Enhancing load frequency control of multi-area multi-sources power system with renewable units and including nonlinearities using cuckoo search algorithm

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Abstract

A new optimization technique called Cuckoo Search (CS) algorithm for optimum tuning of PI controllers for Load Frequency Control (LFC) is suggested in this paper.The foremost aims of the Load Frequency Control (LFC) is to maintain the frequency at nominal value and minimize the unscheduled tie line power flow between different control areas. The penetration of renewable energy sources into the grid is a recent challenge to the power system operators due to their different modelling rather than conventional units. In this paper, enhancing load frequency control of multi-area multi-sources power system with nonlinearities including renewable units is proposed using a new application of proportional–integral–derivative controller with proportional controller in the inner feedback loop, which is called as PID-P controller. To investigate the performance of the proposed controller, a thermal with reheater, hydro, wind and diesel power generation units with physical constraints such as governor dead band, generation rate constraint, time delay and boiler dynamics are considered. The proposed controller parameters are optimized using different heuristic optimization techniques such: Linearized Biogeography-Based Optimization technique, Biogeography-Based Optimization technique and Genetic Algorithm. The ability of the system to handle the large variation in load conditions, time delay, participation factors, and system parameters has been verified comprehensively. Simulation results are introduced to show the enhanced performance of the developed CS based controllers in comparison with Genetic Algorithm (GA), Linearized Biogeography-Based Optimization and conventional integral controller. These results denote that the proposed controllers offer better performance over others in terms of settling times and various indices.

1. INTRODUCTION

LFC is established to act during small and slow changes in real power and frequency. In a controllable area, LFC monitors the system frequency and tie-line power flows, computes the total change in the required generation (referred to area control error ACE) and changes the set point of the generation units within the area to save the average time of the ACE at a small value. Therefore, ACE, which reflects the integration of power net-interchange and frequency deviation, is considered as the controlled output of LFC, as both tie-line power and frequency errors will be enforced to zero when the ACE is driven to zero by the action of LFC [1]. Generally, numerous studies [2-9] have been carried out to improve the performance of LFC schemes; starting from classical control systems to modern control theories. It was deduced that most of the conventional controllers perform adequately at an operating point at which the controllers are designed but their performance may be dramatically changed when there is a large change in the operating point or system parameters [10]. Thus, hybrid control structure can be regarded as one of the most promising solutions to solve such limitations as deduced in [11-13].

Many researchers have concluded that fuzzy logic controller as mentioned in can improve the closed loop performance of I/PI/PID controllers and handle any changes in operating point or in system parameters by online updating of the controller parameters [14]. In [15], the frequency stability of power systems has been improved by the participation of high-penetration of wind power in grid frequency control, with the account in mind the both area are identical and the nonlinearities has been neglegted. Moreover, it is also observed from different research studies that the performance of the power system does not only depend on the artificial techniques employed but also on the controller structure and objective fitness function. Recently, with the global trend toward the renewable resources, and with the ascending level of renewable energy units penetration into the grid, new research area is raised to test the performance of the different LFC schemes against different participation factors and system parameters. Therefore, authors believe that there is still much room for developing efficient LFC schemes. Thus, the main contribution of this paper is to validate the superiority of PID-P controller as a new application in the field of load frequency control of multi-area multi-sources power system in presence of both conventional and renewable units with taking into consideration the physical constraints and nonlinearities. The controller parameters have been optimized using several recent optimization algorithms: Genetic Algorithm (GA), Biogeography-Based Optimization (BBO) and Linearized Biogeography-Based Optimization technique (LBBO) techniques while the integral time multiplied absolute error (ITAE) is the objective function. To examine the roubstness of the proposed controller, a thermal with reheater, hydro, wind and diesel power generation units with physical constraints such as governor dead band (GDB), generation rate constraint (GRC), time delay and boiler dynamics are considered. System modeling is developed in MATLAB/SIMULINK environment.

this paper introduces a modern optimization algorithm called CS for the optimum tuning of PI controller parameters in LFC problem. The motivation behind this research is to ensure and prove the robustness of CS based PI, and to enhance the performance of frequency deviation and tie line power under various loading conditions in presence of system nonlinearities.

II.System modelling

As a matter of fact, PID controller is widely used due to its simplicity and robustness. On the other hand, it is inherently difficult to control the integrating process within it efficiently [16]. In [17], a PID-P controller has been proposed to overcome the structural limitation of PID controller in controlling integrating and unstable process. The structure of PID-P controller is illustrated in [10]. For such structure, an inner feedback loop with P controller is used to convert the unstable open loop or integrating process to open loop stable process, and then the PID controller can control the overall open loop stable process. To validate the capabilities of the optimized PID-P controller, two unequal areas with conventional and renewable units including nonlinearities are considered as shown in Figure 1. Area-1 consists of reheat thermal, hydro and wind power plants while area-2 consists of reheat thermal, hydro and diesel power plants.

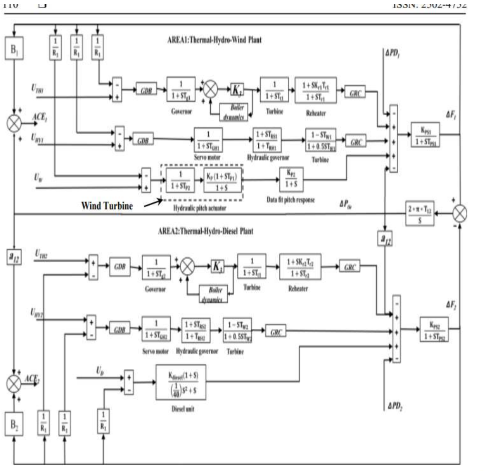


Figure 1. Transfer function model of multi-area multi-source power system with nonlinearities

The constraints that affect the power system performance such as generation rate constraint (GRC), governor dead band (GDB) and time delay are also included. Besides, boiler dynamics configuration is considered in thermal plants to generate steam under pressure where changes in the steam flow and deviations in pressure are sensed and the turbine control valves and boiler control introduce the resultant action. Furthermore, reheat turbine is included in this study as an effective nonlinearity. The block diagram of boiler dynamics configurations .

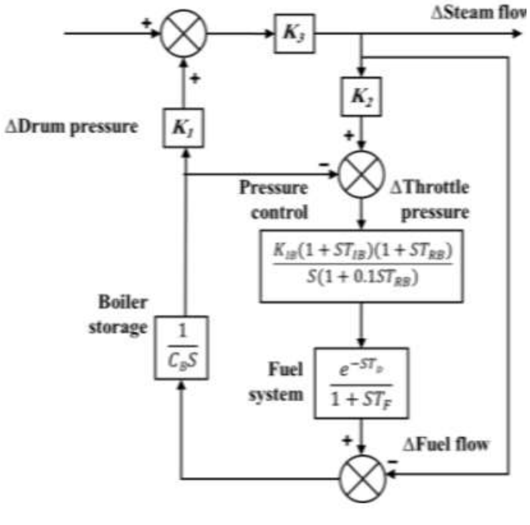


Figure 2. Transfer function model of boiler dynamics

It is worth mentioning that most of the published research studies didn't take into consideration the impact of all physical constraints and nonlinearities mentioned before. For example, in [19, 20] the effect of delay time in the system performance has been neglected, while in [21], the physical constraints and nonlinearities have been completely ignored. In [22], only reheat turbine as nonlinearity has been included. In [23], only GRC as a physical constraint has been considered while in [12], the effect of GRC and GDB has been investigated. In [24], the effect of reheat turbine, GRC and delay time has been studied without consideration of other nonlinearities and physical constraints. It is worthy to say that combining of all aforementioned physical constraints and nonlinearities may be considered a new area of research bearing in mind renewable energy resources. It is noteworthy that the participation factors for different plants are assumed as in [18]. So, factors of 0.575 and 0.3 are assigned to thermal and hydro plants respectively while a factor of 0.125 is considered for both wind and diesel units. In the present investigation, a dead band nonlinearity of 0.05% is considered for the thermal plant and 0.02% for the hydro plant. A GRC of 3% per minute is considered for thermal units while considering 270% per minute for the hydro unit to raising generation and 360% per minute to lowering generation [18]. As well, to measure the reliability, efficiency, and robustness of the optimized PID-P controller implemented in the LFC scheme of the proposed power system, five test procedures are applied.

III.Genetic Algorithms - Introduction

Genetic Algorithm (GA) is a search-based optimization technique based on the principles of **Genetics and Natural Selection**. It is frequently used to find optimal or near-optimal solutions to difficult problems which otherwise would take a lifetime to solve. It is frequently used to solve optimization problems, in research, and in machine learning.

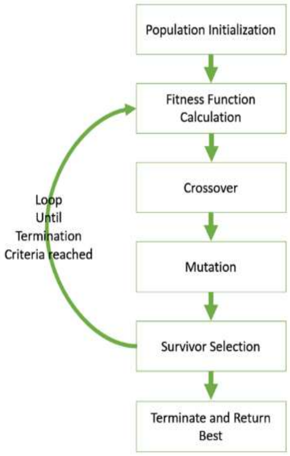
Introduction to Optimization

Optimization is the process of **making something better**. In any process, we have a set of inputs and a set of outputs as shown in the following figure.

Optimization refers to finding the values of inputs in such a way that we get the “best” output values. The definition of “best” varies from problem to problem, but in mathematical terms, it refers to maximizing or minimizing one or more objective functions, by varying the input parameters.

The set of all possible solutions or values which the inputs can take make up the search space. In this search space, lies a point or a set of points which gives the optimal solution. The aim of optimization is to find that point or set of points in the search space.Genetic Algorithms are sufficiently randomized in nature, but they perform much better than random local search (in which we just try various random solutions, keeping track of the best so far), as they exploit historical information as well.

Each of the following steps are covered as a separate chapter later in this tutorial.



IV.Biogeography-based optimization (BBO

Biogeography-based optimization (**BBO**) is an evolutionary algorithm (EA) that optimizes a function by stochastically and iteratively improving candidate solutions with regard to a given measure of quality, or fitness function. BBO belongs to the class of metaheuristics since it includes many variations, and since it does not make any assumptions about the problem and can therefore be applied to a wide class of problems.

BBO is typically used to optimize multidimensional real-valued functions, but it does not use the gradient of the function, which means that it does not require the function to be differentiable as required by classic optimization methods such as gradient descent and quasi-newton methods. BBO can therefore be used on discontinuous functions.

BBO optimizes a problem by maintaining a population of candidate solutions, and creating new candidate solutions by combining existing ones according to a simple formula. In this way the objective function is treated as a black box that merely provides a measure of quality given a candidate solution, and the function's gradient is not needed.

V.Linearized BBO (LBBO)

Linearized BBO (LBBO) with Local Search and Re-initialization This section introduces several new components to BBO. One drawback of BBO is that it treats each solution feature independently − that is, it is not rotationally invariant. This means that BBO generally performs poorly when applied to non-separable functions.

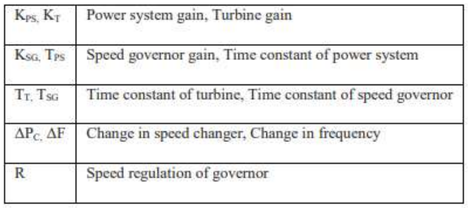
5.1 LBBO Migration For each solution, zk, the immigration rate λk is used to probabilistically decide whether to immigrate or not. If we decide to immigrate, κ emigrating solutions are probabilistically chosen using their emigration rates, where $\kappa \in [1, N]$ is a randomly-selected parameter.

5.2 Gradient Descent LBBO is augmented in this paper with several local search operators to improve its performance as it nears the global optimum. LBBO, like many EAs, is primarily intended for global search. It is therefore effective at finding the neighborhood of the global optimum, but has difficulty in homing in on the exact optimum.

Gradient descent algorithm: We implement boundary search in LBBO as follows. If any of the dimensions of the best individual in the population are within a certain threshold of the search space boundary, then we move that dimension to the search space boundary and perform local search (gradient descent) on the other dimensions.

CUCKOO OPTIMIZATION ALGORITHM

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, Pa = 0.25 and number of iterations=50 as control variables.



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

VI.Simulation results

. First Test Procedure: 1% Step Load Increase in Area-1

to investigate the dynamic performance of the selected controller, a step load increase of 1% is applied in area-1. The controller parameters are optimized using GA, BBO and LBBO and CSA as optimization techniques and (ITAE) as an objective function as discussed before. The system dynamic responses for the optimized PID-P controller for the two areas are shown in Figure 3. It is observed that the CSA tuned PID-P controller has the least settling time while the BBO tuned PID-P controller has the least overshoot where the absolute value of the peak is considered as an overshoot in this study regardless of its direction (overshoot or undershoot).

(b) Change in frequency of area-2, (c) Change in tie line power

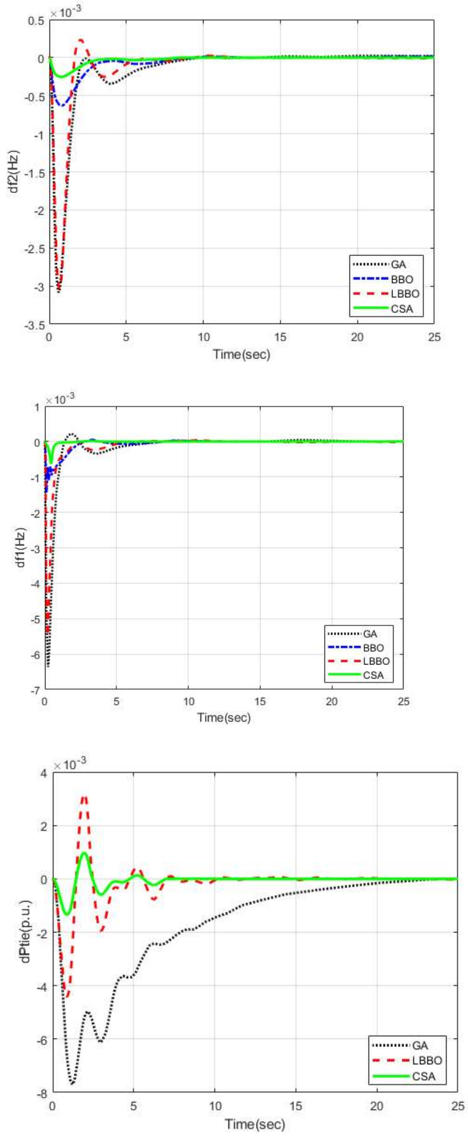
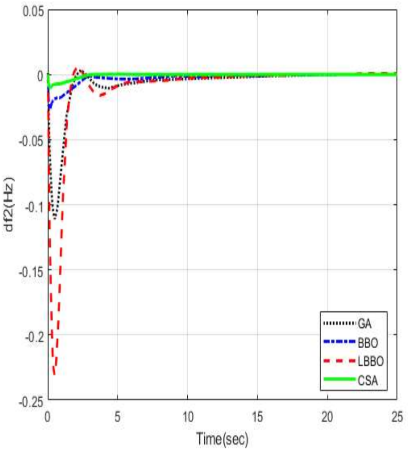
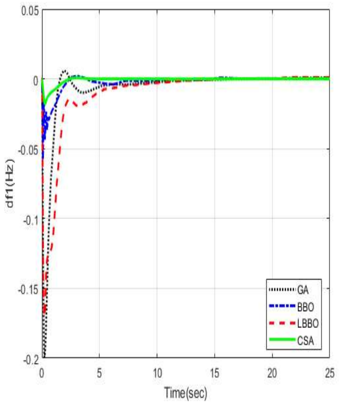


Figure 3. Test system performance for 1% step load increase in area-1, (a) Change in frequency of area-1, (b) Change in frequency of area-2, (c) Change in tie line power

Second Test Procedure:

30% Step Load Increase in Both Areas A very large step load increase of 30% in both areas is applied to confirm the superiority of PID-P controller to wide change in operating conditions. Figure 4 depicts the performance dynamics of PID-P controllers without re-tuning the controllers' parameters. Also, it can be deduced that the LBBO optimized PID-P controller has the best settling time while BBO optimized PID-P controller has the best overshoot.





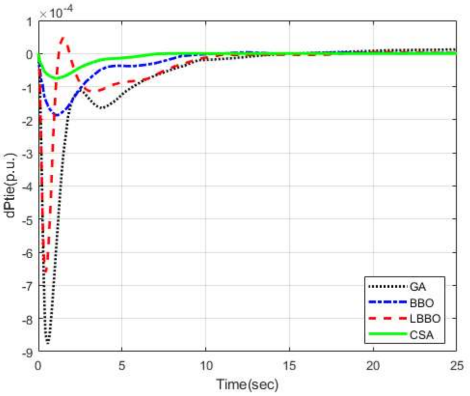


Figure 4. Test system performance for 30% step load increase in both areas, (a) Change in frequency of area-1,

3.3. Third Test Procedure:

Sensitivity Analysis The sensitivity analysis is carried out to investigate the ability of the controller to handle wide changes in operating conditions and system parameters without retuning the controller parameters. Taking one at a time, the operating load conditions, GRC,RH, TGH, TRS, TT and R vary with ±25% from their nominal values. It is observed that, the system is stable in all cases and the effect of the variation in operating loading conditions and system time constants on the system performance can be neglected. For GA tuned PID-P controller, the maximum increasing in settling time is 0.92 sec for 25% increasing in GRC while for BBO tuned PID-P is 1.3 sec for 25% decreasing in GRC. For LBBO tuned PID-P controller, the corresponding maximum increasing in settling time is 2.59 sec for 25% decreasing in droop characteristic R.

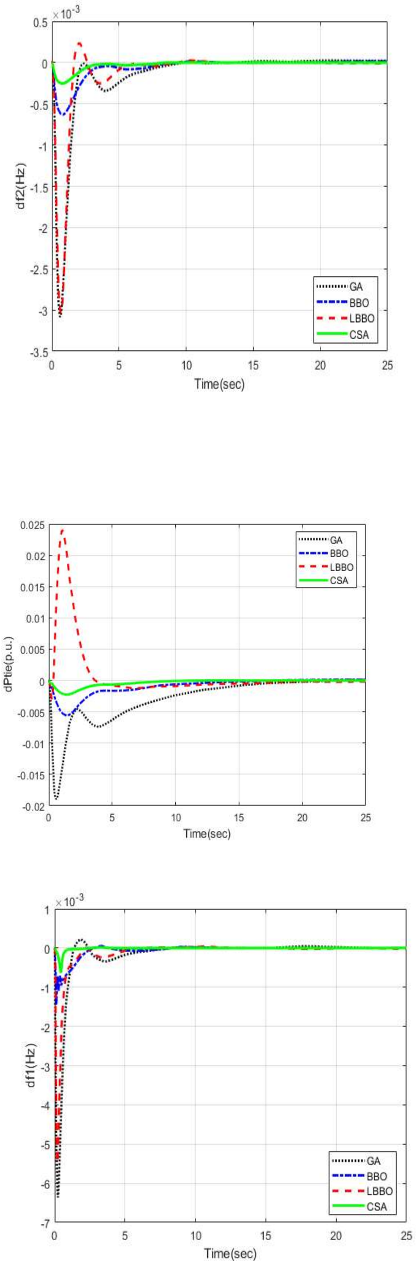
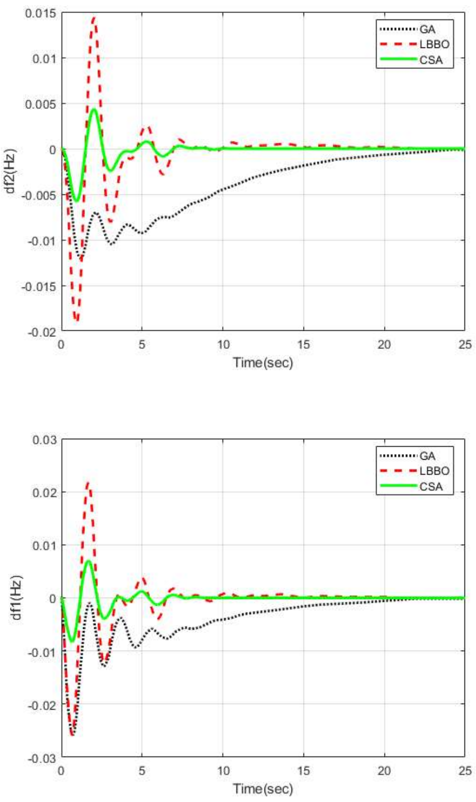


Figure 5. Test system performance for updated participation factors, (a) Change in frequency of area-1, (b) Change in frequency of area-2, (c) Change in tie line power

3.4. Fourth Test Procedure:

Changing Participation Factors' Values The performance of PID-P controller to wide change in participation factors without the need to re-tune the controller parameters is also investigated. To update the participation factors to the new values, two conditions are observed. The first one is that the participation factors must not be identical in the two areas and the second one is that the unit with the biggest participation factor must not be the same in the two areas. The updated participation factors for thermal, hydro and wind units in area-1 are changed to 0.3, 0.6, and 0.1 respectively while for thermal, hydro, diesel units in area-2 are assumed 0.7, 0.1, and 0.2 respectively. Then the dynamic performance of the proposed controller under such participation factors variation is tested as shown in Figure 5. It is obvious that the system has a stable performance with no need to re-optimize controller's parameters



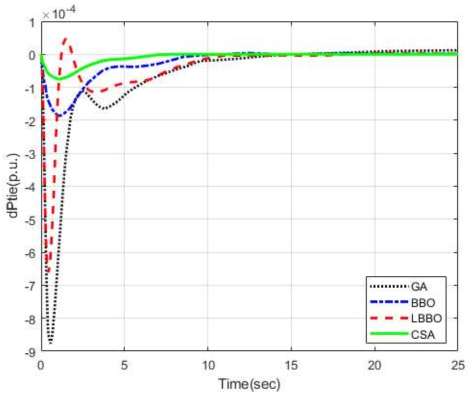


Figure 6. Test system performance for 0.5 sec delay time, (a) Change in frequency of area-1, (b) Change in frequency of area-2, (c) Change in tie line power

VII.Conclusion

CS algorithm is suggested in this paper to tune the parameters of PI controllers for LFC problem. In this paper, enhancing LFC of multi-area multi-sources power system including both renewable units and conventional units using a new application of PID-P controller is presented. Such LFC improvement takes into consideration the physical constraints and nonlinearities. The PID-P controller is evaluated for a multi-area multi-source including thermal with reheater, hydro, wind and diesel units. It is deduced that the PID-P controller has the same advantages of the PID controller plus the ability to overcome the PID controller structural limitation in the integration process by converting it to an open loop stable process via the internal feedback loop. Different test procedures, including wide changes in system parameters, load conditions, participation factors and time delay, are applied to examine LFC enhancement using optimized tuned PID-P controllers. It is clear that, the LBBO tuned PID-P controller achieves significant improvement of 71.87%, 69.2% and 24.04% in the settling time for the frequency deviation in area-1, area-2 and tie line power flow respectively in the presence of 0.01 p.u step load increase in area-1 as compared to DE optimized PIDD controller as a recent published controller for such system. As a future work the performance of the selected controller can be investigated in the presence of FACTS controllers such as TCSC (Thyristor Controlled Series Compensation) and UPFC(Unified Power Flow Controller) also it can be integrated to a hybrid control strategy with artificial intelligence based controllers such as fuzzy ,reinforcement and neural network controllers.

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