Oil Shale, 2011, Vol. 28, No. 1S, pp. 214–222
doi: 10.3176/oil.2011.1S.13
ISSN 0208-189X
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CHARACTERISTIC NUMBERS OF PRIMARY CONTROL IN THE ISOLATED ESTONIAN POWER SYSTEM

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Characteristic numbers of Primary Control for a small control area of interconnected power systems, such as Estonian Power System, become a major consideration in perturbation's islanding (isolated operating), or in initiating black start situation. Against a background of independence of the transmission system and electricity production towards the recently opened electricity market in Estonia arise the actuality of reliability in the context of the quality of supply (frequency and voltage) and successful parallel operation. Characteristic numbers of Primary Control, such as the network power frequency characteristic, governor droop and load response influence to the frequency regulation process in case of significant frequency deviation. Because of solely dependence on Primary Control executed by IPS central regulator, the limited number of frequency affecting events can be obtained for the reasonable figures. The controlled system separation test is the only opportunity for Estonian Power System that investigates the capability of frequency regulation. Primary Control relates to the supply and load responses that stabilize frequency whenever there is a change in load-resource balance. Based on the methodology suggested by ENTSO-E and local measurements, the study state behavior of Primary Control of the isolated Estonian Power System is described in the case study. The paper presents the characteristic numbers of Primary Control in the isolated system under the system contingencies such as the artificially created failure produced by network or switch-offs of individual generating blocks and switch-offs of the HDVC link.

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Introduction

Estonian Power System, with maximum load approx 1500 MW and national generating capacity during maximum time approx. 2300 MW, like the other power systems in the Baltic States was originally designed as a part of the former Unified Power System of the U.S.S.R. and, therefore, systems of the Baltic States are interconnected with that system. Besides that, Estonian power system is interconnected via a high-voltage direct current (HVDC) transmission link with Finland that is part of the Nordic power system. These interconnections are power corridors for bulk-energy exports and imports to the Baltic power systems. However, the power systems of the Baltic States are solely dependent on IPS/UPS Power System for Primary Control executed by IPS central regulator. The ability to operate isolated and execute the primary control within the system with its own resources to mitigate a frequency deviation will be investigated during the controlled system separation test of Estonian and IPS/UPS Power System. Figure 1 shows the separation scheme. The characteristic numbers of Primary Control evaluated based on the number of data collected during the fast and slow changes in supply with and without utilization of AFC (automatic frequency control) function of HVDC link have been studied and presented.

Primary Control relates to the supply and load responses that stabilize frequency whenever there is a change in the load-resource balance. During the contingency, such as failures produced by network (line openings) or the switch-offs of individual generating blocks and switch-offs of the HDVC link, the frequency changes due to the mismatch in load and generation. The level to which the frequency drops depends on the starting point as well as the system inertia. It is the system inertia, which provides the initial ability of the system to oppose the change in frequency. Physically, it may loosely be defined by the mass of all the synchronous rotating generators and motors

Fig. 1. Separation scheme for the controlled separation test.

connected to the system. If the system inertia is high, the frequency will fall slowly and vice versa, during any system contingency. System inertia is not frequency control per time, but it does influence the time taken for frequency to change after a loss of generation or load. Higher system inertia provides more time to the generator governors to respond to a change in frequency, and hence it is desirable. The system contribution to the frequency variation thus comprises two components namely supply (generators governor response) and load responses [2].

Load response is the reduction in the power consumption in response to a decline in the frequency and occurs simultaneously or with a minimal time lag as the frequency changes. Load frequency response is not a question of consideration of the current case study.

Primary response is the governor response, which occurs within the 3-10 s time frame. The changes in the generator output are in response to the change in frequency and are independent of any command. Generator governor response stabilizes the frequency whenever there is a change in the load-resource balance, but does not restore the frequency to the rated frequency level.

The case study presents the characteristic numbers of Primary Control in the isolated Estonian Power System based on real time data recovered by the SCADA systems and measuring equipments LEM and REMI.

Methodology

The method used to calculate the characteristic numbers of Primary Control in the Estonian Power system context has been adopted from the methodology suggested by ENTSO-E (European Network of Transmission System Operators for Electricity - former UCTE) [1].

The main purpose of this frequency analysis is to estimate the operational reliability of the isolated network.

System contingencies such as the switch-offs of individual generating blocks or failures produced by network (line openings) and switch-offs of the HDVC link have been recovered and analyzed to obtain the characteristic numbers of the isolated Estonian Power System.

The following characteristics are calculated in the case study.

Network power frequency characteristic

The network power frequency characteristic also known as composite frequency response characteristic or the stiffness of the system [4] represents the total action of the primary frequency control provided by generators and the self-regulating effect of the load. The network power frequency characteristic is negative, if the frequency drops, hence the generator output increases. The network power frequency characteristic is positive, if the frequency increases, hence the generator output decreases.

$$\lambda = -\frac{\Delta P}{\Delta f},$$

where:

λ – positive and expressed in MW/Hz,

ΔP – power deviation responsible for the disturbance, the power imbalance,

Δf – quasi-steady-state frequency deviation caused by the disturbance, determined from a "smoothing line" drawn between 10 and 30 seconds.

As any physical value, the frequency goes through a transitory state in response to a perturbation before stabilizing at a new value. The maximum deviation from the target frequency during the transitory period is called the dynamic frequency deviation.

Power-frequency characteristic of units

Power–frequency characteristic of unit also known as the governor droop or droop of generating unit is the characteristic by which a generator governor causes the output of the generator to change in response to a change in frequency. Estonian Grid Code [3] currently requires the governor droop to be set to 2–8%. The droop of a generating unit is an important parameter of primary frequency control. A lower droop increases the response of a unit but would cause more stress in the generating unit as it would react more strongly to each deviation. On the other hand, a unit with a low droop is more likely to succeed in switching to islanded mode in case of a major disturbance and tends to reduce the quasi-steady state frequency deviation following an imbalance.

$$s_G = \frac{-\Delta f / f_n}{\Delta P / P_n},$$

$$\Delta f = f - f_n,$$

where:

ΔP – the variation in active power output of a generator,

Δf – the variation in system frequency,

f_n – rated frequency,

P_n – rated active power output.

The both variations, according to the methodology suggested by ENTSO-E, are defined in the abstract, there are no definitions for f in frequency variation expression and ΔP. Furthermore, the system frequency immediately before disturbance differs from the rated frequency 50 Hz, and there is no necessity to use it in the expression of variation of system frequency. In the case study the following equation was used [5, 7]:

$$\Delta P = P_B - P_A,$$
$$\Delta f = f_B - f_A^{'},$$
$$f_A^{'} = f_A \pm \Delta f_0.$$

P_A – actual active power immediately before disturbance,
P_B – actual active power immediately after disturbance,
Δf – the variation in system frequency,
f'_A – frequency immediately before disturbance,
f_A – actual frequency immediately before disturbance,
Δf_0 – dead band of primary control,
f_B – actual frequency immediately after disturbance.

To avoid the indistinctness in interpretation of time window to be measured, the “Immediately after disturbance” is interpreted in the case study as 30 seconds after disturbance, but “Immediately before disturbance” is still the subject to interpretation.

Case study

A controlled separation test of the Estonian Power System from synchronously connected UPS/IPS grid has been performed in April 2009. The main purpose of separation was to investigate the capability of frequency regulation in isolated Estonian Power System during the fast and slow changing in supply with and without utilization of AFC (automatic frequency control) function of HVDC link. The initial parameters of Estonian Power system were maximum load during the test approx 800 MW and generating capacity approx. 820–725 MW. In separation test thermal power plants generators, smallest one with net capacity about 20 MW and largest one with net capacity 160–190 MW, were attended. Some of the large units worked in half capacity. Only thermal power plants generators had operating governors to respond to frequency deviation and performed Primary Control within the separated system.

The separation test was divided into the five stages:

In the first stage of the separation test EPS was separated from the UPS/IPS grid due to the artificially created failure produced by network (line opening) with a surplus about 72 MW. At the beginning of the test AFC of HVDC link was out of work. In response to the change in the load-resource balance the frequency in the system decreased by Δf = 161 mHz. The droop of large generating units was between 3–6%, droop of small units was 8%. Network power frequency characteristic of the current variation in active power output has been found to be 1056 MW/Hz. The following figures indicate the response of resources to the different failure events. Figure 2 shows the response of the large unit to the failure produced by network.

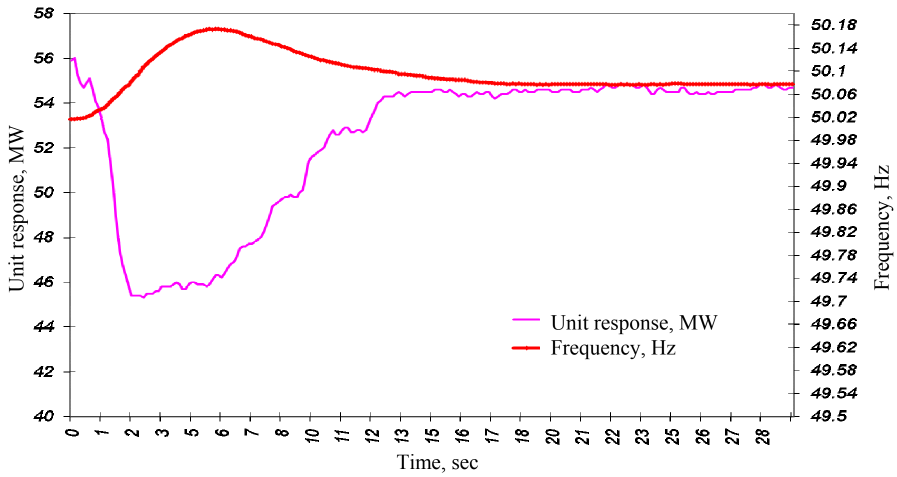

Fig. 2. Response of the large unit to failure produced by network event.

Before the next test stage the supply and load responses stabilize the frequency in the system for 50.01 Hz and AFC of HVDC link was switched on. Unexpectedly the active power flow arised instantly to 73 MW causing shortage in Estonian Power System and frequency droop $\Delta f = 206$ mHz. Thermal units in tandem with AFC of HVDC link stabilized frequency after 30 seconds. The droop of large generating units was between 2–5%, that of small units droop 5%. Network power frequency characteristic the current variation in active power output was 879 MW/Hz.

In the second stage with process duration for 180 seconds change in the output of one large unit from 150 MW to 80 MW was slow. All frequency regulation was done by AFC of HVDC link. Network power frequency characteristic is not considered in context of such disturbance. Figure 3 shows response of large units to slow changes in generation amount within the isolated system.

In the third stage the switch-off of individual generating block with the output of 100 MW was performed. Frequency in the isolated system dropped by $\Delta f = -420$ mHz. In the frequency stabilizing process all the primary regulation recources within the isolated system were attended. The droop of large generating units was between 3–6%, droop of small units was 8%. Network power frequency characteristic for the current variation in active power output was 242 MW/Hz. Figure 4 shows the response of the small unit to generation loss.

In the fourth stage AFC of HVDC link was switched off, and due to that in the isolated power system a deficit about 51 MW occurred, frequency dropped for $\Delta f = -286$ mHz. The droop of large generating units was between 3–6%, droop of small units was 8%. Network power frequency characteristic for the current variation in the active power output was

305 MW/Hz. Figure 5 presents the changes in active power via HVDC link and system frequency in the stage of AFC switch-offs.

In the fifth stage EPS was reconnected with UPS/IPS.

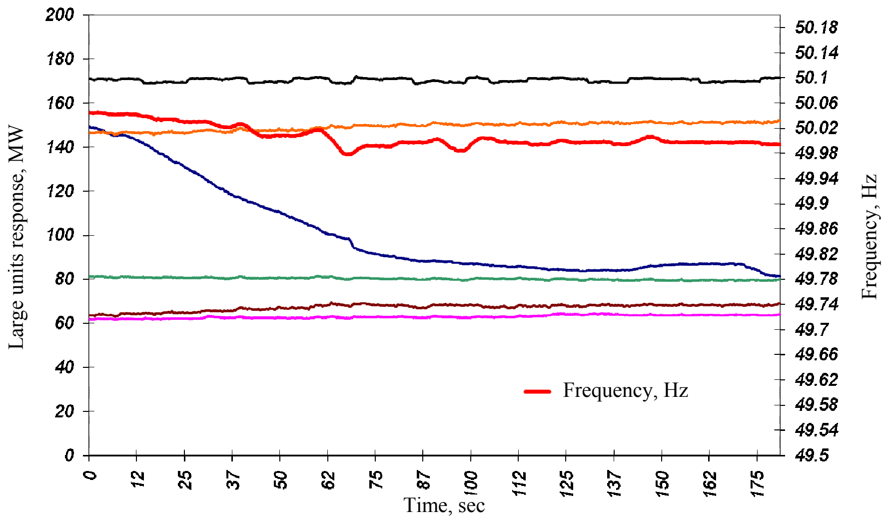

Fig. 3. The response of large units to slow changes in generation amount within the isolated system.

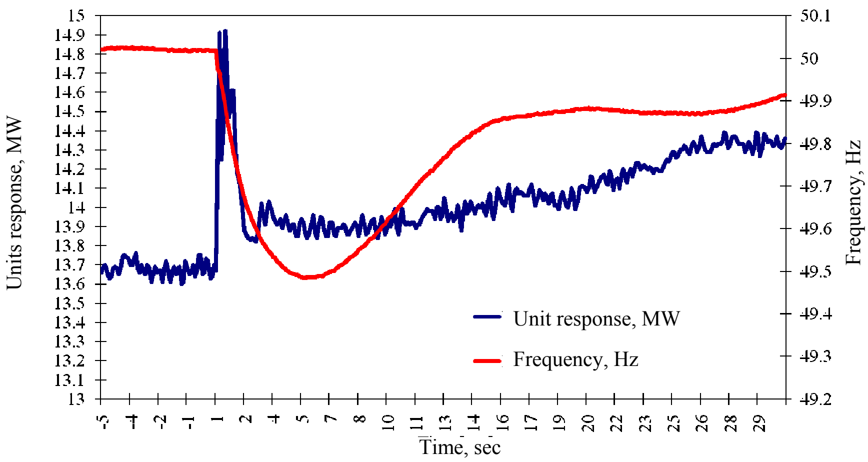

Fig. 4. The small unit response to generation loss event.

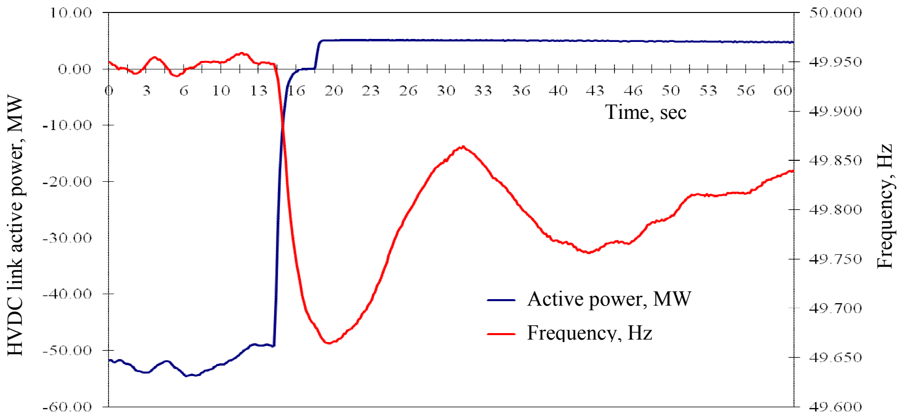

Fig. 5. Changes in active power via HVDC link and system frequency in the stage of AFC switch-offs.

Conclusions

The main purpose of the controlled separation test was to investigate the capability of frequency regulation in isolated Estonian Power System. The system response was adequate to the disturbances, system Primary Control operated properly. Despite that Estonian Grid Code [3] has mandated the requirement of operating governors for all generators for connection to the grid, calculated droops show the requirements for adjustments. From the results obtained, it is evident that the power frequency characteristic of the network is a highly variable parameter and it is difficult to accurately quantify natural response of the system. The common factors affecting the network power frequency characteristic are: system size, frequency at the start of the incident, loading of generators, losses, load consumption, number of generators in service at the time of incident, type of generation, governor action or speed control mode type, time of day and season [5].

Acknowledgements

The authors are greatly indebted to the Estonian TSO Company Elering OÜ and Nordic Energy Link for the provision of the frequency response data and test results to publish in this paper.

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Received November 4, 2010