# Enhancing the Performance of Multi Area AGC in Deregulated Environment Tuned with SSSC

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***Abstract*— This paper presents decentralized control scheme for Load Frequency Control in a Power System by appreciating the performance of the methods in a two area hybrid interconnected power system. This project analysis is done with the use of Automatic Generation Control of Interconnected Power system using Load Frequency control.The whole system is tuned with the help of integral controller to reduce the area control error and error in tieline which may cause improvement in the steady state output of interconnected hybrid system. Load frequency control (LFC)including PI controller is proposed in order to suppress frequency deviations for a power system involving gas, hydro and thermal plants owing to load and generating power fluctuations caused by penetration of renewable resources. Restructuring of whole power system is done by dividing it into GENCO, TRANSCO, DISCO and ISO which has been explained in detail in the report. The power generated by the GENCO has to be sold to DISCO at optimum rates. DISCO and GENCO will have contracts within its own area or with interconnected area and thus the power is exchanged between their interconnected area according to the contracts scheduled between them.In this system there are four GENCOs namely, steam, hydro and gas and four DISCO interconnected using bilateral contract and the modeling of the system is done using MATLAB simulation. It employs Synchronous static series compensator.. The robustness and reliability of the various control schemes is examined through simulations. The significant improvement of optimal transient performance is observed with the addition of a these controllers.**

***Keywords*— Generating Company (GENCO), Distribution Company (DISCO), Transmission Company (TRANSCO), Disco Participation Matrix (DPM), Automatic Generation Control (AGC),Synchronous static series compensator (SSSC).**

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## I. INTRODUCTION

ThThe high Indian population coupled with increase in industrial growth has resulted in an urgent need to increase the installed power capacity. In India, majority of power production, around 65 per cent is from thermal power stations. Due to problems related to uncertainty in pricing and supply of fossil fuels, renewable resources have been identified as a suitable alternative like solar, wind, and biogas plants are using in recent days. However, standalone operation of renewable resources is not reliable as they are intermittent in nature. The intermittent nature of resource increases the frequency deviations which further add to the deviation caused by load variation. This necessitates the grid connection of renewable resources like biogas. Automatic Generation control is a significant control process that operates constantly to balance the generation and load in power system. The AGC system is responsible for frequency control and power exchange. It improves the reliability of the system and creates the system more accurate. AGC also maintains the system frequency constant and makes the system more stable. Every bit the load demand increases or decreases, the speed of generator prime mover sets also changes which cause deviation in frequency of the arrangement and thus affect the steady state stability of the organization. Automatic generation control regulates the force production of generator in accordance with the change in system frequency, connect line power, so as to keep the system frequency within the allowable limit. To attain zero steady state error and to conserve the system frequency constant, a control scheme is required. Hare study of the two areas hybrid restructured power systems is performed in which each field receives its own automatic generated controller (AGC) which keeps the tie line power and system frequency constant by varying the generation according to the area control error (ACE). The AGC varies the gear up the location of generators of that country, which minimize the average time of ACE (Area Control Error). In a deregulated system GENCOs sell power to DISCOs at competitive cost and hence, DISCOs have various selections for the transaction of power from any of the GENCOs of its own area or different country. In each arena, an automatic generation controller (AGC) supervises the tie line power and system frequency, also calculates the net change in the generation required, which is related to the area control error (ACE) and modifies the gear up position of the generators within that country due to which net average time of ACE is at minimum. Optimization of auxiliary controller gains has been the main area of attraction. Intelligent control techniques provide a high adoption to changing weather. In this paper the gain of proportional controller is controlled by the use of SSSC. P.SUMAN [16] This paper shows the capability of SSSC in improving the transient stability margin of a power system. The most frequently used controller in LFC is Proportional Integral Controller (PI). It is simpler and better dynamic response in comparison to other controllers. From simulation results, it is shown that PI controller and SSSC are very effective in controlling the power flow, and the response time of them is also very fast.

## II. RESTRUCTURED POWER SYSTEM

The problems caused by load and frequency control become more difficult in large interconnected systems having many stations scattered over a wide area. Thus Restructured power system is needed which is basically divided into three parts GENCOs (generating companies), TRANSCOs (transmission companies), and DISCOs (distribution companies). The GENCOs generates power and DISCOs have freedom to have contracts with any generating company for the sake of power trading. To visualize the contracts between GENCOs and TRANSCOs, the concept of DISCO participation matrix (DPM) is used. The DISCO participation matrix is in the configuration of rows and columns where row represents number of GENCOs and columns represents the number of saucers. The total burden on the GENCOs of an area is the sum of cpf s (elements of DPM) and the Pu MW load of all the DISCOs of that country. The ISO may be empowered to prepare regulations for transactions between providers and consumers, scheduling and dispatch of generators, loads and network services, maintenance of system sobriety and reliability, congestion management, service quality assurance and promotion of economic efficiency.

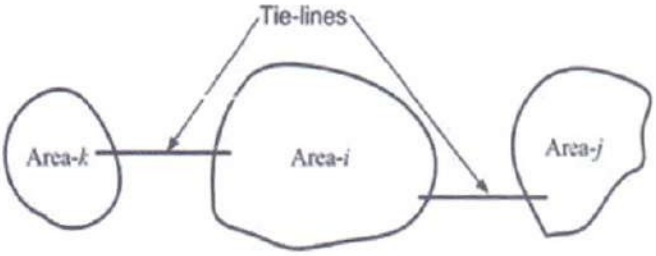


Fig.1. Configuration of power system under deregulated environment.

$$DPM = \begin{bmatrix} cpf_{1,1} & cpf_{1,2} & .. & .. & cpf_{1,8} \\ cpf_{2,1} & cpf_{2,2} & .. & .. & cpf_{2,8} \\ . & . & .. & .. & . \\ . & . & .. & .. & . \\ cpf_{15,1} & cpf_{15,2} & .. & .. & cpf_{15,8} \end{bmatrix}$$

DPM=

| | D1 | D2 | D3 | D4 |
|---|---|---|---|---|
| G1 | 0.2 | 0.1 | 0.3 | 0.6 |
| G2 | 0.6 | 0.8 | 0.6 | 0.4 |
| G3 | 0.2 | 0.1 | 0.1 | 0 |

The cpf is the contract participation factor. In DPM diagonal element shows the local requirement. The requirement of one region discos value to other regions GENCO value is shown aside the off diagonal element. The steady system consists of four-area. Area-1 consists of three GENCOs and two DISCOs. Their contract at some moment of time is selected as per DPM matrix shown above. The total of all the entrances in a column in this matrix is unity. Coefficients that distribute area control error (ACE) to several GENCOs are termed as an ACE participation factor (apfs). Note that because the same

$$\sum_{j=1}^{m} apf_j = 1$$

Where m is the GENCO in each area.

## IV. MATHEMATICAL CALCULATION OF ACTUAL AND SCHEDULED STEADY STATE POWER FLOW

The actual and scheduled steady state power flows along the given tie line is:-

$\Delta P_{tiei\text{-}j}$ Schedule = [Demand from Genco of the area i by the disco of area j – Demand from Genco of area j by the disco of the area i]

The tie line error is given by:-

$\Delta P_{tiei\text{-}j}\ error = \Delta P_{tiei\text{-}j}\ actual - \Delta P_{tiei\text{-}j}\ scheduled$ The tie line error disappears the steady state error. The ACE signal given to the ISO is:-

$ACE_i = B_i * \Delta f_i + \Delta P_{tiei\text{-}j}\ error$

$\Delta f_i$ error is change in frequency of area 'i' and

$B_i$ is a frequency Biase factor of area 'i'

The schedule tie line power is:-

$\Delta P_{tie}1\text{-}2 = -(0.2*0.1+0.1*0.1)+(0.1*0.1) = 0.02$ pu.

For optimal design, we must articulate the state model. This is accomplished by writing the differential equations describing each person Individual block of figure in terms of state variable.

In this paper the dynamic performance is obtained using MATLAB software for $\Delta f$, $\Delta P_g$ $and$ $\Delta P_{tiei\text{-}j}$ for different load disruption.

## V. STATIC SYNCHRONOUS SERIES COMPENSATOR

Static Synchronous Series Compensator (SSSC) is one of the important series FACTS devices. SSSC is a solid-state voltage source inverter, injects an almost sinusoidal voltage, of variable magnitude in series with the transmission line. The injected voltage is almost in quadrature with the line current. A small part of the injected voltage, which is in phase with the line current, provides the losses in the inverter. Most of the injected voltage, which is in quadrature with the line current, emulates an inductive or a capacitive reactance in series with the transmission line. This emulated variable reactance, inserted by the injected voltage source, influences the electric power flow through the transmission line.

The voltage sourced converter based arrangement compensator, called SSSC gives the virtual recompense of transmission line impedance by infusing the controllable voltage in arrangement with the transmission line. The capacity of SSSC to work in capacitive and also inductive mode makes it exceptionally compelling in controlling the force stream of the framework. SSSC is one of the imperative parts of FACTS family which can be introduced in arrangement in the transmission lines. With the capacity to transform its reactance trademark from capacitive to inductive, the SSSC is exceptionally compelling in controlling force stream in force frameworks. An assistant settling sign can likewise be superimposed on the force stream control capacity of the SSSC in order to enhance power framework wavering steadiness. The applications of SSSC for force wavering damping, steadiness upgrade and recurrence adjustment can be found in a few references. As of late, new computerized reasoning based methodologies have been proposed to outline a FACTS-based supplementary damping controller. These methodologies incorporate molecule swarm improvement, hereditary calculation , differential advancement, and multi-objective evolutionary calculation. The applications incorporate sparing burden dispatching, force framework stabilizers PSS, and so forth. The proposed controller has been connected and tried under diverse aggravations for a multi-machine power framework. The framework comprises of three generators partitioned into two subsystems and are joined through an intertie. For the outline reason, MATLAB/Simulink model of the force framework with SSSC controller is created. Reproduction results are exhibited at diverse working conditions and under different unsettling influences to demonstrate the viability of the proposed controller. The results demonstrate that the proposed controller. The results

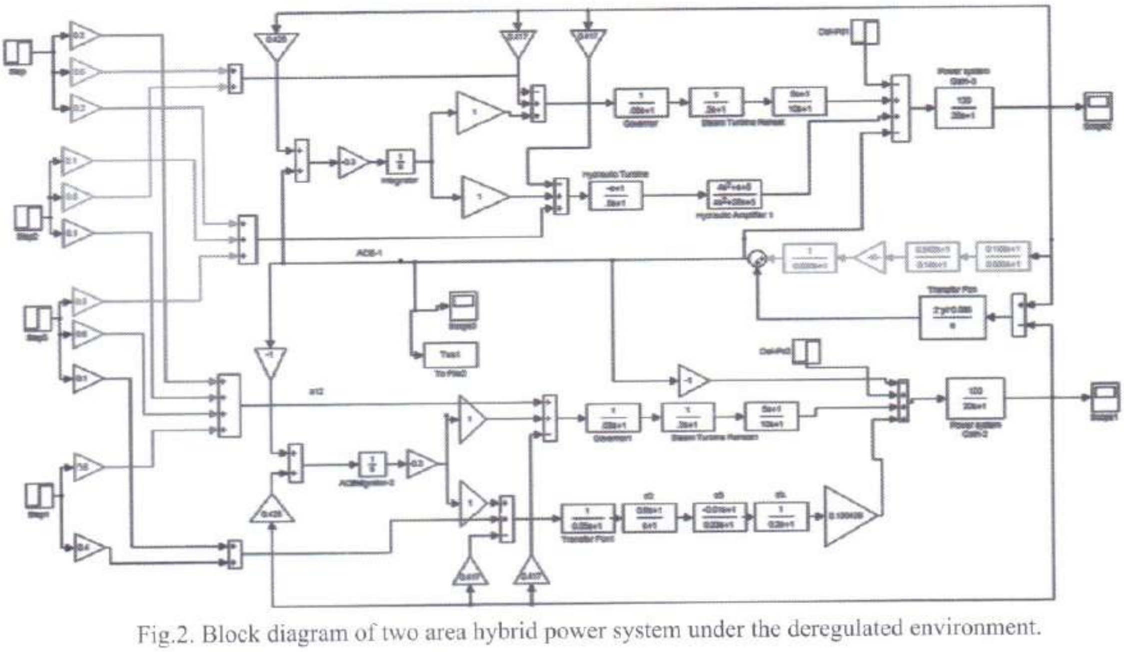

Fig.2. Block diagram of two area hybrid power system under the deregulated environment.

demonstrate that the proposed SSSC-based controller can enhance the voltage profile and transient solidness of the test framework more productive than the ordinary lead-slack controller of above gadgets. In view of this the main objectives of the present work are: To develop the two area Simulink model of hydrothermal system under load following. To develop the model of SSSC, andto compare the improvement of dynamic performance of the system with SSSC. The rest of the paper is organized as follows: A general overview on FACTS systems is given firstly. Dynamic mathematical model considered in this work. Describes the mathematical model of SSSC to be incorporated into the system. Demonstrates the results and discussions and some conclusions are presented finally.

OPERATING PRINCIPLE

A SSSC operated without an external electric energy source as a series compensator whose output voltage is in quadrature with, and controllable independently of, the line current for the purpose of increasing or decreasing the overall reactive voltage drop across the line and thereby controlling the transmitted active power. The SSSC may include transiently rated energy storage or energy absorbing devices to enhance the dynamic behavior of the power system by additional temporary real power compensation, to increase or decrease momentarily, the overall resistive voltage drop across the line.

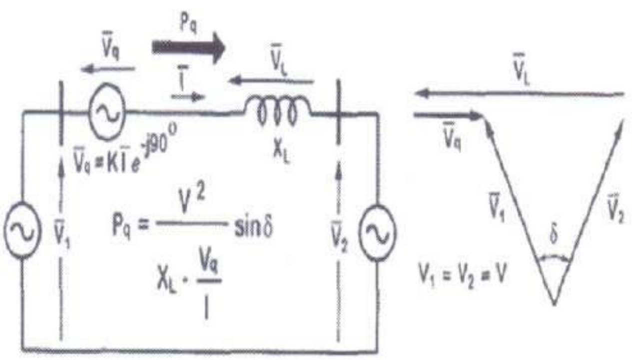

Fig.3 The elementary two-machine system with SSSC

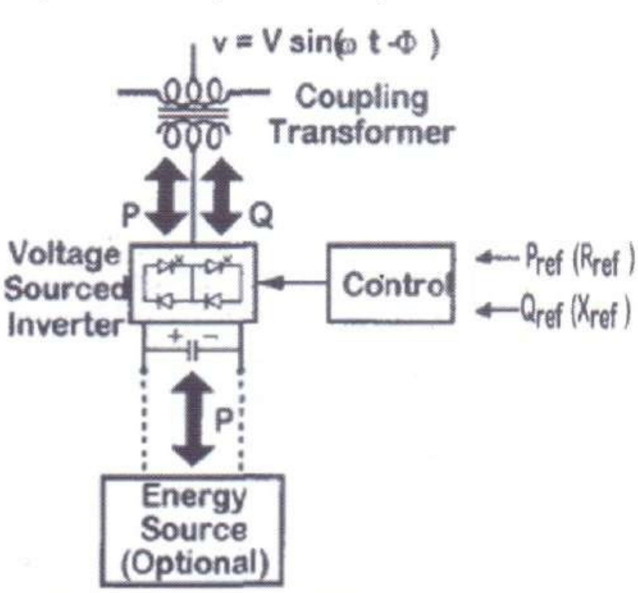


Fig. 4 Block diagram of Static Synchronous Series Compensator

Where

V1 is the voltage magnitude of machine-1.

V2 is the voltage magnitude of machine-2.

Φ is the phase difference between these voltages.

I is the current flowing from machine-1 to machine-2.

VL is the voltage drop across the line impedamce.

Pq is the active power flowing through the line.

Vq is the injected voltage by SSSC

**DESIGN OF SSSC**

The block diagram of SSSC to be incorporated in the two area system in order to reduce the frequency deviations is provided in Figure 3 shown below. The frequency deviation of area 1 can be seen as input to the SSSC device. It can be seen from Fig 3 that the structure of SSSC consists of gain block KSSSC , time constant TSSSC and two stage phase compensation blocks having time constants T1 , T2 , T3 , T4 respectively.

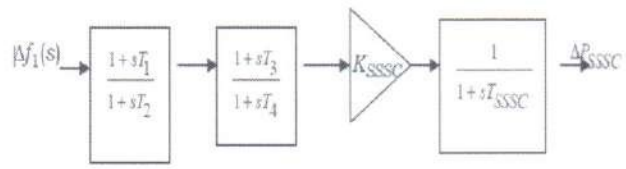

Fig 5 Design of SSSC

**STUDIED SYSTEM**

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 interconnection. Also, represent by a series connected voltage source Vs along with a transformer leakage reactance Xs. The SSSC controllable parameter is Vs, which in fact represents the magnitude of injected voltage

## VI. RESULTS AND DISCUSSION

The simulation is carried out on Four-Area interconnected deregulated system. The PI and TCPS controller is implemented with and without bacterial foraging technique. The integral constant $K_i$ is optimized and used in simulation in two different model of the system. In this system frequency of the system is compared. The tie line power is also considered before and after the deregulation. The simulation results and comparisons are shown in Fig. 7 to Fig. 22. Using Simulink/MATLAB formulation the optimum AGC controller gain value, representing the scheduling of generators, tie line power exchange is done. With the help of BFO value of Ki is obtained, which is applied to AGC in interconnected four area system under the deregulated environment.

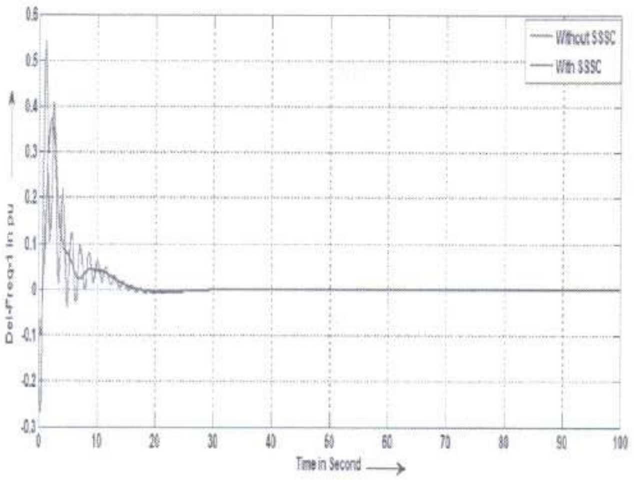


Fig. 7. Frequency comparison of Area-1 with and without SSSC.

Table 1. Parameters comparison for frequency of Area-1.

| Controller | Rise time | Settling time | Peak time |
|---|---|---|---|
| Without SSSC | 0.0026 | 3.8146e-005 | 7.8477e-006 |
| With SSSC | 0.0020 | 2.6210e-008 | 2.5709e-008 |

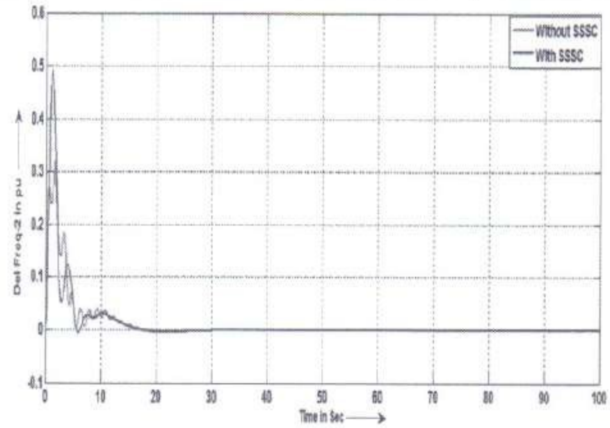


Fig. 8. Frequency comparison of Area-2 with and without SSSC

Table 2.Parameters comparison for frequency of Area-2

| Controller | Rise time | Settling time | Peak time |
|---|---|---|---|
| Without SSSC | -0.0306 | 5.4641e-006 | -9.5667e-007 |
| With SSSC | -0.0255 | 1.9267e-007 | 3.4105e-007 |

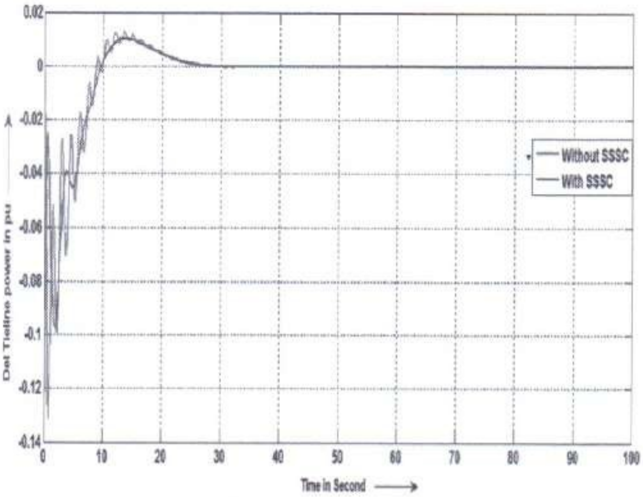


Fig. 9. Comparison of Tie-line power with and without SSSC

Table 3. Parameter comparison of tieline

| Controller | Rise time | Settling time | Peak time |
|---|---|---|---|
| Without SSSC | 0.0401 | 5.1086e-006 | 8.4133e-007 |
| With SSSC | 0.0633 | 1.0203e-007 | 8.2925e-008 |

## VII. CONCLUSIONS

This Paper encapsulates automatic generation control of the power system after deregulation includes bilateral contracts. DPM facilitates bilateral contracts simulation. Controller gains are optimized by Proportional integral controller and SSSC. This is study using simulation on Two area hybrid power system considering different contracted scenarios. The dynamic and steady state responses for generated power change, for the frequency change and tie line powers change are shown. The simulation reveals that the conventional PI with SSSC gives better performance than Proportional integral controller without SSSC. This method reduces the peak deviation in frequencies and improves the tie line power.

## APPENDIX-1

The various Parameters are as follows:

$f$= 50 Hz, $R_1$=$R_2$= 2.4 Hz/ per unit MW, $T_g$ = 0.08 sec, $T_p$=20 sec

$P_{tie,max}$ = 200 MW

FOR STEAM PLANT

$T_r$=10 sec, $k_r$ = 0.5,, $P_{r1}$ =2000MW, $T_t$ = 0.3 sec $K_{p1}$= 120 Hz.p.u/MW, $K_d$ =4.0 ki = 5.0 $T_w$ = 1.0 sec., $K_p$ = 26 , B1 =.25

FOR HYDRO PLANT

$K_{p2}$=120 Hz.p.u/MW, B2=.25

FOR GAS POWER PLANT

$T_{G1}$=0.05 $K_{GP}$=1.6 $T_{G2}$=0.6 $T_{G3}$=-0.01, $T_{G4}$=0.23, $T_{G4}$=0.2

FOR SSSC

$T_1$=0.030, K=0.29, $T_2$=0.542, $T_3$=.14, $T_4$=.542, $T_5$=.14

## REFERENCES

[1] Vaibhav Donde, M.A. Pai and Iran A. Hiskens, "Simulation and Optimization in a AGC System after Deregulation," IEEE Trans. Power Systems, VOL. 16, no. 3, AUGUST 2001.

[2] Ranjit Roy, S.P.Ghoshal and Praghnesh Bhatt, "Evolutionary Computaion based Four-Area Automatic Generation Control in Restructured Environment" in third International Conference on Power Systems, Kharagpur, India, 27-29th Dec, 2009.

[3] Surya Prakash and S.K. Sinha, "Intelligent PI Control Technique in Four Area Load Frequency Control of Interconnected Hydro-themal Power System," in International Conf. on Computing, Electronics and Electrical Technologies [ICCEET], 2012.

[4] Kanika Wadhwa, J. Raja and S.K. Gupta, "BF Based Integral Controller for AGC of Multiarea Thermal System under Deregulated Environment",IEEE 5th Power India Conference,19-22th Dec,2012.

[5] E.Rakhahani and J.Sadeh, "LOAD Frequency Control of Multi-Area Restructured Power System,"IEEE Trans. Power Systems,2008.

[6] F.Liu, Y.H.Song, J.Ma, S.Mei and Q.Lu, "Optimal Load Frequecy Control in Restructured Power Systems," IEE Proc.-Gener. Transm. Distrib., Vol. 150, No.1, Jan,2003.

[7] Kevin M. Passino, "Biomimicry of Bacterial Foraging for Distributed Optimization and Control," IEEE Control Syst. Mag., vol. 22, no. 3,pp.52-67,Jun. 2002.

[8] B. Parashuramulu and Ashwani Kumar. "Load Frequency Control of Hybrid Systems in Open Access Environment" IEEE Annual India Conference (INDICON),2010.

[9] Richard D.Christie and Anjan Bose, "Load Frequency Control Issues In Power system Operations After Deregulation,"IEEE Transaction Power Systems,1995.

[10] Elyas Rakhshani and Javed Sadeh, "Simulation of Two-Area AGC System in a Competitive Environment Using Reduced-Order Observer Method," IEEE Transaction Power Systems, 2008.

[11] J.Nanda, S. Mishra, L.C. Saikia, Maiden application of Bacterial Foraging based optimization technique in multi area automatic generation control, IEEE Transaction on Power system 24(May(2)) (2009) 602-609.

[12] Praghnesh Bhatt, Ranjit Roy and S.P. Ghoshal, GA/particle swarm intelligence based optimization of two specific varieties of controller devices applied of two-area multi-units automatic generation control, Electrical Power and Energy System 32(2010) 299-310.

[13] Praghnesh Bhatt, Ranjit Roy and S.P. Ghoshal, Optimized multi area AGC simulation in restructured power systems, Electrical Power and Energy System 32(2010) 311-322.

[14] Abido MA. Thyristor controlled phase shifter based stabilizer design using simulated annealing algorithm. In: Proceedings of the IEEE conference on power tech, Budapest; 1999. p. 307.

[15] NAIMUL HASAN, IBRAHEEM, SHUAIB FAROOQ[6] In this paper hydro and nuclear power plant comprises of area-1 and area-2 respectively. The real time simulation provides a quick solution for prototyping new functions in different types of industrial processes and device controlled with a complex distributed control system.

[16] P.SUMAN PRAMOD KUMAR, N.VIJYASIMHA, C.B.SARAVAN This paper discuses the basic operating and performance characteristics of SSSC It presents some of the results of TNA simulation carried out with an SSSC hardware model presented in an depth pulse GTO based converter model is designed to represent the operation of STATCOM and SSSC

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