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Optimal Control of Thermal Hydro Gas AGC In Deregulated Power Systems With CES

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Abstract

This paper presents a suitable mathematical model of Thermal-Hydro (T-H), Thermal-Hydro-Gas (T-H-G) Automatic Generation Control (AGC) system under deregulated environment. The variable power consumption as well as intermittent load variation may cause large fluctuations on system frequency. To reduce the system oscillations Capacitive Energy Storage (CES), which will supply and absorb active, reactive powers quickly, can be applied. The system transfer function model comprises thermal, hydro and gas power generations with governor models and system load for studying the dynamic response for small load perturbations along with the model of capacitive energy storage system. Integral controllers have been considered in both the areas whose optimal values are obtained by minimising the Integral Squared Error (ISE) technique. The particle swarm optimization (PSO) is applied to solve the control problem to achieve the controller parameters and also to optimize the Integral Controllers of two area power system in deregulated environment. The dynamic responses without and with CES unit are compared. Simulation studies reveal that with the application of the CES unit, there is an improvement in AGC in terms of peak amplitudes and deviations in frequencies of both the areas.

Introduction

In the traditional power systems, the generation, transmission and distribution are owned by a single entity called a vertically integrated utility (VIU), which supplies power at regulated rates. Such VIUs are interconnected by tie lines to other VIU's to enhance reliability. Following a load disturbance within a VIU, the frequency of that VIU experiences a transient change, and the feedback mechanism comes into play and generates an appropriate rise/lower signal to the turbine to make the generation follow the load. In steady state, the generation is matches with the load, driving the tie line power and frequency deviations to zero.

As deregulation in electric industry is a fast approaching reality, the operation and regulation of the power system in this new type of environment will be different from as it was in the regulated scheme. Under deregulation the power system structure changed in such a way that would allow the evolving of more specialized industries for generation (GENCO), transmission (TRANSCO) and distribution (DISCO). In the context of open access, increased competition two questions have been consistently rising; (i) how can system reliability and security be maintained and (ii) how can be economic efficiency maintained?. As a result, the concept of independent system operator (ISO) as an unbiased coordinator to balance reliability with economics has emerged [2-3]. However, the common operational objectives, i.e. restoring the frequency and the net interchanges to their desired values for each control area remain.

In order to reduce the system frequency deviation to a minimum value during the load variations, the storage system such as battery energy storage system (BESS) can be incorporated. The use of BESS to improve the LFC dynamics of West Berlin Electric Supply System has been presented in [17]. Study in [18] have revealed that use of BESS is helpful in meeting sudden requirements of real power and is effective in reducing the peak deviations of frequency and tie-line power. Thus it reduces the steady-state values of time error and inadvertent interchange accumulations. Presented the effectiveness of small sized magnetic energy storage units (both super conducting and normal loss types) to improve the load-frequency dynamics of two-area thermal power system is presented by Banerjee et al in [23]. Study of governor dead-band and GRC effect on LFC along with BESS is presented by Chun et al in [19]. Fuzzy gain scheduled SMES unit for improvement of LFC in two-area thermal power system is presented in [21]. Feasibility of using an IGBT convert or instead of thyristor convertor as a power conditioning system with the SEMS is presented in [22]. Some more applications of SMES for improving the LFC area also mentioned in [23–27].

The main objective of the paper is to consider the three types of generators to be part of AGC (Thermal, Hydro, Gas) and study the improvement in AGC of two area power system under deregulated environment when CES is used to improve the dynamic performance of the system. The performance of the system is compared with the two area deregulated AGC system without CES. To achieve the controller parameters, the Particle Swarm Optimization (PSO) [28-32] is used to solve the objective function. This paper is organized as follows, In section 2 we first briefly present the AGC model proposed in [16] and which overcomes the limitations of the earlier models proposed in [1-15]. Dynamic model of the Gas generating station is also includes as a part of the considered model. In the section 3 we present the dynamic model of Capacitive Energy Storage (CES) system used for the improvement of the system response. Particle Swarm Optimization algorithm used for the optimization of controller parameters is discussed in section 6. Simulation results are given in section 5, to highlight the difference between the performance of the Thermal-Hydro-Gas AGC systems with and without Capacitive Energy Storage (CES) system inclusion.

AGC In Deregulated Power Systems

The conventional model, that’s being used by several researchers [1-15] is essentially a simple extinction of traditional Elgerd model [1]. In this AGC model, the concept of disco participation matrix (DPM) is included to the conventional AGC model to incorporate the bilateral load contracts. The DPM gives the extent of consumption of a DISCO from a particulate GENCO. In a power system with m DISCOs and n GENCOs, the DPM is given as

$$DPM = \left[\begin{array}{cc|cc} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ \hline cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{array}\right]$$

cpf_{ij} is the "generation participation factor", which shows the participation factor of GENCO i in the load following of DISCO j. The sum of all the entries in a column in this matrix is unity ($\sum_{i=1}^{n} cpf_{ij} = 1$). Whenever a load demanded by a DISCO changes, it is reflected as a local load in the area to which this DISCO belongs.

These information signals which are not present in the conventional AGC. In [1] introduction of these signals are justified arguing that these signals give an indication regarding which generator has to follow to which DISCO. As there are many GENCOs in each area, AGC signal has to be distributed among them according to their participation in the AGC. "ACE (Area Control Error) participation factors (apf)" are the coefficient factors which distributes the ACE among GENCOs. If there are 'm' number of GENCOs then $\sum_{i=1}^{m} apf_i = 1$.In this model, the scheduled value of steady state tie line power is given as

$\Delta P_{1-2,scheduled}$ = (demand of DISCOs in area II from GENCOs in area I) -
(demand of DISCOs in area I from GENCOs in area II)

Then the tie line power error $\Delta P_{1-2,error}$ is expressed as

$$\Delta P_{1-2,error} = \Delta P_{1-2,actual} - \Delta P_{1-2,scheduled}$$

$\Delta P_{1-2,error}$ is used to generate the respective ACE signals instead of ΔP_{tie} in traditional power systems. ACE of ith area will be given as

$$ACE_1 = B_1 \Delta F_1 + \Delta P_{1-2tie,error}$$

$$ACE_2 = B_2 \Delta F_2 + \Delta P_{2-1tie,error}$$

The two area AGC system considered has two individual areas connected with a tie line. The deviation in each area frequency is determined by considering the dynamics of the governors, turbines, generators and loads represents in that area. The tie line deviation between the areas is computed as the product of the tie line constant and the frequency deviation difference between two areas. Figure 1 shows the AGC model of the two area system considered. Figure 2 shows dynamic models of the generators in the modeling of each area. The state space representation of AGC model is given by

$$\dot{x} = Ax + Bu + \Gamma p + \beta q \qquad (1)$$

Where x is state vector, u is control vector and p is disturbance vector. A, B and Γ and β are the constant matrices associated with state, control, disturbance and bilateral contract vectors respectively. The tie line power in two area AGC is given as

$$\Delta P_{tie12} = \frac{T_{12}}{s}\left(\Delta f_1 - \Delta f_2\right) \tag{2}$$

The scheduled power on the tie line in the direction from area I to area II is

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

From the AGC model, frequency and tie line power error signals are used to generate the ACE signal in respective area [1]. This ACE of the area is written as

$$ACE_1 = B_1.\Delta f_1 + \Delta P_{tie12-error} \tag{3}$$

$$ACE_2 = B_2.\Delta f_2 + \Delta P_{tie21-error} \tag{4}$$

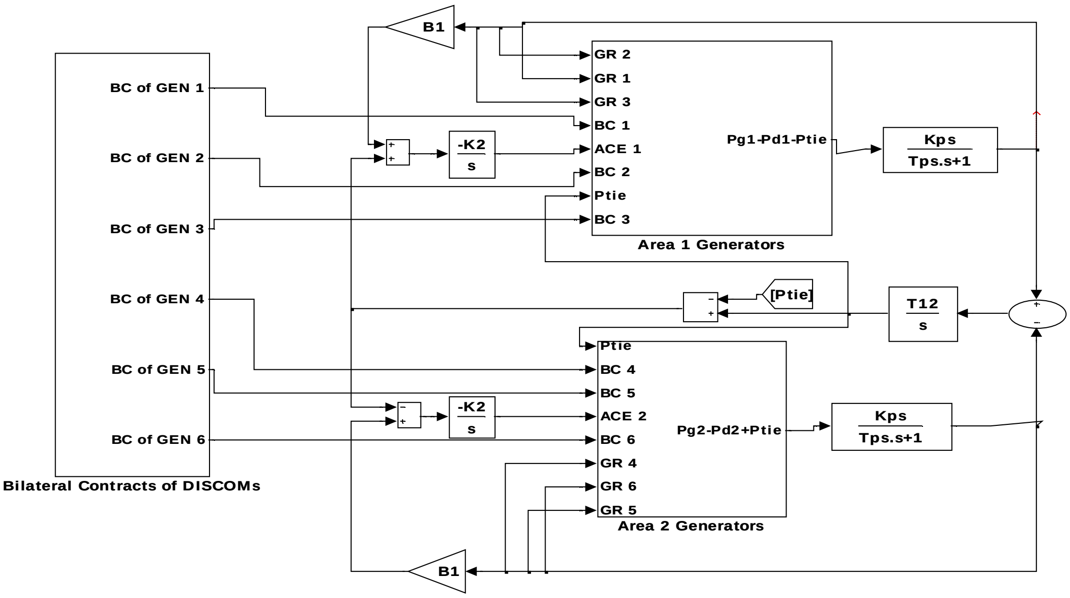


Figure 1: Modified model of AGC in deregulated power systems with Thermal, Hydro and Gas generators

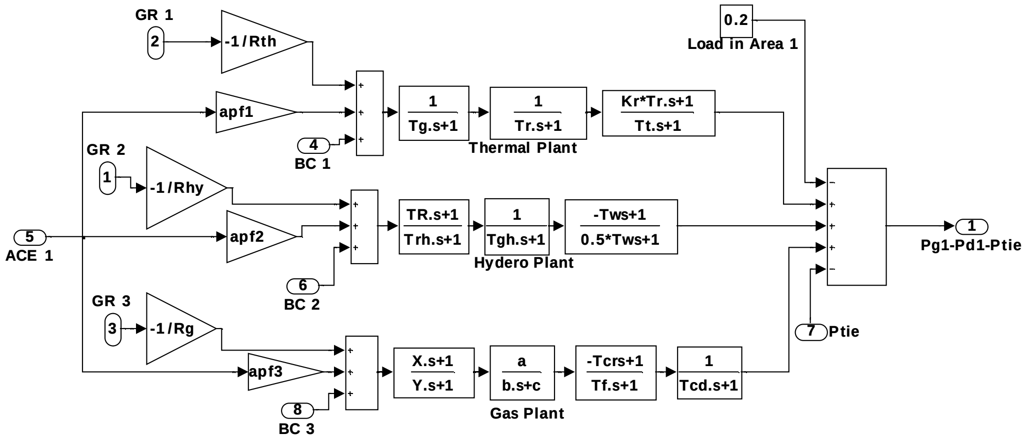


Figure 2: Sub system of the area 1 generators

Capacitive Energy Storage Systems

A Capacitive Energy Storage (CES) is represented as combination of a super-capacitor or a cryogenic hyper-capacitor (CHC), a power conversion system (PCS) which includes a inverter/rectifier. The storage capacitor also consist of many discrete capacitors connected in parallel, having lumped capacitance C .During the normal operating of grid, the capacitor can be changed to a set value of voltage which is less than the full charge. Charging in the steady state mode and the power modulation during dynamic oscillatory period is controlled by the application of the proper voltage to the capacitor so that the desired current flows into or out of the CES. This control is provided by controlling the firing angle of the converter bridges. The capacitor is initially charged to its normal voltage, Edo by the PCS. Once the voltage of the capacitor has reached, Edo it is kept floating at this voltage by continuing Supply from the PCS to compensate for Dielectric and other leakage losses of the capacitor. The energy stored at any instant,

$$W_c = \frac{CE_d^2}{2} MJ$$

Where

C = capacitance of CES (farad), Ed=Dc Voltage applied to the Capacitor.

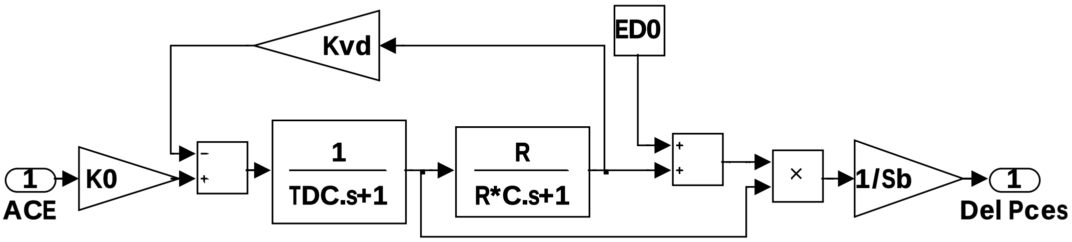


Figure 3: Block diagram of Capacitive Energy Storage

Particle Swarm Optimization

Particle swarm optimization is a population-based stochastic optimization algorithm which is first introduced by Kennedy and Eberhart in 1995 [28-29]. PSO algorithm gives high quality solutions within shorter calculation time and stable convergence characteristics than other stochastic methods such as genetic algorithm [30]. PSO uses particles which represent potential solutions of the problem. Each particles fly in search space at a certain velocity which can be adjusted in light of proceeding flight experiences. The projected position of i_{th} particle of the swarm x_i, and the velocity of this particle v_i at $(t+1)_{th}$ iteration are defined and updated as the following two equations:

$$v_i^{t+1} = v_i^t + c_1 r_1 \left(p_i^t - x_i^t \right) + c_2 r_2 \left(g_i^t - x_i^t \right)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1}$$

Where, i = 1, ..., n and n is the size of the swarm,

c_1 and c_2 are positive constants,

r_1 and r_2 are random numbers which are uniformly distributed in [0, 1],

t determines the iteration number,

p_i represents the best previous position (the position giving the best fitness value) of the i_{th} particle,

and g represents the best particle among all the particles in the swarm.

The flowchart of standard PSO algorithm is presented in Fig.4. At the end of the iterations, the best position of the swarm will be the solution of the problem. It cannot always possible to get an optimum result of the problem, but the obtained solution will be an optimal one. The complex problem with many local optima and optimization parameters the standard PSO algorithm may fall into premature convergence, so the craziness based PSO algorithm is effective in finding out global optimization in very complex search spaces is developed [31]. PSO algorithm used for load frequency control is presented in [32]. The main difference between PSO and crazy-PSO is the propagation mechanism to determine new velocity for a particle as follows:

$$v_i^{t+1} = r_2 sign\left(r_3\right) v_i^t + \left(1 - r_3\right) c_1 r_1 \left(p_i^t - x_i^t \right) + \left(1 - r_2\right) c_2 \left(1 - r_1\right) \left(g^t - x_i^t \right)$$

$$x_i^{t+1} = x_i^t + v_i^{t+1} + P\left(r_4\right) sign\left(r_4\right) V_{cr}$$

Where p_i is the local best position of particle i, and

g_i is the global best position of the whole swarm.

r_1, r_2, r_3 and r_4 are random parameters distributed uniformly in [0, 1],

and c_1, c_2 are named step constants and are taken 2.05 generally. The sign is a function defined as follows for r_3 and r_4,

$$sign\left(r_3\right) = \begin{cases} -1 \Leftarrow r_3 \le 0.05 \\ 1 \Leftarrow r_3 \succ 0.05 \end{cases}$$

$$sign(r_4) = \begin{cases} -1 \Leftarrow r_4 \le 0.05 \\ 1 \Leftarrow r_4 \succ 0.05 \end{cases}$$

In birds flocking or fish schooling, since a bird or a fish often changes directions suddenly, in the position updating formula, a craziness factor, V_{cr}, is used to describing this behaviour. In this study, it is decreased linearly from 10 to 1. P(r4) is defined as

$$P(r_4) = \begin{cases} 1 \Leftarrow r_4 \le P_{cr} \\ 0 \Leftarrow r_4 \succ P_{cr} \end{cases}$$

where P_{cr} is a predefined probability of craziness and is introduced to maintain the diversity of the particles. It is taken 0.3 in this study. The crazy-PSO algorithm can prevent the swarm from being trapped in local minimum, which would cause a premature convergence and lead to fail in finding the global optimum [12, 13].

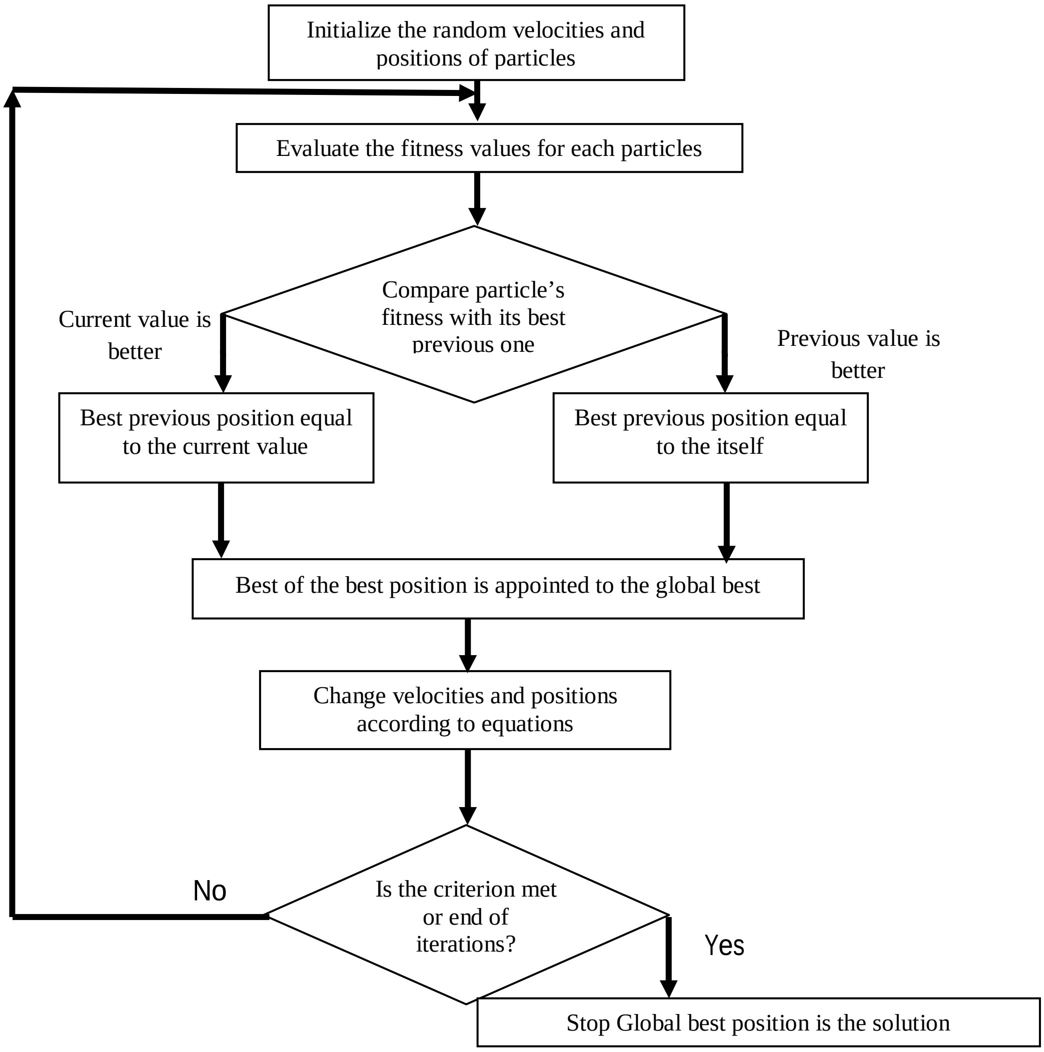


Figure 4: Flow chart for particle swarm optimization.

The two area system in the deregulated case with identical areas can be optimized with respect to system parameters to obtain the best response. The parameter involved in the feedback is the integral controller (K_I). The optimal value of K_I depend upon the cost function used for optimization. The integral of squared error criterion (ISE) is used in this case, The objective of this controller is achieved by minimizing a performance index (J). Where J is given as

$$J = \int \left(\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie12-error}^2 \right) dt$$

Simulation Results

Case 1:

Two area AGC model with Thermal Hydro Gas generating systems is used to illustrate the performance of the present model. To study this model, consider a case where all the DISCOs contract with the GENCOs for power as per the bellow DPM:

$$\text{DPM}=\begin{bmatrix} 0.1 & 0 & 0.2 & 0 \\ 0.2 & 0.1 & 0.1 & 0.5 \\ 0.3 & 0.2 & 0.3 & 0.1 \\ 0.2 & 0.1 & 0 & 0.2 \\ 0.2 & 0.2 & 0.3 & 0.2 \\ 0 & 0.4 & 0.1 & 0 \end{bmatrix}$$

It is assumed that each DISCO demands 0.01pu power from GENCOs as defined in DPM and each GENCO participated in AGC as defined by following apfs: apf1=0.33, apf2=0.33, apf3=0.34, apf4=0.33, apf5=0.33, apf6=0.34.

For the DPM mentioned above GENCOs generation must be

$$\Delta P_{m1} = 0.003; \Delta P_{m2} = 0.009; \Delta P_{m3} = 0.009; \Delta P_{m4} = 0.005;$$
$$\Delta P_{m5} = 0.009; \Delta P_{m6} = 0.005$$

The total local load in area 1

$$\Delta P_{L1,LOC} = \text{Load of DISCO}_1 + \text{Load of DISCO}_2$$

=0.02 pu MW (no un contracted load)

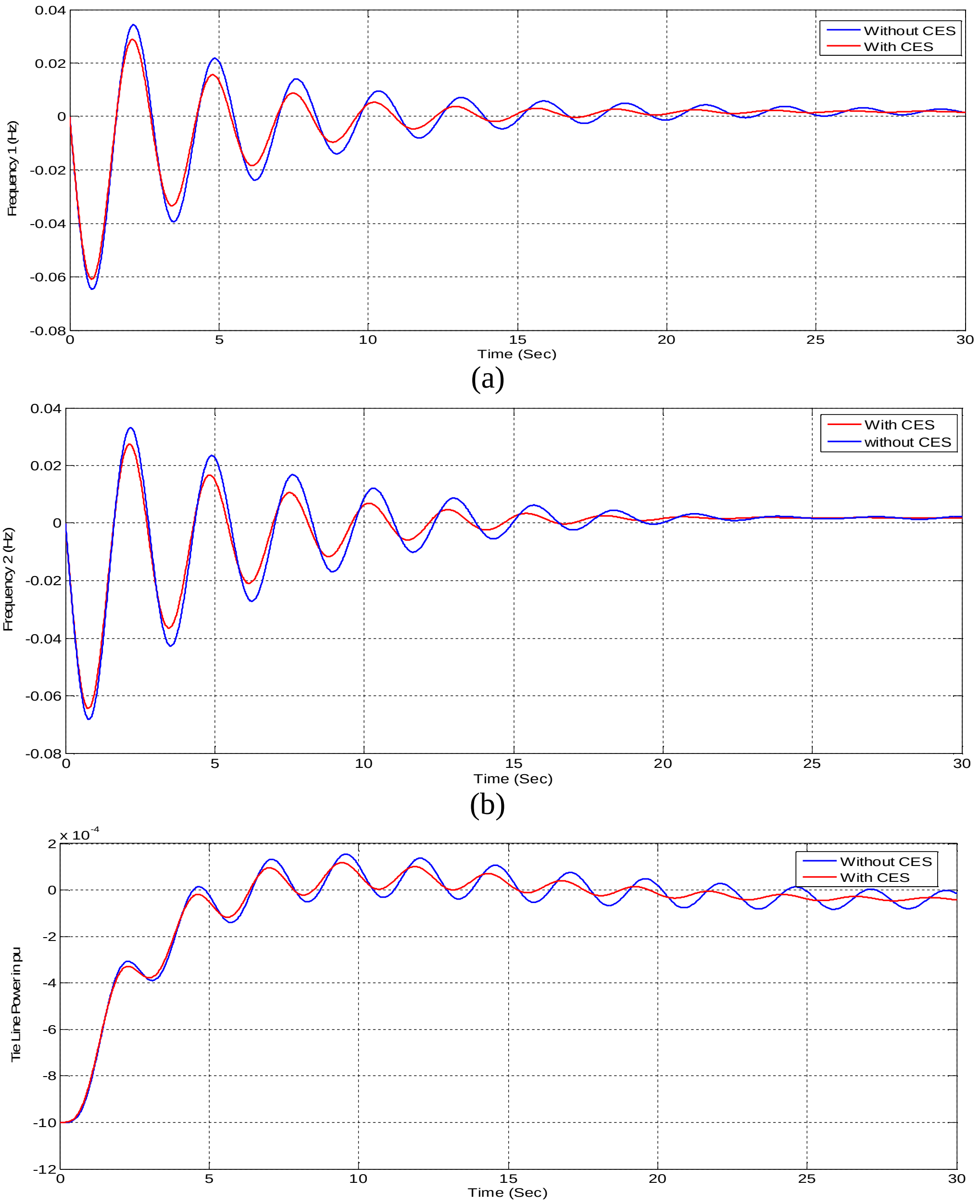
Similarly, the total local load in area 2

$$\Delta P_{L2,LOC} = \text{Load of DISCO}_3 + \text{Load of DISCO}_4$$

=0.02 pu MW (no un contracted load)

Tie line power can be calculated by using the formula given in the above section and is given by 0.001pu as shown in the results.

The response of the system is shown in figure 5.



(a)

(b)

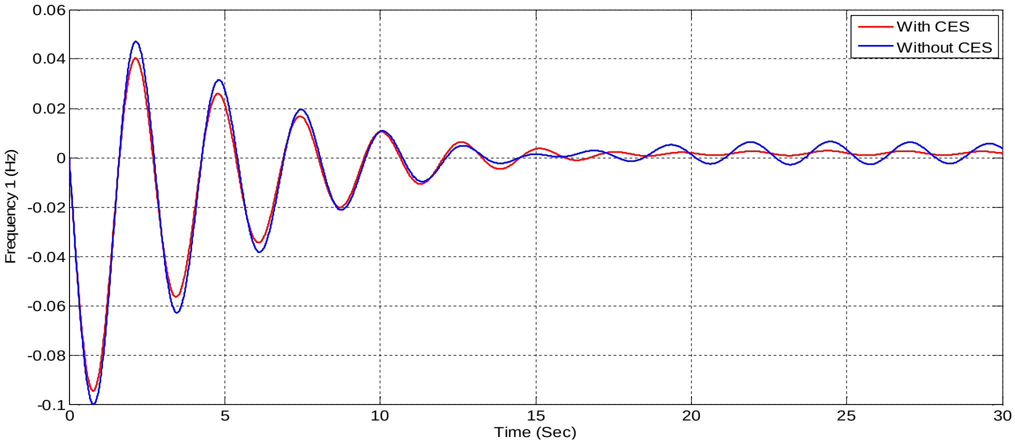
(c)

Figure 5: (a,b) Frequency deviations in area 1 and 2 (Hz), (c) Tie line power

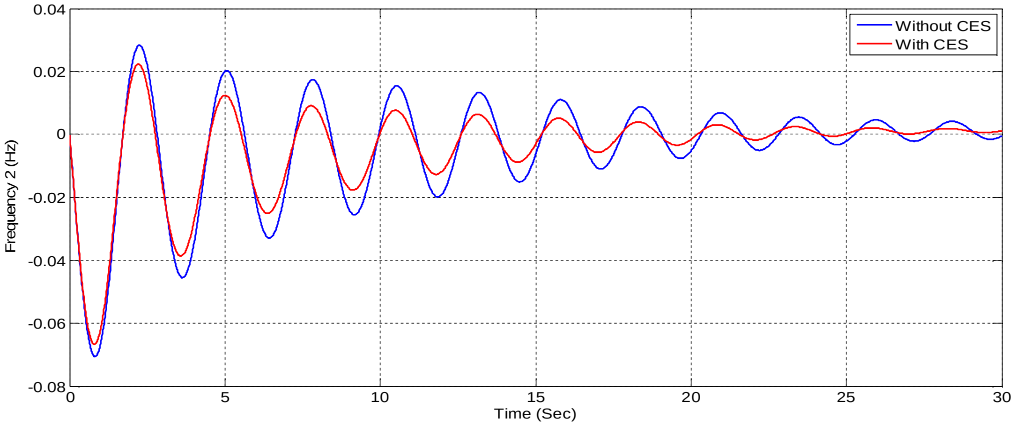
Results in the figure 5 shows that, to meet the DISCOs demand each generator is generating power according to their participation matrix mentioned in the DISCO participation matrix. Due to power balance between the generated power by the GENCOs and load demand by the DISCOs, the frequency in each area is settled to its rated value (frequency deviation in the response is settled to zero). The tie line power is also observed to be at its calculated value is also observed to be at its calculated value from the simulation results. This testifies that the designed controller is succeeded in controlling the generation and frequencies of the system to maintain the system balance and inclusion of capacitive energy storage system improves the performance of generating control which is compared to the case where capacitive energy storage is not present.

Case 2: Contract Violation

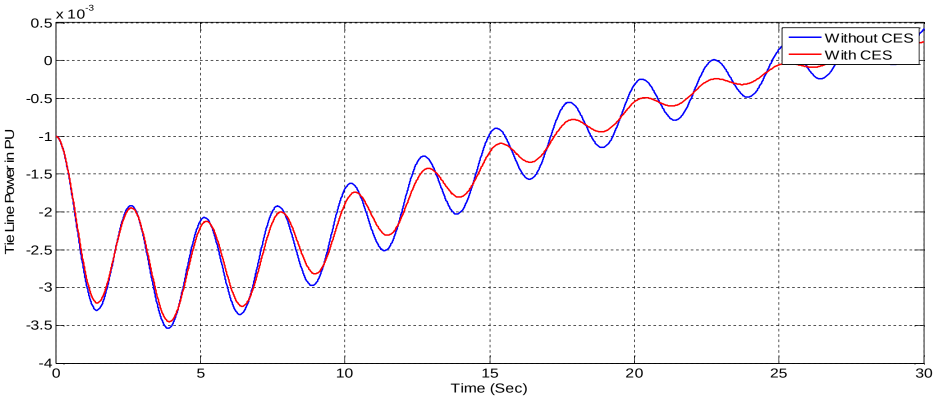
It may happen that a DISCO violates a contract by demanding more power than that specified in the contract. This excess power is not contracted out to any GENCO. This un contracted power must be supplied by the GENCOs in the same area as the DISCO. It must be reflected as a local load of the area but not as the contract demand. Consider that DISCOs in area 1 are violating contracts and demanding an excess power of 0.01pu. The response of the system is shown in figure 6 with this contract violation for the disturbance shown in the figure 5 and for the same DPM as above case. Each GENCO participated in AGC as defined by following apfs apf1=0.33, apf2=0.33, apf3=34, apf4=0.33, apf5=0.33, apf6=0.34. The response of the system with contract violation is shown in figure 6.



(a)



(b)



(c213)

Figure 6: (a,b) Frequency deviations in area 1 and 2 (Hz), (c) Tie line power

The simulation results in figure 6 shows that the disturbance in area 1 causes frequency variation in area 1 to be more than the same area 2. From the response of the generators it is clear that, as a primary action generators in both the areas are responding at the beginning for the disturbance in area 1. But when the secondary control comes in to action, generators in area 1 are only responding for the disturbance in the corresponding area and remaining generators are ineffective in steady state. The tie line power is also unchanged in the steady state because there is no contribution of area 2 generators for the disturbance in area1.

Conclusions

Simulation model for automatic generation control in deregulated power systems is presented which includes three types of generating systems(Thermal-Hydro-Gas). Frequency variation due to bilateral contracts have been studied with the help of DISCO participation matrix. Dynamic model of Capacitive Energy Storage systems used in the analysis is presented in the paper. Dynamic model to study the effect of a CES in AGC of Deregulated power system is proposed. Controller parameters are also selected using PSO algorithm in multi area AGC system with CES.

Further to improve the system performance, particularly using CES robust frequency controllers are successfully implemented in two area power systems. Finally comparative studies have been made between AGC system with and without CES. Simulation results shows that CES is successful in damping the frequency variations during the load disturbances.

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