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# Implementation of Load Frequency Control of Multi Area SSSC and CES Based System under Deregulation Using SA

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**ABSTRACT**

This paper deals with the application of evolutionary optimization technique for designing the gain of integral controller in a multi area hydrothermal system under deregulation. The technique used for optimization is Simulated Annealing. A two area hydrothermal system in the presence of Static Synchronous Series Compensator and Capacitive Energy Storage under deregulation is considered to exemplify the optimum parameter search. The performance index is considered in the search of optimal Automatic Generation Control (AGC) parameters. The results presented in this paper demonstrate the superior working of SA.



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## INTRODUCTION

The process of maintaining several sets of balances form the process of successful operation of power system. The two balances which are predominant factors to keep frequency constant are load-generation scheduled and actual tie line flows Concodia *et al*. (1954), Kothari *et al*. (1980). A good operation of system is identified by its constant frequency of operation and quality of supplied power to its consumers. This is generally carried out by varying the generation as per the load demand. Generally if frequency is low, then the amount of generation is increased and if the frequency is high, the generation is decreased. The electric industry at current stage is undergoing change from a form of vertically integrated utility system which provides power at regulated rates to a system that constitutes companies competing with each other to sell power at lower rates. The various entities in such a type of system are generating companies (GENCOs), transmission companies (TRANSCOs) and distribution companies (DISCOs). The fundamental role of LFC in this type of power system structure is to enable exchange of power and also to provide better conditions for trading of power.

The concept of control of generation in power systems under open market scenario has been presented in Robert *et al*. (1996). The implementation of independent system operator (ISO) to balance the economics along with efficient working of the system has also been presented in Jayanth *et al*. (1997). A detailed review of how the concept of LFC under open market scenario can be simulated and assessed has been presented in Bjorn *et al*. (1998), Donde *et al*. (2000).

On the other hand, various FACTS devices have been widely employed for the control of power systems which provide better stability to the system in Marimuthu *et al*. (2012, 2014), Praghnesh *et al*. (2009). Static Synchronous Series Compensator (SSSC) and Capacitive Energy Storage (CES) are seen as effective devices to bring about better dynamic response of the system.

To compare the improvement of dynamic performance of the system by optimizing the gain of integral controller in a SSSC and CES based hydrothermal system under deregulation; the evolutionary technique like SA has been employed. Simulation results depict that the SA technique gives good results in terms of Peak time, settling time and overshoot and the performance index value is also less as compared to the other method.

### 1. *System Investigation:*

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.

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The detailed transfer function models of speed governors and turbines are discussed and developed in the IEEE committee report on dynamic models for steam and hydro Turbines in power systems (1973).

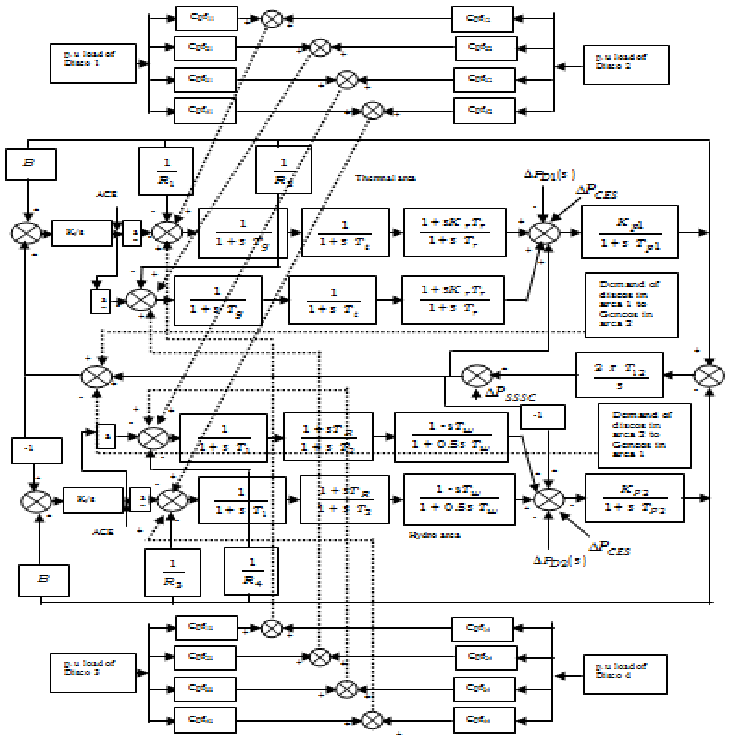



**Fig. 1:** Two Area SSSC and CES based Hydrothermal System under Deregulation.

The detailed small perturbation transfer function block diagram model of two area hydrothermal system under open market scenario is shown in Fig. 1 Nominal parameters of the system are given in the Appendix.

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

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

is considered in this work to compare the performance of the system.

## 2. *Design of CES:*

The frequency deviation or Area control error signal can be employed as the control signal for the CES unit. Fig. 2 shows the block diagram representation of CES unit employed in the system. It can be seen from Fig. 2 that the structure of CES consists of gain block $K_{CES}$, time constant $T_{CES}$ and two stage phase compensation blocks having time constants $T_1$, $T_2$, $T_3$ and $T_4$ respectively.

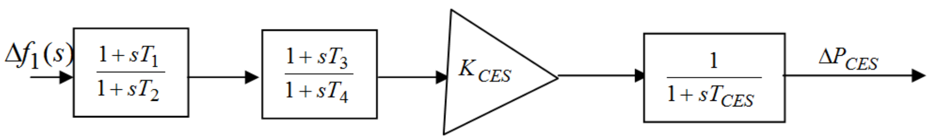



**Fig. 2**: Block Diagram of CES.

## 3. *Design of SSSC:*

The block diagram of SSSC to be incorporated into the system in order to improve the dynamic performance as shown in Fig. 3. The frequency deviation of area 1 can be considered as input to the SSSC device. It can be seen from Fig. 3 that the structure of SSSC consists of gain block $K_{SSSC}$, time constant $T_{SSSC}$ and two stage phase compensation blocks having time constants $T_1$, $T_2$, $T_3$ and $T_4$ respectively.

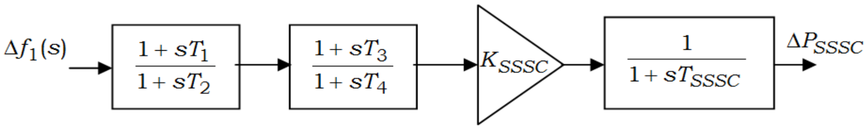



**Fig. 3:** Block Diagram of SSSC.

### 4. *Simulated Annealing Method:*

The SA procedure Kalyanmoy *et al*. (2000) simulates the process of slow cooling of molten metal to achieve the minimum function value in a minimization problem. The cooling phenomenon is simulated by controlling a temperature with the concept of Boltzmann probability distribution. The Boltzmann probability distribution, a system in thermal equilibrium at a temperature $T$ has its energy distributed probabilistically according to equ. (2).

$$P(E) = \exp^{\left(\frac{-E}{kT}\right)} \quad (2)$$

Where, $k$ is the Boltzmann constant. Therefore at any instant the current point is $x_t$ and the function value at that point is $E(t) = f(x_t)$, then the probability of the next point being at $x_{t+1}$ depends on the difference in the function values at these two points i.e. $\Delta E = E(t+1) - E(t)$ and is calculated using the Boltzmann probability distribution given by equ. (3).

$$P\left(E(t+1)\right) = \min\left[1, \exp^{\left(\frac{-\Delta E}{kT}\right)}\right] \quad (3)$$

In order to simulate the thermal equilibrium at every temperature, a number of points '$n$' is tested at a particular temperature before reducing the temperature. The algorithm is terminated when sufficiently small temperature and small enough change in function values are obtained.

## RESULTS AND DISCUSSIONS

A multi area SSSC and CES based hydrothermal system under deregulation has been considered for the study. The simulation has been conducted SIMULINK in MATLAB 7.9.0. It is to be noted that each Genco participates in LFC as per the following participation factors: apf1 = 0.5, apf2 = 0.25, apf3=0.25, apf4 = 0.5, apf5 = 0.25 and apf6 = 0.25. A step load disturbance of 0.4% is considered in either of the areas. A special case of contract violation has also been considered in which an additional load of 0.3% is considered in both the areas after the time span of 35 sec and 70 sec. It is to be noted that this additional load is taken up by the Genco's which lie in the area in which contract violation has occurred. The Disco Participation Matrix Considered in this work is given by

$$\begin{bmatrix} 0.1 & 0.0 & 0.3 & 0.4 \\ 0.0 & 0.1 & 0.0 & 0.2 \\ 0.3 & 0.4 & 0.1 & 0.0 \\ 0.2 & 0.0 & 0.2 & 0.1 \\ 0.2 & 0.3 & 0.0 & 0.1 \\ 0.2 & 0.2 & 0.4 & 0.2 \end{bmatrix}$$

Table 1 shows the peak time, overshoot and settling time for the frequency deviations obtained during various values of gain of integral controller obtained through optimization method. Table 2 shows the value of performance index obtained during optimization technique. It can be observed from Table 1 and 2 that the performance of SA is better than without SA techniques in terms of Peak time, settling time and overshoot and also the performance index of the system is very less as compared to the other technique.

Fig. 4 shows the comparison of frequency deviation of both areas and tie line power error deviation with respect to normal case. Fig. 5 shows the various generations of Genco's in thermal area during normal case. Fig. 6 shows the generations of Genco's in hydro area during normal case. Fig. 7 depicts the comparison of frequency deviation of both areas and tie line power error deviation with respect to contract violation case. Fig. 8 shows the various generations of Genco's in thermal area during contract violation case. Fig. 9 shows the generations of Genco's in hydro area during contract violation case. Fig. 10 and 11 depict the performance index of the system for normal case and contract violation case.

**Table 1:** Comparison of Performance of Techniques.

| S. No. | Technique | Integral Gain values | Area Considered | Peak time (sec) | Overshoot (Hz) | Settling Time (sec) |
|---|---|---|---|---|---|---|
| 1 | With CES | $k_{i1} = 0.5$ | Thermal area | 0.615 | 0.0033294 | 4.955 |
| | | $k_{i2} = 0.5$ | Hydro area | 1.06 | 0.005398 | 3.615 |
| 2 | With CES and SSSC | $k_{i1} = 0.5$ | Thermal area | 2.28 | 0.0031329 | 4.82 |
| | | $k_{i2} = 0.5$ | Hydro area | 0.9 | 0.00598913 | 3.14 |
| 3 | Simulated Annealing | $k_{i1} = 1.35$ | Thermal area | 2.73 | 0.00294557 | 7.04 |
| | | $k_{i2} = 0.267$ | Hydro area | 0.88 | 0.00590737 | 3.525 |

**Table 2:** Comparison of Performance Index Values for Normal Case.

| S. No. | Optimization Technique | Performance Index |
|---|---|---|
| 1 | With CES | $2.783\times10^{-5}$ |
| 2 | With CES and SSSC | $2.635\times10^{-5}$ |
| 3 | Simulated Annealing | $2.241\times10^{-5}$ |

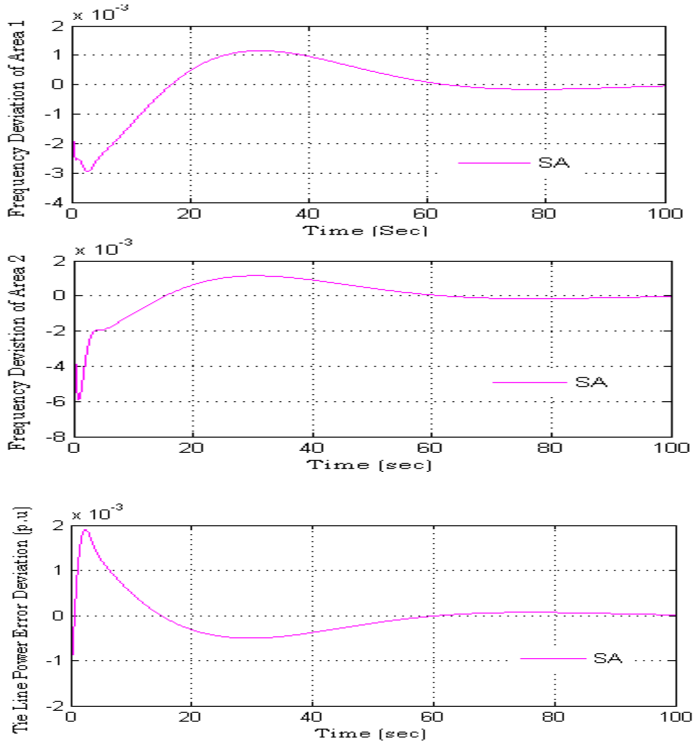



**Fig. 4:** Frequency and tie line power error deviations during normal case.

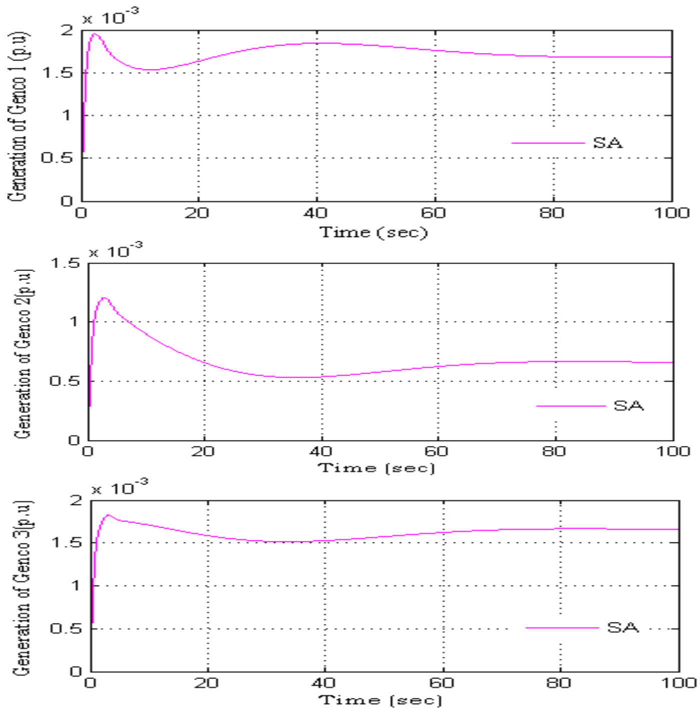



**Fig. 5:** Generation of Gencos of Thermal area during normal case.

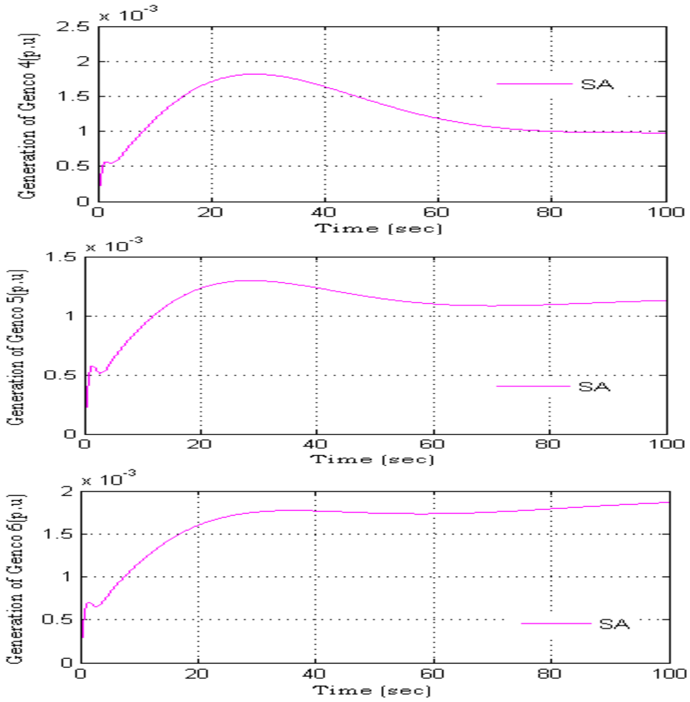



**Fig. 6:** Generation of Gencos of Hydro area during normal case.

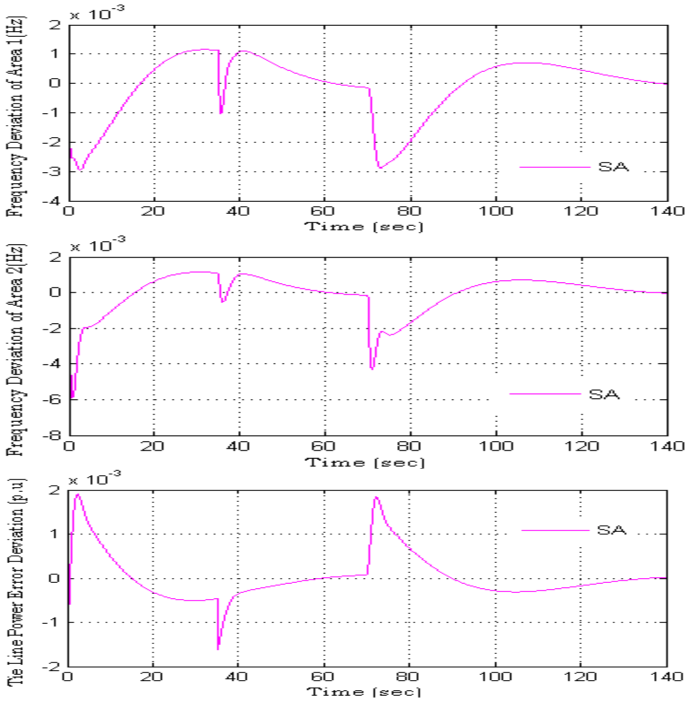
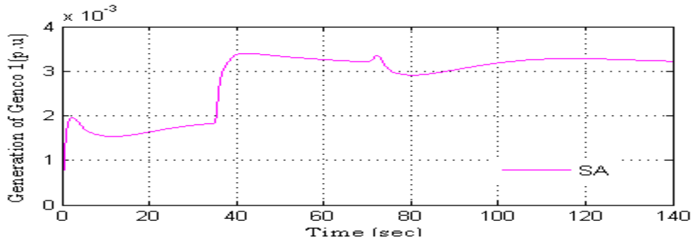



**Fig. 7:** Frequency and tie line power error deviations during contract violation case.



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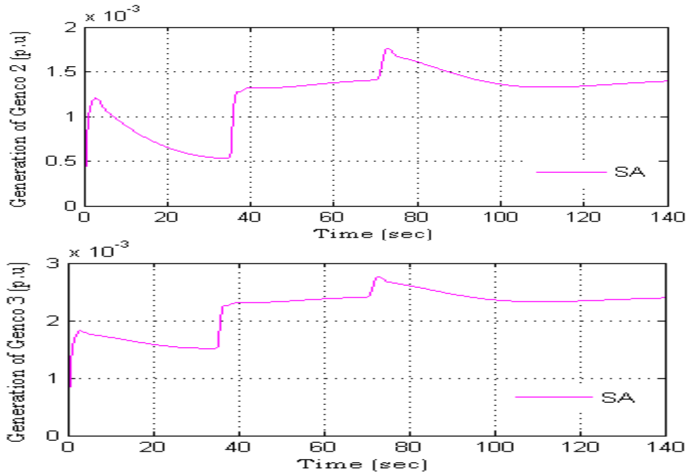


**Fig. 8:** Generation of Gencos of Thermal area during Contract violation case.

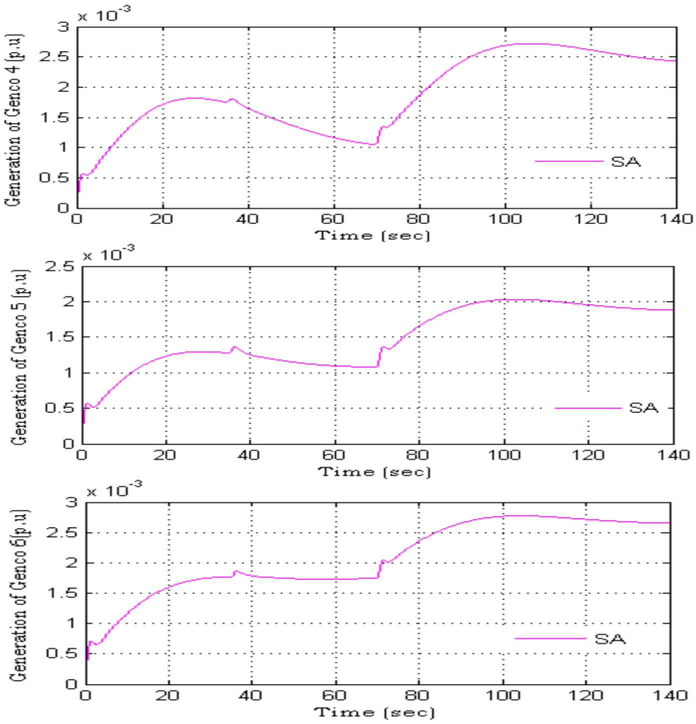


**Fig. 9:** Generation of Gencos of Hydro area during Contract violation case.

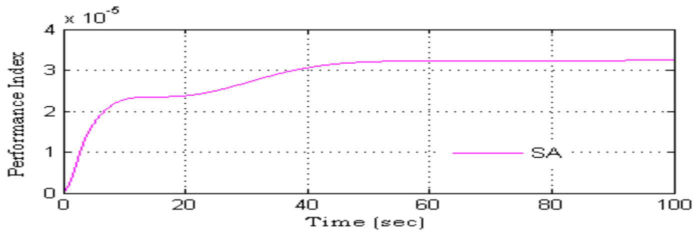


**Fig. 10:** Comparison of Performance index values during Normal case.

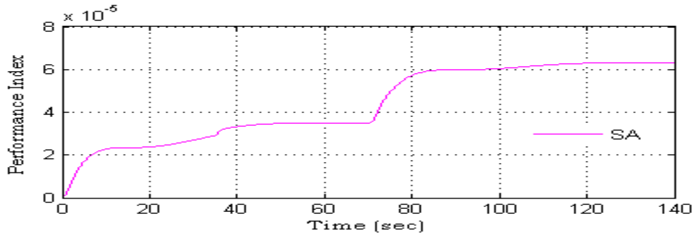


**Fig. 11:** Comparison of Performance index values during Contract Violation.

### 6. *Conclusion:*

The Simulated Annealing Optimization technique have been successfully applied to tune the gain of integral controller. A two- area hydrothermal system under deregulated scenario in the presence of SSSC and CES has been used to demonstrate the method. The performance index namely ISE has been used in the application of different optimization techniques. Out of all the methods proposed Simulated Annealing shows better results in terms of minimum performance index and also the integral controller tuned by Simulated Annealing brings about better response in terms of overshoot and settling time as shown in the simulation.

### *Appendix:*

*a) System data:*

$T_{p1}, T_{p2}$ =20s; $K_{p1}, K_{p2}$ =120Hz/p.u. Mw; $P_{r1}, P_{r2}$ =1200Mw; $T_t$ =0.3s; $T_g$ =0.08s, $T_w$ =1s; $T_r = 5s$, $T_1 = 41.6s$, $T_2$ =0.513s; $R_1, R_2$ = 2.4Hz/pu Mw; $T_{12}$ = 0.0866s; $B_1, B_2$ = 0.4249p.u Mw/Hz;

*b) CES data:*

$T_1$=0.279s; $T_2$=0.026s; $T_3$=0.411s; $T_4$=0.1s; $K_{CES}$=0.3; $T_{CES}$=0.0352s;

*c) SSSC data:*

$T_1$=0.188s; $T_2$=0.039s; $T_3$=0.542s; $T_4$=0.14s; $K_{SSSC}$=0.292; $T_{SSSC}$=0.03s;

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