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Robust Utkin's Observer Based Controller for Deregulated Hydro-Thermal LFC Problem

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Abstract: This paper presents a new nonlinear observer based control strategy popularly known as Utkins observer based controller has been proposed to solve load frequency control of a multi area Hydro-Thermal deregulated system. The proposed control strategy has inherent capabilities to tackle certain nonlinearities and uncertainties of the highly non linear power system. The performance of Utkins observer based controller is tested on two area Hydro-Thermal deregulated power system including bilateral contacts when system is subjected to sudden disturbance. The dynamic response of the system with proposed Utkins observer based controller is compared with dynamic response of the system with Conventional PI controller.

Keywords:— Bilateral contracts; Hydro-Themal Deregulated System; Load Frequency Control; Utkin's functional Observer; Utkin's Observer based Controller.

I. INTRODUCTION

Load Frequency Control (LFC) problem aims for zero percentage deviation in tie line power and frequency by maintaining a balance between generation and load[1-3].In deregulated power system, the consumers have their choice to select electric power supplier from the competitive pool. In this type of system[6], highly competitive different power Generation Companies (GENCO) will deliver their product (power) to their customers, over a common set of Transmission companies (TRANSCO) and distribution companies, operated by the independent system operator (ISO).In deregulated operation of the system, in contrast to regulated operating system, the following differences can be observed: 1) a regulated system power market is a monopolistic where as a deregulated system can said to be a non monopolistic. This means consumers have a right to choose a company to buy electricity in deregulated system. 2) Probability of buying high quality supply improves in deregulated system. 3) In deregulated system prices always are under control. 4) Because of high competitive world exists in deregulated system, system advances more technically, economically and reliably.

In this deregulated market, a DISCO can make contract with any GENCO in the same control area or in other control area under the guidelines of ISO. DPM matrix is used to represent contracts of DISCO's with GENCO's. To satisfy these contracts a transmission line is required which posses bulk amount of power exchange capacity between them effectively and efficiently.

During last few decades, various controllers have been proposed by authors to improve dynamic performance of LFC. Conventional PI controller, modern feedback controllers are used for load frequency control problem. The only disadvantage with PI controller is more settling time and more overshoot in frequency response. Other modern feedback controllers suffer from the drawback of all states are not being available for the purpose of formulating a state feedback control law. In the recent past various control strategies for different applications are designed based on Sliding Mode Control (SMC) strategy [5][13].Sliding motion or sliding mode may be defined as the evolution of the state trajectory of a system confined to a specified hyper plane (switching surface) of the state space with stable dynamics. The hyper plane in state space where the switching function is zero is called switching surface.

Utkin's Observer based controller has following features. 1) Fast controllability 2) system performance not altered due to sudden change of parameters. This paper presents a new load frequency control strategy designed based on Utkin's observer for load frequency control of a multi area Hydro- Thermal deregulated system.

In this paper section II discusses the mathematical modelling of two area deregulated Hydro-Thermal system, modelling of Utkin's observer based controller and steps for algorithm are explained in section III, Simulation results are discussed in section IV, Conclusion is given finally in section V.

II. MATHEMATICAL FORMULATION OF TWO AREA HYDRO-THERMAL DEREGULATED SYSTEM

Deregulated system consists of GENCOs, DISCOs, TRANSCO's and ISO with a goal of constant frequency. The proposed deregulated power system contains two areas. Each area contains [2] two generators (one is hydro and another thermal plant) and also two DISCOS's as shown in Fig. 1. Block diagram of two area deregulated [6][2] Hydro-Thermal system is represented in Fig 2. In the deregulated system a GENCO has provision that it can supply power to DISCO either in the same area or in the other control area or it may supply power to both areas with the help of AC tie line. Alternatively by following guidelines of ISO a DISCO in one control area can make contract with GENCO in area 1 or GENCO in area 2 or with GENCO in both areas which is known as "bilateral transactions". The main objective of ISO is to monitor the ancillary services in the market, one of such service is LFC.DPM is a matrix in the open market and it represents contracts made between GENCO and DISCO, number of rows in DPM is equal to number of GENCO in all the areas and number columns equal to all the DISCO. In this matrix, an element indicates the amount of load power contracted between GENCO and DISCO. Hence, total column elements belongs to DISCO1 of DISCO Participation Matrix is $\sum cpf_{ij}=1$.

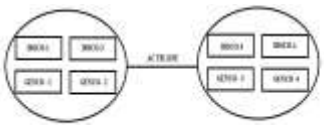

FIG. 1 REPRESENTION OF TWO AREA HYDRO-THERMAL DEREGULATED SYSTEM.

DISCO Participation Matrix**,**

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

In the above matrix cpf's represent contract participation factor. The load contract between DISCO 2 and GENCO 1 is entered as (1,2). Diagonal elements represents contract between DISCO and GENCO with in the same area. Off diagonal elements corresponds to contracts between DISCO in one area and GENCO in other areas. As there is large number of GENCO in each control area GENCO makes use of ACE signal for their power contribution before making contract with DISCO. The coefficients which indicate this contribution are called as ''ACE participation factors (apf)'' and $\sum_{j=1}^{M} apf_{ij} = 1$ where M is the total number of GENCOs in each area. The tie line power flow under[1] steady state is given as:

$$\Delta P_{tie1-2scheduled} = \sum_{j=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_L - \sum_{j=3}^{4}\sum_{j=1}^{2} cpf_{ij} \quad (1)$$

$$\Delta P_{tie1-2error} = \Delta P_{tie1-2scheduled} - \Delta P_{tie1-2actual} \quad (2)$$

$$\sum_{j=1}^{ni} apf_{ji} = 1 \quad (3)$$

Area control error (ACE) in the steady state is expressed as

$$ACE_i = B_i \Delta f_{ierror} + \Delta P_{ierror} \quad i=1,2 \quad (4)$$

Two area Hydro-Thermal system [1][14] under deregulated environment in the steady state is represented with state space equations as

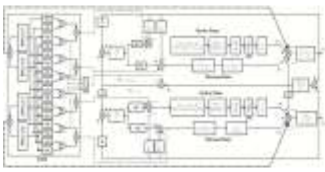

FIG.2 RESTRUCTURED SYSTEM FOR LFC IN A DEREGULATED ENVIRONMENT CONNECTED WITH AC TIE LINE.

$$\dot{x} = A^{new}x + B^{new}u \quad (5)$$

$$y = cx \quad (6)$$

A fully controllable and observable[1][14] dynamic model for a two area power system is proposed, where "x" is state vector and "u" is the vector of power demands of DISCOs.

$$u = \begin{bmatrix} \Delta P_{L1} & \Delta P_{L2} & \Delta P_{L3} & \Delta P_{L4} \end{bmatrix}^T \quad (7)$$

$$x = \begin{bmatrix} \Delta f_1 & \Delta f_2 & \Delta P_{G1} & \Delta P_{G2} & \Delta P_{G3} & \Delta P_{G4} & \Delta P_{m1} & \Delta P_{m2} & \Delta P_{m3} & \Delta P_{m4} & \int ACE_2 & P_{tie1-2} \end{bmatrix}^T \quad (8)$$

III. Design of Utkin's Observer based controller

In the design of Utkin's state observer, sliding mode control strategy can be used. This Utkins observer based controller [2-3] has the ability to bring coordinates of the estimator error dynamics to zero in finite time. Additionally, switched-mode observers have attractive measurement noise resilience that is similar to a Kalman's filter. In this Utkins observer based controller [6], when system enters in to sliding mode, the order of observer dynamics is reduced by one. The estimator error for a single estimated state is brought to zero in finite time and after that time for the other estimator errors decay exponentially to zero. Therefore using Utkins observer based controller [2-3][6] all the estimated states are brought to zero with in finite time.

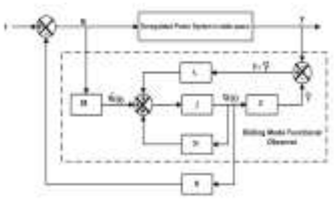

FIG 3 Block diagram of Utkins observer based controller.

Consider a linear time-invariant system described by

$$\dot{x} = Ax(t) + Bu(t) \quad (9)$$

$$y(t) = C\,x(t) \quad (10)$$

$$Z(t) = Lx(t) \quad (11)$$

Where $x(t) \in R_n$, $u(t) \in R_m$ and $y(t) \in R_p$ the state input and the output vectors are, respectively $Z(t) \in R_r$ is the vector to be estimated. The pair (C, A) is detectable, (A, B) is controllable, $A \in R_{nxn}$, $B \in R_{nxm}$, $C \in R_{pxn}$ and $L \in R_{rxn}$ known constant matrices. Without loss of generality, it is assumed that $\text{rank}(c) = p$, $\text{rank}(L) = r$,

$\text{rank}\begin{bmatrix} L \\ C \end{bmatrix} = r - \tilde{r} + p$, $\tilde{r} \le r$ and C takes the form $C = \begin{bmatrix} I_p & 0 \end{bmatrix}$ (otherwise the system can always be transformed into this form).

Consider the following Utkin's functional observer

$$\dot{w}(t) = Nw(t) + Jy(t) + Hu(t) + \Gamma\,\text{sgn}(Me(t)) \quad (12)$$

$$\hat{z}(t) = w(t) + Ey(t) \quad (13)$$

$$e(t) = z(t) - \hat{z}(t) \quad (14)$$

Where $w(t) \in R^r$, $M \in R^{\tilde{r}xr}$, $\Gamma \in R^{rx\tilde{r}}$, $\text{sgn}(.)$ is the sign function and also the sliding[6] surface is given by

$$Me(t) = 0 \quad (15)$$

Sliding motion will take place on the surface

$$S = \{(e_1(t), e_y(t)) : e_y(t) = 0\}$$

In view of the dimension of matrix *M*, the error vector *e* (*t*) can be written as

$$e(t) = \begin{bmatrix} e_y(t) \\ e_1(t) \end{bmatrix} \quad (16)$$

Where $e_y(t) \in R^{\tilde{r}}$ and $e_1(t) \in R^{r-\tilde{r}}$. The problem to be solved in this paper is to design a Utkin's functional observer of the form(12)-(14) where *N, J, H, E, M* and Γ are to be[6] determined such that $e(t)$ slide along the surface $Me(t) = 0$ and $e_1(t) \to 0$ as $t \to \infty$.

Steps for the design of Utkin's functional observer:

Step-1: Minimize the observer [6] matrix N selecting $L = I_n$

Step-2: Matrix L is [6] divided into $L = \begin{bmatrix} L_1 \\ L_2 \end{bmatrix} = \begin{bmatrix} GC \\ L_2 \end{bmatrix}$

Step-3: Verify the condition [6]

$$rank\begin{bmatrix} L_2A \\ CA \\ C \\ L_2 \end{bmatrix} = rank\begin{bmatrix} CA \\ C \\ L_2 \end{bmatrix}$$

Step-4: Utkins observer based controller exists when the above condition is fulfilled otherwise Utkins observer based controller doesn't exist.

Step-5: Calculate using the following expression

$$F_{22} = L_2AM_2 - L_2\bar{A}\Sigma^{+}\begin{bmatrix} CAM_2 \\ CM_2 \end{bmatrix} \quad (17)$$

Step-6: calculate G_2

$$G_2 = (I - \Sigma\Sigma^{+})\begin{bmatrix} CAM_2 \\ CM_2 \end{bmatrix} \quad (18)$$

Step-7: Verify the pair (F_{22}, G_2) is detectable or not [6], if detectable continue otherwise N_{22} cannot be made Hurwitz as a result Utkins observer based controller doesn't exist.

Step-8: Using pole placement method obtain Z_2 to make N_{22} Hurwitz

Step-9: compute F_{21} [6]

$$F_{21} = L_2 AM_1 - L_2 \overline{A}\Sigma^+ \begin{bmatrix} CAM_1 \\ CM_1 \end{bmatrix} \quad (19)$$

Step-10: compute G_1 [6]

$$G_1 = (I - \Sigma\Sigma^+) \begin{bmatrix} CAM_1 \\ CM_1 \end{bmatrix} \quad (20)$$

Step-11: compute N_{21} .

$$N_{21} = F_{21} - Z_2 G_1 \quad (21)$$

Step-12: Choose any Z_1 [6] and to compute $N_{11}$and N_{12} respectively

$$N_{11} = F_{11} - Z_1 G_1 \quad (22)$$

$$N_{12} = F_{12} - Z_1 G_2 \quad (23)$$

Step-13: Compute E_1, K_1, E_2 and K_2.[6]

$$\begin{bmatrix} E_1 & K_1 \end{bmatrix} = L_1 \overline{A}\Sigma^+ + Z_1 (I - \Sigma\Sigma^+) \quad (24)$$

$$\begin{bmatrix} E_2 & K_2 \end{bmatrix} = L_2 \overline{A}\Sigma^+ + Z_2 (I - \Sigma\Sigma^+) \quad (25)$$

Step-14: Compute J_1 and J_2 respectively.[6]

$$K_1 = J_1 - N_{11} E_1 - N_{12} E_2 \quad (26)$$

$$K_2 = J_2 - N_{21} E_1 - N_{22} E_2 \quad (27)$$

Step-15: Compute P_1 and P_2 using equations

$$P_1 = L_1 - E_1 C \quad (28)$$

$$P_2 = L_2 - E_2 C \quad (29)$$

Step-16: Compute H [2]

$$H = PB \quad (30)$$

Step-17: Calculate error dynamics of observer, sliding occurs on plane $e_y(t) = 0$ when-- is making Hurwitz but N is not Hurwitz.

Step-18: Stable error response is obtained by the switching surface in the Utkins observer based controller.

Step-19: Then plot the required parameters.

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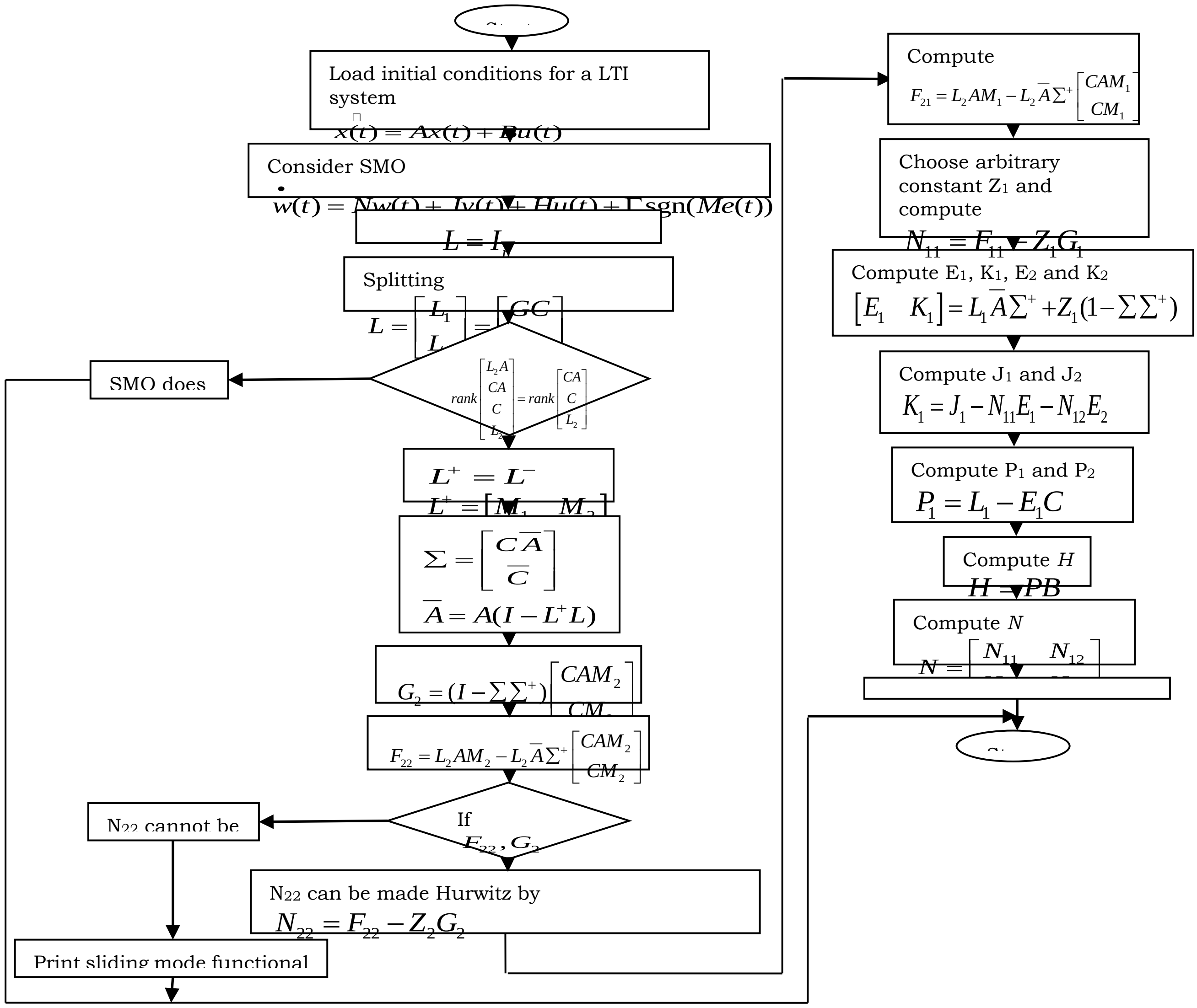

Flow Chart for the design of Utkin's observer based controller.

GENCOs parameters	Area1		Area2	
	Genco-1	Genco-2	Genco-3	Genco-4
T_T(S)	0.32	0.30	0.03	0.32
T_g(s)	0.06	0.08	0.06	0.07
R(Hz/pu)	2.4	2.5	2.5	2.7

TABLE: 1 GENCO PARAMETERS[14][8-9]

Control Area Parameters	Area-1	Area-2
$K_{p\ (pu/Hz)}$	102	102
T_p(s)	20	25
$B_{(pu/Hz)}$	0.425	0.396

TABLE: II CONTROL AREA PARAMETERS[14][8-9]

IV. SIMULATION RESULTS

Simulation work is done using MATLAB version R2010a. Operating system is WINDOWS 7. System configuration: Core I3 Processor, 3 GB RAM, 320 HDD. A Standard Two Area Hydro-Thermal Deregulated system [1] [5] is considered for simulation studies. System parameters are given in Tables I and II [14] [8-9].

$$\Delta P_{m1} = 0.2(0.1)+0.5(0.1)+0.2(0.1)+0.3(0.1) = 0.12\,puMW$$

Utkins observer based controller is proposed for two area Hydro-Thermal deregulated system and tested for different loading conditions with one possible contract scenario. The dynamic response of two area Hydro-Thermal deregulated system with Utkins observer based controller based optimal controller is compared with conventional PI controller.

Contract scenario:

A DISCO in one area can make contract with GENCO in the same area or GENCO in the other area or GENCO in both areas and all the contracts are represented with below matrix [8-9].

$$DPM = \begin{bmatrix} 0.2 & 0.5 & 0.2 & 0.3 \\ 0.2 & 0 & 0.2 & 0.1 \\ 0 & 0.25 & 0.4 & 0.5 \\ 0.6 & 0.25 & 0.2 & 0.1 \end{bmatrix}$$

Assume that each DISCO demands[5][8-9] 0.1puMW total power from other GENCOs and the elements of DPM matrix indicate the contracts of DISCO from all other GENCO and all the GENCOs involves in AGC based on following *apfs*.

$$apf_1 = 0.6, apf_2 = 1 - apf_1 = 0.4$$
$$apf_3 = 0.5, apf_4 = 1 - apf_3 = 0.5$$

In the steady state power output from a GENCO must be equal to total load of DISCOs in contract with it. It is expressed as

$$\Delta P_{mi} = \sum_j^j cpf_{ij} \Delta P_{Lj}$$

So, for this scenario [8-9]

$$\Delta P_{m2} = 0.05\, puMW$$
$$\Delta P_{m3} = 0.115\, puMW$$
$$\Delta P_{m4} = 0.115\, puMW$$

In the simulation results, dotted line with circles indicates response of Frequency signal in area-1 vs. time of the system without any controller, dashed line indicates response of Frequency signal in area-1 vs. time of the system with PI controller, and dark line indicates response of Frequency signal in area-1 vs. time of the system with Utkins observer based controller based Optimal controller.

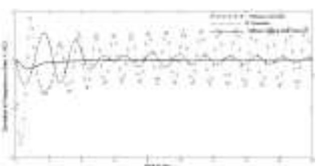

Fig. 4(a) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in Frequency vs. time)

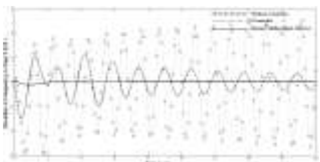

Fig. 4(b) Response of Hydro-Thermal system with Utkins observer based controller (Area-2: Deviation in Frequency vs. time).

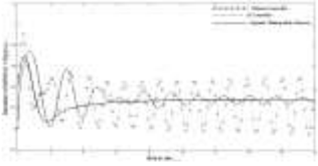

Fig. 5(a) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in GENCO-1 Power Output vs. time).

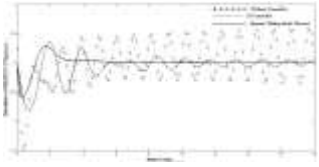

Fig. 5(b) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in GENCO-2 Power Output vs. time).

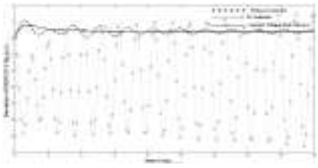

Fig. 5(c) Response of Hydro-Thermal system with Utkins observer based controller (Area-2: Deviation in GENCO-3 Power Output vs. time).

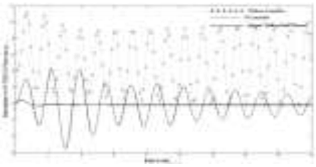

Fig. 6 Response of Hydro-Thermal system with Utkins observer based controller (Deviation in Tie Line Power Flow)

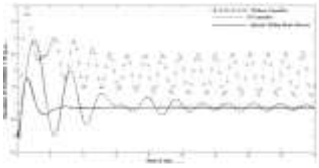

Fig. 7(a) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in TURBINE-1 Power Output vs. time).

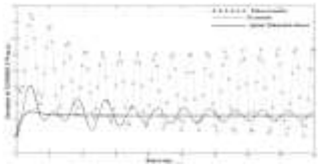

Fig. 7(b) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in TURBINE-3 Power Output vs. time)

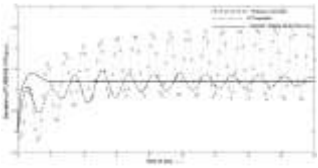

Fig. 7(c) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in TURBINE-4 Power Output vs. time)

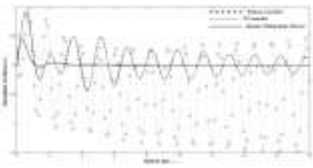

Fig. 8(a) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in SERVOMOTOR-2 vs. time).

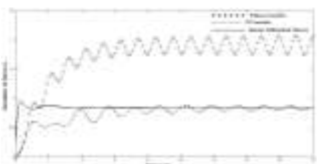

Fig. 8(b) Response of Hydro-Thermal system with Utkins observer based controller (Area-1: Deviation in SERVOMOTOR-4 vs. time).

V. CONCLUSION

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In this paper, Utkins observer based controller is proposed for Load Frequency control problem in multi-area deregulated Hydro-Thermal system. Proposed Utkins observer based controller based optimal controller is tested on two-area deregulated Hydro-Thermal system including bilateral contracts and its performance is compared with conventional PI controller. Utkins observer based controller measures system states and gives acceptable dynamic response when system is subjected to change in load demands. This Utkins observer based controller damp out frequency oscillations quickly in each control area and peaks are reduced effectively compared to conventional PI controller.

VI. NOMENCLATURE

ISO	Independent System Operator
VIU	Vertically Integrated Utilities
DISCO	Distribution Companies
GENCO	Generation Companies
TRANSCO	Transmission system
DPM	DISCO Participation Matrix
cpf	Contract Participation Factor
apf	Area control error Participation factor
LFC	Load frequency control
SMO	Utkins observer based controller
ACE	Area control error
B	Frequency Bias
R	Speed Regulation
T_t	Turbine Time Constant
T_g	Governor Time Constant
T_P	Power system equivalent time constant
P_m	Turbine power output
P_G	Governor Output
K_P	Power system equivalent gain
f	Area frequency
P_d	Area load disturbance
T_{12}	Tie line synchronizing coefficient between areas1-2.

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