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Load Frequency Control of Deregulated Power System Using Different Fuzzy Controllers

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Abstract: ***Load frequency control (LFC) plays a vital role in power system operation and control. The LFC of deregulated system is to not only balance the generation and demand but to allocate generation between various systems. In deregulated environment, LFC is one of the ancillary services. With the help of conventional controllers, we cannot achieve better performance. To achieve better performance, a Fuzzy PID (FPID) controller is presented in this paper. The gains Kp ,Ki, Kd are tuned from the knowledge base and fuzzy inference. To improve the system performance further, a multi-stage fuzzy controller is designed. The multi-stage controller uses the fuzzy switch to blend a proportional derivative (PD) fuzzy logic controller with an integral fuzzy logic input. It operates on fuzzy values, passing the consequence of a prior stage on to the next stage as fact. Simulations under three different scenarios are done, and its performance is compared with the FPID and PID controllers on the basis IAE, ITAE, ITSE performance indices.***

Keywords: LFC, PID, Fuzzy PID, MSFPID, Deregulated power system

1. Introduction

The main goal of the LFC is to maintain zero steady state errors for frequency deviation and good tracking load demands in a multi-area deregulated power system. In addition, the power system should fulfill the requested dispatch conditions [6]. In practice different conventional control strategies are utilized for LFC viz., Proportional and integral (PI), Proportional, Integral and Derivative (PID) and Optimal control [2,8]. The PI controller improves steady state response simultaneously allowing a transient error with little or no overshoot. The PID controller improves the transient response so as to reduce error amplitude with each oscillation and then output is eventually settled to a final desired value. Better margin of stability is ensured with PID controllers. The limitation of conventional PI and PID controllers are slow and lack of efficiency in handling system non-linearity. The optimal control is quite often impractical for the implementation.

To overcome these difficulties fuzzy controllers are introduced in LFC. Fuzzy modeling is the method of describing the characteristics of a system using fuzzy inference rules. The method has a distinguishing feature in that it can express linguistically complex nonlinear systems. . The fuzzy controllers does not require the information of the system states like conventional controllers and the control rules can be framed easily with the knowledge of system operator. With the help of fuzzy proportional integral derivative (FPID) methods, the steady state as well as transient response of the system is improved [9]. The FPID controller requires a three-dimensional rule base. However, in practice, this is difficult to obtain because, three-dimensional information is usually beyond the sensing capability of a human expert, and it makes the design process more complex. Therefore, to overcome the above difficulties the multi-stage fuzzy PID (MSFPID) controller is a better solution [1].

2. Deregulated Power System

The traditional power system industry has a "vertically integrated utility" (VIU) structure and treated as a single utility company which monopolies generation, transmission and distribution in a certain geographic region [6]. The last decade has witnessed drastic changes in the electric power industry in many parts of the world. The usage of electricity has been growing tremendously in the upward trend with the modernization of society. Interconnection between networks and interaction between companies is usually voluntary to improve system reliability and performance [6]. In order to achieve better service, reliable operation, the power industry in many countries had undergone significant changes and was reforming in to a free market, which is also known as deregulation. A worldwide trend towards restructuring and deregulation of the power industry has been developed in the last one and half decade and the electric utilities around the world are confronted with restructuring, deregulation and privatization. The traditional vertically monopolistic structure has been deregulated and these vertically integrated utilities no longer exist. With the introduction of deregulation to the electricity market, consumers have the option to choose the power supplier. Factors such as the prices and reliability of the power supply will have the increasing importance.

3. LFC in Deregulation

In deregulated power system, generation companies (GENCOs) may or may not participate in the AGC task. On the other hand, distribution companies (DISCOs) have the liberity to contact with any available GENCO in their own or other areas. There can be various combinations of contacts between each Disco and the available Gencos. All these contracts are visualized in the form of ‘‘generation participation matrix (GPM)’’ conveniently in the generalized model. The GPM shows the participation factor of each Genco in the considered control area and a Disco determines each control area. The rows of a GPM correspond to Gencos and the columns to Discos that contract power. For example, for a large-scale power system with “M”control area (Discos) and "N" Gencos, the GPM will have the following structure [6].

$$GPM = \begin{bmatrix} gpf_{11} & gpf_{12} & \cdots & gpf_{1(m-1)} & gpf_{1m} \\ gpf_{21} & gpf_{22} & \cdots & gpf_{2(m-1)} & gpf_{2m} \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ gpf_{(n-1)1} & gpf_{(n-1)2} & \cdots & gpf_{(n-1)(m-1)} & gpf_{(n-1)m} \\ gpf_{n1} & gpf_{n2} & \cdots & gpf_{n(m-1)} & gpf_{nm} \end{bmatrix} \quad (1)$$

In the above, gpf_{ij} refers to 'generation participation factor' and shows the participation factor of $Genco_i$ in total load following requirement of Disco j based on the contract. Sum of all entries in each column of GPM is unity. i.e,

$$\sum_{i=1}^{n} gpf_{ij} = 1$$

Any entry in a GPM that corresponds to a contracted load by a Disco, demanded from the corresponding Genco, must be reflected to the control area system. This introduces new information signals that were absent in the traditional AGC structure. These signals identify that Genco has to follow a load demanded by which Disco. The Block diagram of the generalized LFC scheme for control $area_i$ in a restructured system is shown in Fig.1. Dashed-dot lines show interfaces between areas and the demand signals based on the possible contracts. These new information signals are absent in the traditional LFC scheme. As there are many Gencos in each area, ACE signal has to be distributed among them due to their ACE participation factor in the LFC task and $\sum apf = 1$

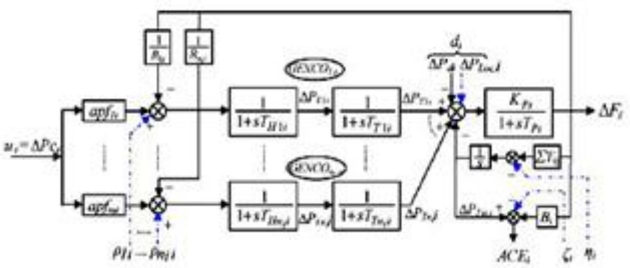

Figure 1: Modified control area in a deregulated environment

The generalized LFC equations for the deregulated power system is given by

$$d_i = \Delta P_{Loc,i} + \Delta P_{di} \quad (2)$$

$$\eta_i = \sum_{\substack{j=1 \\ j\neq i}}^{m} T_{ij} \Delta f_j \quad (3)$$

η_i = Area interface

$$\xi_i = \sum_{\substack{k=1 \\ k\neq i}}^{m} \Delta P_{tie,ik,schdule} \quad (4)$$

ζ_i = scheduled tie line power deviation of area i

$\Delta P_{tie,ik,schedule}$ = Σ (Total Power Export – Total power Import)

$$= \sum_{\substack{j=1 \\ j\neq i}}^{n} \left(\sum_{k=1}^{m} gpf_{kj} \right) \Delta P_{Lj} - \sum_{k=1}^{m} \left(\sum_{\substack{j=1 \\ j\neq i}}^{n} gpf_{jk} \right) \Delta P_{Li} \quad (5)$$

$$\Delta P_{tie,i-error} = \Delta P_{tie,i-actual} - \xi_i \quad (6)$$

$$\Delta P_{mi} = \sum_{j=1}^{n} gpf_{ij} \Delta p_{Lj} \quad (7)$$

$\Delta P\ Loc_i$ = deviation in total local demand of area i
$\Delta P\ Loc_{j\text{-}i}$ = deviation in contracted demand of $Disco_j$ in area i
$\Delta PUL_{j\text{-}i}$ =deviation in un-contracted demand of Disco j in area i

With the help of these generalized model equations, we can model the multi area power system under deregulation.

4. PID, FUZZY PID and MSFPID Controllers

A. PID Controller:

The PID controller improves the transient response so as to reduce error amplitude with each oscillation and then output is eventually settled to a final desired value. Better margin of stability is ensured with PID controllers. The mathematical equation for the PID controller is given as

$$y(t) = k_p u(t) + k_i \int u(t) + k_d \frac{d}{dt} u(t)$$

Where y (t) is the controller output and u (t) is the error signal. Kp , Ki and Kd are proportional, integral and derivative gains of the controller. The limitation of conventional PI and PID controllers are slow and lack of efficiency in handling system non-linearity.

B. Fuzzy Controller Design

Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. Because of the complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. On the other hand, their robustness and reliability make fuzzy controllers useful for solving a wide range of control problems in power systems. In general, the application of fuzzy logic to PID control design can be classified in two major categories according to their manner of construction [1].

1. A typical LFC is constructed as a set of heuristic control rules, and the control signal is directly deduced from the knowledge base.
2. The gains of the conventional PID controller are tuned online in terms of the knowledge base and fuzzy inference, and then, the conventional PID controller generates the control signal.
3. In this paper, the second method is used. The block diagram for Fuzzy PID controller is shown in fig.2

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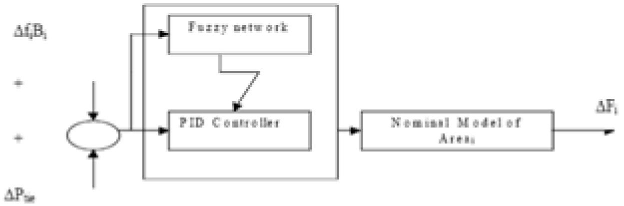

Figure 2: Block diagram of fuzzy PID controller

Fuzzy PID controller for each of the three areas is designed. The proposed controller is a two level controller. The first level is a fuzzy network, and the second level is a PID controller. The structure of the classical FPID controller is shown in Fig.3 in which the PID controller gains are tuned online for each of the control areas.

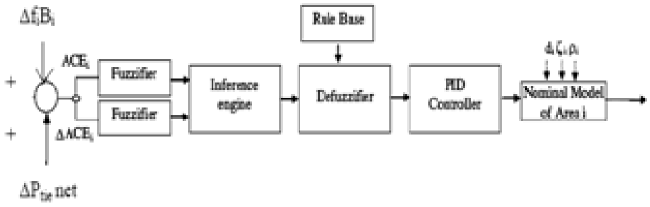

Figure 3: Scheme of Fuzzy network

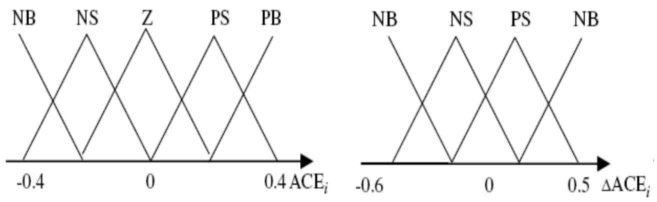

Figure 4: Memberships for ACE and ΔACE

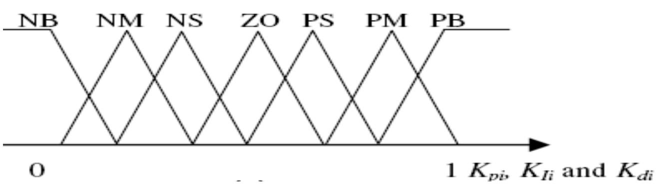

Figure 5: Memberships for Ki, Kp, Kd

Table I: Rule Table for K_{pi} AND K_{ii}

ΔACE

ACE	NB	NS	PS	PB
NB	NS	PS	NB	NB
NS	PB	NM	ZO	NM
Z	NB	PB	NS	PM
PS	PB	PM	NB	PB
PB	NB	NS	NB	NM

ΔACE

ACE	NB	NS	PS	PB
NB	NM	NB	NB	NB
NS	NM	NB	NB	NM
Z	NB	PB	PB	NM
PS	PM	PB	PB	PB
PB	PS	NM	NM	PM

Table II: Rule Table for K_{di}

ΔACE

ACE	NB	NS	PS	PB
NB	NS	PS	NB	NB
NS	PB	NM	ZO	NM
Z	NB	PB	NS	PM
PS	PB	PM	NB	PB
PB	NB	NS	NB	NM

C. Multi Stage Fuzzy PID Controller

A multi-stage fuzzy PID controller with fuzzy switch is a kind of controller where the PD controller becomes active when certain conditions are met. The resulting structure is a controller using two-dimensional inference engines (rule base) to perform reasonably the task of a three-dimensional controller. The proposed method requires fewer resources to operate, and its role in the system response is more apparent, i.e. it is easier to understand the effect of a two-dimensional controller than a three-dimensional one. This controller strategy combines the fuzzy PD controller and the integral controller with a fuzzy switch. The fuzzy PD stage is employed to penalize fast change and large overshoots in the control input due to corresponding practical constraints. The integral stage is used in order to get disturbance rejection and zero steady state error. The block diagram for MSFPID is shown Fig.5

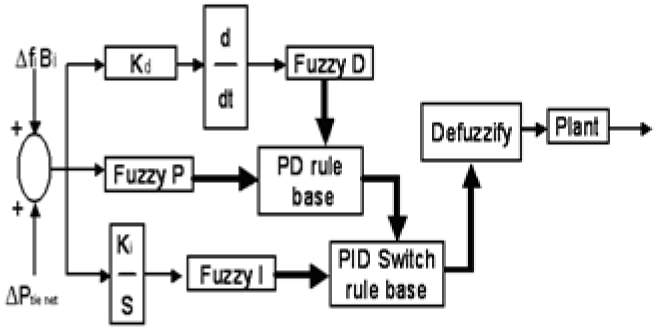

Figure 5: Block diagram of MSFPID

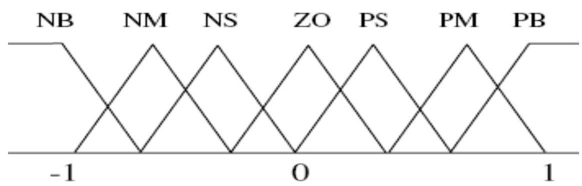

Figure 6: Symmetric fuzzy membership partition for input and output variables

Table III: (a) PD Rule Base Table III (b) PID Rule Base

(a) ΔACE

ACE	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZO
NM	NB	NB	NB	NM	NS	ZO	PS
NS	NB	NB	NM	NS	ZO	PS	PM
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NS	ZO	PS	PM	PB	PB
PM	NS	ZO	PS	PM	PB	PB	PB
PB	ZO	PS	PM	PB	PB	PB	PB

(b) PD values

∫ACE	NB	NM	NS	ZO	PS	PM	PB
NB	NB	NM	NS	NB	PS	PM	PB
NM	NB	NM	NS	NM	PS	PM	PB
NS	NB	NM	NS	NS	PS	PM	PB
ZO	NB	NM	NS	ZO	PS	PM	PB
PS	NM	NM	NS	PS	PS	PM	PB
PM	NB	NM	NS	PM	PS	PM	PB
PB	NB	NM	NS	PB	PS	PM	PB

5. Simulation

Simulation studies are done for different operating scenarios.

Scenario-1: Pool Co Based Transactions

In this scenario, GENCOs participate only in load following control of their own areas. The contracts between DISCOs and available GENCOs are represented based on the following GPM. It is noted that the GENCOs of area 3 do not participate in the AGC task. The scheduled contracts between gencos and Discos are represented in the form of generation participation matrix.

$$GPM = \begin{bmatrix} 0.6 & 0.5 & 0 & 0 & 0 & 0 \\ 0.4 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \end{bmatrix}$$

Scenario-2: Combination of Pool Co and Bilateral based transactions

In this scenario, DISCOs have the freedom to have a contract with any GENCO in their own or other areas. Consider that all the DISCOs contract with the available GENCOs for power as per the GPM shown below and all the GENCOs are participating in the AGC task.

$$GPM = \begin{bmatrix} 0.25 & 0 & 0.25 & 0 & 0.5 & 0 \\ 0.5 & 0.25 & 0 & 0.25 & 0 & 0 \\ 0 & 0.5 & 0.25 & 0 & 0 & 0 \\ 0.25 & 0 & 0.5 & 0.75 & 0 & 0 \\ 0 & 0.25 & 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

Scenario 3: Contract violation

In general, DISCOs may violate a contract by demanding more power than that specified in the contract. The excess power that is demanded by a DISCO is reflected as a local load of that particular area (unconstructed demand). Consider scenario 2 again, It is assumed that in addition to the specified contracted load demands, DISCO 1 in area 1, DISCO 1 in area 2 and DISCO 2 in area 3 demand 0.05, 0.04 and 0.03 pu MW as large un-contracted loads, respectively. The GPM is same as the above case. A step load disturbance of 0.1 pu is considered for each DISCO in areas 1 and 2 for poolco. In case of Bileteral and Contract violation scenarios, step load disturbance of 0.1 pu is considered in all the three areas.

6. Results

Performance of Controllers:

Scenario-1: Pool Co Based Transactions

It is assumed that a large step load of 0.1pu is demanded by each DISCO in areas 1 and 2.

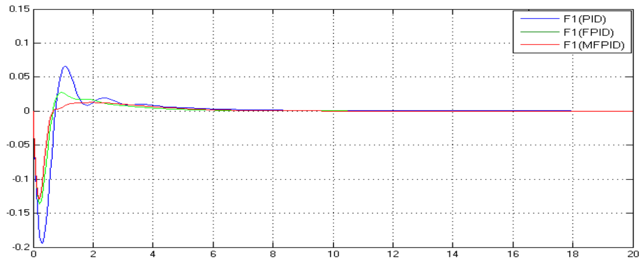

Figure 7: Frequency deviation in Area1 (ΔF1) with PID, FPID and MSFPID controllers

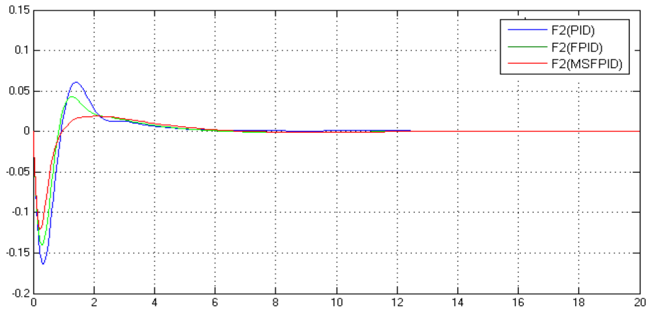

Figure 8: Frequency deviation in Area2 (ΔF2) with PID, FPID and MSFPID controllers

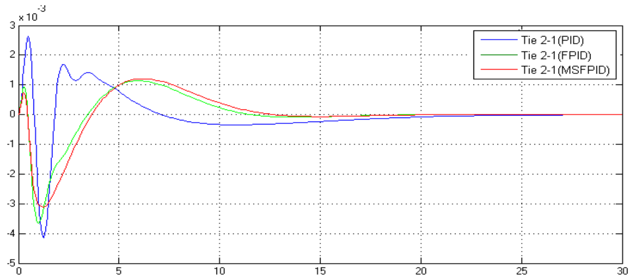

Figure 9: Tie line power flow variation (ΔP tie 2-1) with PID, FPID and MSFPID

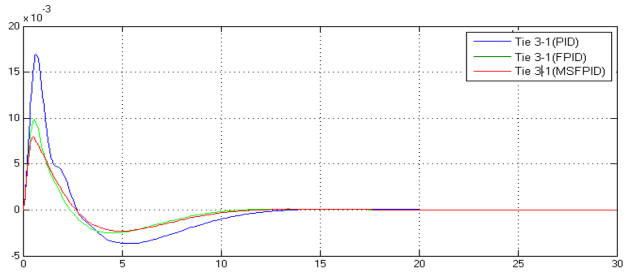

Figure 10: Tie line power flow variation (ΔP tie 3-1) with PID, FPID and MSFPID controllers

Scenario-2: Combination of Pool Co and Bilateral based transactions

It is assumed that a large step load of 0.1pu is demanded by each DISCO in three areas

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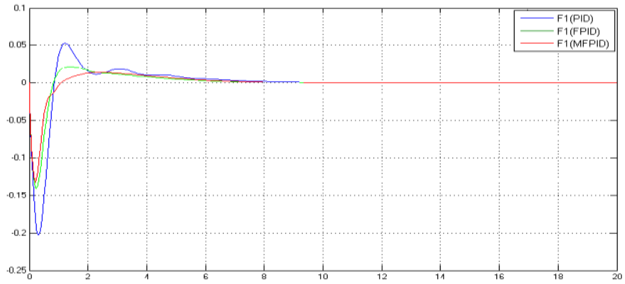

Figure 11: Frequency deviation in Area1 (ΔF1) with PID, FPID and MSFPID controllers

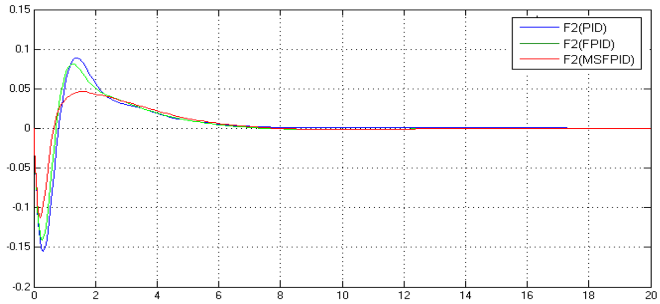

Figure 12: Frequency deviation in Area2 (ΔF2) with PID, FPID and MSFPID controllers

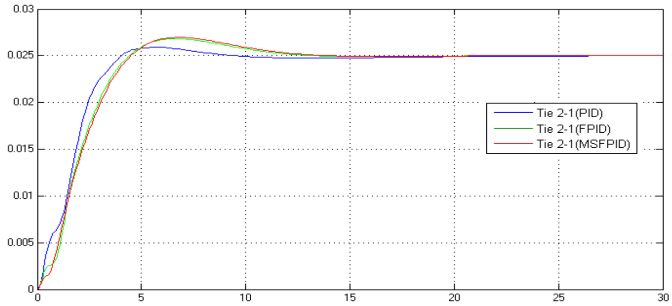

Figure 13: Tie line power flow variation (ΔP tie 2-1) with PID, FPID and MSFPID controllers

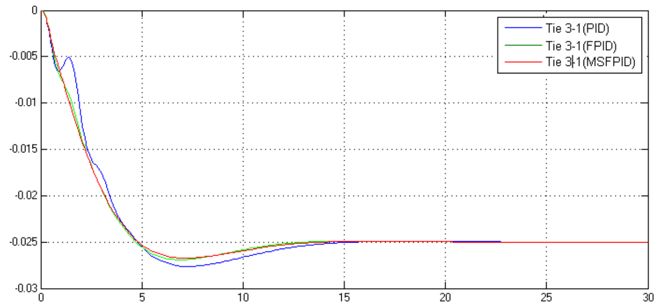

Figure 14: Tie line power flow variation (ΔP tie 3-1) with PID, FPID and MSFPID controllers

Scenario-3: Contract Violation

It is assumed that a large step load of 0.1pu is demanded by each DISCO in three areas and in addition to the specified contracted load demands, DISCO 1 in area 1, DISCO 1 in area 2 and DISCO 2 in area 3 demands 0.05, 0.04 and 0.03pu as large un-contracted loads, respectively.

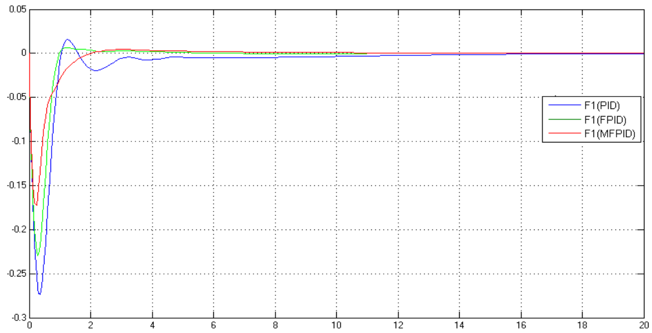

Figure 15: Frequency deviation in Area1 (ΔF1) with PID, FPID and MSFPID controllers

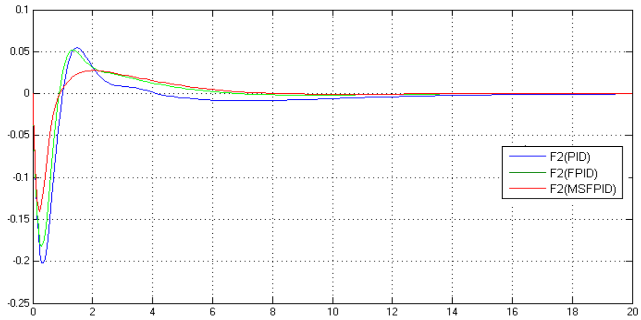

Figure 16: Frequency deviation in Area2 (ΔF2) with PID, FPID and MSFPID controllers

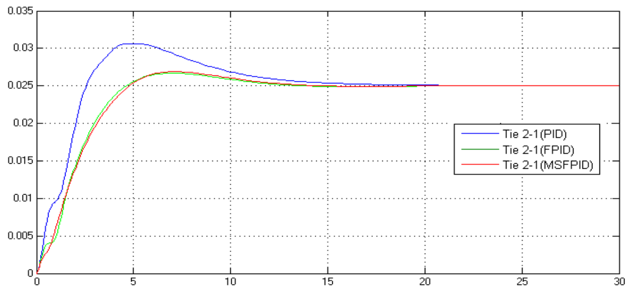

Figure 17: Tie line power flow variation (ΔP tie 2-1) with PID, FPID and MFPID controllers

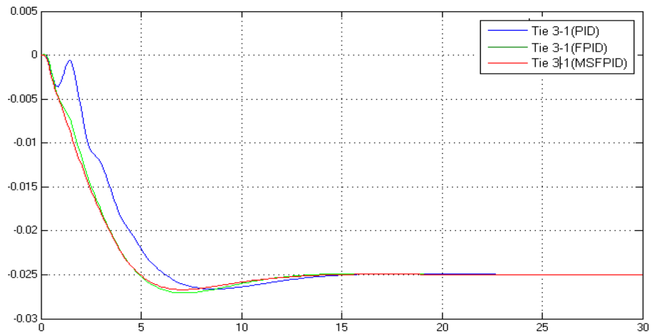

Figure 18: Tie line power flow variation (ΔP tie 3-1) with PID, FPID and MSFPID controllers

Table VI: Performance indices of IAE, ITAE, and ITSE under different scenarios

	Poolco		
	IAE	ITAE	ITSE
PID	47.49	18.55	4.65
FPID	23.84	12.37	1.54
MSFPID	**22.93**	**9.98**	**1.11**
	Bilateral		
	IAE	ITAE	ITSE
PID	59.62	26.28	6.29
FPID	38.12	18.36	2.89
MSFPID	**34.28**	**14.7**	**2.02**
	Violation		
	IAE	ITAE	ITSE
PID	95.90	36.56	11.79
FPID	28.12	19.06	3.88
MSFPID	**28.06**	**15.33**	**1.18**

7. Conclusion

The modeled system is tested under three different scenarios namely, poolco based transactions, combination of poolco and bilateral transactions and contract violation transactions. The frequency deviation and tie line power variations in three areas under different scenarios are less with MSFPID controller when compared to FPID and PID controllers. The system performance characteristics in terms 'IAE', 'ITAE', 'ITSE' reveals that the performance of MSFPID is comparatively better than other controllers.

Appendix

Table VII: GENCO Parameters

	1-1	2-1	1-2	2-2	1-3	2-3
Rated(MW)	1000	800	1100	900	1000	1020
T_T **(s)**	0.32	0.30	0.30	0.32	0.31	0.34
T_G(s)	0.06	0.08	0.06	0.07	0.08	0.06
R(Hz/pu)	2.4	2.5	2.5	2.7	2.8	2.4
A(apf)	0.5	0.5	0.5	0.5	0.6	0.4

Table VIII: Control area parameters

Parameter	Area-1	Area-2	Area-3
K_P(Hz/pu)	120	125	120
T_P(s)	20	25	20
B(pu/Hz)	0.4250	0.3966	0.3522
T_{ij}(pu/Hz)	T_{12}=0.245, T_{13}=0.212		

Table IX: PID controller gains:

Area	K_d	K_p	K_i
1	0.2	0	0.3
2	0.3	0.1	0.9
3	0.1	0.3	0.6

References

[1] H. Shayeghi , H.A. Shayanfar , A. Jalili , Multi-stage fuzzy PID power system automatic generation controller in deregulated environments Energy Conversion and Management 47 (2006) 2829–2845
[2] Elgerd OI. Electric energy system theory: an introduction, New York: McGraw-Hill; 1971
[3] Liu F, Song YH, Ma J, Lu Q. Optimal load frequency control in the restructured power systems. IEE Proc Gener Transm Distrib 2003; 15(1):87–95
[4] H.Shayeghi, H.A. Shayanfar, O.P.Malik. Robust decentralized neural networks based LFC in a deregulated power system, Energy Conversion and Management 77(2007)241-251
[5] Zeynelgil HL, Demiroren A, Sengor NS. The application of ANN technique to automatic generation control for multi-area power system. Elect Power Energy Syst 2002; 24:354–545
[6] Bevrani H, Mitani Y, Tsuji K. Robust decentralized AGC in a restructured power system. Energy Convers Manage 2004; 45:2297–312.
[7] Lim KY, Wang Y, Zhou R. Robust decentralized load frequency control of multi-area power system. IEE Proc Gener Transm Distrib 1996; 43(5):377–86.
[8] Chang C, Fu W. Area load frequency control using fuzzy gain scheduling of PI controllers. Elect Power Syst Res 1997; 42:145–52.
[9] Petrov M, Ganchev I, Taneva A. Fuzzy PID control of nonlinear plants. In: 2002 first international IEEE symposium on intelligent system; September 2002. p. 30–5.
[10] Adams MJ. Multi-stage fuzzy PID controller with fuzzy switch. In: Proceeding of the IEEE international conference on control applications, vol. 4; 2001. p. 323–7.
[11] Christie RD, Bose A. Load frequency control issues in power system operations after deregulation. IEEE Trans Power Syst 1996; 11(3):1191–200.

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