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Evaluation of frequency control application for distributed generation in Turkey

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ABSTRACT

Ancillary services are essential for the safe, secure and reliable operation of power systems. They presently include both mandatory and competitive services such as voltage control, frequency control and system restart. Since these services were and are still mostly provided by centralized power plants, controls of voltage and frequency in the Turkish power system are also performed by power plants with installed capacity of 50 MW and greater. However, the number of private sector power plants connected to the national grid at medium voltage has been increasing continuously. The positive impact and the contribution of such plants should be realized better by further actions.

In this paper, frequency control ability in natural gas fired private power plants connected to medium voltage level is studied. Data taken from a real power plant operation is used for this study. With the growth of such distributed generation units (DGU) on distribution grid and with the deregulation of the electricity sector, the frequency control may become an applicable scenario for DGU.

Introduction

Today's power systems are undergoing major changes as the penetration of generating units at medium voltage grids has been increasing continuously [1,2]. Such generation units, also called distributed generation, can have a significant impact on some parameters such as voltage profile, power quality, reliability, and frequency [3,4]. This impact cannot be neglected and should be taken into consideration in system operation [5]. Although some studies are available on frequency response of renewable generating units [6–8], this paper focuses on frequency control of gas engine type power plants because the major portion of renewable units in Turkey are connected directly to the high voltage transmission grid, not to the distribution grid.

Combined heat and power (CHP) plants utilizing gas engine or gas turbine are mostly preferred in industrial applications for higher energy efficiency. These type of plants rated from 5 MW to 50 MW can be connected to the distribution grid easily. The number of CHP plants owned and operated by private sector producers has been increasing. The requirements and rules set by the Turkish Grid Regulating Authority have to be satisfied by the private plants for effective grid operation [9–11]. For reliability purpose, reserves have to be taken into consideration as well.

Although frequency control is a new subject for Turkey, it has been carried out successfully in practice and is being continued as well. The chronological development of the frequency control in Turkey is given in Table 1. As can be seen from the table, the connection of the Turkish transmission system into the Union for the Coordination of Transmission of Electricity (UCTE/ENTSO-E) [12] was initiated in September 2010. Statistical data given in Table 2 shows that the number of outages in the selected power plant which is located at the south side of Turkey, is reduced to zero with the UCTE connection.

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 [13]. Many studies exist on frequency control for mostly conventional generators having stable characteristics. Not only frequency control [14] but also other issues such as protection [15], stability and design have been covered [16–22]. But, there is not enough contribution in the literature on frequency control associated with private sector power plants [14]. In the available literature, the focus is generally given to test procedures. If DG units are operated with a control mechanism, additional benefits can be achieved, especially with high penetrated units in distribution grid.

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Table 1
Official gazette/regulatory authority.

Date	Official gazette/regulatory authority	Explanation
27.12.2008	27,093	Electricity Market Ancillary Service Regulation was published
01.07.2009		Primary frequency control was initiated
22.03.2010		Synchronous testing with ENTSO-e and dead band was set as 0 (zero)
13.05.2010	27,580	Some modifications on ancillary service
19.08.2010	27,677	Some modifications on ancillary service
18.09.2010		UCTE connection was initiated. Reserve capacity of country was decreased to 300 MW (from 700 MW, almost halved)
15.10.2010	27,730	Some modifications on ancillary service
10.02.2011	27,842	Penalties seriously increased
15.03.2011		Reserve capacity was decreased to 1%
17.12.2011	28,145	Some modifications on ancillary service
23.12.2011	28,151	Penalties seriously increased
19.01.2012		Test periods were 3 years instead of 1 year

Table 2
Statistical data of a power plant in Turkey.

Date	Events number out of 50.00 ± 0.2 Hz
28.12.2009–31.12.2009	6
Jan'10	8
Feb'10	4
Mar'10	0
Apr'10	1
May'10	6
Jun'10	2
Jul'10	10
Aug'10	9
01.09.2010–18.09.2010	3
18.09.2010–Later	0

Due to common usage of generating units with gas engines, their primary frequency control application is emphasized in this study. After an overview of frequency control methods and operational characteristics, the frequency control ability of units with gas engines is evaluated through the test results of a real power plant.

Frequency control

When there is an imbalance between electricity demand and supply amount, it is important to control frequency, and maintain it within the desired limits. For this purpose, frequency control by means of active power can be implemented. The first step is to describe the power system dynamics by the following power balance equation [9,10]:

$$\frac{dW_k}{dt} = P_g - P_c \tag{1}$$

where $W_k = \frac{1}{2}J\omega^2$, is kinetic energy of all rotating machines, P_g is power generation, P_c is power consumption, J is the moment of inertia of all the machines synchronized to the system and ω is angular speed (rad/s).

Eq. (1) describes how the unbalance between generation and consumption (P_g–P_c) will change the rotating energy (dW) in the system. After differentiating Eq. (1) to calculate small changes, the balance can be expressed in the following form:

$$J\omega\frac{d\Delta\omega}{dt} = \Delta P_g - \Delta P_c \tag{2}$$

If we assume that the change in frequency is small, then $\omega = \omega_N$ and $\Delta P_c = K_n\Delta f$. Thus, $J = 2\frac{W_k}{\omega_N^2}$ and Eq. (2) can be expressed as follows:

$$2\frac{W_k}{f_N}\frac{\Delta f}{dt} = \Delta P_g - K_n\Delta f \tag{3}$$

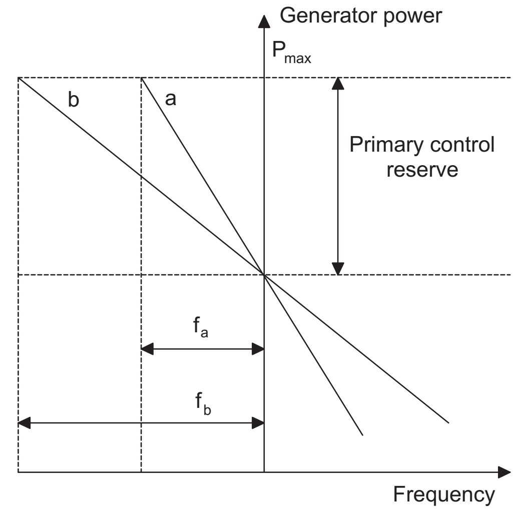

Fig. 1. Power control of two generators having different droops.

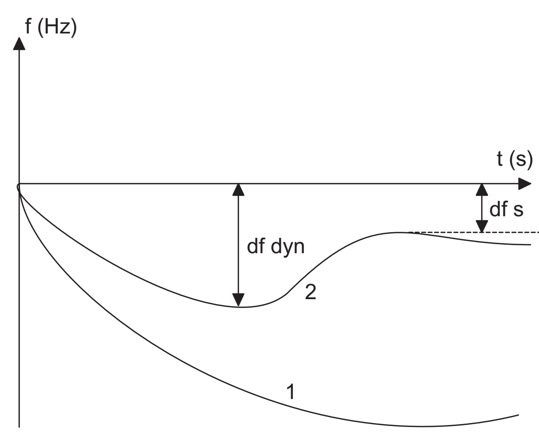

Fig. 2. Frequency drop after power plant trip.

By solving Eq. (3), frequency deviation function can be derived as given in Eq. (4).

$$\Delta f = \frac{\Delta P_g}{K_n(1 - e^{-f_N K_n/(2W_k)t})} \tag{4}$$

where $\frac{2W_k}{f_N K_n}$ is time constant (T), which is typically 5–10 s and K_n is natural control gain of the network [23,24].