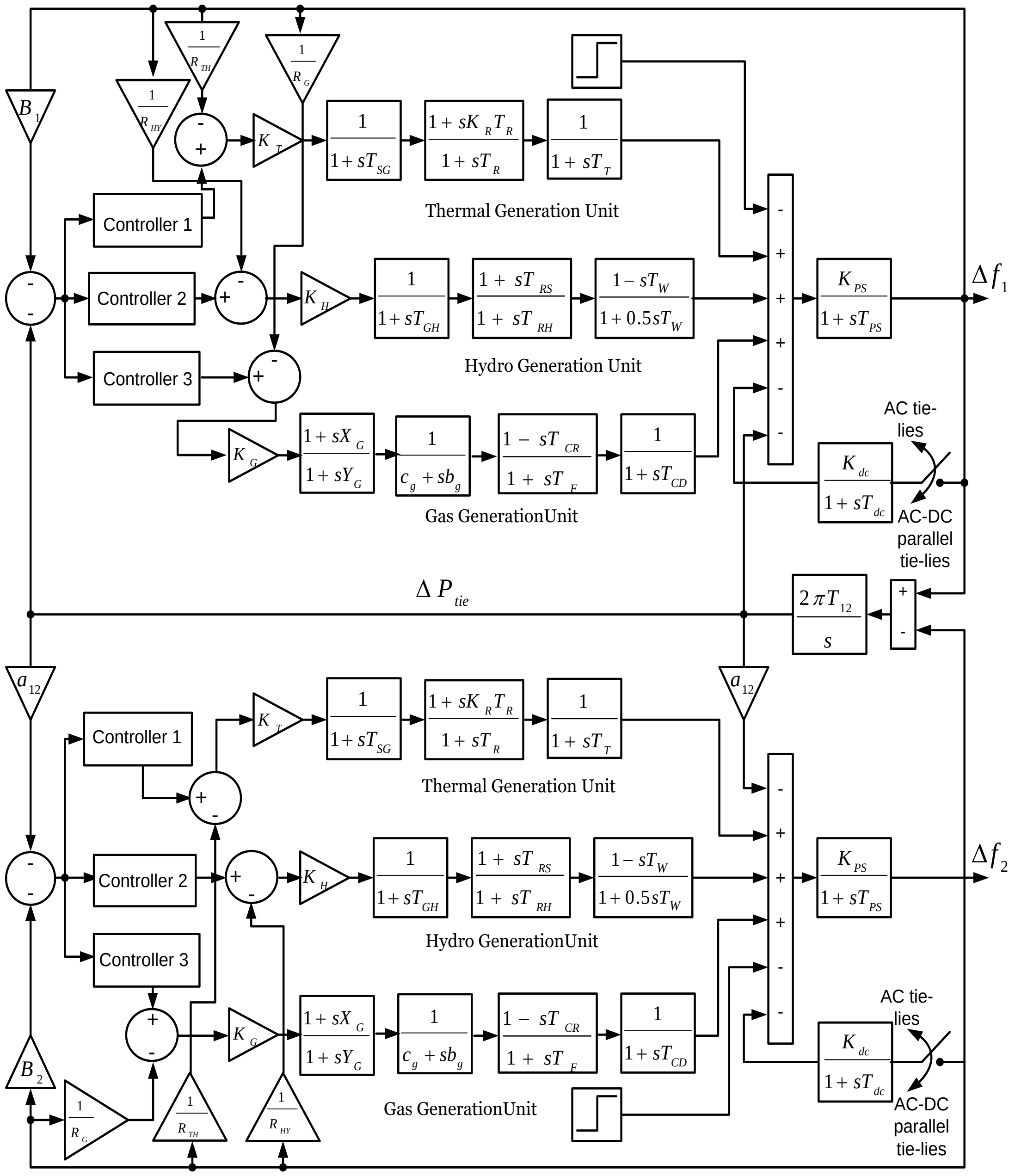

Figure 1. Model of hybrid generation system with AC-DC interconnecting lines.

2. System investigated

In the above article a LFC strategy in a two area coordinated multiple number of sources based in the power system is explained. The regulated field comprises of reheated thermal, a hydro and a gas system as in Fig. 1. A load turnover in the form of step signal for 0.01pu is applied to study the dynamic behaviour of the system under study. Each area is controlled by 2DFuzzy PID controller for frequency and tie line power deviation. There are three generating systems having their own governing systems. The inputs to the 2D fuzzy are operated on the basis of the area control errors (ACEs) as given in Eq.1 and 2.

$$ACE\_1 = \Delta P_{t\_1-2} + B_1 \Delta f_1 \quad (1)$$

$$ACE\_2 = \Delta P_{t\_2-1} + B_2 \Delta f_2 \quad (2)$$

Here ACE_1 and ACE_2 are the area control errors of the two said areas. ΔPt_1-2 , Δ Pt_2-1 are the change in the tie line power of area 1 and area 2. Δf1 and Δf2 are the change in the frequency deviations of two areas respectively.

3. Grasshopper algorithm for optimization

This is a nature-exhilarated algorithm, based on the congregate attitude of grasshoppers [26]. Usually, they can adhere to a massive swarm. In this algorithm, the base feature of the swarm is slow. The movement of the grasshoppers ends after attainment of food with suitable orientation. Eqs.3-7 explains the mathematical model of the behavioral swarming of grasshoppers.

Grass Hopper Optimization

- The Swarm is being Initialized by Eq.3

$$X_{GHOi} = (i = 1, 2, 3, ..., n) \tag{3}$$

- c_i_{max}, c_i_{min} and maximum number of iteration (*Lmax*) is Initialized by Eq.4

$$c\_i = c\_i_{max} - L\frac{c\_i_{max} - c\_i_{min}}{L_{max}} \tag{4}$$

Where c_i_{max} and c_i_{min} are the constants of the GHO algorithm.

- Fitness of each search agent is evaluated by Eq. 5

$$X_{GHOi} = (rn)_1 s_i + (rn)_2 g_i + (rn)_3 w_i \tag{5}$$

Where *si* is the social inter-response, *gi* is the gravitational force on i[th] grasshopper and *wi* is the wind eviction.*rn1*, *rn2* and *rn3* are the random numbers [0, 1].

- Select the best search agent depending upon the fitness function
    - While (L< Lmax)
    - Update c as per the equation given in Eq.4.
        - For (each grasshopper)
            - The distance between each set is calculated by Eq.6.

$$S_i = \sum_{\substack{j=1 \\ j\neq 1}}^{N} s(dk_{ij})\hat{d}^{ij}, s(dk) = f(e^{-dk/l}) - e^{-dk}$$
$$dk_{ij} = |x_j - x_i|, \hat{dk}^{ij} = (X_{GHOi} - X_{GHOj})/dk_{ij} \tag{6}$$

f and *l* are the parameter to be chosen for suitable values, dk_{ij} is the distance vector.

- Position of the current agent is updated by Eq.7

$$X_{GHOi}^{dk} = c\_i\left(\sum_{\substack{j=1 \\ j\neq 1}}^{N} c\_i\frac{ubk_d - lbk_d}{2} S_i\left(\left|x_{GHOj}^{dk} - x_{GHOi}^{dk}\right|\right)\frac{x_{GHOj} - x_{GHOi}}{dk_{ij}}\right) + \hat{T}_{dk} \tag{7}$$

Here T_{dk} is the target.

- Get back the current agent if going outside the boundary
- End for
- Update the best agent.
- Increase the Iteration by 1 in Eq.4.

- End while

Set the optimum agent.

4. Control Approach

In this article Type 2 FLC is introduced for the interconnected system with proper grading factors for the conventional fuzzy controller. The PID controller parameters are optimised based on the ITAE given in Eq.9 of the two area system using GWO algorithm for AC and AC-DC Parallel tie line. Finally the superiority of the proposed controller is established when compared with fuzzy [9] and PID controller [10].The system parameters are defined in Table.5 in appendix.

4.1. PID controller

The proportional integral derivative controller (PID) is the most popular, robust, well understood feedback controller that can provide distinguished result for dynamic plant. The PID algorithm has three steps, the proportional (Lp), integral (Li) and the derivative (Ld). A first has the effect of minimizing the rise time, an integral control has the effect of reducing the steady-state error, and a last has the effect of the stability increase of the system by shortifying the overshoot, and remodelling the transient response. The error signal (e (t)) is the discrepancy observed between the reference input (r (t)) and the Plant output (y (t)). The controller output (u (t)) is modulated for any disturbance (d (t)) observed in the plant and tunes the PID accordingly.

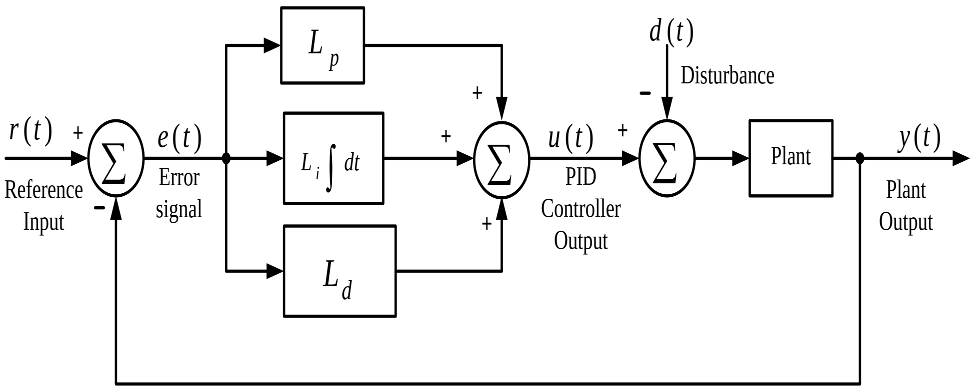

Figure 2. The Configuration of PID controller.

4.2. Type 1 Fuzzy Logic Controller

In this controller five functions of membership are defined as negative big (NB), negative small (NS), zero (Z), positive small (PS) and positive big (PB) for both ports as given in Fig.4. This controller needs (MFs) ^ 2 sets of rules to reproducing the fuzzy output. The rule set for the controller is depicted as per the output requirement in a Mamdani interface system. The system output is a fuzzy value and required to get converted to a real number using a suitable defuzzyfication approach.

4.2. Proposed Controller (Type 2 Fuzzy Logic Controller)

This controller has an upgraded disturbance handling efficacy due to the modulated membership function, as compared to type-1 Fuzzy. For this controller, the primary membership grade is same as that of the Type-1 fuzzy set in a predefined boundary as given in Fig.4. In conformity to each fundamental membership, there exists a secondary function (which can also be within same or different boundary w.r.t. the Type 1), as in Fig.5; this defines the probability of the prime member. The extra part is the value of the function at each instant of fuzzy 1, called its footprint of uncertainty (FOU) [24]. This is the cumulative number of fundamental membership function and presented as a sandwiched amidst the gap of both LMF

(*L1*) and UPF (*L2*).A three dimensional Type-2 fuzzy set can be defined as in Eq.8 where *L3* and *L4* are the gain of the fuzzy 1 controller.

$$F(A)=\{(ACE, x), \mu_{F(A)}(\forall ACE, x) \mid \forall ACE, xJ_{ACE} \mid \subseteq [a, b]\} \qquad (8)$$

F (A) is the Type 2 Fuzzy set, *a*, *b* are the set boundary preferably [0, 1], $\mu_{F(A)}$ is the Type 1 Fuzzy set, ACE and *x* are the primary and secondary membership functions respectively. The compiled block diagram of the proposed controller is given in Fig.3.

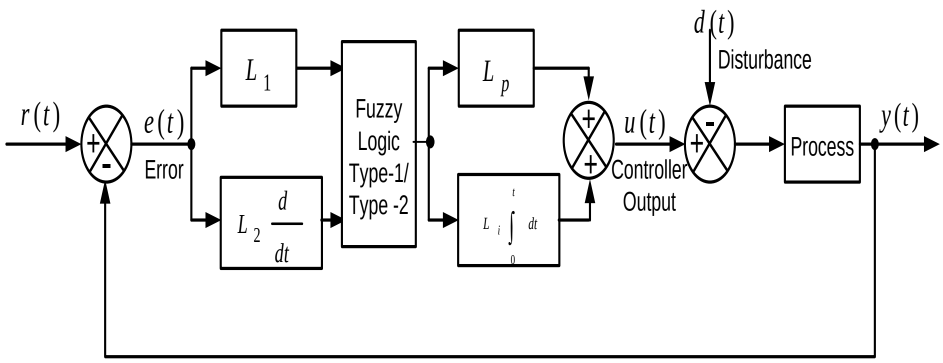

Figure 3. The Type-1 and type-2 fuzzy controller and its organisation.

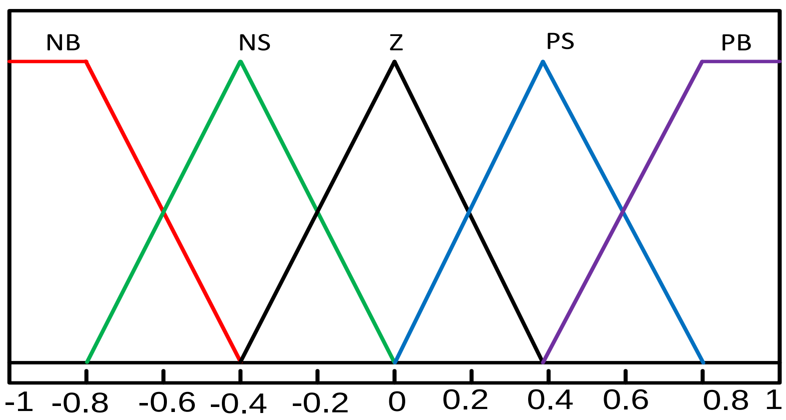

Figure 4. The Membership functions for Type-1 fuzzy controller.

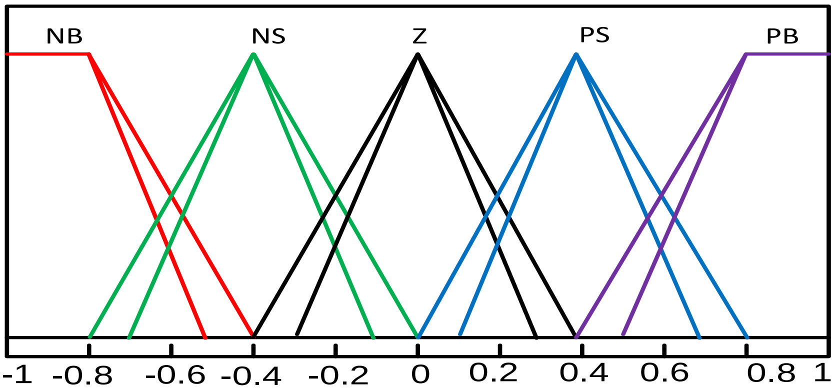

Figure 5. Membership functions for Type-2 fuzzy controller.

5. Result and analysis

The supremacy of the controller is defined on the basis of the span of response achieved after the condition of instability when offered in the form of disturbance. Practical systems cannot also capable of achieving the set performance because of the trade-off between the response and stability is always desirable. This can anyway be done by optimized selection of controller constraints.

In this article a type 2 fuzzy PID controller is defined for AGC by considering the ITAE as the objective function as selected by GHO and manipulating the weights of MFs by suitable gains. The ITAE is explained as in Eq.9.

$$ITAE=\int_0^t (|\Delta f_1|+|\Delta f_2|+|\Delta P_{tie}|)\cdot t\cdot dt \quad (9)$$

5.1. Result analysis With AC Tie-line only

To analyse the compelling pursuance of the power network as in Fig 1 with AC tie lines, a step perturbation of 0.01p.u is applied in field 1. The accretion of the proposed type 2 fuzzy controller, fuzzy 1 and PID is given in Table 1 and the comparative analysis of change of frequency of both the areas and the tie line power are pro-founded in Fig. 6, 7 and 8.

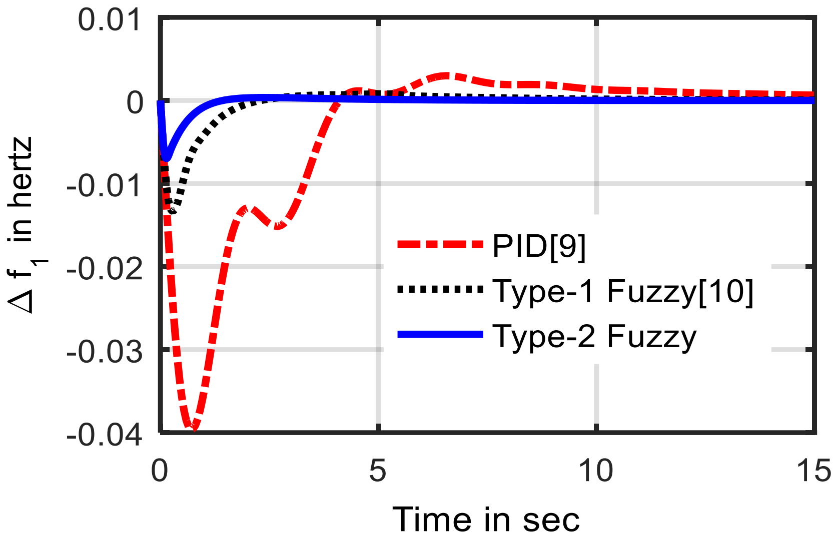

Figure 6. The variation in the Frequency in area 1 with AC tie-line.

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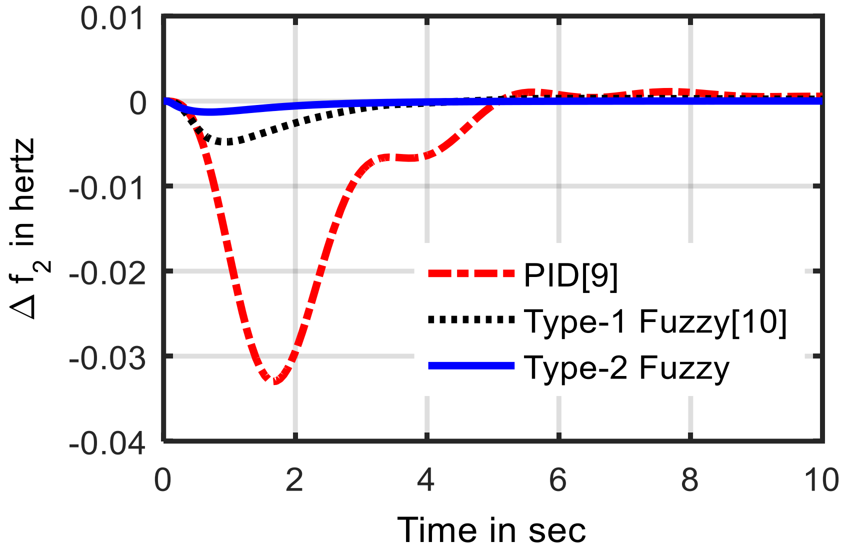

Figure 7. The variation in Frequency in area 2 with AC tie-line.

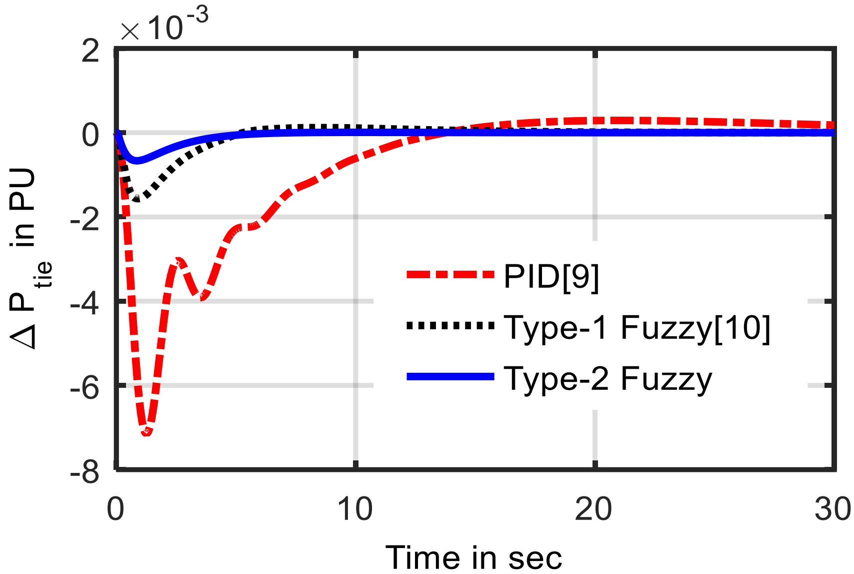

Figure 8. The variation in Tie-line power with AC tie-line.

Table 1. The optimum gains all controllers with AC tie-line.

Controller	Parameters	Optimum Values		
		Thermal	Hydro	Gas
Type-2 Fuzzy	L_1	1.9076	0.1685	1.1456
	L_2	0.1000	1.2594	1.2456
	L_3	1.0278	0.1000	0.2456
	L_4	1.8852	1.9254	0.5874
Type-1 Fuzzy	L_1	1.9985	0.1002	1.9782
	L_2	1.9874	1.1278	1.0734
	L_3	1.9679	0.1032	1.9790
	L_4	1.9926	0.7264	1.6516
PID	L_P	0.779	0.5805	0.5023
	L_I	0.2762	0.2291	0.9529
	L_D	0.6894	0.7079	0.6569

Table 2. The Response indices with AC tie-lines.

Deviations	Time Domain Factors	Type-2 Fuzzy	Type-1 Fuzzy[10]	PID[9]
Δf_1	T_s in sec	1.0934	5.9948	16.7793
	O_{sh} in Hz	0.0003	0.0007	0.0030
	U_{sh} in Hz	-0.0070	-0.0133	-0.0396
Δf_2	T_s in sec	2.1256	3.2587	10.3475
	O_{sh} in Hz	0.00001	0.0003	0.0011
	U_{sh} in Hz	-0.0013	-0.0048	-0.0330
ΔP_{tie}	T_s in sec	1.7163	3.0297	10.4699
	O_{sh} in Hz	0.000007	0.0001	0.0003
	U_{sh} in Hz	-0.0007	-0.0016	-0.0071

Results obtained from different controllers are compared with that of the work in [9 and 10] and set to be better in in terms of undershoot (U_{sh}), overshoot (O_{sh}) and settling time (T_s) of Δf_1, Δf_2 and ΔP_{tie} as given in Table.2.

5.2. Result analysis With AC Tie-line only

To analyse the variable response of the power network as in Fig 1 with AC-DC tie lines, a step perturbation same as the previous value is applied in field 1. The rise of the controller gain of the proposed type 2 fuzzy controller, fuzzy 1 and PID is given in Table 3 and the comparative analysis of change of frequency of both the areas and the tie line power are pro-founded in Fig. 9, 10 and 11.

Results obtained for all the conditions are compared with that of a recently published work [9 and 10] and it can be concluded that the proposed system work be better in in terms of undershoot (U_{sh}), overshoot (O_{sh}) and settling time (T_s) of Δf_1, Δf_2 and ΔP_{tie} as given in Table.4

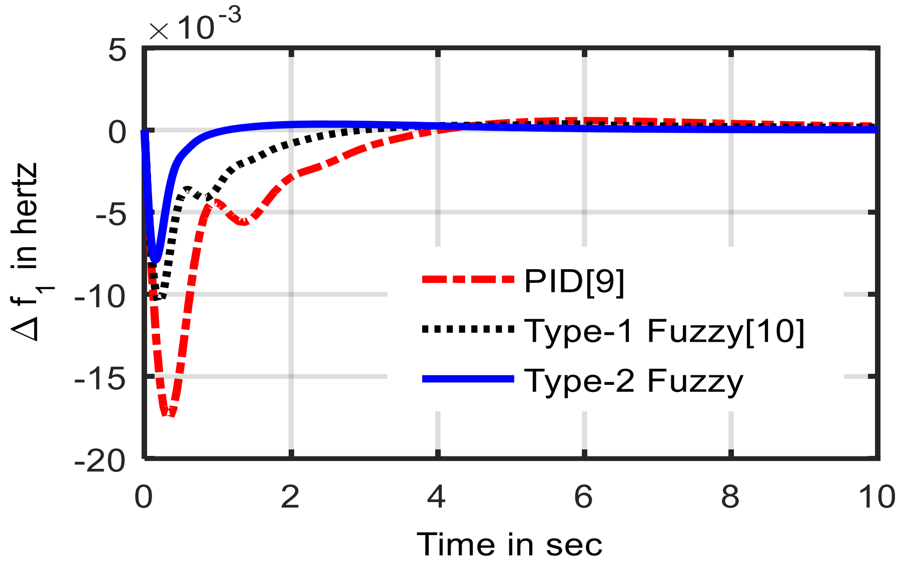

Figure 9. The variation in Frequency in area 1 with AC-DC tie-line.

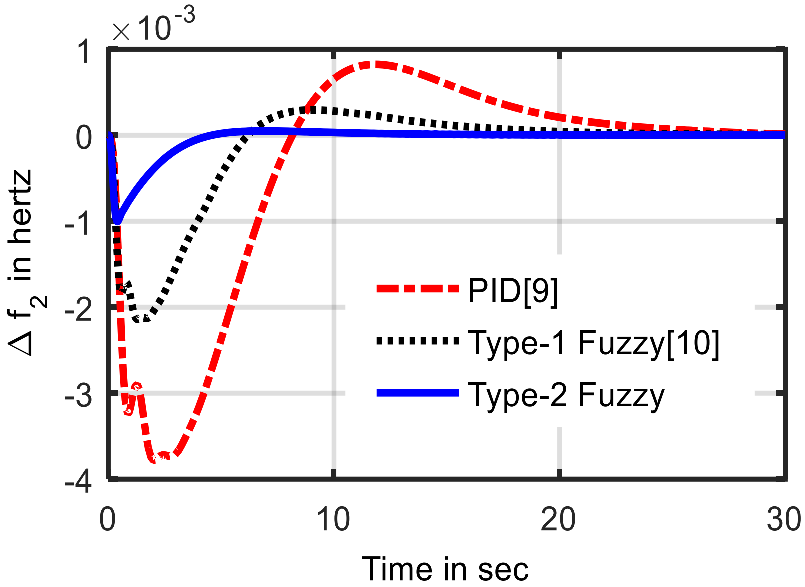

Figure 10. The variation in Frequency in area 2 with AC-DC tie-line.

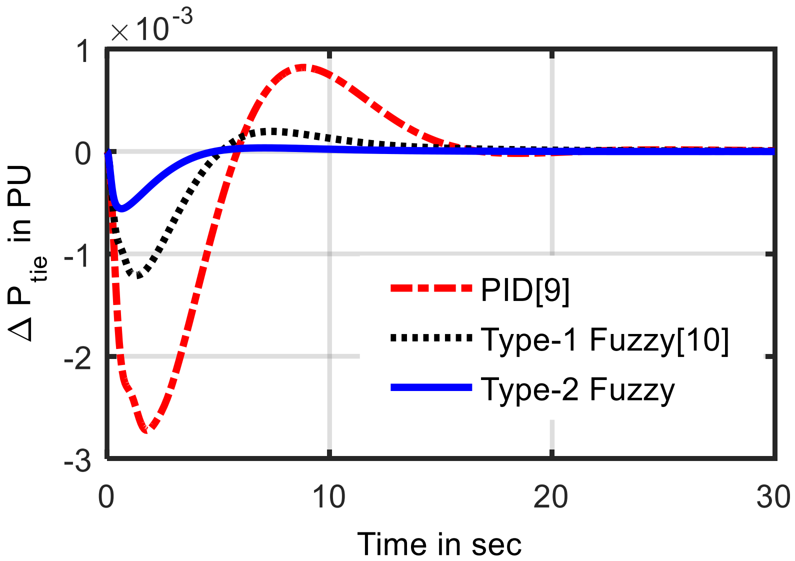

Figure 11. The variation in Tie-line power with AC-DC tie-line.

Table 3. The Optimum gains of all controllers with AC-DC tie-line.

Controller	Parameters	Optimum Values		
		Thermal	Hydro	Gas
Type-2 Fuzzy	L_1	1.6276	1.1541	1.4119
	L_2	0.1000	1.5442	1.9636
	L_3	1.0121	1.0520	1.8606
	L_4	1.2626	0.1000	0.6111
Type-1 Fuzzy	L_1	1.9995	0.9668	1.9969
	L_2	1.9889	1.2913	1.1982
	L_3	1.9975	0.1001	1.9867
	L_4	1.9829	1.9988	1.9882
PID	L_P	1.6929	1.77731	0.9094
	L_I	1.9923	0.7091	1.9425
	L_D	0.8269	0.4355	0.2513

Table 4 The Response indices with AC-DC tie- lines.

Deviations	Time Domain Factors	Type-2 Fuzzy	Type-1 Fuzzy[10]	PID[9]
Δf_1	T_s in sec	0.7506	2.2245	7.0776
	O_{sh} in Hz	0.0003	0.0003	0.0005
	U_{sh} in Hz	-0.0079	-0.0104	-0.0175
Δf_2	T_s in sec	1.6295	4.8078	15.7984
	O_{sh} in Hz	0.00004	0.0002	0.0008
	U_{sh} in Hz	-0.0010	-0.0021	-0.0038
ΔP_{tie}	T_s in sec	1.1322	3.3632	11.5892
	O_{sh} in Hz	0.00003	0.0001	0.0008
	U_{sh} in Hz	-0.0006	-0.0012	-0.0027

6. Conclusion

In this paper, GHO algorithm is used to optimize the controller gain of the proposed Type 2 fuzzy-PID controller in order to handle the LFC problem of a two-area connected multi-source power network. The proposed controller takes advantage of improving the range of Type 1 Fuzzy and makes the system more efficient. Each field has a reheat thermal unit, a hydro unit and a gas unit for study. At the beginning the weights of the PID for AGC are optimized GHO algorithm. ITAE is considered as the objective function for a step change of the load (0.01p.u) and the pursuance is studied. The result received is correlated with that of a recently published article based on DE optimized conventional PID for AGC and Type 1 Fuzzy PID for the equal system. It can be concluded the Type 2 fuzzy PID controller is yielding superior dynamic performance for AC tie-lines and AC-DC parallel tie-lines.

Appendix

The Data used for the two area multi-source power system are taken from Ref. [9-10].

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