

Many Optimizing Liaisons based Assessment of PID Controller Performance for Automatic Generation Control

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Abstract---The main objective of Automatic Generation Control (AGC) is to maintain balance between the total system generations against system load fluctuations, maintaining scheduled frequency and net power interchange with neighboring areas in an interconnected power system. Any mismatch between generation and demand causes deviation in frequency, where high deviation in frequency may lead to system collapse. Thus the system frequency should be controlled. This paper deals with the tuning of AGC of a two area interconnected thermal system using P-I-D controllers. Parameters of these controllers are derived using Many Optimizing Liaisons (MOL) Technique. Dynamic Response and Robustness of the PID controlled AGC, tuned by both the techniques are compared applying 1% step load perturbation in both areas at different conditions. The results reported in this paper demonstrate the effectiveness of MOL over PSO in the tuning of AGC parameters.

Index Terms---Automatic Generation Control, Area Control Error, Many Optimizing Liaisons algorithm, Proportional-Integral-Derivative controller.

I. INTRODUCTION

In an interconnected Power System, the control areas are to be interconnected in order to generate, transport and distribute electric energy maintaining a constant frequency and terminal voltage under normal as well as under load fluctuations. However the imbalance between the generated and consumed power, results in change in nominal frequency. When the amount of the generated power is more than the amount of power demand, then the frequency of the system increases and vice versa. In order to maintain the frequency and the tie line power flow at their scheduled value automatic generation control (AGC) is used.

The first attempt in the area of AGC has been to control the frequency of a power system via the governor of the synchronous machine. This technique was subsequently found to be insufficient and a supplementary control was included to the governor with the help of a signal directly proportional to the frequency deviation plus its integral. The system nominal frequency depends on balance between the real powers generated and consumed. Cohn has initiated early works on AGC[2]. Lee and Coworkers in 1991, proposed the first self tuning control method for AGC[3]. Talaq suggested a fuzzy gain scheduling method for conventional PI controller in [4].

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Gozde and Taplamacioglu, proposed PSO algorithm for AGC system for an inter connected thermal power plants in 2011[5]. Almost all past works were to be appreciated that the overall performance of AGC in any power system depends on the proper design of both primary control loop i.e. selection of R and secondary control loops i.e. selection of gain for supplementary controller. Over the past decades, many control strategies have been proposed for AGC viz. Proportional and integral (PI), Proportional, Integral and Derivative (PID) and Optimal controllers.

M.E.H.Pedersen, A.J.Chipperfield[10], proposed Simplifying particle swarm optimization using [8,9] in the year 2009.

B.K Sahu and P.K. Mohanty [6,7] have discussed the modeling and comparative analysis of PID controller of Automatic Voltage Control system via Many Optimizing Liaisons.

The main features of AGC loops are to maintain

- i. Frequency at scheduled value.
- ii. Net interchanges of power with neighboring areas.

In this paper, PID controllers are used to improve the dynamic performance of AGC of a two area thermal system.

Proportional Integral Derivate (PID) controller

The PID controller has been successfully used for over 50 years. It is a robust, easily understood controller that can provide excellent control performance despite the varied dynamic characteristics of control areas. PID controller consists of three basic modes, the proportional mode, the integral and the derivative modes. A proportional controller has the effect of reducing the rise time, but never eliminates the steady-state error. If the proportional gain is too high, the system can become unstable where as a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. An integral controller has the effect of eliminating the steady-state error, but it may obtain weak transient response. High integral gain can cause overshoot and low value will make the system sluggish. A derivative controller has the effect of increasing the stability of the system, reducing the overshoot, and improving the transient response. If the derivative gain is sufficiently large it can cause a process to become unstable. The gains of the controller are tuned by the MOL.

The main aim of this work is the application of MOL algorithm to tune the parameters of the PID controllers in an interconnected system. In view of the above, the present work investigates the following aspects:

- i) To optimize the parameters of the conventional PID controllers using MOL algorithm.

ii) To compare the performance of MOL optimized PID controlled AGC for two area interconnected thermal power system with [1].

II. PROPOSED METHOD

In order to represent a basic simple model of an interconnected power system, in this work deal with two Thermal areas of equal size of 1000MW consisting both reheat with governor dead band mechanism. The introduction of dead band makes the system non-linear.

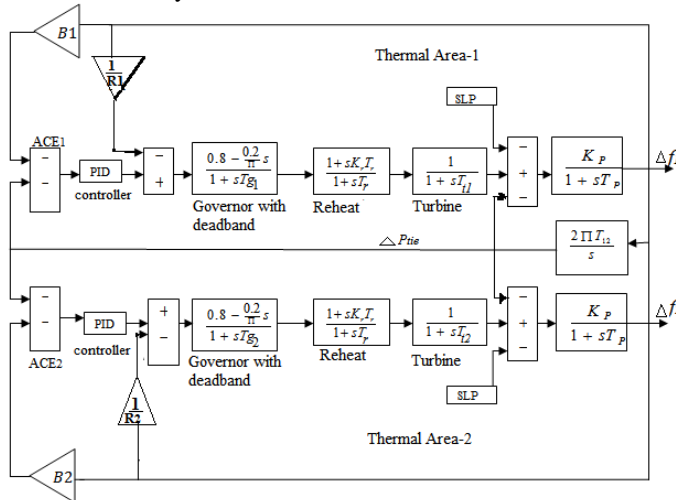


Fig.1 Block diagram of two area interconnected Thermal system

In the design of PID controllers (two in number) for this work the six gains are selected in such a way that the desired response obtained of the closed loop system which refers that the system should have a minimum settling time and a very less value of overshoot as well as undershoots with less oscillations due to a 1% Step Load Perturbation as

$$u_1 = K_{p1} \cdot ACE_1 + K_{i1} \cdot \int ACE_1 \cdot dt + K_{d1} \cdot \frac{d}{dt}(ACE_1) \quad (1)$$

$$u_2 = K_{p2} \cdot ACE_2 + K_{i2} \cdot \int ACE_2 \cdot dt + K_{d2} \cdot \frac{d}{dt}(ACE_2) \quad (2)$$

The value of Area Control Error is sum of bias factor and tie-line power deviation. The area control error in both areas consists of tie-line power error of the intermediate area and frequency error, given by

$$ACE_1 = B_1 + \Delta P_{TIE} \quad (3)$$

$$ACE_2 = B_2 + \Delta P_{TIE} \quad (4)$$

In this work, the constraint of setting the gains of PID controller is a major problem. Therefore, the PID gains should be in limits, i.e.,

$$\begin{aligned} K_{pmin} &\leq K_{pi} \leq K_{pmax} \\ K_{imin} &\leq K_{ii} \leq K_{imax} \\ K_{dmin} &\leq K_{di} \leq K_{dmax} \end{aligned}$$

Where i is the number of controller gains (here i = 2 due to two controllers).

Kp , and Kd_{min} are the minimum values of controller parameters and maximum allowable values of controller parameters are Kp_{max} , Ki_{max} and Kd_{max}

Hence forth, in this work PID parameters are constrained with in [0, 2.5].

The main aim of tuning the system is minimizing the value of Area Control Error (ACE). In order to achieve this, the fitness function J is taken as

$$J = \int_0^T [ACE_i^2] \cdot t \, dt \quad (5)$$

Where ACE_i = Area control error of i^{th} area,
T = simulation time.

III. Tuning algorithm used in the proposed work Many Optimizing Liaisons Algorithm

In this paper the response of simplified PSO algorithm named Many Optimizing Liaisons (MOL) which was proposed by Pedersen and Chipper field in 2009[10] has been evaluated, to derive the PID controller parameters by minimizing the error, coordinated with the frequency control. By setting the parameter $C_1 = 0$, MOL removes the need for an extra random deviate in velocity recurrence relation and most importantly, eliminates the need for a previous best solution for every particle. Instead of iterating over all agents in the swarm as done normally in PSO [1], the MOL picks the agent to update at random, thereby minimizing the memory and time used for computation.

The MOL algorithm.

Step 1:

Initialize the values of time constants of governor 'Tg', reheat 'Tr', turbine 'Tt' and power system 'Tp'. in their respective control areas.

Initialize the values of Kp , $R1$, $R2$, and primary control loop gains $B1$ and $B2$ in their respective control areas.

Step 2

Initialization of particles

Initialize x_i where $i = 1, \dots, n$ with D uniform random values each representing the gains of PID controller with upper and lower bounds '0.1' and '2.5' respectively.

Here Dimension is taken for particles as [1x6].

Step 3

Initialization of random vector

Random variables are chosen within limits i.e.;

$$rand \leftarrow U(0, 1)$$

Step4

Initialization of vector g

Initialize vector g with random locations in all D dimensions.

Evaluate the fitness of vector g using best of particles, $pbest$.

Calculate the fitness of vector x_i , for which $ACE=0$ (3&4).

Step 5

Update the Velocity of particles

Using below equation velocity of particle is updated

$$V_i^{(t+1)} = w \cdot V_i^t + C1 \cdot rand1 \cdot (pbest_i - P_i^t) + C2 \cdot rand2 \cdot (gbest_t - P_i^t)$$

By making the parameter C1=0, eliminates particle best, there by equation is rewritten as

$$V_i^{(t+1)} = \omega \cdot V_i^t + C_2 \cdot rand(gbest_t - x_i^t) \quad (6)$$

Step 6

Update the position of Particles

Using below equation the position of particle is updated

$$X_i^{(t+1)} = x_i^t + V_i^{(t+1)} \quad (7)$$

Step7

The above steps are repeated for swarm's best Position f (gbest) which represent the best controller gains in minimizing Area Control Error.

IV. RESULTS AND DISCUSSION

The AGC system with PID controllers tuned by MOL algorithm is shown in fig 1. The gains of the PID controllers are tuned by MOL algorithm. If proportional gain (k_p) is very high the system can become unstable where as a small gain results in a small output response to a large input error, and a less responsive or less sensitive controller. High integral gain (K_i) can cause overshoot and low value will make the system sluggish. If the derivatives gain (k_d) is sufficiently large it can cause a process to become unstable. These gains depend on the process to be controlled. For an AGC system the typical ranges used in literature are (0.1-2.5). After running the optimization algorithm for several times it is found that the minimum and maximum values of gains for different objective functions lie in the chosen range. A small step load perturbation (SLP) of 1% is applied to both areas to study the dynamic response of the PID controlled AGC. The optimum values of PID controller gains are depicted in table I.

TABLE I

Optimum gains of PID for both areas tuned by PSO and MOL algorithm

Algorithm	PID controller gains for area-1			PID controller gains for area-2		
	Kp1	Ki1	Kd1	Kp2	Ki2	Kd2
PSO	2.3285	2.4883	1.5280	1.7152	1.1256	1.8945
MOL	1.1112	1.8311	1.4328	1.4251	2.2472	2.2194

The settling time and peak overshoots of ΔF1, ΔF2 and ΔPtie are tabulated below employing PSO[1] and MOL algorithms.

TABLE II

Settling time and peak overshoots of ΔF1, ΔF2 and ΔPtie

Algorithm	Dynamic response					
	ΔF1		ΔF2		ΔPtie	
	Ts in sec	Osh in p.u	Ts in sec	Osh in p.u	Ts in sec	Osh in p.u
PSO	12.95	-0.0278	15.32	-0.0271	15.75	-0.0035
MOL	10.55	-0.0262	12.41	-0.0232	15.42	-0.0028



From table I and table II it is clearly shown that the dynamic response i.e. change in frequency and change in tie line power is optimized employing MOL technique.

From fig.2, fig.3 and fig.4 respectively shows the variations in ΔF1, ΔF2 and ΔPtie for both PSO [1] and MOL algorithms and thus concludes that MOL has better transient behavior over algorithm employed in [1].

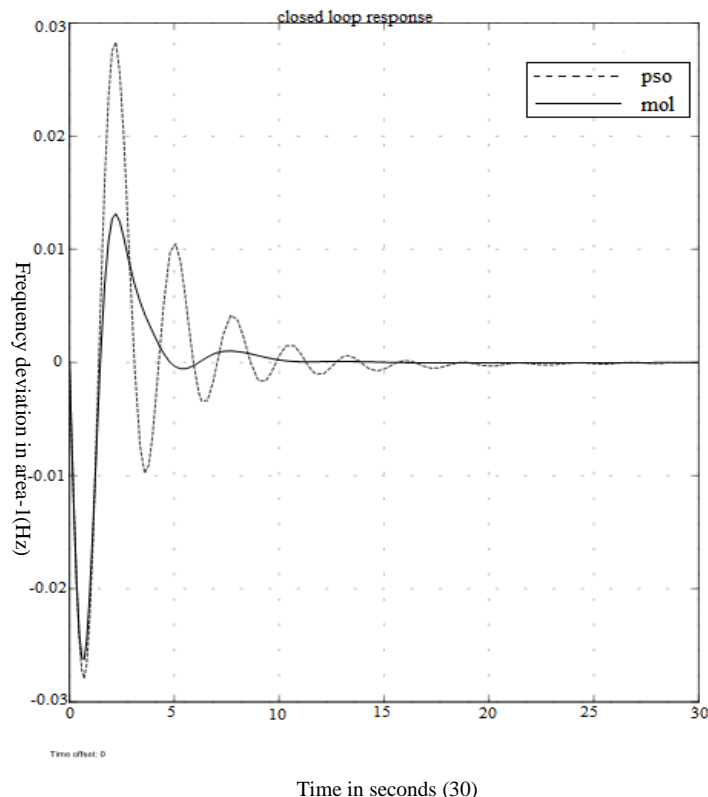


Figure 2 Frequency deviation in area-1

Frequency deviation in area-2(Hz)

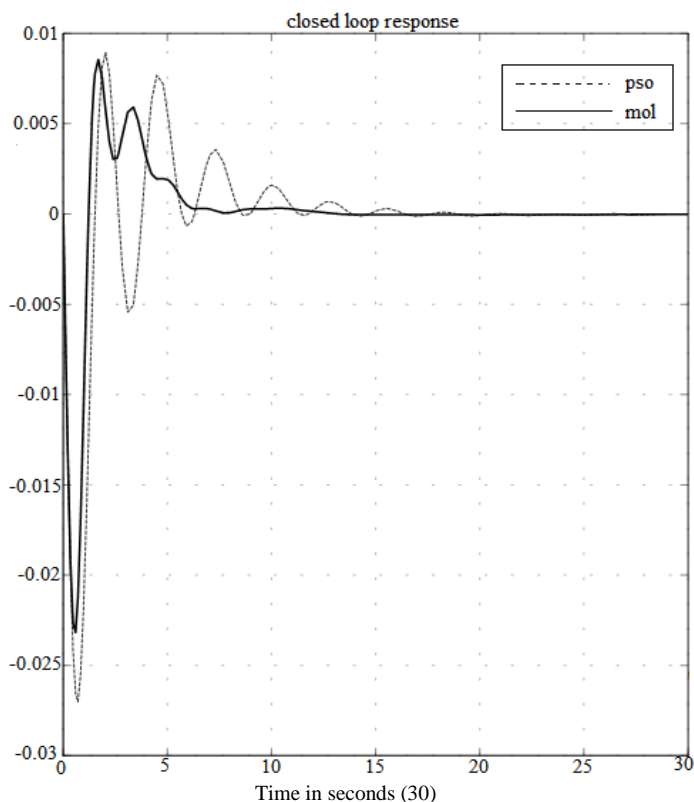


Figure 3 Frequency deviation in area-2

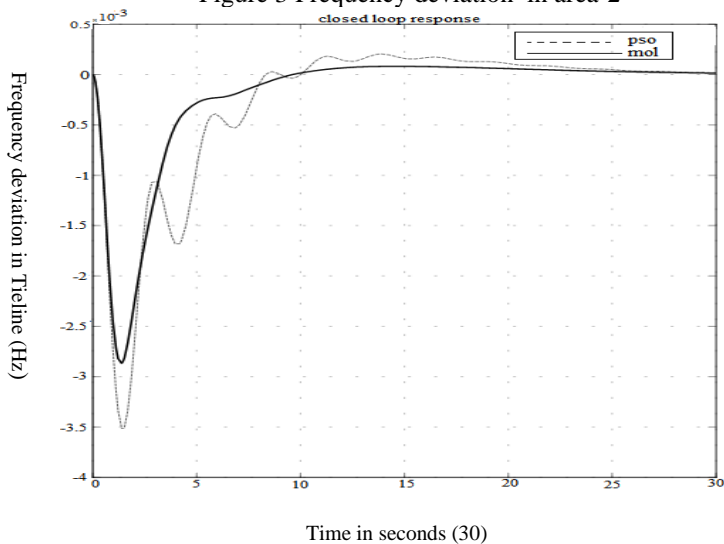


Figure 4 Tie Line power deviation

V. ROBUSTNESS ANALYSIS

Each thermal area consists of non-linear governor with time constant T_g , turbine with time constant T_t , and reheat with gain K_r and time constant T_r . For robustness analysis all these parameters are varied from -50% to +50% in steps of 25% by applying 1% SLP in both areas. The controller gains obtained from [1] and MOL algorithm are used and compared to study the robustness of the system.

Table III
 Settling times T_s for $\Delta F1, \Delta F2$ and ΔP_{tie}

Parameters	%age Deviation	T_s for $\Delta F1$ (sec) [1]	T_s for $\Delta F1$ (sec) MOL	T_s for $\Delta F2$ (sec) [1]	T_s for $\Delta F2$ (sec) MOL	T_s for ΔP_{tie} (sec) [1]	T_s for ΔP_{tie} (sec) MOL
T_g	50%	18.88	15.82	19.5	16.47	16.59	16.49
	25%	13.97	11.88	15.84	12.66	15.32	15.10
	Normal	12.95	10.55	15.32	12.41	15.75	15.42
	-25%	13.19	11.08	15.45	12.55	15.91	15.82
	-50%	13.07	11.92	15.43	12.41	15.85	15.75
T_t	50%	15.42	13.72	17.43	12.54	15.82	15.82
	25%	13.06	11.08	15.09	10.08	15.72	15.54
	Normal	12.95	10.55	15.32	12.41	15.75	15.42
	-25%	13.04	11.05	15.39	10.50	15.82	15.41
	-50%	13.16	11.63	15.46	10.57	15.90	15.54
K_r	50%	16.09	14.04	16.42	14.40	11.50	11.45
	25%	13.62	11.53	15.16	13.58	13.29	13.21
	Normal	12.95	10.55	15.32	12.41	15.75	15.42
	-25%	10.40	8.62	13.06	10.09	16.8	16.61
	-50%	17.44	14.48	13.35	10.39	16.28	16.22
T_r	50%	18.39	15.45	20.64	18.84	18.39	17.28
	25%	15.65	13.29	18.15	15.70	17.5	16.89
	Normal	12.95	10.55	15.32	12.41	15.75	15.42
	-25%	9.85	8.28	11.46	10.95	14.01	13.97
	-50%	8.25	8.14	9.62	9.24	11.79	11.59

Table IV
 Over Shoot calculation for $\Delta F1, \Delta F2$ and ΔP_{tie}

Parameters	%age deviation	Osh for $\Delta F1$ (Hz) pso[1]	Osh for $\Delta F1$ (Hz) MOL	Osh for $\Delta F2$ (Hz) pso[1]	Osh for $\Delta F2$ (Hz) MOL	Osh for ΔP_{tie} Hz $\times 10^{-3}$ pso[1]	Osh for ΔP_{tie} Hz $\times 10^{-3}$ MOL
T_g	50%	-0.0305	-0.0292	-0.0294	-0.0255	-4.0	-3.3
	25%	-0.0294	-0.0276	-0.0285	-0.0245	-3.8	-3.1
	Normal	-0.0278	-0.0262	-0.0271	-0.0232	-3.5	-2.8
	-25%	-0.0262	-0.0245	-0.0251	-0.0215	-3.2	-2.6
	-50%	-0.0241	-0.0225	-0.0232	-0.0195	-2.9	-2.5
T_t	50%	-0.0315	-0.0309	-0.0301	-0.0262	-4.4	-3.6
	25%	-0.0292	-0.0284	-0.0295	-0.0255	-4.0	-3.3
	Normal	-0.0278	-0.0262	-0.0271	-0.0232	-3.5	-2.8
	-25%	-0.0255	-0.0240	-0.0245	-0.0211	-2.9	-2.4
	-50%	-0.0226	-0.0210	-0.0215	-0.0190	-2.4	-2.1
K_r	50%	-0.0242	-0.0255	-0.0233	-0.0203	-2.5	-1.9
	25%	-0.0256	-0.0243	-0.0248	-0.0214	-2.9	-2.3
	Normal	-0.0278	-0.0262	-0.0271	-0.0232	-3.5	-2.8
	-25%	-0.0306	-0.0291	-0.0298	-0.0254	-4.2	-3.6
	-50%	-0.0345	-0.0334	-0.0343	-0.0294	-5.7	-4.9
T_r	50%	-0.028	-0.0273	-0.027	-0.0232	-3.5	-2.9
	25%	-0.028	-0.2630	-0.027	-0.0231	-3.5	-2.8
	Normal	-0.027	-0.0262	-0.0271	-0.0232	-3.5	-2.8
	-25%	-0.0278	-0.0260	-0.0270	-0.0229	-3.5	-3.4
	-50%	-0.0276	-0.0261	-0.0628	-0.0230	-3.4	-2.7

Table III and IV shows the transient behavior of interconnected power system optimization using reference[1] and MOL algorithm.

From the tables the robustness analysis gives the idea of controlled operation of particular respective tuned PID gain

values with a 1% step disturbance on both areas and we can restore the system into a new operating point with minimum deviation in ACE.

VI. CONCLUSION

The results obtained from the simulation studies show that the MOL tuned system achieves better dynamic performance, i.e., less Overshoot, better settling times than the results obtained in [1]. From the study it can be concluded that PID controlled AGC for the two area interconnected system tuned by MOL algorithm gives acceptable and reliable management the frequency and tie line power deviations (ΔP_{tie}). There by it can be concluded as Many Optimizing Liaisons gives comparatively better and faster performance over PSO algorithm [1].

APPENDIX

$$\begin{aligned}T_{g1}=T_{g2}=0.3s, T_{i1}=T_{i2}=0.8s, \\T_p=20s, T_r=10s, T_{12}=0.707 \\B_1=B_2=0.425 p.u. MW/Hz, \\K_r=0.5, K_p=120 Hz/p.u., \\R1=R2=2.4 Hz/p.u.\end{aligned}$$

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