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Battery energy storage for load frequency control of an interconnected power system

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Abstract

This paper deals with load frequency control of an interconnected reheat thermal system considering battery energy storage (BES) system. Area control error (ACE) is used for the control of BES system. Time domain simulations are used to study the performance of the power system and BES system. Results reveal that BES meets sudden requirements of real power load and very effective in reducing the peak deviations of frequency and tie-power and also reduces the steady state values of time error and inadvertent interchange accumulations. © 2001 Elsevier Science B.V. All rights reserved.

Keywords: Load frequency control; Battery energy storage system; Power generation control

1. Introduction

A lot of work reported in the literatures to improve the performance of load frequency control (LFC). One alternative to improve the performance of LFC is the introduction of storage facilities during peak load period and specially a battery energy storage (BES) facility. Since BES can provide fast active power compensation, it also can be used to improve the performance of load frequency control. BES also improves the reliability of supply during peak load periods. Storage facilities possess additional dynamic benefits such as load leveling, spinning reserve, area regulation, long line stabilization, power factor correction and black start capability. Some of these applications have been successfully demonstrated at a 17 MW BES facility in Berlin [1] and 10 MW/40 MWh Chino facility in Southern California [2]. Kottick et al. [3] have studied the effect of a 30 MW battery on the frequency regulation in the Israeli isolated power system. Their study was performed on a single area model representing the whole power system and containing a first order transfer function that represented the BES performance. However, they have not considered the effect of generation rate constraints on dynamic performances. Lu et al. [4] have studied the effect of battery energy storage system on two area reheat thermal system considering conventional tie-line bias control strategy. Their study reveals that a BES with simple control can effectively reduce frequency and tie-line power oscillations following sudden small load disturbances. However, they have considered generation rate constraint (GRC) of 10%/min for reheat type unit, but modern reheat type units have GRCs of 3%/min [5].

In this paper, an incremental BES model is proposed. The effect of BES on two area interconnected reheat thermal system is studied considering conventional tie-line bias control strategy. A GRC of 3% per min is considered for reheat type units to obtain realistic responses. The results show that with the use of BES, the dynamic performance of LFC can greatly improve the overshoots of frequency deviations, tie-power deviation and reduce the steady state values of time error and inadvertent interchange accumulations.

2. BES model

A schematic description of a BES plant is given in Fig. 1. The main components of the BES facility are, an

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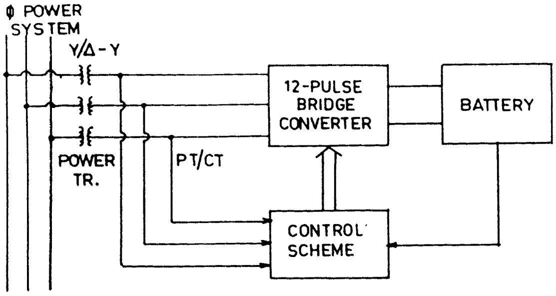

Fig. 1. Schematic description of a BES plant.

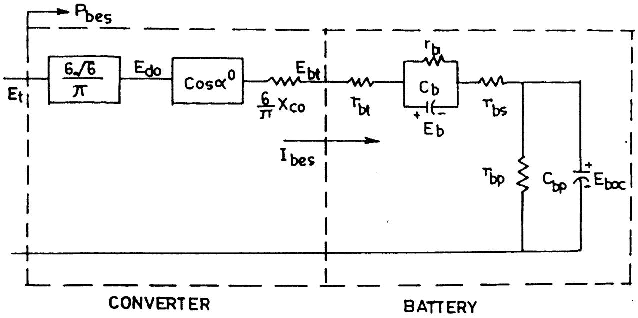

Fig. 2. Equivalent circuit of BES.

equivalent battery composed of parallel/series connected battery cells, a 12-pulse cascaded bridge circuit connected to a $Y/\Delta - Y$ transformer and a control scheme. The ideal no load maximum d.c. voltage of the 12-pulse converter is expressed as [6],

$$E_{\mathrm{do}} = E_{\mathrm{do1}} + E_{\mathrm{do2}} = \frac{6\sqrt{6}}{\pi} E_{\mathrm{t}} \tag{1}$$

where E_{t} is the line to neutral r.m.s. voltage.

The equivalent circuit of the BES can be represented as a converter connected to an equivalent battery as shown in Fig. 2. In the battery equivalent circuit [7], E_{boc} is battery open circuit voltage; E_{b} is battery overvoltage; r_{bt}, connecting resistance; and r_{bs} stands for internal resistance.

The terminal voltage of the equivalent battery is obtained from,

$$\begin{aligned} E_{\mathrm{bt}} &= E_{\mathrm{do}} \cos \alpha^{\mathrm{o}} - R_{\mathrm{c}} I_{\mathrm{bes}} \\ &= \frac{3\sqrt{6}}{\pi} E_{\mathrm{t}}(\cos \alpha_1^{\mathrm{o}} + \cos \alpha_2^{\mathrm{o}}) - \frac{6}{\pi} X_{\mathrm{co}} I_{\mathrm{bes}} \end{aligned} \tag{2}$$

where, α_i^{o} is firing delay angle of converter i; X_{co} stands for commutating reactance; I_{bes} is d.c. current flowing into battery; r_{b} denotes overvoltage resistance; c_{b} is overvoltage capacitance; r_{bp} is self discharge resistance; c_{bp} stands for battery capacitance.

From equivalent circuit of BES (Fig. 2), we can write the expression of d.c. current flowing into the battery as

$$I_{\mathrm{bes}} = \frac{(E_{\mathrm{bt}} - E_{\mathrm{boc}} - E_{\mathrm{b}})}{(r_{\mathrm{bt}} + r_{\mathrm{bs}})} \tag{3}$$

According to the converter circuit analysis active and reactive power absorbed by the BES system are [6],

$$P_{\mathrm{bes}} = \frac{3\sqrt{6}}{\pi} E_{\mathrm{t}} I_{\mathrm{bes}}(\cos \alpha_1^{\mathrm{o}} + \cos \alpha_2^{\mathrm{o}}) \tag{4}$$

$$Q_{\mathrm{bes}} = \frac{3\sqrt{6}}{\pi} E_{\mathrm{t}} I_{\mathrm{bes}}(\sin \alpha_1^{\mathrm{o}} + \sin \alpha_2^{\mathrm{o}}) \tag{5}$$

There are two control strategies (i) P–Q modulation and (ii) P-modulation. But only incremental active power is considered in load frequency control and hence we select P-modulation in this paper.

For P-modulation $\alpha_1^{\mathrm{o}} = -\alpha_2^{\mathrm{o}} = \alpha^{\mathrm{o}}$. Therefore,

$$P_{\mathrm{bes}} = \frac{6\sqrt{6}}{\pi} E_{\mathrm{t}} I_{\mathrm{bes}} \cos \alpha^{\mathrm{o}} = (E_{\mathrm{do}} \cos \alpha) I_{\mathrm{bes}} \tag{6}$$

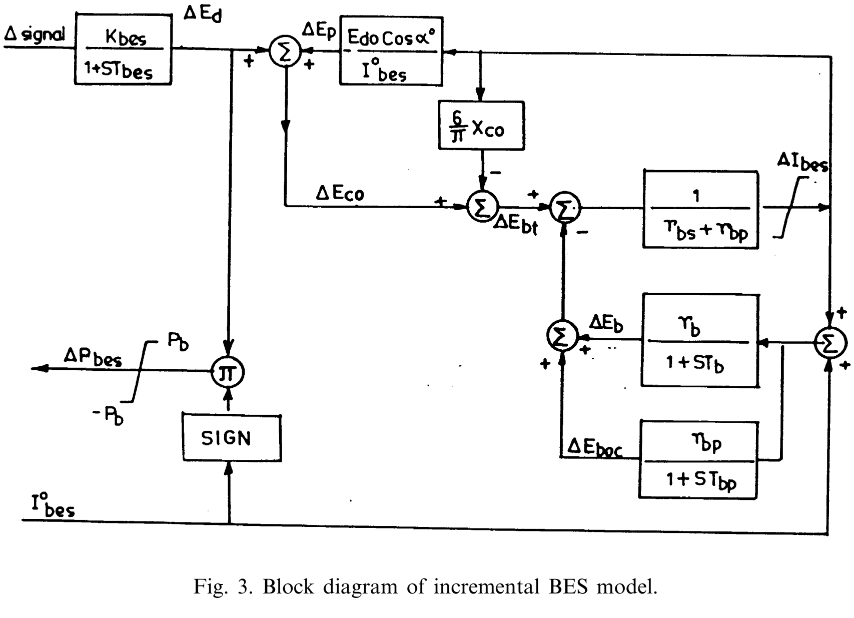

Fig. 3. Block diagram of incremental BES model.