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Impact of energy storage units on load frequency control of deregulated power systems

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A R T I C L E I N F O

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A B S T R A C T

Energy storage units are very vital for damping the oscillations due to the sudden changes in power system. The integration of small capacity energy storage unit to the power system in each area can effectively restrain the system oscillations. Hence in this paper, the energy storage devices, SMES (Superconducting Magnetic Energy Storage) units and RFB (Redox Flow Batteries) have been integrated into the interconnected deregulated LFC (Load Frequency Control) power system model and their effectiveness in improving the system performance has been realized and compared. The proposed controller design is applied to an interconnected two-area two-unit thermal deregulated power system with one reheat and one non-reheat unit in each area. This paper also proposes a new design of intelligent controller for load frequency control of interconnected deregulated power systems with energy storage devices using Artificial Cooperative Search algorithm. To prove the scalability of the proposed framework, the design has also been implemented on a three-area interconnected deregulated power system model. The simulation results show the effective and efficient performance of RFB energy storage unit and the effectiveness of ACS (Artificial Cooperative Search) algorithm tuned controller in improving the system performance of interconnected deregulated power system.

1. Introduction

Fast acting energy storage devices, such as SMES (Superconducting Magnetic Energy Storage) or battery energy storage can effectively damp out power frequency and tie-line power oscillations caused by small load disturbances. Though expensive, these hold promise as potential devices for improving dynamic performance of power systems. Generally, during the occurrences of small load disturbances and with the optimized gains for the PI (Proportional plus Integral) controller, the frequency oscillations and tie-line power deviations persist for a long duration. In these situations, the governor system may no longer be able to absorb the frequency fluctuations due to its slow response. Fast acting energy storage devices can effectively damp electromechanical oscillations in a power system, because they provide storage capacity in addition to the kinetic energy of the generator rotor, which can share the sudden changes in power requirement. To compensate for the sudden load changes, an active power source with fast response such as an Energy Storage unit is expected to be the most effective counter measure [1,2]. In this paper, the energy storage units, SMES (Superconducting Magnetic Energy Storage) unit and RFB (Redox Flow Batteries) are integrated into the LFC (Load Frequency Control) model in deregulated environment and their effectiveness in improving the system damping has been compared.

The SMES unit is a well established energy storage unit and has been reported in many research works for improving the power system performance [3–11]. Redox Flow Batteries are rechargeable batteries with an excellent short-time overload output response. Recently, the application of RFB units in LFC operations has been on the increase because of its practical advantages [12–15]. Results have been simulated using MATLAB SIMULINK and the performance of SMES units and RFB units in enhancing the LFC operation have been compared. ACS (Artificial Cooperative Search algorithm) [16], a swarm intelligence algorithm developed for solving complex numerical optimization problems has been used to tune the power system controller and has been applied to a two-area two-unit interconnected deregulated power system with energy storage units.

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2. Energy storage units

2.1. Superconducting Magnetic Energy Storage unit

The configuration of thyristor controlled SMES unit is shown in Fig. 1 [17]. A superconducting inductance coil and a 12 pulse bridge converter connected to a transformer are present in SMES unit. The bridge controller monitors the exchange of energy between the superconducting coil and the power system. During normal operating state of the grid, the superconducting coil is charged to a level less than the full capacity of the coil from the grid. The dc magnetic coil and ac grid are connected through a power conversion system which consists of an inverter/rectifier. Once the coil is charged to its set point, the superconducting coil conducts current, which supports an electromagnetic field, with no loss.

In LFC operation, the sensed ACE (area control error) is used to control the dc voltage Ed across the inductor coil. In this study, inductor voltage deviation of SMES unit of each area is based on ACE of the same area in power system. Moreover, the inductor current deviation is used as a negative feedback signal in the SMES control loop. So, the current variable of SMES unit is intended to be settling to its steady state value [8,18,19]. Fig. 2 shows the block diagram of SMES unit.

ΔE_d is the incremental change in converter voltage (kV). In LFC operation, the sensed ACE (area control error) is used to control the dc voltage E_d across the inductor coil. ΔI_d is the incremental change in SMES current (kA); T_{dC} is the converter time delay (s); K_o is the gain of the SMES control loop for ACE signal (kV/unit ACE); K_{Id} is the gain of the inductor current deviation feedback loop (kV/kA) and S is the Laplace operator. The optimal gain settings have been obtained for a deterministic load disturbance of a particular magnitude, and these gains need not be optimal for any other load.

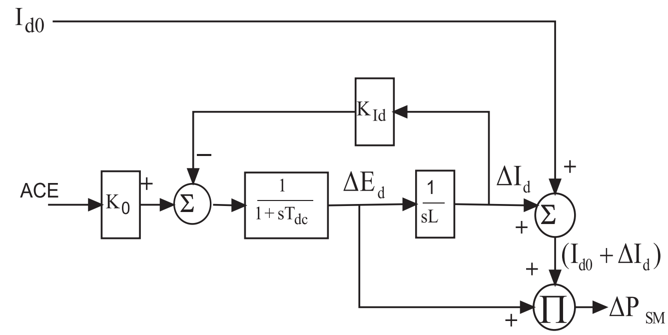

Fig. 2. The Schematic diagram of SMES unit.

2.2. Redox Flow Battery system

Redox Flow Batteries are rechargeable batteries with an excellent short-time overload output response. Redox flow batteries offer an economical, low vulnerability means to store electrical energy at grid scale. Redox flow batteries also offer greater flexibility to independently tailor power rating and energy rating for a given application than other electrochemical means for storing electrical energy. Redox flow batteries are suitable for energy storage applications with power ratings from 10's of kW to 10's of MW and storage durations of 2–10 h. RF batteries in practical applications have a number of advantages such as ability to operate at normal temperature, temperature changes are bare minimum and standby losses are very small. Hence, RFBs have a long service life, flexibility in layout, ease of capacity increase, and free from degradation due to the repetition of short charge–discharge cycles quick responses. RFBs are not aged by frequent charging and discharging and have outstanding function during overload [13]. Simple operating principle, quick response, long service life, suitability for high capacity systems, quick start up and ease in maintenance are the salient features of these batteries which makes it suitable for LFC.

RFB have been integrated in LFC system to improve the system response in occurrence of small load disturbances [12,15] as shown in Fig. 3. When then load demands are low, the RFB charges and the stored energy is delivered back to the system during the peak load demands. The dual converters which are connected with the batteries perform both AC-DC and DC-AC conversions. A simplified transfer function block representation of the RFB [12] [15], is given in Fig. 4. The RF batteries are capable of very fast response and so hunting due to a delay in response will not occur. For this reason the ACE (Area Control Error) is used as the command value for the RFB in controlling the output response in the LFC problem [20–23].

The controller of RFB is designed in the equivalent one area system to reduce the frequency deviation of inertia centre. The equivalent system is derived by assuming the synchronizing coefficient T_{12} to be large. The control purpose of RFB is to suppress the deviation of ΔF quickly against the sudden change of ΔP_d, the percent reduction of the final value after applying a step change ΔP_d is given as a control specification and the control gain of RFB is calculated.

3. An interconnected deregulated power system model

To improve the efficiency of operation of the existing power system scenario, deregulation principles has been introduced into the power system structure. In deregulated environment, the

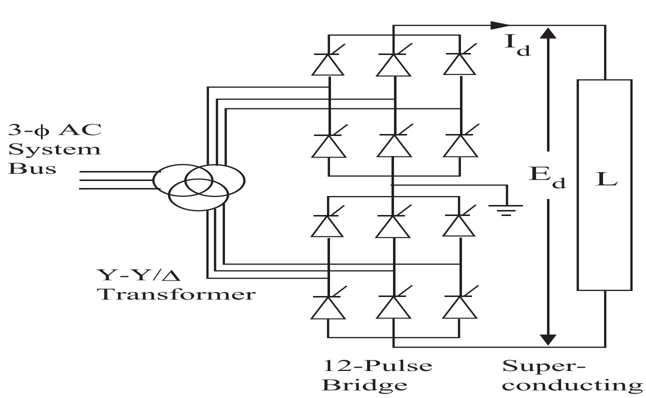

Fig. 1. The Schematic diagram of SMES unit.

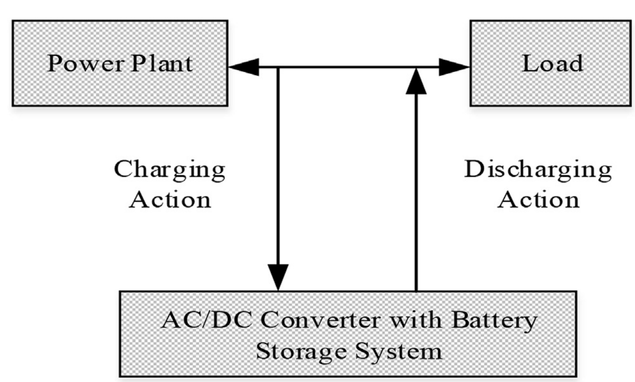

Fig. 3. Integration of RFB units in power system.