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Research paper

AGC of multi area power system based PSO under deregulated conditions

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Abstract

In This research PIDF (Proportional Integral Derivative with Filter) is suggested to control the ACE (area control error) signal of automatic generation control circuit (AGC) for two-area multi units system under deregulated conditions, each area consist of two thermal reheat units with physical GRC (generating rate constrain). The parameters of the PIDF controller are tuned using PSO (particle swarm optimization) technique. To improve the system performance, Redox Flow Batteries (RFB) is presented in one area and one of FACTS components IPFC (Inter Line Power Flow Controller) is installed in tie line. The performance of the proposed controller is assessed under different working conditions of deregulated power market. Finally, a comparison will be made on the system response when testing with varying the load conditions and system parameter through MATLAB environment 2015Rb.

Keywords: *PIDF (Proportional Integral Derivative Filter); ACE (Area Control Error); GRC (Generation Rate Constraint); RFB (Redox Flow Batteries); IPFC (Inter Power Flow Controller); DPM (Distribution Participation Matrix); PSO (Particle Swarm Optimization).*

1. Introduction

The continuous change in the structure of power system and the entry of renewable energy sources into the network, have made it the most important challenge to maintain a perfect balance between the load demands and the amount of energy generation [1].

The main purpose of AGC is to preserve a constant balance between the load demand and energy generated, also in order to maintain the stability of power flow in the tie line between multi areas within the acceptable limits and reach to the better power flow control.

The electrical grid consist of (generation, transmission and distribution) may be managed by a single reference, which feeds consumers at regular rates under established plans and control systems. In an open energy market, generation companies may be involved in the process of controlling the generation, on the other hand distribution companies may contract with generating companies or other independent sources of energy for the transfer of power between various areas [2].

FACTS controllers [3] Have an important and effective role in controlling the transfer of power between different areas and maintaining system stability as well as rising the portability of power transfer by compensating the network with inductive or reactive power, there are some research that have used one of these equipment to obtain the perfect control system and achieve optimal stability. The IPFC favourites on UPFC (unified power flow controller) for compensating multi line and introduce good power flow control [4-5].

In order to eliminate the AGC problem during peak load period on grid, it has needful to place a secondary exporter and available energy source to feed the additional loads required and improve the generation control problem such as battery systems [6-9]. RFB (redox flow batteries) have many advantages in applications that need high capacity and long charging storage, which act as a fast power supply as well as helping to dampen frequency fluctuations[10], [11].

Various research papers around the world have proposed different techniques to control generation in such systems to reduce the frequency deviation, control the amount of power transmitted in the connecting lines, and keep them within the permissible limits.

In [1], the researchers dealt with the design of AGC circuit for two-area multi thermal units under deregulated environment using PIDF, the parameters of proposed controller is tuned by using DE (Differential Evaluation) technique.

Authors, V. Donde, et al. [12] discuss the analysis of AGC problem for two-area also investigate the concept of generation and distribution companies and their participation in the control of generation. Chidambaram et al. [13] have suggest BFO (Bacterial Foraging Optimization) algorithm to tune the integral gain of AGC for multi-unit system under deregulated construction with (RFP) and (IPFC). Newly in [14] K.P. Singh Parmar et al. have discuss multi area – multi unit in deregulated environment with use various type of unit (reheat thermal, hydro and gas).

By looking at the various researches and studies in this field, we observe that the power system performance relies on the type of technique used to find the controller parameters used. In this paper we will use the (PIDF) controller to control the ACE signal , because it's very simply structural and better in terms of performance and cost. PSO technique will use to tune PIDF parameters (K_P, K_i, K_d, N). Also, in order to improve the system performance IPFC will be connects in series with the power transfer lines between areas and RFB is used in one area. All parameters for the system used in this research are identical to the data and the structured system used in [1].

2. System construction

The system suggested for this study consist of two-area each one have two units, this system is mostly used in many studies of AGC problem under the same environment. (Area 1, Area2) consist of two generation units (reheat thermal turbine) included GRC and two distribution units for each of them as illustrated in figure.1.

Where,

R_1, R_2 and R_3, R_4 the speed regulation parameters for system.

(B_1, B_2) Frequency bias factor.

(Tg_1, Tg_2) and(Tg_3, Tg_4) governor time constants for area1 and area2 respectively.

(T_{t1} ,T_{t2}) and(T_{t3}, T_{t4}) turbine time constants for area1 and area2 respectively.

(ΔP_{D1} , ΔP_{D2}) changes in load demand.

(K_{ps1} , K_{ps2}) gains of power system.

(T_{ps1} , T_{ps2}) time constant of power system.

(T_{12}) synchronizing coefficient .

(ΔF_1 , ΔF_2) deviation of frequency .

With GRC of 3%/min for reheat thermal turbine [1]. All data are given in appendix 1.

Since there is more than one generating and distribution companies in this system, it is possible to have more than one type of power transaction between these companies to participate in the control of generating and distribution of required loads, For example, if distribution units contract with generation units in the same area this is called (poolco based transaction) , If the distribution units contract with the generating units in another area, this is called (bilateral based transaction) . To analyse and know the nature of the contract between the distribution and generation units, the DPM (Distribution Participation Matrix) has been developed [1].

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix}$$

As shown in DPM above, the (cpf) represent the contract participation factor. The number of rows and columns is equal to the number of generation and distribution units respectively. The summation of all factors in one column must equal [1].

The scheduled tie line power can be given as:

$$\Delta P_{Tie12}^{scheduled} = \left(\begin{matrix}\text{Demand of disturbution units in area1 to} \\ \text{generation units in area2)} -\end{matrix}\right) - \left(\begin{matrix}\text{Demand of disturbution units in area2 to} \\ \text{generation units in area1)}\end{matrix}\right)$$

Where scheduled change in power transfer was Submitted as in [1-3].

$$\Delta P_{Tie12}^{actual} = \frac{2\pi T12}{S} (\Delta f1 - \Delta f2)$$

$$\Delta P_{Tie12}^{error} = \Delta P_{Tie12}^{actual} - \Delta P_{Tie12}^{scheduled}$$

$$ACE_1 = \Delta P_{Tie12}^{error} + B_1 \Delta f_1$$

$$ACE_2 = a_{12} \Delta P_{Tie12}^{error} + B_2 \Delta f_2$$

ACE is the result of summation the error of change in power transfer with frequency deviation signal. Since each area has two generating units for each one , the controller output must share at fixed rates of control according to the proportion of each unit of them in the control of generation (AGC). This factor known as ACE participation factors (apfs) [1].

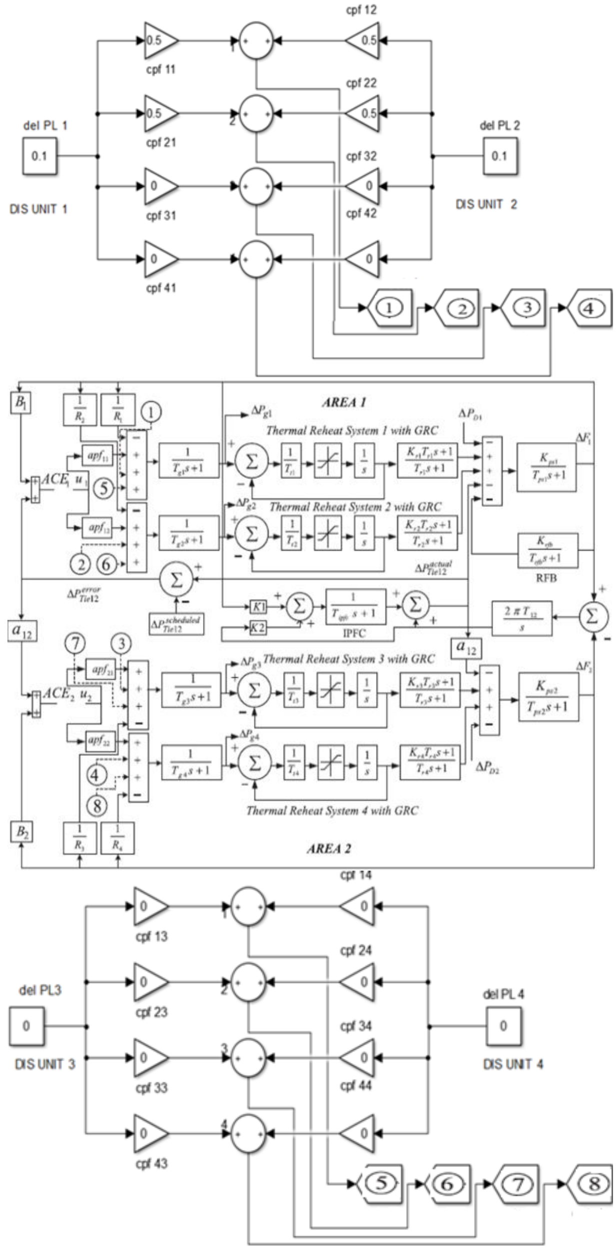


Fig. 1:.System Model with IPFC and RFB Including GRC Constrain

3. Control strategies

3.1. PIDF controller

The preferable famous controller used in various advanced industrial control processes is PID controllers because of its good performance and its reflection on adjusting the system response to the right direction, which ensures that the error value is reduced to zero. Figure.2 show the building on PID controller with filter . where K_P , K_i , K_d and N are the gains of proportional, integral , derivative and filter coefficient. With the suitable value of K_P , K_i , K_d and N ,the system will reach to the best performance. The controller transfer function :

$$TF_{PID} = \left[K_P + K_I \frac{1}{S} + K_D \left(\frac{NS}{S+N}\right)\right]$$

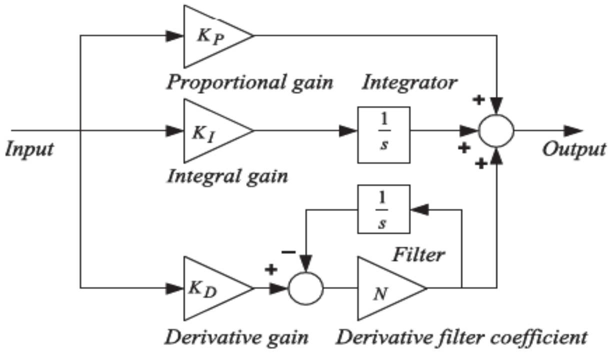


Fig. 2:.PIDF Structure.

3.2 IPFC construction

As adopted in ref. [13], IPFC will be taken on the same model, where it appears in figure.3. We note that interest has increased recently because it helps in transferring the active power amidst transmission lines in besides its original role in compensating the reactive power, which helps the increase in stability and the suppression of the fluctuation[1,3].

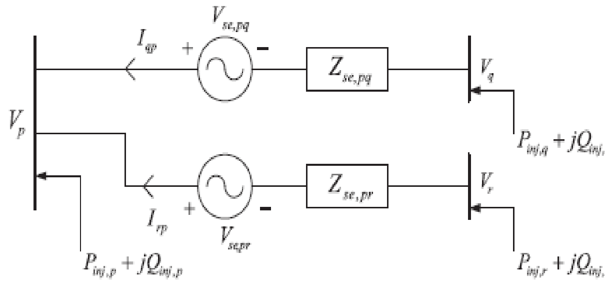


Fig. 3:. Power Compensation Model for IPFC.

The power compensated to system submitted as follows[1,13] :

$$P_{inj.p} = \sum_{n=q,r} V_p V_{se,pn} b_{pn} \sin(\theta_p - \theta_{se,pn})$$

$$Q_{inj.p} = -\sum_{n=q,r} V_p V_{se,pn} b_{pn} \cos(\theta_p - \theta_{se,pn})$$

$$P_{inj.n} = -\sum_{n=q,r} V_n V_{se,pn} b_{pn} \sin(\theta_n - \theta_{se,pn})$$

$$Q_{inj.n} = -\sum_{n=q,r} V_n V_{se,pn} b_{pn} \cos(\theta_n - \theta_{se,pn})$$

3.3. RFB construction

Energy storage systems are important and vital systems to feed the network and maintain its stability, especially in times of peak load when the system is unable to correct the signal required to compensate the continuous change in load, so it became necessary to provide alternative storage systems that are capable of processing capacity and quickly response to reduce frequency drop and maintenance its power transfer in tie lines within limits. In this study will be used the RFB as it have several advantages such that long operation live, low losses and fast response[11,13]. The transfer function of RFB can be submitted as in [13].

$$\Delta P_{rfb} = \frac{K_{rfb}}{1+ST_{rfb}} \Delta F_1$$

Where K_{rfb} : RFB gain , T_{rfb} : RFB time constant

4. PSO algorithm

The main part of this study is to reach the correct PID gains values, which helps ameliorate the behaviour of the system, reduces frequency deviation and keeps the amount of power transferred in the tie lines within the normal values. Recently, there have been many mathematical optimization techniques that have demonstrated great improvement and wide flexibility over the previous trial and error methods, Which in turn also helped control complex and nonlinear systems and give a desirable system response.

PSO is a quite easy-to-understand technique that can be implemented with simple steps of software code, it need rudimentary software operator and it is inexpensive on the one hand providing speed and memory requirements. It may be used to find solutions to many complex problems [15].

PSO is approach from genetic technique[16], a set of random solutions that the system is configured to handle, but it differs from the genetic algorithm. Each

possible solution can have its own random velocity, each of these solutions is called particles this is done in a hypertext space. Each particle keeps route of its ordinates in space and related with the preferable result (fitness) that reaches it and stores that value this named pbest, other value of "best" spoor also. The best value (global) among all the other values that are spoor is called "gbest" which represent the preferable value and preferable position acquired from any particle.

In PSO notion, every time of iteration, update the velocity (accelerating) of each particle to reached its pbest and gbest (global). Acceleration is deliberate by a random term, with separate deliberate numbers being created for acceleration toward pbest and gbest [17].

The PSO technique is based on two essential equations: **velocity modification equation :**

$$V_i^{k+1} = WV_i^k + C_1 rand_1 \times (pbest_i - S_i^k) + C_2\, rand_2\, (gbest_i - S_i^k)$$

Where, $V_i^k =$ velocity of agent i at itteration k

$w =$ weighting function

$c =$ weighting factor $rand_i =$ random number between $0 - 1$

$pbest_i = p -$ best of agent I

$S_i^k =$ current position of agent i at iteration k

$gbest_i = g -$ best of the group

The first part in the velocity equation referred to above WV_i^k is the charge of particle motion. W has a direct effect on the velocity and particle exploration. Programmatically, when the velocity value of each particle is calculated, the particle position is then updated based on the velocity and the previous position by using

Position modification equation:

$S_i^{k+1} = S_i^k + V_i^{k+1}$, $S_i^{k+1} =$ updated value ,

$S_i^k =$ current value

$V_i^{k+1} =$ modified velocity

This steps is repeated several times to the extent that the program stops with the iteration value that specified in the code.

5. Proposed controller

In this paper two non-identical PIDF controllers are used in AGC problem analysis, where the input to them is the error signal and output control signal u_1 and u_2 .

The parameters of two PIDF (for two areas) controller K_P , K_i , K_d and N have been optimized based on multi objective function PSO algorithm as shown in section (4) and shown in figure 4. Where the flow chart of PSO algorithm is shown in figure.5.

Also the objective function is one of most important things to think about and choose correctly depending on the specifications and system limitations before you get into solving any problem using optimization techniques to find the gains of controller.

Through previous studies, it became clear that the best objective function in LFC (load frequency control) analysis [18-20] is: Integral of time multiplied Absolute error (ITAE). The objective function equation is shown below:

$$J = \mathrm{ITAE} = \int_0^{t_{sim}} (|\Delta F1| + |\Delta F2| + |\Delta P_{Tie}|).\, t.\, dt$$

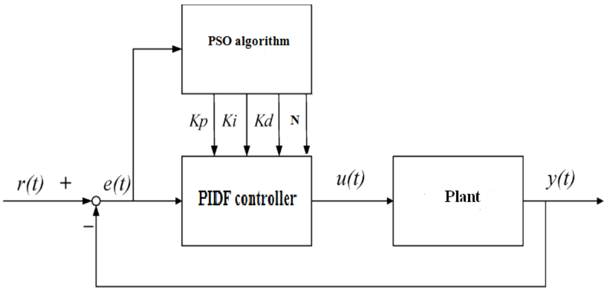


Fig. 4: PIDF Controller Base PSO.

6. Simulation and results

Two cases will be implement and discuss in this paper.

Case1: poolco based transaction:

It means that distribution units contract with generation units in the same area, in this we suggest that load applied on area 1 only means that load on distribution unit 1 $\Delta PL1 = 10\%$, on distribution unit 2 $\Delta PL2 = 10\%$ and $\Delta PL3 = 0$, $\Delta PL4 = 0$ for distribution unit [3-4] respectively. Assumed that the DPM is given as in [1] for equal participate rate in Generation by generation units:

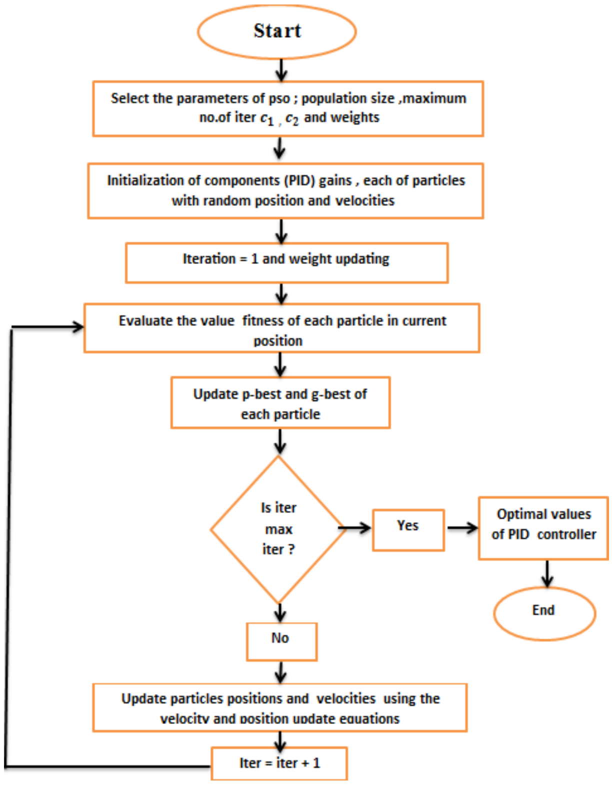


Fig. 5:.PSO Algorithm Flow Chat.

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

Where, $apf_{11} = 0.75$, $apf_{12} = 0.25$, $apf_{21} = 0.5$, $apf_{22} = 0.5$, $\Delta P_{Tie12}^{scheduled} = 0$.

The system was implemented according to Figure.1. A review of the results obtained in this study shows that the system used in the poolco case was implemented. The response of the frequency deviation and the change in tie line power transfer is shown in Figure 6(a-c) under poolco case. The results were compared between three curves using PIDF controller based PSO algorithm, the first without the (IPFC and RFB) , the second with the addition (IPFC) only and the latter with addition both (IPFC and RFB) .When we add the FACT component representative by (IPFC) we observe a clear improvement in the response and performance of the system through its advantage in controlling the flow of power when connected in tie line and capability of reactive power compensation, but sometimes we find that adding it alone is not enough to make a clear improvement in system performance, therefore another addition of power storage devices represented by (RFB) was added with (IPFC) to improve system response, eliminate oscillation and reach stability as soon as possible at minimum settling time and peak over/under shoot. This improvement can be seen clearly through the performance index of system response for poloco case in terms of max over/under shoot and settling time which given in table 1.

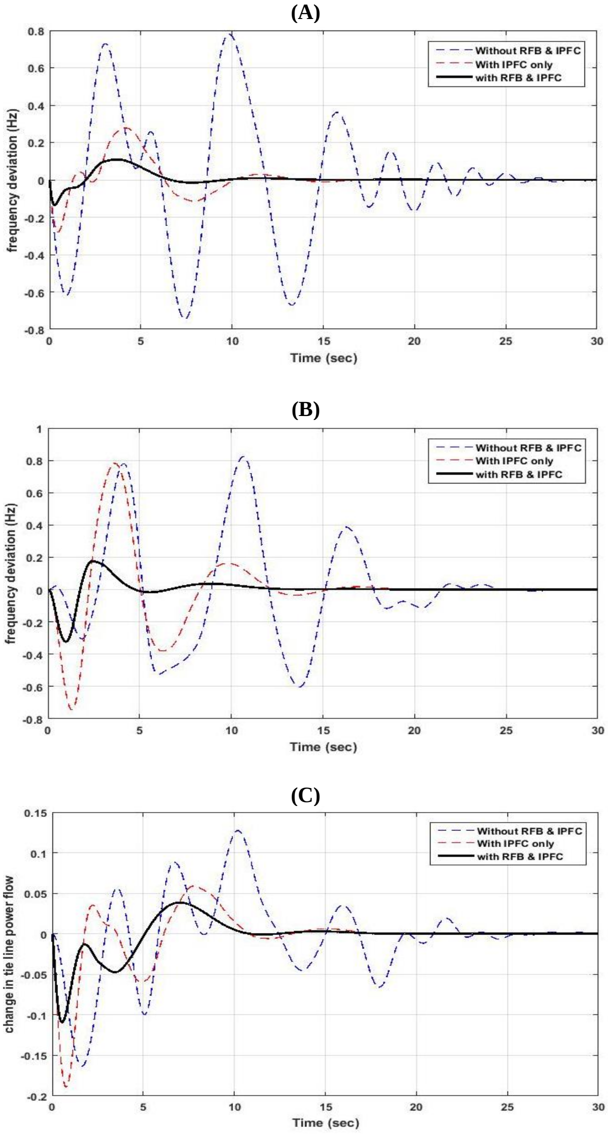


Fig. 6:.A/ frequency deviation of Area 1 B/Frequency Deviation of Area 2 C/Change in Tie Line Power Transfer (Poolco Case).

Table 1: Performance Index for Two Area Thermal Units System (Poolco Case)

Performance and parameters index		Without RFB &IPFC		With IPFC only		With RFB & IPFC	
Over/Under shoot		OV	UN	OV	UN	OV	UN
	ΔF_1	0.78	-0.746	0.278	-0.279	0.104	-0.135
	ΔF_2	0.822	-0.603	0.78	-0.745	0.176	-0.322
	ΔP_{tie}	0.128	-0.163	0.058	-0.198	0.038	-0.109
ITAE		141.452		25.920		6.287	
Settling time (sec)	ΔF_1	36.131		8.2442		6.9846	
	ΔF_2	34.4908		8.8521`		6.0835	
	ΔP_{tie}	35.6397		8.3033		7.9846	

Case2: bilateral based transaction

It means that distribution units contract with the generation units in own area or another generation unit in another area.

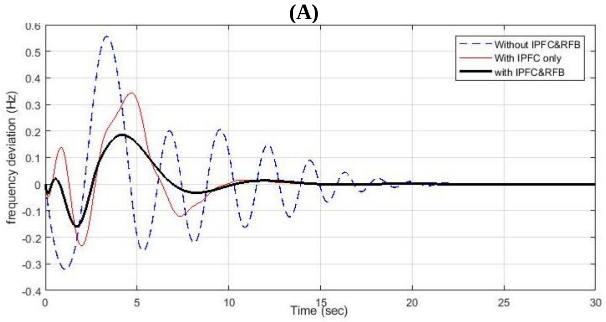
Assumed that the DPM and other data is given as in [1].

$$DPM = \begin{bmatrix} 0.4 & 0.25 & 0.75 & 0.3 \\ 0.3 & 0.2 & 0 & 0.25 \\ 0.2 & 0.2 & 0.25 & 0.25 \\ 0.1 & 0.35 & 0 & 0.2 \end{bmatrix}$$

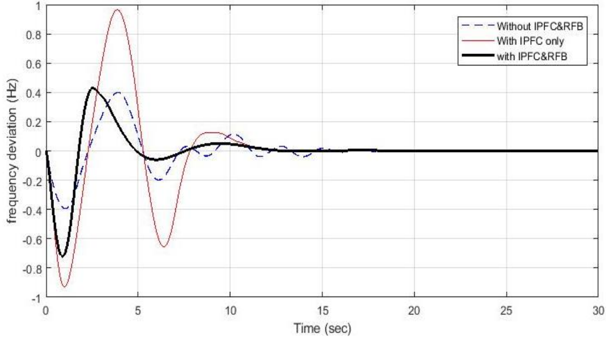
The load applied on area 1 $\Delta PL1 = 15\%$. $\Delta PL2 = 5\%$, and load applied on area [2] $\Delta PL3 = 15\%$, $\Delta PL4 = 5\%, \Delta P_{Tie12}^{scheduled} = 0.0675$.

The same applies to the implementation of the system in the form of (bilateral case) as shown in Fig.7 (a-c). Where we observed a clear improvement on the AGC task represented by system performance when added together (IPFC&RFB) to the system, in addition to acceptable reduction in frequency deviation and access to stability at a few time than the system operate alone. This can be demonstrated through table 2, which shows the system's performance index.

(A)



(B)



(C)

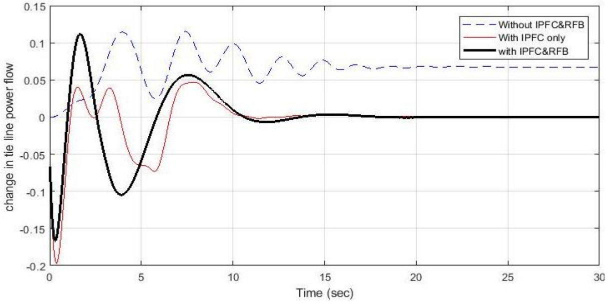


Fig. 7:.A/ Frequency Deviation of Area1 B/ Frequency Deviation of Area2 C/Change in Tie Line Power Transfer (Bilateral Case).

Table 2: Performance Index for Two Area Thermal Units System (Bilateral Case)

Performance and parameters index		Without RFB &IPFC		With IPFC Only		With RFB & IPFC	
0ver/Under shoot		OV	UN	OV	UN	OV	UN
	ΔF_1	0.555	-0.32	0.342	-0.232	0.185	-0.159
	ΔF_2	0.4	-0.397	0.965	-0.929	0.43	-0.721
	ΔP_{tie}	unstable	unstable	0.047	-0.197	0.112	-0.165
ITAE		55.493		25.689		11.645	
Settling time (sec)	ΔF_1	27.18		7.211		6.607	
	ΔF_2	24.56		6.06		6.046	
	ΔP_{tie}	unstable		5.408		7.949	

Consequently, as shown in table 3 better performance of the system in terms of max over/under shot and settling times in tie line power and frequency deviation is achieved with using proposed PSO technique optimized PIDF controller compared to other published approach.

Table 3: Comparison of Performance Index with Published Research

Performance index		Poolco		Bilateral	
		Ref [1] 2015	Proposed work 2018	Ref [1] 2015	Proposed work 2018
0ver shoot	ΔF_1	0.105	0.104	0.2314	0.185
	ΔF_2	0.118	0.176	0.4542	0.43
	ΔP_{tie}	0.0463	0.038	0.205	0.112
ITAE		17.63	6.2873	64.2	11.6455
Settling time (sec)	ΔF_1	20.9	6.9846	25.34	6.607
	ΔF_2	21.44	6.0835	27.23	6.046
	ΔP_{tie}	21.41	7.9846	25.37	7.949

For the purpose of testing the efficiency and potentiality of control system in the face of change in what may occur in system parameters such as time constant of governor T_g, time constant of turbine T_t and change in load conditions, with the influence of adding (IPFC and RFB), parameters were changed and the system response test was measured when increasing and decreasing , under using same controller (PID gains tuning based on PSO) for poolco case only. By following the results shown in the figures (8/a-c) , (9/a-c) and (10/a-c) for the identification of the system behaviour and its impact on changing parameters. We can conclude that the response of the system has remained almost the same in terms of settling time and peak over shot, indicating that the control system is characterized as a robust control system that makes it capable of being used with other systems data with values that may increase or decrease or with the possibility of an increase in applied load.

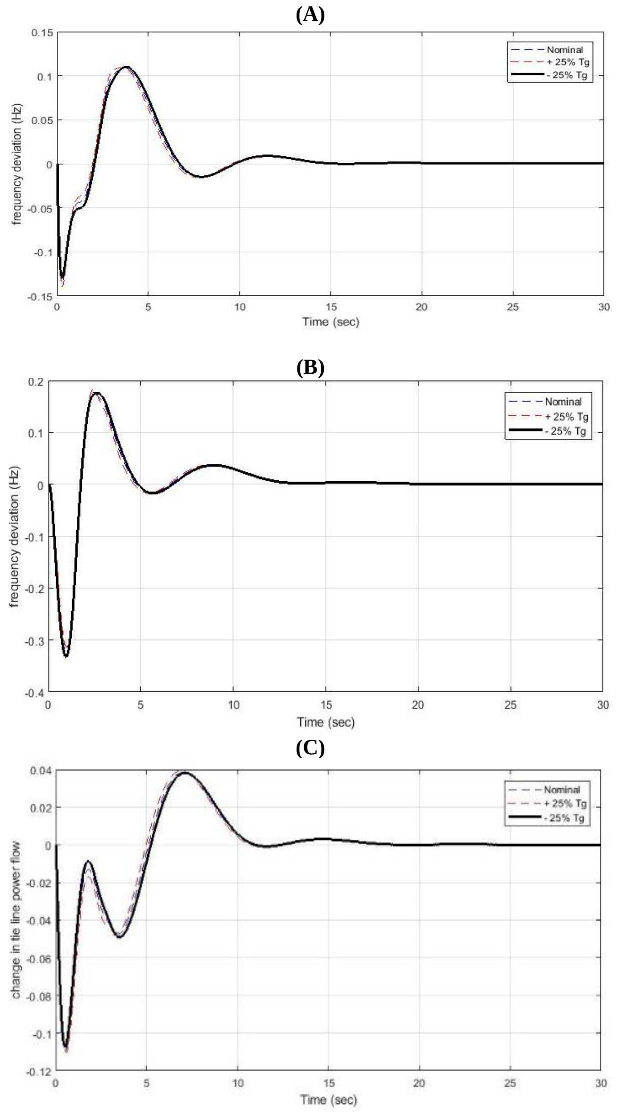
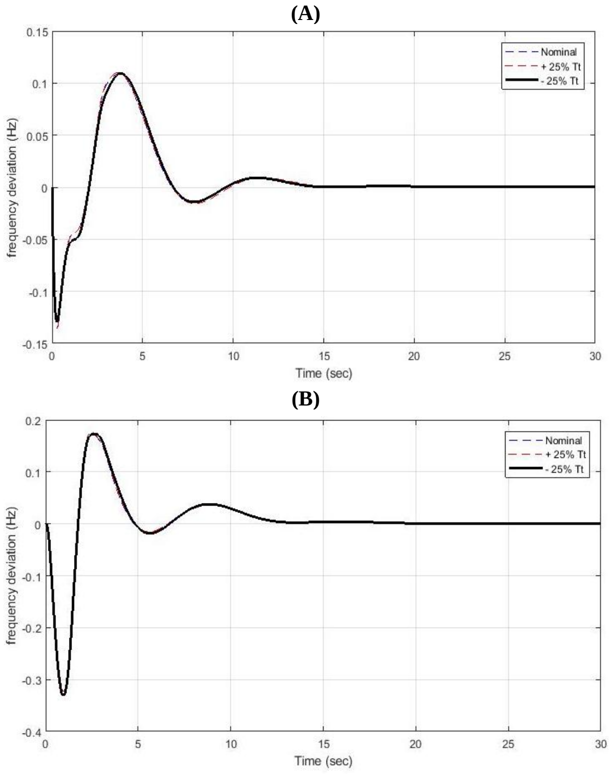


Fig. 8: System Response with Different Value of T_g A/ Frequency Deviation for Area 1 B/ Frequency Deviation for Area 2 C/ Change in Tie Line Power Transfer



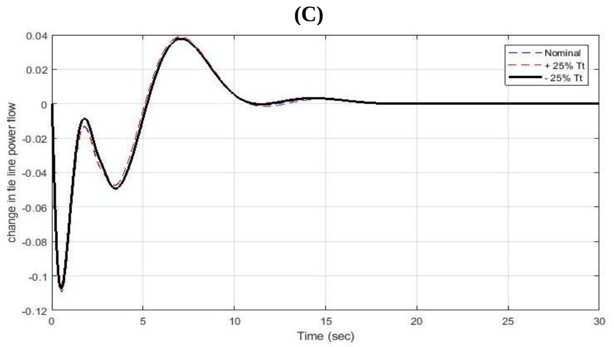


Fig. 9: System Response with Different Value of T_t A/ Frequency Deviation for Area 1 B/ Frequency Deviation for Area 2 C/ Change in Tie Line Power Transfer

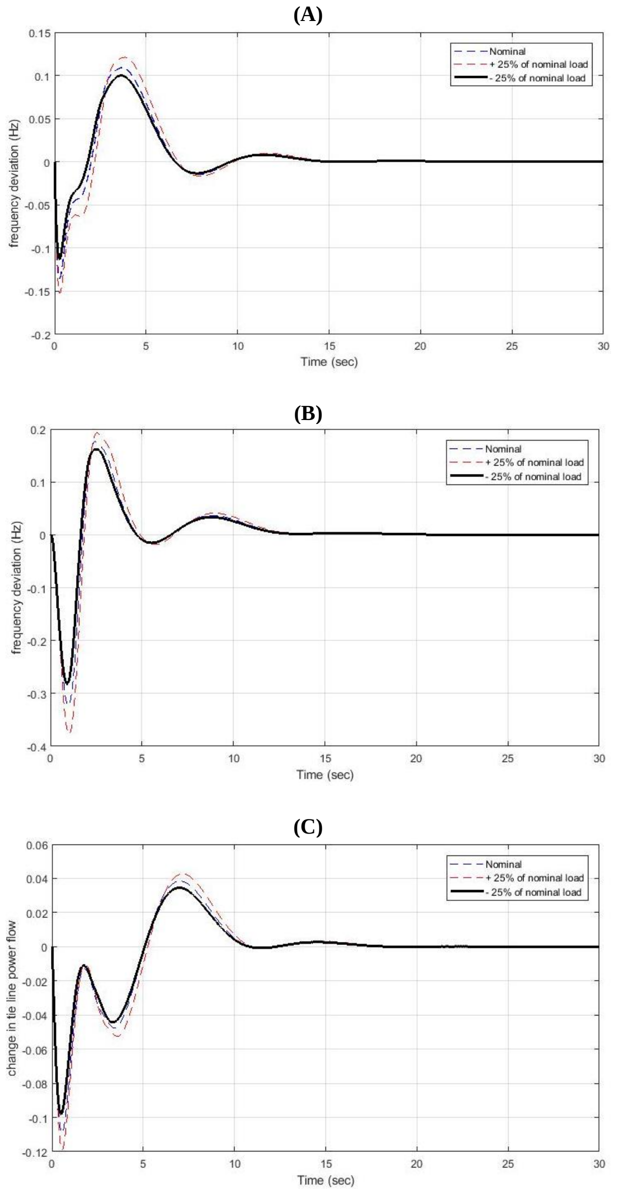
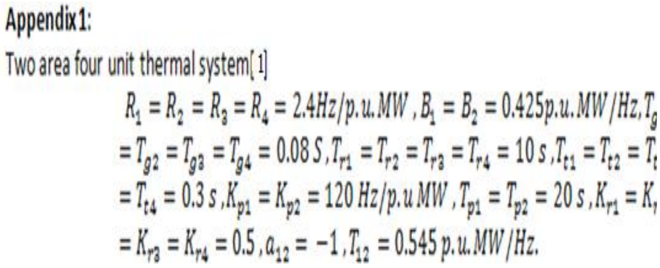


Fig. 10: System Response with Different Value of Load Conditions A/ Frequency Deviation for Area 1 B/ Frequency Deviation for Area 2 C/ Change in Tie Line Power Transfer

7. Conclusion

In this study a particle swarm optimization algorithm (PSO) is used to optimize the gains of PIDF controller for automatic generation control analysis of multi area-multi units system under deregulated environment. It is observed that a good and acceptable dynamic performance of the system was obtained using the proposed PSO control technique. Physical GRC constrain made the system more realistic, therefore, GRC inclusion is important for getting better prudence for analysis of AGC problem. All cases of power transaction that occur in deregulated power market is achieved. It is also possible to conclude that the IPFC has achieved a significant improvement in the behaviour of the system when added, but in bilateral transaction case this improvement is limited because the amount of tie line power is limited to its scheduled value. It can also be noted that RFB has provided a clear improvement in the system performance when added in coordination with the IPFC compared with adding IPFC alone, where the frequency deflection rate is fading to zero and the system tends to become more stable. From the result of simulation it is concluded that effect of changing in load condition and system parameters on the dynamic response can be neglected.



Appendix1:

Two area four unit thermal system[1]

$$R_1 = R_2 = R_3 = R_4 = 2.4 Hz/p.u.MW, B_1 = B_2 = 0.425 p.u.MW/Hz, T_g$$
$$= T_{g2} = T_{g3} = T_{g4} = 0.08\,S, T_{r1} = T_{r2} = T_{r3} = T_{r4} = 10\,s, T_{t1} = T_{t2} = T$$
$$= T_{t4} = 0.3\,s, K_{p1} = K_{p2} = 120\,Hz/p.u\,MW, T_{p1} = T_{p2} = 20\,s, K_{r1} = K$$
$$= K_{r3} = K_{r4} = 0.5, a_{12} = -1, T_{12} = 0.545\,p.u.MW/Hz.$$

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