Electrical Power and Energy Systems 33 (2011) 35–42

Contents lists available at ScienceDirect

Electrical Power and Energy Systems

journal homepage: www.elsevier.com/locate/ijepes

Robustness of damping control implemented by Energy Storage Systems installed in power systems

W. Du [a,b,*], H.F. Wang [b], S. Cheng [c], J.Y. Wen [c], R. Dunn [d]

[a] The Southeast University, Nanjing, China
[b] The Queen's University of Belfast, Belfast, UK
[c] Huazhong University of Science and Technology, China
[d] The University of Bath, Bath, UK

ARTICLE INFO

Article history:
Received 26 August 2008
Received in revised form 14 June 2010
Accepted 13 August 2010

Keywords:
Energy Storage System (ESS)
Power system oscillations
Equal-area criterion
Small-signal stability analysis
BESS and SMES

ABSTRACT

An Energy Storage System (ESS) installed in a power system can effectively damp power system oscillations through controlling exchange of either active or reactive power between the ESS and power system. This paper investigates the robustness of damping control implemented by the ESS to the variations of power system operating conditions. It proposes a new analytical method based on the well-known equal-area criterion and small-signal stability analysis. By using the proposed method, it is concluded in the paper that damping control implemented by the ESS through controlling its active power exchange with the power system is robust to the changes of power system operating conditions. While if the ESS damping control is realized by controlling its reactive power exchange with the power system, effectiveness of damping control changes with variations of power system operating condition. In the paper, an example of power system installed with a battery ESS (BESS) is presented. Simulation results confirm the analytical conclusions made in the paper about the robustness of ESS damping control. Laboratory experiment of a physical power system installed with a 35 kJ/7 kW Superconducting Magnetic Energy Storage (SMES) was carried out to evaluate theoretical study. Results are given in the paper, which demonstrate that effectiveness of SMES damping control realized through regulating active power is robust to changes of load conditions of the physical power system.

1. Introduction

In addition to the advantage of being able to accommodate the intermittence of renewable generation, an Energy Storage System (ESS) installed in a power system can help to enhance system stability by regulating its exchange of active and reactive power with the power system. Superconducting Magnetic Energy Storage (SMES), Battery Energy Storage System (BESS), Flywheel Energy Storage (FES), and Pumped Storage Hydro Power Station (PSHPS) are commonly used ESS in power system stability control [1–3]. To investigate and validate the capability of those ESS in one of the important applications of stability control – to suppress power system oscillations, various tools and techniques have been used, such as the modal analysis based on linearized models for SMES [4–8], modeling power electronics into power systems for BESS [9–11], simulation and laboratory experiment for FES [12] as well as application of advanced control theory for BESS [13,14]. Research results obtained so far indicate that ESS control can significantly enhance power system stability by damping system oscillations effectively, which has been confirmed by field applications of BESS and PSHPS reported in [15] and [16] respectively.

This paper investigates the robustness of damping control implemented by ESS to variations of power system operating conditions. The focus of investigations is to study the difference of ESS damping control when it is realized by controlling exchange of either active or reactive power between ESS and power system. The paper proposes a new analytical method for the small-signal analysis of ESS control to damp power system oscillations based on the linearized equal-area criterion. By using the proposed method, it is demonstrated in the paper that effectiveness of ESS damping control realized by regulating exchange of active power does not change with variations of power system operating conditions; while it does when ESS damping control is realized by regulating exchange of reactive power. Hence ESS damping control is more robust to variations of power system operating conditions if it is implemented through regulating exchange of active power than via controlling exchange of reactive power. In the paper, an example power system installed with a BESS is presented. Simulation results of the example power system have confirmed analytical conclusions obtained. Laboratory experiment of a physical power

* Corresponding author. Address: School of Electrical Engineering, Southeast University, Nanjing, China.

E-mail addresses: ddwenjuan@gmail.com, jrest@anl.gov (W. Du).

0142-0615/$ - see front matter © 2010 Elsevier Ltd. All rights reserved.
doi:10.1016/j.ijepes.2010.08.006