Application of Heuristic Search Algorithm to Design Automatic Generation Control in Power System

Ms. Lakshmishree C. Patil
Dept. of Electrical and Electronics
KLE Technological University
Hubballi, India
lakshmishreepatil@gmail.com

Mrs. Minal Salunke
Dept. of Electrical and Electronics
KLE Technological University
Hubballi, India
minal@kletech.ac.in

Dr. S. B. Karajgi
Dept. of Electrical and Electronics
KLE Technological University
Hubballi, India
shrikant.karajgi@kletech.ac.in

***Abstract*—This paper presents a Heuristic Search Algorithm, Conventional Particle Swarm Optimization (CPSO) which is employed to design Automatic Generation Control (AGC) for an isolated power system to minimize the variation in frequency due to changes in load demand. Further, Advanced Particle Swarm Optimization (APSO) with a velocity update strategy is introduced to ensure that the particles will orbit toward their optimum point quickly which guarantees faster convergence.**

***Index Terms*—CPSO, AGC, APSO**

I. INTRODUCTION

With only the primary control action of the turbine speed governor, a variation of real power and steady-state frequency deviation is observed due to sudden changes in load. This deviation/fluctuation due to a change in load demand causes disturbances in control areas. Thus, one of the crucial challenges with the operation of the power system has been the Load Frequency Control (LFC) dilemma [1]. LFC ensures that the real power output is regulated by altering the frequency of that particular system.

The restoration of the frequency to a marginal value necessitates additional control activity to adjust the speed reference set point, which is referred to as Automatic Generation Control (AGC). AGC is a supplementary controller provided on selected governing units and the reference set point is regulated which in turn manages the power of the prime mover to adapt to the fluctuations caused in the system load. For the study of LFC, a PID controller is employed to reduce any frequency variation brought on by any change in the load.

The majority of existing power systems need to function efficiently and transparently, thus the controllers must always be developed with all of these objectives in mind. Many researches have been conducted to resolve the issue of frequency deviation by employing various regulators like the traditional PI or PID controller. These attempts were not fruitful in the presence of elements that are either varying with time or non-linear [2]. Designing a reliable controller using Artificial Intelligence (AI) approaches such as Ant colony optimization, and Genetic Algorithm solves this challenge [3]. This paper incorporates the above-mentioned idea and attempts to design a controller whose gains are modified to obtain the best possible outcome by applying an AI technique of CPSO to attain the highest level of LFC efficiency. The efficiency of the controller tuned by employing CPSO is studied, and further an APSO technique with a modified velocity update equation is used to achieve faster convergence of the controller parameters.

II. LOAD FREQUENCY CONTROL

The primary goal of LFC is to preserve a relatively uniform frequency and to distribute the load among the generators. A speed governor, a turbine, as well as a generator are the primary parts of an independent area's power system. The generator is fed with a step load input in the system.

A. Speed Governor

The speed changer contains a servo motor that can be manually or automatically operated. The real power generation can be set to the desired value by adjusting the speed changer settings. For a solitary area of the power system, the Speed Governing system can be modeled as shown in Fig.1.

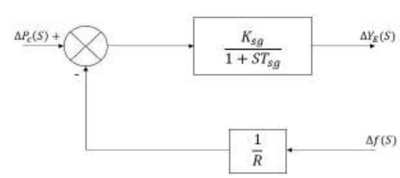

Fig. 1. Block diagram of Speed Governor.

$$\triangle Y_E(S) = \frac{K_{sg}}{1 + ST_{sg}}[\triangle P_c(S) - \frac{\triangle f(S)}{R}] \quad (1)$$

where,

$\triangle P_c(S)$: Commanded power change
$\triangle f(S)$: Change in frequency
R : Speed regulation
K_{sg} : Gain of governing

T_{sg} : Time constant of governing
$\triangle\, Y_E(S)$: Input to the turbine

B. Turbine

The input $\triangle\, Y_E(S)$ to the turbine affects the corresponding change in mechanical power output of the turbine $\triangle\, P_t$. Assuming a non-reheated steam turbine, the model is represented by a single-time constant transfer function. Fig. 2 represents the corresponding block diagram of the turbine.

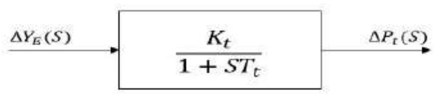

Fig. 2. Block diagram of Turbine.

$$\frac{\triangle\, P_t(S)}{\triangle\, Y_E(S)} = \frac{K_t}{1+ST_t} \tag{2}$$

where,
K_t : Gain of turbine
T_t :Time constant of turbine

Assuming that the generator shaft loss is negligible, we get,
$\triangle\, P_t(S) = \triangle\, P_D(S)$
And, the variation in the output of the generator's real power is
$\triangle\, P_g(S) = \triangle\, P_t(S)$

C. Generator and Load Model

The system has several kinds of frequency-sensitive loads like an induction motor, synchronous motors, and many more. The equivalent load will change with a change in frequency.
Change in composite load is given by the following equation:

$$\triangle\, P_D^{'} = \triangle\, P_D + B \triangle f \tag{3}$$

where,
B is the sensitivity of frequency-dependent load.
The power mismatch is given by:

$$P_m = \triangle\, P_g - \triangle\, P_D^{'} \tag{4}$$

The power mismatch is accounted for by the inertia of the rotating masses as a corresponding change in total kinetic energy.
Rate of change of kinetic energy = $2H\frac{d}{dt} \triangle f$
where,
H is the Generator Inertia constant.
Therefore, from (3) and (4), we get,

$$\triangle\, P_g - \triangle\, P_D - B \triangle f = 2H\frac{d}{dt} \triangle f \tag{5}$$

Applying Laplace transform to (5), the relationship between the output to the input of the isolated power system is obtained as in (6) and is represented in Fig.3.

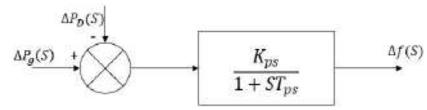

Fig. 3. Block diagram of Generator and Load.

$$\frac{\triangle\, f(S)}{\triangle\, P_g(S) - \triangle\, P_D(S)} = \frac{K_{ps}}{1+ST_{ps}} \tag{6}$$

where,
Gain of power system area, $K_{ps} = \frac{1}{B}$
Time constant of power system area, $T_{ps} = \frac{2H}{B}$

The complete block diagram of a standalone power system is depicted in Fig.4.

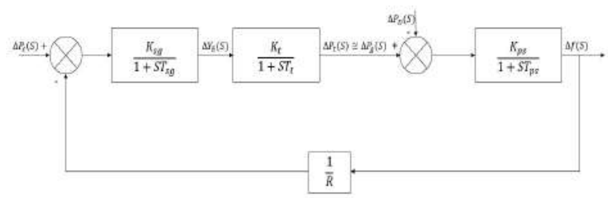

Fig. 4. Dynamic model of an isolated power system area.

D. Steady State Analysis

By using the Final Value Theorem, the steady-state model may be created from the dynamic model of a solitary power system area.
For steady-state analysis, the gains K_{sg} and K_t are chosen such that $K_{sg} * K_t \approx 1$. Thus, the block diagram for steady-state analysis is obtained as shown in Fig.5.

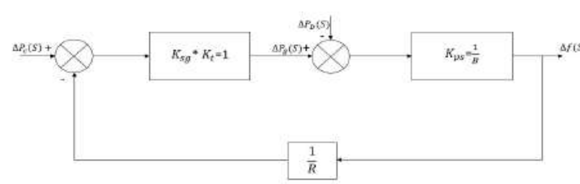

Fig. 5. Steady-state block diagram of a standalone power system area.

From the above figure, the steady-state frequency deviation of the system is derived and represented in the following equation (7).

$$\triangle\, f = \frac{\triangle\, P_c - \triangle\, P_D}{B + \frac{1}{R}} \tag{7}$$

III. Automatic Generation Control

In any application, deviation of steady-state frequency is noticed when there is a slight adjustment of the load. This deviation cannot be minimized by the turbine speed governor alone and hence, the Automatic Generation Control is used for the additional control action where the system frequency is restored.

An isolated power system with a PID controller that ensures AGC is shown in Fig.6.

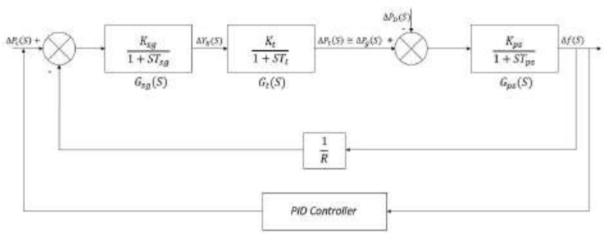

Fig. 6. Model of a solitary power system area with AGC.

For better operation we consider, $K_{sg} * K_t = 1$.
Thus, the complete transfer function model with the primary control system as well as secondary control that is AGC being used for an isolated power system is obtained as in (8)

$$\frac{\triangle f}{-\triangle P_D} = \frac{(1+ST_{sg})(1+ST_t)}{(B+2SH)(1+ST_{sg})(1+ST_t)+\frac{K_i}{S}+K_p+SK_d+\frac{1}{R}} \quad (8)$$

The plot in Fig.7 depicts that the frequency deviation of an isolated power system has been minimized by employing AGC with some assumed nominal values of gains of the PID controller.
Thus, AGC acts as a supplementary controller as well as a frequency controller.

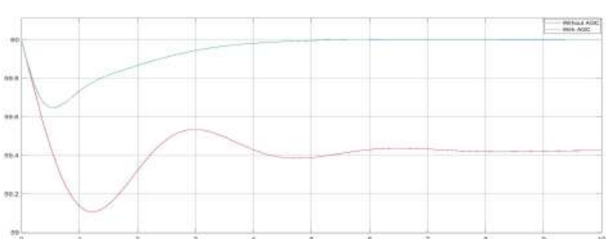

Fig. 7. Variation of the frequency with time(without and with AGC).

The AGC can ensure better minimization of frequency deviation by obtaining the optimal values of controller gains K_p, K_i, and K_d.

IV. Overview of Particle Swarm Optimization

Particle Swarm Optimization (PSO) is developed by Kennedy and Eberhart (1995) and is a powerful population-based meta-heuristic improvement algorithmic program impressed by swarm behavior ascertained in nature like fish and bird schooling [4]. It is a numerical technique for fine-tuning a problem by recursively attempting to improve a particular solution on a given measure of quality.

In PSO, the representation of each particle in a swarm is achieved using the particle's position and velocity. Based on the particle's exploration, the swarm's best experience, and its previous values, the particles update their position and velocity. This algorithm for PSO is well depicted in Fig.8.

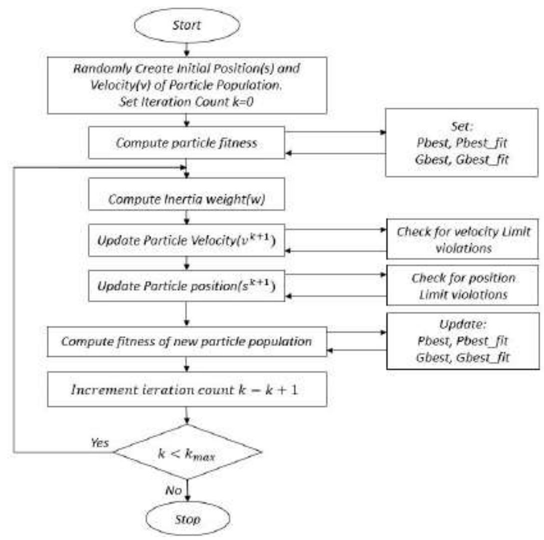

Fig. 8. Algorithm of Particle Swarm Optimization.

Here, we have considered two optimizations of Particle Swarm that is Conventional and Advanced.

A. Conventional Particle Swarm Optimization

For CPSO, the modification of a particle i's velocity is achieved using the Velocity Update Equation (9)

$$v_i^{k+1} = w^{k+1}v_i^{k} + c_1r_1[pbest_i^{(k)} - x_i^{k}] + c_2r_2[gbest^k - x_i^{k}] \quad (9)$$

where,
v_i^k : Velocity of an individual i at k^{th} iteration
w : Inertial weight parameter
c_1 and c_2 : Acceleration factor
r_1 and r_2 : Random figures in the range [0,1]
x_i^k : Individual i's position at k^{th} iteration
$pbest_i^k$: Best individual position particle i at k^{th} iteration
$gbest_i^k$: Best global position of a particle i in a group at k^{th} iteration

The parameters w, $c1$, and $c2$ in the velocity update equation must be determined in advance.

The velocity update equation has the following three terms:

- Term-1 is the Inertia part. The value of w is determined by the equation (10).

$$w^{k+1} = w_{max} - \frac{k(w_{max} - w_{min})}{k_{max}} \quad (10)$$

where,
k_{max} = Maximum Number of iteration set

w_{max} and w_{min} = Maximum and Minimum values of inertia weight set

- Term-2 represents the Cognitive part.
- Term-3 represents the SOCIAL part of CPSO.

The position component of every particle is updated using the following update formula.

$$x_i^{k+1} = x_i^k + v_i^{k+1} \tag{11}$$

B. Advanced Particle Swarm Optimization

In APSO, the velocity update equation is modified by adding a term that ensures faster convergence compared to CPSO. The initialization of parameters in APSO is the same as that of CPSO. The modified velocity equation is as shown in equation (12) and the position update equation is given by (13).

$$v_i^{k+1} = w^{k+1} {v_i}^k + c_1 r_1 [{pbest_i}^{(k)} - {x_i}^k] + c_2 r_2 [gbest^k - {x_i}^k] + w^{k+1} \frac{c1}{c2} [{pbest_i}^k - gbest^k] \tag{12}$$

$$x_i^{k+1} = w x_i^k + v_i^{k+1} \tag{13}$$

The acceleration coefficients are responsible for the movement of particles and hence are often set such that $c_1 + c_2 \leq 4$ [5].

Individual particle updates and move to a new position from the current position by using the velocity and position equations, (9) and (11) for CPSO, and equations (12) and (13) for APSO.

V. Implementation of CPSO and APSO for AGC in Isolated Power System

An isolated power system having the Turbine time constant $T_t = 0.5s$, Governor time constant $T_g = 0.2s$, Governor speed regulator $R = 0.05pu$, and Generator inertia constant $H = 5s$ with a PID controller is designed in SIMULINK where the load varies by 0.8% for a 1% change in frequency for a turbine with a rated power of $250MW$ at a frequency of $60Hz$, considering $50MW$ as a sudden variation in load. Here, for best results Integral Time multiplied Absolute Error (ITAE) [6] is considered as the fitness function which is given by the (14). ITAE integrates the absolute error over a certain period. It ensures that the settling time of the system is as minimum as possible, and hence is one of the best methods which ensures that the PID controller's gains are enhanced [7]. The performance index of ITAE is sensitive, and it produces smaller overshoots compared to other techniques [8], [9]. A sufficiently large time of $T = 10s$ is chosen as it is not practical to integrate up to infinite time. This time is chosen such that the error at time t is negligible where $t < T$ [10].

$$ITAE = \int_{t=0}^{t=final} | \triangle f| * t * dt \tag{14}$$

Fig.9 represents the SIMULINK model of a solitary power system area with the above-specified parameters.

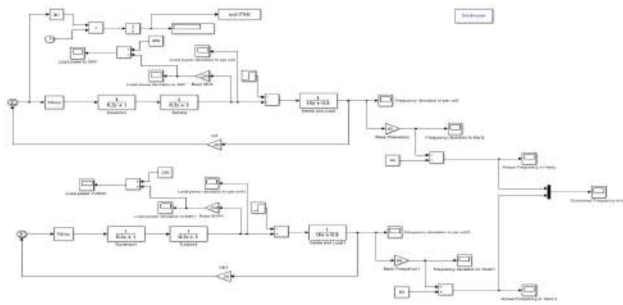

Fig. 9. SIMULINK model of solitary power system with AGC.

The heuristic search algorithms of CPSO and APSO are applied to the model, and further, the convergence curves are compared.

VI. Results

Fig. 10 shows the convergence obtained by applying CPSO to the model of the isolated power system area.

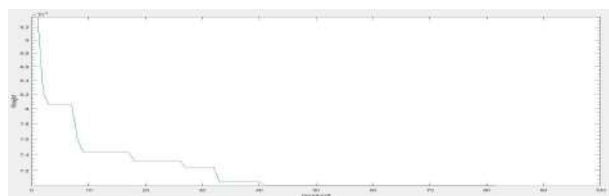

Fig. 10. Convergence curve using CPSO.

The best solution for the gains is obtained at iteration number 82. These optimal values are used to further obtain the frequency deviation plot as shown in Fig.11.

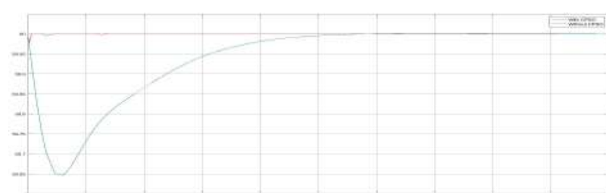

Fig. 11. Frequency deviation with and without CPSO.

The convergence curve obtained by employing APSO is shown in Fig.12.

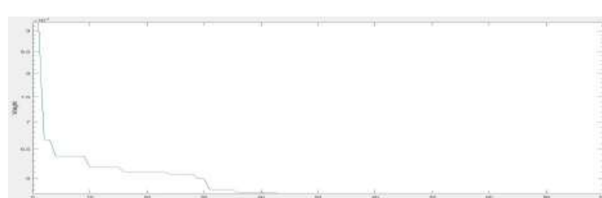

Fig. 12. Convergence curve using APSO.

The frequency deviation of the isolated model when APSO is applied is shown in Fig.13, and it is obtained by utilizing the optimal values of gains achieved at iteration number 43.

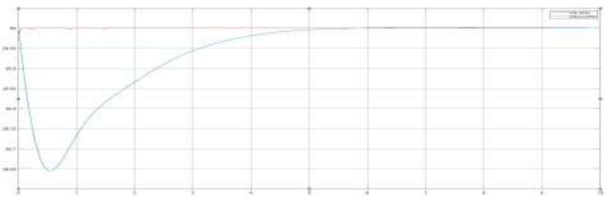

Fig. 13. Frequency deviation with and without APSO.

VII. Conclusion

From the above application of CPSO and APSO to AGC in a power system, it is observed that the APSO requires fewer iterations to converge and obtains the optimal values of gains which ensures the minimization of frequency deviation compared to the convergence obtained by using CPSO. Thus, the deviation of frequency caused by a change in load can be efficiently minimized or eliminated by employing a heuristic search algorithm.

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