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Simulation Study Of A Two Area AGC System Along With CES Unit Under Teaching Learning Based Algorithm Approach

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Abstract

This paper deals with Automatic Generation Control (AGC) of a two area multi-unit hydrothermal power system with appropriate generation rate constraints (GRC). In the two area system, there are two thermal systems and one hydro system has been used for the study. The effect of capacitive energy storage units included in each area and the performance of AGC is studied. Dynamic responses of frequency deviations of each area is compared with other area and tie line power deviations are studied under 1% load disturbance for comparison of performance. The integral gains optimum value without and with CES units are obtained using Teaching learning based optimization Algorithm (TLBOA) by minimizing an objective function which is quadratic in the deviation terms. It has been observed from the analysis that, following small load perturbations, the dynamic performance of AGC has been improved significantly since the area frequency oscillations and tie-line power deviations have been damped out in the presence of CES units.

Keywords Automatic generation control (AGC), Area control error (ACE), Teaching learning based algorithm, Capacitive energy storage (CES)

1 Nomenclature

H = inertia constant (MW/sec)
ΔP_D = Incremental load change (p.u)
D = $\Delta P_d / \Delta f$ (p.u/Hz)
ΔP_g = Incremental generation change (p.u)
R = Governor Speed regulation parameter. (Hz/puMW)
T_g = Steam governor time constant(s)

T_t = Steam turbine time constant (s)
B = Frequency bias factor pu MW/Hz
f = Nominal system frequency (Hz)
T_p = 2H / f. D (s)
K_P = 1/D (Hz/pu)
K_{Ii} = Integral gain of PID controller in area i
K_{di} = Derivative gain of PID controller in area i
K_{pi} = Proportional gain of PID controller in area i
B = (D+ 1/R) (i.e. Frequency response characteristics)
ACE = Area Control Error
Δf = Incremental change in frequency (Hz)
ΔP_g = Incremental generation (p.u MW)
ΔP_{tie12} = Incremental change in tie-line power (p.u MW)
T_{12} = Synchronizing coefficients.
T_W = hydraulic turbine time constant (s).
$T_1=T_2=T_3=T_4=T_{R1}=T_{R2}$=Hydraulic governor time constant

2 Introduction

Power system is mainly consisting of different control areas. Tie-lines which are used for interconnecting control areas and under abnormal situation energy transfer between inter-areas. Many studies have been reported in the past about the Load frequency control (LFC) (also termed automatic generation control (AGC))[1-6].Different control techniques, such as classical control approach, optimal control, sub optimal control approach, adaptive and self-tuning control approach are employed in earlier days to obtain a suitable gain for LFC controller.

Application of an energy storage device with fast response time can be inserted into the system to damp out the frequency oscillations and tie line power deviations due to the variations in the system loads. Now a day variety of storage technologies like pumped storage hydroelectric system, battery energy storage systems (BESS), superconducting magnetic energy storage (SMES) and capacitive energy storage (CES) etc. major draw backs of BESS are its limited life cycle, limitation related to voltage and current, environmental hazards. The disadvantage of pumped hydroelectric unit is larger in size, environmental and topographic limitation. For SMES, the limitations are SMES coil cannot be so upgraded also it requires continuous operating liquid helium system. In addition to that SMES requires continuous flow of current [7-9].

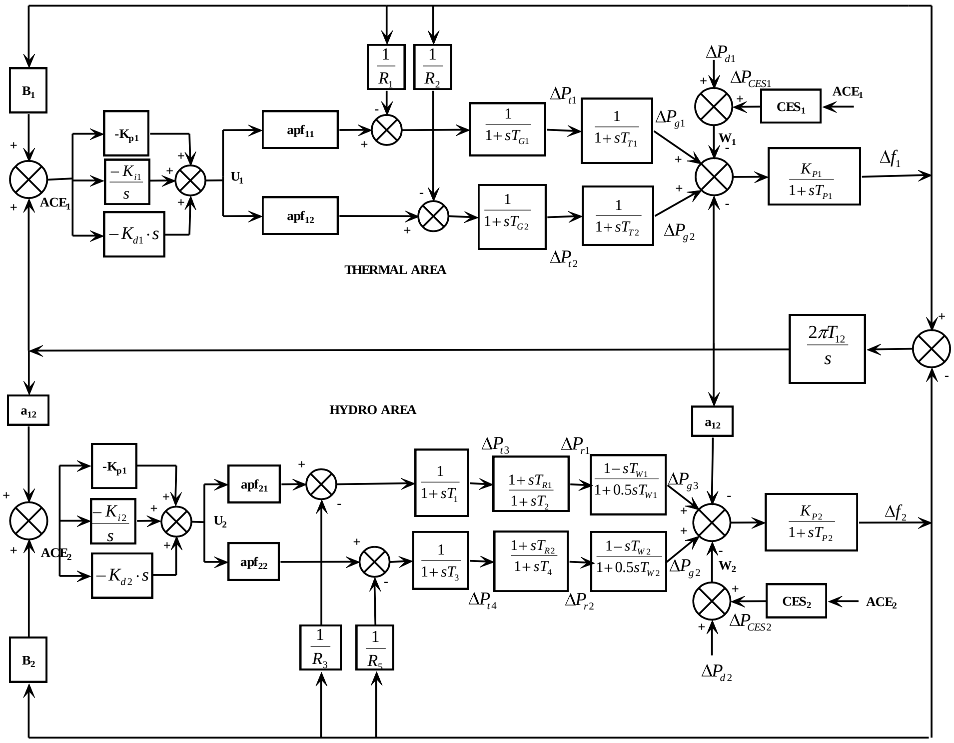


Fig.1. LTI model of interconnected multiunit hydrothermal system with CES and PID controller.

Incorporation of capacitors is one of the latest technologies in power and energy systems. The capacitor can be used to store and supply energy as required. The main disadvantage of capacitor for the application of bulky energy storage is that it's low energy density and less dielectric losses [10]. CES unit has many features as compared to other technologies. It has the ability to damp out the power frequency oscillation and tie-line power deviation caused by the load variation [11-12].

CES units are free from maintenance and do not involve any environmental hazards. CES can be so upgraded using additional capacitor banks modules. This article examines the dynamic performance of PID controller used in the supplementary control of AGC. Hydrothermal power system with CES unit improves the dynamic performance.

3 Hydro-thermal power system model

A two area multiunit hydrothermal power system is taken for analysis as shown in figure 1. Area consisting of two non-reheat thermal units and area 2 consists of two hydro unit. Generation rate constraint is taken as 10% per minute for thermal units and for hydro units 270% per minute for raising and 360% per minute for lowering generation from IEEE standards for power plant response to load charges [13]. The transfer function models used for this work are developed as in IEEE Committee report on dynamic models for steam and hydro turbines in the power system studies [14].

Fig. 1 shows the Matlab/Simulink model of two area multi-unit hydrothermal power system with PID controller and CES unit. Area participation factors (apf) are also considered as the system under investigation is a multi unit two area system. apfs are the ratios in which generating units adjust their power output. It is noted that in area 1, $apf_{11}+ apf_{22} =1$ and in area 2, $apf_{21}+apf_{22}=1$.Here $apf_{11} = apf_{12} = apf_{21} = apf_{22} = 0.5$ has been considered, which means all the units share the load change equally. The values of for all three areas, PID controllers and CES unit are given in the Appendices.

4 Capacitive Energy Storage (CES)

The main aim of incorporating CES is to supply or absorb some energy due to sudden increase or decrease of load. So obviously for implementing CES a power handling system is needed. This is also called power conditioning system (PCS). Capacitor store the energy, similar to the applied potential in its electrostatic field created between the plates. PCS consists of a power conversion system, bypass resistor, DC breaker with dump resistor, Reversing switch arrangement and the capacitor bank. Power conditioning system consists of 3-phase dual converters. Capacitor bank is consists of many number of capacitors arranged in parallel, with equivalent capacitance C as shown in Fig. 2. To represents its leakage and dielectric loss, an equivalent resistance R_i which is connected in across the capacitor C [11][16].

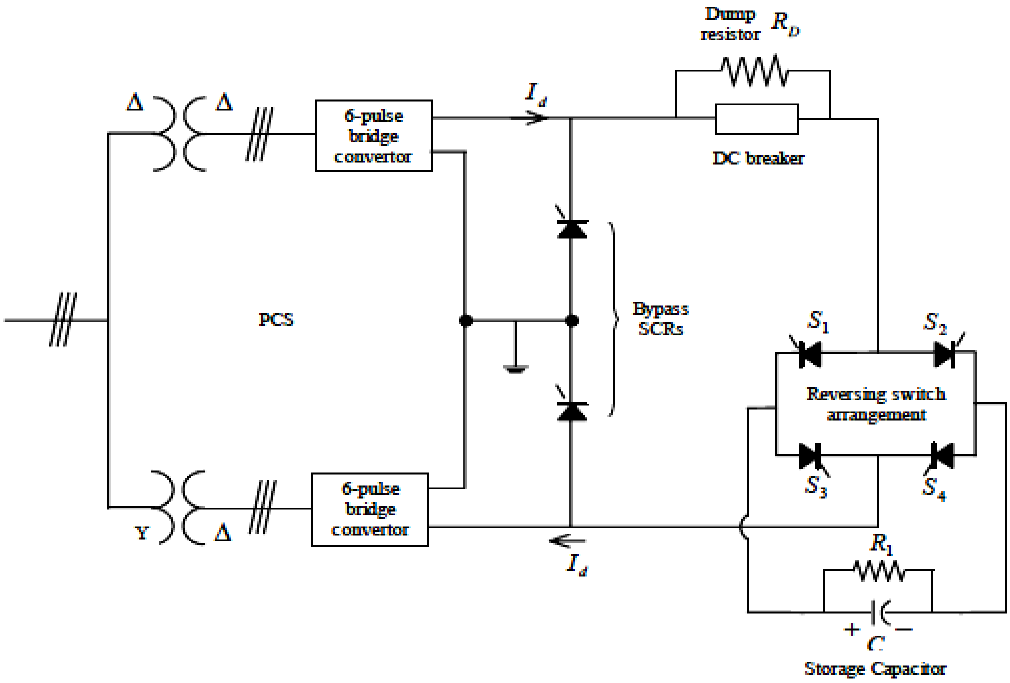


Fig.2. Electrical circuitry of CES unit

Under normal operating condition, the capacitor can be charged to its rated value. The reversing switch arrangement offered the change of current direction in the capacitor during charging and discharging. Under charging mode, the thyristor switches S_1 and S_4 are in on state and S_2 and S_3 are in off state. Under discharging mode, switches S_2 and S_3 are on and S_1 and S_4 are off. This is decided by the gate controller which works in response to the load condition. Whenever there is a sudden rejection in load, the excess energy in the system is absorbed by the capacitor through the power conditioning system, faster than the governor and other control mechanism starts acting**.** Similarly in the case of a sudden increase in load demand, at the instant it to release the stored energy via PCS to grid. If the bridge converter may fail, the bypass SCR's provide a path for the current I_d and also dc breaker diverted I_d into energy dump resistor R_D to protect the reversal switch arrangement.

To analyze the effect of CES unit on AGC. Capacitor bank of 3.8 MJ storage capacities can be considered. The voltage across capacitor can be given as E_d. Assuming negligible losses [5].

$$E_d = 2E_{d0}\cos\alpha - 2I_d R_D \tag{1}$$

By adjusting firing angle α the capacitor voltage E_d will vary from its maximum positive value to its maximum negative value.

The operating point of a capacitor is taken as the value in which its maximum allowable energy absorption is equal to its maximum allowable energy discharge. E_{d0} denotes the initial voltage and $E_{d\max}$ and $E_{d\min}$ denote the maximum and minimum limits of voltage respectively, then.

$$\frac{1}{2}CE_{d\max}^2 - \frac{1}{2}CE_{d0}^2 = \frac{1}{2}CE_{d0}^2 - \frac{1}{2}CE_{d\min}^2 \tag{2}$$

And hence

$$C_{do} = \left[\frac{E_{d\max}{}^2 + E_{d\min}{}^2}{2}\right]^{\frac{1}{2}} \tag{3}$$

Capacitor voltage is kept within some limits ie. During a sudden discharge of load, if the capacitor voltage changes to high value, capacitor absorbs some excess energy and if another sudden load removal occurs earlier than the restoration of its normal voltage, more energy will be absorbed by the capacitor which may cause the capacitor bulkily and discontinuous control occurred. To overcome this effect upper limit value for the capacitor voltage is taken as 138% of the rated value [16].

$$\therefore E_{d\max} = 1.38E_{d0} \tag{4}$$

Substituting (4) in (3) gives

$$E_{d\min} = 0.30 E_{d0} \tag{5}$$

5 Control strategies for CES unit

All Block diagram representation of CES unit with capacitor voltage feedback is shown in Fig. 3 [16]. Area Control Error (ACE) signal is taken as the input to the CES unit. The ACE for i^{th} area is given as

$$ACE_i = B_i \Delta f_i + \Delta P_{tiei,j} \tag{6}$$

For the sudden restoration of capacitor voltage to its normal value after a sudden load charge, sensing the voltage variation in the control loop of CES unit a negative feedback signal is applied as shown in Fig 3.

Generally current deviation in i^{th} area the is represented as

$$\Delta I_{di} = \frac{K_{ACEi}.ACE_i - K_{vdi}.\Delta E_{di}}{1 + sT_{DCi}} \tag{7}$$

Capacitor voltage deviation ΔE_{di} is then specified by

$$\Delta E_{di} = [\frac{R_i}{1 + sC_i R_i}] \Delta I_{di} \tag{8}$$

The total output power from the CES unit is specified as

$$\Delta P_{CES} = \Delta I_{d0} (E_{d0} + \Delta E_{di}) \tag{9}$$

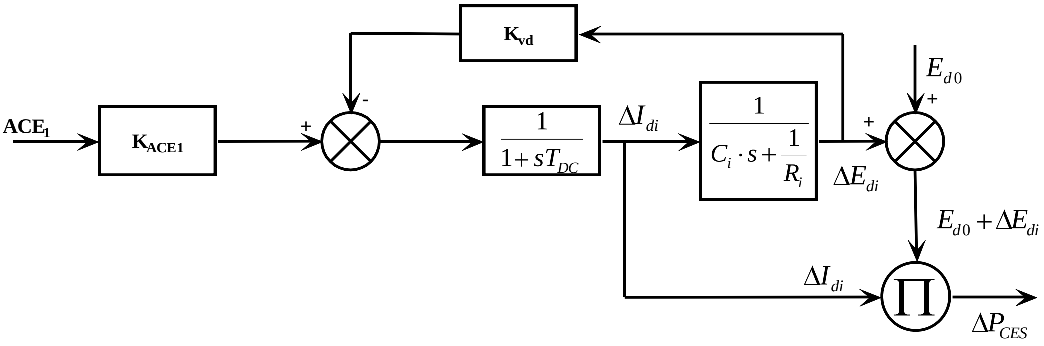


Fig.3. CES block diagram representation

6 Teaching Learning Based Optimization

TLBO algorithm is motivated from normal teaching-learning process and it is proposed by Rao et al. [17]. The main idea of the algorithm is how the learners output is influenced by a teacher's class. In this algorithm, there are two learning phases: (i) teacher phase (through teacher) and (ii) learner phase (interaction of learners). In this optimization algorithm a collection of learners are taken as a population and different subjects are taken as different design variables. Every time learner's output is related to the 'fitness' value of the optimization problem. Teacher is treated as the best solution of entire population. The design variables are the different terms in the objective and the optimum solution is the best value of objective function. The workings of two learning phases are.

Fig. 4. shows the flowchart of TLBOA [18]

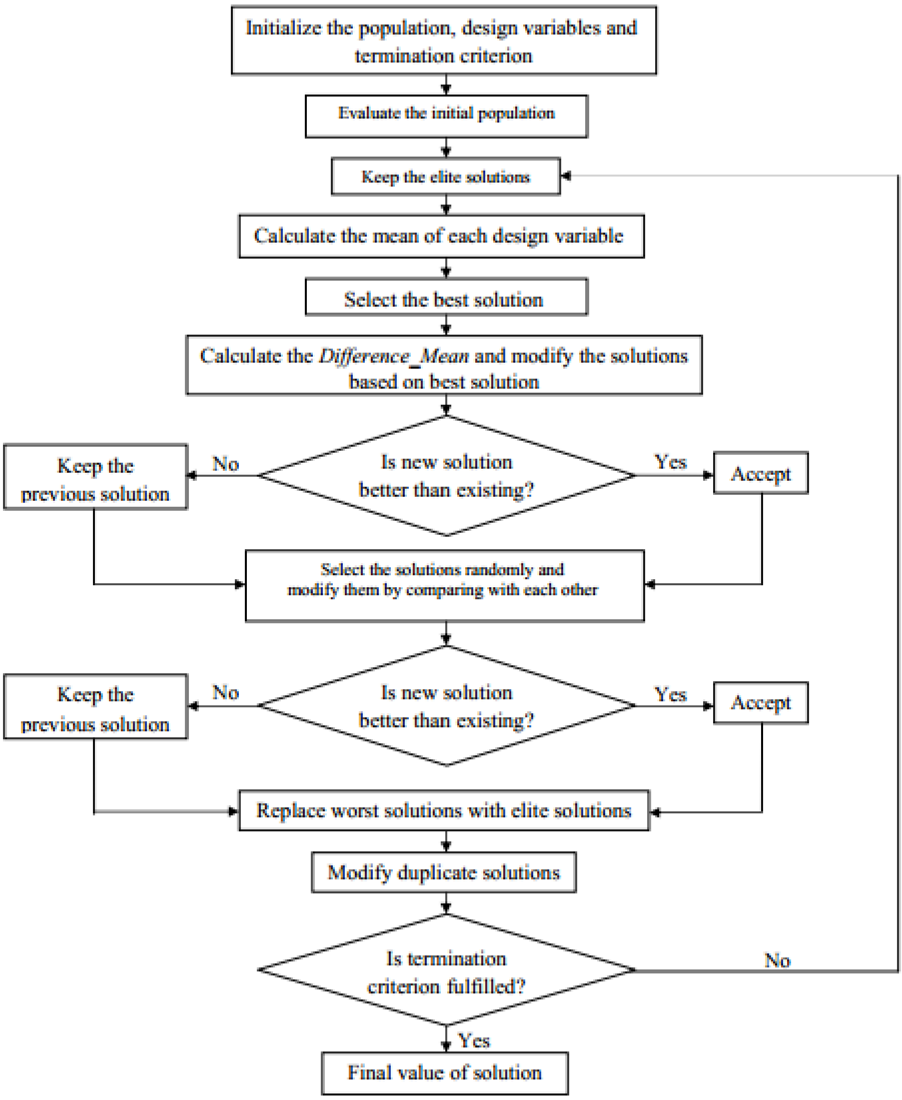


Fig.4. Flowchart of the genetic algorithm

6.1 Teacher phase

In this phase shows the efforts of a teacher in a class tries to improve the mean result of the subject taken by him or her depending their own capability. Assume that total number of subjects (i.e. design variables)is '*m*' and total number of learners is '*n*' (i.e. population size, *k*=1,2,…,*n*) and the mean result of 'j^{th}' subject(j=1,2,…,m) is $M_{j,i}$. $Xnew^{g}_{(\,)}$ is denoted as the overall best result from all subjects in the entire population. Consider the natural thinking that teacher is considered as a highly educated person and his or her students can produce better results. To identify the best learner, consider the algorithm as a teacher. To create a new set of improved learners, a random weighted differential vector is created from the current mean and the desired mean parameters and added to the existing population of learners [19]

$$Xnew^{g}_{(\,)} = X^{g}_{(\,)} + rand \times \left(X^{g}_{Teacher} - T_F M^{g}\right) \tag{10}$$

T_F is the teaching factor which decides the mean value is changed by the teaching parameter T_F . Normally T_F is either 1 or 2. T_F is randomly obtained as

$$T_F = round\left[1 + rand(0,1)\{2-1\}\right] \tag{11}$$

Suppose if $Xnew^{g}_{(\,)}$ shows better result than $X^{g}_{(\,)}$, it is replaced by $Xnew^{g}_{(\,)}$.

6.2 Learner phase

In learner phase, any leaner likes to enhance his or her knowledge they also doing random interaction with each other. In this method the learner acquire more things from other learner who has more knowledge. The random interaction between different learners are given by [19]

$$Xnew^{g}_{(\,)} = \begin{cases} X^{g}_{(\,)} + rand \times \left(X^{g}_{(\,)} - X^{g}_{(r)}\right) \\ f\left(X^{g}_{(\,)}\right) < f\left(X^{g}_{(r)}\right) \\ X^{g}_{(\,)} + rand \times \left(X^{g}_{(\,)} - X^{g}_{(r)}\right) \end{cases} \tag{12}$$

Whenever the iteration reaches its maximum number of allowable iteration, the algorithm terminates.

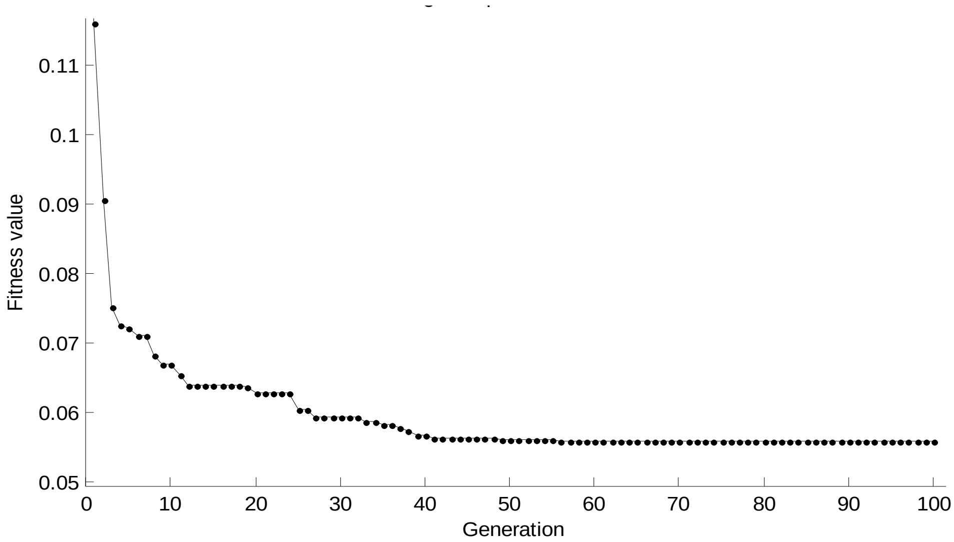


Fig.5. TLBOA convergence plot.

7 Optimization of PID gain setting

Integral Time Squared Error (ITSE) technique [16] is used for tuning optimum PID gain settings. A performance index (J) is minimized using TLBO Algorithm in the presence of GRC to obtain gain values of K_{i1} and K_{i2} for integral controller, K_{p1}, K_{i1}, K_{d1} and K_{p2}, K_{i2}, K_{d2} for PID controller. Optimum values of Integral and PID controller gains of both areas are given below.

$$J = \int_0^t (\Delta f_1{}^2 + \Delta f_2{}^2 + \Delta P_{tie12}{}^2) t dt \tag{13}$$

Parameters for TLBO Algorithm:

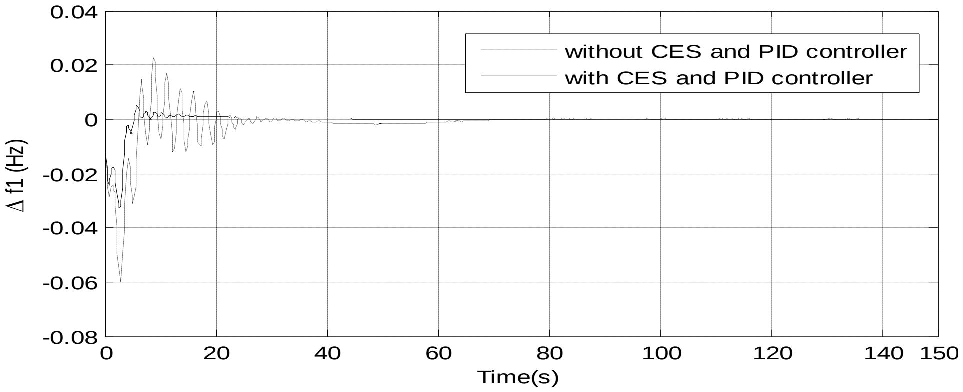
Population Size: 10
Number of Iterations: 100
Number of design variables: 3
Limit of design variable: [0.01, 0.11]

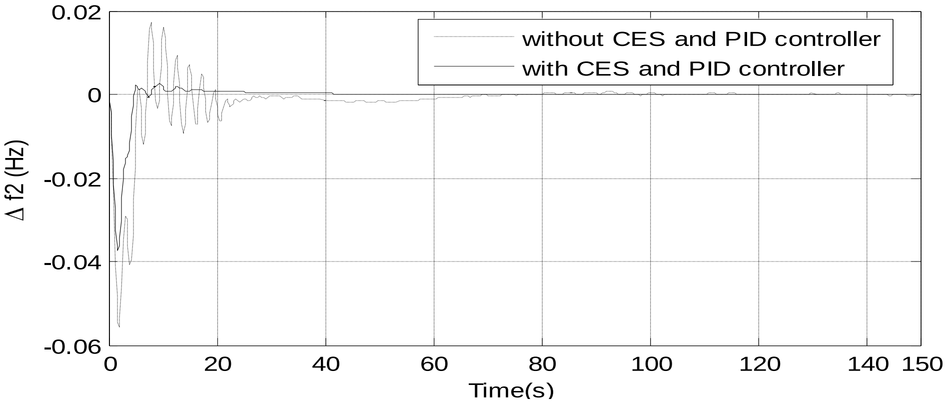
Table 1 Optimum values of integral and PID gain settings.

Area	With TLBOA-PID controller and without CES	With TLBOA-PID controller and CES
Thermal	K_{p1}=0.7134 K_{i1}=0.0548 K_{d1}=0.2347	K_{p1}=0.1046 K_{i1}=1.3958 K_{d1}=0.0196
Hydro	K_{p2}=0.8013 K_{i2}=0.3822 K_{d2}=0.4603	K_{p2}=0.0663 K_{i2}=-0.0488 K_{d2}=-0.6042

8 Dynamic responses

With GRCs, simulation studies are done using MATLAB/Simulink to obtain the performance of two-area hydrothermal system with and without CES and PID controller under 1% step load perturbation in area 1. It is evident that the dynamic responses with CES and PID controller is improved than without CES. Dynamic responses of frequency and tie line power deviations for 1% step load perturbation in area 1 with and without CES and PID controller shown in Fig. 6.





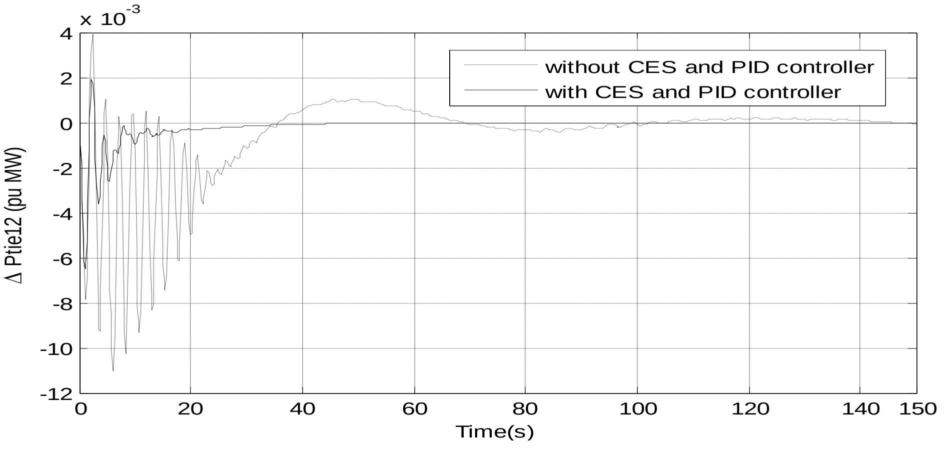
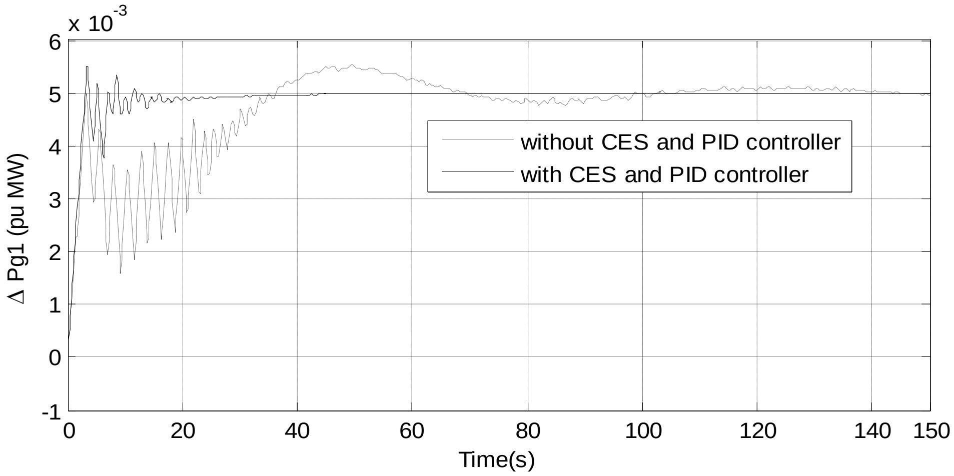
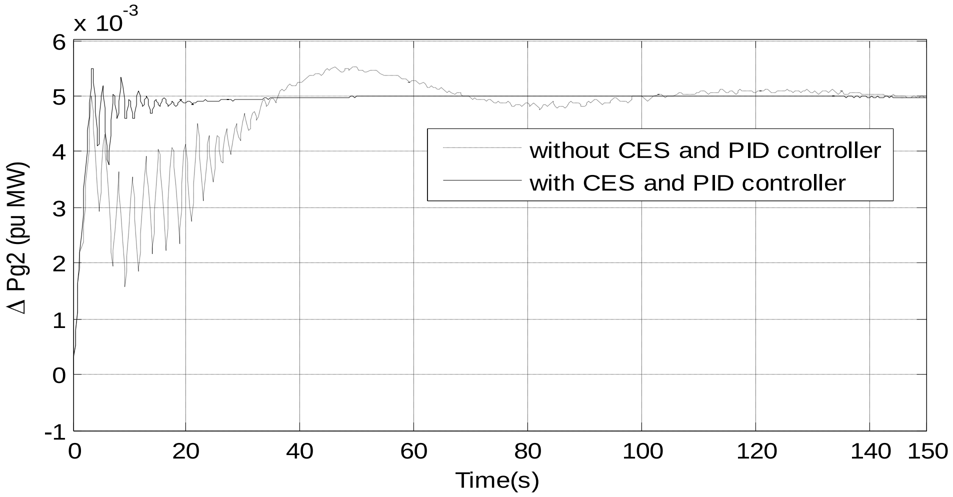


Fig.6. Dynamic responses and tie line power deviations for 1% step load perturbation in area 1 with and without CES and PID controller.

Fig. 7. Shows the dynamic response of changes in power generation in both the areas. The responses for frequency deviation (Δf1 and Δf2), tie-line power deviation (ΔP_{tie12}) and change in power generation (ΔPg1 and ΔPg2 in area 1 and ΔPg3 and ΔPg4 in area 2) are plotted and compared.





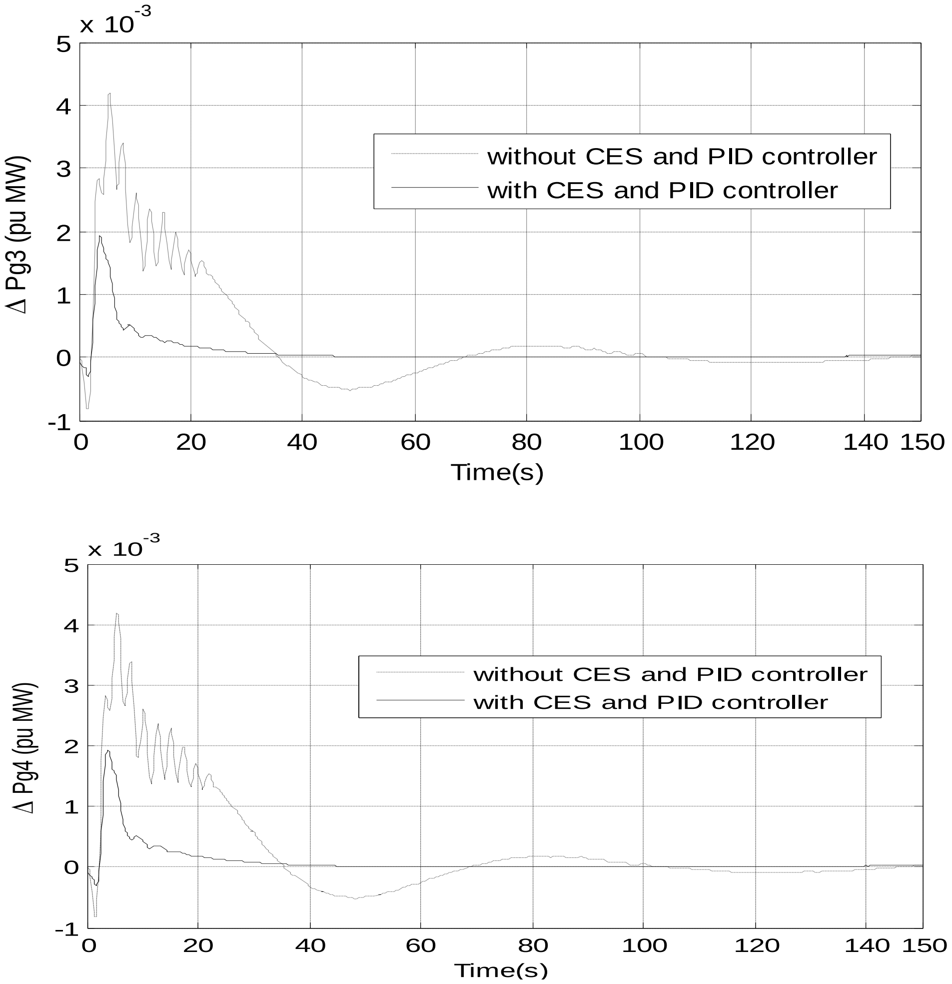


Fig.7. Dynamic responses of change in power generation in both the areas following a 1% step load perturbation in area 1

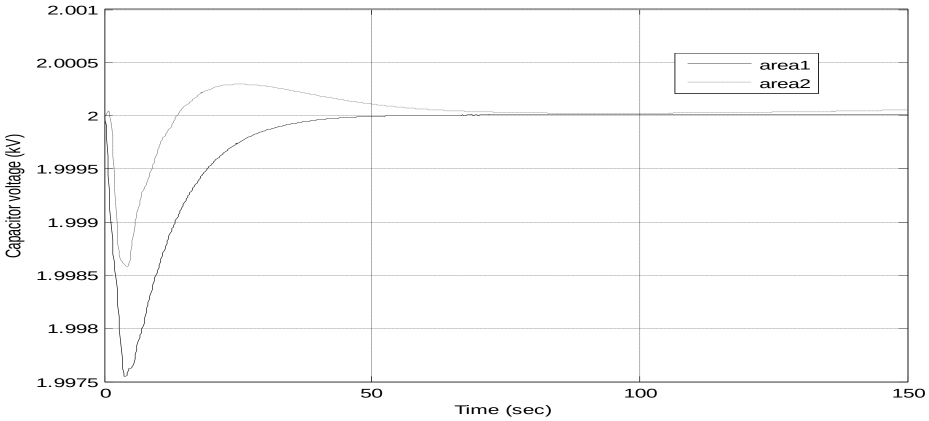


Fig.8. Voltage deviations in CES unit following a 1% step load disturbance in area1.

Table 2. Peak overshoot (M_P) and settling time (T_S) response

Area	With TLBOA-PID controller and without CES		With TLBOA-PID controller and CES	
	M_P (sec)	T_S (sec)	M_P (sec)	T_S (sec)
Thermal	0.0211	68	0.0032	18
Hydro	0.0184	70	0.0046	20
Tie-Line	0.0131	145	0.00394	32

Table.2. shows that the time response parameters maximum peak over shoot and settling time is reduced when we add a CES unit in the above system. In both hydro and thermal system, settling time is significantly reduced this shows that the CES response is faster than the turbine and other control actions response.

As the load disturbance has occurred in area 1, at steady state, the power generated by generating units in area 1 are in proportion to the ACE participation factors. Therefore, as in Fig. 7, at steady state, $\Delta P_{g1ss} = \Delta Pd1 \times apf11 = 0.01 \times 0.5 = 0.005$ p.u. MW and $\Delta P_{g2ss} = \Delta Pd2 \times apf12 = 0.01 \times 0.5 = 0.005$ p.u. MW. Similarly $\Delta P_{g3ss} = \Delta P_{d2} \times apf21 = 0 \times 0.5 = 0$ p.u. MW and $\Delta P_{g4ss} = \Delta P_{d2} \times apf21 = 0 \times 0.5 = 0$ p.u. MW at steady state. Fig.5.shows TLBOA convergence plot, it is clear from the plot that fitness value is reduces as the number of generation increases and reaches a constant value. Fig. 8 shows the voltage deviations in the CES units in areas 1 and 2, for a sudden load increase of 0.01 p.u. in area 1. A faster voltage restoration, sense the capacitor voltage deviation and give it as a negative feedback signal in the CES control loop.

9 Conclusion

In this work a LTI mathematical model of two area multi-unit hydro thermal power system with and without CES and PID controllers has been studied. As per IEEE Committee report on power plant response to load change have also been considered in the simulation.

The Analysis seems to have revealed that the area of CES and PID controller in AGC is capable of damp out the frequency and tie-line power deviations are reduced significantly. Because of the inherent characteristics of variable loads, the operating point of a power system may vary time to time. Thus at nominal operating point, the fixed gain controller design may fail to give better control performance over a wide range of operating conditions therefore the PID controller gains are optimized using TLBO algorithm technique. Simulation results expose that frequency and tie-line power deviation following sudden load disturbance can be damped by using CES and TLBOA optimized PID controller.

9 Appendix

(A)System Data

$P_{R1} = P_{R2} = 1200$ MW
$T_{P1} = T_{P2} = 20$ s
$K_{P1} = K_{P2} = 120$ Hz / p.u MW
$T_{R1} = T_{R2} = 10$ s
$K_{R1} = K_{R2} = 0.5$
$T_{TI} = T_{T2} = T_{T3} = T_{T4} = 0.3$ s
$T_{12} = 0.0866$ s
$T_{G1} = T_{G2} = T_{G3} = T_{G4} = 0.08$ s
$R_1 = R_2 = R_3 = R_4 = 2.4$ Hz / p.u MW
$D_1 = D_2 = 8.33\times10^{-3}$ p.u MW / HZ
$B_1 = B_2 = 0.425$ p.u MW / Hz
$P_{D1} = 0.01$ p.u MW
$P_{D2} = 0$ p.u MW
$T_1=T_3=41.6$s
$T_2=T_4=0.513$s
$T_{w1}=T_{w2}=1$s

(B) Capacitive Energy Storage Data

C = 1.0f
$R = 100\Omega$
$T_{DC} = 0.05$ s
$K_{ACE} = 70$kA/ unit MW
$K_{vd} = 0.1$ kA/kV
$E_{do\,=}$ 2kV

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