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# Design of integral controller for Load Frequency Control of Static Synchronous Series Compensator and Capacitive Energy Source based multi area system consisting of diverse sources of generation employing Imperialistic Competition Algorithm

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ABSTRACT

This paper presents the design of integral controller for Load Frequency Control (LFC) under deregulated environment having diverse sources of power generation employing Imperialistic Competition Algorithm (ICA). Static Synchronous Series Compensator (SSSC) along with Capacitive Energy Storage (CES) has also been proposed to further increase the dynamic performance of the system in terms of peak time, overshoot and settling time. The concept of soft computing techniques greatly helps in overcoming the disadvantages posed by the conventional controllers. Open transmission access and the evolving of more socialized companies for generation, transmission and distribution affects the formulation of LFC problem. So the traditional LFC system is modified to take into account the effect of bilateral contracts on the dynamics. Simulation results show that the Imperialistic Competition Algorithm based system employing Static Synchronous Series Compensator and Capacitive Energy Source has better dynamic performance over the system without these parameters.



## Introduction

Electric power generation and consumption should perfectly go hand-in-hand if an electric energy system is to be strictly maintained in its nominal state characterized by nominal frequency, voltage profile and load flow configuration. But because of the random nature of the power demands, the power generation consumption at equilibrium, cannot be strictly met in reality. Thus, a power deviation occurs. This imbalance causes a deviation of system frequency and tie-power from its scheduled values. The successful operation of a power system is the process of properly maintaining several sets of balances. Two of these balances are between load-generation and scheduled and actual tie line flows. These two balances are predominant factors to keep the frequency constant. Constant frequency is identified as the primary index of healthy operation of system and the quality of supplied power to consumer as well. Both of these balances are maintained by adjusting generation keeping load demand in view. If frequency is low, generation is increased and if the actual outflow is greater than the scheduled outflow, generation is decreased. Since system conditions are always changing as load constantly varies during different hours of a day, precise manual control of these balances would be impossible. Load Frequency Control (LFC) is developed to maintain a (nearly) constant frequency and to regulate tie line flows [1,2].

Under open market system (deregulation) the power system structure is changed in such a way that would allow the evolving of more specialized industries for generation (Genco), transmission (Transco) and distribution (Disco). A detailed study on the control of generation in present demand on interconnected system is given in [3]. The concept of independent system operator (ISO) as an unbiased coordinator to balance reliability with economics has also emerged [4,5]. The assessment of Automatic Generation control (AGC) in a deregulated environment is given in [6]. The detailed review over deregulation issue and explains how an AGC system could be simulated after deregulation is given in [7]. Nandha et al. [8] have shown the performances of several types of classical

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**Nomenclature**

| | |
|---|---|
| $\alpha$, $\beta$ | weighting factors |
| $\Delta f_1$ | change in frequency in area 1 |
| $\Delta f_2$ | change in frequency in area 2 |
| $\theta_c$ | phase angle of the current |
| $\theta_m$ | phase angle of the voltage at bus *m* |
| $\theta_n$ | phase angle of the voltage at bus *n* |
| $I$ | current flow from bus *m* to *n* |
| $J$ | performance index |
| $V_m$ | voltage magnitude of the bus *m* |
| $V_n$ | voltage magnitude of the bus *n* |
| $V_s$ | SSSC voltage |
| $X_s$ | SSSC reactance |
| $X_L$ | line reactance |
| $X_T$ | total reactance |
| $S_{mn}$ | power flow from the bus *m* to *n* |
| $P_{mn}$ | real power flow from bus *m* to *n* |
| $Q_{mn}$ | reactive power flow from bus *m* to *n* |
| $\Delta P_{tie12}$ | change in tie line power |
| $\Delta P_{SSSC}$ | change in power output of SSSC |
| $K_{SSSC}$ | gain of the SSSC |
| $T_{SSSC}$ | time constant of SSSC |
| $T$ | time constant of compensation blocks |
| $K_{CES}$ | gain constant of CES |
| $T_{CES}$ | time constant of CES |
| apf | AEC participation factor |
| *DPM* | Disco participation matrix |
| $n_{count}$ | total number of countries |
| $N_{imp}$ | most powerful countries from *n*th empire |
| $N_{col}$ | remaining countries from *n*th empire |
| $ic_n$ | cost of *n*th imperialist |
| $IC_n$ | normalized cost |
| $IP_n$ | initial number of colonies of the *n*th empire |
| $col_n^i$ | position of *i*th colony of the *n*th imperialist |
| $I_n$ | position of *n*th imperialist |
| $newcol_n^i$ | updated positions of colonies of *n*th empire |
| $TP_n$ | total power of *n*th empire |
| $\xi$ | positive number less than 1 |
| $NTP_n$ | normalized power of *n*th empire |
| $ps_n$ | possession probability of *n*th empire |

controller in Automatic Generation Control for an interconnected multi area thermal system.

On the other hand, the concept of utilizing power electronic devices for power system control has been widely accepted in the form of Flexible AC Transmission Systems (FACTS). A Static Synchronous Series Compensator and Thyristor Controlled Phase Shifter (TCPS) for two area hydro-hydro power system in [9]. In addition, a small capacity CES unit to the system significantly improves the dynamic responses of the system is given in [10–12]. A Static Synchronous Series Capacitor and Capacitive Energy Storage are expected to be an effective apparatus for the analysis of tie-line power flow control of an interconnected power system [13]. The proposed control strategies will be new ancillary services for the stabilization of frequency oscillations of an interconnected power system.

In recent years intelligent methods such as Genetic algorithm (GA), Simulated Annealing (SA), Particle Swarm Optimization (PSO) and Imperialistic Competition Algorithm (ICA) have been applied to various problems of electrical engineering. The salient feature of these soft computing techniques are that they provide a model-free description of control systems and do not require any model identification. A detailed study on the ICA applied to unit commitment problem is given in [14]. This paper deals with ICA for designing the gain of integral controller in a multi area interconnected hydrothermal system with SSSC and CES under deregulation.

The remainder of the paper is organized as follows: Section 'LFC under deregulated scenario' focuses on Load Frequency Control under restructured scenario. Section 'Modeling of SSSC and CES' emphasizes on modeling and implementation of SSSC and CES. The concept of ICA applied to LFC is discussed in Section 'Imperial istic Competition Algorithm'. The results and discussions are presented in Section 'Results and discussions'.

## LFC under deregulated scenario

Electric power systems are generally very complex, nonlinear dynamic systems. The control valves associated with high pressure turbine are controlled by the load frequency controller for very small variations [15]. The AGC system investigated is composed of an interconnection of two areas. Area 1 comprises of a reheat system and area 2 comprises of hydro system. Whenever a load demanded by a Disco changes it reflects as a local load in the area to which this Disco belongs. As there are three Gencos and two Discos in each area. Area Control Error (ACE) signals has to be distributed among them in proportion to their participation in the AGC. Coefficients that distribute ACE to several Gencos are termed as ACE participation factors (apfs). It should be noted that $\sum_{j=1}^{m} \text{apf}_j = 1$, where m is the number of Gencos. The system under study is multi area hydrothermal system under deregulated scenario. All the various elements of the system such as governor, turbine and power system are represented by first order transfer function according to IEEE Committee report on Dynamic models for Steam and Hydro turbines in power systems [15]. Fig. 1 shows the transfer function block diagram of a two-area interconnected hydrothermal system with SSSC and CES under open market scenario. The parameters of two-area model are defined in Appendix.

The performance index (PI) namely, integral of square of error (ISE) given by

$$J = \int_0^t \left( \alpha \cdot \Delta f_1^2 + \beta \cdot \Delta f_2^2 + \Delta P_{tie12}^2 \right) \quad (1)$$

is considered in this work to compare the performance of system with ICA in coordination of SSSC and CES.

## Modeling of SSSC and CES

### *Design of SSSC*

A SSSC employs a self-commutated voltage-source switching converter to synthesize a three-phase voltage in quadrature with the line current, emulates an inductive or a capacitive reactance so as to influence the power flow in the transmission lines. The compensation level can be controlled dynamically by changing the magnitude and polarity of injected voltage, $V_s$ and the device can be operated both in capacitive and inductive mode. The schematic of an SSSC, located in series with the tie-line between the interconnected areas, can be applied to stabilize the area frequency oscillations by high speed control of the tie-line power through