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Monitoring frequency control in the Turkish power system

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ABSTRACT

Frequency control is a key ancillary service for the secure and reliable operation of power systems, and especially in isolated power systems such as Turkey which is not yet synchronously connected to the UCTE European system. Frequency control has been defined in the Turkish power system as a mandatory remunerable ancillary service that is provided by generating units and managed by the system operator. This paper develops a centralized monitoring system of frequency that informs the System Operator if the generating units comply with the technical requirements of the Turkish Grid Code. The system consists of a reference model that validates the real operation of the primary and secondary regulation of the generating units comparing it with the desired behavior established by the technical requirements of the Turkish Grid Code. A number of quantitative measures, based on the deviation between the real and the desired response are proposed to evaluate the adequacy of each unit behavior. Application examples of the proposed monitoring system of frequency control are provided using real data of different Turkish power plants.

1. Introduction

Ancillary services are a set of functions required for the secure and reliable operation of power system [1–3]. The three main ancillary services are frequency control, voltage control and black start provision. Ancillary services are provided by generating units. However, as system operators are the entities responsible of the secure operation of power systems, they manage and supervise ancillary services. This paper focuses on frequency surveillance by means of active power control of generating units.

Active power control is designed to reestablish the necessary equilibrium between generation and demand in order to maintain the frequency of the power system within the admissible range. Active power control include primary, secondary (AGC) and tertiary (non-spinning reserve) regulation, operating within different time scopes.

The development of a monitoring approach is determined by the specific technical and economical formulation of the service in the power system considered. Within the Turkish power system, frequency control (primary, secondary and tertiary) is a mandatory remunerable ancillary service, defined in the Turkish Grid Code and Ancillary Services Regulation [4–7]. It should be noted that although the AC links with neighboring countries have already been developed, the Turkish power system is not yet synchronously connected to the UCTE European system (tests of the synchronous connection of the Turkish and UCTE European systems are currently being performed). High quality frequency control is crucial not only in isolated operation of Turkish system but also for the successful interconnection to UCTE European system. Hence, the Turkish system operator has to monitor the correct provision of the frequency control ancillary service by each generating unit.

Frequency monitoring has attracted much attention and several approaches have been reported in the literature [8–12]. However, the emphasis is put on the description on systems and tools to monitor the system frequency over an area, and no attention has been paid in the literature on the monitoring by the system operator of the individual response of each generator to primary and secondary frequency control requirements. Precisely, performance criteria are imposed to control areas rather than to generating units in a number of power systems such as NERC [13], UCTE [14] and Spanish [15] power systems.

This paper proposes a novel centralized monitoring system of the frequency control for the Turkish power system to validate its correct fulfillment by each individual generating unit. The model has been developed for the Turkish system operator. The monitoring is based on a reference model that compares the actual response of primary and secondary regulation of the generating units with the desired behavior established by the technical specifications of the Turkish Grid Code. When the unit is not having the desired performance, it is also important to evaluate how far its response from the desired one is. A number of quantitative measures, based on the deviation between the real and the desired response are proposed to evaluate the adequacy of each unit behavior. Two application

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examples of the central monitoring system of frequency control are provided using real data of different individual Turkish power plants (a hydro and a CCGT unit). Since both primary and secondary provision is remunerated in Turkey, the system proposed in this paper is the starting point to regulate decreases in the unit remuneration when the performance is poor. This will be also an incentive to poor response units to perform the necessary changes in unit control to meet the system operator desired response.

The simple and intuitive centralized monitoring of frequency control proposed in this paper can be imported by any system operator by just specifying the desired response based on the technical requirements and regulations of the grid code of the power system considered.

It should be noted that the system proposed in this paper tackles the problem of monitoring frequency control from the system operator point of view (both from system security and economic assessment sides). The SO imposes maximum deviations of system frequency and speed response limits to each unit depending on its size, age and technology (for instance, the requirements are higher for hydro units than CCGT units since they behave faster). It does not consider the detailed AGC block diagram of the units: the system operator is not interested in which control system has each unit, it just surveys if they behave correctly in order to guarantee system security and regulate remunerations/penalizations of providing frequency control service. When a generator performance is not adequate it provides neither the unit internal explanation of the failure, nor the solutions or modifications of the control systems in order to solve the misbehavior. Each generator should be responsible of solving any inadequate response if they want to be paid for providing this important ancillary service.

The paper is organized as follows. Section 2 provides an overview of the primary, secondary and tertiary frequency control loops and their technical regulation in Turkey. The centralized monitoring system proposed in this paper is explained in Section 3. Section 4 illustrates the performance of the monitoring system using real data of two Turkish power plants (hydro and CCGT). The hydro power plant exhibits an adequate behavior whereas the performance of the CCGT power plant needs to be improved. Finally, conclusions are drawn in Section 5.

2. Overview of frequency control

2.1. Primary, secondary and tertiary controls

Frequency control by means of active power provision is implemented in three control loops: primary, secondary and tertiary.

Primary control can be defined as the automatic increase or decrease of the output power of a generating unit due to frequency deviations. It is based on its speed–droop characteristic. The time constant of the dynamic response of primary control lies within the range of few seconds (1–10 s).

Following a system disturbance, primary control can prevent large variations of frequency, but on the contrary it does not bring the system frequency back to its scheduled value. Thus, a frequency deviation will remain in steady state after primary control operation. The aim of secondary control (AGC) is to bring the system frequency to its scheduled value. Power systems are usually divided into different interconnected areas with possible scheduled interchanges between them. An additional objective of AGC is to maintain area interchanges at the scheduled values. The time constant of the secondary control is within the range of a few minutes (1–3 min). Secondary regulation is affected mainly by the up and down speed variation of the generating units and the maximum and minimum technical operational limits of the units.

Generating units controlled by AGC change their generation. Thus, they use part of their available regulation band, which is therefore reduced. The aim of tertiary control is to replace this secondary reserve in use, thus increasing the available reserve to the initial scheduled value. Tertiary reserve is usually provided by non-spinning generators that can be started and connected to the grid before 15–20 min after the order is sent.

If a generating unit participates in secondary control its output results form joint operation of the primary and secondary control loops. Thus, if the response of the unit is not adequate it becomes difficult in most of the cases to detect whether it is because of deficient primary control, deficient secondary regulation or both. The approach followed in this paper is to monitor the combined response of the primary and secondary frequency control loops.

2.2. Frequency control in the Turkish power system

Power plants with 50 MW or more installed capacity must participate in primary frequency control (excluding solar, wind, wave and tidal power plants and canal and river hydropower plants), with a limit of 5% of their corresponding rated power. This reserve can be supplied by another legal entity approved by the system operator and contracted by the power plant in case the generator is not able or is not willing to provide the service.

Power plants, excluding renewable generators, with more than 100 MW installed capacity are obliged to participate in secondary frequency control. For these purpose they should have monitoring infrastructure and sign secondary frequency control agreement with TEIAS (Turkish system operator).

Associated requirements and remuneration of primary and secondary control are both determined by the Turkish Ancillary Services Regulation [8–11].

3. Centralized monitoring system of frequency control

3.1. Principles of the monitoring system

The monitoring of frequency control is based on a reference model of the desired response of the unit. The actual response of a unit is compared to that of its reference model, which takes into account unit characteristics and desired response. Both primary and secondary components of frequency control are monitored at the same time since the global response of the unit is due to a combination of the response of both the primary and the secondary control loops. Fig. 1 shows the proposed reference model.

The inputs to the reference model are the system frequency deviation *FreqDev* [Hz] and the unit power setpoint *PSet* [MW]. The output of the reference model is the desired power output *PDes* [MW] of the unit which is obtained from the dynamic primary response of the unit (modeled by a first order linear system of gain k_PR and time constant T_PR), the secondary regulation response yielded by the ramp limits of the units, the primary and secondary regulation maximum and minimum limits, and the overall operating unit maximum and minimum limits. An error between the actual and the desired response is allowed. In other words, an admissible band around the desired power is fixed. If the actual power *PGen* lies within the allowed band the response of the unit is considered adequate. Whenever the actual power *PGen* goes outside this allowed band, the response is considered inadequate. It should be noted that the frequency control presented is monitored at a unit level. A unit can be a single generator if the generator is directly controlled or a plant comprising several generators (for instance a CCGT comprising a gas and a steam turbine) if primary and secondary control is performed at a plant level.