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Design of Optimal PID Controller for LFC and AVR in Power System using PSO

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Abstract: This paper considers the determination of the optimal values for the proportional-integral derivative (PID) controller parameters of load frequency control (LFC) and Automatic Voltage Regulator (AVR) system of single area power system using the particle swarm optimization (PSO) technique. The LFC loop controls real power and frequency and AVR loop controls reactive power and voltage. This work demonstrates the application of PSO method to search optimal PID controller parameters (Kp,Ki,Kd) of LFC and AVR for single area power system. The simulation results demonstrate the effectiveness of the designed system in terms of reduced settling time, overshoot and oscillations. The results are compared with conventional PID, Fuzzy and GA based controllers.

Keywords: Automatic Voltage Regulator (AVR), Load Frequency Control (LFC), Particle swarm optimization (PSO), Proportional integral and derivative controller (PID).

I. Introduction

In power system, both active and reactive power demands are never steady they continuously change with the rising or falling trend. Steam input to turbo generators(or water input to hydro generators) must therefore, be continuously regulated to match the active power demand, failing which the machine speed will vary with consequent change in frequency, which may be highly undesirable. The quality of power supply must meet certain minimum standards with regard to constancy of voltage and frequency. The function of excitation control is to regulate generator voltage and reactive power output. The desired real power outputs of the Individual generating units are determined by the system generation control. The voltage and frequency controller has gained importance with the growth of interconnected system and has made the operation of power system more reliable.

The LFC and AVR of an isolated power system have been reported and a number of control schemes like Proportional and Integral (PI), Proportional, Integral and Derivative (PID) and optimal control. The conventional method exhibits relatively poor dynamic performance as evidenced by large overshoot and transient frequency oscillations. The artificial intelligence search techniques are used to find parameters optimization of LFC and AVR considering proportional-integral-derivative controller (PID) for an isolated power system. The selection of the optimal parameters of the PID controller is converted to a simple optimization problem which is solved by a PSO algorithm.

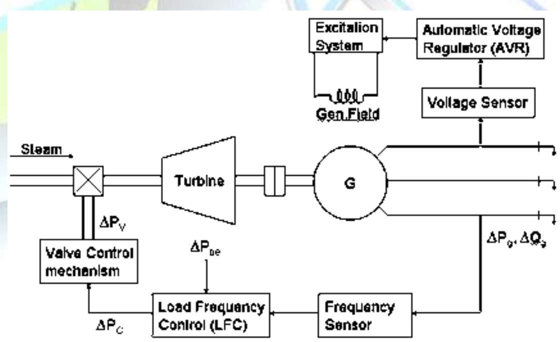

Fig 1: Diagram of a LFC and AVR of a synchronous generator

II. Plant Model

In an interconnected power system, LFC and AVR Equipment are installed for each generator. The schematic diagram of the voltage and frequency control loop is represented in fig.1. The controllers are set for a particular

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operating condition and take care of small changes in load demand to maintain the frequency and voltage magnitude within the specified limits.

A. Load frequency Control (LFC)

The aim of LFC is to maintain real power balance in the system through control of system frequency. Whenever the real power demand changes, a frequency change occurs. This frequency error is amplified, mixed and changed to a command signal which is sent to turbine governor. The governor operates to restore the balance between the input and output by changing the turbine output. This method is also referred as Megawatt frequency or Power-frequency (P-f) control .PSS is a fixed parameter analogue type device with lead-lag compensation, washout, and amplifier gains, which are limited and may lose effective damping robustness for overall operation.

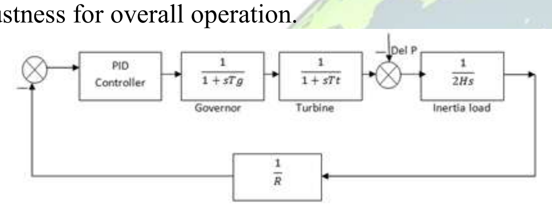

Fig 2: Block diagram of LFC with PID controller

B. Automatic voltage regulator (AVR)

The aim of this control is to maintain the system voltage between limits by adjusting the excitation of the machines. The automatic voltage regulator senses the difference between a rectified voltage derived from the stator voltage and a reference voltage. This error signal is amplified and fed to the excitation circuit. The change of excitation maintains the VAR balance in the network. This method is also referred as Megawatt Volt Amp Reactive (MVAR) control or Reactive-Voltage (QV)control.

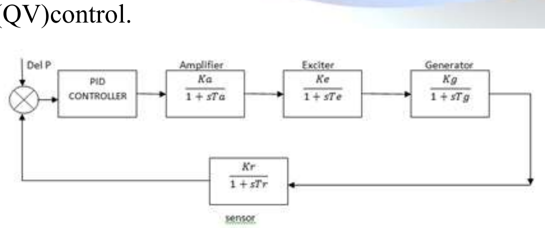

Fig 3: Block diagram of AVR with PID controller

II. PARTICLE SWARM OPTIMIZATION (PSO)

PSO, a proposed algorithm by James Kennedy and R.C.Eberhart is one of the modern heuristic algorithms, it has been motivated by the behaviour of organisms, such as fish schooling and bird flocking. Generally, PSO is characterized as a simple concept, easy to implement, and computationally efficient. Unlike the other heuristic techniques, PSO has a flexible and well-balanced mechanism to enhance the global and local exploration abilities. It shares many similarities with evolutionary computation techniques such as Genetic Algorithms (GA). The PSO algorithm starts with random initialization of population and velocity. The search for the optimum solution is continued unless one of the stopping criteria is reached. The stopping criteria are either the maximum iterations are reached or there is no further improvement in the optimal solution. The PSO is initialized with a group of random particles (solutions) and then searches for optima by updating generations. In every iteration, each particle is updated by following two best values. The first one is the best solution (fitness) it has achieved so far (the fitness value is also stored) this value is called pbest. Another "best" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in population. This best value is a global best called as gbest. The particle takes part of the population as its topological neighbours the best value is a local best and is called lbest.

Let x and v denote a particle coordinates (positions)and its corresponding flight speed (velocity)in a search space, respectively. Therefore, the i-th particle is represented as $x_i=(x_{i1},x_{i2},\ldots,x_{id})$ in the d-dimensional space .The best previous position of the i-th particle is recorded and represented as $pbest_i=(pbest_{i1},pbest_{i2},\ldots,pbest_{id})$.the index of the best particle among the all particles in the group is represented by the gbest. The rate of velocity for the particle **i** can be represented as $\mathbf{v_i=(v_{i1},v_{i2}\ldots v_{id})}$.The modified velocity and positions of the each particle can be Calculated using the current velocity and the distance from the following equations,

$$V_{id}^{(t+1)}=\omega.v_{id}^{(t)}+c1*rand()*(pbest_{id}-x_{id}^{(t)})+c2*rand()*(gbest_{d}-x_{id}^{(t)}) \quad (5)$$

$$X_{id}^{(t+1)}=x_{id}^{(t)}+v_{id}^{(t+1)},\ i=1,2,3...n.,d=1,2...m \quad (6)$$

where c1 and c2 are cognition and social parameters respectively, rand1() and rand2() are constant numbers in the range of [0,1], w is the inertia weight. Vi represents the velocity of the ith particle and Xi is its position, pbesti and gbest are local best and global best positions respectively. The velocity of particle in equation depends on its previous velocity, its own thinking and social psychological adaptation of the population.

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The inertia weight ω is set according to the following equation ,

$$\omega = \omega_{max} - \frac{(\omega_{max} - \omega_{\min})}{iter_{max}} \times iter \qquad (7)$$

The advantages of PSO over the other optimization techniques are Lower sensitivity to the nature of the objective function Derivative free property unlike genetic algorithm Easy implementation and Fast convergence.

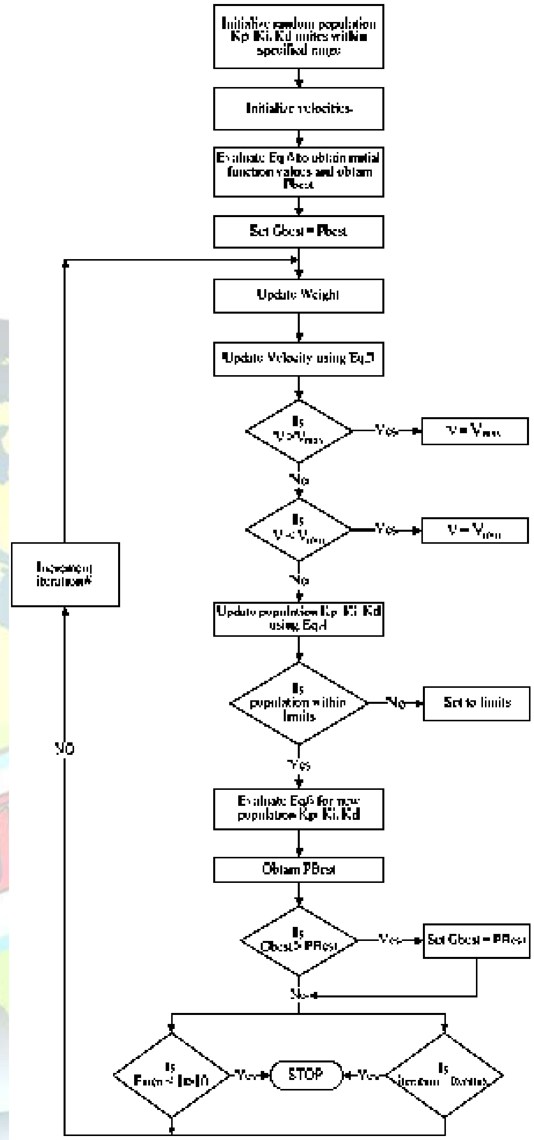

Fig 4: PSO flow chart

The PID controller parameters are adjusted to keep the LFC and AVR at an optimum level of performance under varying operating conditions. It requires a performance index which is the function of system parameters. The commonly used performance indexes are, integral square error (ISE), integral of the absolute magnitude of error (IAE), integral time square error (ITSE), integral of time multiply by absolute error (ITAE). ITAE

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performance index which produces smaller overshoots and oscillations.

The ITAE is given as,

$$ITAE = \int_0^{\infty} t\,|e(t)|\,dt \quad (7)$$

In this approach an **ITAE** criterion is used for evaluating the PID controller. A set of good control parameters P, I and D can yield a good step response that will result in performance criteria minimization in the time domain. Therefore, the performance criterion is defined as follows,

$$Ji = min\left(\sum_{m=1}^{M}(t * absolute(error))\right) \quad (8)$$

The PID parameters are subjected to the following constraints.

$0 < Kp < 100$
$0 < Ki < 100$
$0 < Kd < 20$

.

IV. Simulation Model Of LFC And AVR With PSO Based PID Controller

To verify the efficiency of proposed algorithm a practical higher order system in Fig.4 is considered. The PSO algorithm is used to search an optimal parameter set containing Kp, Ki and Kd. The optimum values generated by the algorithm are stored in work space and shared with the LFC and AVR simulink model.

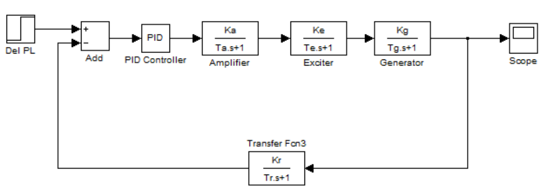

Figure 5: Simulink model of AVR with PID controller

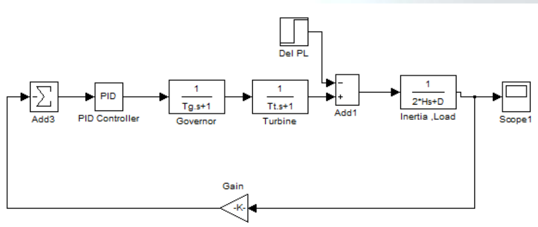

Fig 6: Simulink model of LFC with PID controller

Table I: Simulation Parameters

	Simulation Parameters
LFC	Tg = 0.095, Tt = 0.5, H = 10, D = 0.8, R= 10, ΔPL = 0.10, 0.20
AVR	Ka =1.1165, Ta =0.2, Te = 0.4, Kg = 0.75, Tg =1.4, Kr= 1, Tr = 0.05

Table II: PSO Parameters

No.of particles	20
No. of swarms	3
No. of iterations	200
c1,c2	2,2
Wmax,Wmin	0.9,0.4
Maximum particle velocity	(Upperbound-lower bound)/No. of iterations

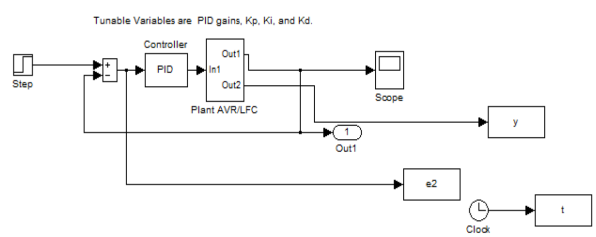

Fig 6: Simulink model of LFC and AVR with PSO based PID controller

V. Simulation Results

The LFC and AVR are simulated using PSO based PID controller, for different values of load and regulation.

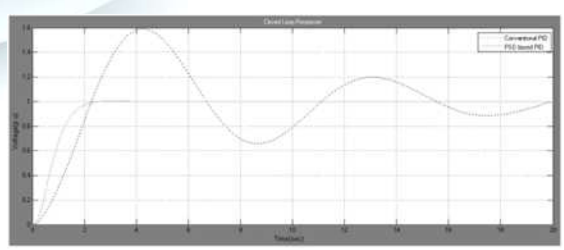

Fig 7:Performance of AVR with PSO based PID controller for ΔP_L=0.1 p.u

It is observed that the settling time of AVR with PSO based PID controller is 4 seconds and there is no transient

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peak overshoot. As seen from the result, the PSO-PID controller could create very perfect step response of the terminal voltage in AVR system.

The LFC model was simulated with different loads and regulations. The change frequency for a load of 0.1 p.u and regulation 'R' value as 10.

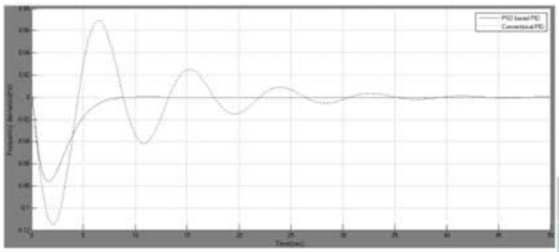

Fig 8: Performance of LFC with PSO based PID controller for ΔP_L=0.1 p.u

It is observed that the settling time of LFC with PSO based PID controller is 8 seconds and the peak overshoot is -0.07. These results clearly indicate that the PID controller parameters quickly and efficiently. In order to demonstrate the effectiveness of the proposed controller, simulations are carried out for various performance indexes.

Table III: Comparison results of AVR for various performance indexes

Performance indexes	**Kp**	**Ki**	**Kd**	**Mp**	**Ts**	**Tr**
ISE	8.4	8.2	2.2	1.16	8.2	1.3
ITSE	1.6	1.03	0.19	Nil	10.5	5.4
IAE	1.63	1.37	0.54	1.05	7.4	1.8
ITAE	0.84	0.61	0.26	Nil	3.8	1.2

Table IV: Comparison results of LFC for various performance indexes

Performance indexes	**Kp**	**Ki**	**Kd**	**Mp**	**Ts**
ISE	7.79	2.25	1.53	-0.09	10.8
ITSE	11.4	3.8	4.14	-0.07	8.20
IAE	16.9	8.64	6.16	-0.06	11.5
ITAE	16.9	7.31	7.22	-0.05	6.20

VII. CONCLUSIONS

The conventional controllers used for this problem have large settling time, overshoot and oscillations. Hence, when evolutionary algorithms are applied to control system problems, their typical characteristics show a faster and smoother response. An intelligent technique has been proposed for combined voltage and frequency control in an isolated power system. The proposed PSO-PID controller provides a satisfactory stability between frequency overshoot and transient oscillations with zero steady state error. The work can be extended in future by including non-linear parameters to the system modelled and thereby comparison can be made with respect to linear system. Also the other evolutionary computing techniques like Hybrid Particle Swarm optimization (HPSO), GA-PSO, Hybrid GA, Fuzzy PSO, Distributed Evolution etc., and can be implemented to improve the performance characteristics.

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