Load frequency control in two area multi units Interconnected Power System using Multi objective Genetic Algorithm

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Abstract: - In this paper, load frequency control in two-area multi- units interconnected hydro thermal power system has been investigated. When an interconnected power system is subjected to heavy load disturbances, the system frequency and tie-line power flow are disturbed which leads to system instability. To stabilize the system frequency oscillations and tie - line power flow variations, a PID controller in coordination with Thyristor controlled phase shifter (TCPS) is proposed in this work. The parameters of PID controller and TCPS controller is tuned by using the proposed Global Ranking Multi objective Genetic algorithm (GRMOGA). The objective of this work is to improve the dynamic performance of the interconnected power system under heavy load disturbances. By the application of the proposed algorithm, the optimal gain values of the controllers are selected. Simulation studies are carried out by applying those optimal parameters values in the developed model and to show the effective performance of the proposed controller comparative analysis has been made with conventional PID and single objective GA PID controller.

Key-Words:- Load frequency control, Hydrothermal power system, PID controller, TCPS controller, Genetic algorithm, Multi objective optimization

1 Introduction

A typical large-scale power system consists of many control areas interconnected together and power is exchanged between control areas through tie-lines. In such systems, frequent changes occur due to the imbalance between the electrical load and the power supplied by system connected generators. Thus a control system is essential to offset the effects of the random load changes and to keep the frequency and the voltage at the constant values [1]. The active power and frequency control is referred to as load frequency control (LFC), which is also responsible for supplying sufficient and reliable electric power with good quality [2]. The main objectives of Load Frequency Control (LFC) are to keep the system frequency at the schedule value and regulate the generator units based primarily on area control error (ACE). During the early stage, the LFC is based on centralized control strategy [3] but it has complex computation and storage complexities. To overcome the mentioned difficulties, decentralized LFC has been developed [4]. The most widely used decentralized LFC system in power industry is PID control [5-7]. However, because of the inherent characteristics of the changing loads, the fixed gain controller may no longer be suitable in all operating conditions. Several approaches have been reported to improve the performance of power system under dynamic condition by choosing the variable gain values of the PID controller.

Fuzzy gain scheduled proportional and integral (FGPI) controller [8] for two-area interconnected power system has been reported. A new robust load frequency control using fuzzy logic has been suggested [9], to control the valve position limits and the parametric uncertainties. Genetic Algorithm based fuzzy logic controller is employed [10] to LFC in two area interconnected power system by considering the effects of governor dead band and generation rate constraints. Designing of an optimal PI controller for LFC in two area interconnected thermal power system using real coded GA has been reported [11]. One of the population based stochastic search optimization algorithm such as, Particle swarm optimization is applied [12] for automatic generation control (AGC) problem in three area interconnected thermal units to obtain the optimal gains of PID controller. A new algorithm of Bacteria foraging optimization Algorithm (BFOA) is presented [13] for optimal designing of PI controller for LFC in two area interconnected power system to damp out the system oscillations and to

overcome the premature convergence problem. Similar population based optimization algorithm of Artificial Bee Colony [14] is applied to the interconnected reheat thermal power system in order to tune the parameters of PI and PID controllers which are used for AGC. From the literature survey it concludes that, a secured, reliable and stable operation of power system depends on the proper selection of controller parameters and the above mentioned approaches are based on single objective optimization.

The practical control problems are characterized by several objectives, such as small overshoot, fast response, minimum steady state error, fast settling time and also it has to provide economical control action. The objectives are conflicting with each other, which must be satisfied simultaneously. In this work, the LFC synthesis is formulated as a multi objective optimization problem and is solved using Global Ranking Multi Objective Genetic algorithms (GRMOGA). The two area interconnected power system with different units (Thermal - Hydro) coordinate with a Flexible Alternating Current Transmission System device (FACTS) namely Thyristor controlled phase shifter (TCPS), which is located in series with the tie-line between two interconnected area to reduce the frequency oscillations and improve the system voltage are considered.

2. System Description

Each area of the power system consists of speed governor, turbine unit and generator unit as shown in Fig. 1. Each area has three inputs and two outputs. The inputs are the controller input (F_{ref}), load disturbances (denoted as ΔP_{D1} and ΔP_{D2}) and tie-line power flow (ΔP_{tie}). The outputs are the generator frequency deviations (ΔF_1 and ΔF_2) and Area Control Error (ACE_i). In the system under study, the conventional integral controller was replaced by PID controller and it has the following structure [15]:

$$K(s) = K_p + K_i / s + K_d s \qquad (1)$$

where K_p is the proportional gain, K_i is the integral gain and K_d is the derivative gain. The control signal for PID controller can be given in the following equation:

$$U_i(s) = - K(s) * ACE_i(s) \qquad (2)$$

The control action, which depends upon the Area Control Error (ACE), which is a linear combination of net tie-line power error (ΔP_{tie}) and frequency error (ΔF) and is represented as [16]:

$$ACE_i = \sum_{j=1}^{n} \Delta P_{tie\ i.j} + B_i \Delta F_i \qquad (3)$$

where B_i is frequency bias coefficient, $\Delta P_{tie\ i,j}$ is the tie-line interchange error and ΔF_i is the frequency error component. The GRMOGA based optimal controller is proposed in order to improve the frequency regulation and dynamic performance of the system. In order to analyse the efficient performance of the proposed controller, 0.01 pu MW load perturbation is applied in area 1 & 2 and then the dynamic performance of the proposed controller is compared with those of conventional and GA controllers.
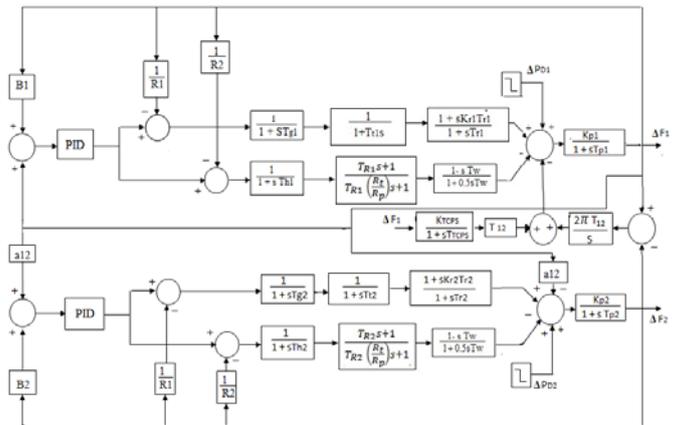
Fig. 1 Block Diagram of Two area interconnected hydrothermal power system

2.1. Modelling of TCPS unit

The schematic arrangement of the two area interconnected power system with TCPS unit placed near area1 and is connected in series with the tie-line are as shown in Fig. 2. The resistance of the tie-line is neglected. TCPS is a device that changes the relative phase angle between the system voltages. Therefore the real power flow can be regulated to mitigate the frequency oscillations and enhance power system stability.
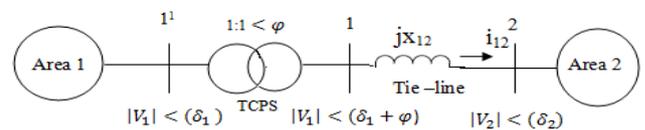
Fig. 2   Schematic diagram of Two-area interconnected power system with TCPS Unit

Considering area 1 has surplus power and transfer to area 2 through tie line which is given by:

$$P_{tie\ 1,2} = \frac{|V_1||V_2|}{X_{12}} \sin(\delta_1 - \delta_2) \qquad (4)$$

where δ_1 and δ_2 are the power angles of end voltages V_1 and V_2 respectively. For small deviations the

power angles and tie line power changes with small amount. The incremental tie-line power flow from Area 1 to Area 2 can be expressed as [17]:

$$\Delta P_{\text{tie }1,2} = \frac{2\pi T_{12}}{s} \left(\Delta F_1(s) - \Delta F_2(s) \right) \qquad (5)$$

where T_{12} is the synchronizing power coefficient , ΔF_1 and ΔF_2 are the frequency deviations of area 1 and area 2 respectively. Therefore the tie line power flow changes to $P_{\text{tie}1,2} + \Delta P_{\text{tie}1,2}$.

When a TCPS is placed in series with the tie-line the power flow from area 1 to area 2 can be expressed as:

$$\Delta P_{\text{tie }1,2}(s) = \frac{2\pi T_{12}}{s} \left[\Delta F_1(s) - \Delta F_2(s) \right] + T_{12}\Delta\varphi(s) \qquad (6)$$

The detailed equations are derived in [10]. If the frequency deviation in area 1 (ΔF_1) is sensed, it can be used as input signal (i.e. $\Delta Error1 = \Delta F_1$) to the TCPS unit to control the TCPS phase shift angle ($\Delta\varphi$) , which in turn controls the tie-line power flow. Thus the phase shift angle $\Delta\varphi(s)$ can be represented as:

$$\Delta\varphi(s) = \frac{K_{\text{TCPS}}}{1+s\ T_{\text{TCPS}}} \Delta F_1(s) \qquad (7)$$

where K_{TCPS} is the gain of the TCPS controller; T_{TCPS} is the time constant of TCPS controller; $\Delta F_1(s)$ is the input signal. Now, the tie - line power flow equation (6) becomes:

$$\Delta P_{\text{tie }1,2}(s) = \frac{2\pi T_{12}}{s} \left[\Delta F_1(s) - \Delta F_2(s) \right] + T_{12} \frac{K_{\text{TCPS}}}{1+sT_{\text{TCPS}}} \Delta F_1(s) \qquad (8)$$

There are two parameters such as stabilization gain K_{TCPS} and time constant T_{TCPS} to be optimized for the optimal design of the TCPS controller.

3. Problem Formulation

The objective of this work is to obtain a better transient response under sudden load changes which results in varying system parameters as well and restore the frequency to its nominal value as quickly as possible. In an interconnected power system to minimize the tie - line power flow variations between neighboring control areas is also considered. This is accomplished through optimization of the parameters of PID controller and TCPS controller based on performance index values to have minimum undershoot, minimum overshoot and minimum settling time of ΔF_1, ΔF_2 and ΔP_{tie} for area1 and area2 respectively . In this study, the LFC problem is formulated as multi objective optimization problem in which two objective functions have to be minimized subject to the constraints .The following objective functions are considered to select the optimal parameter values:

1. Performance Index Function (J_1)
2. Minimum Overshoot Function (J_2)

3.1 Performance Index Function (J_1)

Fast transient responses meant to provide minimum undershoot, minimum overshoot and minimum settling time of ΔF_1, ΔF_2 and ΔP_{tie} for area1 and area 2 respectively. This is achieved through optimization of PID and TCPS controller parameters based on performance index values. A performance index can be defined by the Integral of squared error value (ISE) of the frequency deviation of both areas and tie line power flow. The objective function J_1 is set to be,

$$J_1\left(K_{\text{Pi}}, K_{\text{Ii}}, K_{\text{Di}}, K_{\text{TCPS}}, T_{\text{TCPS}}\right) = \int_0^{t_{\text{sim}}} \left(ACE_i{}^2\right) \, dt \qquad (9)$$

It is clear that the gain value of the controller, which provides the lowest value of the ISE (J_1) is better than the other parameter values. The design problem can be formulated as the following constrained optimization problem, where the constraints are the controller parameters and their boundaries values. Minimize J_1 Subject to the following constraints:

- PID controller parameter constraints

$$K_{\text{Pi}}^{\min} \ll K_{\text{Pi}} \le K_{\text{Pi}}^{\max}$$
$$K_{\text{Ii}}^{\min} \ll K_{\text{Ii}} \le K_{\text{Ii}}^{\max}$$
$$K_{\text{Di}}^{\min} \ll K_{\text{Di}} \le K_{\text{Di}}^{\max} \qquad (10)$$

- Limit on TCPS gain values

$$K_{\text{TCPS}}^{\min} \ll K_{\text{TCPS}} \le K_{\text{TCPS}}^{\max}$$
$$T_{\text{TCPS}}^{\min} \ll T_{\text{TCPS}} \le T_{\text{TCPS}}^{\max} \qquad (11)$$

3.2 Minimum overshoot function (J_2)

The objective of minimum overshoot and settling time can be achieved by maximizing the damping ratio [12]. In view of this the second objective function J_2 is set to be:

$$J_2(\xi_i) = \frac{1}{\text{Min} \left(\sum_{i=1}^{n}(1-\xi_i)\right)} \qquad (12)$$

Where ξ_i is the damping ratio and n is the total number of dominant eigenvalues. The limit of damping ratio is as follows:

$$\xi_i^{\min} \ll \xi_i \le \xi_i^{\max} \qquad (13)$$

J_1 and J_2 are contradictory objectives since to reduce the steady state error or to obtain fast settled value (i.e. to minimize J_1), the controller must exert more effort to maximize damping ratio and hence the value of J_2 would increase and vice versa. By considering the objectives (J_1, J_2) and the constraints of the LFC problem can be formulated as a

constrained multi objective optimization problem and stated as follows:

Minimize (J) = [J$_1$, J$_2$] subject to the constraints from (10) to (13).

4. Multi-objective Genetic Algorithm

By maintaining a population of solutions, genetic algorithms can search for many non-inferior solutions in parallel. This characteristic makes GAs very suitable for solving Multi – objective problems. Unlike single objective optimization, the solution to the problem is not a single point, but a family of solution known as the Pareto-optimal set [16]. A Pareto optimal set is a set of solutions that are non-dominated with respect to each other [17]. Pareto-based fitness assignment suggested by Goldberg [18],   assigns rank 1 to the non-dominated individuals and removes them from competition, then finds a new set of non-dominated individuals, with rank 2, and so on. The Non-Dominated Sorting Genetic Algorithm (NSGA) was first introduced by Srinivas and Deb [19] to solve multi objective optimization problems. This has few disadvantages like high computational complexity, lack of elitism and need for specifying the sharing parameter. To overcome these, Deb et al. developed NSGA-II [20]. Mohamed et.al [15] tested with Global Ranking Genetic Algorithm (GRGA) by choosing new fitness assignment to reduce the computational complexity of NSGA II and applied for rotary inverted pendulum system.

In this proposed work GRMOGA algorithm is applied to solve the LFC problem of two area interconnected power system. The main components involved in GRMOGA algorithm are as follows:
(i)   Global Ranking Fitness Assignment
(ii)   Dominance Rank
(iii)   Crowding Distance

4.1. Global Ranking Fitness Assignment

For each individual solution (X$_i$) the objective function (J$_1$) is evaluated and the solution those who have the least value will be assigned a sub-rank 1 as r$_1$(X$_i$) =1. The solution those who have the next higher value will be assigned a sub-rank 2 and so on. Similarly the second objective function (J$_2$) is evaluated for each solution and sub ranks are assigned as per values. Then by using the sub rank of each individual the global rank value is assigned. The rank of a solution is given by the vector R (X$_i$),

$$R (X_i) = [r_1(X_i) \quad r_2(X_i) \quad \text{------} \quad r_m (X_i)]^T$$

where r$_m$(X$_i$) is the sub-rank of (X$_i$) for mth objective function in this case m = 2. The vector R (X$_i$) is calculated for each solution (X$_i$) then its global rank is found by [15]:

$$G (i) = \sum_{j=1}^{m} r_j (X_i) \qquad (14)$$

Where m is the total number of objectives and G (i) is the global rank for (Xi).

4.2 Dominance Rank

Consider an individual X$_i$ at generation t which is dominated by p$_i$ individuals in the current population. The dominance rank for the individual X$_i$ is given by,

$$Rank (X_i) = 1 + p_i \qquad (15)$$

If there is no solution would dominate a non-dominated solution in a population, then the non-dominated solutions are assigned as rank 1. Once the ranking is done, a dominance rank fitness is assigned to each solution based on its rank. The dominance rank fitness assignment is employed in elitism mechanism, where the current population and offspring produced from the genetic operation of the parents are combined to form a new population C$_p$, with size 2N, where N is the population size. In order to select N individuals from C$_p$ to form a new generation, all the individuals in C$_p$ will be ranked based on dominance rank fitness method and the best N individuals are chosen. However, in certain cases, the number of individuals with the rank '1' (Non-dominated solutions) may exceed N. In such cases, a second sorting procedure based on crowding distance among the non-dominated solutions is applied [15].

4.3 Crowding Distance

The crowding distance is a measure of how close an individual is to its neighbours. The aim of evaluating crowding distance is to obtain a uniform spread of solutions along the best-known Pareto front without using a fitness sharing parameter. The procedure for evaluating crowding distance is as follows [21]:

Step 1: Rank the population and identify non-dominated fronts F$_1$, F$_2$, ….. F$_r$.
        For each front j = 1, ….., r repeat Steps 2.

Step 2: For each objective function, sort the solutions in F$_j$ in the ascending order.
       Let   L = $|F_j|$ and $f_{(i,m)}$ represent the ith solution in the sorted list with respect to the objective function m. Assign crowding distance ranges as , $cd_m f_{(1,m)} = \infty \ and \ cd_m f_{(L, m)} = \infty$ and for i = 2, …… L -1 as:

$$cd_m f_{(i,m)} = \sum_{i=1}^{m} \frac{f_{(i+1,m)} - f_{(i-1,m)}}{f_i^{max} - f_i^{min}} \qquad (16)$$

where m is the number of objectives, f_i^{max} and f_i^{min} are the maximum and minimum values of ith objective function respectively.

4.4 Structure of GRMOGA

A random population of N size is generated. The objective values for each individual are evaluated and then the fitness functions are calculated based on global fitness assignment. By using the binary tournament selection [15], the parents are selected based on their global rank values. In this study the size of the selected parents is chosen as N/2 (half of original population size). The selected population generates off springs (N size) by crossover and mutation operations. In this work, simulated binary crossover scheme and polynomial mutation are used. This new population (offspring) along with parents are combined and sorted according to the dominance rank and the crowding distance in elitism. By the application of these two sorting mechanisms, a population of N size is produced as a new generation. Now the initial population is replaced with this new population, and then the above mentioned procedure is repeated until the termination condition is met. The structure of GRMOGA is shown in Fig. 3.
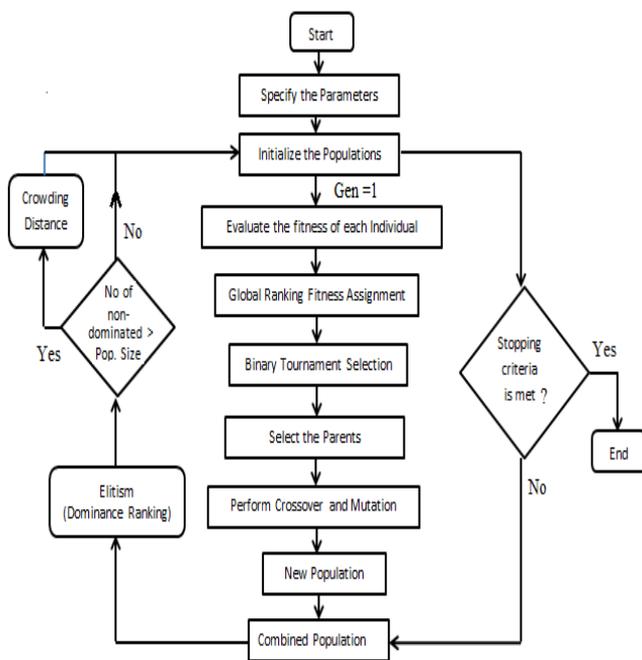
Fig. 3 Flow chart of Global Ranking Genetic Algorithm

5. Simulation Results and Discussion

The system model is simulated under dynamic condition using Matlab 7.1. A variety of test cases are considered such as by considering a 10% step increase in load demand in area1 and area 2 and also by considering 20% changes in the system parameters (K_{pi}, T_{pi} & T_{12}). The population of GA is taken as 20 individuals and the maximum number of generations of 100 is chosen as stopping criteria. The performance of GA generally depends on the crossover and mutation probabilities. The best result of the GA was obtained in this work with the following selection parameters: No. of generations: 100, population size: 50, crossover probability: 0.6, mutation probability: 0.03. The upper and lower limits of PID controller gain values K_P, K_I and K_D are selected as (-10, 10), (-5, 5) and (-3, 3) respectively. The boundaries for TCPS controller gain values K_{TCPS}, T_{TCPS} and phase angle variations are chosen as (-2, 2), (0, 2) and (-10º, 10º) respectively similarly the limits on damping ratio is chosen as (0.1, 0.7). Once the generation has reached the stopping criteria; it was found that there is no change in the fitness value of all individuals. It concludes that, the single objective optimization (GA) has reached the optimal solution. Fig. 4 shows the convergence of objective function (J_1) for single objective GA PID controller.
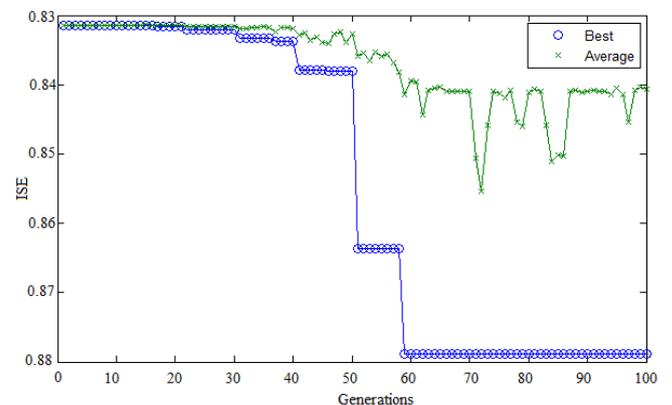
Fig. 4 Convergence of objective function (J_1) for GA

For the given multi objective functions (J_1, J_2) the pareto optimal set of PID controller parameters, TCPS gain values, damping ratio and the corresponding fitness functions are evaluated using the proposed algorithm. The system performance under different loading conditions , where 10% increase in load demand is applied in area1 (case I) and 10% increase in load demand is applied in area 2 (case II) and 10% increase in load demand is applied in area1& area 2 simultaneously (case III)

are taken into consideration for comparative study analysis.

Fig. 5 shows the performance index tracking and damping ratio tracking of the pareto-front solutions for test case I. The pareto-front solutions for all the three test cases and the corresponding PID controller and TCPS gain values are reported in Table 1(Appendix I). From Fig. 5, it is found that the solution s1 has less overshoot and long settling time and solution s3 has more overshoot and small settling time whereas solution s2 has compromise value as compared to other solutions. Thus it implies that, any result which improves one of objective function will have a poor performance measure with respect to the other (conflicting) objective function. This is because the multi-objective optimization produces a set of non-dominated solution [19].
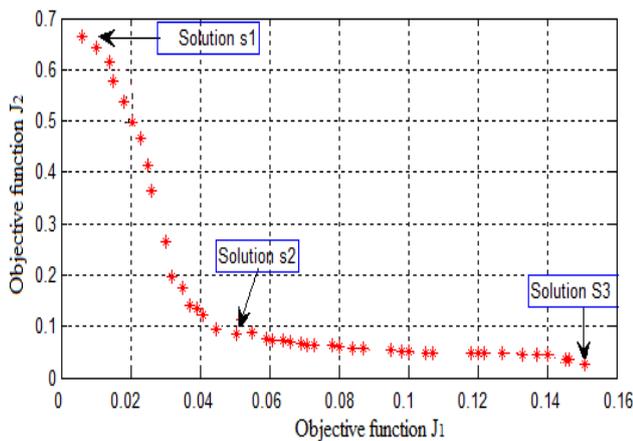
Fig. 5 Pareto optimal solutions for Case I
The convergence curve of objective function (J) for multi objective GA PID controller is shown in Fig 6.
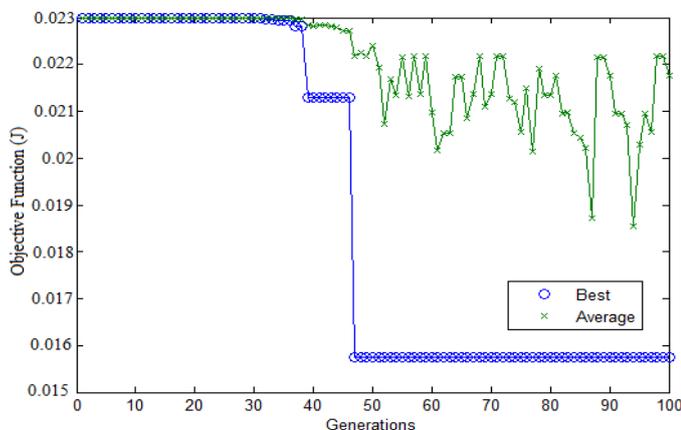
Fig. 6 Convergence of objective function (J) for multi objective GA

From Fig. 6, it concludes that the objective function value is converged at 45th generation. In case of single objective GA, it is converged after 60th generation. Hence the proposed algorithm provides fast response as compared to single objective GA. To illustrate the effectiveness of the proposed controller for the system under study, simulation studies are carried out subjected to severe load disturbance conditions in three different test cases. In all the three test cases, the PID controller tuned by Conventional method (Ziegler-Nichols), single objective optimization (GA) and multi objective optimization (GRMOGA) with ACE as the input signal. The PID controller parameter values and TCPS gain values for all the three tuning methods and their performance measures values are reported in Table 2 (Appendix I) and the comparative analysis of performance are shown in Figs. 7-9. (Appendix II).

5.1 Case I: 10% increased Step Load Disturbance (SLD) applied in area 1

A heavy disturbance of 10% SLD is applied in area 1 at t =0 sec, the system becomes highly oscillatory. The frequency variations in area1 & area2 (ΔF_1, ΔF_2) and tie - line power flow deviations are shown in Fig. 7. It is found that, the oscillations are greatly reduced by the proposed controller. It can also be seen that the TCPS phase angle is more effectively modulated to damp the power system oscillations when frequency deviation signal is employed. Further, it can be seen that the performance of proposed GRMOGA PID controller is superior to a conventional PID controller and single objective GA PID controller by smaller overshoot and settling time. The ISE value is decreased by 69.28%, minimum damping ratio is improved by 98.89% and the settling times of ΔF_1, ΔF_2 and ΔP_{tie} are reduced by 34.1%, 45.3% and 35.11% respectively when compared to the conventional controller. This case study concludes that the proposed GRMOGA is better in terms of convergence characteristics. Hence, the proposed controller greatly enhances the system stability and also improves the dynamic characteristics of power system.

5.2 Case II: 10% increased Step Load Disturbance (SLD) applied in area 2

A severe load disturbance of 10% SLD is applied in area 2, at t = 0 sec, but area 1 is operating at nominal load. The dynamic response of the system is shown in Fig 8. This illustrates that the system is unstable and becomes more oscillatory. The

frequency deviation in area 2 has more overshoot and long settling time as compared to area1. This is due to the effect of severe disturbance applied in area 2. The stability of the system is maintained with the application of controller. The effective performance of the proposed controller is also evidenced. This case study concludes that, the stability of the system is improved by the proposed GRMOGA controller under disturbance condition. The change in tie line power flow to meet the demand is also verified. The proposed controller has small change in power flow and quickly reaches the steady state as compared to conventional and GA controller. The ISE value is decreased by 74.8%, minimum damping ratio is improved by 91.23% and the settling times of ΔF_1, ΔF_2 and ΔP_{tie} are reduced by 58.2%, 66.4% and 59.3% respectively as compared to conventional controller.

5.3 Case III: 10% increased Step Load Disturbance (SLD) applied in Areas 1 & 2

The effective performance of the proposed controller is also verified by applying increased load at both areas simultaneously. A step load disturbances of 10% increase in demand in areas 1 &2 are applied simultaneously at time t = 0 sec. The response of system under the above disturbance condition is shown in Fig. 9. The heavy disturbance leads to more oscillations in conventional and GA controller as compared to the proposed controller. The stability of the system is greatly affected in case of conventional controller. The system frequency variations does not reach the steady state within the simulation time of 100sec, thus for this case the simulation run time has extended up to 120sec to get the steady state response of conventional controller. Tie line power flow variations are also verified that, the proposed controller has small variations and reaches the steady state quickly when compared to the conventional and single objective controller. The ISE value is decreased by 83.2%, minimum damping ratio is improved by 85.1% and the settling times of ΔF_1, ΔF_2 and ΔP_{tie} are reduced by 96.4%, 94.2% and 97.5% respectively as compared to conventional controller. The ISE value is decreased by 58.4%, minimum damping ratio is improved by 36.1 % and the settling times of ΔF_1, ΔF_2 and ΔP_{tie} are reduced by 28.7%, 34.5% and 38.5% respectively as compared to the single objective GA controller. Further, it can be seen that, the proposed GRMOGA controller exhibits a better performance under heavy load disturbance conditions (increased in both areas) as compared to other two test cases.

6. Conclusion

This paper presents the optimal parameter tuning of PID and TCPS controller by employing Global Ranking Multi objective Genetic algorithm to load frequency control in two area interconnected hydro thermal power system. The conflicting objectives like minimum Integral square error and the maximum damping ratio of dominant eigenvalues are chosen and GRMOGA technique is applied to generate pareto - optimal solution set. Further a fuzzy based membership function value assignment is employed to choose the best compromise solution from the obtained pareto - optimal solution set. Simulation study was performed under different loading conditions and disturbances to show the effective performance of the proposed controller. It is observed that the proposed controller exhibits a better performance when load disturbances are applied in both areas simultaneously (heavy load condition). The robustness analysis is also performed by changing the system parameters under varying load conditions. The superior performance of the proposed GRMOGA optimized PID controller is justified by comparing the results with conventional and single objective optimized controller for the same interconnected power system. From the comparative study it is concluded that, the proposed controller is robust in its operation and exhibits good damping performance for both frequency and tie line power deviations under varying load conditions in the two area interconnected hydrothermal system.

References:

[1] Allen J. Wood Bruce, F. Wollenberg, *Power generation, operation and control*, John Wiley & sons, New York, 1994

[2] Olle I. Elgerd, *Electric Energy Systems Theory*, Tata McGraw – Hill, New Delhi, 2006.

[3] Xiangjie Liu, Xiaolei Zhan, Dianwei Qian, Load Frequency Control considering Generation Rate Constraints, *Proceedings of 8th World Congress on Intelligent Control and Automation*, 2010, pp.1398- 1401

[4] K.Okada, R.Yokoyama, G.Shirai, H.Sasaki, Decentralized Load Frequency Control with Load Demand Prediction in Multi-area Power Systems, *Proceedings of International Conference on Control*, 1988, pp.649-654

[5] Y. Moon, H. Ryu, J. Lee, S.Kim, Power System Load Frequency Control Using Noise-Tolerable PID Feedback, *Proceedings of IEEE International Symposium on Industrial Electronics*, vol.3, 2001, pp. 1714 –1718.

[6] X .Yu, K. Tomsovic, Application of Linear Matrix Inequalities for Load Frequency Control with Communication Delays, *IEEE Transaction on Power Systems*, Vol.19, No.3, 2004, pp. 1508-1515.

[7] D. Rerk Preedapong, A. Hasanovic, A. Feliachi, Robust Load Frequency Control Using Genetic Algorithms and Linear Matrix Inequalities, *IEEE Transaction on Power Systems*, Vol.18, No.2, 2003, pp.855- 861

[8] Ilhan Kocaarslan,C.Ertug rul, Fuzzy logic controller in interconnected electrical power systems for Load frequency control*, Int .Journal of Electrical Power and Energy Systems,* Vol.27, No. 8, 2005, pp.542–549.

[9] Ho Jae Lee, Jin Bae Park, Young Hoon Joo , Robust load-frequency control for uncertain nonlinear power systems: A fuzzy logic approach, *Int. Journal of Information Sciences*, Vol. 176, No.23, 2006, p-p.3520–3537.

[10] Chia-Feng Juang, Chun-Feng Lu, Power System Load Frequency Control By Genetic Fuzzy Gain Scheduling Controller*, Journal of the Chinese Institute of Engineers,* Vol.28, No.6, 2005, pp. 1013-1018.

[11] S. Ramesh, A.Krishnan, Modified genetic algorithm based load frequency controller for interconnected power system, *Int. Journal of Electrical Power Engineering,* Vol.3, No.1, 2009, pp. 26–30.

[12] S.P. Ghoshal , Optimizations of PID gains by particle swarm optimizations in fuzzy based automatic generation control, *Int. Journal of Electric Power Systems Research,*Vol.72, No.3, 2004, pp. 203-212.

[13] E.S. Ali , S.M. Abd-Elazim, Bacteria foraging optimization algorithm based load frequency controller for interconnected power system, *Int. Journal of Electrical Power and Energy systems*, Vol.33, No. 3, 2011, pp.633–638..

[14] M. Haluk Gozde, Cengiz Taplamacioglu, İlhan Kocaarslan, Comparative performance analysis of Artificial Bee Colony algorithm in automatic generation control for interconnected reheat thermal power system, *Int. Journal of Electrical Power & Energy System*s, Vol. 42, No.1,2012, pp.167-178.

[15] Mohd Rahairi Rani et.al,. Multi-objective Optimization for PID controller Tuning using the Global Ranking Genetic Algorithm, *Int. Journal of Innovative Computing, information and Control*, Vol. 8, No.1(A) , 2012, pp.269-284.

[16] Coello CAC, A comprehensive survey of evolutionary based multi-objective optimization, *Int. Journal of Knowledge Inform System*, Vol.1, 1999, pp. 269–308.

[17] Abdullah Konak, David W. Coit , Alice E. Smith, Multi-objective optimization using genetic algorithms: A tutorial, *Int.Journal of Reliability Engineering and System Safety*, V ol.91, 2006, pp. 992–1007.

[18] Goldberg DE, *Genetic algorithms in search, optimization, and machine learning,* Boston: Addison-Wesley, 1989.

[19] N.Srinivas, K. Deb, Multi-objective optimization using non-dominated sorting in genetic algorithms, *IEEE Trans Evol. Computation,* Vol.2, No.3, 1994, pp. 221-248.

[20] K. Deb, A. Pratap, S. Agarwal and T. Meyarivan, A fast elitist multi-objective genetic algorithm: NSGA-II, *IEEE Trans Evol. Computation,* Vol.6, 2002, pp.182–197.

[21] Abdullah Konak, David W. Coit, E. Alice, Smith, (2006). Multi-objective optimization using genetic algorithms: A tutorial, *Int. Journal of Reliability Engineering and System Safety*, Vol.91, No.9, 2006, pp. 992–1007.

Appendix I

Table 1. Optimal Parameters and Performance measures

Loading Condition	Solution	J_1	J_2	PID Controller Parameters						TCPS Gain values		
				Area 1			Area2			K_{TCPS}	T_{TCPS}	$\Delta\varphi$
				K_{P1}	K_{I1}	K_{D1}	K_{P2}	K_{I2}	K_{D2}			
Case I	s1	0.006	0.671	6.675	1.956	1.645	6.525	1.536	1.443	1.435	1.007	3°
	s2	0.051	0.097	6.117	1.987	1.434	4.876	1.004	1.023	1.056	1.011	6°
	s3	0.152	0.022	8.890	1.112	1.056	5.110	1.767	0.987	1.166	1.055	-4°
Case II	s1	0.005	0.876	8.432	2.123	1.912	6.822	1.818	1.660	1.663	1.092	5°
	s2	0.084	0.052	6.456	2.715	-1.525	5.453	1.585	1.112	1.155	1.122	-2°
	s3	0.225	0.046	9.242	1.912	-1.093	4.825	1.148	1.056	1.009	1.234	-7°
Case III	s1	0.007	0.774	6.144	2.024	-1.232	5.876	1.986	1.545	1.533	1.002	7°
	s2	0.075	0.087	5.367	1.754	-1.421	4.524	1.456	0.076	1.354	1.076	-5°
	s3	0.187	0.035	8.632	1.356	-1.589	5.034	1.197	0.965	1.035	1.112	8°

Table 2. Performance Analysis

Loading condition	Controller	PID Controller Parameters						TCPS Gain values		Settling Time			%Overshoot			Damping Ratio
		Area 1			Area 2											
		K_{P1}	K_{I1}	K_{D1}	K_{P2}	K_{I2}	K_{D2}	K_{TCPS}	T_{TCPS}	ΔF_1	ΔF_2	ΔP_{tie}	ΔF_1	ΔF_2	ΔP_{tie}	ξ
	Conventional	4.164	-1.456	2.124	5.645	2.987	1.512	1.515	1.054	56	68	56	40	36	-90	0.2123
Case I	GA	8.625	-1.155	2.654	8.127	2.482	1.142	1.476	1.157	34	36	34	21	10	-51	0.2754
	GRMOGA	9.642	1.956	1.456	6.665	2.386	1.955	1.063	1.256	22	23	21	8	2.4	-12	0.1167
	Conventional	8.758	-1.764	2.697	5.886	1.081	2.251	1.824	1.194	77	88	82	36	42	-81	0.1834
Case II	GA	7.164	-1.434	1.965	6.512	-1.231	1.892	1.256	0.867	26	36	32	8	21	-8.3	0.2205
	GRMOGA	9.267	1.352	1.994	8.062	1.382	2.002	1.052	0.995	20	22	24	1	0.5	0	0.2412
	Conventional	7.354	-1.712	2.065	6.235	1.414	2.075	1.210	0.823	115	112	114	75	62	-57	0.3226
Case III	GA	8.867	1.623	2.413	9.197	0.932	1.265	1.615	1.034	44	46	42	46	48	-4.6	0.4145
	GRMOGA	8.043	1.691	3.714	5.425	0.986	2.702	1.203	1.679	18	16	18	8	22	-2	0.4504

Appendix II
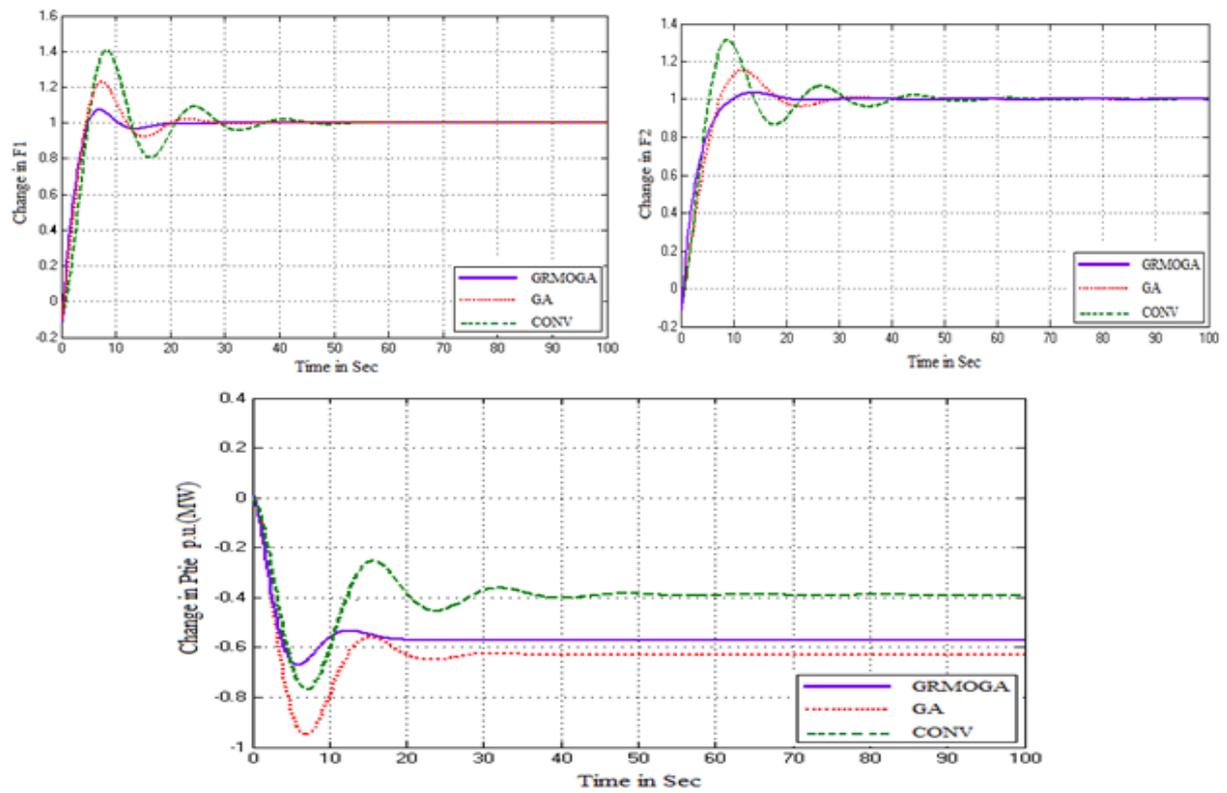
Fig. 7 Variations of ΔF_1, ΔF_2 and ΔP_{tie} (Case I)
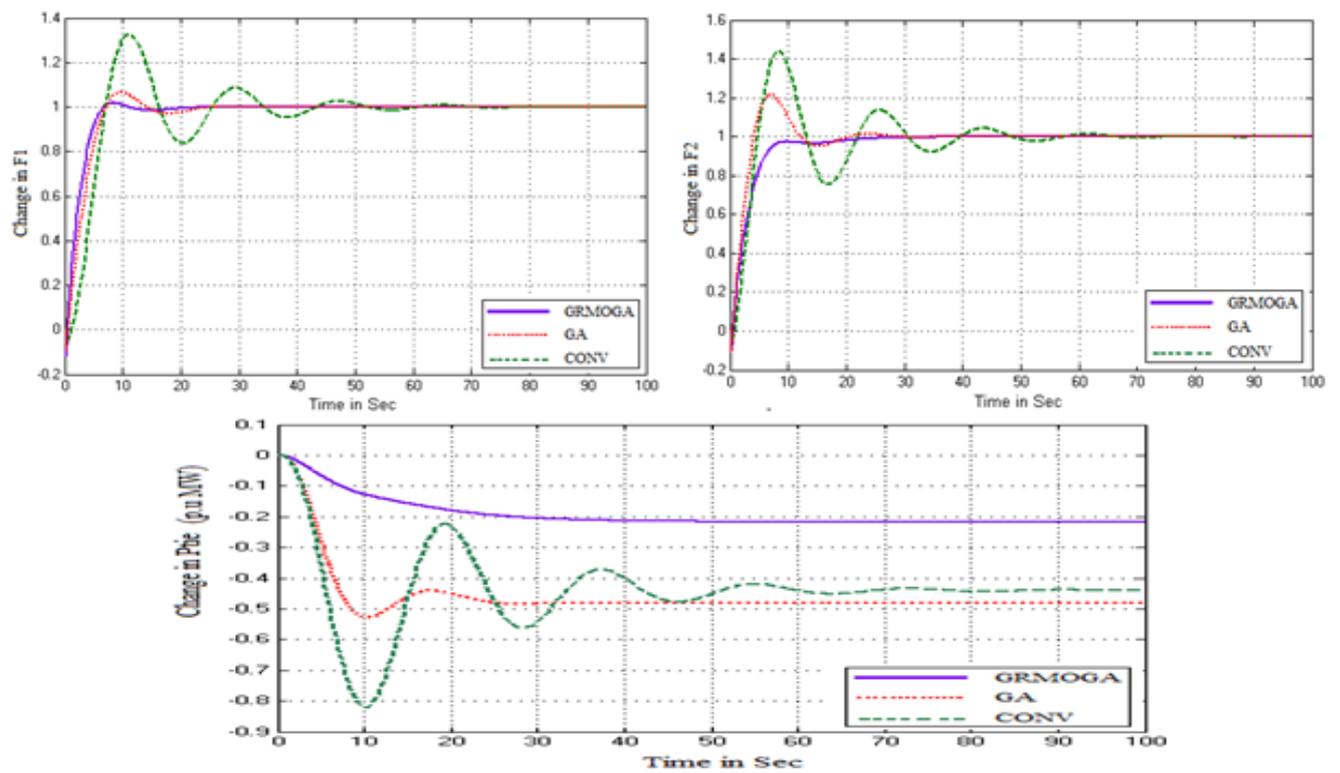
Fig. 8 Variations of ΔF_1, ΔF_2 and ΔP_{tie} (Case II)

Fig. 9 Variations of ΔF_1, ΔF_2 and ΔP_{tie} (Case III)