ANALYSIS OF MULTI OBJECTIVE LOAD FREQUENCY CONTROL USING CUCKOO SEARCH ALGORITHM FOR A CONTROLLED CASE

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Abstract

The present work focus on multi-objective frequency controller to regulate operating frequency by controlling the governor settings. The proposed controller has to restore the frequency deviation within limits in a short span of time period, since interconnected power system has many frequency dependant loads. However, the proposed controller aimed at minimum peak overshoot and shortest settling time. A multi objective function was created by considering these dynamic response specifications. The potential of soft computing methodologies is used to optimize the objective function. To test the superiority of Cuckoo Search optimization (CS) algorithm, different observation sets are generated. The proposed optimizing algorithm performs better and reasonably maintains good equilibrium between frequency changes and transient oscillations.

Keywords: Transient response; PID constants; Automatic load frequency control (ALFC); cuckoo search algorithm (CS); Bacteria foraging optimization (BFO).

1. INTRODUCTION

In a power plant, the potential energy of fuels is transformed into either mechanical or heat energy. As electrical grid has no structural way to store energy, it is needed to maintain equilibrium between generation and power absorbed by load every instant. Naturally some energy is stored in the inertia of large generators, compensates these load changes. If violations are beyond the restrictive limits, leads to voltage agitations, large frequency variations and electromechanical oscillations. If corrective measures are not procured in right time then system may collapse, resulting in widespread blackouts. In this context, automation is the only approach to determine and activate these measures via the control of the generators [1].

In the operation and control of power system, Automatic Generation Control (AGC) place crucial role in maintaining balance in system. Mainly AGC has two control loops such as Automatic Load Frequency Control (ALFC) and Automatic Voltage Regulator (AVR). Thus, excitation control of the generator maintains voltage and removal of power difference between generation and load maintained by frequency control. Though loads are dynamic in nature, but their variations are comparatively sluggish. The controllers present in the system are set at an operating point and they take care of minute changes in demand without exceeding the limits of frequency and voltage. The controller gains have to be reset either manually or automatically if the changes in load demand increases drastically. Mainly ALFC, focus to offer reduced steady state frequency deviation, better damping to frequency oscillations and further reducing overshoot of frequency fluctuations to maintain stability. This is achieved by conventional controllers like Proportional–Integral (PI) and Proportional–Integral-Derivative (PID) controllers [2]. Since the system load is never steady these conventional controllers cannot sustain more due to their lack of efficiency. Therefore, this motivates the researchers towards the techniques like artificial intelligence in order to have better transient response with respect to conventional controllers.

The present work explores the potential of using soft computing techniques in controllers and their advantages over conventional methods. Most popular controller used in industrial applications is PID controller. So, it requires efficient and effective methods to control the different parameters of the plant. Now-a-days evolutionary algorithm exhibits their prominent place to resolve complex optimization problems. For an interconnected power system, PID controller gains are tuned using Genetic Algorithm (GA) [3].

Bacteria Foraging Optimization algorithm (BFOA) is one of the leading algorithms used by research scholars for its potentiality in resolving day to day world optimization problems. BFOA is employed to find the optimal controller parameters to mitigate oscillations in ALFC. The performance of PI controller is assessed by BFO algorithm with respect to conventional controller and Genetic Algorithm. BFOA is giving superior results compared to others over wide range of parameter variations [4-5]. Cuckoo Search (CS) is the advanced nature-inspired met heuristic algorithms, developed by Xin-She Yang and Suash Deb. Latest literature proves that CS algorithm is more potential than Particle Swarm Optimization (PSO) and GA. Hence, the CS optimization algorithm has been implemented to solve the LFC optimization problem [6-8].

2. ALFC PROBLEM IN SINGLE AREA SYSTEM

Automatic Load Frequency Control (ALFC) acts as an additional provision to balance change in energy and frequency for a short duration in power system to have better exchange conditions towards load and generation side. Load Frequency mainly aims at:

- Acceptable frequency deviation within limits.
- Receiving the traces of changes in load.
- Retaining minimum overshoot of frequency deviation.
- Minimum time required to settle in an acceptable error band.

A change of load power (ΔPL) in single area interconnected power system generates difference between generation and demand. Initially the challenge can be resolved by kinetic energy withdrawal from the system which results in declination of frequency. The system provides control action by means of introducing governor to set the equilibrium point. The speed of prime mover can be controlled by speed governor settings with reference to the load changes to maintain constant frequency is known as primary speed control function. The several control strategies are applied to the system if frequency variation is higher than the predetermined value is termed as secondary speed control function. Therefore, secondary control is carried after primary control with the help of conventional controllers. But these controllers have drawbacks like,

Frequency control requires provision of primary regulation and supplementary regulation as basic requirement. Primary regulation is provided through speed governors which respond to frequency changes by varying turbine outputs. Keeping governors free to operate in the entire frequency range enables smooth control of frequency fluctuations as well as security against grid disturbances.

- Very slow in operation.
- Cannot take care of nonlinearities like governor dead bands effects, generation rate constraints etc.,

To overcome these drawbacks, controller parameters has to be changed according to the changes in load. The controller action should ensure that, system have fast transient recovery and less overshoot in terms of dynamic response. Numerous algorithms dealt with problem of ALFC. But these have barriers like robust control, linear quadratic, pole shifting and variable structure which decrease their execution [6]. To overcome these complications, Evolutionary Algorithms (EA) like, Genetic Algorithm (GA), Bacteria Foraging (BFO), Ant Colony (ACO) and Particle Swarm Optimization (PSO) are dealt with LFC design. Effectiveness of these algorithms suffers from low convergence and frail local search ability, which make them snare in the local minimum. Latest EA, Cuckoo Search(CS)explores search space efficiently on global scale with the help of levy flights rather than random walks. The paper suggests effectiveness of cuckoo algorithm for optimal tuning of controller gains in ALFC problem under controlled case.

3. CUCKOO OPTIMIZATION ALGORITHM FOR TUNING CONTROLLER PARAMETERS

Cuckoo search algorithm is used to optimize the gain constants of PID controller for a single area controlled power system. The optimum values are directly related in minimization of objective function performance index [3]. Therefore, present work is focus on optimizing controller gain constants using optimization algorithms. Initialization of control parameters is done for the proposed optimization problem by selecting the number of host nests, n = 100, levy flight random walk step size, α = 1.5, probability of discovery rate, P_a = 0.25 and number of iterations=50 as control variables. During each iteration, quality of eggs (J) is calculated for corresponding nest values (K_p, K_i and K_d). In each iteration, better nests are generated after elimination of worst nests and new nests (updated K_p, K_i and $K_d$values) are generated based on levy flight random walk. The search for best nest (optimum K_p, K_i and K_d) is proceeded until the maximum number of iterations is met. The cuckoo search algorithm is summarized using pseudo code given below:

*Begin

*Objective function F(X) where X = { x_1 , x_2, x_3, ………. x_n}

Create initial random population of *n* nests with different solutions.

Set the lower and upper limits for the constraints of PID controller gains.

While (*t* < Maximum iterations) & (termination criteria not yet reached)

Obtain cuckoos randomly using levy flights X_{New}

Based on objective function evaluate the fitness value(F_{new}).

Get a nest from random population X_j.

If f(X_{New})< f(X_j), then Xj = X_{New}

Nests with worse solution i;e f(x) > P_a is abandoned

Rate of New nests created at new location = Rate of nests abandoned

By keeping quality solution, current best solution is evaluated.

End while condition

Post optimization process and produce results

*End

K_{PS}, K_T	Power system gain , Turbine gain
K_{SG} , T_{PS}	Speed governor gain , Time constant of power system
T_T , T_{SG}	Time constant of turbine , Time constant of speed governor
ΔP_C , ΔF	Change in speed changer, Change in frequency
R	Speed regulation of governor

4. SYSTEM UNDER INVESTIGATION

ALFC under investigation consists of generator, turbine and governor. Determination of frequency change calculation is carried using simulation with MATLAB software package. The parameters of the system under study are listed in the appendix. The transfer functions of ALFC blocks under system are given below:

Generator transfer function:

$$P(s) = \frac{Kps}{1+STps} \quad \text{-----(1)}$$

Turbine transfer function:

$$T(s) = \frac{Kt}{1+STt}$$ --(2)

Speed governor transfer function:

$$G(s) = \frac{Ksg}{1+STsg}$$ ---(3)

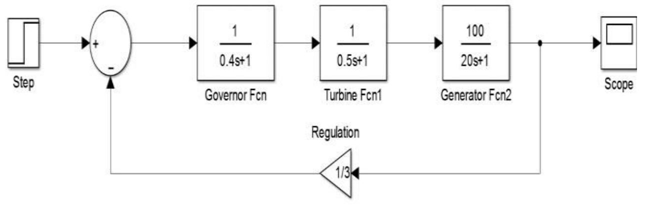


Fig 4.1. Block diagram of ALFC without PID controller

The open loop transfer function without droop characteristics of ALFC is given below:

$$\frac{\Delta f(s)}{\Delta Pc(s)} = \frac{KsgKpsKt}{(1+STps)(1+STt)(1+STsg)}$$ ---------------------------(4)

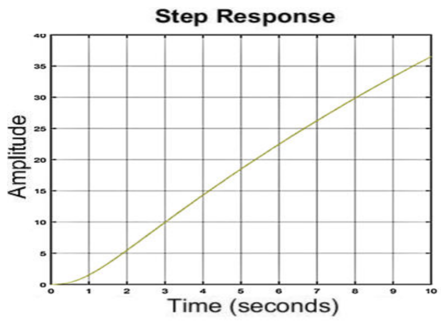


Fig 4.2. Open loop response of LFC

The closed transfer function with droop characteristics of ALFC is:

$$\frac{\Delta f(s)}{\Delta Pc(s)} = \frac{RKsgKpsKt}{R(1+STps)(1+STt)(1+STsg)+KpsKsgKt}$$ ------------(5)

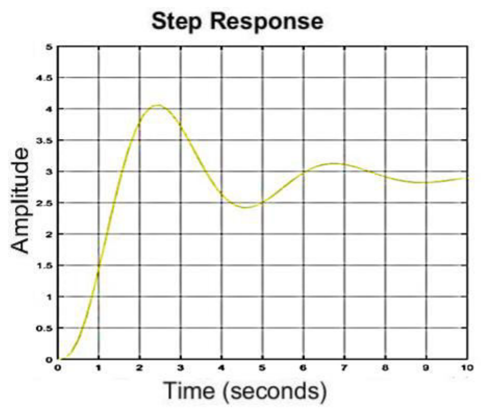


Fig 4.3. Closed loop response of LFC

The simulation of open loop and closed loop response undoubtedly illustrates that LFC with droop characteristics improves the performance of system by reducing the frequency deviation. But closed loop response depicts out the severity of transient response. Transient response is not appreciable in ALFC problem since frequency deviation directly affects the frequency dependant loads coupled to power system which in turn cause breakdown of system. Literature declares that PID controller ensures to overcome the drawbacks of closed loop response. The control signal of the PID controller is stated by the equation:

$$U(s) = \left(K_P + sK_D + \frac{K_I}{s}\right)$$ ------------------------------------(6)

The controller design point towards the determination of constants K_p(Proportional constant), K_i (Integral constant), and K_d(Derivative constant) meeting the required performance specifications. The performance of controller can be characterized based on different performance indices of the transient response. Mainly controller performance indices speak about error with respect to time and time taken to reach final value. The first and foremost step before going to optimize the controller parameters is choose the criteria to evaluate the fitness or objective function of the system. The controller performance indices(PI) are termed as PI1: Rise Time(t_r), PI2: Peak Overshoot (M_p), PI3: Settling Time(t_s), PI4: Steady State Error(E_{ss}), PI5: IAE (Integral Absolute Error), PI6: ISE (Integral Square Error), PI7: ITAE (Integral Time Absolute Error), PI8: ITSE (Integral Time Square Error).Since controller has many performance indices, few of them can be combined to from objective function (F). Generally, it can be given as set of performance indices with weighted sum.

$$F(i) = \text{minimize } (\sum \Phi(i)PI)$$ -----------------------------(7)

Where objective function vectors given as,

$$PI = [PI1 \;\; PI2 \;\; PI3 \;\; PI4 \;\; PI5 \;\; PI6 \;\; PI7 \;\; PI8]^T$$

$\Phi(i)$ = [Φ_1 Φ_2 Φ_3 Φ_4 Φ_5 Φ_6 $\Phi_7\Phi_8$] vector weights [10].Since objective function framed comprises of multiple and conflicting objectives it can be termed as multi-objective fitness function. Mainly optimization problem aims to provide best solution while compromising these conflicting objectives. The objective function addressed in this paper is PI1: rise time to measure the response of system, PI2: overshoot to measure the oscillation, PI3: settling time to measure the performance of the closed loop system and PI4: minimum error deviation. Vector weights are given as:

$$\Phi(1) = [(-e^{-\beta})(1-e^{-\beta})(e^{-\beta})(1-e^{-\beta}) \;\; 0\;0\;0\;0]$$ ------(8)

$$F(1) = e^{-\beta}(ts - tr) + (1 - e^{-\beta})(Mp + Ess)$$ ----(9)

To prove the superiority of the objective framed in the paper, other indices like IAE, ISE and ITAE also considered [11-13]. IAE and ISE minimization results in reduced peak overshoot response and long settling time because these indices weighs equally all errors irrespective of time. This long settling time can be overcome by using ITAE, where errors are weighted by their time. IAE, ISE and ITAE performance equations are termed as:

$$ISE = \lim_{t\to\infty} \int_0^t e(t)^2 dt$$ --------------------------------(10)

$$IAE = \lim_{t\to\infty} \int_0^t e(t)dt$$ ----------------------------------(11)

$$ITAE = \lim_{t\to\infty} \int_0^t te(t)dt$$ -------------------------------(12)

$\Phi(2) = [0\ 0\ 0\ 0\ \ 1\ 1\ 0\ 0]$ ---------------------------------(13)

$F(2) = ISE + IAE$---(14)

$\Phi(3) = [0\ 0\ 0\ 0\ \ 1\ 1\ 1\ 0]$ ----------------------------------(15)

$F(3) = ISE + IAE + ITAE$--------------------------------(16)

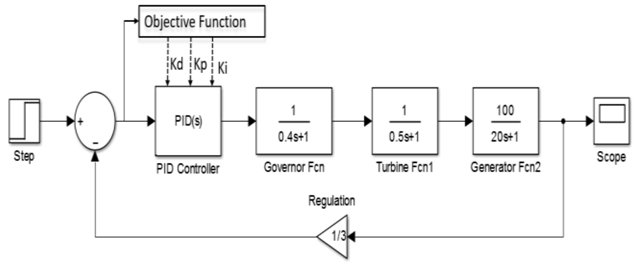


Fig 4.4. Block diagram of alfc with pid controller

5. RESULTS & DISCUSSIONS

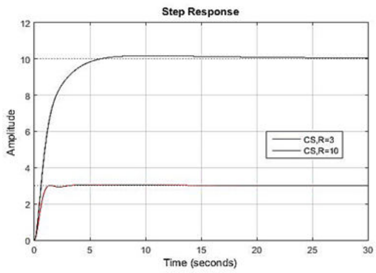
To analyse the effectiveness of the proposed Cuckoo Search (CS) method for ALFC problem, various cases are scrutinized in optimizing PID controller parameter gains. The goal behind optimization is to quest for the optimal controller gains with better transient response. The proposed CS, BFO algorithms are programmed in MATLAB with I5 processor and 8GB RAM. The results obtained are best for CS, BFO algorithms based on objective function OF.

Case 1: Effect of change in speed regulation

In this case, effect of speed regulation is analysed by varying from 3 to 10%. The frequency deviation of single area system is shown in Fig: 5.1& 5.2. From these, it can be observed that oscillations are mitigated with proposed optimization algorithm. Moreover, the proposed algorithm outpaces the BFO in damping oscillations efficiently and reducing the maximum peak overshoot. Hence compared to BFO, PID based CS enhance the stability of system and improves the transient characteristics.

The transient specifications of single area system under different regulation conditions are shown in Table:1.It is observed that rise time and settling time associated with 3% regulation is small compared with 10% regulation, outpace with respect to steady state error and peak overshoot. The Steady State error reduced by 63.64% with increased regulation in both CS and BFO algorithms.

Fig 5.1. Effect of speed regulation with CS



Case 2: Effect of change in β

To analyse the predominance of proposed controller, objective function value is considered as performance index with respect to change in β. It is noteworthy that lower the objective function value, better the transient response of the system. Maximum peak overshoot value plays vital role when compared to other transient specifications especially in the study of load frequency applications. Peak overshoot is directly proportional to frequency fluctuation in the power system. Therefore, extreme deviation will affect the frequency dependant loads coupled to system leads to unstable condition. At a point of time it may lead to power system breakdown. The maximum frequency deviation of single area system under different β values are shown in Table: 1. it is clear that frequency deviation associated with CS is smaller one compared with BFO. As β varied from 0.5 to 1, frequency deviation 4 to 9% decrease associated with CS and exhibit contrary with BFO by increasing from 4.5 to 6%. Due to high value of M_p in BFO, performance index value of objective function also beats BFO. The performance indices of CS, BFO under different β values are shown in Table: 1.the frequency deviation with respect to change in β value is illustrated in Fig 5.3 &5.4.

Table: 1 Performance indices values of objective function F1

			M_P	(E_{SS})	(T_s)	(T_r)	(F)
CS	R= 3%	β = 0.5	1.97	0.250	2.36	0.75	1.85
		β = 1	1.89	0.250	1.12	0.74	1.49
	R=10%	β = 0.5	1.75	0.090	4.84	2.72	2.01
		β = 1	1.58	0.090	4.51	2.49	1.79
BFO	R = 3%	β = 0.5	47.4	0.250	2.83	0.15	20.39
		β = 1	49.84	0.250	2.32	0.16	32.46
	R=10%	β = 0.5	30.14	0.090	3.60	0.28	13.91
		β = 1	32.11	0.090	5.46	0.27	22.25

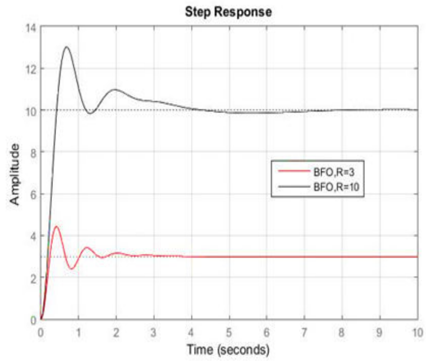


Fig 5.2. Effectof speed regulation with BFO

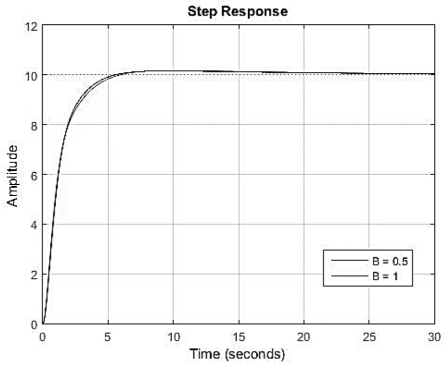


Fig 5.3. Effect of β on Frequency deviation when R=10% using CS

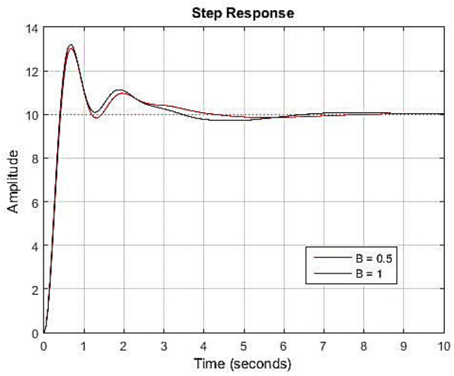


Fig 5.4. Effect of β on Frequency deviation when R=10% using BFO

Case 3: Investigation on controller and controller gains

Desired system performances, like fast response, zero steady state error and less overshoot are achieved through incorporation of P,I and D controller actions respectively. Normally PI controller increases the oscillations and frequency deviation which is not appreciable in load frequency control. Addition of D controller damps these oscillations and reduces frequency deviation which in turn improves the performance of system. To investigate controller efficiency for transient response, PI and PID controller structure was chosen in the work. Time domain specifications of both controllers are listed below Table: 2. It clearly states, with PID controller there is drastic fall of peak overshoot (i.e) frequency deviation compared to PI controller which is most desirable characteristics of load frequency control issue. Therefore, system performance depends on proper choice of controller structure. Response of PI and PID controller on the system is shown in Fig:5.5.

Table:2 Time domain specifications of different controllers

	PI controller	**PID controller**
Rise time	0.32	0.75
Overshoot	22.85	1.97
Settling time	1.88	2.36
Steady state error	0.25	0.25

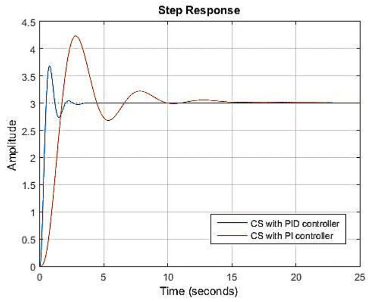


Fig 5.5. Response of PI & PID controller using Cuckoo Search algorithm

As controller parameter gains are tuned by optimization algorithm, effectiveness of algorithm can be investigated from these. Controller gains play vital role in terms of stability of system under study. Control theory says that, higher the gain values, system is prone to instability. So, minimum and maximum limits of the controller gains are chosen as [0.1 10] in the present work. It is observed from Table:3, that optimized gains of controller are high in BFO compared to CS.

Table:3 PID Controller gains of different algorithms

		K_P	K_I	K_d
CS	R = 3%	1.03	0.10	0.93
	R = 10%	1.47	0.10	1.33
BFO	R = 3%	5.49	5.62	5.33
	R = 10%	10.00	9.03	10.00

Case 4: Investigation on objective function

Objective function can be validated by its quality of solution. To analyse the superiority of objective function F1outlinedin the paper is compared with different objective functions which are taken from other literatures [10 -12].

$$F1 = \left(1 - e^{-\beta}\right)(Mp + Ess) + e^{-\beta}(ts - tr)$$

$$F2 = ISE + IAE$$

$$F3 = ISE + IAE + ITAE$$

Time domain specifications are given in the Table: 4 for all objective functions. It clearly shows that objective function F1 performance dominate the other two objective functions with respect to peak overshoot and controller gains. Performance of PID controller for different objective function is depicted in the Fig: 5.6, 5.7, and 5.8. Therefore, objective function F1 is best suited for load frequency control problems.

Table:4 Performance indices of objective functions with PID controller

		M_P	(E_{SS})	(T_s)	(T_r)
CS	*F1*	1.97	0.250	2.36
	F2	17.06	0.250	1.92
	F3	22.85	0.250	1.88
BFO	*F1*	47.46	0.250	2.83

	F2	60.24	0.250	2.50
	F3	61.524	0.250	2.06

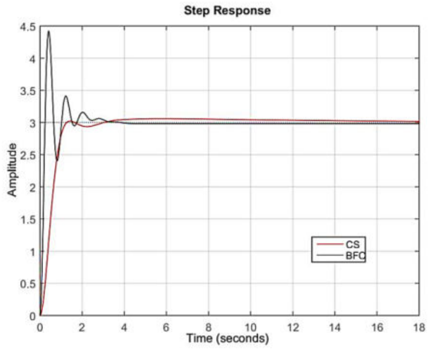


Fig: 5.6 Response of Objective function F1 with time domain specifications

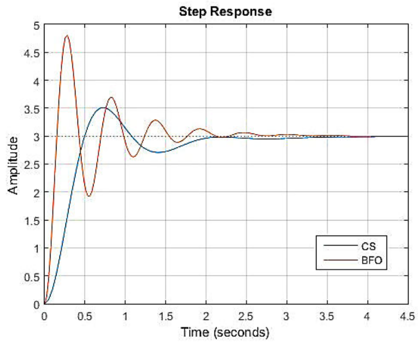


Fig: 5.7 Response of Objective function F2 with IAE & ISE

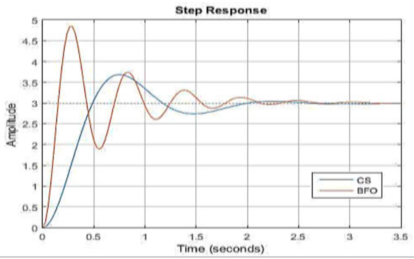


Fig:5.8 Response of Objective function F3 with IAE, ISE and ITAE

6. CONCLUSION

In real time load variations are dynamic in nature. Accordingly, the generation has to be set to meet demand. Disparity between load and generation directly relates to change in frequency of the system. ALFC is a closed loop feedback system responds to change in frequency by varying the control valve lift of governor and further varying the generation based on droop characteristics. This mode of operation is known as controlled case or free governor mode of operation. Stability of grid is improved when more number of units is operating under controlled mode.

A controller can further enhance the stability providing damping to frequency variations. Many research articles carried automatic load frequency control using PI controller. But PI controller suffers with high frequency variations. Results shows that PID controller provides high damping to these variations with reference to Table: 2. Therefore, a single area power system with intelligent PID controller under controlled case is studied using cuckoo search optimization algorithm. Optimization algorithm tune the controller gains and satisfies the goal of objective function. An objective function framed with respect to time domain specifications and compared with output tracking performance indices like IAE, ISE, and ITAE etc. To analyse the superiority of objective function framed is tested with CS and BFO optimization algorithms.

The simulation carried emphasis that CS optimization algorithm provides outstanding damping to frequency deviations over BFO. As magnitude of controller gains are directly related to stability of system CS afford best controller gains over BFO. Therefore, cuckoo search algorithm is best suited for automatic load frequency control problems. Multi area power system can be analysed with same objective function as a part of future scope.

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