A NOVEL PRICE BASED LOAD FREQUENCY CONTROL APPROACH TO DAMP OUT SYSTEM OSCILLATIONS UNDER DEREGULATED POWER ENVIRONMENT

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Abstract: *After the emergence of deregulated electricity market, electricity is priced based on the demand and the generations existing at that instant of time. Even though the transition of existing vertically integrated power system into deregulated power environment improves the efficiency of the power system, the unexpected rapid load changes and outage of generating units lead to drastic frequency fluctuations. Hence it requires proper ancillary services to serve the system load. Load Frequency Control (LFC) is an ancillary service needed to maintain the system frequency under dynamic conditions. This paper focusses on unscheduled interchange price based LFC for a two area electricity market. The analysis of system response improvement is carried out with Particle Swarm Optimization (PSO) tuned Thyristor Controlled Phase Shifter (TCPS). This work is applied in deregulated environment by employing DISCO (Distribution Company) participation matrix (DPM). The optimal values of the gain and time constant parameters of TCPS are obtained using PSO. The robustness of the proposed method is checked for a two area system with four Generation Companies (GENCOs) and one Distribution Company (DISCO) each .It is found that, the proposed approach gives promising results in damping out the system oscillations with reduced unscheduled interchange between the areas.*

Key words: *Competitive Electricity Market, DISCO Participation Matrix, Thyristor Controlled Phase Shifter, Unscheduled Interchange Price.*

1. Introduction

Due to the emergence of deregulated electricity market, there has been a transformation of vertically integrated utility into several new entities. To name a few like Generation Companies (GENCOs), Distribution Companies (DISCOs), Transmission Companies (TRANSCOs) and Independent System Operator (ISO). In the emerging competitive electricity market, the GENCOs and DISCOs have the liberty to sign the contract with their preferred GENCOs and DISCOS in different areas for the transaction of power. This type of contract of power in deregulated market is called as bilateral power transactions.

In this research effort, the visualization of bilateral power transactions existing between two areas is done with the incorporation of DISCO participation matrix [1]. The commitment of ISO is to manage all the ancillary services and to administer the transactions that exist between the GENCOs and DISCOs. Out of these ancillary services, the load frequency control is one that is carried out in a deregulated environment automatically, depending on the price existing at that time based on Availability Based Tariff (ABT). The Unscheduled Interchange (UI) of power is a tool for load frequency control. This UI power and its respective charges make the DISCOs to take part in frequency control. This is achieved by forcing them either to reduce the power consumption, when the frequency is less or to increase the power consumption, when the frequency is high. This helps the market participants to gain benefit, if the frequency is under control.

It is also addressed that the under circumstances of sudden load disturbance the generators can adjust upto 5% of its actual capacity [2]. Instead of area control error, Generation Control Error (GCE) is employed to automate the significant effect of UI charge in load frequency regulation. The steps involved in calculating GCE are also addressed. A positive value of GCE denotes that in order to make profit the generation should be increased. And a negative value of GCE indicates that the generation should be decreased to make more profit. It is understood that due to the automation of UI price in load frequency regulation, the response of the generators is fast compared to manually adjusting generation based on UI price. The generating companies are not paid incentives for extra power generation under peak load condition. At the same time, the generating companies have also gained financial advantages without decreasing the generation in accordance with the load during off-peak hours. This has resulted in grid indiscipline, during pre-ABT periods. These problems are overcome by the incorporation of ABT [3].

The introduction of UI mechanism in frequency regulation consumes more time compared to conventional AGC, but it is found to be an efficient tool to eradicate the flaws in grid discipline of Indian Electricity Market [4,5]. The impact of different UI rates on the automatic generation controller of a single area power system is dealt in [6]. In a two area power system, the stiffness of electromagnetic coupling between the rotor and the stator in the generating system is specified by the synchronizing power co-efficient. The high value of synchronizing power co-efficient results in small oscillations in the generator output. In each generator these oscillations, which are normally negligible, will develop into significant oscillations in tie-line power flow [7].

In this proposed work, a two area power system with higher value of tie line synchronizing power co-efficient is considered. This higher value of synchronizing power coefficient leads to some adverse effect in the dynamic performance of the power system. It is evident that the FACTS devices are one of the potential sources to improve the flexibility in power system operation and control [8]. Employing automatic controllers with FACTS devices can act as a good source to reduce the adverse effects of too rigid tie-lines. Though, these controllers produce negative damping, they have been preferred over the uncontrolled system that allows continuous change in load and generation values which result in undesirable oscillations in tie-line power flow.

Unified Power Flow Controller (UPFC) and TCPS are very robust to system loading conditions and the first swing stability is highly enhanced in the system by the use of these devices. TCPS is very effective under light load perturbations. It is observed that the damping is significantly increased by the phase shifter compared to no regulation and exciter-augmented stability [9]. TCPS is a series connected FACTS device which improves stability of the power system and minimizes real power losses by injecting series voltage with a phase angle that is capable to wipe out oscillations. The employment of TCPS greatly aids in enhancing the transient performance of the system like settling time and peak overshoot [10]. TCPS performs faster to restore the system back to its normal state, when there are sudden load disturbances, and it is employed for load frequency control in deregulated environment [11]. The analyses of Automatic Generation Control, Co-ordination of AGC with TCPS are performed [12]. It reveals that power system stability can be improved by the use of TCPS and the study shows that TCPS is economical. From the review of literature, it is clear that TCPS is proved to be a better choice to damp out oscillations in AGC problem in both vertically integrated utility and open access market.

On the other hand, no work has been concentrated on the impact of TCPS under deregulated market scenario considering UI price in LFC. The application of PSO for AGC problem is dealt [13]. In the proposed work, PSO is adopted to optimize the parameters of TCPS in such a way to achieve better dynamic performance.

The major goals of this present work are listed as follows.

- To develop the linear model of UI Price based LFC with TCPS under deregulated power market.
- To analyze the impact of TCPS under deregulated market scenario by considering UI price in LFC.
- To optimize the parameters of TCPS using PSO to achieve improvement in transient performance.
- To compare the response of the proposed model without and with optimally tuned TCPS.

The remaining portion of this manuscript is structured as follows. In Section 2 a brief insight into deregulated electricity market availability based tariff is elaborated; Section 3 gives the schematic model of the proposed work. Section 4 gives the brief description about the PSO and its implementation for this research work. In Section 5 comprehensive simulation results and elaborate discussions are presented. Section 6 presents the remarkable conclusions arrived out of this research attempt.

2. Deregulated electricity market

In a deregulated power market, the participating GENCOs and DISCOs will give their bids describing their desired power transaction. Based on the bids the supply and demand curves will be drawn. The point of intersection of the supply and demand curves fixes the market clearing price. DPM is an index that shows the contract signed between GENCOs and DISCOs. The order of DPM takes its value based on the number of GENCOs and DISCOs in the system. The sum of entries in each column of DPM should be unity. Since each value in a column of DPM is the fraction of power demand of a DISCO that has to be met by the particular GENCO. The sample system taken for this work has four GENCOs and one DISCO in each area. It is represented as a block diagram in Figure.1

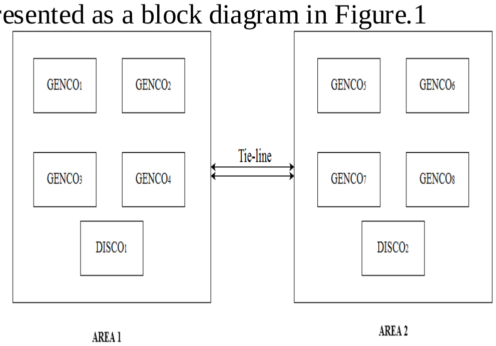

Figure 1. Diagrammatic representation of deregulated electricity market with two areas

Hence, the DPM is as expressed in equation (1).

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} \\ cpf_{21} & cpf_{22} \\ cpf_{31} & cpf_{32} \\ cpf_{41} & cpf_{42} \\ cpf_{51} & cpf_{52} \\ cpf_{61} & cpf_{62} \\ cpf_{71} & cpf_{72} \\ cpf_{81} & cpf_{82} \end{bmatrix} \quad (1)$$

Where, cpf_{ij} is the contract participation factor.

As per DPM, the change in tie-line power flow is the difference between demand of DISCO in area 2 from GENCOs in area 1 and the demand of DISCO in area 1 from GENCOs in area 2 as given in equation (2)

$$\Delta P_{tie1-2,scheduled} = \sum_{j=1}^{4} cpf_{j2} * \Delta P_{L2} - \sum_{j=5}^{8} cpf_{j1} * \Delta P_{L1} \quad (2)$$

and it is expected that the actual change in tie-line power flow should follow the scheduled value.

Under real time open access market, there is a possibility that demand actually drawn by the DISCO does not match the contract already made. i.e. is contract violation. The impact of this contract violation is evident particularly in the area to which the DISCO belongs to. The sharing of load by the GENCOs during contract violation in that specific area is performed based on the Area Control Error Participation Factor, such that the area control error is to be diminished by the coactions of all the GENCOs in that area.

Let ΔP_{gi} be the change in generation in $GENCO_i$ in an area j. If a local demand is requested by a DISCOin that area, then ΔP_{gi} is given by equation (3).

$$\Delta P_{gi} = (cpf_{i1} * \Delta P_{L1}) + .. + (cpf_{in} * \Delta P_{Ln}) + (apf_i * Local\ demand\ of\ area\ j) \quad (3)$$

where, n is the total number of DISCOs.

In India, Central Electricity Regulatory Commission (CERC) has framed ABT to regulate the load consumption. According to this, the charge imposed on power consumed is based on the three parts, namely fixed charge, charge for the scheduled interchange of power and charge for the unscheduled interchange of power. The UI charge is based on the frequency prevailing at that time i.e., the UI price is inversely proportional to the frequency. The UI price is updated periodically based on frequency, in which the CERC narrows down the normal operating frequency range to enhance the frequency regulation. The curve, which gives the relation between UI price and frequency as per CERC framework 2012, is shown in Figure.2

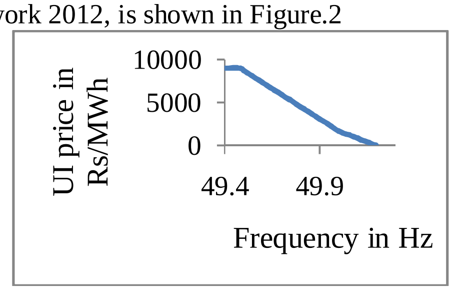

Figure 2. Variation of UI charge (Rs/MWh) with respect to Frequency (Hz) based on CERC 2012 regulation

3. Schematic model of the proposed system

A two area power system is considered with four GENCOs and one DISCO in each area. The UI price is incorporated as the secondary control loop in LFC. Instead of taking the steady state frequency error as the direct feedback, the error signals which are derived from the comparison of UI price signal that is obtained from the frequency and the incremental cost signal are taken as feedback. This comparison is based on the GCE algorithm and thereby, the Area control error is converted into GCE. The general representation of ABT based frequency regulation for an area *i* is shown in Figure.3.

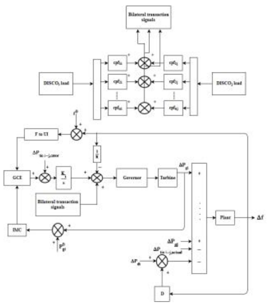

Figure 3. Block diagram of ABT based frequency regulation for an area *i* under deregulated environment

The generations in all the GENCOs are supposed to adhere to the DPM. This is accomplished by the local economic dispatch controller, which is operated by the appropriate actuating signal from the global economic dispatch controller. The block diagram of UI price based load frequency regulation model of an area'i' is shown in Figure.4

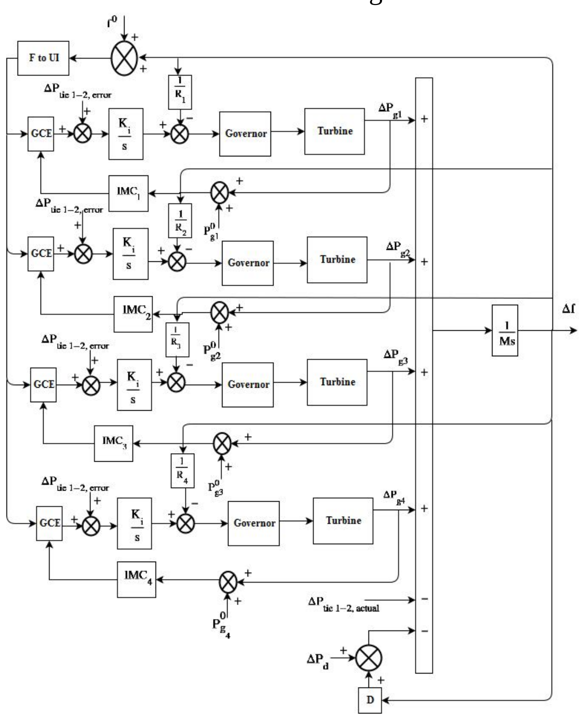

Figure 4. Block diagram of UI price based load frequency regulation model of an area *i*

Let, S (f) be the frequency signal and S(ρ) be the UI price signal and f^o be the system frequency under initial conditions and Δf be the change in frequency due to change in demand ,

$S(f) = f^0 + \Delta f$ (4)

If S(f) > 50.2 Hz.

$S(\rho) = 0$ Rs/MWh (5)

If 50 Hz < S(f) ≤ 50.2 Hz.

$S(\rho) = 8250*(50.2-S(f))$ Rs/MWh (6)

If 49.8 Hz < S(f) ≤ 50Hz

$S(\rho) = 1650+14250*(50-S(f))$ Rs/MWh (7)

If 49.48 Hz <S(f) ≤ 49.8 Hz

$S(\rho) = 4500+14062.5*(49.8-S(f))$ Rs/MWh (8)

If S(f) ≤ 49.48 Hz

$S(\rho) = 9000$ Rs/MWh (9)

Let S(γ) be the incremental fuel cost and is computed using equation (10),

$S(\gamma) = 2*a_i*S(P_g) + b_i$ Rs/MWh (10)

Where, a and b represents the incremental value of cost co-efficients.

$S(P_g)$ is given by

$S(P_g) = P_g^0 + \Delta P_g$ MW (11)

Where, P_g^0 is the initial scheduled power and ΔP_g is the load shared by the generator.

The GCE Algorithm is employed to calculate the generation control error which is given by a flowchart in Figure.5 with ρ and γ representing the UI price signal and marginal cost.

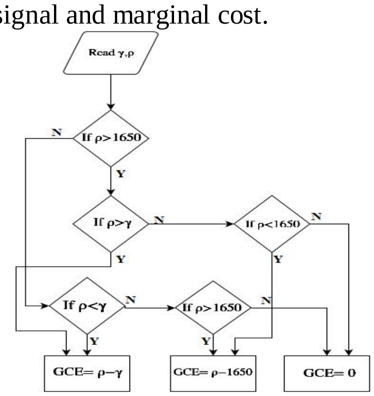

Figure 5. Flowchart for GCE Algorithm

The modeling of TCPS adheres the procedures used in ref [10]. The interconnection of TCPS in an area is shown in Figure.6 and the block diagram of a two area system with TCPS is depicted in Figure 7.

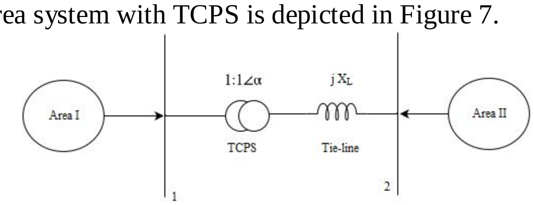

Figure 6. TCPS interconnection near Area 1

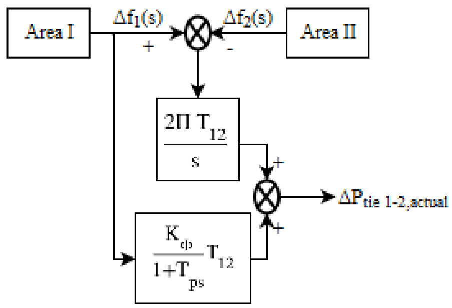

Figure 7. Block diagram of a two area system with TCPS

4. Implementation of PSO for the proposed work

PSO is a stochastic optimization method, which is motivated by the behavior of swarms, such as disorganized collection of moving things like insects, birds, etc. PSO has the unique characteristics of simple to implement and fast convergence rate. PSO has the resilience than other optimization algorithms to curb the balance between the global and local optimal points of the search space. This feature of PSO quell the issue of premature convergence hence, promisingly ensures enhancement of search capability.

The PSO technique finds the optimal solution by employing the population of particles. Each particle denotes a candidate solution to any proposed problem. The researchers have also started to focus on the variations in conventional PSO with an idea to improve the robustness further [13, 14]. The performance index which is chosen for this work, is Integral Squared Error criterion [ISE]. It is given by equation (12),

$$J=\int (\Delta f_1^{\,2} + \Delta f_2^{\,2} - \Delta P^2_{tie,1-2})\, dt \qquad (12$$

The parameters employed for PSO are listed in Table 1.

Table 1: Parameters employed in PSO to tune the gain and time constant values of TCPS transfer function $K_ø$ and T_{PS}

S. No	Parameters	Values
1	Number of Iterations	50
2	Population size	25
3	Number of particles	2
4	C_1 and C_2	2,2
5	Constriction factor, C	0.7
6	Lower and Upper bound for $K_ø$	1, 10
7	Lower and Upper bound for $K_ø$	0.01, 0.1

The flowchart for the implementation of the proposed work is shown in Figure. 8

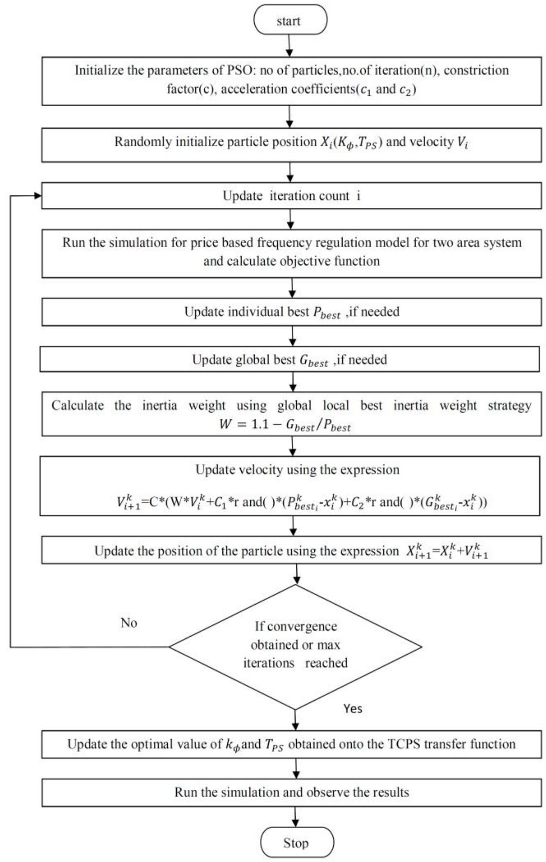

Figure 8. Flowchart for implementation of price based frequency regulation with PSO tuned TCPS

5. Results and discussion

A two area deregulated power system is considered to demonstrate the performance of the proposed UI price based frequency regulation. The UI price based secondary frequency control loop has an integral controller meant for each GENCO and it is optimally tuned by employing the MATLAB PID tuner. The automatic PID tuner allows it to achieve a good balance between the performance and the effectiveness of the integral controller. The two areas are assumed to be identical, each with a capacity of 5000 MW. The data of the test system are given in Tables 3-5. Three test cases are considered to validate the proposed method. In case (i) and (ii), it is assumed that there exists contract between the GENCOs and DISCOs of area 1 with 100 MW increase and decrease in the demand of $DISCO_1$respectively. In case (iii), bilateral contract occurs between the GENCOs and DISCOs, where each DISCOs in both the areas have 100 MW load variations. The impact of TCPS in damping out the system oscillations is tested in all the cases. The DPM, which represents the contract between the

GENCO and the DISCO for case I, is DPM=

$$\begin{vmatrix} 0 & 0 \\ 0.5 & 0 \\ 0.4 & 0 \\ 0.1 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \\ 0 & 0 \end{vmatrix}$$

Whereas for case II,

$$DPM = \begin{vmatrix} 0 & 0 \\ 0.25 & 0.15 \\ 0.2 & 0.15 \\ 0.05 & 0 \\ 0 & 0 \\ 0.25 & 0.3 \\ 0.2 & 0.3 \\ 0.05 & 0.1 \end{vmatrix}$$

5.1 Case (i): Unilateral contract with 100 MW increase in demand of DISCO$_1$

With the sudden increase of 100 MW in DISCO$_1$, the system frequencies in area 1 and 2 oscillate in conventional price based load frequency regulation model. While incorporating TCPS near area I, the generation control error of each plant is driven to match the load increase. Hence, it is observed from Figures 9(a) - (b) that the frequency oscillations are damped out in the plant response..

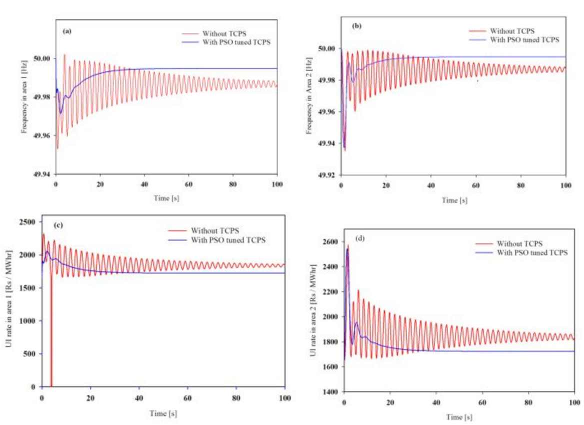

Figure 9. (a) Frequency in area 1(Hz). (b) Frequency in area 2 (Hz). (c) UI rate in area 1 (Rs/MWhr). (d) UI rate in area 2 (Rs/MWhr)

The UI price signals in area 1 and 2 as shown in Figure.9 (c) – (d) follow a smooth curve with a decrease in UI price of about 100 Rs/MWhr, when TCPS is employed

5.2 Case (ii): Unilateral contract with 100 MW decrease in demand of DISCO$_1$.

When, DISCO$_1$ withdraws its demand by 100 MW, the system frequency suddenly increases and thereby, the UI price signal drops to zero. When TCPS is connected, the momentary fluctuations in the response are diminished and there is an improvement of 0.04% in frequency. The response of the system for this case is shown in Figures 10(a)-(d)

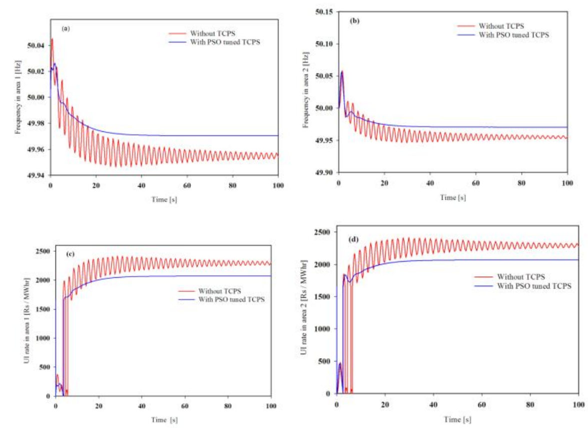

Figure 10. (a) Frequency in area 1(Hz). (b) Frequency in area 2 (Hz). (c) UI rate in area 1 (Rs/MWhr). (d) UI rate in area 2 (Rs/MWhr)

5.3 Case (iii): Bilateral contract with a decrease in demand of 100 MW in DISCO$_1$of area 1and an increase in demand of 100 MW in DISCO$_2$of area II:

Under bilateral contract, when the DISCOs reduce their demand, GENCOs have to reduce their generation accordingly. The GENCOs do not havethe opportunity to gain profit by generating power unnecessarily, when there is no requirement unlike pre-ABT period. In area 1 the system frequency suddenly rises and settles down to closer to the nominal frequency whereas, in area 2 due to the increase in demand the system frequency abruptly drops down and finally comes down closer to the nominal value. Furthermore, the frequent variations in system response of both the areas are nulled out within 1.5 seconds, due to the appropriate action of TCPS by giving a phase shift to the voltage signal in area 1. The improvements in the area response and tie-line power deviations are observed due to the action of TCPS and they are shown in

Figures 11(a) - (d).

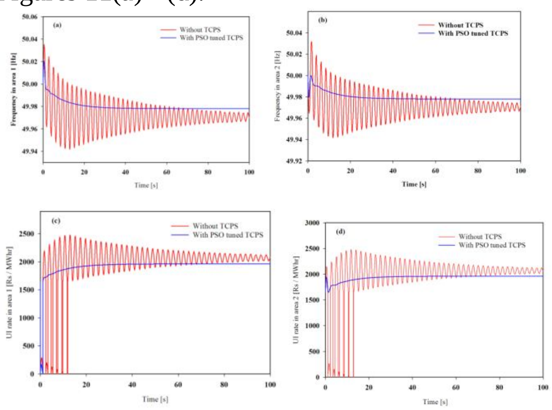

Figure 11. (a) Frequency in area 1(Hz). (b) Frequency in area 2 (Hz). (c) UI rate in area 1 (Rs/MWhr). (d) UI rate in area 2 (Rs/MWhr)

The optimal values of TCPS parameters for the above cases using PSO are given in Table 2.

Table 2 : PSO optimized values of $K_ø$ and T_{PS}

Cases	$K_ø$	T_{PS}
(i)	10	0.0999
(ii)	9	0.075
(iii)	5.4797	0.0733

6. Conclusion

In this work, the price based load frequency control for a two area deregulated power system with PSO tuned TCPS is proposed. For a load frequency control problem, choosing an appropriate value of synchronizing power co-efficient certainly gives better system response. Since it is proved that the parameters to which the synchronizing power co-efficient are dependent to each other, they cannot be adjusted for the proposed problem. Hence, an attempt is made to introduce a phase shift in the frequency response of area 1 by incorporating TCPS at area 1. It is observed that the frequency oscillations are significantly damped out by the positive impact of TCPS. Furthermore, the proposed method yields a notable reduction in unscheduled interchange price signal. As a result, the market participants can get profit accordingly.

Appendix A

Table 3: System Data

Parameters	G_1	G_2	G_3	G_4
Capacity(MW)	1500	1500	1000	1000
b (Rs/MWh)	800	1000	1600	2000
c (Rs/MW^2h)	0.3	0.3	0.4	0.4

where b and c are the cost coefficients of each generator

Table 4: Area Parameters

M(MW-s/Hz)	1000
D(MW/Hz)	100
F^0 (Hz)	50
synchronizing power co-efficient, T_{12} (p.u)	0.545
System Marginal Cost (Rs/MWhr)	1850

Table 5: Droop, Governor and Turbine Time constant

Parameters	M1	M2	M3	M4
Droop R	6%	6%	6%	6%
Governor time constant T_{sg}(sec)	0.3	0.3	0.3	0.3
Turbine time constant T_t (sec)	0.5	0.5	0.5	0.5

where
M1,M2, M3 and M4 are the machines in an area and it is identical for both areas,
M is the inertia constant and
D is the damping coefficient.

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