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Full Length Article

Non dominated Cuckoo search algorithm optimized controllers to improve the frequency regulation characteristics of wind thermal power system

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ABSTRACT

Controllers in some power system problems are required to satisfy different performance objectives, which could be conflicting with one another. Therefore in the process of their gain tuning, when the problem is formulated within an optimization framework, it becomes necessary to achieve multiple objectives with a method multi-objective optimization method. This work presents a new method of multi-objective optimization method to optimize several controller parameters. The problem deals with optimization of controllers of doubly fed induction generator modeled for frequency regulation in an interconnected two-area wind power integrated thermal power system. The gains of integral controller of automatic generation control loop and the proportional and derivative controllers of doubly fed induction generator inertial control loop are optimized in a coordinated manner by employing a multi-objective non-dominated sorting based Cuckoo search algorithm. The algorithm is formed by synthesizing the parallel searching abilities of Cuckoo search algorithm (CSA) with the non dominated sorting methodology adopted in Non dominated sorting genetic algorithm (NSGA-II). Based on the set of selected instances, the algorithm termed as non dominated sorting Cuckoo search (NSCS), exhibits better efficiency of optimization compared to the NSGA-II, CSA, genetic algorithm, and particle swarm optimization. The performance of the designed controller is further compared with the performance obtained with a modified version of NSCS, which includes the method of archiving in it. The designed set of controllers perform robustly even with the variation in disturbances, parameter and operating conditions in the system.

1. Introduction

As the power system operates in a stressed manner with varieties of constraints and depleting conventional resources, the capacity expansion policy has favored integration of renewable energy resources (RER) with conventional power grid. Recently, one of the promising alternative RERs has been the wind energy, using Wind energy conversion system (WECS). Among several of the operational issues of a WECS integrated system, the automatic generation control (AGC) of power system integrated with wind power has become an important aspect of study. Unlike conventional thermal power generators, the wind generators based on variable speed wind turbine (VSWT), respond differently to the variations in network frequency [1] because of the presence of power electronics converters. They have been depicted to participate in system frequency support [2], even though their speed remains decoupled from the grid frequency. VSWTs driving doubly fed induction generators (DFIGs) are designed to regulate their rotational speed in wide ranges by utilizing their stored rotational kinetic energy to provide short term active power support [3], when required.

With larger penetration of wind farms based on DFIG, the overall natural inertial response capability of the system may get compromised, as their power electronics converters decouple the natural dynamics between ΔP and Δf. However, an additional supplementary control mechanism in DFIG controllers can help in restoring the inertial response capability of the system [4–6]. In another approach [7], the research proposes to partially utilize the stored kinetic energy of WECS, and suggests communicating the response of WECS to the conventional units so that they balance the load sharing in a coordinated manner.

As the nature of responses of WECS and conventional generators are different, it is therefore necessary to design controllers

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for each of them so that a better frequency regulation capability can be derived without affecting the AGC controllers adversely. An efficient mean of gain and time constants tuning is required to achieve robust performance. The controller gains may be tuned efficiently in the domain of optimization. Recently, several intelligent techniques based on optimization like Genetic algorithm (GA) [8], Particle swarm optimization (PSO) [9], and Cuckoo search algorithm (CSA) [10] have been extensively utilized for optimizing varieties of non-linear and non-convex power system problems, including some problems in the field of AGC. Other nature inspired intelligent optimization methods like the Bacteria Foraging Optimization Algorithm (BFOA) [11], Imperialist Competitive Algorithm (ICA) [12], Differential Evolution (DE) algorithm [13] and Firefly Algorithm (FA) [14] have been extensively utilized for optimizing power system problems. Recently Teaching–learning based optimization (TLBO) algorithm [15], quasi-oppositional harmony search (HS) (QOHS) algorithm [16] are also applied for optimizing controller gains in AGC. The recent literatures focused on the performances of CS algorithm in various research areas of electrical engineering and its application [17–20]. Owing to some conflicting objectives in AGC, and the differences in the characteristics of WECS and thermal systems, a complex objective function with multiple objectives may have to be optimized using an multi objective optimization algorithm [21,22]. The non dominated sorting genetic algorithm (NSGA-II) [23,24], has been proven to give a more competent solution compared to some of the other single objective based optimization methods. However, the mutation strategies of the GA used in NSGA-II may still be improved, if more efficient evolution strategy could be utilized. In order to achieve a better evolving non dominated sorting based algorithm, this work primarily focuses on the following objectives.

i. To tune the controller parameters of AGC and the inertial control blocks of DFIG simultaneously in a coordinated manner, with the help of an efficient multi-objective optimization method. The proposed multi-objective optimization method is developed by combining the non dominated strategy of NSGA-II with the evolution principle of CSA. The new algorithm is termed as Non dominated sorting cuckoo search ($NSCS_1$).
ii. In the above algorithm of $NSCS_1$, the process of formation of niche and archives of non dominated solutions is included and the modified $NSCS_1$ is termed as $NSCS_2$. This version of the algorithm was first reported in the work [25], where it aims to solve some benchmark mathematical functions.
iii. To compare the optimization efficiencies of $NSCS_1$ and $NSCS_2$, with those of several intelligent technique based optimization algorithms i.e., NSGA-II, PSO, GA and CSA.

The widely accepted two area thermal system was considered as the test system, with penetration of wind power in each of the areas. The test system is explained in Section 2 along with the system model with its main components. Section 3 discusses about the objective function that is to be optimized, so that maximum benefit may be derived from the presence of DFIG based WECS in the system. A brief overview of different intelligent techniques is elaborated in Section 4, including the detail algorithm steps involved in $NSCS_1$ and $NSCS_2$. The simulation and results in section 5, evaluate the relative optimization efficiencies of $NSCS_1$ and $NSCS_2$ compared to the results obtained with NSGA-II and other algorithms mentioned above. Verifying, the results comparatively with other optimized controller performances, the proposed algorithm of $NSCS_2$ optimized DFIG controller is then tested for its performance in the given two area system. At the end, conclusions are presented in Section 6.

2. Two area thermal systems with DFIG based wind power generation

The linearized model for the load frequency control of two-area interconnected power system having both thermal and wind power resource is depicted in Fig. 1. As depicted in the figure, the generators for wind power in both the areas are DFIGs which can supply real power both via the stator and rotor of the induction generator. Further as depicted in Fig. 2, two back to back power electronics converters through a DC link capacitor help to establish interface between the rotor and stator. The converters enable to capture wind energy over a wide range of wind speeds following the scheme of maximum power point tracking (MPPT). Any intermittency of wind flow or disturbance in the grid is smoothened by the controllers for both the converters by suitable control of both active and reactive power outputs from them.It is well known that, large wind farms with numbers of wind turbines have a significant amount of kinetic energy stored in the rotating mass of their blades. For a given step change in the load ΔP_L, at a wind penetration level (Lp), the inertial contribution from the wind farm can be ramped up by increasing the power step beyond the steady state power setting. The controller of the grid side converter of DFIG can be set at this altered power setting to extract more rotational energy [26]. The methodology of the controller is elaborated here.

2.1. Inertial controller of DFIG

The rotational speed of a wind turbine driving a DFIG, is decoupled from the grid frequency by the grid side converter. Therefore, the DFIG does not naturally contribute to the inertia of the grid. To make the generator capable of having a frequency support capability by deriving additional active power from the kinetic energy of the turbine blades, an additional auxiliary signal is added as shown in Fig. 3. It can be seen from the figure that, the inertial controller of DFIG adds a signal defined in Eq. (1), to the reference power output that is tracked by the equivalent controller of the DFIG [27,28].

$$\mathrm{p_f^*} = -\mathrm{K_{df}}\frac{\mathrm{d}\Delta \mathrm{f}_0'}{\mathrm{dt}} - \mathrm{K_{pf}}\Delta \mathrm{f}_0' \qquad (1)$$

where K_{pf} and K_{df} are the proportionality constants of the frequency deviation and its derivative respectively.

When this controller is operational, the DFIG or its equivalent system recovers the optimal speed after the frequency transient is over. The constants K_{wp}, and K_{wi} of the PI controller should be properly chosen so that a fast speed recovery with lesser transient speed variation [7] can be achieved. The controller should also be able to avoid stalling of DFIG. When the system frequency restores to a new steady state that is slightly less than the nominal value, the frequency deviation is regulated by the load damping as well as generator's speed-droop effects. The washout block (see Fig. 3), avoids a longer period frequency support from the DFIG. Any steady state error in the frequency deviation can be eliminated by the integral controller (K_i) in the AGC loop. After the initial transient is over, the DFIG operates without having any frequency support capability. The values of all the time constants and the power limit of nonconventional generation considered in this work, are given in the Appendix (A.2).

3. Formulation of the objective function

For the success of any optimization problem, the suitable design of objective function is an important issue. There are many prevalent time domain based performance indices generally used for the purpose of the controller gain optimization in AGC. Four of them are Integral time square error (ITSE), Integral square error (ISE),