JAYA Algorithm-Optimized Load Frequency Control of a Four-Area Interconnected Power System Tuning Using PID Controller

Sunita Pahadasingh
School of Electrical Engineering
Kalinga Institute of Industrial Technology Deemed to be University, Bhubaneswar, Odisha, India
spahadasingh@gmail.com

Chitralekha Jena
School of Electrical Engineering
Kalinga Institute of Industrial Technology Deemed to be University, Bhubaneswar, Odisha, India
chitralekha.jenafel@kiit.ac.in

Chinmoy Kumar Panigrahi
School of Electrical Engineering
Kalinga Institute of Industrial Technology Deemed to be University, Bhubaneswar, Odisha, India
panigrahichinmoy@gmail.com

Bibhu Prasad Ganthia
Electrical Engineering Department
Indira Gandhi Institute of Technology
Sarang, Odisha, India
jb.bibhu@gmail.com

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Abstract-This study examined the design of a Load Frequency Control (LFC) component in a four-area interconnected power system. LFC maintains the frequency of a power system within a prescribed limit. Various controllers for the LFC of a power system have been proposed. The PID controller is a classical approach to LFC. A PID controller that uses a filter in the derivative part amplifies and smooths out the high-frequency noise. The selection of the appropriate optimization method to tune controller gains plays a vital role for LFC. In this work, the PID controller was optimized using the Particle Swarm Optimization (PSO) and the JAYA optimization methods and was simulated in Matlab-Simulink. After studying and comparing the results, it was concluded that the PID controller using the JAYA algorithm provided better LFC in terms of system settling time, overshoot, undershoot, and performance index compared to other optimization methods.

Keywords-load frequency control; AGC; tie line; PIDN; PSO; JAYA

I. INTRODUCTION

An electric power system is a sequential arrangement of components to generate, transmit, distribute, and utilize power while continuously protecting it [1]. A power system has two important parameters that need to be constantly monitored and corrected: voltage and frequency. A generator generates power at some voltage and frequency, and these parameters should be controlled when there is a mismatch between active or reactive power generation and demand [2]. There are basically two methods to perform such control. When the active power demand is not equal to the active power generation, the frequency should be controlled, and when the reactive power demand is not equal to the reactive power generation, the voltage should be controlled [3]. Control of voltage and frequency can be performed in two ways, which are the primary and secondary control mechanisms. The primary control mechanism examines the aspects of generation, as generation remains constant most of the time while demand varies [5]. In the primary control mechanism, the Automatic Generation Control (AGC) has to match the demand by varying the generation. But in emergency conditions, where it is not possible to control generations, the load should be controlled, which is known as the load side management [6]. AGC can control voltage as well as frequency, i.e. load frequency control plus excitation control [7]. In AGC, there is a generator that generates active power P_g and reactive power Q_g . The generator gets input power from a turbine, and the turbine gets input power from the boiler [8]. While the steam comes from the boiler, there is a governor valve placed in the boiler to control the steam. When the active power is delivered to the bus, there is a comparator that receives and senses the frequency f_g coming from the generator [9]. The comparator has a reference frequency f_{ref}, which has to be maintained, and if there is any difference between f_g and f_{ref}, there will be an error f_e which will be operated by the generator valve. This whole closed loop is the LFC [10].

II. INTERCONNECTED SYSTEM

The operation of more than one interconnected areas is known as an interconnected system or power pool or pool operation [12]. Under normal operating conditions, each control area carries its own load and each control area adopts beneficial regulating and control strategies. These are two basic operating principles of a multi-control area system [11]. Unlike a small system, where a sudden change in load causes a large

Corresponding author: Bibhu Prasad Ganthia

frequency drop and could result in a system blackout, the interconnected systems don't have these problems. In an interconnected power system, a sudden change in load causes a large frequency drop [13]. Peak demands occur at various hours of the day in various areas of an interconnected system, so the ratio of peak to average load is smaller than that of an individual load. A control area in an interconnected system is characterized by the same frequency throughout, and the frequency deviations in different areas are represented as $\Delta F1$, $\Delta F2$, $\Delta F3$,… In an interconnected system, each area has a generator, a speed governing system, and a turbine. Each area has three inputs, i.e. the controller input (ΔP_{ref}), load distribution(ΔP_D), and tie-line power error (ΔP_{tie}) [14]. Each area has two outputs, which are the generator frequency (ΔF) and the Area Control Error (ACE), which is the signal fed into the integrator:

$$ACE = B\Delta F + \Delta P_{tie} \quad (1)$$

where B is the frequency bias parameter.

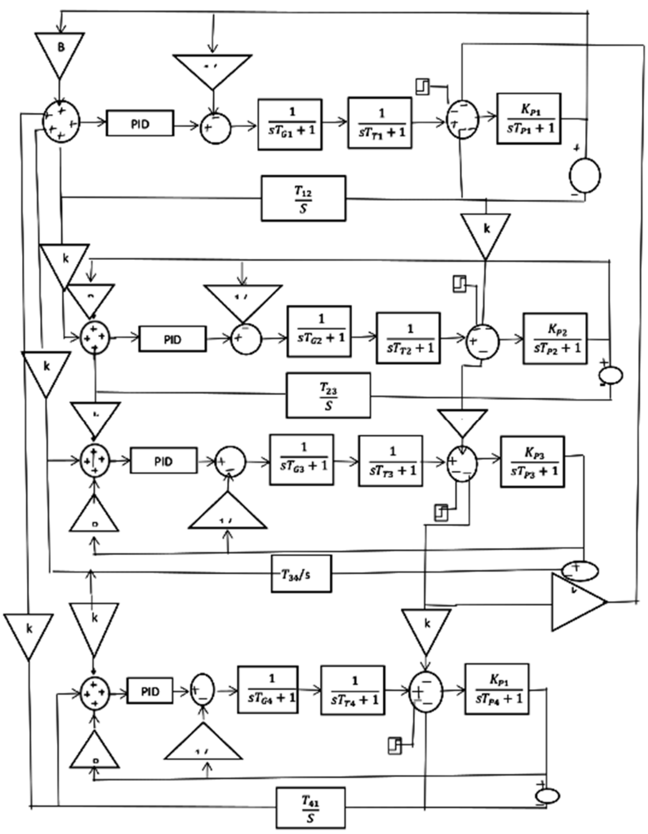

Fig. 1. Simulation model of four area power system.

III. PID CONTROLLER WITH DERIVATIVE FILTER

When an interconnected or micro-grid power system is subjected to a change, it is very crucial to adjust the gain parameters of the PID controller [15]. As the PID controller often ignores the noise and non-linear effects, most of the time it does not work properly in practical problems. For this reason, a first-order filter is put on the derivative term to tune it [16], as it reduces the high-frequency noise and smoothes it out, so chattering due to noise does not occur and the derivative will not reduce the high-frequency noise [17]. The transfer function of the PID controller with derivative filter (PIDN) is given as:

$$TF_{PIDN} = K_p + K_i(\frac{1}{s}) + K_d(\frac{1}{\frac{1}{N}+\frac{1}{s}}) \quad (2)$$

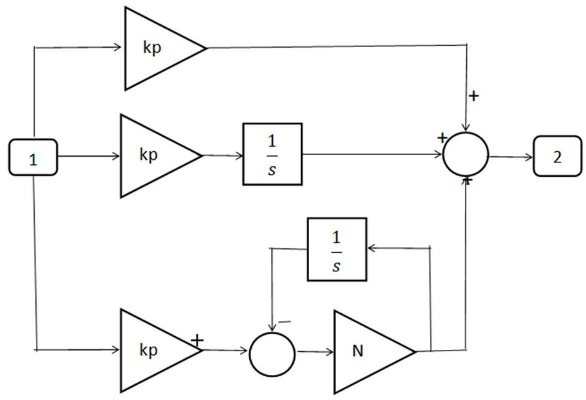

Fig. 2. Simulink model of PIDN controller.

IV. PARTICLE SWARM OPTIMIZATION METHOD

In PSO, a particle is each member of a population, called a swarm. Each particle has a velocity in a given direction [18], similar to the speed of a bird in the direction of food. Each particle searches for the optimal value by an updating generation (iteration). In each iteration, every particle is updated by following the two best values. The best one is the best solution (fitness), while the second best is tracked by the PSO optimizer. After finding the two best values, the velocity and position have to be updated for each particle, using:

$$x_i^{t+1} = x_i^t + v_i^t * t \quad (3)$$

$$v_{k+1}^i = wv_k^i + c_1r_1(xBest_i^t - x_i^t) + c_2r_2(gBest_i^t - x_i^t) \quad (4)$$

where *xBest* is the best particle position and *gBest* is the best global position. The best global position is the main strategy that all birds follow because this is the position of the bird closest to the food. The parameter w is the inertia weight. This is the main key factor, as it has the major role to change the position of each particle in the search space, from the previous position to a new one by updating velocity. c_1, c_2 are two positive constants, and r_1, r_2 are two random parameters within [0, 1]. The current position can be updated by adding the velocity v to the old position:

$$Present = old\, position + velocity\ (v) \quad (5)$$

The main aim of the PSO algorithm is to follow the bird which is closest to the food. Its main steps are given below:

- Step 1: Initialize the parameters and the population. At first, initialize the position x_i and velocity v_i randomly for each particle.
- Step 2: Compute the fitness value $f(x_i^t)$ of each particle, and choose the particle with the best fitness value *gBest*.

- Step 3: Update the position and velocity of each particle, by (3) and (4).
- Step 4: Check again the fitness value $f(x_i^t)$ and then find again the best global *gBest*.
- Step 5: Update $t = t + 1$.
- Step 6: the output comes as *gBest* and x_i^t

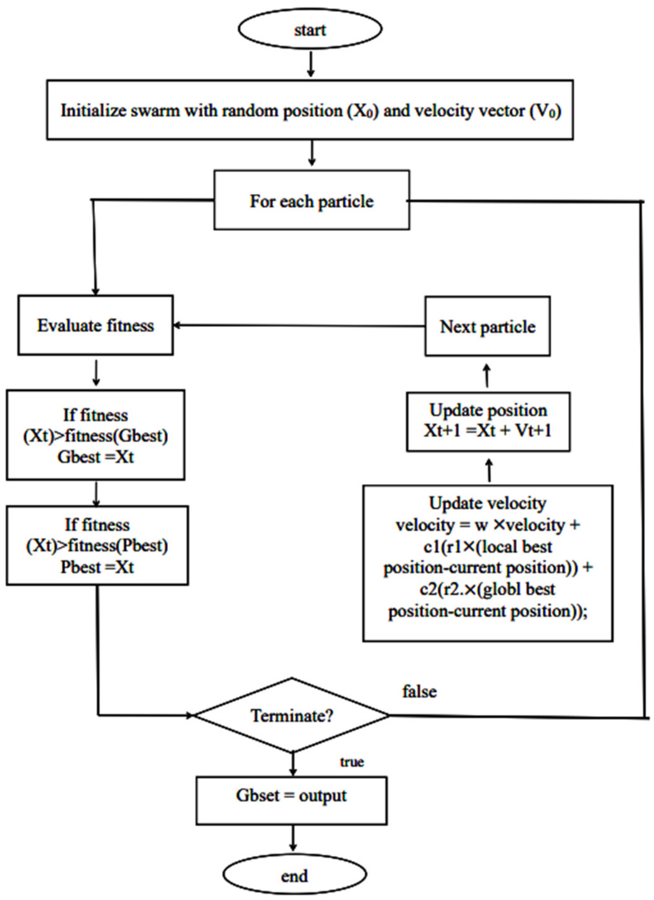

Fig. 3. Flowchart of PSO algorithm.

V. JAYA OPTIMIZATION TECHNIQUE

JAYA is a specific parameter-less algorithm. This algorithm was formulated to solve various constrained or unconstrained optimization problems. Its concept is based on the fact that the solution for a given particular problem should move towards its best solution, as its major objective is victory, meaning that it should avoid the worst solution [19, 20]. JAYA has some control parameters, such as population size and the number of generations. However, unlike other algorithms, JAYA does not have any specific parameters. For example in PSO, the inertia coefficient w and c_1, c_2, r_1, and r_2 have to be updated. But in the case of the JAYA algorithm, such specific parameters are not required to obtain the optimal solution. The terms used in the JAYA algorithm are iteration, design variable, candidate solution, best and worst values for the solution, modified solution, and update solution. The JAYA algorithm can be described as follows:

- Let $f(x)$ be the objective function
- Minimize/maximize $f(x)$:

$$l_i \leq x_j \leq u_j, \quad j=1,2,3 \ldots m$$

- At any iteration t, assume there are m design variables and n candidate solutions.
- For n values,
  - $f(x)best$ is the best value of $f(x)$
  - $f(x)worst$ is the worst value of $f(x)$
- The fitness value can be computed from $n \times m$.
- $X_{j,k}$ is the value of the j^{th} variable for the k^{th} candidate.
- $X_{j,k}^t$ is the value of the variable during the t iteration.
- X_{best} is the best value of the variable.
- X_{worst} is the worst value of the variable.
- The position update equation is given by:

$$X_{new} = X_{j,k} + r_1(X_{best} - |X_{j,k}|) - r_2(X_{worst} - |X_{j,k}|)$$

- X_{new} is the updated value of the variable $X_{j,k}$.
- r_1, r_2 are two random numbers between 0 to 1.
- $r_1(X_{best} - |X_{j,k}|)$ is the tendency of the solution to move closer to the best solution.
- $-r_2(X_{worst} - |X_{j,k}|)$ is the tendency of the solution to avoid the worst solution.
- Concerning the t iteration:

$$X_{new}^t = X_{j,k}^t + r_1(X_{best}^t - |X_{j,k}^t|) - r_2(X_{best}^t - |X_{j,k}^t|)$$

- Now, a greedy selection has to be made, by comparing the obtained solution with the previous one, to check whether the obtained solution is better or not.
- For minimization, if $f_{new} < f_{old}$ update the solution, otherwise not.
- For maximization, if $f_{old} < f_{new}$ update the solution, otherwise not.
- $f_{new} = f(x_{new})$ is the fitness value at x_{new}, and f_i is the previous fitness value at x_i. For minimization, if $f_{new} < f_i$ then replace x_i with x_{new} and f_i with f_{new}. For maximization, if $f_{new} > f_i$ then replace x_i with x_{new} and f_i with f_{new}.
- The algorithm stops when the number of iterations reaches its maximum value.

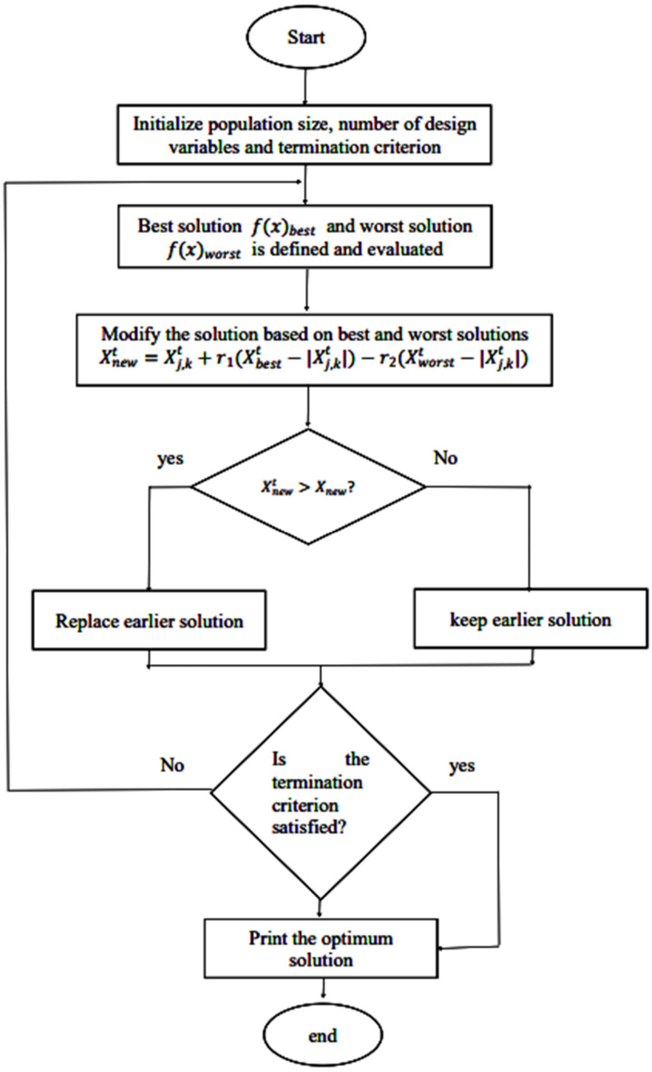

Fig. 4. Flowchart of the JAYA algorithm.

VI. SIMULINK RESULTS

Figure 5 shows the four-area model with a PID controller. Figure 6 represents the Jaya optimization in PID controller gain for the frequency control in each area of the AGC. Figure 7 represents the JAYA optimization in PIDN controller gain for the frequency control in each area of the AGC. The controller block tuned the gains for the optimized data set for the JAYA algorithm and the frequency of each area of the AGC controlled concerning the demand of the grid. The deviation in frequency and the corresponding tie-line power were investigated. The value of the proportional, integral, and derivative constants, the derivative filter, and an objective function were obtained after optimizing using the PSO and then the JAYA methods. The efficacy of the JAYA-based PID controller with the derivative filter was shown by comparing it with the PSO simulation result. The changes in frequency and the corresponding tie-line deviations under load disturbance of 0.1p.u in four areas are shown in Figures 8-11, for JAYA, PSO, and GA methods. The JAYA method minimized the error during the controller objective function operation in the system model of AGC.

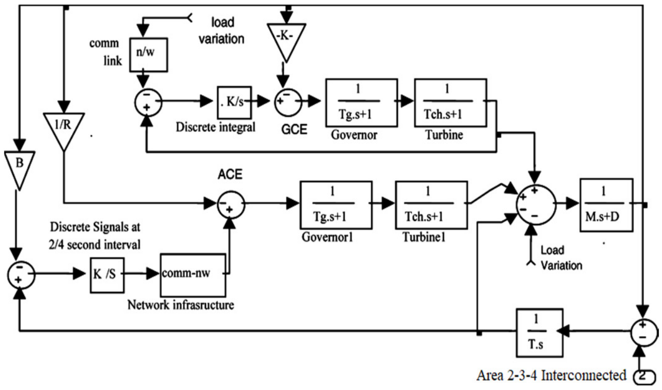

Fig. 5. Four area model with PID controller.

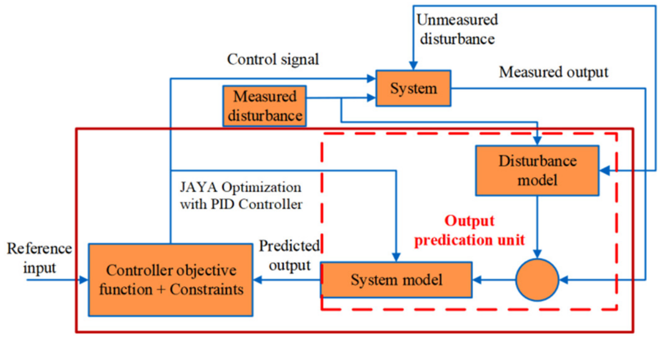

Fig. 6. JAYA optimization with PID controller.

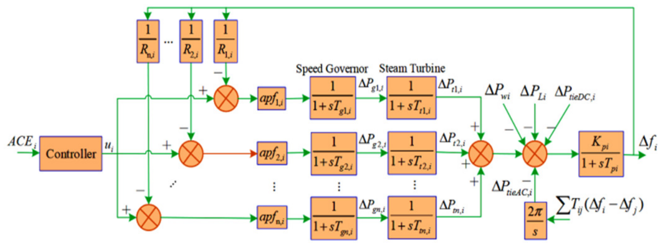

Fig. 7. PIDN controller block for frequency control in AGC.

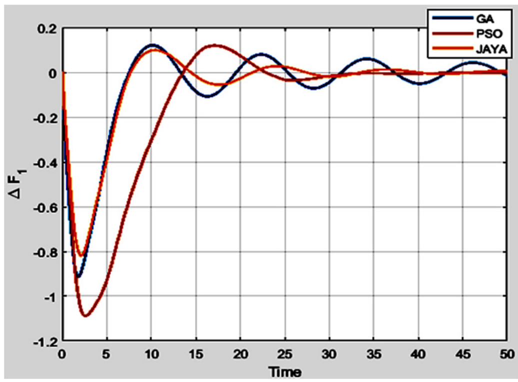

Fig. 8. Frequency response of area 1 using PID controller

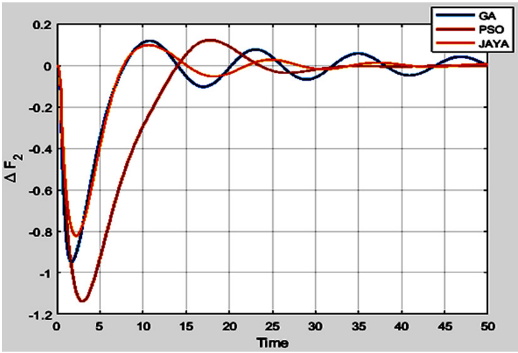

Fig. 9. Frequency response of area 2 using PID controller.

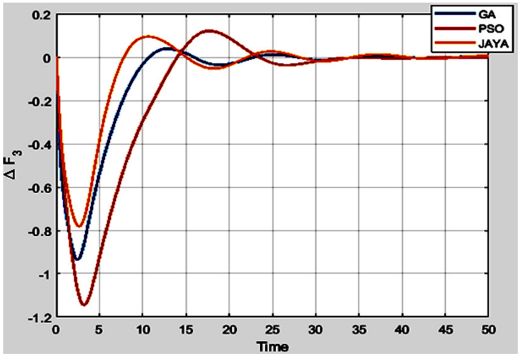

Fig. 10. Frequency response of area 3 using PID controller.

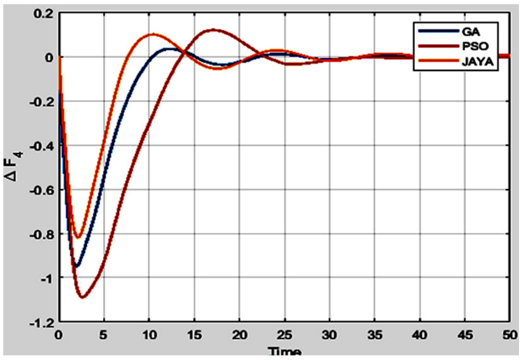

Fig. 11. Frequency response of area 4 using PID controller.

TABLE I. TUNED PID CONTROLLER GAINS

Controller Gains	PSO	JAYA
Kp1	0.0112	0.0218
Ki1	6.5402	2.7319
Kd1	3.7943	4.7272
ITAE1	4.7943	4.7272
Kp2	0.2176	0.2762
Ki2	3.2531	2.4062
Kd2	5.7291	5.4251
ITAE2	5.7291	5.4251
Kp3	0.0221	0.2373
Ki3	4.6011	2.1165
Kd3	4.1982	3.4231
ITAE3	4.1982	3.4231
Kp4	0.0262	0.0254
Ki4	4.7198	2.3068
Kd4	3.6846	3.3076
ITAE4	3.6846	3.3076

VII. DISCUSSION

From Figures 8-11, it is clear that the settling time for the JAYA optimization method is faster than for GA and PSO optimizations. The frequency variation is less by 18-20% when using the proposed controller method. The gains were limited by the optimization method and the errors were reduced by 8% for area 1, and 11% for area 2. The frequency deviation error was reduced by 4% in area 3 and 6% in area 4. The PID-controlled JAYA optimization method improved the transient stability of the multi-area system by 14% of rated values.

VIII. CONCLUSION

This study used a PSO and a JAYA optimized PID controller in a four-area power system. The proposed method was compared to traditional control algorithms. A PID controller was used to examine the results of the proposed method. Simulations were carried out in Matlab-Simulink. It was observed that the JAYA tuned PID controller exhibited better performance than PSO and GA in terms of settling time, peak overshoot, and undershoot. Thus, the JAYA-based PID controller helped maximize the power quality of the AGC. Further analysis of this topic can be carried out using different optimization methods. Different controllers, like the fractional order proportional derivative controllers (PIDN) (FOPID), and FOPID (1+PI) can be tested for improved ALFC in a power system.

APPENDIX

f = 50Hz, $B_1 = B_2 = B_3 = B_4$ = 0.425pu MW/Hz, PR = 1,000MW (rating), PL=1,500MW (nominal loading), $R_1 = R_2 = R_3 = R_4$ = 2.4Hz/p.u. MW, $T_{G1} = T_{G2} = T_{G3} = T_{G4}$ =0.08, $T_{T1} = T_{T2} = T_{T3} = T_{T4}$ =0.03, $T_{P1} = T_{P2} = T_{P3} = T_{P4}$ =20, K=-1, T_{12}=T_{23}=T_{34}=T_{41}=0.545.

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AUTHORS PROFILE

Sunita Pahadasingh is working on her Ph.D. in the School of Electrical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, Odisha, India. Her research area is AGC smart grids.

Chitralekha Jena, is an assistant professor in the School of Electrical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, Odisha, India.

Chinmoay Kumar Panigrahi, is a professor in the School of Electrical Engineering, Kalinga Institute of Industrial Technology, Bhubaneswar, Odisha, India.

Bibhu Prasad Ganthia is an assistant professor in the Department of Electrical Engineering, Indira Gandhi Institute of Technology, Sarang, Dhenkanal, Odisha, India. His research areas include renewable energy systems and power system control.