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Load frequency control in deregulated power system integrated with SMES–TCPS combination using ANFIS controller

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ABSTRACT

In this paper, the application of Adaptive Neuro Fuzzy System (ANFIS) controller is used for mitigating the various Load Frequency Control (LFC) issues in a two area hydrothermal power system under deregulated environment is highlighted. To improve the LFC performance, combination of Super Conducting Magnetic Energy Source (SMES) and Thyristor Controlled Phase Shifters (TCPS) are included in its control area. The implementation of SMES–TCPS combination arrests the initial fall in frequency as well as the tie line power deviations after a sudden load disturbance. To investigate the effectiveness of the proposed approach, the dynamics of the system is analyzed with unilateral, bilateral and contract violation cases for a small load perturbation and the comparative results are also presented. The simulated results show that the performance of ANFIS controller is better than the conventional PI controller and the Fuzzy logic controller.

Introduction

LFC is addressed as one of the most important services in electric power system design and it has been used for several decades to meet two main objectives, viz., maintaining the system frequency and the tie line power deviations within specified values. The fundamental theory of LFC has been explained in [1–3]. LFC is generally considered as secondary level control and also a dominant operation in the area of automatic generation control (AGC) [3].

After restructuring, competitive electricity market have engaged with new market players like generating companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs), and Independent System Operators (ISO). These market players equalize the generation and load demand to maintain a stable system under highly competitive and distributed control environment [4–7]. A large power system network consists of many GENCOs and DISCOs and each of these GENCOs and DISCOs have different contract with each other for power transactions [6–10]. Pai et al. explained the different types of contract available in deregulated markets [6]. In addition with this, ISO provides several ancillary services for stable and secure power system operation. As per NERC standard, regulation and load following are considered as the two frequency related ancillary services [7]. The critical function of LFC is still continuing in deregulated power system with contract scenarios and deregulation policies. Bose et al. reported the various LFC issues in a deregulated power system [5].

Various researchers have focused on different types of fast acting energy storage devices to damp out the area frequency oscillations and tie line power deviations due to an unexpected load variation [11–13]. A detailed description of various energy storage technologies like battery energy storage systems (BESS), pumped storage hydroelectric system, super capacitors, superconducting magnetic energy storage (SMES) are described in [12–14] along with its advantage and disadvantages. Banerjee et al. explained the effect of magnetic energy storage for improving the load-frequency dynamics [11]. Active and reactive power control is one of the key factors of SMES [16]. This is one of the major reasons for considering it as a stabilizer for power frequency oscillations in LFC issues. The feasibility of SMES for mitigating power system dynamics issues has been reported in [12,13]. Moreover, applications of Flexible AC Transmission (FACTS) devices improve the power transfer capability and maintain the dynamic stability of the system [10,15,17,18]. So, the usage of FACTS devices gives better stability in the power system network. Bhatt et al. reported that Thyristor Controlled Phase Shifters (TCPS) can be effectively used for stabilizing the power frequency oscillations in an interconnected system.

Literature survey highlights that several researchers proposed different controller strategies for minimizing the load frequency

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Nomenclature

f	system frequency
B	frequency bias constant
R	governor speed regulation parameter
AGC	automatic generation control
LFC	load frequency control
ACE	area control error
GENCO	Generation company
DISCO	Distribution company
TRANSCO	Transmission company
ISO	independent system operator
VIU	vertically integrated utility
DPM	DISCO participation matrix
apf	area participation factor
cpf	contract participation factor
T_P	power system equivalent time constant
T_G	governor time constant
T_T	turbine time constant
T_{12}	tie-line synchronizing coefficient between areas
ΔP_{tie12}	net tie-line power flow
K_{TCPS}	TCPS gain constant
T_{TCPS}	TCPS time constant
$K\varphi$	TCPS gain constant
K_{SMES}	SMES gain constant
T_{SMES}	SMES time constant

control issues in a deregulated environment. These classical controllers used for AGC are proportional, integral, derivative and their combinations which are explained in [14–16,19,20]. In addition to these controllers, soft computing techniques like fuzzy logic, artificial neural network (ANN), ant colony algorithm, genetic algorithm (GA), particle swam optimization (PSO) etc are also implemented for LFC issues [4,15,16]. Khuntia et al. implemented the ANFIS controller in a multi-area power system under conventional scenario [21].

For analyzing the various LFC issues in a deregulated power system, the test system consists of a two area hydrothermal deregulated power system. In this model, TCPS unit is placed along with the tie-line and SMES unit is placed in its control area. To mitigate the various LFC issues in a two-area hydrothermal power system, SMES–TCPS combination is placed in the two control areas and the transient performance of the same is evaluated. Actual power generation in each GENCOs, area frequency oscillations and tie-line power deviations for three different contract scenarios is also calculated. Simulation studies are carried out under MATLAB/Simulink environment with ANFIS controller and the results are compared with the conventional PI and fuzzy logic controllers. Detailed time domain analysis is also included in the further sections.

Deregulated power system

After restructuring, the entire VIU is divided into different organizations viz., generation companies (GENCOs), transmission companies (TRANSCOs), distribution companies (DISCOs), and independent system operators (ISO). The deregulated structure contains a number of GENCOs and DISCOs, each DISCO having contract with GENCOs in their area or any other control area. Such transactions are called "bilateral Trading" and these transactions have to be implemented through ISO only. The DISCO Participation Matrix (DPM) is used to express these different contracts in a matrix form. This DPM helps us to identify these contracts easily. In a DPM matrix, number of rows and columns represent the number of GENCOs and number of DISCOs respectively [6]. Each entry in the DPM is represented as contract participation factor (cpf) and it is the ratio of each GENCOs participation to total DISCO demand. In a DPM matrix, diagonal elements represent the local demand and off-diagonal elements represent the contribution from other areas. In general *cpf* can be written as:

$$\sum_i cpf_{ij} = 1.0.$$

For simulation purpose, we consider a two area AGC system under open market scenario in which area-1 comprises of two non-reheat thermal units, viz. GENCO-1 and GENCO-2 and area-2 having two hydro units viz. GENCO-3 and GENCO-4. Transfer function model of a two area deregulated hydrothermal power system with SMES and TCPS as shows in Fig. 1. The system parameters are explained in Appendix A. The contract between GENCOs and DISCOs are represented using DPM matrix explained in [6]. The corresponding DPM will become

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \tag{1}$$

The scheduled power flow through tie-line under steady state condition is expressed as $\Delta P_{tie12,sch}$ = (Demand of DISCOs in area-2 from GENCOs in area-1) – (Demand of DISCOs in area-1 from GENCOs in area-2). The scheduled tie-line power flow is given as:

$$\Delta P_{tie12,sch} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\Delta P_{Lj} \tag{2}$$

The actual power flow through tie line is expressed as

$$\Delta P_{tie12,act} = \frac{T_{12}}{s}(\Delta\omega_1(s) - \Delta\omega_2(s)) \tag{3}$$

At any time instant, error occurring in the tie-line power is

$$\Delta P_{tie12,err} = \Delta P_{tie12,act} - \Delta P_{tie12,sch} \tag{4}$$

Under steady state condition, if the actual power flow in the tie line meets the scheduled power flow then the $\Delta P_{tie12,err}$ will become zero. In general, this error signal is used to generate the conventional ACE signal which is defined below:

$$ACE_i = B_i\Delta\omega_i + \Delta P_{tie12,err}, \quad i = 1,2 \tag{5}$$

Under steady state condition, the desired generation of a GENCO in pu MW can be expressed in terms of cpf and the total load demand of DISCOs including uncontracted demand is shown below

$$\Delta P_{Gi} = \sum_j cpf_{ij}\Delta P_{Lj} - apf\sum \Delta P_{UCi} \tag{6}$$

where ΔP_{Gi} is the desired power generation, ΔP_{Lj} is the total demand of *j*th DISCO and ΔP_{UCi} is the uncontracted demand.