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An Analysis of Energy Storage Systems for Primary Frequency Control of Power Systems in South Korea

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Abstract

Energy storage systems (ESSs) have a quick response and outstanding functions when used for frequency regulation. This paper examines the effect of an ESS used in conjunction with the primary frequency control (PFC) of a power system in South Korea. A simple low order system frequency response (SFR) model is used to undertake a simulation with MATLAB Simulink. The simulation includes gas, hydro and steam turbines and the ESS with the PFC. The results show that the ESS has a remarkable effect in the PFC and that it is more efficient in a weak grid. When more ESSs are added, the substitution effect is weaker according to the simulation results.

Keywords: Energy Storage System (ESS); Frequency regulation; Primary Frequency Control (PFC)

1. Introduction

The controlling frequency is an essential aspect when operating a power system. However, as the proportion of Renewable Energy Sources (RES) in power systems continues to increase, the stiffness of power systems is decreasing due to their very low or even lack of inertia and their intermittency, which weakens the stability of the

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power system [1]. A conventional generator can provide good frequency control but at a slow speed due to its physical and/or thermal limitations [2, 3]. To counteract the side effect of RESs, many studies to develop frequency operation schemes for power systems are being conducted. In a study, frequency control was provided by Doubly Fed Induction Generators (DFIG) and converter based wind turbines [1]. Latter, the PFC control scheme, which uses the power of electric vehicles, was introduced [4]. Other works, involved the use of ESSs for frequency control in power systems [5-7]. In particular, ESSs take center stage with regard to frequency control because they have a very rapid response and bidirectional transmission to/from a power system. This application of ESSs has been demonstrated in several countries [7, 8]. In South Korea, the Korea Electric Power Corporation (KEPCO) has installed a 200 MW ESS for frequency control. Moreover, KEPCO plans to increase ESS capacity to 500 MW for frequency regulation by 2017.

In this paper, the effects of ESSs when used for PFC are analyzed in MATLAB Simulink using the SFR model, governor-turbine models, and an ESS model reflecting the power system in South Korea. The frequency response determined by a dynamic simulation and the results are analyzed. This paper focuses on the minimum frequency of the system because this factor is most critical in relation to PFC.

2. Simple power system modeling of a power system in South Korea

2.1. Frequency control of a power system

The frequency of a power system is related to the balance of active power according to this equation.

$$M\frac{d(\Delta f / f_0)}{dt} + K\Delta f = -\Delta P \qquad (1)$$

Where M (= 2H) is the inertia constant of the system (s), f_0 is the system nominal frequency (Hz), K is the power/frequency characteristic of the system (PU/Hz), and ΔP is the amount of generator/load change (PU) [2]. When the active power of a load or a generator is suddenly changed, an active power imbalance occurs and the frequency deviates from the nominal frequency. Therefore, for stable operation of a power system, it is necessary to hold the system frequency at the nominal frequency.

Generally, there are three control layers to sustain the system frequency [9]. Primary frequency control (PFC) is a rapid local control method that regulates the active power of generators and controllable loads. It is used to mitigate deviations of the system frequency. Secondary frequency control (SFC) is a centralized generation control method that regulates the active power of generators. It is used to restore the system frequency to its nominal value. Tertiary frequency control (TFC) refers to the manual control of the actions of dispatching and generation unit commitment. This control method is used when secondary control is incapable of restoring the system frequency.

In South Korea, the Korea Power Exchange (KPX) is in charge of managing the frequency control of power systems using their energy management system (EMS) based on the operating rules of South Korea. In their operating rules, the nominal frequency is set to 60 ± 0.2 Hz and the amount of frequency regulation reserve exceeds 1,500 MW [10]. This regulation reserve is similar to the first and secondary control methods.

2.2. Simplified power system model

An actual power system consists of many elements, such as the generator, load, transformer and others. Therefore, the system is constantly changing and is very difficult to model precisely. For this reason, a simple low order system frequency response (SFR) model is used to simulate power system frequency responses [11]. This simple model averages the frequency response of an actual power system to a first-order transfer function using the system inertia M and the load damping constant D. This model can show the short-term dynamic response of the frequency at a specific operating point. It is used to analyze the frequency responses of power systems with the governor-turbine model of generators to provide proper frequency control [11].