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Evaluation of Power System ASR Indices for IDN-FOPD Controller based Automatic Generation Control of a Two-Area Thermal Restructured Power System

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Abstract*—This paper presents the evaluation measures for achieving the power system Ancillary Services Requirement (ASR) indices subject to the AGC assessment of a 2 area thermal restructured system. A novel Iintegral Derivative along with Fractional Order Proportional Derivative (IDN-FOPD) controller is proposed to design AGC loop. The parameters of IDN-FOPD are tuned utilizing the Big Bang Big Crunch algorithm. An extensive comparative analysis been carried out with Proportional-Integral (PI) and Fractional Order Proportional-Integral-Derivative (FOPID) controller. Power system ASR indices are computed based on the dynamic response of the control input deviations and mechanical power generation deviations. Results arrived depicts that BBBC tuned IDN-FOPD controller improves the output retort of the test system.

Keywords: Ancillary Services Requirement Indices, AGC, Big Bang Big Crunch algorithm, IDN-FOPD controller.

I. INTRODUCTION

In an interconnected power system, little unexpected changes in the load in whichever of the regions causes the changes of the frequencies of every single zone and furthermore there is a variance of power in tie-line. The fundamental objectives of Automatic Generation control (AGC) are, to keep up the nominal frequency and the optimal power output (megawatt). The AGC movement is facilitated by the Area Control Error (ACE) which is a component of system frequency and tie-line flow [1, 2].

Several optimization techniques play an important role to find the optimal controller parameters of a several standard controllers [8]. The advantages of BBBC[11] algorithm are to be used for optimization of PI, FOPID and IDN-FOPD controllergains of AGC loop for two-area thermal interconnected deregulated power system for different transactions. The purpose of this paper to develop more effective and fast restoration plan using ASR indices based AGC assessment for a two-area thermal power system.

II. DESIGN OF IDN-FOPD CONTROLLER USING BIG BANG BIG CRUNCH ALGORITHM

In Figure 1 there are two blocks integer order-IDN controller and fractional order-PD controller [5, 7].

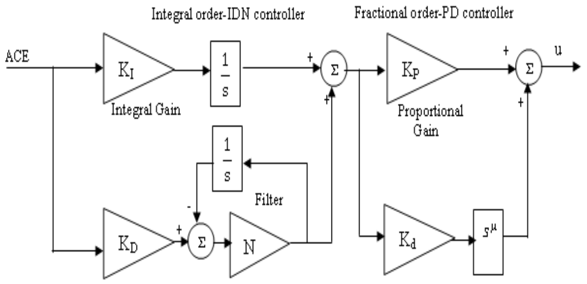

Fig. 1. Proposed IDN-FOPD controller

The BBBC algorithm [11, 12] are utilized to decide the ideal requirements of IDN-FOPD controllers which can be defined in the accompanying way:

$$J = \int_0^{t_{sim}} (\beta_1 \Delta F_1^2 + \beta_2 \Delta F_2^2 + \Delta P_{tie}^2)\, dt \qquad (1)$$

$$Minimize\ J \qquad (2)$$

Subject to

$$K_I^{min} \le K_I \le K_I^{max}, K_D^{min} \le K_D \le K_D^{max}, N^{min} \le N \le N^{max}, K_p^{min} \le K_p \le K_p^{max}, K_d^{min} \le K_d \le K_d^{max}, \mu^{min} \le \mu \le \mu^{max} \qquad (3$$

III. MODELING OF TWO-AREA THERMAL POWER SYSTEM IN RESTRUCTURED ENVIRONMENT

In the deregulated power system, Discos in each zone can bond with Gencos in its own or different zones. Such exchanges are called bilateral exchanges[2]. Every one of the exchanges must be cleared through a fair element called an ISO the linea model of two-area thermal restructured power system as shown in Fig 2 [3,4].

The dynamic models of reheat bicycle mix condensation turbine are appeared in Fig 3 [12].

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The principle requirements of these models are the time constants T_{SC}, T_{RH} and T_{CO} of Steam Chest (SC), Reheater (RH) and Cross-Over (CO) pipe respectively and the power divisions F_{HP}, F_{IP} and F_{LP} of High Pressure (HP), Intermediate-Pressure (IP) and Low Pressure (LP) turbines separately.

The regular estimations of different time constants and power bits of thermal reheat turbine can be intended for various generation schedules by expelling the heat balance data is appeared in the appendix[12].

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \quad (4)$$

$$\Delta P_{Tie\ 12}^{scheduled} = \sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\,\Delta P_{Lj} - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\,\Delta P_{Lj} \quad (5)$$

The actual tie-line power is given as

$$\Delta P_{Tie\ 12}^{actual} = \frac{2\pi T_{12}}{s}(\Delta F_1 - \Delta F_2) \quad (6)$$

$$\Delta P_{Tie\ 12}^{Error} = \Delta P_{Tie\ 12}^{actual} - \Delta P_{Tie\ 12}^{scheduled} \quad (7)$$

$$ACE_1 = \beta_1 \Delta F_1 + \Delta P_{Tie12}^{Error} \quad (8)$$

$$ACE_2 = \beta_2 \Delta F_2 + a_{12} \Delta P_{Tie12}^{Error} \quad (9)$$

$$\Delta P_{mi} = \sum_{j=1}^{4} cpf_{ij}\,\Delta P_{Lj} \quad (10)$$

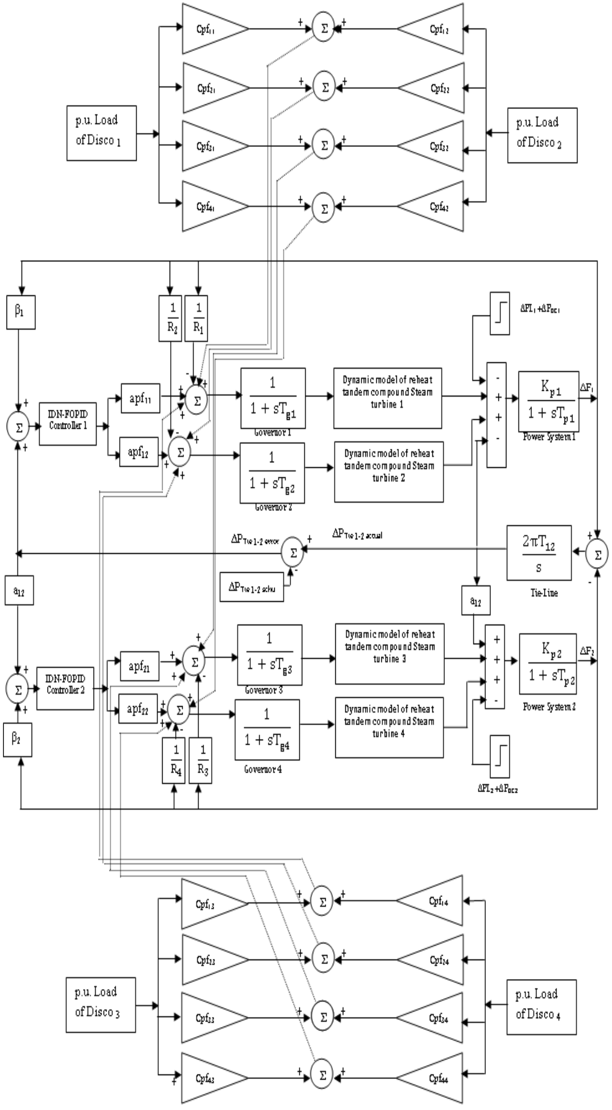


Fig. 2.Transfer function model for Test System

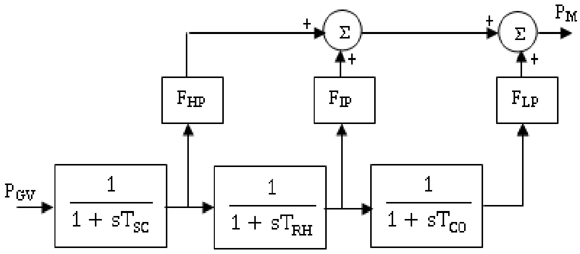


Fig. 3. Dynamic model of a reheat tandem compound steam turbine

IV. EVALUATION POWER SYSTEM ANCILLARY SERVICE

The various power system AncillarySystem Restoration indices (ASR_1, ASR_2, ASR_3 and ASR_4) are as follows

Step 1: The ASR_1 is difference between the input deviation of area 1 $\Delta P_{C1}(\tau_P)$ and steady state value of control input deviation $\Delta P_{C1}(\tau_s)$

$$ASR_1 = \Delta P_{c1}(\tau_p) - \Delta P_{c1}(\tau_s) \quad (11)$$

Step 2: The ASR_2 is the difference between deviation of ystearea 2 $\Delta P_{C2}(\tau_P)$ and steady state value of control input deviation $\Delta P_{C2}(\tau_s)$

$$ASR_2 = \Delta P_{c2}(\tau_p) - \Delta P_{c2}(\tau_s) \quad (12)$$

Step 3: The ASR_3 is obtained from difference between the maximum and generation deviation of $Genco_1$

$$ASR_3 = \Delta P_{M1}(\tau_p) - \Delta P_{M1}(\tau_s) \quad (13)$$

Step 4: The ASR_4 is obtained from difference between the maximum and generation deviation of $Genco_2$

$$ASR_4 = \Delta P_{M2}(\tau_p) - \Delta P_{M2}(\tau_s) \quad (14)$$

Step 5: The ASR_5 is obtained from difference between the maximum and generation deviation of $Genco_3$

$$ASR_5 = \Delta P_{M3}(\tau_p) - \Delta P_{M3}(\tau_s) \quad (15)$$

Step 6: The ASR_6 is obtained from difference between the maximum and generation deviation of $Genco_4$

$$ASR_6 = \Delta P_{M4}(\tau_p) - \Delta P_{M4}(\tau_s) \quad (16)$$

V. SIMULATION RESULTS AND OBSERVATIONS

In this test framework have two generating units in every zone with same capacities is considered. In this study, the control parameters of IDN-FOPD are tuned with help of BBBC algorithm. These IDN-FOPD controllers are implemented in a proposed test system for different types of transactions with different generation schedules and compared with PI and FOPID controller. The dynamic model steam turbine parameters have been used AGC loop under varying generation schedule condition. The corresponding ASR indices are calculated using Eq (11)-(16) from dynamic responses of control input deviations and mechanical power generation of the proposed test system.

Scenario 1: Poolco based transaction, the DPM is considered as [3, 4]

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0.0 & 0.0 \\ 0.5 & 0.5 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 0.0 \end{bmatrix} \quad (17)$$

The comparative dynamic output response of the thermal system with various controller is shown in Fig 4. From the simulation results ASR Indices are evaluated using Eqn (11)-(16) from control input deviations and mechanical power generation deviations of each area for the test system using proposed IDN-FOPD controller.

Scenario 2 : Bilateral based transaction ,the DPM is considered as

$$DPM = \begin{bmatrix} 0.1 & 0.0 & 0.2 & 0.5 \\ 0.4 & 0.4 & 0.2 & 0.0 \\ 0.3 & 0.0 & 0.3 & 0.3 \\ 0.2 & 0.6 & 0.3 & 0.2 \end{bmatrix} \quad (18)$$

The corresponding ASR indices are shown in Tables 1-3 .

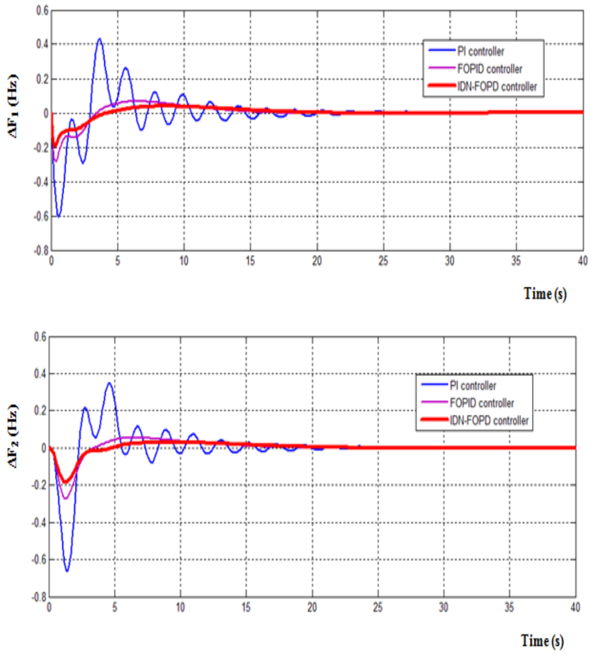
Moreover, the dynamic performance and ASR indices are improved using IDN-FOPD controller.

(i) In the event that, $0.3 \leq ASR_1, ASR_2 \leq 0.5$, The integral control activity is required depending on the execution criteria.

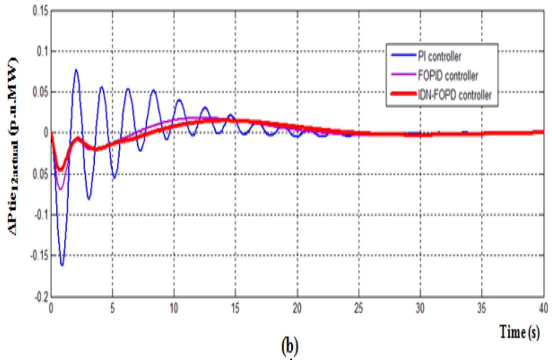
(ii) In the event that $ASR_1, ASR_2 \geq 0.5$at that point the FACTS controller is expected to progress tie-line power oscillations).

(iii) If $0.02 \leq ASR_3, ASR_4,\ ASR_5, ASR_6 \leq 0.05$ then the test system required the adjustment of frequency oscillations in an interconnected power system. The traditional burden of AGC loop may never again have the capacity to lessen the huge frequency oscillation because of the moderate response of the governor for eccentric load variations. Consequently proceeding with the change in power system designs and their In situations where a sensational decrease in frequency happens amid the restoration procedure, it is important to diminish the measure of the load which is associated, which can be practiced by the use of under load shedding plan.

(iv) In the event that$ASR_3, ASR_4,\ ASR_5, ASR_6 \geq 0.05$, at that point the test system is vulnerable. Major actions involved in this restoration process are start up of black start units, cranking of non-black start units, restoration of islands, and synchronization of islands.



(a)



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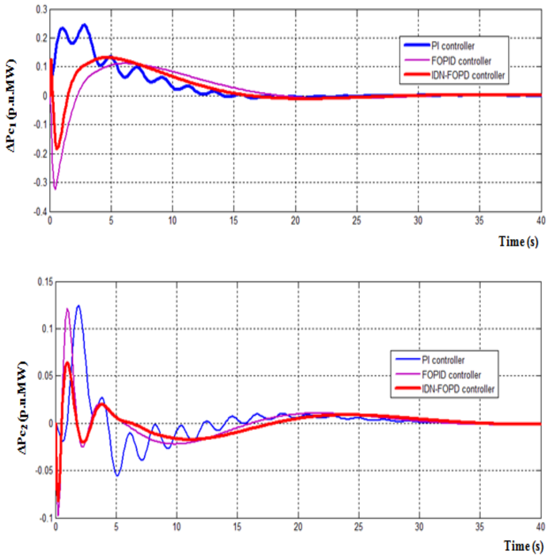

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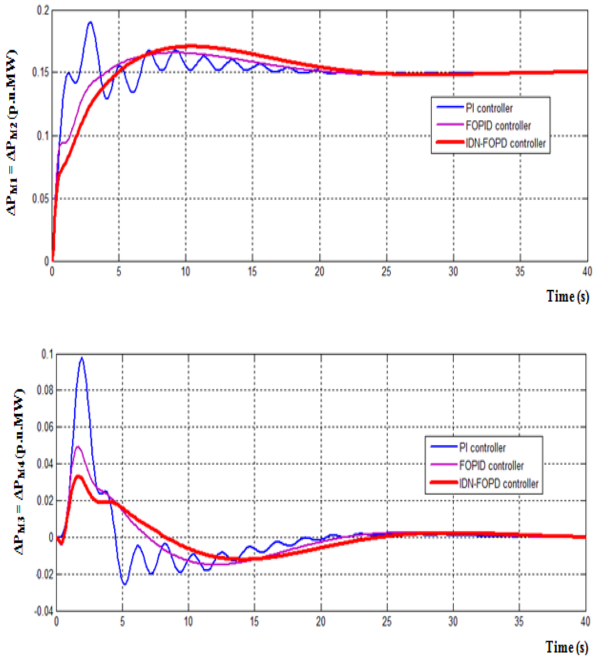
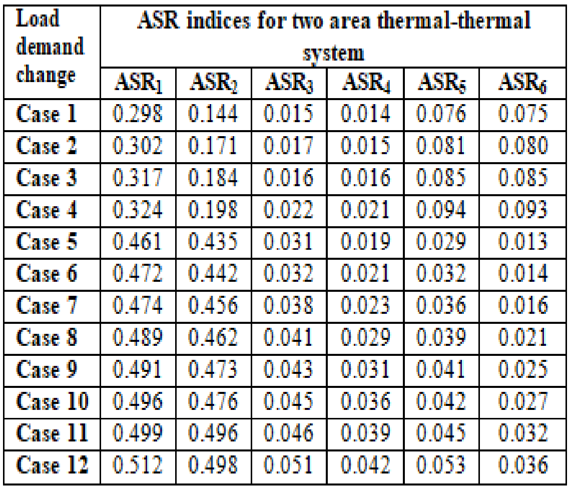


(d)

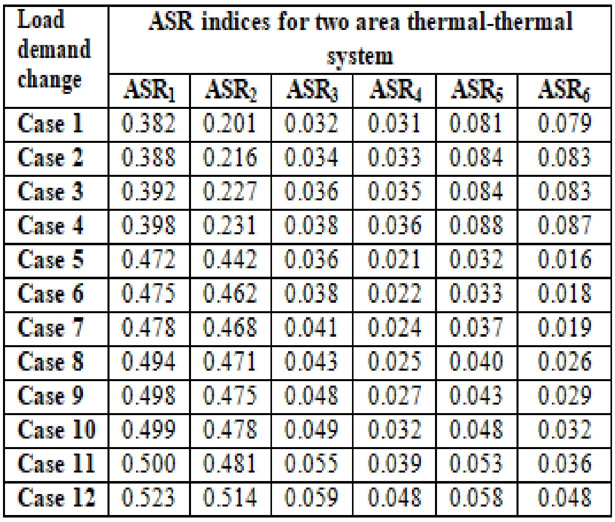
Fig. 4. Dynamic responses (a) frequency changes, (b) Tie- line power deviations, (c) Control input changes and (d) change in power generation using PI, FOPID and IDN-FOPD in case 1

A. Table 1: ASR indices for a Two area power system using IDN-FOPD controller considering 100 % generation schedules



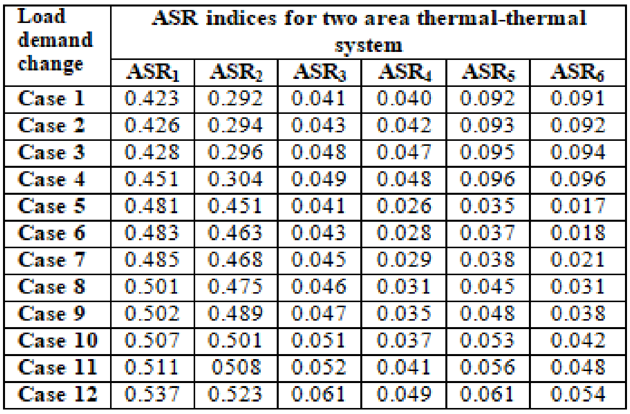
Load demand change	ASR indices for two area thermal-thermal system					
	ASR_1	ASR_2	ASR_3	ASR_4	ASR_5	ASR_6
Case 1	0.298	0.144	0.015	0.014	0.076	0.075
Case 2	0.302	0.171	0.017	0.015	0.081	0.080
Case 3	0.317	0.184	0.016	0.016	0.085	0.085
Case 4	0.324	0.198	0.022	0.021	0.094	0.093
Case 5	0.461	0.435	0.031	0.019	0.029	0.013
Case 6	0.472	0.442	0.032	0.021	0.032	0.014
Case 7	0.474	0.456	0.038	0.023	0.036	0.016
Case 8	0.489	0.462	0.041	0.029	0.039	0.021
Case 9	0.491	0.473	0.043	0.031	0.041	0.025
Case 10	0.496	0.476	0.045	0.036	0.042	0.027
Case 11	0.499	0.496	0.046	0.039	0.045	0.032
Case 12	0.512	0.498	0.051	0.042	0.053	0.036

B. Table 2: ASR indices for a Two area power system using IDN-FOPD controller considering 80 % generation schedules



Load demand change	ASR indices for two area thermal-thermal system					
	ASR_1	ASR_2	ASR_3	ASR_4	ASR_5	ASR_6
Case 1	0.382	0.201	0.032	0.031	0.081	0.079
Case 2	0.388	0.216	0.034	0.033	0.084	0.083
Case 3	0.392	0.227	0.036	0.035	0.084	0.083
Case 4	0.398	0.231	0.038	0.036	0.088	0.087
Case 5	0.472	0.442	0.036	0.021	0.032	0.016
Case 6	0.475	0.462	0.038	0.022	0.033	0.018
Case 7	0.478	0.468	0.041	0.024	0.037	0.019
Case 8	0.494	0.471	0.043	0.025	0.040	0.026
Case 9	0.498	0.475	0.048	0.027	0.043	0.029
Case 10	0.499	0.478	0.049	0.032	0.048	0.032
Case 11	0.500	0.481	0.055	0.039	0.053	0.036
Case 12	0.523	0.514	0.059	0.048	0.058	0.048

C. Table 3: *ASR indices for a Two area power system using IDN-FOPD controller considering 50 % generation schedules*



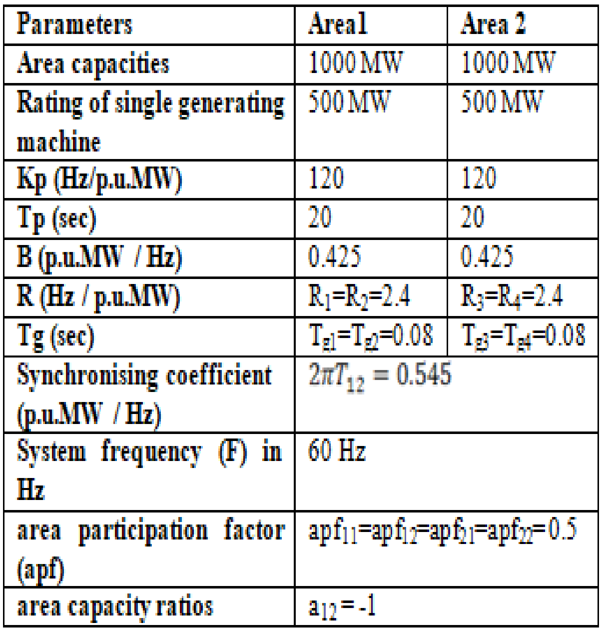
Load demand change	ASR indices for two area thermal-thermal system					
	ASR_1	ASR_2	ASR_3	ASR_4	ASR_5	ASR_6
Case 1	0.423	0.292	0.041	0.040	0.092	0.091
Case 2	0.426	0.294	0.043	0.042	0.093	0.092
Case 3	0.428	0.296	0.048	0.047	0.095	0.094
Case 4	0.451	0.304	0.049	0.048	0.096	0.096
Case 5	0.481	0.451	0.041	0.026	0.035	0.017
Case 6	0.483	0.463	0.043	0.028	0.037	0.018
Case 7	0.485	0.468	0.045	0.029	0.038	0.021
Case 8	0.501	0.475	0.046	0.031	0.045	0.031
Case 9	0.502	0.489	0.047	0.035	0.048	0.038
Case 10	0.507	0.501	0.051	0.037	0.053	0.042
Case 11	0.511	0508	0.052	0.041	0.056	0.048
Case 12	0.537	0.523	0.061	0.049	0.061	0.054

VI CONCLUSION

The proposed IDN-FOPD controllers are designed using BBBC. The reenacted outcomes show that the BBBC algorithm based IDN-FOPD controller's exhibition is quick, progressively precise, and superior to the PI and FOPID controllers. Furthermore, the restoration procedure for the thermal-thermal system using IDN-FOPD controller's ensures improved ASR indices in order to provide reduce the restoration time, thereby improving the system reliability.

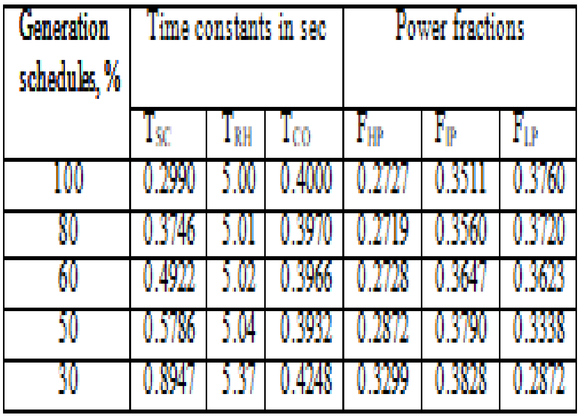
VII APPENDIX

a. Table 4: Control area and Gencos parameters (Thermal generating unit)



Parameters	Area1	Area 2
Area capacities	1000 MW	1000 MW
Rating of single generating machine	500 MW	500 MW
Kp (Hz/p.u.MW)	120	120
Tp (sec)	20	20
B (p.u.MW / Hz)	0.425	0.425
R (Hz / p.u.MW)	$R_1=R_2=2.4$	$R_3=R_4=2.4$
Tg (sec)	$T_{g1}=T_{g2}=0.08$	$T_{g3}=T_{g4}=0.08$
Synchronising coefficient (p.u.MW / Hz)	$2\pi T_{12} = 0.545$	
System frequency (F) in Hz	60 Hz	
area participation factor (apf)	$apf_{11}=apf_{12}=apf_{21}=apf_{22}=0.5$	
area capacity ratios	$a_{12}=-1$	

b. Table 5: Steam turbine data at different generation schedules



Generation schedules, %	Time constants in sec			Power fractions		
	T_{SC}	T_{RH}	T_{CO}	F_{HP}	F_{IP}	F_{LP}
100	0.2990	5.00	0.4000	0.2727	0.3511	0.3760
80	0.3746	5.01	0.3970	0.2719	0.3560	0.3720
60	0.4922	5.02	0.3966	0.2728	0.3647	0.3623
50	0.5786	5.04	0.3932	0.2872	0.3790	0.3338
30	0.8947	5.37	0.4248	0.3299	0.3828	0.2872

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