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Impact of energy storage system on load frequency control for diverse sources of interconnected power system in deregulated power environment

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ABSTRACT

This paper focuses Load Frequency Control (LFC) mechanism for multi-generating two areas interconnected power systems with energy storage system in a deregulated power environment. The two areas, demarcated as Area-I and Area-II, consist of thermal, hydro and gas power units. This paper also incorporates the economic load dispatch mechanism into the LFC for economical division of load during load deviation. Small signal stability analysis through participating factor has also been done to determine the oscillation state of the system, i.e., frequency deviation in both areas. Therefore, proper controller is required to reduce the oscillation of the system. The optimum value of the integral gain of the integral controller has to be selected to achieve the goal. Hence, Opposition-based Harmonic Search (OHS) technique is used for the optimization purpose. During major disturbance in the areas, primary and secondary controllers are not sufficient to reduce the frequency and tie-line power oscillation due to slow response of the governor mechanism. Therefore, energy storage system, i.e., Redox Flow Battery (RFB), is used for improvement of the dynamic response of the system which has very small time constant and quick response. The proposed control mechanism has been analyzed in a deregulated power environment with the help of different simulation case studies to find out improved dynamic performance over integral control strategies.

Introduction

In dynamic operations of power system, it is important to ensure reliable supply of electric power. This objective also entails the requirement for maintaining the frequency at a nominal value and good tie-line power flow profile, which is always affected by the constant change in the load demand in any power system. This requirement usually includes matching system generation with the system load which is the prime objective of LFC. Therefore, LFC is an essential mechanism in electric power system which balances supply of generated power and its demand in each control area in order to maintain the system frequency at nominal value and the power exchange between areas at its prescribed scheduled value.

The total generation of interconnected power systems comprises different sources of generation, such as, thermal, hydro, nuclear and gas. However, nuclear plants are considered to be the base load supplier because they provide the maximum output due to high efficiency and do not come under the LFC system. Gas power generation can easily meet the variable load demand. Therefore, it is used for peak demands only. In the available literature on this subject, a few researchers are found to have studied the LFC in the conventional power system by considering multi-source generating units [1,2]. Parmar et al. [2] designed a controller in deregulated environment for multi-source generation, including thermal-hydro-gas systems. Considering the present scenario, this paper focuses on multi-source power generation in each of the two areas. However, due to reduction in the system spinning reserve [3] in recent years and high time constant of hydro governor, LFC alone is not sufficient to take the load at higher disturbance. Therefore, energy storage system is the only solution to improve the dynamic response of the system. Kunisch et al. [4] explored the possibility of utilizing battery energy storage system in the LFC mechanism. Again, Liu and Wu [3] pursued their work further on Battery Energy Storage (BES) for LFC considering non-linearity of the system by incorporating deadband and Generation Rate Constraint (GRC). Aditya and Das [5] simulated the system with BES and designed the LFC for hydro-thermal power generation by incorporating a non-minimum phase system, which comprises

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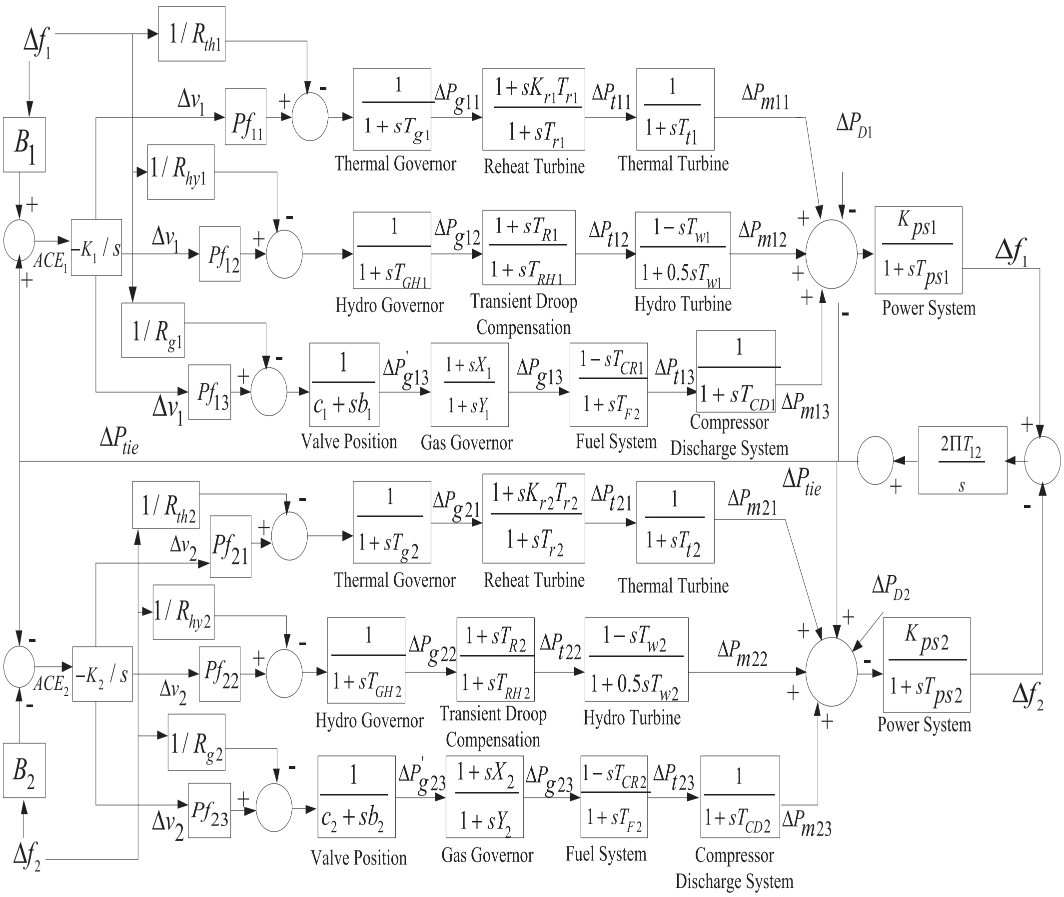

Fig. 1. Block-diagram of the interconnected power system for stability analysis.

hydro plant characteristics in thermal units. The BES can be effectively applied with the implementation of Flexible AC Transmission System (FACTS) device. Thyristor Controlled Phase Shifter (TCPS) in the interconnected power system further improves the LFC mechanism [6–8]. Paramsivam presented his work with the Redox Flow Batteries (RFB) in coordination with the Unified Power Flow Controller (UPFC) for improved frequency regulation support of LFC [9] through Artificial Bee Colony Algorithm. From literature, it can be concluded that energy storage system can improve the performance of LFC by active and fast power compensation. The storage facility also improves the reliability of the power transmission system during load changes.

In recent years, in light of the advancements in the power generation system, it has become necessary to review the LFC mechanism in the changed environment. Therefore Kumar et al. [10,11], Christie [12], Donde et al. [13] have described their work on deregulated power environment by considering different aspects of LFC. Fatim designed robust controller in the restructured environment by incorporating new features in the power system [14]. A few authors considered Genetic Algorithm (GA) and other techniques for optimization purpose [15,16] establishing its effectiveness in the LFC. The concept of deregulated power structure was explored by a few other authors in a decentralized control mechanism [17], which is applicable to the LFC system. Chidambaram made further investigation into the LFC by incorporating RFB in the concept of deregulation. The study further established the useful application of BES for the interconnected power system [18]. Certain other work have also been presented on conventional as well as non-conventional control schemes in the restructured power system [19–21].

Soft computing plays a very important role in optimization of the proposed controllers. Therefore, GA is a widely accepted optimization process and many papers have been published focusing on this aspect along with the LFC programming [22]. Due to certain limitations in GA, particle swarm optimization (PSO) has been included in the LFC program for the interconnected power system [16]. Due to premature convergence and stagnation of GA, PSO and some other optimization techniques, the harmonic search algorithm [23–25] is considered to be a better choice to overcome this drawback. It enables getting accurate and optimized value for the integral controller. Therefore, OHS technique [23] is used here for getting an optimized value for the gain of integral controller.

In the view of the above discussion, this paper seeks to propose an efficient LFC model in coordination with an energy storage system along with the non-linearities under deregulated power environment of an interconnected power system. The paper has been organized in the following manner:

(a) Modeling and stability analysis of the multi-source power generation of the two areas interconnected power system.
(b) OHS technique for optimization purpose of integral controller gain of the interconnected power system.
(c) Linearized modeling aspects of RFB, i.e., energy storage system, applicable to the proposed LFC mechanism.
(d) Study of the proposed LFC mechanism in coordination with the RFB under deregulated power environment with different simulation case studies.
(e) Results, discussion and conclusions.

Small signal stability analysis

The proposed interconnected power system has diverse sources of power generating stations. Area-I consists of a combination of