

Automatic Generation Control of a Two Area Thermal-Thermal Deregulated Power System with HES and TCPS units for Unscheduled Interchange Price Signals



M. Poonkodi, I.A. Chidambaram

Abstract— Automatic Generation Control (AGC) plot for two area inter-connected thermal to thermal Deregulated Power System (DPS) utilizing Unscheduled Interchange (UI) price signal, which has an effect on the power markets is proposed in the paper. Unscheduled Interchange price is one of the most important parts of Availability Based Tariff (ABT) which goes about as an optional control system for regulating the grid frequency. These UI price signals vacillate according to change in grid frequencies which can be open by the participants (generator or load) associated with the grid. The customary AGC system, however, attempts to carry the error of frequency to 0, yet it will be an ineffectual answer for taking an interest producing penalty deviations with frequency. This plan additionally gives the system operator adaptability to plan the generation in an ideal way. In this examination, the execution of a Proportional Integral (PI) controller is proposed because beneficial AGC of 2 area thermal and thermal deregulated system works under the impacts of bi-lateral contracts over the dynamics. The tuning of PI controller parameters is illuminated by utilizing a Moth-Flame Optimization (MFO) algorithm. Further to improve the AGC performance, the Hydrogen Energy Storage (HES) units is incorporated into its control area which can adequately moist the electromechanical motions in a power system, as they give guarantee from the storage limit notwithstanding the generator rotors dynamic energy which can share abrupt deviations in power requirement. The Thyristor Controlled Phase Shifter is proposed in arrangement with tie line between any inter-connected areas that may be applied to balance out frequency motions of the area by fast control of power in tie line over the interconnections. Execution of HES-TCPS units' blend captures the underlying frequency fall just as the power deviations in tie line for an abrupt load unsettling influence and the outcomes show that the charges of UI are extensively limited while keeping up at normal frequency worth. Furthermore, proposed strategy yields an eminent decrease in the control input deviation yet, in addition, guarantees superior

soundness for the unscheduled interchange price signals therefore, the market participants can get benefit accordingly.

Keywords Availability Based Tariff, Hydrogen Energy Storage, Moth-Flame Optimization (MFO) algorithm, Unscheduled Interchange prices

I. INTRODUCTION

Within the restructured interconnected power system, Automatic Generation Control (AGC) is considered as the vital control to sustain the system frequency and power deviations in tie line contained by permissible limit by directing the output power of every generator while meeting out the changes in the load demand [1-2]. Frequency linked price based management is much analyzed in the non-regulated electricity market [3-6]. Hence, conventional Automatic generation control is to be upgraded such that the price signal of U1 along with the cost can be included in the system to congregate the AGC loop objectives. The models primary loop is alike with the normal automatic generator control which replies to the frequency variations, while the models secondary loop also known as ABT control loop is not alike from basic automatic generator control. Initially the frequency is transformed to U1 price signal and then it is distinguished with the generators marginal cost to produce an error signal which is termed as generator control error (GCE). The GCE move forwards the reference power setting when amplified in order to control the generation which deteriorates the change in frequency [7]. Few control structures and methods are proposed in the literature for improving the performance of automatic generation control. But the advanced controllers are quite complex and required users to familiarize while adopting while reducing the applicability [8].

While PI controller and its deviation stay a favourite choice for researchers owing to its simplicity in structure, reliability, approximation between cost and performance.

In the proposed work, a nature inspired algorithm called Moth Flame Optimization (MFO) put forth by Mirjalili [9] is proposed for PI controller parameter tuning.

The electromechanical oscillations prevailing in a power system can be adequately reduced by incorporating dynamic Energy Storage Systems (EES), as extra energy storage ability is given as an increment to the kinetic energy stored in the generator rotors moving mass [10].

Manuscript published on November 30, 2019.

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The energy storage devices distribute the rapid changes in the power prerequisite in the load.

In the proposed work, a 2 area power system with a higher value of tie-line synchronizing power co-efficient is considered.

This higher value of the synchronizing power coefficient leads to some adverse impact in the dynamic performance. FACTS devices are one of the potential sources to improve the adaptability in power system [11]. Employing automatic controllers with FACTS devices can act as a decent source to lessen the adverse effects of too inflexible tie-lines. In spite of the fact that these controllers produce negative damping, they have been preferred over the uncontrolled system that allows the continuous change in load and generation values which result in undesirable oscillations in the power stream at tie line. A Thyristor Controlled Phase Shifter is a series connected flexible AC transmission system gadget that improves stability for the power system and minimizes real power losses by injecting series voltage with a phase angle that is capable to crash oscillations. The work of TCPS greatly aids in enhancing the systems transient performance like settling time along with peak overshoot [12]. TCPS performs faster to restore the system back to its normal state, when there are sudden load disturbances, and it is utilized for the AGC loop in a deregulated environment. In this study, the coordination of AGC with HES and TCPS units is performed and it reveals that power system stability can also be improved. Furthermore, the proposed strategy yields a notable decrease in unscheduled interchange price signals that ensures a better profit of the market participants.

II. AGC FOR A RESTRUCTURED POWER SYSTEM

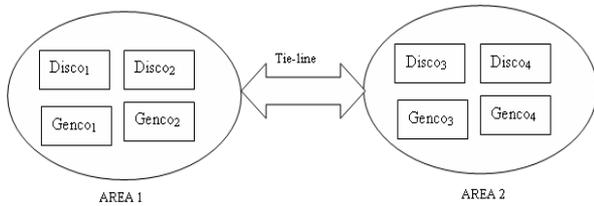


Fig. 1. Basic model

The considered power system is altered in a manner such that it will permit the budding of concerns for a generation, transmission and distribution denoted as Genco, Transco and Disco respectively. In de-regulated power system, Discos and Gencos can bond with each other over its self or other allied areas. The transactions are to be cleared with a neutral substance known as independent system operator (ISO). There are many variations in the operation of AGC in deregulated and conventional environments.

Soon after the deregulation, optimization process and operational behavior are changed. Discos in the new locality can bond any power as of Gencos while ISO has to oversee these contracts. Disco Participation Matrix is considered for elucidate the bonds performed by Dencos along with Discos. In the study of 2 area thermal to thermal interconnected system comprises of 2 Gencos and 2 Discos. The DPM is illustrated as in equation (1).

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix} \quad (1)$$

where cpf denoted contract participation factor which is a per unit.

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

The notation for tie-line power is in equation (3).

$$\Delta P_{Tie\ 12}^{Actual} = \frac{2\pi T_{12}}{s} (\Delta F_1 - \Delta F_2) \quad (3)$$

The desired total power generation is given by,

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

III. COORDINATION OF AGC WITH HES AND TCPS UNITS

A. Mathematical Modeling of HES unit

The transfer capacity of the Hydrogen Aqua Electrolyzer (HAE) can be illustrated as first order lag:

$$G_{AE}(s) = \frac{K_{AE}}{1 + sT_{AE}} \quad (5)$$

$$G_{FC}(s) = \frac{K_{FC}}{1 + sT_{FC}} \quad (6)$$

$$G_{HES}(s) = \frac{K_{HES}}{1 + sT_{HES}} = \frac{K_{AE}}{1 + sT_{AE}} * \frac{K_{FC}}{1 + sT_{FC}} \quad (7)$$

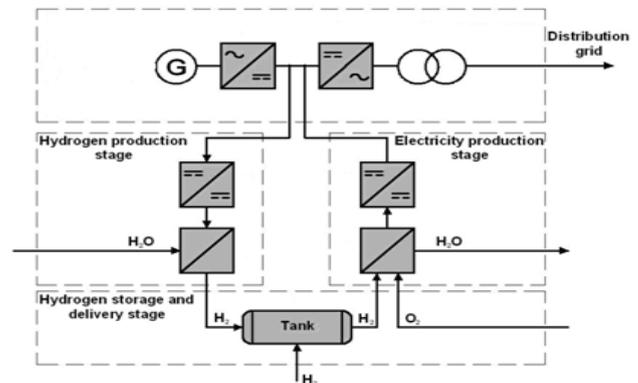


Fig. 2. HAE storage unit

B. Mathematical Modelling of TCPS unit

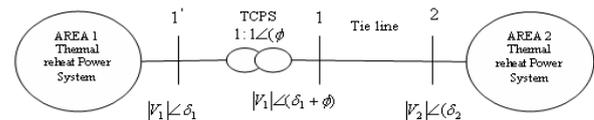


Fig. 3. Application of TCPS

The resistance of the tie line is dismissed. Not including the TCPS unit, the increase in tie-line power stream from area 1 through area 2 can be articulated as,

$$\Delta P_{tie1,2}^0(s) = \frac{2\pi T_{12}}{s} [\Delta F_1(s) - \Delta F_2(s)] \quad (8)$$

The current flow is given by,

$$I_{12} = \left(\frac{|V_1| \angle(\delta_1 + \phi) - |V_2| \angle \delta_2}{jx_{12}} \right) \quad (9)$$

The active as well as reactive power flows at bus 1 is:

$$P_{tie12} - jQ_{tie12} = |V_1| \angle -(\delta_1 + \phi) \left(\frac{|V_1| \angle(\delta_1 + \phi) - |V_2| \angle \delta_2}{jx_{12}} \right) \quad (10)$$

$$P_{tie12} = \frac{|V_1| |V_2|}{x_{12}} \sin(\delta_1 - \delta_2 + \phi) \quad (11)$$

$$\Delta P_{tie12} = \frac{|V_1| |V_2|}{x_{12}} \cos(\delta_1^0 - \delta_2^0 + \phi^0) \sin(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \quad (12)$$

But $(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi)$ is very small and hence, $\sin(\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) = (\Delta\delta_1 - \Delta\delta_2 + \Delta\phi)$

$$\Delta P_{tie12} = \frac{|V_1| |V_2|}{x_{12}} \cos(\delta_1^0 - \delta_2^0 + \phi^0) (\Delta\delta_1 - \Delta\delta_2 + \Delta\phi) \quad (13)$$

$$T_{12} = \frac{|V_1| |V_2|}{x_{12}} \cos(\delta_1^0 - \delta_2^0 + \phi^0) \quad (14)$$

It reduces to

$$\therefore \Delta P_{tie12} = T_{12} (\Delta\delta_1 - \Delta\delta_2) + T_{12} \Delta\phi \quad (15)$$

It is known that

$$\Delta\delta_1 = 2\pi \int \Delta f_1 dt \quad \text{and} \quad \Delta\delta_2 = 2\pi \int \Delta f_2 dt \quad (16)$$

From the Eqn (15) and (16)

$$\Delta P_{tie12} = 2\pi T_{12} \left(\int \Delta f_1 dt - \int \Delta f_2 dt \right) + T_{12} \Delta\phi \quad (17)$$

Laplace Transform of Eqn (17) will be

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}}{s} [\Delta F_1(s) - \Delta F_2(s)] + T_{12} \Delta\phi(s) \quad (18)$$

$$\Delta\phi(s) = \frac{k\phi}{1 + sT_{icps}} \Delta Error_1(s) \quad (19)$$

Now the tie line power flow perturbation is

$$\Delta P_{tie12}(s) = \frac{2\pi T_{12}}{s} [\Delta F_1(s) - \Delta F_2(s)] + T_{12} \frac{k\phi}{1 + sT_{icps}} \Delta F_1(s) \quad (20)$$

IV. PRICE SIGNAL BASED AGC SCHEME

Basic principle Price based AGC loop is given in Fig 4. Each and every generator oversees the UI price (ρ) as well as compares it with its marginal cost (γ). This produces an error signal, which is the distinction in the current UI price along with its very own marginal cost. The error signal is named as Generation Control Error (GCE) is encouraged as an input to the PI controller.

$$GCE = UI \text{ price } (\rho) - \text{marginal cost } (\gamma) \quad (21)$$

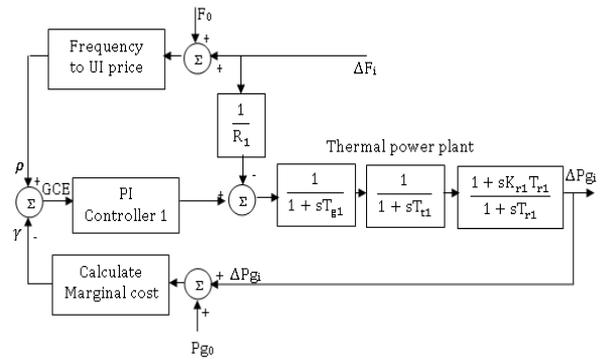


Fig. 4. Price signal based AGC

A. Frequency to UI charge determination

The frequency to Unscheduled Interchange (UI) charge calculation for the year 2014 is shown in Fig 5.

```
function p = fcn(F)
if F <= 49.7
    p = 8240.4;
elseif F <= 50;
    p = 1780 + 20840 * (50 - F);
elseif F <= 50.05
    p = 35600 * (50.05 - F);
else
    p = 0;
end
```

Fig. 5. Frequency ward price of the unscheduled generation.

B. Calculation of Marginal Cost

The characteristics (fuel cost) of generators in INR/h is shown by

$$C_i(P_{gi}) = a_i + b_i P_{gi} + c_i P_{gi}^2 \quad (22)$$

where a_i, b_i, c_i are constants which depicts the cost coefficients for a given generator.

$$(Marginal\ cost)_i = b_i + 2c_i P_{gi} \quad (23)$$

V. DESIGN OF PI CONTROLLER USING MOTH-FLAME OPTIMIZATION (MFO) ALGORITHM

A. Controller structure of PI controller

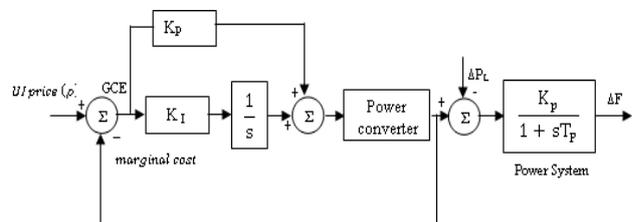


Fig. 6. Block diagram for PI controller with price based AGC loop

A Proportional and integral control refers to the reset action which involves integration of generation control error (GCE) signal over some stretch of time. The rate of change of correcting signals is proportional to the GCE signals.

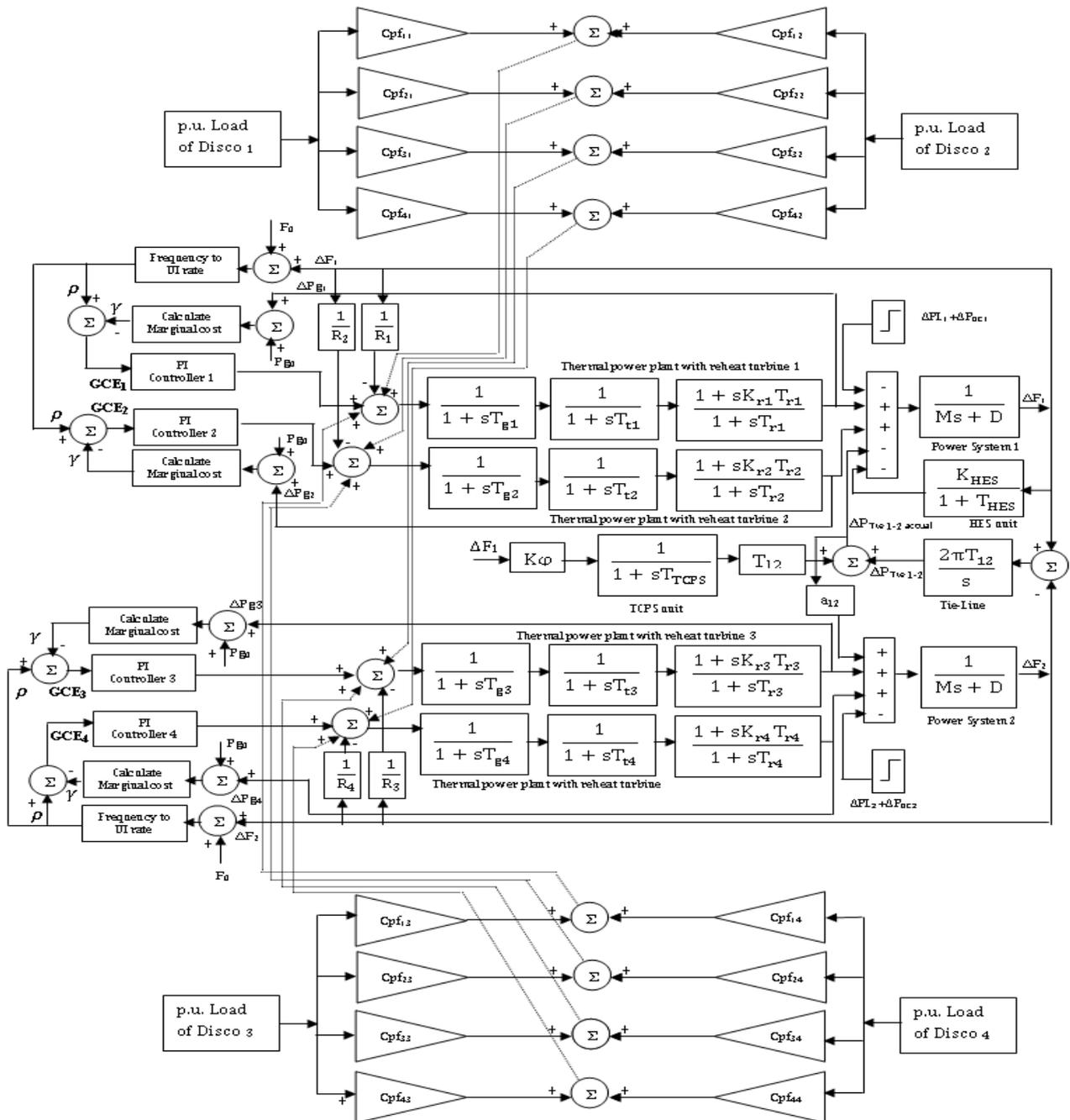


Fig. 7. Price signal based AGC (transfer function model)

In this study, PI controllers are used to increasing the dynamic recital of the price based AGC loop is shown in Fig 7. The PI control action depends on the proportional gain (K_p) and Integral controller gain (K_i) which vary for different applications.

$$u_1 = K_{p1} GCE_1 + K_{i1} \int GCE_1 dt \quad (24)$$

$$u_2 = K_{p2} GCE_2 + K_{i2} \int GCE_2 dt \quad (25)$$

$$J = \int_0^{t_{sim}} [(GCE)^2] dt \quad (26)$$

The design problem is formulated as below, *Minimize* (27)

Subject to (28)

$$K_p^{min} \leq K_p \leq K_p^{max}, K_i^{min} \leq K_i \leq K_i^{max} ,,$$

B. Moth-flame optimization (MFO) Algorithm

Given the logarithmic spiral, position updation is shown in the Eqn (29) [9].

$$S(M_i, F_j) = D_i e^{bt} \cos(2\pi t) + F_j \quad (29)$$

As may be found in the above condition, the following situation of a moth is portrayed as for a fire. The t parameter in the winding condition portrays how much the following situation of the moth should be close to the fire. With a particular ultimate objective to further accentuate abuse, taking into account that t is an irregular number in [r, 1] where r is straight diminished from -1 to -2 through the range of accentuation and is called intermingling steady. With this procedure, moths will in general adventure their comparing flares all the more definitely relating to the number of cycles. So as to overhaul the probability of joining a worldwide arrangement, a given moth is obliged to refresh its position using one of the flares (the relating fire). In each emphasis and in the wake of refreshing the fire list, the flares are arranged dependent on their wellness esteems. From that

point forward, the moths update their situations with respect to their comparing blazes. To allow a lot of abuse of the best promising arrangements, the number of blazes to be taken after is lessened with respect to the cycle number as given in the Eqn (30).

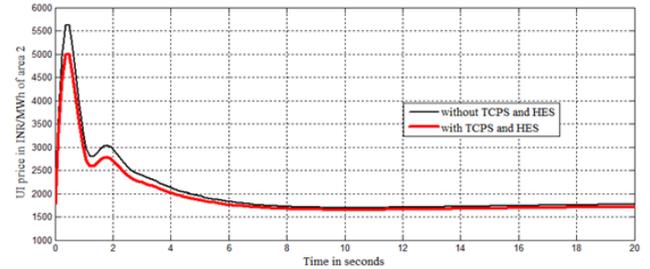
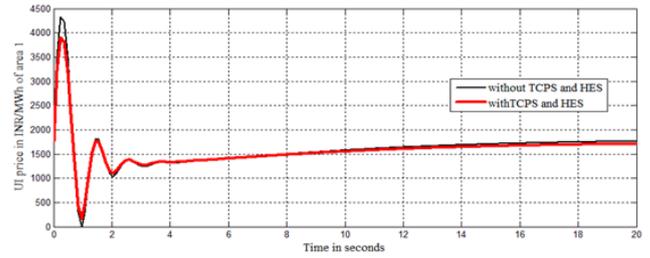
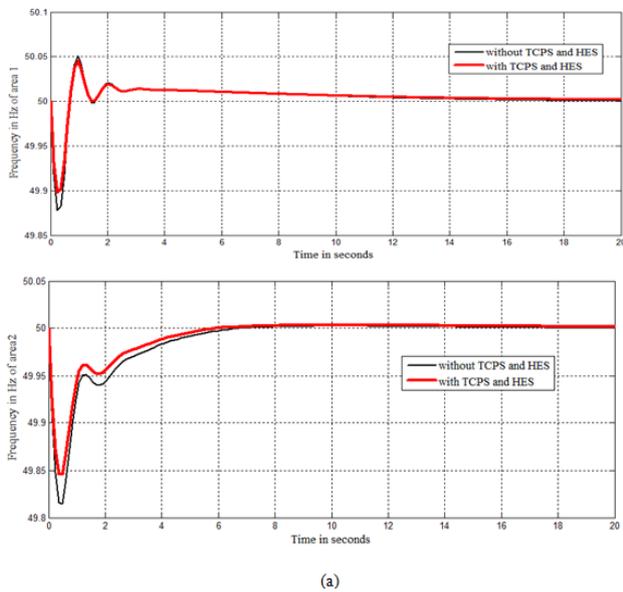
$$N_{flames} = round(N - l * (\frac{N-1}{T})) \quad (30)$$

VI. SIMULATION RESULTS AND OBSERVATIONS

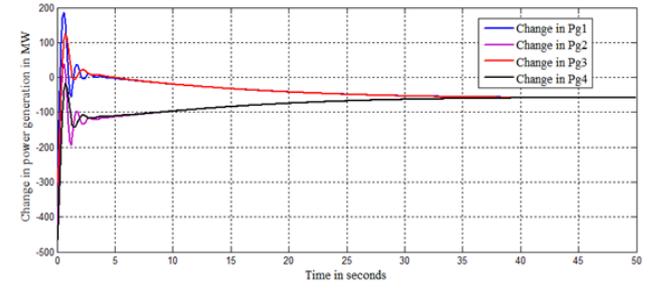
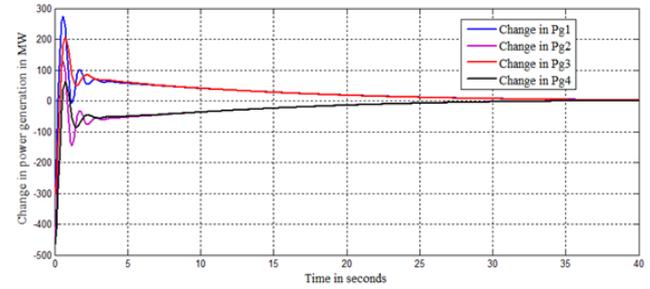
All the Gencos in every area are considered as thermal reheat units. In this study, Moth-Flame Optimization (MFO) In this test, system comprises of two Gencos and two Discos in every area. All the Gencos in each area consider as thermal warm units. In this examination, Moth-Flame Optimization (MFO) algorithm is used for perfect tuning of PI controllers for cost based AGC loop of a two-area thermal-thermal restructured power system. The perfect plan of control sources of info is taken for development issue and the objective work in Eqn (26) is resolved to use the Generation Control Error (21). The ideal control parameters of PI controller, for example, relative addition (K_p) and Integral increase esteem (K_i) is 0.378 and 0.247 individually.

All of the Discos has the agreement with the Gencos and the accompanying DPM alluding to Eq (1) is expressed as,

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0.0 & 0.0 \\ 0.5 & 0.5 & 0.0 & 0.0 \\ 0.0 & 0.0 & 0.5 & 0.5 \\ 0.0 & 0.0 & 0.5 & 0.5 \end{bmatrix} \quad (31)$$

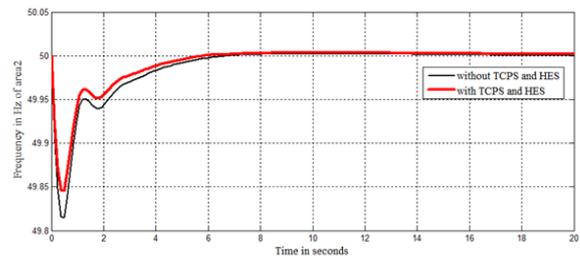
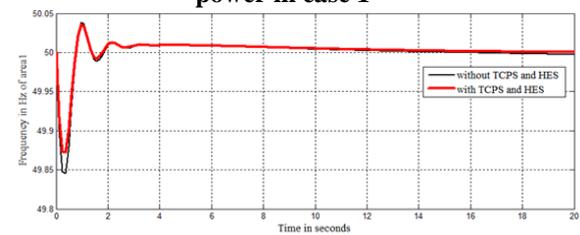


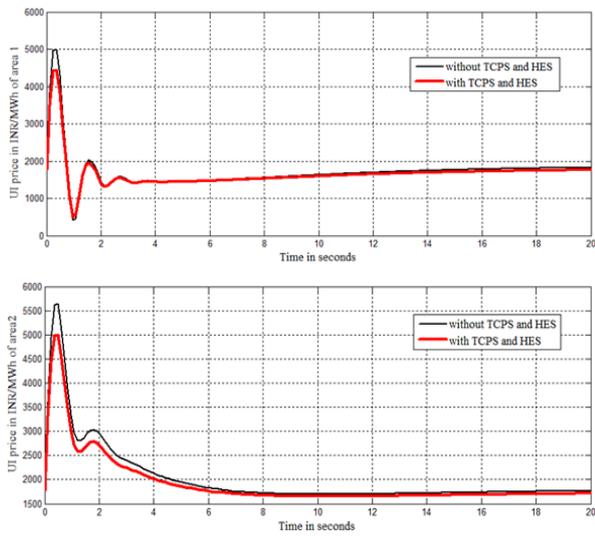
(b)



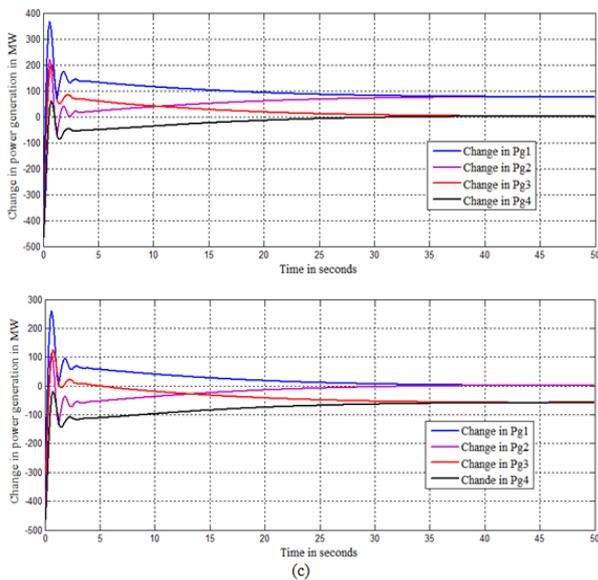
(c)

Fig. 8. Dynamic responses (a) frequency deviations, (b) unscheduled interchange (UI) price and (c) change in power in case 1



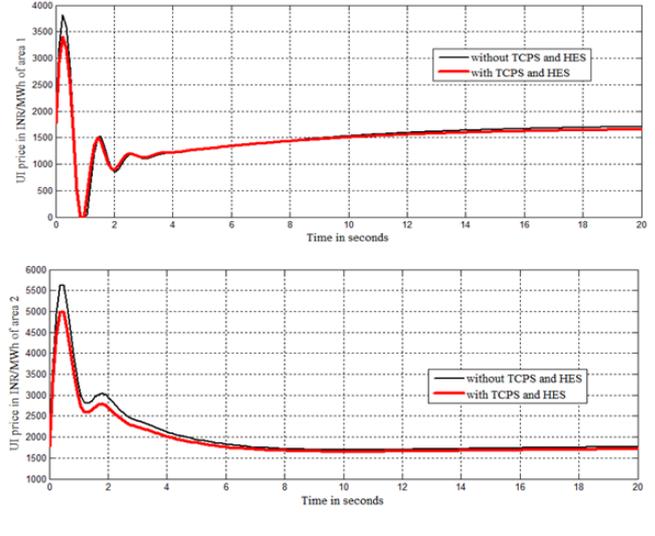


(b)

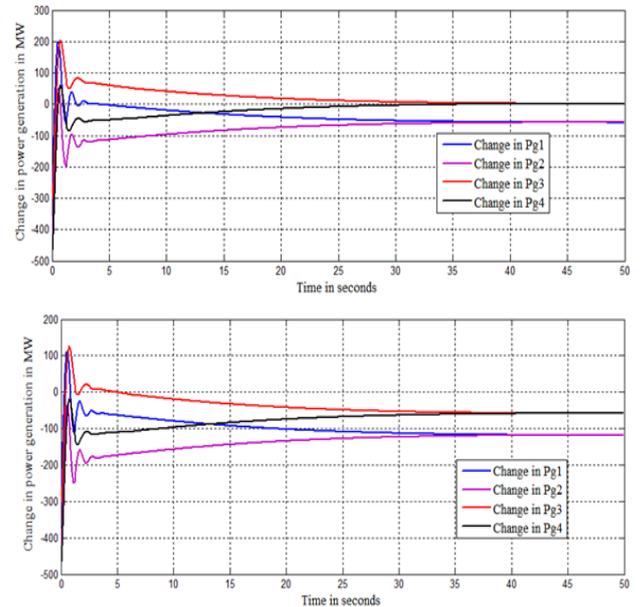


(c)

Fig. 9. Dynamic responses (a) frequency deviations, (b) unscheduled interchange (UI) price and (c) change in power in case 2



(b)

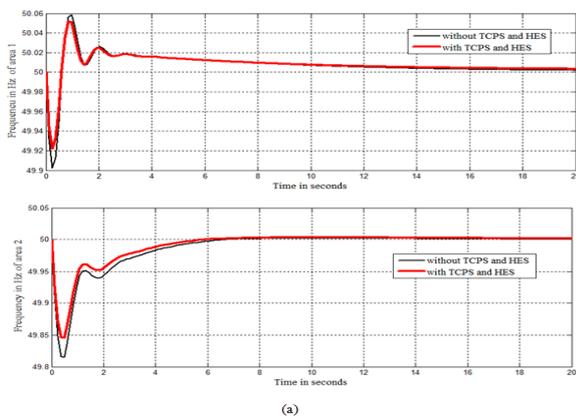


(c)

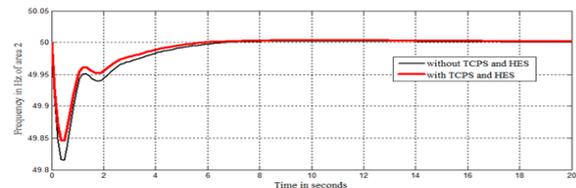
Fig. 10. Dynamic responses (a) frequency deviations, (b) unscheduled interchange (UI) price and (c) change in power in case 3

VII. CONCLUSION

Frequency steadiness and monetary operation are at the same time accomplished. Execution of proposed control on all focal and state generating stations won't just bring about better frequency control, however, legitimacy request dispatch of generation can likewise be guaranteed simultaneously. The UI obligations of members can be radically decreased through this instrument. Additionally, AGC in two-area interconnected DPS having coordinated control activity with HES and TCPS units improved power system elements as well as decreased the UI charge.



(a)



ACKNOWLEDGEMENT

The authors wish to thank the authorities of Annamalai University, Annamalainagar, Tamilnadu, India for the facilities provided to prepare this paper.

APPENDIX

B. Table 1 Generator Data [3]

		Genco ₁	Genco ₂	Genco ₃	Genco ₄
Capacity (MW)		1500	1500	1500	1500
Cost Coefficients	<i>B_i</i> (INR/MWh)	800	1000	800	1000
	<i>a_i</i> (INR/MWh)	0.3	0.3	0.3	0.3

C. Table 2 Generation Schedule (in MW) [3]

	Genco ₁	Genco ₂	Genco ₃	Genco ₄
Schedule 1	1500	1333.33	250	0
Schedule 1	1500	1500	83.33	0
Schedule 1	1500	1500	250	0

D. Table 3 Marginal Costs in INR/MWh [3]

	Genco ₁	Genco ₂	Genco ₃	Genco ₄
Schedule 1	1700	1800	1800	2000
Schedule 1	1700	1700	1700	2000
Schedule 1	1700	1900	1900	2000

E. Table 4: Data for the HES with Fuel Cell unit [10]

Parameter	<i>K_{AE}</i>	<i>T_{AE}</i> (sec)	<i>K_{FC}</i>	<i>T_{FC}</i> (sec)
Value	0.002	0.5	0.01	4

F. Table 1e: Data for the TCPS unit [12]

Parameter	<i>K_φ</i>	<i>T_{TCPS}</i> (sec)	<i>Φ_{Max}</i>	<i>Φ_{Min}</i>
Value	15 rad/Hz	0.1	10°	-10°

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