Design and Performance Analysis of PID Controller for Automatic Generation Control of an Autonomous Power System

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***Abstract*—Proportional Integral Derivative (PID) controller is a generic feedback controller which is widely used in industrial control system, motor drive, process control, and in instrumentation. It provides simplest and most efficient solution to many real word control problems. However, tuning of PID controller gains is a challenge for researchers and plant operators. In this paper, the design problem of PID controller is formulated as an optimization problem. Particle Swarm Optimization (PSO) technique is used to search the optimum controller gain values. Optimal controller gains are obtained by minimizing the objective function. For evaluating the performance of the proposed PSO based PID and Many Optimizing Liaisons (MOL) based PID controller, a comparison of different frequency domain performance indices were undertaken as objective functions. Independent PID controllers were used for Load Frequency Control (LFC) and Automatic Voltage Regulation (AVR) of a single area power system. The comparison shows that MOL tuned PID controller with Integral Time of Absolute Error (ITAE) as performance index is most efficient in improving the step response of the system.**

Keywords— Automatic Voltage Regulation, Load Frequency Control, PID controller, Particle Swarm Optimization.

I. INTRODUCTION

A power system is prone to instability due to faults and sudden changes in the system load. The faults can be sensed through relays and suitable controlling action can be applied to a particular fault. The variations in load, however, cannot be predicted and eliminated. The sudden changes in load can cause variation in frequency and voltage of the system. Thus, for stable operation of the system, the system generation must equal the system demand. Load Frequency Control (LFC) and Automatic Voltage Regulation (AVR) are two important control mechanisms that help in a minimizing the frequency and voltage variations. LFC is used to maintain the system frequency by controlling the real power flow in the system; AVR is used to maintain the voltage profile of the system by controlling the reactive power flow in the system. Both the LFC and AVR are closed loop control systems and because of the inherent non-linearities present in the power system components and synchronous machines, these control loops are compensated by a controller primarily composed of an integral controller [1-2].

PID controller has three tuning parameters i.e. proportional gain, integral gain and derivative gain. Proper selection of these gain values ensures simplest yet most efficient control [3]. However, the tuning of the controller is quite difficult. Previously various conventional techniques such as Ziegler-Nicholes method, Cohen-Coon method, minimum variance method, gain phased margin method, etc. were used in optimal tuning of the PID controller [4]. These methods were difficult to implement in complex control design. Recently, evolutionary computational algorithms such as Artificial Bee Colony (ABC), Bacterial Foraging Algorithm (BFA), Differential Evolution (DE), Genetic Algorithm (GA), Particle Swarm Optimization (PSO), etc. are used to search for the optimal controller gains of the PID controller. PSO has the advantage that it is a derivative free algorithm which does not require an initial solution to start the algorithm [5].

Particle swarm optimization is a population based, heuristic evolutionary technique based on the movement and intelligence of swarms. It is inspired by the social behavior of bird flocking or fish schooling. In a swarm, birds generally follow the shortest path in a particular direction for searching food. Through social interaction with the bird at best location with respect to the food source, the rest of the birds try to reach that location by adjusting their velocities. This technique was first described by James Kennedy and Russell C. Eberhart in 1995 [6]. Much advancement in PSO has been made since then and different variants of PSO algorithm have been introduced [7-8]. The accepted standard PSO algorithm is the global best model of PSO introduced by Shi and Eberhart [9]. Many Optimizing Liaisons (MOL) is a PSO variant in which the cognitive coefficient of the particle is set to zero. MOL is a simplified form of PSO and is also termed as Social only PSO (S-PSO). The advantage of MOL algorithm when compared with PSO algorithm is that in the former the particle is updated randomly whereas, in later, the particle is updated iteratively over the entire swarm which results in less execution time [10]. Secondly, in MOL the swarm's best position is set to zero, this makes particle not to have any persistence in the previously followed path.

The intent of the paper is to design PSO and MOL based PID controllers with different frequency domain performance indices which has been taken as independent objective functions. PID controllers were used for LFC and AVR loop of a single area power system. A comparison of the results obtained with conventional tuned PID controller, PSO tuned PID controller and MOL tuned PID controller are presented in this paper.

II. LFC AND AVR CONTROL LOOPS

Due to sudden changes in load, the generator observes a momentary speed change, which causes a small change in rotor angle δ. This small change in rotor angle causes variation in real power and leads to variation in the system frequency. The LFC loop compares the new frequency with the old frequency and generates a command signal which is fed to the speed governor. The speed governor regulates the steam input to the turbine by some valve controlling mechanism and there by regulates the turbine mechanical output. This mechanical output when fed to the synchronous generator provides the regulated real power output.

The AVR loop is assigned with maintaining the synchronous generator terminal voltage, which in turn maintains the bus voltage manipulating the reactive power output. This is achieved by controlling the excitation of the field winding of the synchronous generator. The AVR loop continuously senses the terminal voltage; this voltage is rectified, smoothened and compared with a pre-set dc voltage reference. The error voltage, after amplification and shaping is used to control the synchronous generator's field excitation.

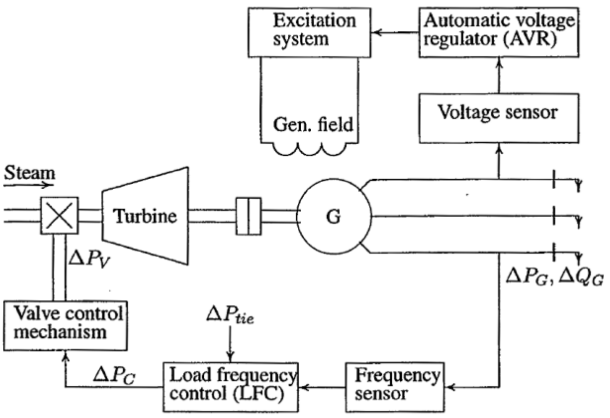

Fig. 1. Schematic diagram of LFC and AVR

The LFC and AVR loops are designed to operate around normal state with small variable excursions. The loops may therefore be modeled with linear, constant coefficient differential equations and can be represented with linear transfer functions [11-12].

A. Linearized model of LFC

LFC requires governor, turbine, inertia and load modeling. The transfer functions of these components can be stated as [13]:

- Governor: The transfer function of governor relates the change in steam valve position (ΔP_V) to change in real power generation (ΔP_g) and is expressed as

$$\frac{\Delta P_V(s)}{\Delta P_g(s)} = \frac{1}{1+\tau_{sg}s} \tag{1}$$

$$\Delta P_g(s) = \Delta P_{ref}(s) - \frac{1}{R}\Delta\omega(s) \tag{2}$$

- Turbine: The transfer function of turbine relates the changes in mechanical power output (ΔP_m) to the changes in steam valve position (ΔP_v) and can be expressed as

$$\frac{\Delta P_m(s)}{\Delta P_v(s)} = \frac{1}{1+\tau_t s} \tag{3}$$

- Inertia & Load: The transfer function of Inertia & Load relates the change in frequency ($\Delta\omega$) to the difference of change in mechanical power (ΔP_m) and change in electrical power (ΔP_e) and can be expressed as

$$\frac{\Delta\omega(s)}{\Delta P_m(s) - \Delta P_e(s)} = \frac{1}{D+2Hs} \tag{4}$$

Thus, the closed loop transfer function relating the load change (ΔP_L) to the frequency deviation ($\Delta\omega$) is

$$\frac{\Delta\omega(s)}{-\Delta P_L(s)} = \frac{(1+\tau_g s)(1+\tau_T s)}{(2Hs+D)(1+\tau_g s)(1+\tau_T s)+\frac{1}{R}} \tag{5}$$

B. Linearized model of AVR

AVR requires amplifier, exciter, generator and sensor modeling. The transfer functions of these components are [13]:

- Amplifier: The transfer function of amplifier relates the amplified voltage (V_R) to the error voltage (V_e) and can be expressed as

$$\frac{V_R(s)}{V_e(s)} = \frac{K_A}{1+\tau_A s} \tag{6}$$

- Exciter: The transfer function of exciter relates the field voltage (V_F) to the amplified voltage (V_R) and can be expressed as

$$\frac{V_F(s)}{V_R(s)} = \frac{K_E}{1+\tau_E s} \tag{7}$$

- Generator: The transfer function of generator relates the terminal voltage (V_t) to the field voltage (V_F) and can be expressed as

$$\frac{V_t(s)}{V_F(s)} = \frac{K_G}{1+\tau_G s} \tag{8}$$

- Sensor: The transfer function of sensor relates the voltage sensed from the generator (V_S) to the terminal voltage (V_t) and can be expressed as

$$\frac{V_S(s)}{V_t(s)} = \frac{K_R}{1+\tau_R s} \tag{9}$$

Thus, the closed loop transfer function relating the generator terminal voltage to the reference voltage is

$$\frac{V_t(s)}{V_{ref}(s)} = \frac{K_A K_E K_G K_R(1+\tau_R s)}{(1+\tau_A s)(1+\tau_E s)(1+\tau_G s)(1+\tau_R s)+K_A K_E K_G K_R} \tag{10}$$

III. PID CONTROLLER TUNING

PID controllers are practical industrial controllers. They are used to improve the dynamic response as well as to reduce or eliminate the steady state error. The controller calculates the error between a measured process value and a desired set point, and this error is reduced by adjusting the controller gains. The gains of a PID controller are: proportional gain (K_P), integral gain (K_I) and derivative gain (K_D). The proportional gain has the effect of reducing the rise time, the integral gain has the effect of eliminating the steady sate error and the derivative gain has the effect of increasing the stability of the system [14]. The Simulink block diagram of a PID controller is shown in fig. 2 and its transfer function is given by,

$$G(s) = K_P + K_I \frac{1}{s} + s.K_D \quad (11)$$

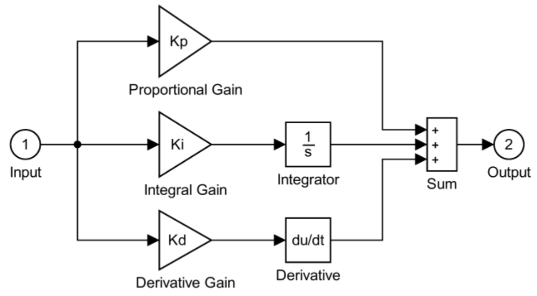

Fig. 2. Simulink block diagram of PID Controller

A. *Conventional tuning*

The procedure of tuning the PID controller by conventional trial and error method is as follows [15]:

Step 1: Set K_D and K_I to zero. By trial and error, select K_P that results in a stable oscillatory performance. In case of multi input system, select K_P that results near to critical damping.

Step 2: Vary K_D with K_P fixed so as to reduce the oscillations and result in reasonable overshoot and settling time.

Step 3: Vary K_I with K_P and K_D fixed, such that there is zero steady state error in minimum time.

B. *Tuning using Particle Swarm Optimization*

For the tuning of PID controller, the PSO algorithm generates a random population of the controller gains, then searches for the optimal set of gain values from this random population that minimizes a defined performance index as objective function. Integral of Time multiplied Absolute Error (ITAE), Integrated Absolute Error (IAE), Integral of Time multiplied Square Error (ITSE) and Integrated Squared Error (ISE) are some of the performance indices. ITAE is chosen as the performance index in this study as it can be easily evaluated analytically in the frequency domain [3-5]. The steps involved in implementation of PSO algorithm for tuning of PID controller are [16-17]:

Step 1: Initialize the particles to some linear positions in the range of K_P, K_I & K_D and set their velocities as zero.

Step 2: Evaluate the initial population by simulating the system model with each particle row value as the PID controller value and calculate the performance index for each particle at their corresponding positions.

Step 3: Initialize local minimum (P_{best}) for each particle.

Step 4: Find best particle (G_{best}) in initial particle matrix based on minimum performance index.

Step 5: Start the iteration, iter =1.

Step 6: Update velocities of the particles by the equation:

$$v_{j,g\,(i+1)} = w.v_{j,g\,(i)} + c_1.r_1.[P_{best\,j,g\,(i)} - x_{j,g\,(i)}] + c_2.r_2.[G_{best\,g\,(i)} - x_{j,g\,(i)}] \quad (12)$$

Step 7: Create new particles from the updated velocity.

Step 8: If any of the new particles violate the search space limit, then choose the particle and generate new values within the particle space.

Step 9: Evaluate performance index for each new particle at their respective position by simulating the system model.

Step 10: Update P_{best} and G_{best} based on minimum value between new performance index and old performance index value.

Step 11: Update the G_{best} value and its performance index.

Step 12: Iteration = iteration + 1.

Step 13: If iteration $\leq$ maximum iteration, go to step 6, otherwise continue.

Step 14: The obtained G_{best} is the optimum set of parameters of the PSO-PID controller.

C. *Tuning using Many Optimizing Liaisons*

In PSO algorithm, the cognitive coefficient (C_1) is set to zero, this results in MOL algorithm. The implementation algorithm of MOL is similar to that of PSO except the fact that C_1=0. Besides this change, the parameters C_2 remains unchanged and the inertia weight is also set similar to PSO. The velocity update equation for MOL algorithm is thus reduced to

$$v_{j,g\,(i+1)} = w.v_{j,g\,(i)} + c_2.r_2.[G_{best\,g\,(i)} - x_{j,g\,(i)}] \quad (13)$$

D. *Performance Index*

In terms of error signal *e(t)*, the performance indices employed in control system design can be given as:

$$ITAE = \int_0^\infty t.|e(t)|.dt \quad (14)$$

$$IAE = \int_0^\infty |e(t)|.dt \quad (15)$$

$$ITSE = \int_0^\infty t.e^2(t).dt \quad (16)$$

$$ISE = \int_0^\infty e^2(t).dt \quad (17)$$

These are also referred as error functions. These integral performance criteria in the frequency domain have their own advantages and disadvantages [3]. For e.g., a disadvantage of the IAE and ISE criteria is that its minimization can result in a response with relatively small overshoot but a long settling time.

IV. SYSTEM INVESTIGATED

A power system consisting of a thermal generating unit of non-reheat type was considered for the simulation. The performance of the system was observed in terms of dynamic response of the system measured in terms of frequency deviation, Δf and voltage deviation ΔV occurring due to an application of a step load perturbation. The system is brought to its stable sate of operation with the use of PID controller. The Simulink model for the system is shown in fig. 3. The system was observed under a step change in load of 0.1 p.u., speed regulation of R = 3 Hz/p.u. and simulation time of t = 10 seconds. The error signal in the calculation of the performance index is taken as sum of frequency deviation, Δf and Voltage deviation, ΔV. Thus, the performance indices can be stated as:

$$ITAE = \int_0^t t.|\Delta f + \Delta V|.dt \quad (18)$$

$$IAE = \int_0^t |\Delta f + \Delta V|.dt \quad (19)$$

$$ITSE = \int_0^t t.[\Delta f + \Delta V]^2.dt \quad (20)$$

$$ISE = \int_0^t t.[\Delta f + \Delta V].dt \quad (21)$$

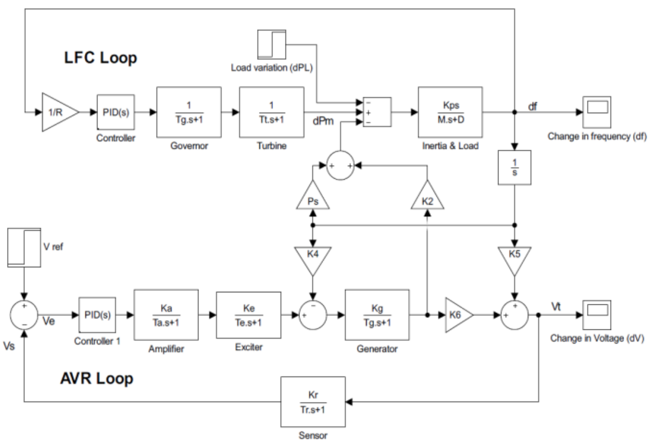

Fig. 3. Simulink model of the system in study

V. RESULTS AND DISCUSSION

A. *Particle Swarm Optimization tuned PID Controller*

Fig. 4 shows the frequency deviations and fig. 5 shows the terminal voltage deviations of the system for different performance indices. Table I provides the comparison of response obtained from different performance indices. The comparison is made in terms of maximum overshoot and settling time of the frequency response and voltage response. Table II shows the values of PSO-PID controller gains obtained from each performance index.

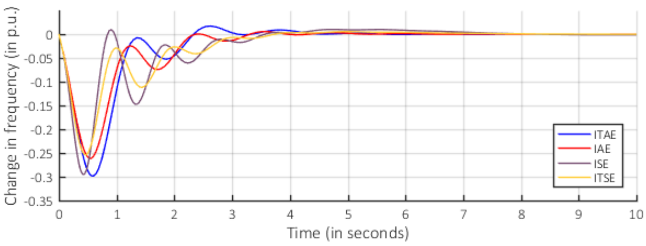

Fig. 4. Frequency deviations for different performance indices (PSO-PID)

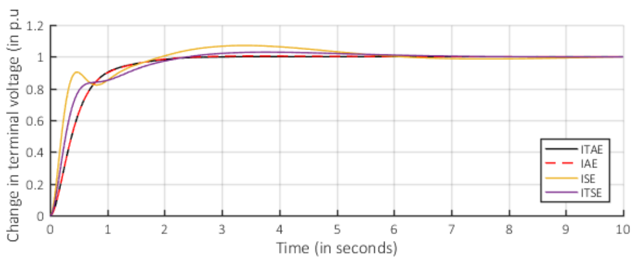

Fig. 5. Terminal voltage deviations for different performance indices (PSO-PID)

TABLE I
COMPARISON OF RESPONSE OBTAINED FROM DIFFERENT PERFORMANCE INDICES (PSO-PID)

Performance Index	LFC Loop		AVR Loop
	Max. Overshoot (p.u.)	*Settling time (s)*	*Settling time (s)*
ITAE	-0.2986	6.650	3.218
IAE	-0.2616	6.983	4.817
ITSE	-0.2537	8.353	7.824
ISE	-0.2951	8.391	10.35

TABLE II
PSO-PID CONTROLLER GAINS OBTAINED FROM DIFFERENT PERFORMANCE INDICES

Performance Index	K_P		K_I		K_D	
	LFC	*AVR*	*LFC*	*AVR*	*LFC*	*AVR*
ITAE	3.19	0.80	2.00	0.38	2.39	0.30
IAE	4.54	0.80	2.00	0.39	2.89	0.30
ISE	5.00	0.80	2.00	0.80	5.00	0.80
ITSE	5.00	0.80	2.00	0.48	4.47	0.50

B. *Many Optimizing Liasons tuned PID Controller*

Fig. 6 shows the frequency deviations and fig. 7 shows the terminal voltage deviations of the system for different performance indices. Table III provides the comparison of response obtained from different performance indices. The comparison is made in terms of maximum overshoot and settling time of the frequency response and voltage response of the single area power system. Table IV shows the values of Many Optimizing Liaisons based Proportional Integral Derivative controller gains obtained from each performance index.

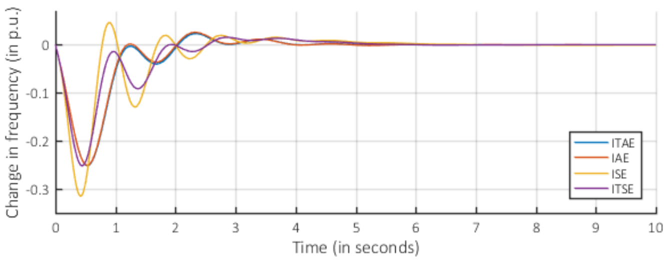

Fig. 6. Frequency deviations for different performance indices (MOL-PID)

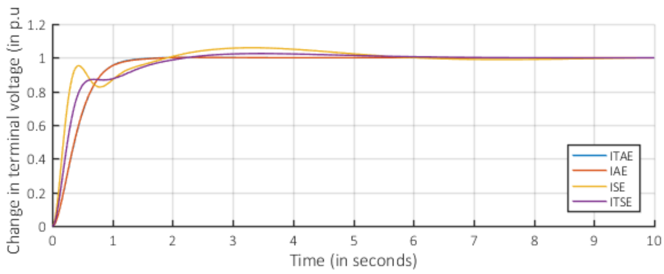

Fig. 7. Terminal voltage deviations for different performance indices (MOL-PID)

TABLE III
COMPARISON OF RESPONSE OBTAINED FROM DIFFERENT PERFORMANCE INDICES (MOL TUNED PID)

Performance Index	LFC Loop		AVR Loop
	Max. Overshoot (p.u.)	*Settling time (s)*	*Settling time (s)*
ITAE	-0.2514	5.833	1.986
IAE	-0.2519	5.871	2.055
ITSE	-0.2519	6.95	7.082
ISE	-0.3153	6.142	9.156

TABLE IV
MOL-PID CONTROLLER GAINS OBTAINED FROM DIFFERENT PERFORMANCE INDICES

Performance Index	***K_P***		***K_I***		***K_D***	
	LFC	*AVR*	*LFC*	*AVR*	*LFC*	*AVR*
ITAE	5.00	0.90	4.57	0.46	3.16	0.29
IAE	5.00	0.90	5.00	0.46	3.20	0.29
ISE	5.00	0.90	5.00	0.89	5.00	0.90
ITSE	5.00	0.90	5.00	0.57	5.00	0.55

C. Comparison of results obtained from Conventional PID Controller, PSO-PID controller and MOL-PID Controller

Fig. 8 compares the frequency deviation of the system obtained from PSO-PID controller and MOL-PID controller, and conventional PID controller. Fig. 9 shows the terminal voltage response of the system obtained from PSO-PID controller, MOL-PID controller and conventional PID controller. The ITAE criterion was chosen for comparison as it showed the best result in terms of overshoot and settling time. Table V shows the optimal gains of PSO-PID controller, MOL-PID controller (from using ITAE as performance index) and Conventional PID controller.

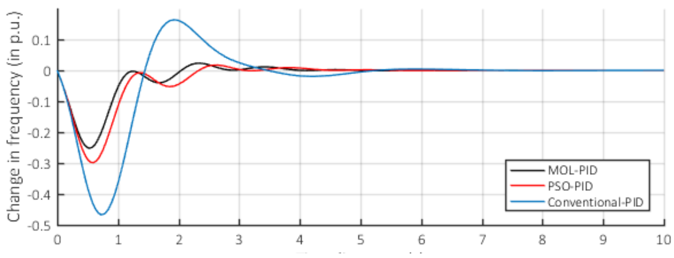

Fig. 8. Comparison of frequency deviation obtained from different tuning methods

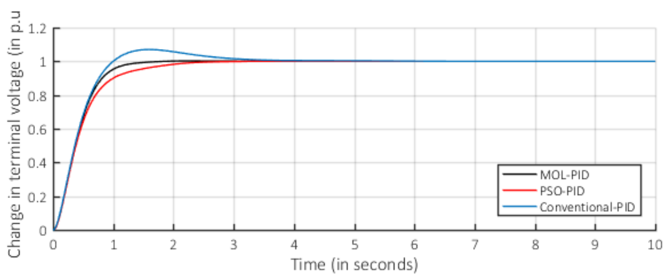

Fig. 9. Comparison of terminal voltage response obtained from different tuning methods

TABLE V
PID CONTROLLER GAINS OBTAINED FROM DIFFERENT TUNING METHODS

Controller	**LFC Loop**			**AVR Loop**		
	K_P	*K_I*	*K_D*	*K_P*	*K_I*	*K_D*
Conventional PID	0.2	1.5	1.2	0.9	0.6	0.3
PSO-PID	3.19	2	2.39	0.80	0.38	0.30
MOL-PID	5	4.57	3.16	0.90	0.46	0.29

VI. CONCLUSION

The conventional PID controllers results in large settling time, overshoot and oscillations. With use of evolutionary algorithms to tune the PID controllers, the typical characteristics show a faster and smoother response. Table VI provides the comparison of using the conventional tuned PID, PSO-PID controller and MOL-PID controller.

For a LFC system simulated for a step load deviation of 0.1 p.u. and regulation of 3 Hz/p.u., the settling time in the case of MOL-PID controller with ITAE as fitness function is 5.833s with a maximum overshoot of -0.2514 p.u., which is least as compared to the PID controller tuned through PSO algorithm and conventional tuning.

For an AVR system, there is no transient peak, also the MOL algorithm tuned PID controller with ITAE as fitness function gives a very small settling time of 1.986 sec as compared to the PID controller tuned through PSO algorithm and conventional tuning.

Thus the MOL-PID controller with ITAE as performance index results in best performance in terms of reduced overshoot and settling time.

TABLE VI
COMPARISON OF DYNAMIC PERFORMANCE RESULTED FROM USE OF DIFFERENT TUNING METHODS

Tuning Method	Dynamic Response		
	Δf		ΔV
	Max. Overshoot (p.u.)	*Settling time (s)*	*Settling time (s)*
Conventional	-0.467	7.956	6.399
PSO	-0.298	6.650	3.218
MOL	-0.251	5.833	1.986

APPENDIX

The simulation parameters for the Simulink model are provided in table below:

TABLE VII
SIMULATION PARAMETERS CONSIDERED FOR SYSTEM MODEL

LFC Loop Parameters	AVR Loop Parameters
Load change, ΔP_L = 0.1p.u.	Amplifier gain, K_A = 10
Base power = 1000 MW	Amplifier time constant τ_A=0.1
Governor time constant τ_{sg}=0.4s	Exciter gain, K_E = 1
Turbine time constant τ_t= 0.5s	Exciter time constant τ_E =0.4s
Load damping constant, D = 1	Generator gain, K_G = 0.8
Inertia constant H =10 MW/MVA	Generator time constant τ_G=1.4s
Speed regulation, R = 3 Hz/p.u.	Sensor gain K_R = 1
	Sensor time constant τ_R=0.05s

The Particle Swarm Optimization parameters used are:

Population size : 30
No. of iterations : 30
Cognitive coefficient, C_1 : 2
Social coefficient, C_2 : 2
Inertia weight : $0.4 \leq w \leq 0.9$

The Many Optimizing Liaisons parameters used are:

Population size : 30
No. of iterations : 30
Social coefficient, C : 2
Inertia weight : $0.4 \leq w \leq 0.9$

REFERENCES

[1] D. P. Kothari and I. J. Nagrath, "Automatic generation and voltage control," in *Power System Engineering*, 2nd ed., New Delhi, India: Tata McGraw Hill, 2011, pp. 409-430.

[2] H. Saadat, "Power System Control," in *Power System Analysis*, New Delhi, India: Tata McGraw Hill, 2002, pp. 527-569.

[3] Z. L. Gaing, "A particle swarm optimization approach for optimum design of PID controller in AVR," *IEEE Trans. on Energy Convers.*, vol. 19, no. 2, pp. 384-391, June, 2004.

[4] J. F. Nirmal, and D. J. Auxilia, "Adaptive PSO based tuning of PID controller for an automatic voltage regulator system," in *Proc. of IEEE Int. Conf. on Circuits, Power and Computing Technology*, Nagercoil, 2013, pp. 661-666.

[5] Y. Valle, G. K. Venayagamoorthy, S. Mohagheghi, J. C. Hernandez and R. G. Harley, "Particle swarm optimization: Basic concepts, variants and applications in power systems," *IEEE Trans. on Evol. Computation*, vol. 12, no. 2, pp. 171-195, April, 2008.

[6] J. Kennedy and R. C. Eberhart, "Particle swarm optimization," in *Proc. of IEEE Int. Conf. on Neural Networks*, Piscataway, NJ, 1995, vol. IV, pp. 1942-1948.

[7] M. Imran, R. Hashim and N. E. A. Khalid, "An overview of particle swarm optimization variants," in *Proc. of Malaysian Tech. Universities Conf. on Eng. & Tech. (MUCET 2012), Part 4 – Inform. And Commun. Technology*, Malaysia, 2013, pp. 491-496.

[8] Z. H. Zhan, J. Zhang, Y. Li, and H. S. H. Chung, "Adaptive particle swarm optimization," *IEEE Trans. on Syst. Man and Cybern. B, Cybern.*, vol. 39, no. 6, pp. 1362-1381, December, 2009.

[9] Y. Shi and R. C. Eberhart, "A modified particle swarm optimizer," in *Proc. of IEEE Int. Conf. on Evol. Computation*, Piscataway, NJ, 1998, pp. 69-73.

[10] S. Panda, B. K. Sahu, and P. K. Mohanty, "Design and performance analysis of PID controller for an automatic voltage regulator system using simplified particle swarm optimization," *J. of The Franklin Institute*, vol. 349, pp. 2609-2625, July, 2012.

[11] A. Chakrabarti and S. Halder, "Automatic Generation Control," in *Power System Analysis-Operation & Control*, New Delhi, India: Prentice Hall India, 2010, pp. 469-506.

[12] P. Dabur, N. K. Yadav and V. K. Tayal, "Matlab design and simulation of AGC and AVR for multi area power system and demand side management," *Int. J. of Comput. and Elect. Eng.*, vol. 3, no. 2, pp. 259-264, April, 2011.

[13] P. Kundur, "Control of active power and reactive power," in *Power Sys. Satbility & Control*, New York, USA: McGraw Hill, 1994, pp. 581-688.

[14] K. H. Ang, G. Chong and Y. Li, "PID control system analysis, design and technology," *IEEE Trans. on Control Syst. Technology*, vol. 13, no. 4, pp. 559-576, July, 2005.

[15] M. Nagendra, and M. S. Krishnarayalu, "PID controller tuning using simulink for multi area power systems," *Int. J. of Eng. Research & Technology*, vol. 1, no. 7, pp. 1-9, September, 2012.

[16] J. Venkatachalam and S. Rajalaxmi, "Automatic generation of two area interconnected power system using particle swarm optimization," *IOSR J. of Elect. and Electron. Eng.*, vol. 6, no. 1, pp. 28-36, June, 2013.

[17] A. Soundarrajan, S. Sumathi and C. Sundar, "Particle swarm optimization based LFC and AVR of autonomous power generating system," *IAENG Int. J. of Comput. Sci.*, vol.37, no.1, Feb, 2010.