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Fuzzy PID AGC of Multi-Area Power System Optimized by Hybrid DEPSO Algorithm with FACTs

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Abstract: This Study Proposes The Agc Of Three Area Power System Having Multi Sources Like Thermal Plant, Hydro Plant And Gas-Turbine Generating Units. A Fuzzy Proportional Integral Derivative Controller (Fpid) Is Proposed Here For Both Ac And Ac-Dc Parallel Tie Line. Differential Evolution Particle Swarm Optimization (Depso) Algorithm Is Considered Here To Optimize Scaling Factors. Facts Are Designed To Enhance The Power Flow Transmission Capability And Also Improve The Dynamic Response Characteristics. The Facts Devices Tcps And Smes Are Used In This Paper. The Proposed Hybrid Depso Optimized Fpid With Facts Is Depicted By Comparing Their Simulation Results. The Comparison Is Basically Done On The Basis Of Undershoot, Overshoot And Settling Time. From The Simulation Results It Reveals That The Presence Of Smes Improves The Dynamic Response Than Tcps. Finally A Combined Effect Of Tcps-Smes Gives A Better Dynamic Response Than The Other Optimized Controlled Values.

Keywords: Agc: Automatic Generation Control, Facts: Flexible Ac Transmission Systems, Tcps: Thyristor Controlled Phase Shifter, Smes: Super Magnetic Energy Storage, Ace: Area Control Error

I. INTRODUCTION

The electrical energy produced basically depends on generating units and load demands. To meet load demands in geographical areas, generators are interconnected through transmission network and forms large complex system. These control areas are interconnected by tie lines to exchange the energy. Different generating units like thermal-power, hydro-power, gas turbine, nuclear and other renewable sources are comes under control areas. This paper describes only the first three generating units due to economy and efficiency [5]. To maintain stable operating condition frequency should be kept constant. The main aim of AGC is to make Area Control Error zero and control the two variables system frequency and deviation of tie line power. Different approaches are introduced for controlling these two variables at their minimum values [1].

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The fundamental idea of AGC of an interconnected hydro thermal system with classical controller has first presented by Nanda, Kothari and Satsangi [2]. Concordia and Kirchmayer [4] studied the LFC of a hydro-thermal system considering the non- reheat steam turbine without generation constraints. Concept of tie power is described in [3-4]. Parmer et al. have presented multi sources generation consisting of thermal power, hydro power and gas turbine generating units, considering DC link which is connected anti parallel with existing system for low frequency stabilization [6,7]. Many control and optimization techniques like PSO, DE and hybrid DEPSO have been proposed for AGC system [8-15]. These optimization techniques are used to tune the controller parameters like PI controller, PID controller and FPID controller. Though the PID controller is simple to design, but it is not suitable for nonlinear system which causes high overshoot values and more settling time to achieve steady state whereas the proposed FLC [16-18] can effectively reduces the severe oscillations happened in transient period. Fuzzy logic controller is suitable for non linear system with low frequency oscillation. Yesil et al. [19] have used a self tuning FPID controller for AGC system. The proposed power system provides continuous power flow by utilizing power electronic devices in form of FACTs devices [20]. Two most promising FACTs devices have proposed in this paper TCPS and SMES. The first one TCPS [21,22] is an effective device for controlling the interchange power. Das et al. [21] have described the application of TCPS for frequency stabilization of an interconnected AGC system. Then SMES is considered for this system to control the active and reactive power simultaneously [23-25]. Then a combined TCPS and SMES [26-27] have proposed in this paper to show the better transient stability.

The aim of this study is to optimize fuzzy PID controller data and also gains parameters of TCPS and SMES of an interconnected power generation with AC link and ACDC tie line tuned by hybrid DEPSO algorithm. A comparison has established between FPID with FACTs and without FACTs devices.

II. MULTI-AREA POWER SYSTEM

A. *Power System Model*

At first the proposed system comprising of an interconnected multi source generation including thermal-power, hydro-power and gas with reheat type turbine assuming SLP in control area1. For each unit there should be regulation parameter and participation factor. Each participation factor summation for each control should be one. The same block model is also used for ACDC link with its transfer function. At first a FPID controller is applied to the two area system as an input to the three generating units for controlling frequency.

Area Control Errors (ACEs) is given as the input and outputs are U_T, U_H and U_G of FPID controller. Then this proposed system also includes addition of FACTs controller considering the same system parameters

$$ACE_1 = \Delta P_{12} + B_1 \Delta F_1 \quad \dots\dots(1)$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta F_2 \quad \dots\dots(2)$$

ΔP_{12} and ΔP_{21}: tie line power deviations
B_1 and B_2 : biasing factor for area1 and area2 respectively
ΔF_1 and ΔF_2 : frequency deviation for area1 and area2 respectively.

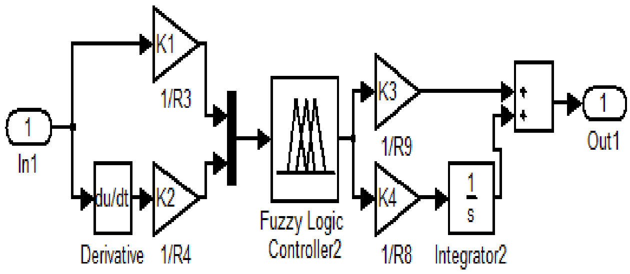

Fig. 1Basic structural diagram for FPID controller

B. Gain scheduling control

The basic structural diagram for FPID controller is shown in Fig. 1[19]. It consists of fuzzy proportional-integral and fuzzy proportional-derivative controllers. In this diagram K_1, K_2 are the input scaling factors and K_3, K_4 are the output scaling factors. For area2 similar FPID controller is used. Since 3 generating units are used in two area AGC system then 12 parameters are to be optimized.

In Fuzzy controller ACE and $\dot{ACE}$ (error derivative) are the inputs. A triangular membership function is used for both inputs and outputs having fuzzy linguistic variables are NB, NS, Z, PS and PB. Defuzzification is done by Center of gravity (COG) method using Mamdani Fuzzy Inference System (FIS). There are 25 rule bases for fuzzy controller.

C. Concept of FACTs

With the rapid increase of an electrical power demand, the existing transmission network is unable to provide an efficient and reliable power supply. Also if we replace the existing transmission network or expand the transfer capability of that system, there is a huge financial problem. So a new technology has employed to solve that problem efficiently and most important is cost effective. This technology is the FACTS device. Hingorani & Gyugyi proposed the concept of FACTs. Generally FACTs employed with high speed thyristors for switching in and out of the transmission line components. The main objective of this device is to replace the existing slow acting mechanical control to fast acting electrical control.

Linearized model of TCPS

It is a device based on both thyristors and phase shifting transformer technologies. The basic structural diagram of TCPS is shown in Fig. 2 [21]. Phase shifting transformers are the transformer consists of complex turns ratio. It acts as controller to power flow and also reduce the transmission losses.

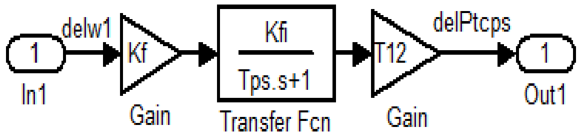

Fig. 2 Representing TCPS as frequency stabilizer

K_f: gain block with nominal system frequency value
K_φ: gain stabilization factor
T_{ps} : Time constant of TCPS

The model of two area multi source power generation is shown in Fig. 3. The nominal values of system parameters are mentioned in Appendix. A [8]

A. Linearized model of SMES

The SMES unit consists of a transformer, 12 pulse converter and superconducting inductor. The structural representation of SMES unit of power system is shown in Fig. 4 [23]. In this scheme during normal operation a superconducting coil is used which can be charged to a base value. In this case forced commutated converter is used with firing angle (α). The converter operates as rectifier for (α = <90°) and operates as inverter for (α = >90°). When the load changes suddenly the energy is released through power converter system. Then it discharged to its initial value to get an equilibrium condition for the governor and control mechanism. Again the coil gets charged to absorb excess energy to maintain steady state. Here

K_f: Nominal frequency
K_{SMES}: Proportional block
T_{SMES}: The time constant of SMES
T_1,T_2, T_3 and T_4 are the time constants.

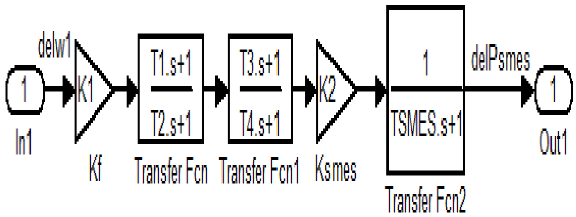

Fig. 4 Representing SMES as frequency stability

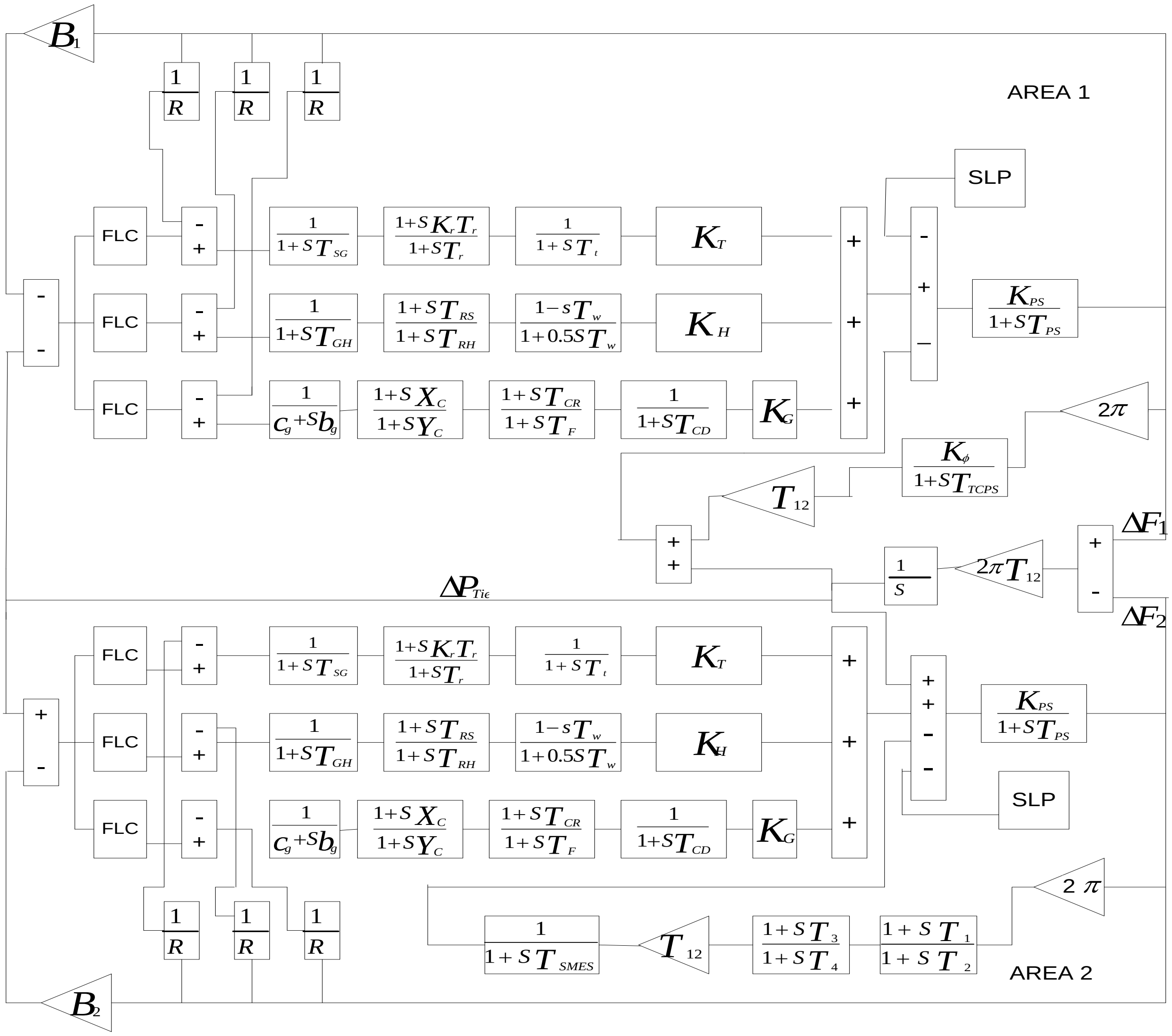

Fig. 3 Block diagram of transfer function for multi source two area systems

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B. Optimization technique

To minimize the control error and suitable objective function, a hybrid algorithm is proposed in this paper named as hybrid DEPSO [14]. It is the combination of DE algorithm [8-9] and PSO algorithm [10-11]. The slow convergence in DE can be resolved by PSO while easily trapping to local optimum of PSO improved by DE. DEPSO works step by step by passing particle to the PSO. Then it computes mutation and crossover and the new result are sent back to PSO until it reaches the maximum iteration.

1. Initialize a random population of size $[N_p \times D]$ where population size is N_p and the dimension of particle id *D*, velocity and position of particle.
2. First generate donor vector V_i for DE operation

$$V_i = X_{i,r1} + F\left(X_{i,r2} - X_{i,r3}\right)$$

   Where r_1, r_2, r_3 are three distinct integers chosen between 1 and N_p and F , the scaling factor.
3. Secondly generate the offspring vector U_i with crossover rate CR

$$U_i = \begin{cases} V_i, rand(D,1) \le CR \\ X_i, \; othrwise \end{cases}$$

4. The target vector X_i has selected in selection process

$$X_i = U_i \; if \; f(U_i) \le f(X_i)$$
$$X_i = X_i \; if \; f(X_i) \le f(U_i)$$

   Where, f is the function to be minimized.
5. Finally detect the P_{best} and G_{best} value.
6. For PSO operation, take X_i as initial population that obtained in step (5) from DE operation.
7. Then velocity and position of each swarm particle has updated

$$v_i^{k+1} = w.v_i^k + c_1 r_1\left(p_{i,best}^k - x_i^k\right) + c_2 r_2\left(p_{i,gbest}^k - x_i^k\right)$$
$$x_i^{k+1} = x_i + v_i^{k+1} \quad \text{........................(8)}$$

8. Fitness function is evaluated and updated for next iterations.

9. Repeat the steps 3-9 until meet the stopping criteria

III. RESULTS AND DISCUSSIONS

Hybrid DEPSO has applied to AGC process to optimize the fuzzy PID, TCPS and SMES controller parameters. At first the gain parameters FPID controller are optimized by the proposed algorithm with suitable system parameters for both AC tie line and ACDC tie line for multi-source two area system. The results are obtained by MATLAB7 2010 software and SIMULINK model. For all algorithms in this proposed application practically [2, 0.01] is taken as upper and lower bounds. The F and CR values for DE operation are taken as 0.8 and 0.2 respectively. The small values are chosen for the boundary limits to avoid the instability due to larger values. The number of iteration for FPID based optimization process applied to AGC is taken as 50. There should be a comparison results to show the priority of the hybrid DEPSO tuned fuzzy PID controller with the FACTs controller devices.

C. A comparisons between FLC with FACTs and without FACTs devices

Addition of FACTs device to the FPID system is optimized with the proposed algorithm. Simulation has carried out for considering 0.01 pu SLP in area1. At first A FPID controller gain parameters are tuned by DEPSO method. Then A TCPS based FPID controller applied to area1 has performed to enhance the power transfer capability. Simulation has also performed for SMES FACT controller applied to arae2 in addition to fuzzy logic. After that a combined controller scheme TCPS fed to area1 and SMES fed to arae2 has performed. Finally a comparison is made among all according to their system performances. From the simulation results it reveals that a combined TCPS and SMES FACTs controller in addition to FPID has the better stability as compared to others in terms of peak overshoot, undershoot and settling times.

G1. Simulation results for AC tie line only

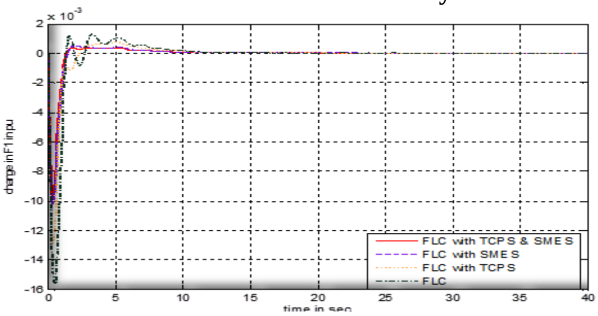

Fig. 5 Frequency deviation for area1

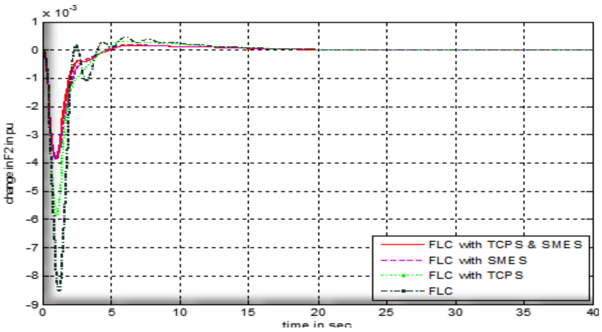

Fig. 6 Frequency deviation for area2

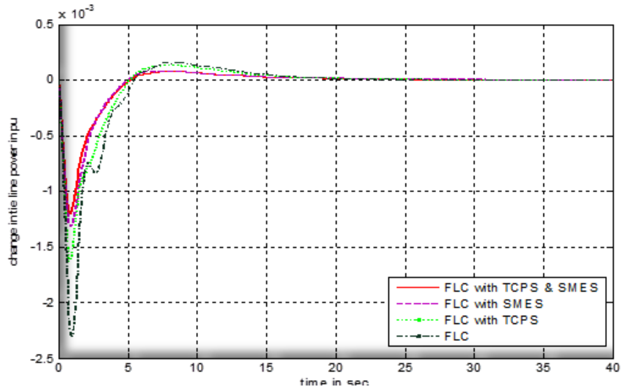

Fig. 7 Tie power deviation of

G2. Simulation results for ACDC link

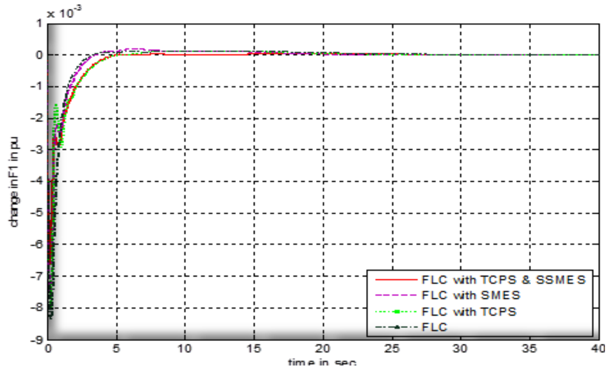

Fig. 8 Frequency deviation for area1

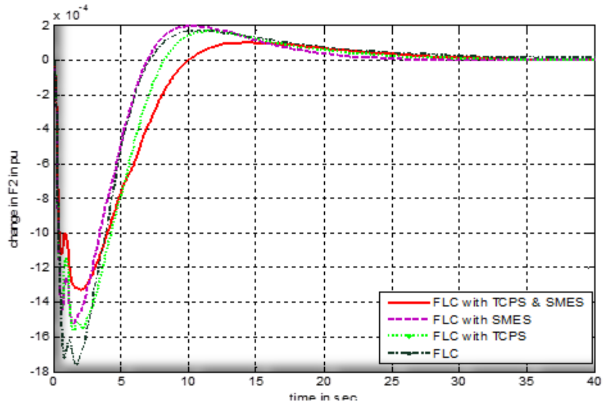

Fig. 9 Frequency deviation for area2

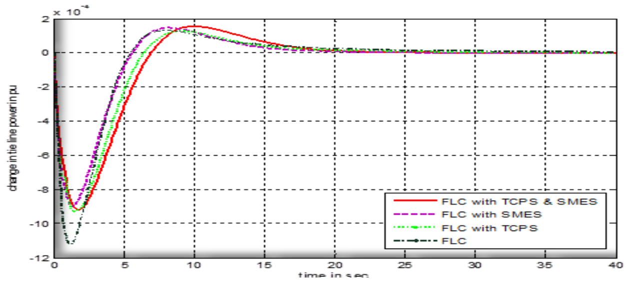

Fig. 10 Tie power deviation of FLC

From the above simulation Fig. 5 to Fig. 10, it is clear that ACDC tie line has better response characteristics than AC tie line only because of low frequency oscillation. A coordination of TCPS and SMES units with FPID has the better transient stability as compared to FPID controller only and also FPID with either TCPS or SMES controller only in terms of overshoot (Osh), undershoot (Ush) and settling time (Ts). The dynamic performance values of AC link and DC link are mentioned in Table 2 and Table 3 respectively.

Table1 Nominal values of system parameters [12]

T_{12}=0.0433,

$T_{SG} = 0.08s$

$B_1 = B_2 = 0.4312$

$f = 60Hz \;\; K_T = 0.543478$

$T_{PS} = 11.49$,

$R_{TH}, R_{HY}, R_G = 2.4Hz/pu$

$K_H = 0.326084$

$c_g = 1, b_g = 0.05$ s

$T_{FF} = 0.23$ s, $T_{CR} = 0.01$ s, $T_{CD} = 0.2$ s

$T_{GH} = 0.2$ s, $X_C = 0.6$ s, $Y_C = 1.0$ s

$T_T = 0.3$ s, $T_{RS} = 5$ s, $T_{RH} = 28.75$ s

$K_R = 0.3$, $T_R = 10$ s, $T_W = 1.0$ s,

$K_G = 0.130438$

IV. OUTPUT RESULTS

Table 2. Performance values Ush (Hz), Osh (Hz), Ts (sec) of frequency and tie power deviations for AC tie line

Algorithm	Controller	ΔF_1			ΔF_2			ΔP_{Tie}		
		U_{sh}	O_{sh}	T_s	U_{sh}	O_{sh}	T_s	U_{sh}	O_{sh}	T_s
DEPSO	FPID	-15.6102	1.2942	9.06	-8.5612	0.4629	10.17	-2.2968	0.1472	4.54
	FPID-TCPS	-12.8511	0.7519	8.69	-5.8639	0.3145	10.07	-1.6334	0.1327	4.07
	FPID-SMES	-10.2724	0.4998	6.79	-3.8780	0.1862	3.81	-1.3159	0.0758	3.49
	FPID-TCPS-SMES	-9.6312	0.3914	6.37	-3.8411	0.1495	3.7	-1.2052	0.0717	3.44

Table 3. Performance values Ush (Hz), Osh (Hz), Ts (sec) of frequency and tie power deviations for ACDC tie li

Algorithm	Controller	ΔF_1			ΔF_2			ΔP_{Tie}		
		U_{sh}	O_{sh}	T_s	U_{sh}	O_{sh}	T_s	U_{sh}	O_{sh}	T_s
DEPSO	FPID	-8.3885	0.1315	2.54	-1.7593	0.1699	6.068	-1.1211	0.1307	4.278
	FPID-TCPS	-7.9888	0.1052	3.89	-1.5641	0.1401	7.08	-0.9301	0.1277	5.1
	FPID-SMES	-7.7255	0.2102	2.83	-1.5239	0.1961	6.01	-0.9031	0.1452	4.41
	FPID-TCPS-SMES	-6.6232	0.0524	2.77	-1.3286	0.1008	6.04	-0.9197	0.1544	3.6

The pictorial bar diagram of dynamic performances are shown in Fig. 11 to Fig. 16.

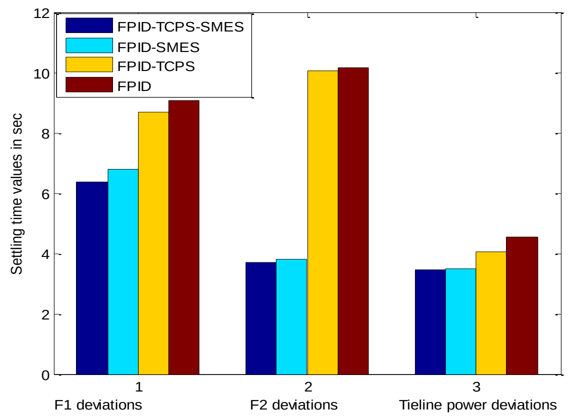

Fig. 11 Settling time bar graph plot for AC tie line only

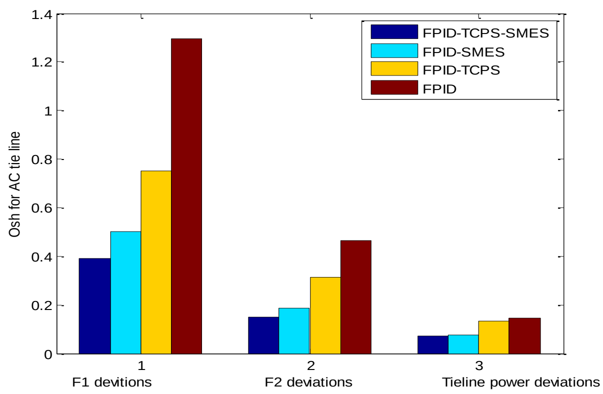

Fig. 12 Overshoot bar graph plot for AC tie line only

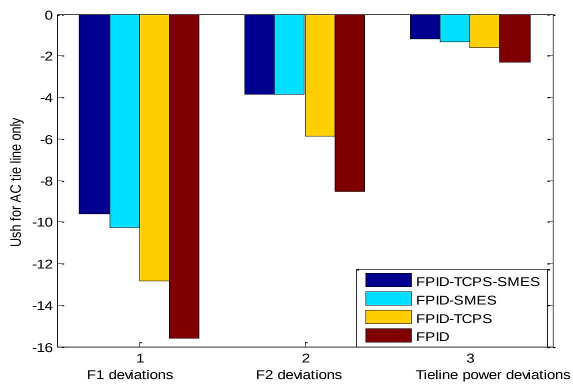

Fig. 13 Undershoot bar graph plot for AC tie line only

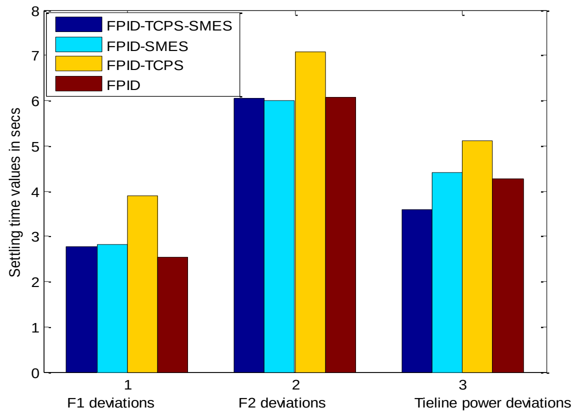

Fig. 14 Settling time bar graph plot for ACDC tie line

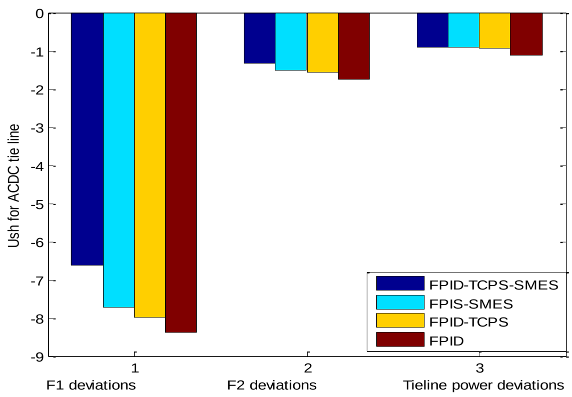

Fig. 15 Undershoot bar graph plot for ACDC tie line

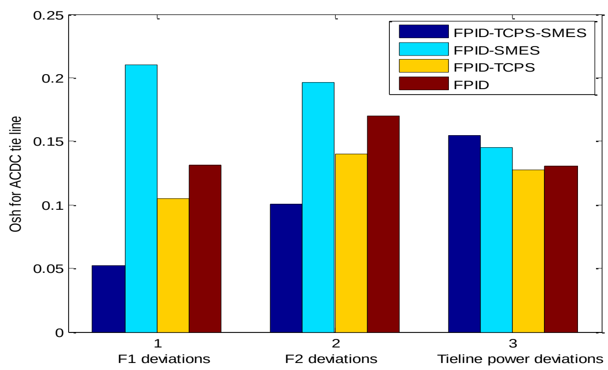

Fig. 16 Overshoot bar graph plot for ACDC tie line

V. CONCLUSION

This paper basically analyzing the impact of FACTs controller devices in addition with fuzzy PID controller to the multi source two area AGC systems for both AC and ACDC tie line. At first a comparison is made in between AC and ACDC link with the help of SIMULINK/ MATLAB coding. Simulation has carried out by taking 1% SLP in arae1 and it concludes that DC link in parallel to existing AC link has better stability. One of the main purposes of FPID controller is to improve the control performance. The structure of this controller is simple. Incorporation of a single TCPS or single SMES in addition with FPID controller also stabilizes the AGC system. This coordination gives better dynamic stability and suppresses the transient nature after load perturbation which improves the transient response of the system.

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Appendix B. Nomenclature

ACE_i Area control error of i[th] control area pu MW

P_{rt} Rated capacity of each control area, MW

P_L Nominal load of the control area, MW

f Nominal system frequency, Hz

D System damping of area, pu MW/Hz

B_i Frequency bias constant of i[th] control area, p u MW/Hz

a_{12} Control area capacity ratio

T_{SG} Speed governor time constant, s

T_T Steam turbine time constant, s

T_{PS} Power system time constant, s

R_{TH}, R_{HY}, R_G Speed regulation parameters of thermal, hydro and gas generating units

K_{PS} Power system gain, Hz/puMW

K_R Steam turbine reheats constant

T_R Steam turbine reheats time constant, s

T_W Nominal starting time of water in penstock, s

T_{RS} Hydro turbine speed governor reset time, s

T_{RH} Hydro turbine speed governor transient droop time constant, s

T_{GH} Hydro turbine speed governor main servo time constant, s

X_G Lead time constant of gas turbine speed governors

Y_G Lag time constant of gas turbine speed governors

c_g Gas turbine valve positioner

b_g Gas turbine constant of valve positioner

T_f Gas turbine fuel time constant, s

T_{CR} Gas turbine combustion reaction time delay, s

T_{CD} Gas turbine compressor discharge volume –time constant, s

u_k Control signal to kth generating unit

Δf_i Incremental change in frequency of ith control area, Hz

T_{12} Synchronizing power coefficient

ΔP_{tie12} Incremental change in actual tie line power frm control area-1to2puMW

ΔP_{Di} Total incremental change in local load of ith control area, pu MW

AUTHORS PROFILE

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