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Load Frequency Control for Two-area Multi-Source Interconnected Power System using Intelligent Controllers

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ABSTRACT

This paper presents the study of intelligent controllers for Two-area multi-source interconnected power system model. The controller gains are optimized using Conventional method, GA and BAT algorithms and investigation is carried out for the best optimization method on the basis of dynamic performance and stability of the power system model. The power system model under investigation two area each area consists of thermal, hydro and Double Fed Induction Generator (DFIG) based wind unit with different participation factor in the total generation for their respective area. It has been observed that an appreciable improvement in the system dynamic performance is achieved using Bat algorithms for load frequency controller for multisource power system model as compared with conventional method and GA algorithm.

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السيطرة على تردد الحمل لمنظومة قدرة لمنطقتين متعددة المصادر باستخدام مسيطرات ذكية

الخلاصة

هذا البحث يقدم دراسة لمسيطرات ذكية لمنظومة قدرة لمنطقتين متعددة المصادر. قيم المتغيرات لمنظومة السيطرة تم حسابها باستخدام خوارزميات متعددة (التقليدية (Conventional)، الخوارزمية الجينية (GA) وخوارزمية الخفاش (BAT). التحقق من المسيطرات تم على أساس الأداء الديناميكي واستقرارية منظومة القدرة. تتكون منظومة القدرة تحت الفحص من منطقتين كل منطقة تتكون من ثلاث مصادر (حرارية، هيدروليكية ومنظومة وحدة رياح) مع اختلاف نسبة مشاركة كل مصدر للتوليد في كل منطقة. من خلال النتائج لوحظ أن هناك تحسن ملحوظ في الأداء الديناميكي واستقرارية المنظومة عند استخدام خوارزمية الخفاش للسيطرة على منظومة القدرة مقارنة باستخدام الطريقة التقليدية والخوارزمية الجينية.

1. INTRODUCTION

In a large power system with diverse sources of power generators, electrical power is generated to meet the demand in an efficiently and reliable manner. In order to achieve the reliability, the power system should be well designed so that it can cope load variations and system disturbances to maintain power quality standard by maintaining rated system parameters i.e. (voltage and frequency) within the acceptable limits. Moreover, frequency and inter-area exchanges within acceptable limits can be achieved through Load Frequency Control (LFC) action. LFC regulates the power output of generators within a prescribed area in response to changes in system frequency and tie-line loading. In the event of availability of a suitable LFC scheme, the selection of a proper approach for its effective implementation has a vital role. Many Practically conventional PID controllers are used for LFC problem and classical optimization techniques for tuning controller gains is based on trial and error method that not only time consuming but also gives suboptimal result. However nonlinear power system are approximated by reduced order linear models which are valid within certain operating ranges and range of operation is changed a different model may be required or the control system should adopt changed model parameters for optimum performance and stability. Moreover, due to complex nature and multivariable condition of the power systems, classical and nonflexible LFC schemes does not gives optimum solutions. Therefore, the performance of such system is evaluated with a flexible method that have capability to give optimum results under non-linear

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conditions. The advent of intelligent methods such as Artificial Neural Networks (ANNs) and fuzzy logic has solved the linear and non-linear problems to great extent. However, from two decades, optimization algorithms like Genetic Algorithm (GA), Evolutionary Programming (EP), Evolutionary Strategies (ES), based on evolution and natural genetics, have been extensively used for linear and non-linear case of LFC for isolated and interconnected power system model. Most recently meta-heuristic techniques like particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Bacteria Foraging Optimization (BFO) and Bat algorithm(BAT) are becoming powerful methods for solving many engineering complex optimization problems and have been used for tuning of controller gains for LFC for interconnected power system [1-9].

In this paper study of three intelligent optimization techniques namely Conventional, Genetic algorithm (GA), and Bat algorithm (BAT) is applied for load frequency problem for two areas multi-source interconnected power system model. The performance is compared on the basis of performance index and dynamic steady state stability of the power system model

2. INTELLIGENT OPTIMIZATION ALGORITHM

2.1. Genetic Algorithms (GA)

The conventional LFC pose difficulties in implementation in modern power systems due to number of system emerging constraints like increasing size, incorporation of renewable energy sources, changing system structure and parametric uncertainties. Most of the conventional LFC methodologies provide model based controllers that are also difficult to use for large-scale power systems associated with nonlinearities e.g., governor dead band effects, generation rate constraints (GRC) and parametric uncertainties. To overcome the limitations of conventional controllers, intelligent LFC schemes have been implemented, which are more flexible and give desirable results.

Genetic Algorithms (GA) are a stochastic global search method that simulates the process of natural evolution. The genetic algorithm initializes with no knowledge of optimum solution and entirely depends on responses from its evolution operators to achieve the best solution. The genetic algorithm initializes without the knowledge of the correct solution and depends solely on responses from its environment and operators to obtain the best solution. It starts at many independent points and conduct parallel search, the algorithm skips local minima, finally converges to an optimal solution. Genetic algorithm has three main functions given as below to obtain an optimum solution.

Reproduction: Reproduction generates new chromosome and the fitness of every Individual is evaluated. This fitness value is used in the selection of fittest individual for reproduction. The common selection method is roulette wheel selection.

Crossover: Crossover allows swapping of information among individuals in the population, randomly two parent strings are selected to generate new child string.

Mutation: Mutation is the occasional random modification of bits' position in a string to create diversity in the string so that GA searches the entire problem space. It is the background operator in the genetic algorithm and the probability of mutation is normally low because a high mutation rate would destroy fit strings and degenerate the genetic algorithm into a random search. This operator tends to enable the evolutionary process to move toward promising regions of the search space. The mutation operator is introduced to prevent premature convergence to local optima by randomly sampling new points in the search space. It is carried out by flipping bits at random, with some (small) probability and finally the termination condition may be specified as some fixed maximal number of generations or as the attainment of an acceptable fitness level.

Several reports are also available on the use of GA in LFC systems and have been used to adjust parameters for different LFC controllers which improve dynamical performance of the power system and also the reduces control effort [10-13]. The basic flow chart for tuning of PID structure based LFC regulators using GA optimization is shown in Fig. 1.

2.2. Bat Algorithm

The nature inspired optimization techniques playing a pivotal role in getting ebullient performance of the system as compared to the conventional approach. A new metaheuristic algorithm based on the echolocation behavior of bats and has been successfully applied for optimization of continuous mathematical functions, industrial and microelectronics applications. The echolocation of microbats has capability to hunt their prey and differentiate types of insects in absolute darkness. Such echolocation behavior can be mathematically formulated to optimize the complex engineering problem. Xin-She Yang [14-16] explored the echolocation behavior of bat and formulated the algorithm for solving mathematical optimization problem. However, some approximation and assumptions considered for formulating the algorithm are as below. Through echolocation, microbats distinguish between food and non-food objects. During hunting, the echo characteristic such as frequency, wavelength, loudness, Pulse emission, amplitude varies in combination with bats velocity, random positions helps in detecting the target.

For simulation purpose, the bats velocity, frequency and position are formulated as:
The new solutions X_{it} and V_{it} at time step t are given as:

$$f_i = f_{min} + (f_{max} - f_{min})\beta \quad (1)$$

$$V_{it} + 1 = V_{it} + (X_{it} - X_0) f_i \quad (2)$$

$$X_{it} + 1 = X_{it} + (V_{it} + 1) \quad (3)$$

where β = [0,1] and uniformly distributed over the region. The best global solution X_o is obtained at each iteration. Then the velocity is increment by the product of $\lambda_i$fi, where fi (or λ_i) is used to tune the velocity deviation with the other factor λ_i(or fi) held constant. The settings can be re-adjusted depending on the problem. The settings of f_{min} and f_{max} depend on the problem. Each bat is designed at random

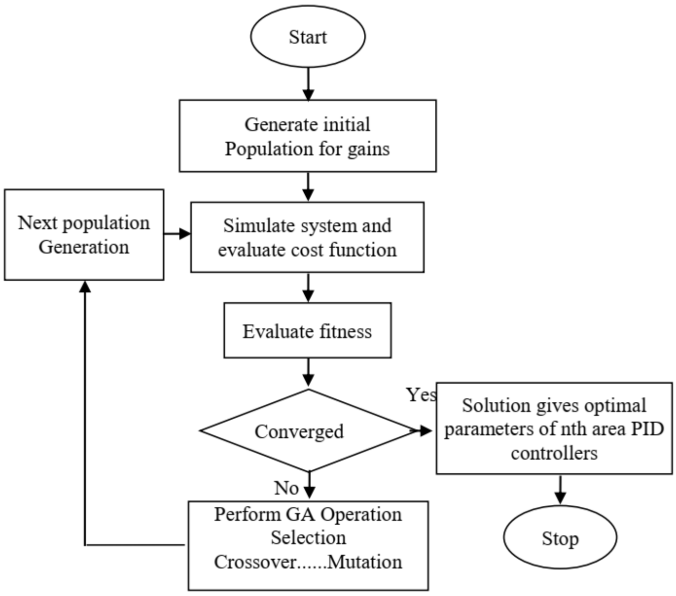

Fig. 1. Flow chart for optimal tuning of PID controller gains using GA.

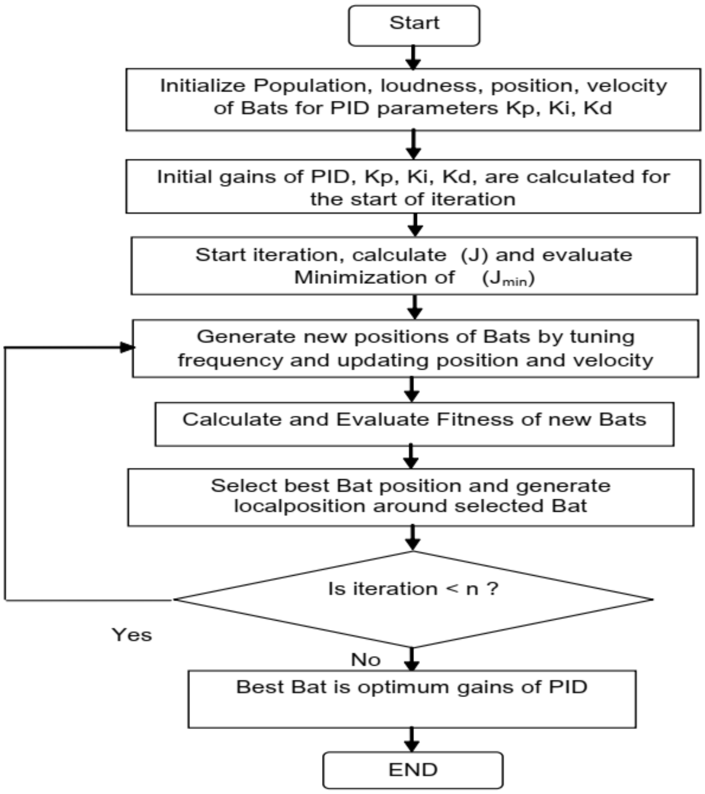

Fig. 2. The flow chart of bat algorithm.

frequency value between the uniformly value [f_{min} , f_{max}]. The random walk is defined as below and used for local best solution.

$$X_{new} = X_{best} + \psi A^t \tag{4}$$

Where ψ is a randomly drawn number between [−1,1]. At is defined as the mean loudness of all the bats at this time step. The process of the updating the velocities and the positions is identical to swarm optimization. The loudness value can be selected arbitrarily. Consider A_{min}= 0 for a bat founds the prey and halt on emitting sound. The control for the pulse emission is given as:

$$A_i^{t+1} = \alpha A_i^t \; and \; r_i^t = r_i^0[1 - \exp(-\gamma t)] \tag{5}$$

where (α and γ) are constant, normally 0.95, ri is rate of emission. Actually, α is like a cooling factor similar to simulated annealing algorithm.

For $0 < \alpha < 1$ and $\gamma > 0$, then

$$A_t \to 0, r_i^t \to r_i^0 \; as \; t \to 0 \tag{6}$$

The bat algorithm is used for the optimal designing of LFC regulator gains for multisource multi-area power system model subject to minimization of objective function. The flow chart of the Bat algorithm for the optimal tuning of LFC regulator is shown in Fig. 2.

2.3. Power System Model

A two area multi source interconnected power system is considered for LFC case study. Both areas are identical and electrical power is generated by thermal with reheat turbine, hydro unit and DFIG based wind turbine to meet the demand of their respective areas. A multisource two area power system model is shown in Fig. 3. Thermal power plant consists of steam turbine either tandem-compound or cross-compound configuration depending on the number of shafts present in the turbine. Most commonly tandem-compound configuration is used and can be of reheating or non-reheating steam cycle. The steam turbine governing system can be Mechanical-hydraulic, Electro hydraulic or Digital Electro hydraulic. For dynamic studies, a steam turbine governing system can be represented by first order transfer function with a time constant. The power output from the turbine is controlled through the position of the control valves, which control the steam flow to the turbines. The perturbed mathematical model of the thermal power plant with speed governor as primary controller is given by Elgerd [2], composed of non-reheat steam turbine generator set to generate electrical energy for the power system. The hydro turbine units take less time to start up and governor response is slightly sluggish due to large inertia of water. The transfer function model of hydro power plant with speed governor as primary frequency control is developed by Kundur [17]. The mathematical model consists of speed governor, hydro turbine and power system. Any mismatch between the generation and demand deviates frequency, sensed by the governor which controls the water input to turbine. The transfer function model of the hydro units represents a non-minimum phase system and power output have oscillations due to water compressibility and large governor droop. The rate of generation for hydro plants is relatively higher as compared to tandem-compound reheat thermal power plants due to slow governor operation. Generally, for hydro units' generation rate is 270% per minute for raising generation and 360% per minute for lowering generation, thermal have the order of 3% per minute. The dynamic transfer function model of reheat thermal units and hydro units have discussed by many authors [18-21]. The wind units normally do not participate in load frequency control. However, with the development of advanced controllers and Doubly Fed Induction Generator (DFIG) based wind turbines the kinetic energy can be extracted stored in the mechanical system of wind turbine and can support in the primary frequency regulation.

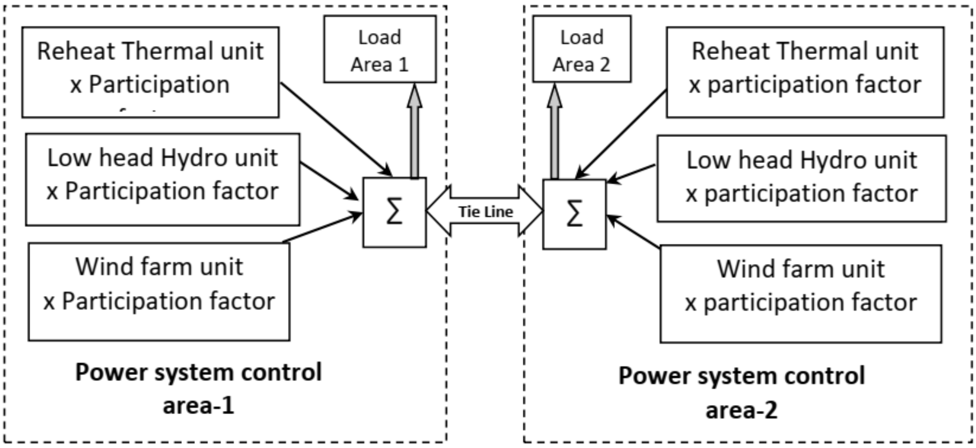

Fig. 3. Diagram of multi-source interconnected power system model.

Under steady state conditions, there is equilibrium between generation and consumption of load. The electrical power generations in each area from DFIG based wind, thermal and hydro power plants are given as:

$$P_{Gh1} = K_{h1} P_{G1} \quad (8)$$

$$P_{Gt1} = K_{t1} P_{G1} \quad (9)$$

$$P_{Gw1} = K_{w1} P_{w1} \quad (10)$$

The power generated in area-1 is given as:

$$P_{G1} = P_{Gh1} + P_{Gt1} + P_{Gw1} \quad (11)$$

$$P_{G1} = K_{h1} P_{G1} + K_{t1} P_{G1} + K_{w1} P_{w1} \quad (12)$$

$$K_{t1} + K_{h1} + K_{w1} = 1 \quad (13)$$

For small load perturbation in area-1, the deviation in power generation (ΔP_{G1}) can be formulated using Eq. (11) as:

$$\Delta P_{G1} = \Delta P_{Gh1} + \Delta P_{Gt1} + \Delta P_{Gw1} \quad (14)$$

Similarly, for area-2, the power equation is given as:

$$\Delta P_{G2} = \Delta P_{Gh2} + \Delta P_{Gt2} + \Delta P_{Gw2} \quad (15)$$

For the control area-1, the relation of load frequency characteristic (D_1),Power system gain constant (K_{P1}),power system time constant(T_{P1}), and bias constant (β_1) are given as:

$$D_1 = \frac{\partial P_{L1}}{\partial f_1} \frac{1}{P_{r1}} \quad (16)$$

$$K_{p1} = \frac{1}{D_1} \quad (17)$$

$$T_{p1} = \frac{2H_1}{f_1 D_1} \quad (18)$$

$$B_1 = D_1 + \frac{1}{R_1} \quad (19)$$

Similarly, for area-2 the parameters are:

$$D_2 = \frac{\partial P_{L2}}{\partial f_2} \frac{1}{P_{r2}} \quad (20)$$

$$K_{p2} = \frac{1}{D_2} \quad (21)$$

$$T_{p2} = \frac{2H_2}{f_2 D_2} \quad (22)$$

$$B_2 = D_2 + \frac{1}{R_2} \quad (23)$$

In a power system, the synchronous generators are normally driven by the steam and hydro generators for thermal and hydro power pants. The turbine is controlled by the governing system equipped at inlet for controlling the speed and maintains the required power output. The mathematical model of multisource two area power system model with is shown in Fig. 4.

2.4. Optimization Problem

The optimization is the minimization or maximization of the objective function which is formulated on the basis of performance index of the system. The objective function for LFC problem of a multisource interconnected power system is formulated on the basis of integral square error (ISE) criterion. Therefore, the performance index (Jn) for nth control area is written as:

$$J_n = \int_0^T ACE_n^2 \, dt \quad (24)$$

Where the ACE is defined as Area Control Error, the combination of deviations in area frequency and tie-line power exchanges from their scheduled values. The objective function J_n is optimized subject to constraint as given below:

$$K_{pn}\text{min} \le K_{pn} \le K_{pn}\text{ max} \quad (25)$$

$$K_{in}\text{min} \le K_{in} \le K_{in}\text{ max} \quad (26)$$

$$K_{dn}\text{min} \le K_{dn} \le K_{dn}\text{max} \quad (27)$$

where, K_{pn}, K_{in} and K_{dn} are parameters of PID controller as an LFC regulator associated with nth control area for the power system model under consideration.

3. SIMULATION AND DISCUSSION OF RESULTS

The transfer function model of multi-source two area interconnected power system model is developed and simulated on MATLAB platform. For simulation studies, the numerical data are selected from Appendix-I. The performance of the developed algorithm is compared with conventional algorithm and GA algorithm and discussed on the basis of minimization of performance indices, peak overshoot and settling time. For the developed power system model, the gains of LFC regulators are tuned using conventional technique, genetic algorithm and Bat algorithm. The optimal gains and the performance indices are shown in Table 1. The dynamic responses of power system with optimal LFC regulators for 1% perturbation are shown in Figs. 5-16.

From dynamic response plots it is quite clear that load disturbance has local dominance and the system states are more affected in the area of disturbance compared to other interconnected control area. The power system for 1% load disturbance in area-1 of multisource interconnected power system is shown in Fig. 5, observations after first sight of inspection are the peak deviations in frequency which is lowest in case of Bat tuned, followed by GA tuned and then the conventionally tuned LFC regulator. Additionally, the response is slightly oscillatory before system settles to steady state. However, the oscillations are due to the presence water inertia at governor of hydro power plant and the DFIG wind turbine dynamics. The bat tuned controller reduces the oscillations as well as improves settling time to achieve the steady state condition as compared to GA and conventionally tuned LFC controller. From Table 1 it is clearly visible that the cost function is also improved in case of Bat algorithm that improves the overall power system dynamics as compared to GA and conventional tuned controller. From Fig. 6, similar trend is observed in dynamics of area-2, but with a less deviation in states such as first peak deviation in case of GA and Bat tuned controller is less in magnitude comparative to area-1, strongly indicating the weak coupling between control areas and strong coherency of multiple generation sources within the control area. The dynamics of tie-line power flow is represented in Fig. 7, from observation it is clear that first peak deviation in tie line power is lower, less oscillatory and settles fast as compared to GA and conventionally tuned LFC regulator. The effect of proposed tuning technique on different sources of power generation is clearly visible in corresponding figures such as Fig. 8, represents the increase in generation by the thermal power plant of area-1 post load disturbance in the same area, the response of Bat tuned LFC regulator is quite appreciable as it acts faster and settles faster for the rate of change of MW power as compared to GA and conventionally tuned LFC regulator. The change in power generation from hydro power plant is visible in Fig. 9, due to water inertia the response of hydro power plant is slightly sluggish and takes more time to achieve steady state. However, from initial response it is clear that Bat tuned LFC regulator response is faster as compared to GA and conventionally tuned regulator. Moreover, change in power generation of DFIG based wind power plant is shown in Fig. 10 and due to appreciable response from Bat tuned LFC regulator there is an appreciable improvement in peak overshoots and settling time as compared to GA and conventional tuned regulator. The frequency and tie-line power deviation tends to zero as soon as the generation increases from diverse sources to satisfy the increased demand. The response in power generation from diverse sources for the disturbed area and interconnected area with the Bat, GA and conventional tuned LFC regulator is shown in Figs. 11-16, and it can be clearly observed that for all the controller the response from thermal power plant to change the generation is fast in comparison to hydro power plant to meet the increased load demand, hence it

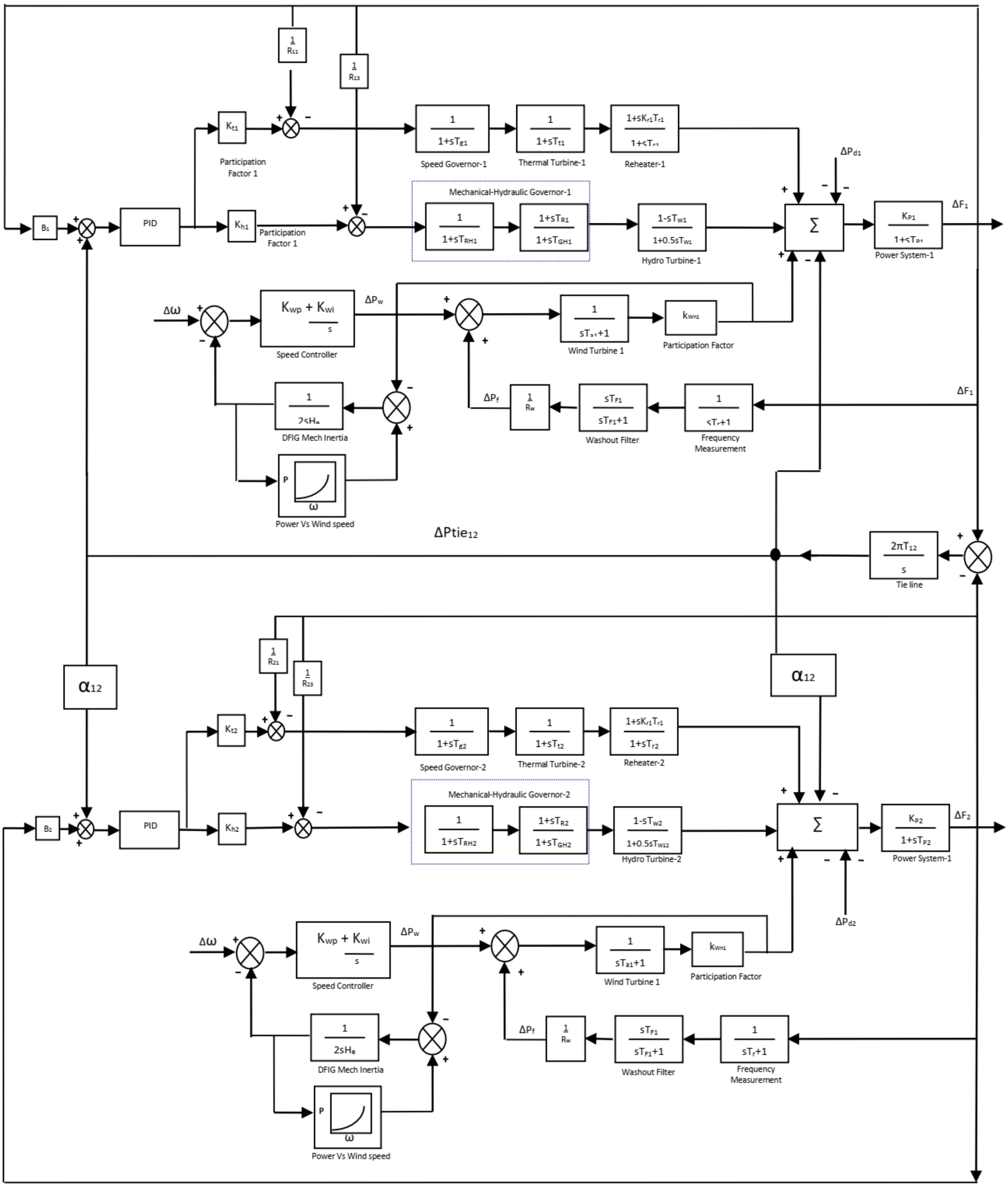

Fig. 4. Power system mathematical model for LFC study.

Table 1
Gain and performance indices

	GAIN			
TUNING METHOD	Kp	Ki	Kd	ISE (1×10^{-4})
Conventional	0.1468	0.59983	0.34684	8.4477
GA	1.1294	0.53148	0.12302	4.2162
Bat	1.41610	1.01623	1.08543	1.9882

can be strongly inferred that the Bat tuned LFC regulator improves the overall dynamics and steady state conditions of the power system.

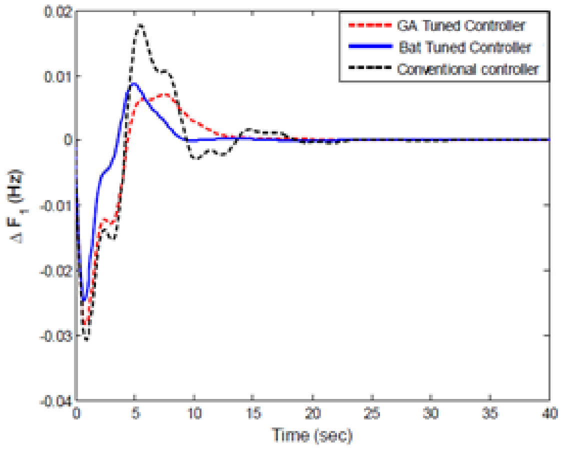

Fig.5. Dynamic performance of area-1 after disturbance in area-1.

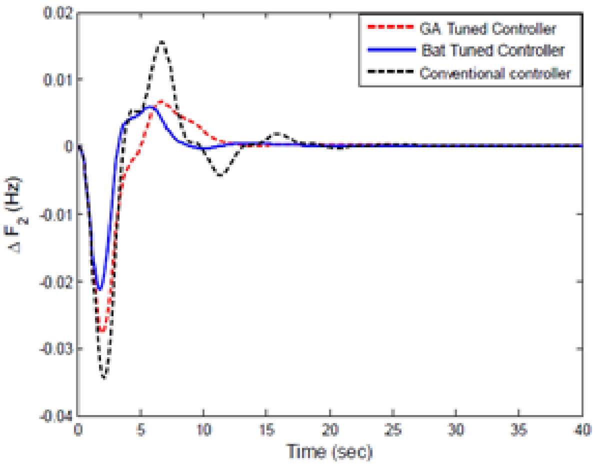

Fig. 6. Dynamic performance of area-2 post disturbance in area-1.

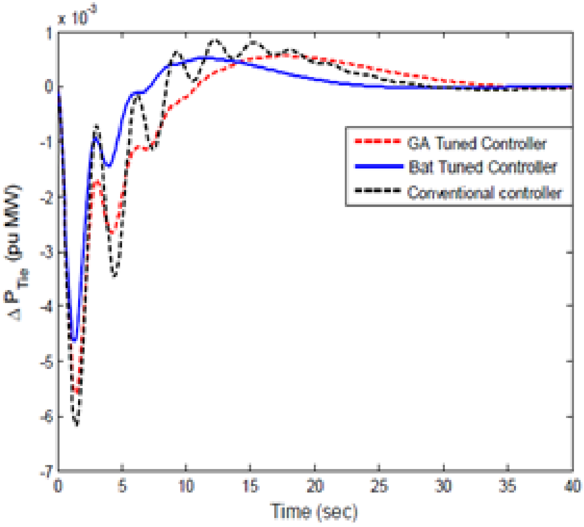

Fig. 7. Dynamic performance of tie-line power post disturbance in area-1.

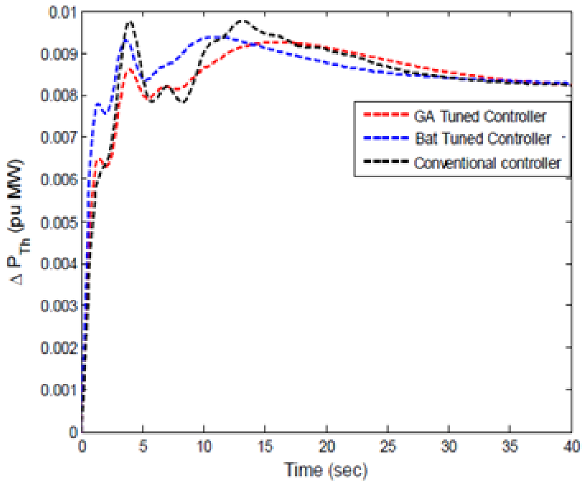

Fig. 8. Thermal power plant output for 1% load perturbation in area-1.

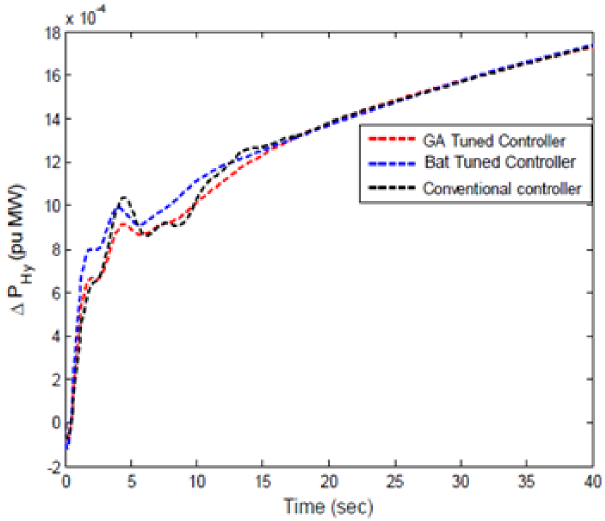

Fig. 9. Hydro power plant output for 1% load perturbation in area-1.

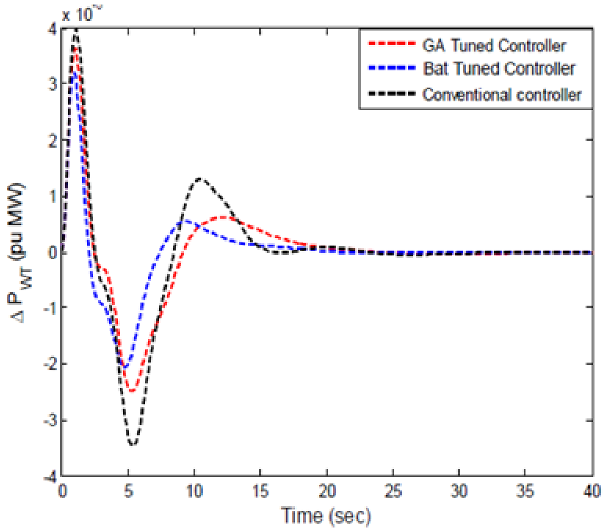

Fig. 10. Wind power plant output for 1% load perturbation in area-1.

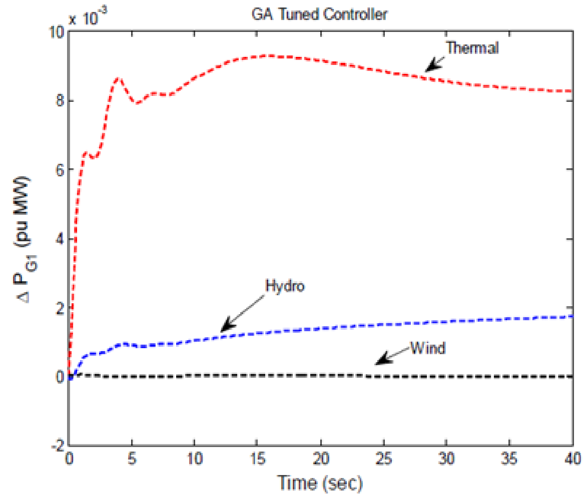

Fig. 11. Change in generation in area-1 for 1% load perturbation in area-1.

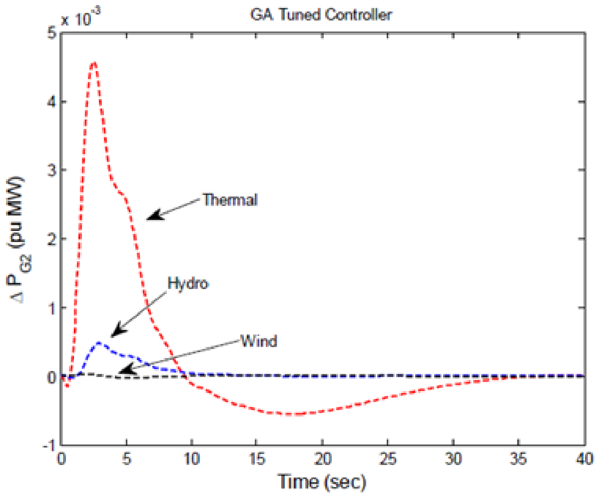

Fig. 12. Change in generation in area-2 for 1% load perturbation in area-1.

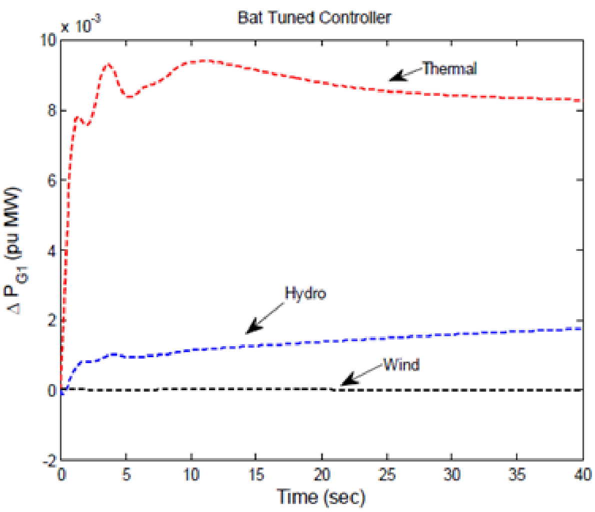

Fig. 13. Total power output in area-1 for 1% load perturbation in area-1.

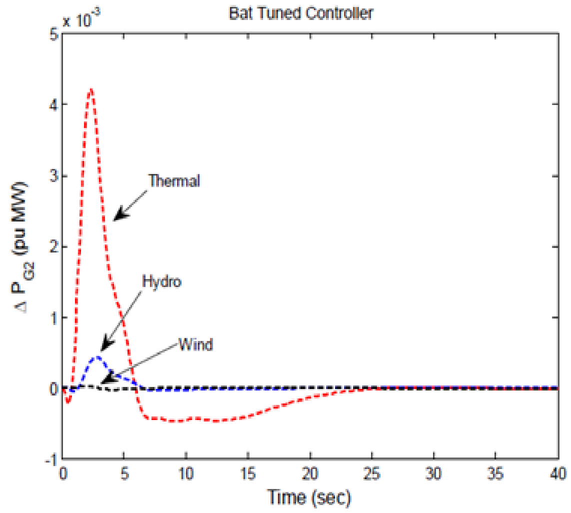

Fig. 14. Total power output in area-2 for 1% load perturbation in area-1.

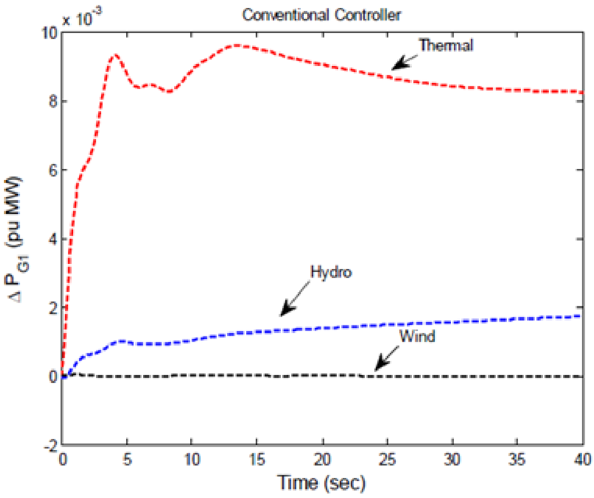

Fig. 15. Total power output in area-1for 1% load perturbation in area-1.

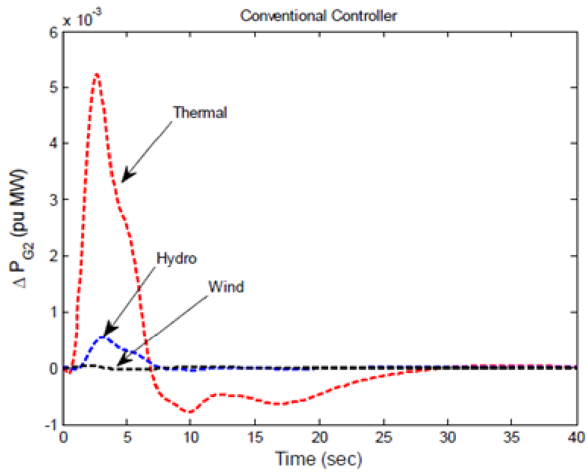

Fig. 16. Total power output in area-2 post 1% load perturbation in area-1.

4. CONCLUSION

LFC has become more significant today with the increasing size and complexity of power systems. The control techniques can be used to design centralized LFC schemes for these systems for their successful operation in the wake of load perturbations.

In this paper Bat tuned LFC controller is implemented for the two area multi-source interconnected power system model and results are compared with GA and conventional tuned LFC controller. Only area-1 is disturbed with 1% increase in load demand and effect on the power system dynamics is observed for Bat, GA and conventional load frequency controller. Since the disturbance has local dominant nature which is transferred to non-disturbed areas via weak tie-line between the interconnected control area. From investigation it is revealed that the performance of the system improves remarkably with Bat tuned load frequency controller comparatively to conventional and GA tuned load frequency controller. The performance indices of the load frequency controller also increase remarkably in case of optimum gains obtained by Bat algorithm method.

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Appendix I
System Data

Load (MW)	Generation (MW)			Share of Power Generation			Regulation Hz/pu MW			Pri (MW)	KPi	TPi (Sec)	βi (pu W/Hz)
	Thermal	Hydro	Gas	Kti	Khi	Kgi	Rti	Rhi	Rgi				
900	300	300	300	1/3	1/3	1/3	2.4	2.4	2.4	2000	133.33	22.22	0.4242
1000	400	300	300	2/5	3/10	3/10	2.4	2.4	2.4	2000	120	20	0.4250
1100	500	300	300	5/11	3/11	3/11	2.4	2.4	2.4	2000	109.09	18.18	0.4258
1200	600	300	300	1/2	1/4	1/4	2.4	2.4	2.4	2000	100	16.67	0.4267