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Optimized load-frequency simulation in restructured power system with Redox Flow Batteries and Interline Power Flow Controller

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ABSTRACT

This paper proposes the Load Frequency Control (LFC) of an interconnected two-area multiple-unit thermal reheat power system in a restructured environment. In the restructured scenario, various kinds of apparatus with large capacity and fast power consumption may cause a series problem of frequency oscillations. The oscillation of system frequency may sustain and grow to cause a series frequency stability problem if no adequate damping is available. Moreover, the larger amount of the steam stored in steam chest and reheater of thermal power plant delays the control valve motion to increase the mechanical power output after the load perturbation. So in order to stabilize the system, impacts of Interline Power Flow Controller (IPFC) in series with tie-line and Redox Flow Batteries (RFB) at the terminal of area 1 have been investigated. The Bacterial Foraging Optimization (BFO) algorithm is used to optimize the integral gains of the Load-frequency Controller under different transactions in the competitive electricity market. Compliance with North American Electric Reliability Council (NERC) standards for Load Frequency Control has also been established in this work. Simulation studies reveal that the RFB coordinated with IPFC units for LFC loop has greater potential for improving the system's dynamic performance.

1. Introduction

The electric power business at present is largely in the hands of Vertically Integrated Utilities (VIU) which own generation, transmission and distribution systems that supply power to the customer at regulated rates. The VIU is usually interconnected to other VIU is almost always for the transmissions of power and denoted as tie-line. Thus, electric power can be bought and sold between VIU along these tie-lines and moreover, such interconnection provides greater reliability. The major change that has happened is the emergence of Independent Power Producer (IPP) that can sell power to VIU. Given the present situation, it is generally agreed that the first step in deregulation will be to separate the generation of power from the transmission and distribution, thus putting all the generation on the same footing as the IPP. In an interconnected power system, a sudden load perturbation in any area causes the deviation of frequencies of all the areas and also in the tie-line powers. This has to be corrected to ensure the generation and distribution of electric power with good quality. This is achieved by Load Frequency Control, also known as Automatic Generation Control (AGC). The main objectives of LFC [1,2] are to be maintained the desired megawatt output and the nominal frequency in an interconnected power system besides maintaining the net interchange of power between control areas at predetermined values. With the restructuring of electric utilities, Load Frequency Control requirements should be expanded to include the planning functions necessary to ensure the resources needed for LFC implementation are within the functional requirements. So most of the methods that may be proposed must have a good ability to track the contracted or non-contracted demands and can be used in a practical environment. A lot of studies have been made about LFC in a deregulated environment over last decades. These studies try to modify the conventional LFC system to take into account the effect of bilateral contracts on the dynamics [3] and improve the dynamical transient response of the system under competitive conditions [4–7].

This paper proposes a control scheme that ensures reliability and quality of power supply, with minimum transient deviations and ensures zero steady state error. The importance of decentralized controllers for multi area load-frequency control system, where in, each area controller uses only the local states for feedback, is well known. The stabilization of frequency oscillations in an interconnected power system becomes challenging when implements in the future competitive environment. So advanced economic, high efficiency and improved control schemes [8,9] are required to ensure the power system reliability. The conventional

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load-frequency controller may no longer be able to attenuate the large frequency oscillation due to the slow response of the governor [10]. The recent advances in power electronics have led to the development of the Flexible Alternating Current Transmission Systems (FACTS). These FACTS devices are capable of controlling the network condition in a very fast manner [11] and because of this reason the usage of FACTS devices are more apt to improve the stability of power system. Several FACTS devices, such as Thyristor Controlled Series Capacitor (TCSC), STATic synchronous COMpensator (STATCOM), Thyristor Controlled Phase Shifter (TCPS), Static Synchronous Series Compensator (SSSC), Unified Power Flow Controller (UPFC), Interline Power Flow Controller (IPFC), have been developed in recent decades [12]. An Interline Power Flow Controller consists of a set of converters that are connected in series with different transmissions lines which can effectively manage the power flow control in multi line systems. The schematic diagram of IPFC is illustrated in Fig. 1. The UPFC and IPFC consists at least two converters. It is found that, in the past, much effort has been made in the modeling of the UPFC to compensate a single transmission line for power flow analysis [13–15], whereas the IPFC is conceived for the compensation and power flow management of multi-line transmission system. Therefore, UPFC is not attractive for compensating multi-line systems from economical point of view [16]. Interline Power Flow Controller not only can compensate each transmission line separately but also can compensate all of them at the same time. It employs a number of Voltage Source Converters (VSC) linked at the same DC terminal; each of them can provide series compensation for its own line [17]. In this way, the power optimization of the overall system can be obtain in the form of appropriate power transfer through the common DC link from over-loaded lines to under-loaded lines [18]. A simple model of IPFC with optimal power flow control method to solve overload problem and the power flow balance for the minimum cost [19] has been proposed.

In this paper IPFC is being install in the tie-line between any interconnected areas, which is used to stabilize the area frequency oscillations by high speed control of tie-line power through the interconnections. In addition it can also be expected that the high speed control of IPFC can be coordinated with slow speed control of governor system for enhancing stabilization of area frequency oscillations effectively. Under these situations, the governor system may no longer be able to absorb the frequency fluctuations. In order to compensate for sudden load changes, an active power source with fast response namely Redox Flow Batteries are expected as the most effective counter measure. The Redox Flow Batteries will, in addition to load leveling, a function conventionally assigned to them, have a wide range of applications such as power quality maintenance for decentralized power supplies. The Redox Flow Batteries are the excellent short-time overload compensator and the response characteristics possessed in the particular [20,21]. The effect of generation control and the absorption of power fluctuation required for power quality maintenance are expected. However, it will be difficult to locate the placement of RFB alone in every possible area in the interconnected system due to the economical reasons. Therefore RFB coordinated with IPFC are capable of controlling the network conditions in a very fast and economical manner.

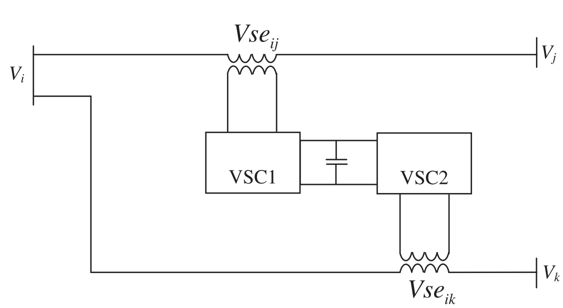

Fig. 1. Schematic diagram IPFC.

Now-a-days the complexities in the power system are being solved with the use of Evolutionary Computation (EC) such as Differential Evolution (DE) [22], Genetic Algorithms (GA), Practical Swarm Optimizations (PSO) [23], and Ant Colony Optimization (ACO) [24], which are some of the heuristic techniques having immense capability of determining global optimum. Classical approach based optimization for controller gains is a trial and error method and extremely time consuming when several parameters have to be optimized simultaneously and provides suboptimal result [23,24]. Some authors have been applied GA to optimize the controllers gain more effectively and efficiently than the classical approach. But the premature convergence of GA degrades its search capability. Recent research has brought out some deficiencies in using GA, PSO based techniques [25,26]. The Bacterial Foraging Optimization [BFO] mimics how bacteria forage over a landscape of nutrients to perform parallel non-gradient optimization [27]. The BFO algorithm is a computational intelligence based technique that is not affected larger by the size and non-linearity of the problem and can be convergence to the optimal solution in many problems where most analytical methods fail to converge. This more recent and powerful evolutionary computational technique BFO [28] is found to be user friendly and is adopted for simultaneous optimization of several parameters for both primary and secondary control loops of the governor. In this study, BFO algorithm is used to optimizing the integral controller gains for the load frequency control of a two-area thermal power system without and with IPFC and RFB. To obtain the best convergence performance, a cost function is derived by using the tie-line power and frequency deviations of the control areas and their rates of changes according to time integral. The main function of LFC is to regulate a signal called Area Control Error (ACE), which accounts for error in the frequency as well as the errors in the interchange power with neighboring areas. Conventional Load Frequency Control uses a feedback signal that is either based on the Integral of ACE or is based on ACE and it is Integral. These feedback signals are used to maneuver the turbine governor set points of the generators so that the generated power follows the load fluctuations. However, continuously tracking load fluctuations definitely causes wear and tear on governor's equipment, shortens their lifetime, and thus requires replacing them, which can be very costly.

Control Performance Criteria (CPC) has been formerly used to evaluate AGC performance. The Control Performance Standard (CPS) is specifically designed to comply with the performance standards imposed by the North American Electric Reliability Council (NERC) for equitable operation of an interconnected system. Control Performance Standard 1 (CPS1) and Control Performance Standard 2 (CPS2) are derived from rigorous theoretical basis. CPS1 is a measurement to asses the performance of frequency control in each area. CPS2 is designed to restrain the ACE 10-min average value and in doing so provides a means to limit excessive unscheduled power flows that could results from large ACE. This paper presents a novel load frequency controller which is being manipulated by Fuzzy logic system whose rules are designed to reduce wear and tear of the equipment and assures the NERC's control performance standards [29,30], CPS1 and CPS2. Considering the power system Load Frequency Control, this paper establishes a fuzzy logic controller to predict the future frequency of the target object, thus forecasting the optimized controller is designed, which follows the Control Performance Standards through the fuzzy logic rules. This control structure is a decentralized, integral type controller whose parameter is automatically tuned using Bacterial For-