Meta heuristic Cost Effective Optimization Method for an Integrated Design of a Controller at load disturbances in Generation Control

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Abstract — **This work depicts a broad scheme to design an improved load frequency control (LFC) for an interconnected electrical power system. In an interconnected power system, small load perturbations in any of the area leads to frequency and tie line power fluctuation in each and every coverage area. Due to an increase in difficulties of an electrical power system network, there is a need to enhance and develop new control methodologies. Power system performance and evaluation does not only rely on the control structure but also relies on well-tuned controllers. For this reason, a meta heuristic multi objective optimization approach for and integrated design of a controller at various load disturbances has provided insight that each of them has their own distinctive characteristics to find resolutions if the utilization is implemented for particular domain purpose. An observation was carried out on transfer function model of two area multi source interconnected power system incorporating RFB energy storage system and UPFC Facts device at various loading conditions. Here, proposed Strawberry Algorithm SBA provided optimal plotted values of PID controller by mitigation of cost function ITAE. The proposed simulation extended in comparison between SBA and DEA at 85% to 90% loading conditions. A two area interconnected thermal power system with governor dead- band non linearity for the design and and enhanced analysis aim is considered, where the PID controller is designed through flower pollination algorithm for AGC is modeled and carried out. A new kind of methodology is designed to model a multi-cost function which contains weighted optimization function (s). This method takes less time and effort to get the weights for multi cost function. With a single run of the approached algorithm yields both global minimum and optimal weights. The re evaluation performance of the scope analysis are comparable with pareto optimal resolutions. Where the cost function also includes performance response for a various percentage of loads so that obtained gain parameters are optimal for different load variations and this manipulation could be observed in Δf_1, Δf_2, ΔP_{tie} responses. The simulated results clearly indicated the superiority of the SBA over DEA. Further, the results were validated in response of variation in the frequency and tie line variables obtained using cost functions based on Integrated Time multiplied Absolute Error (ITAE) and compared with Differential Evolutionary (DE), Learning, Search and Design Algorithms.**

Keywords* — *Load Frequency Control (LFC), Automatic Generation Control (AGC), Flower Pollination Algorithm (FPA), Strawberry Algorithm (SBA), Differential Evolutionary Algorithm (DE), Particle Swarm Optimization Algorithm (PSO), Area Control Error (ACE), Integral of Time multiplied Absolute Error (ITAE), Integral of Time Multiplied Squared Error (ITSE), Integral of Squared Error (ISE), Integral of Absolute Error (IAE).

I. INTRODUCTION

Electrical energy is the most distinctive form of energy, because it can be transported easily at moderate costs and high efficiency. Power system as one of the global networks with integral interconnected systems which vivid to supply undisturbed energy to all consumers. To make the stable system and mitigate the losses, the generation should be equal to demand through a control modeled mechanism and the frequency of the system should be close to the pre evaluated value at all instances. There are two control variables to be maintained to achieve the optimal stability of an electrical power system . The frequency variable adjusted maintains the real power balance and the reactive power or tie-line power exchange maintains the voltage profile [1-3]. The overall effects of the two variables are weighted together to form one distinct variable which is the Area Control Error (ACE). In addition to this, the total ACE can be used to achieve and improve the stability of an isolated power system network with a single control area. Thus, the input to the Load Frequency Control (LFC) or Automatic Generation Control (AGC) is the Area Control Error ACE, as the ACE is plotted to zero by the AGC, both the frequency errors and the tie-line powers become zero. Therefore, Automatic Generation Control simultaneously maintains the power exchange between the control areas at the scheduled values by adjusting the power of specific generating units and it is required to regulate the moderated frequency at specified nominal values [4, 5]. The AGC of an integral interconnected electrical power system limited to the optimal selection of controllers by investigating the impact of physical constraints, effect of Flexible AC transmission systems (FACTS) devices [6, 7] and Energy Storage Devices [8-10].

The standard and non-standard definitions and elaborations for LFC on electric power system network were approved by the IEEE standards committee in 1968 [11]. The operating problems of the system regulation and factors affecting integral interconnected systems were portrayed [12]. To achieve the standards for AGC, there is a necessary need to have a system model with issues to achieve the margin of AGC. These parameter changes, time delay, uncertainties [13, 14], generator rate constraints (GRC) [15, 16], governor dead band non-linearity, effects of deregulation and load characteristics and perturbations were discussed in literature point of view. In reference to the challenges, control methodologies such as classical control, modern control and intelligent control techniques have been implemented to the LFC problem [17-18]. A proportional-integral (PI) controller is proposed for LFC with its gains adjusted using the evolutionary algorithms and genetic algorithm (GA) [19] for a proper AGC re evaluation and performance. A modeled concept proposed by Ahamed et al. based on reinforcement learning method in LFC [20]. The elaboration on the design of PID controller for a two-area non-reheat interconnected power system utilizing bacteria foraging optimization algorithm (BFOA) based on LFC has been discussed in [21]. The science work in [22, 23] depicts the basic merits of frequency control and tie line power flow control in an interconnected electrical power system network. The innovative concept for AGC frequency regulator designs of a multi area energy system was explained by Elgerd.

The notion of utilizing Flexible AC transmission System (FACTS) devices to improve power operation and control during steady state and dynamic condition, the FACTS devices have improved the controllability of both reactive and real power. An explanation was implemented to reach the dynamic stability of the electrical power system by firstly introducing a damping controller based on the thyristor-controlled phase shifter (TCPS), Kazem et al [24]. An adaptive and effective particle swarm optimization based on non-linear time-varying acceleration coefficients (NTVAC-PSO) is depicted for resolving optimization problems and model of unified power flow controller (UPFC) for damping of power oscillation [25]. Balancing of power supply and demand is always a mimic challenge particularly at peak loads. As the results, serious investigations about reliable operations may occur. So, it is convenient and sustainment to include battery energy storage (BES) devices to improve the AGC problem. [26-28]. Achievement with Interline Power Flow Controller (IPFC) to tie- line and RFB for an effective and enhanced system performance was portrayed [29]. Differential Evolution (DE) algorithm [30] based on proportional integral (PI) and proportional integral derivative (PID) controllers are put to discussion for Automatic Generation Control (AGC) of an integral interconnected power system network. Particle swarm optimization (PSO) methodology is used in a large number of multi engineering problems and it also enhances to address optimal adjusting of AGC [31]. Due to the superior local & global search capabilities Artificial Bee Colony (ABC) algorithm is used for adjust of AGC controller [32].

II. INVESTIGATION A

i. *Proposed model under study*

A distinct strawberry algorithm (SBA) which is proposed for adjusting the parameters of PID controller in the two area multi source interconnected system which is an integration of hydro, gas and reheat thermal turbine power plants. The parameters of controller are optimized using SBA through minimization of ITAE. Using ancillary FACTS devices like Unified Power Flow Controller (UPFC) and energy storage device such as Redox Flow Batteries (RFB) are embedded in the proposed model to analyze its performance. Comparison of the simulated results of SBA with differential evaluation algorithm (DEA) at various loading condition indicates that the proposed genuine algorithm promptly performed in damping the tie line oscillation and stabilizing the frequency of the system.

ii. *The Proposed Approach*

To study and analysis the proposed work, a transfer model of interconnected two area power system with the combination of multi sources thermal, hydro and gas [33, 34] along with UPFC & RFB [35] has been consider and is represented in figure. 1. Where U_T , U_G and U_H are the control outputs; K_T , K_G and K_H are the participation elements for thermal, hydro and gas units respectively; T_{SG} sec, T_t and T_r are the thermal speed governor time constant, steam turbine and reheat time constant in sec respectively; T_{GH}, T_{RH}, T_{RS} & T_W are the various time constant in penstock, speed governor reset time, speed governor transient droop and speed governor main servo in seconds respectively for hydro unit. Where as T_F is a gas unit the time constant; X_C is lead time constant and Y_C is lag time constant; c_g , b_g are the gas turbine valve position; T_{CR} and T_{CD} are the gas turbine combustion reaction time delay and discharge volume time constant in sec respectively; K_{PS} is power system gain in Hz/p.u. MW, T_{PS} is power system time constant in sec; ΔF is incremental change in frequency and ΔP_D is change in load. The vivid parameters of the system are in A.2.

iii. *Analysis of Objective Functions and Values Sensitivity Towards Controller*

In recent times, many control techniques and strategies have been simulated for AGC including Proportional and integral (PI), Proportional Integral Derivative (PID) and Optimal controllers [36] and variable structure control. In this reference, PID controllers are used to enhance the performance of AGC for a two area thermal system. In this work SBA is applied to tune the parameters of the PID controllers. There are three control parameters, i.e Proportional gain(K_P),Integral gain constant(K_I) and Derivative gain constant (K_D). The controllers in both the areas are considered to be identical so that $K_{P1} = K_{P2} = K_P$, $K_{I1} = K_{I2} = K_I$, and $K_{D1} = K_{D2} = K_D$. From the figure. 1 below, the error inputs to the optimal controllers are the respective area control errors (ACE) indicated by;

$$e1(t) = ACE1 = B1\Delta f1 + \Delta PTie. \quad (1)$$

$$e2(t) = ACE2 = B2\Delta f2 + \Delta PTie. \quad (2)$$

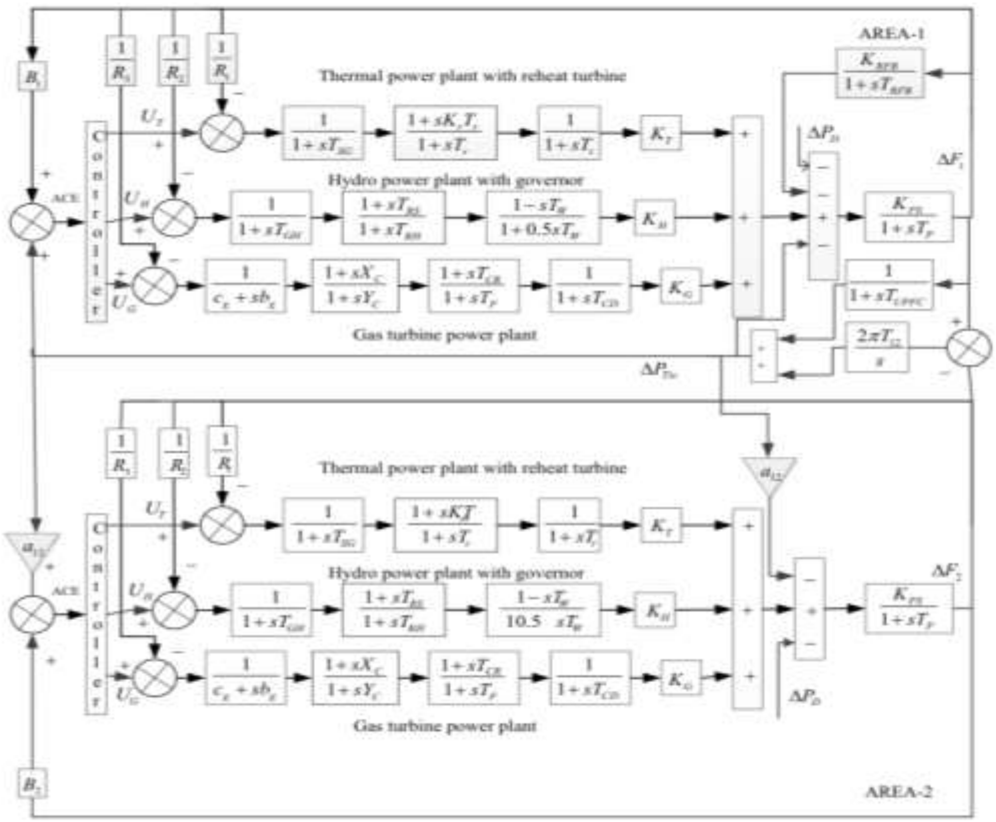


Figure 1: Transfer function model of two area multi source interconnected thermal power system

The control inputs of the power system *Ut, Uh, Ug* related PID structure are obtained as:

$$Ut = KP1ACE + KI1iACE + KD1\left(\frac{dACE}{dt}\right) \quad (3)$$

$$Uh = KP2ACE + KI2iACE + KD2\left(\frac{dACE}{dt}\right) \quad (4)$$

$$Ug = KP3ACE + KI3iACE + KD3\left(\frac{dACE}{dt}\right) \quad (5)$$

In the proposed model of a PID controller, the objective function is first defined based on the desired specifications and constraints. The implementation of cost function to adjust the controller is based on a performance index that entails the entire closed loop quick response. The performance reevaluation criteria usually considered in the controller design is the Integral of Time multiplied Absolute Error (ITAE).

$$ITAE = i\ 0\ to\ tsim\ [|\Delta f1| + |\Delta f2| + |\Delta PT\ ie|].t.dt \quad (6)$$

In[37, 38], the proposed objective function was based on fixed step load perturbation and the obtained controller parameters were optimal at fixed step load. Where as in this work the objective function includes responses of various percentage step load changes, hence the designed controller parameters give optimal response under various load disturbances.

iv. Scope Analysis and Results

The presupposed cost function ITAE is utilized to adjust the optimal controller for postulated model with the help of SBA algorithm. The above assumed system is modeled and simulated using MATLAB 2020b version for 1% load disturbance for various loading conditions i.e 25%, 50%, 75% & 90% in Area-1 of proposed model with and without UPFC & RFB. The controlled responses Δf_1, Δf_2, ΔP_{tie} obtained for SBA tuned controllers at a particular loading conditions are shown in figs. 3(a), 3(b), 3(c), 4(a), 4(b) & 4(c). To justify the obtained simulated responses and performance of SBA, a comparison made between SBA and DEA on the proposed model at 90% loading condition with 1% disturbance along with both UPFC & RFB were presented in figs. 5(a), 5(b)& 5(c). It is clearly observed from the simulated results that SBA performance is better as compared to DEA. The rate of convergence of SBA for the proposed model is given in figure 2.

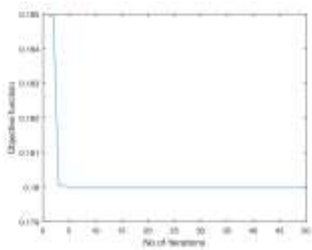
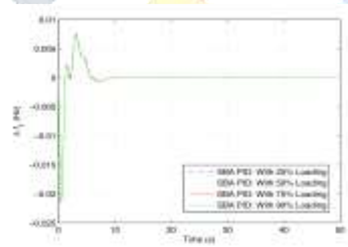


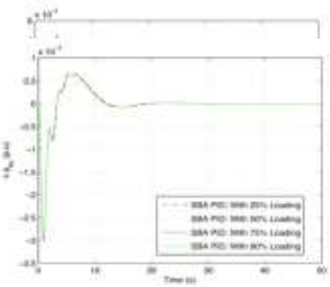
Figure 2: High Rate of Convergence of SBA

v. Presumptions

An observation is carried out on transfer function model and simulation of two area multi source interconnected power system network incorporating RFBand UPFC at loading conditions. Here, presupposed SBA gives optimal parameter values of PID controller by mitigation of cost function ITAE. The assumed model extended in comparison between SBA and DEA at 85% to 90% loading condition. The simulated results clearly shows the superiority of the SBA over DEA.



(a)



(c)

Figure 3: (a)Change in frequency of area-1 for various loading conditions. (b)Change in frequency of area-2 for various loading conditions. (c)Change in tie line power for various loading conditions.

The presupposed algorithm has three main differences with the trivial nature-inspired optimization methods: duplication elimination of the computational tails at all repetitions, subjecting all tails or agents to both small and large movements from the inception to end, and the lack of conveyance (information to exchange) between tails. Moreover, it has the merit of using only three parametric values to be adjusted by user. This presupposed algorithm is carried out to precisely test the functions and the scope analysis are compared with DEA, GA and PSO. The presupposed algorithm is also utilized to solve an open challenge in the field of robust control theory.

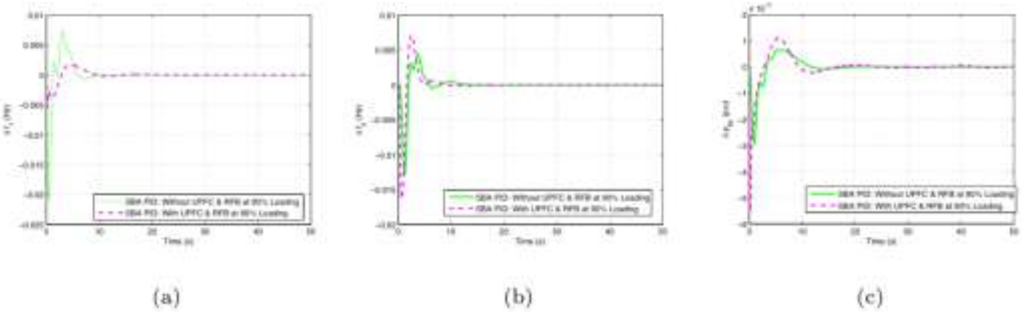


Figure 4: With & without UPFC & RFB (a)Change in frequency of area-. (b)Change in frequency of area-2. (c)Change in tie line power.

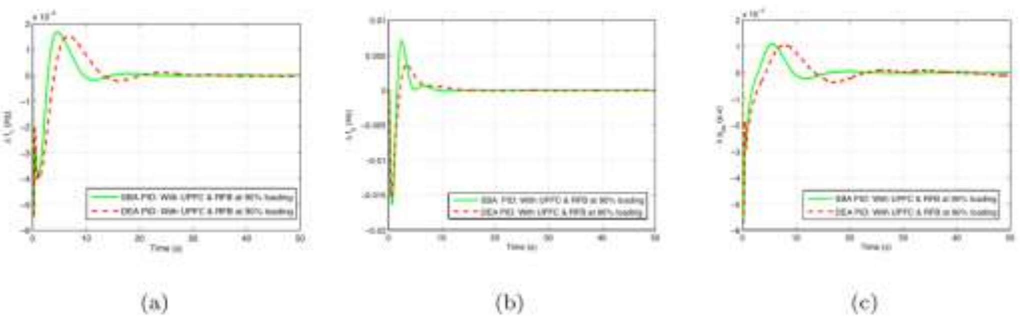


Figure 5: (a)Comparison of change in frequency of area-1. (b)frequency of area-2. (c)tie line power.

III. INVESTIGATION B

i. *Proposed model under study*

This part represents the presupposed model and performance reevaluation of FPA based Proportional Integral Derivative (PID) controllers for AGC of an interconnected electrical power system. A two-area thermal electrical power system with speed governor dead-band non-linearity is achieved for the design and scope analysis. A different technique is made to design a cost effective or multi-objective function which involves the weighted performance indexed functions such as ITSE, ITAE, ISE and IAE. These weights are the functions of the presupposed system response as modeled and simulated. It is analyzed that the dynamic indexed performance of new effective cost optimized PID controller is better than others pin pointed in the references. The cost function has performance response for different percentage of loads, so that the gain parametric values are optimal for dynamic load conditions.

ii. *The Proposed Approach*

The primary objective of the Automatic generation control (AGC) is to take control of the power system frequency to the specified distinct nominal value for small disturbance in load. An interconnected thermal power system is referred in figure.6. Each area is gathered with the non-reheat turbine and a governor designed along with dead band non-linearity. These areas are connected through a tie line and the whole coverage system is under observation. In figure.6, B_1 and B_2 are the frequency (bias) parameters; ACE_1 and ACE_2 are the area control errors; U_1 and U_2 are the control outputs from the designed controller; R_1 and R_2 are the governors speed regulation values in p.u. Hz; T_{G1} and T_{G2} are the speed governor time constants denoted in seconds; ΔP_{G1} and ΔP_{G2} are the changes in governor valve positions given in (p.u.); T_{T1} and T_{T2} are the turbine time constants denoted in seconds; ΔP_{T1} and ΔP_{T2} are the changes in turbine output powers; ΔP_{D1} and ΔP_{D2} are the load demand changes; ΔP_{Tie} is the incremental change in tie line power denoted in (p.u.); K_{PS1} and K_{PS2} are the power system gains; T_{PS1} and T_{PS2} are the power system time constants noted in seconds; T_{12} is the synchronizing coefficient and Δf_1 and Δf_2 are the system frequency deviations denoted in Hz. The relevant parameters of the presupposed model are given in Appendix A.2. The transfer function of governor with nonlinearity is given by equation 4.1 [39]

iii. Analysis of Objective Functions and Values Sensitivity Towards Controller

In recent times, many control methodologies and strategies have been proposed for AGC which include, Proportional and integral (PI), Proportional, Integral, Derivative (PID), etc [40]. In this context, PID controllers are used to improve the dynamic performance of AGC for a two area thermal power system. Where PI and PID control action depends on K_P, K_I, K_D gains which vary for different applications. The tuning of these variable depends on the desired responses of the system. The main function of AGC is to take control of load frequency and tie line power during load disturbances. So the error signals of frequency and tie line power are utilized design to tune the PID controller. The error inputs to the controllers are the respective area control errors (ACE) given by equations (7) and (8)

$$e1(t) = ACE1 = B1\Delta f1 + \Delta PTie \tag{7}$$

$$e2(t) = ACE2 = B2\Delta f2 + \Delta PTie \tag{8}$$

The control inputs of the power system u_1 and u_2 with PID structure are given by equations (9) and (10)

$$u1 = KP1ACE1 + KI1iACE1 + KD1\left(\frac{dACE1}{dt}\right) \tag{9}$$

$$u2 = KP2ACE2 + KI2iACE2 + KD2\left(\frac{dACE2}{dt}\right) \tag{10}$$

The controllers in both the control areas are considered to be similar i.e., $K_{P1} = K_{P2}$, $K_{D1} = K_{D2}$, $K_{I1} = K_{I2}$,. In this context, flower pollination algorithm (FPA) is used to adjust the PID controller for a two area Interconnected system. Proportional gain constant (K_{P1}), Integral gain constant (K_I), Derivative gain constant (K_D) are considered as variables describing a population defined in FPA. FPA needs a cost function which utilizes the design criteria to evaluate the flower constancy of the defined population.

An objective function is created which uses the variables of the population from FPA and passes through a model containing two area thermal system and obtains the error signals frequency, tie line power. The performance of these responses is measured using performance functions [41] like Integral of Time multiplied Absolute Error (ITAE), Integral of Time multiplied Squared Error (ITSE), Integral of Absolute Error (IAE), Integral of Squared Error (ISE), given by equations (11), (12), (13) and (14) respectively.

$$J1 = IAE = i\ 0\ to\ tsim\ [|\Delta f1| + |\Delta f2| + |\Delta PTie|].dt \tag{11}$$

$$J2 = ISE = i\ 0\ to\ tsim\ (\Delta f1)sqr + (\Delta f2)sqr + (\Delta PTie)2.dt \tag{12}$$

$$J3 = ITAE = i\ 0\ to\ tsim\ (|\Delta f1| + |\Delta f2| + |\Delta PTie|).t.dt \tag{13}$$

$$J4 = ITSE = i\ 0\ to\ tsim\ [(\Delta f1)sqr + (\Delta f2)sqr + (\Delta PT\ ie)2].t.dt. \tag{14}$$

The cost effective function is simulated to consider all the criteria through a weighted sum method and is reevaluated by equation (15)

$$J5 = \omega 1.IAE + \omega 2.ISE + \omega 3.ITAE + \omega 4.ITSE. \tag{15}$$

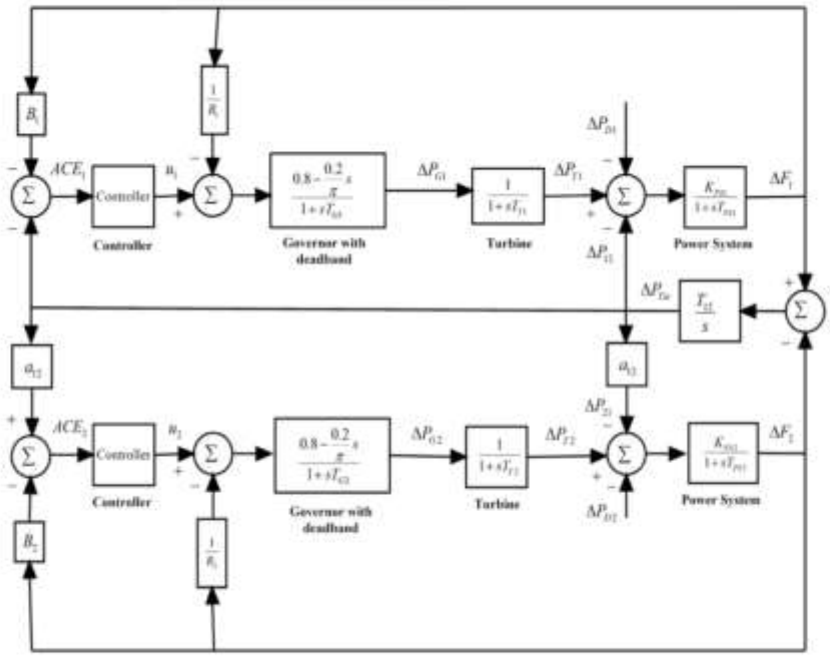


Figure 6: Transfer function model of two-area interconnected thermal power system

where, ω1, ω2, ω3, ω4 are multiplied with IAE, ISE, ITAE, ITSE respectively. All these weights should satisfy the following equations as (16)

A summation of weights from i = 1 to N (Δωi) =1, ωi > 0 (16)

Pareto optimality is utilized for picking these weights. In this proposed model, following technique is analyzed to assign weights to the objective function. For this reason, the performance function behavior is revised from [42]. It presents the following conclusions.

- The ISE and ITSE functions are appropriate to utilize for measuring the performance index when error value is greater than one and vice versa with ITAE and IAE.
- The ITSE and ITAE are good measures when error signal holds for a long time and helps to improve the steady state error.
- While ISE and IAE are needful to mitigate the initial transients. So they are utilized when the transient time is less than one second.

The alternate responses that are investigated depicts all situations, highlighting the vivid fact, that which one of the above reevaluation criteria are better suited for steady time intervals, from a control point of reference. When a cost function gets a response from presupposed model for a population in FPA.

This response is segmented for a small range of step time. A condition is designed to utilize the conclusions of performance criteria. This condition assists to assign the highest parametric value to $\Delta\omega_{ji}$ when j^{th} performance criteria are suited for step time, while the others are assign with minimum values. Later the ωj are found from equations (17) and (18).

N = Total simulation time/Definite time interval step (17)

w_j = *1/N [A summation of* j^{th} *performance from I = 1 to N* $\Delta\omega_{ji}$ *]* (18)

Using these weights and equation (15) flower constancy for FPA is found. This procedure is carried for a fixed number of iteration in FPA, then weights obtained for total best is chosen as fixed weights (or) optimal weights. The FPA restarts its procedure for finding the solution for PID controller parameters K_P, K_I, K_D using objective for which now has known weights. Thus, resolution for desired PID controller is determined. In [8, 30, 37, 38], the proposed cost function was based on fixed step load disturbance and the obtained controller parameters were optimal at fixed step load. But the presupposed system load is dynamic, so there is a requirement to make a controller that give optimal response for different load conditions. In this reference, the cost function includes responses of various percentage step load manipulations, so the designed controller parameters give optimal response for most load perturbations.

iv. Scope Analysis and Results

In this section a two area thermal system with governor dead band is used to hypothesize the proposed theory along with FPA. The simulation is performed by using MATLAB 2020b on a X86-64 processor base with 4GB ram. It is observed that FPA has parametric indexes p, N size of population and itermax, maximum number of iterations. The parameter p denotes the amount of global and local search for FPA. To choose this validated parameter, the per proposed method is modeled and simulated for various values of p values and this ranges from 0.1 to 1 with a step size of 0.01. The performance for parameter p and respective global minima shown in figure. 7(a).

Figure: 7(a) shows that cost function is constantly minimized between 0.5 to 0.6. This is carried out for a number of times and in each case above condition is true, so p is chosen as 0.55. A Similar case study is done for a maximum number of iteration, which shows that after 40 iterations count value of global minima remains constant as shown in figure. 7(b). Similarly from the figure. 7(c) we have obtained the parameter population size as N = 30.

The cost function contains multiple performance criteria as mentioned in above section, with equation (18) a set of the combination for weights are created. These weights combined together will result in 65, 536 permutations. By using constraint equation (18), this number is reduced to 367. Each summation of the weights is passed through FPA and respective global minima are determined and restored. These summation of weights along with the restored vector of global minima are traced through pareto efficiency algorithm and following pareto optimal weights are determined [0.1420 0.3020 0.1290 0.4250]. These integration of weights are re-sorted according to ascending order of global minima. The first 10% of weight combinations that yields best global minima are analyzed by plotting their histogram as shown in figure.7(d).

Proposed technique would divide the response like Δf_1 into definite time interval (0.01s) as shown in figure. 7(e). To illustrate the theory behind the proposed approach following example is made . As Δf_1 described in figure. 7(e) contains various points, among them a point at 1.02s is taken and it has the error value 0.1507. As per proposed theory because this point had magnitude less than one and evaluated at time greater than one, ITAE chosen to be best suited cost function for minimizing error at this point, so $\Delta\omega_{ji}$, ITAE is assigned with a higher value, while weights related to ITSE, IAE, ISE is assigned with the lowest value. Similarly this procedure is applied to Δf_2, ΔP_{tie} signals. The mean of step weights $\Delta\omega_{ji}$, three signals is found for objective function. It is followed by step weights of other performance functions. This procedure is carried out for total simulation time (20s). Now equation (18) is used to find the weights ω1, ω2, ω3, ω4 from this step weight vectors. As mentioned in the proposed method, all this procedure is carried out for single population and using equation (15) flower constancy of the population is found. This is carried out for 20 iterations in FPA then weight obtained for total global minima is fixed and are given as [0.1255 0.1000 0.5796 0.1949]. The figure .8 shows the responses for both methods and it is observed that proposed method has slightly good response when compared to pareto method. Hence proposed method is easy to implement and is compared to pareto method.

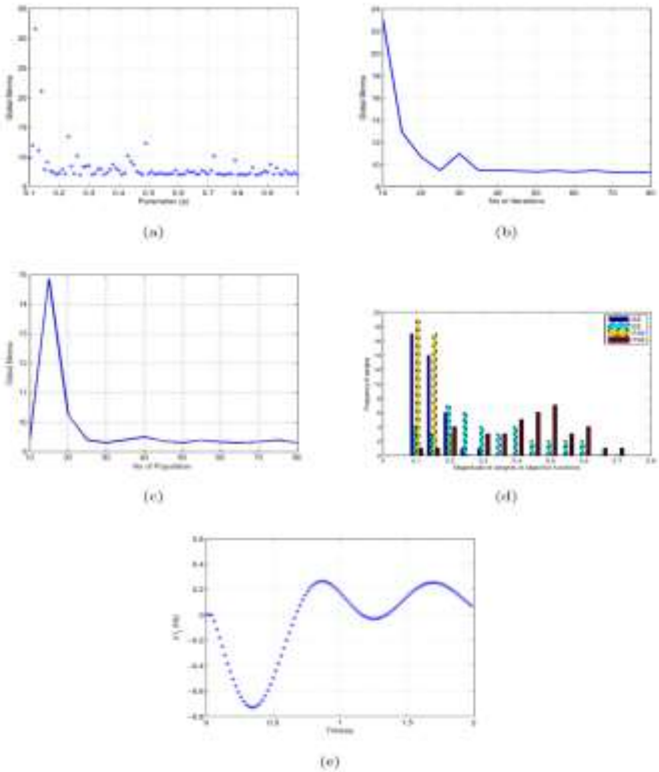


Figure 7: (a) Change in the global minima with respect to Parameter p of FPA. (b) Change in the global minima with respect to Number of Iteration of FPA. (c) Change in the global minima with respect to Population of FPA. (d) Magnitude of the weights of cost functions Vs Frequency of the weights. (e) Discrete response from presupposed model for Δf_1 Vs time.

The second aspect of proposed theory is to construct a cost function which includes a performance for various load percentages (1%, 9%, 29%, 54%, 64%, 79%, 89%) to obtain tuned parameters for a controller of considered system. This yielded gain parameters which is optimal for any load manipulation between (1 to 100%). These gain parameters were tested for 15.00%, 36.00%, 54.00%, 72.00% load disturbance. Again obtained gain parameters tuned for 15.00% fixed load and test for 36.00%, 54.00%, 72.00% load changes. The similarity of the above two performances is seen in the Figures. 9, 10 and 11 for $\Delta f1$, $\Delta f2$, ΔP_{tie} respectively. It is concluded that chosen parameters for presupposed method are optimal for most load manipulations, so these could give optimal performance for dynamic loads also.

Cost effective design optimization problems need multi objective optimization methods to resolve the challenges, and it it is often very problematic to obtain high quality Pareto fronts precisely.

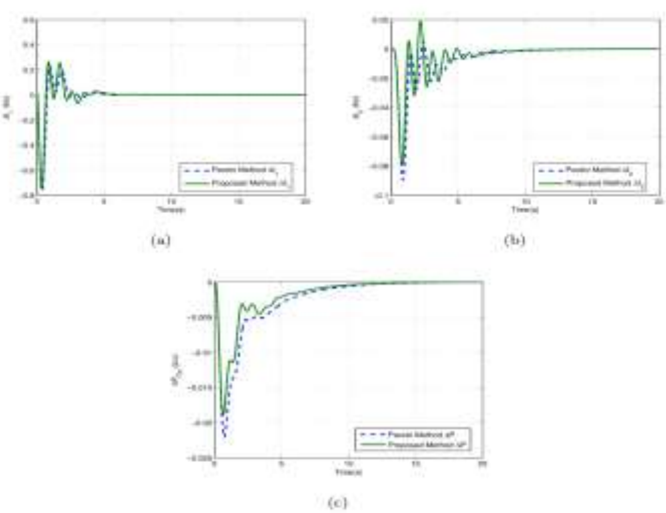


Figure 8: Comparison of proposed and pareto methods with variations in the FREQUENCY of AREA-1, FREQUENCY of AREA-2 and TIE LINE POWER flow. (a)Δf_1 (b)Δf_2 (c)ΔP_{tie}

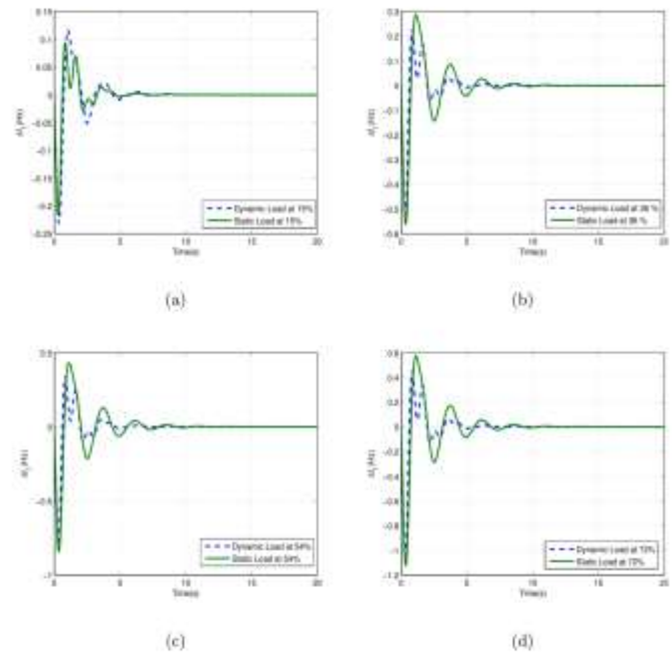


Figure 9: Change in the FREQUENCY of AREA-1 (a) At 15% load variation. (b) At 36% load variation. (c) At 54% load variation. (d) At 72% load variation.

FPA is extended to resolve cost effective optimization problems and the comparison of the presupposed algorithm has been observed which depicts that FPA is efficient with a better convergence rate.

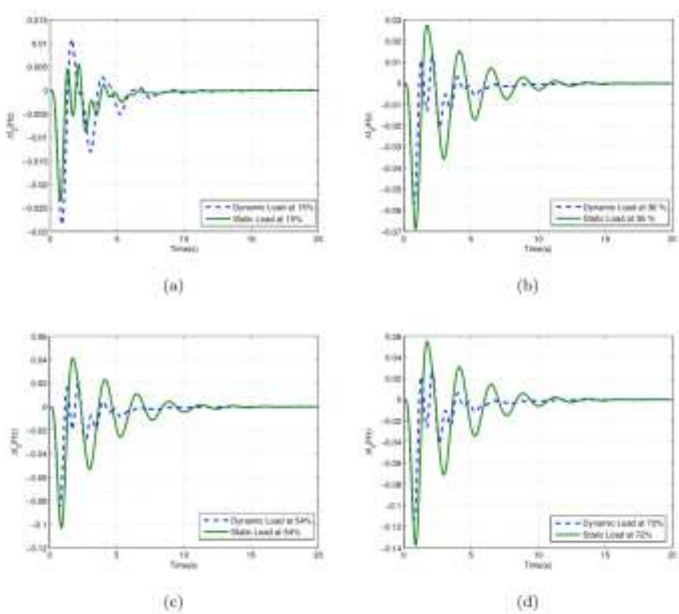


Figure 10: Change in the FREQUENCY of AREA-2 (a)At 15% load perturbation. (b)At 36% load perturbation. (c)At 54% load perturbation. (d)At 72% load perturbation.

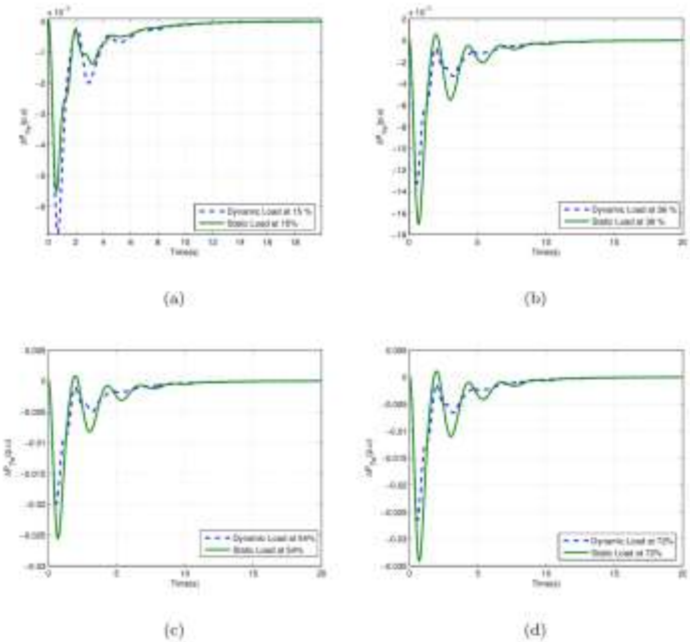


Figure 11: Change in the TIE LINE POWER (a)At 15% load perturbation . (b)At 36% load perturbation . (c)At 54% load perturbation. (d)At 72% load perturbation.

v. Presumptions

In this section a two area interconnected thermal power system with governor dead- band non linearity for the design and analysis purpose is considered, where the PID controller is designed through flower pollination algorithm for AGC is carried out. A new kind of approach is made to design a multi-objective or cost function which contains weighted optimization functions. This technique takes less effort to obtain the weights for multi objective function. With a single run of the approached algorithm yields both optimal weights and global minimum. The performance of the results are comparable with pareto optimal solution.. Where the cost function also includes performance response for a various percentage of loads so that obtained gain parameters are optimal for different load conditions and this change could be observed in Δf_1, Δf_2, ΔP_{tie} responses.

IV. CONCLUSION AND FUTURE WORK

The optimal building of controllers does not only develop with the category of objective function & constraints used but also with the methodologies that will foster these objectives. New meta-heuristic algorithms like SBA & FPA were used for optimal design of PID controller in two area interconnected thermal power system and two area interconnected multi source thermal power system at numerous percentage load perturbations. Statistical tidings to evaluate the meta-heuristic algorithms like SBA & FPA and their precursors like Differential Evolutionary Algorithms, were also obtained. Further analysis as disused on the literature point of view, both Strawberry (SBA) and Flower Pollination (FPA) Algorithms prove to obtain better analysis performance and design of distinct controllers. Current study on the design of ALFC controller has ignited some solutions over the least areas of research which are broadly important for efficient and optimum operation of an electrical power system network.

As ALFC control is through remote operation attained by an entity for instance Independent system operator (ISO) which is far away from generating units and stations. But the decentralized generating and control unit is placed in each of these generation stations whose integral operation would yield good performance than the present ALFC. The advancement of decentralized control is in its theoretical level. Hence there is a further scope in this direction of research and analysis. The integration of more renewable energy to an electrical power system demands good controllers because they do not evolve natural inertia based kinetic energy to provide sudden deficiency of electrical power. Modeling of these electrical power system network, design, control and evaluation performance w.r.t LFC is a major problem and needs resources and time. Due to the deregulation of power system network there is a rise in private partnerships for production and transmission of power through the electrical power systems. They are achieved based on power purchase agreement (PPA) which has the power transfer from one control area to another one. The private partnerships participants do not regulate the system parameters but employee ISO to provide spinning reserves to attain frequency and other parameters of the designed system. So this directs to a complicated design constraint for the modeling of LFC controller. So there is necessity for a good techniques to foster these constraints. To implement this methodology there is a need of practical tidings from which the presupposed model can be made. Performing and implementing this work involves both resources and time.

Present day power system transmission line capacities are extended using power flow controllers and energy management systems. These devices should work in conjugation with the generating stations, so that overall efforts to maintain power balance is fruitful. To demonstrate and understand this scenario, an interconnected model of power system with UPFC & RFB is considered . To develop a controller for this system a PID controller is employed for AGC and SBA is utilized to designed the optimal controller. It is observed that the system under goes for various loading conditions, shows promising results for frequency and tie line power as compare with DEA, that indicates integration of these device is very fruitful. Present work on the design of AGC controller has shed some light over the few areas of research which are very important for efficient operation of power system along with some other aspects that intrigued while going through this work is stated for future scope.

APPENDIX A

A.1 SBA and FPA Pseudo Coding

A.1.1 SBA Coding

Part:1 straw.m

```
clc;
clear all
N = 50; %number of mother plants; N must be an even number
 m = 3; %number of variables
ul = [ -2 -2 -2]; %lower bound of variables
uh = [2 2 2]; %upper bound of variables
z=ones(1,N);
drunner = 50; %length of runners
droot = 5; %length of roots
a = 0; %used in the definition of fitness function
kmax = 50; %maximum number of iterations or repetitions at each run
r1 = ul'*z+(uh-ul)'*z.*rand(m,N); %each column of r1 represents the location
f_best = 100; %an arbitrary initial value for f_best. %f_best contains the best (minimum) value obtained for objective function so far.
f = zeros(1, 2*N); %the i-th column of f contains the value of objective function when the i-th column of r2 is substituted in it
x_best = ones(m,1); %x_best involves the best solution performed so far (at each iteration and run)
for k=1:kmax %each run (simulation) stops after kmax iterations
r2 = [r1+drunner*(rand(m,N)-.5) r1+droot*(rand(m,N)-.5)];
for i=1:m for j=1:N*2 if r2(i,j)>uh(i)  r2(i,j) = uh(i); %if a solution (runner or root) lies at the margin  of  the legal area, it is put at the apex
end f = for end for end elseif r2(i,j)<ul(i) r2(i,j) = ul(i); end end
zeros(1, 2*N); j=1:2*N f(j) = objective_fun(r2(:,j)'); f_sorted = sort(f,'ascend ');
j =1:N/2 r1(:,j) = r2(:,find(f==f_sorted(j),1)); %fitness evaluation
for j=1:2*N if f(j)>0 weights(j) = 1/(a+f(j)); else weights(j) = a+abs(f(j)); end end
for j=N/2+1:N chosen_index = fortune_wheel(weights);
r1(:,j) = r2(:,chosen_index); end if min(f)<f_best f_best = min(f) x_best = r2(:,find(f==min(f),1)) end best_so_far = f_best; X = f_best; end
x_best f_best kp1=x_best(1); ki1=x_best(2); kd1=x_best(3);
open('E:\Ahmed_11919183\Running\SBA\Three_Area_Thermal_Hydro_Gas_UPFC_RFB ');
```

```
opt=simset('srcworkspace ','current ');
sim('E:\Ahmed_11919183\Running\SBA\Three_Area_Thermal_Hydro_Gas_UPFC_RFB ',[0 50], opt );
```

Part:2 Objective Function

```
function H=objective_fun(x_best) kp1=x_best(1);
ki1=x_best(2); kd1=x_best(3);
open('E:\Ahmed_11919183\Running\SBA\Three_Area_Thermal_Hydro_Gas_UPFC_RFB '); opt=simset('srcworkspace ','current ');
sim('E:\Ahmed_11919183\Running\SBA\Three_Area_Thermal_Hydro_Gas_UPFC_RFB ',[0 50], opt ); H=max(itae);
```

Part:3 Fortune_wheel

```
function choice = fortune_wheel(weights)
accumulation = cumsum(weights);
p = rand() * accumulation(end); chosen_index = -1;
for index = 1 : length(accumulation)
if (accumulation(index) > p) chosen_index = index; break;
end end
choice = chosen_index;
```

A.1.2 FPA Coding

Part:1 new_fpa_opt.m

```
clear all; clc;
para =[40 0.7]; n=para(1); p=para(2); N_iter =30;
d=3; Lb =[0 0 0]; Ub =[10 10 10]; sol=ones(n,d); for i=1:n, sol(i,:)=Lb+(Ub-Lb).*rand(1,d); kp1=sol(i,1);
ki1=sol(i,2); kd1=sol(i,3); kp2=kp1; ki2=ki1; kd2=kd1;
fitness(i)=objective_fun_mod(kp1,ki1,kd1,kp2,ki2,kd2); end
[fmin,I]=min(fitness); best=sol(I,:);
s=sol; for t=1:N_iter; for i=1:n,
if rand>p, L=Levy(d);
dS=L.*(sol(i,:)-best); s(i,:)=sol(i,:)+dS; s(i,:)=simplebounds(s(i,:),Lb,Ub); else epsilon=rand;
JK=randperm(n); s(i,:)=s(i,:)+epsilon*(sol(JK(1),:)-sol(JK(2),:)); s(i,:)=simplebounds(s(i,:),Lb,Ub); end
kp1=s(i,1); ki1=s(i,2); kd1=s(i,3); kp2=kp1; ki2=ki1; kd2=kd1;
fnew=objective_fun_mod(kp1,ki1,kd1,kp2,ki2,kd2); if (fnew<=fitness(i)),
sol(i,:)=s(i,:); fitness(i)=fnew; [fmin,I]=min(fitness); best=sol(I,:); end end end
disp(['Total number of evaluations ',num2str(N_iter*n)]); disp(['Best Solution =',
num2str(best),'fmin=',num2str(fmin)]);
kp2=best(1); kp1=kp2; ki1=best(2); ki2=ki1; kd1=best(3); kd2=kd1; %lo=0.25;
open('E:\Ahmed_11919183\Revise\FPA\Matlab_Programming\Main_Program_Static\PID\One');
sim('E:\Ahmed_11919183\Revise\FPA\Matlab_Programming\Main_Program_Static\PID\One');
```

Part:2 Objective Function

```
function [J5]=objective_fun_mod(kp1,ki1,kd1,kp2,ki2,kd2)

J1 =0; J2 =0; J3 =0; J4 =0; [t,delf1,delf2,delP]=sim_data(kp1,ki1,kd1,kp2,ki2,kd2); for k=1:length(t),

T=t(k); F1=abs(delf1(k)); F2=abs(delf2(k)); P=abs(delP(k)); if (T <=1.25)

if(P<0.1&&(F1<1||F2<1)||P<0.01) w1 =0.6; w2 =0.2; w3 =0.1; w4 =0.1;

else w1 =0.2; w2 =0.6; w3 =0.1; w4 =0.1; end else

if(P<0.1&&(F1<1||F2<1)||P<0.01) w1 =0.1; w2 =0; w3 =0.8; w4 =0.1; else w1 =0.1; w2 =0.1; w3 =0.2; w4 =0.6; end end

J1=J1+w1*(F1+F2+P*10); J2=J2+w2*(F1*F1+F2*F2+P*P); J3=J3+w3*T*(F1+F2+P*10); J4=J4+w4*T*(F1*F1+F2*F2+P*P);

End

 J5=J1+J2+J3+J4;
```

Part:3 Sim_data

```
function[t,freq1,freq2,Ptie]=sim_data(kp1,ki1,kd1,kp2,ki2,kd2)

open('E:\Ahmed_11919183\Revise\FPA\Matlab_Programming\Main_Program_Static\PID\One');opt=simset('srcworkspace','current');

 sim('E:\Ahmed_11919183\Revise\FPA\Matlab_Programming\Main_Program_Static\PID\One',[0 20],opt); t=delta_f(:,1);

freq1=delta_f(:,2); freq2=delta_f1(:,2); Ptie=delta_p(:,2);
```

Part:4 simplebouns

```
function s =simplebounds(s,Lb,Ub)

ns_tmp=s; I=ns_tmp <Lb; ns_tmp(I)=Lb(I); J=ns_tmp >Ub; ns_tmp(J)=Ub(J); s=ns_tmp;
```

A.2 NOMINAL PARAMETERS OF THE SYSTEMS

Table A.2.1: Two-area multi source interconnected thermal power system parameters.

Variables	Typical Values
B_1, B_2	0.4312p.u.MW/Hz, 0.4312p.u.MW/Hz
R_1, R_2	2.4Hz/p.u, 2.4Hz/p.u
T_{SG}	0.08s
T_t	0.3s
K_R	0.3
T_R	10s
K_{ps1}, K_{ps2}	68.9566Hz/p.u.MW, 68.9566Hz/p.u.MW
T_{ps1}, T_{ps2}	11.49s, 11.50s
T_{12}	0.0433
A_{12}	-1
T_w	1s
T_{RS}	5s
T_{RH}	28.75s
T_{GH}	0.2s
X_C	0.6s
Y_C	1s
C_g	1
B_g	0.05s
T_F	0.23s
T_{CR}	0.01s
T_{CD}	0.2s
K_T	0.543478
K_H	0.326084
K_G	0.130438
K_{DC}	1
K_{RFB}	0.67
T_{RFB}	0s
T_{UPFC}	0.01s

Table A.2.2: Two-area interconnected thermal power system parameters.

Variables	Typical Values
f	60HZ
B_1, B_2	0.045, 0.045
R_1, R_2	2.4Hz/p.u, 2.4Hz/p.u
T_{g1}, $-T_{g2}$	0.08s, 0.08s
T_{t1}, T_{t2}	0.3s, 0.3s
T_{r1}, T_{r2}	10s, 10s
T_{p1}, T_{p2}	20s, 20s
K_{r1}, K_{r2}	0.5, 0.5
K_{p1}, K_{p2}	120Hz/p.u.MW, 120Hz/p.u.MW

A.3 NOMENCLATURE

fo, $f*$	Nominal frequency
W_{kin}	Kinetic energy of area
B_1, B_2	Frequency bias coefficient
ΔP_D	Incremental load demand change
ΔP_c	Incremental change in speed changer position
ΔP_m	Change in mechanical power input
ΔP_L	Incremental change in electrical power load
ΔP_G	Incremental generation change
$H.$	Inertia Constant
$D.$	Load damping coefficient
$\Delta f.$	Frequency deviation
$A_{12.}$	Area Capacity Ratio
R_1, R_2 & R_3	Governor speed regulation parameters
$(u_1, u_2, u_T, u_H\, u_G)$	Control outputs from the controller
P_{tie}	Tie-line power
T_{T1}, T_{T2}, T_{t1}, T_{t2}	Turbine time constants
T_{SG}, T_{g1}, T_{g2}	Governor time constants
T_{p1}, T_{p2}, T_{PS}	Power System time constants
T_{12}	Synchronising coefficient
K_{Ps}	Power system gain constant
$K_{I.}$	Integral gain for controller
$K_{D.}$	Derivative gain for controller
$K_{P.}$	Proportional gain for controller
ΔP_{12}	Incremental power flow on the tie-line from area 1 to area 2
N	Size of population
T	Trial of population
O_{sh}	Overshoot
U_{sh}	Undershoot
(t_s).	Settling time
T_{r1}, T_{r2}, T_r	Turbine reheat time constants
K_{r1}, k_{r2}, $K_{r.}$	Turbine reheat constants
T_{GH}	Hydro turbine governor time constant
T_{RS}	Hydro turbine speed governor reset time
T_W	Starting time of water in hydro turbine
(c_g)	Gas turbine valve position

(b_g)	Tim constant of the valve position
X_C	Lead time constant of gas turbine governor
Y_C	Lag time constant of gas turbine governor
T_{CR}	Gas turbine combustion reaction time delay
T_F	Gas turbine fuel time constant
T_{CD}	Compressor discharge volume time constant
K_T , K_H , K_G	Participation factors of gas, hydro and thermal units

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