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NSGA-II based optimal control scheme of wind thermal power system for improvement of frequency regulation characteristics

S. Chaine, M. Tripathy *, S. Satpathy

Department of Electrical Engineering, Veer Surendra Sai University of Technology, Burla, Odisha 768018, India

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Abstract This work presents a methodology to optimize the controller parameters of doubly fed induction generator modeled for frequency regulation in 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 the multi-objective non-dominated sorting genetic algorithm-II. To reduce the numbers of optimization parameters, a sensitivity analysis is done to determine that the above mentioned three controller parameters are the most sensitive among the rest others. Non-dominated sorting genetic algorithm-II has depicted better efficiency of optimization compared to the linear programming, genetic algorithm, particle swarm optimization, and cuckoo search algorithm. The performance of the designed optimal controller exhibits robust performance even with the variation in penetration levels of wind energy, disturbances, parameter and operating conditions in the system.

1. Introduction

With ever increasing power demand and wide varieties of constraints the capacity expansion of existing power system has created the need of integrating Wind Energy Conversion Systems (WECS) with conventional power grid. Increasing levels of wind generation have resulted in an urgent need for the assessment of their impact on frequency control of power systems. As the penetration of the wind power into the grid increases, their contribution to ancillary services (e.g. voltage and frequency control) becomes more significant and new concerns in the performance of the primary frequency regulation system arise. To analyze the operational issues of the integrated system in a secure manner, research work in the area of Automatic Generation Control (AGC) of power system with considerable penetration of WECS becomes the key area of focus. Among different types of WECS, the more prevalent types based on variable speed wind turbine (VSWT), have

* Corresponding author. Tel.: +91 663 2430055.
E-mail addresses: sabitachaine@yahoo.com (S. Chaine), manish_tripathy@yahoo.co.in (M. Tripathy), satyajits880@gmail.com (S. Satpathy).
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power electronic interfaces which along with the pitch angle control enables their rotational speed to remain decoupled from the grid frequency. Unlike conventional thermal power based generators, wind farms respond differently to the variations in network frequency even though their capacity to ramp up/down real power generation maintaining reserve margin is always possible [1]. They have been depicted to participate in system frequency support [2], in the event of any such requirement. VSWTs driving Doubly Fed Induction Generators (DFIG) are designed to regulate their rotational speed in wider ranges by utilizing their stored rotational kinetic energy to facilitate short term active power support in the event of network frequency excursions [3].

With larger penetration of wind farms based on DFIG, the overall natural inertial response capability of the system reduces. This is due to the fact that the power electronics converters decouple the natural dynamics of $\Delta P \sim \Delta f$ that is found in the conventional generators. It prevents them from responding to the changes in system frequency. However, by introducing an additional supplementary control mechanism in DFIG controllers the inertial response capability of the system can be restored [4–7]. In [4], a proposed current controller facilitates inertial response from a DFIG-based system by providing pseudo-hidden inertia to the system. The work in [5], has tried to explore the possibility of providing greater leverage in the rotor speed variation so that considerably more kinetic energy available from the turbine-DFIG units may be utilized. Control strategies which incorporates additional network frequency dependent control signal in their structure, have been suggested in [6,7] to provide short-term frequency regulation. Further, work in [8] proposes to emulate the proportional control implemented in conventional generators to achieve primary frequency regulation. Similarly, work in [9], proposes a method, which not only modifies the inertial control scheme to partially utilize the stored kinetic energy of WECS, but also suggests the WECS response to be communicated to the conventional units so that they can take care of the load imbalance. The impact of different levels of wind penetration resulting in varying degrees of active power support from DFIG based wind farms, on its frequency response characteristics are analyzed in a two thermal area AGC [10].

Looking at the past research, it is therefore necessary to design efficient controllers of WECS, to achieve better frequency regulation of the integrated system without interfering with the performance of AGC controllers adversely. Therefore, the gains and time constants related to any controller could be properly tuned so that they exhibit consistency and robustness under different conditions. The process of tuning may be addressed in the domain of optimization, using any particular algorithm. During recent past, many intelligent technique based optimization techniques like Genetic Algorithm (GA) [11], Particle Swarm Optimization (PSO) [12], Cuckoo Search Algorithm (CSA) [13] and Linear Programming (LP) [14] have been extensively utilized for optimizing varieties of non-linear and non-convex power system problems, including the AGC [11,12]. However, looking at the conflicting natures of different types of objectives in AGC, and differences in the behavior of response of WECS and thermal systems, it may be beneficial to use a multi objective optimization algorithm [15,16]. The Non dominated Sorting Genetic Algorithm-II (NSGA-II) [15], was shown to give better efficiency compared to similar earlier versions and it has provided better solutions. In the view of above discussion, the objectives of the present paper are as follows.

(i) To propose a control scheme that can effectively extract the kinetic energy from DFIG, in order to prevent the initial frequency fall during load perturbation.
(ii) To tune the various controller parameters of AGC and the inertial control blocks of DFIG simultaneously in a coordinated manner, with the help of multi-objective optimization known as NSGA-II. A multi objective optimization may be necessary, since the controllers of DFIG and thermal units operate in different time frames of interest. The controller of DFIG is needed only for a transient period but the integral gains of AGC are required throughout the period of dynamics.
(iii) To compare the optimization efficiency of NSGA-II, with those of several conventional and intelligent techniques based optimization algorithms like, LP, PSO, GA and recently proposed CSA.

For the study, a two area thermal system with the penetration of wind power is considered. The work is organized as follows. In Section 2, a general overview of frequency control aspects of DFIG is discussed. Section 3 introduces the system model with its main components. Section 4 discusses about the objective function that is optimized to maximize the performance of the DFIG in the AGC. A brief overview of the intelligent techniques is elaborated in Section 5. The simulation and results obtained following several tests related to the performance of the DFIG controller are explained and analyzed in Section 6. At the end, conclusions are presented in Section 7.

2. Frequency control aspects of DFIG

The primary frequency control is implemented to compensate the imbalance between the real power load demand and generation in an interconnected power system. It has been a general practice, that the variable speed wind turbines are controlled to utilize the maximum power available from the wind energy. Therefore, any further increase in the generation of power is not possible, so that the DFIG can participate in the secondary control of frequency deviation, unlike the thermal units. However, the stored kinetic energy in the inertia of WECS could be utilized to provide a transient nature of primary frequency control in the interconnected system. Permanent active power controllability in WECS units can only be achieved by regulating either the pitch angle or the speed of the wind turbine. Different types of control methods are briefly reviewed in [17]. Proposed inertial control scheme allows the kinetic energy stored in the rotational masses to provide improved frequency support by the DFIG. The response of the later is also communicated to the conventional generators to help in coordinating their controls.

3. 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 highlighted in the figure the generators for wind power in both the areas