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Integrating SSSC with Variable Structure Observer based Optimal Controller for Damping Frequency Oscillations of Deregulated Power System

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Abstract

In this paper design of integrated static synchronous series capacitor (SSSC) and variable structure system observer (VSSO) based optimal controller for damping of frequency oscillations in Multi Area Power System (MAPS) under deregulated environment is presented. A Thermal-Thermal power system is considered for simulation study. SSSC is a series connecting device which is connected with tie line of the system. The low frequency oscillations of system are minimized by designing the gain of SSSC. The high frequency oscillations are minimized by designing observer based optimal controller. The design of VSSO matrix is a function of transformed System matrix obtained from optimal sliding mode control law. The performance of deregulated system with integrated control strategy (SSSC+ VSSO based Controller) is tested & simulation results are presented and compared to Neuro Fuzzy Sliding Mode Controller (NFSMC) and PI controller.

Keywords: Deregulated power system, static synchronous series capacitor, Neuro Fuzzy Sliding Mode Controller and Variable structure system observer.

INTRODUCTION

The change in load initiates tie line power flow results deviations in frequency. For proper trade of power in the Tie lines control of frequency [1-7] is a great challenge to a power system engineer particularly in a deregulated Environment. These days' series FACT devices in tie line are commonly used for damping frequency oscillations [8]. One kind of series controlled FACT device, Static Synchronous Series capacitor (SSSC) is used to suppress these power oscillations effectively and also controls the Tie-line power flow in specified limits [9].

Many authors studied these coordinated control strategies with different combinations. Few of them are, coordinated control of H_∞ controller and SSPS [10]. A TCPS and PSO based fine turning PID controller, this method suppress frequency oscillations effectively [11]. The frequency response of each CA can be improved by adjusting parameters of SSSC and SMES using Probabilistic Methods Applied to Power Systems [12]. A dual mode control strategy with FABFM plus SSSC and TCPS is demonstrated for LFC [13]. Performance improvement by employing TCPS for AGC of a hydrothermal system under deregulation is presented in [14] and Redox Flow Batteries (RFB) with IPFC presented [15]. The authors earlier have proposed Neuro Fuzzy Sliding Mode Controller (NFSMC) for LFC Problem of MAPS in Deregulated Environment [16]. All these popular strategies were designed with a basic assumption that, all the system variables are available for execution of control law. As the system behaviour is uncertain and model wise it is highly nonlinear, the performance of system with designed controllers is doubtful [17].

Under these limitations, there is a necessity for design of a robust Load Frequency Controller to minimize the settling time, also to mitigate both the high frequency and low frequency oscillations. This is the main objective of this proposed control strategy. The name of the proposed control strategy is "Variable Structure Observer based Optimal Controller (VSSOC)". The integral parts of VSSOC are an observer and an optimal controller. This strategy assumes a SSSC is cascaded with tie line. The feature of the designed sliding mode observer [18-25] is to estimate all the state variables by taking Δf_1 & Δf_2 as inputs. Then system is converted in to state space model with observed states. These observer states are given as input to design control law using an optimal sliding mode controller. The desired response of the system with optimal controller is obtained by setting the gain through minimization of performance index. Dynamic Model of Restructured Power System for AGC, SSSC and NFSMC is given in section II. In section III Design of Proposed VSSOC with SSSC is discussed. The simulation results were presented in section IV and finally the conclusions are given in section V.

$$J_1 = \frac{1}{2}\int_{t_s}^{\infty} \widetilde{X}_1^T [\widetilde{Q}_{11} - \widetilde{Q}_{12}\widetilde{Q}_{22}\widetilde{Q}_{21}^T]\widetilde{X}_1 + V^T \widetilde{Q}_{22} V]dt$$

$$V = \widetilde{X}_2 + \widetilde{Q}_{22}^{-1}\widetilde{Q}_{12}^T \widetilde{X}_1$$

$$\widetilde{X}_2 = -\widetilde{Q}_{22}^{-1}(\widetilde{A}_{12}^T P + Q_{12}^T)\widetilde{X}_1$$

$$\widetilde{Q} = (M^{-1})^T Q M^{-1} = \begin{bmatrix} \widetilde{Q}_{11} & \widetilde{Q}_{12} \\ \widetilde{Q}_{21} & \widetilde{Q}_{22} \end{bmatrix}$$

$$\widetilde{X}_2^T \widetilde{Q}_{21}\widetilde{X}_1 = \widetilde{X}_1^T \widetilde{Q}_{12}\widetilde{X}_2$$

Step-5: Matrix Riccati equation is solved and P matrix evaluated.

$$P.(\widetilde{A}_{11} - \widetilde{A}_{12}\, Q_{22}^{-1}\, Q_{12}^T) + (\widetilde{A}_{11} - \widetilde{A}_{12}\, Q_{22}^{-1}\, Q_{12}^T)^T P - P.\widetilde{A}_{12}\, Q_{22}^{-1}\, Q_{12}^T P + D^T D =$$

Step-6: The surface is designed using optimal control law.

$$H = [\widetilde{Q}_{22}^{-1}(\widetilde{A}_{12}^T P + \widetilde{Q}_{12}^T) \quad I] \times MP\widetilde{A}_s + \widetilde{A}_s^T P - P\widetilde{B}_s \widetilde{R}_s^{-1} \widetilde{B}_s^T P + \widetilde{Q}_s)$$

Where,

$$\widetilde{A}_s = \widetilde{A}_{11} - \widetilde{A}_{12}\widetilde{Q}_{22}^{-1}\widetilde{Q}_{12}^T ; \widetilde{B}_s = \widetilde{A}_{12} ; \widetilde{R}_s = \widetilde{Q}_{22})$$

Step-7: The control law for equivalent control

$$K_e = (SB)^{-1} S\, A$$

Step-8: The corrective control law is given by

$K_r = (SB)^{-1} S\, \delta$ (δ is sliding margin)

Step-9: the cumulative control law

$$u = -K.X = -(K_e + K_r).X$$

Step-10: Eigen values of hyper plane λ_H calculated by

$$\lambda_H = eig\,(A - BK)$$

Step-11: Sliding Eigen values λ_s [25] calculated by

$$\lambda_s = eig\,(\widetilde{A} - \widetilde{B}K)$$

The flow chart for VSSOC is given in Fig. 7.

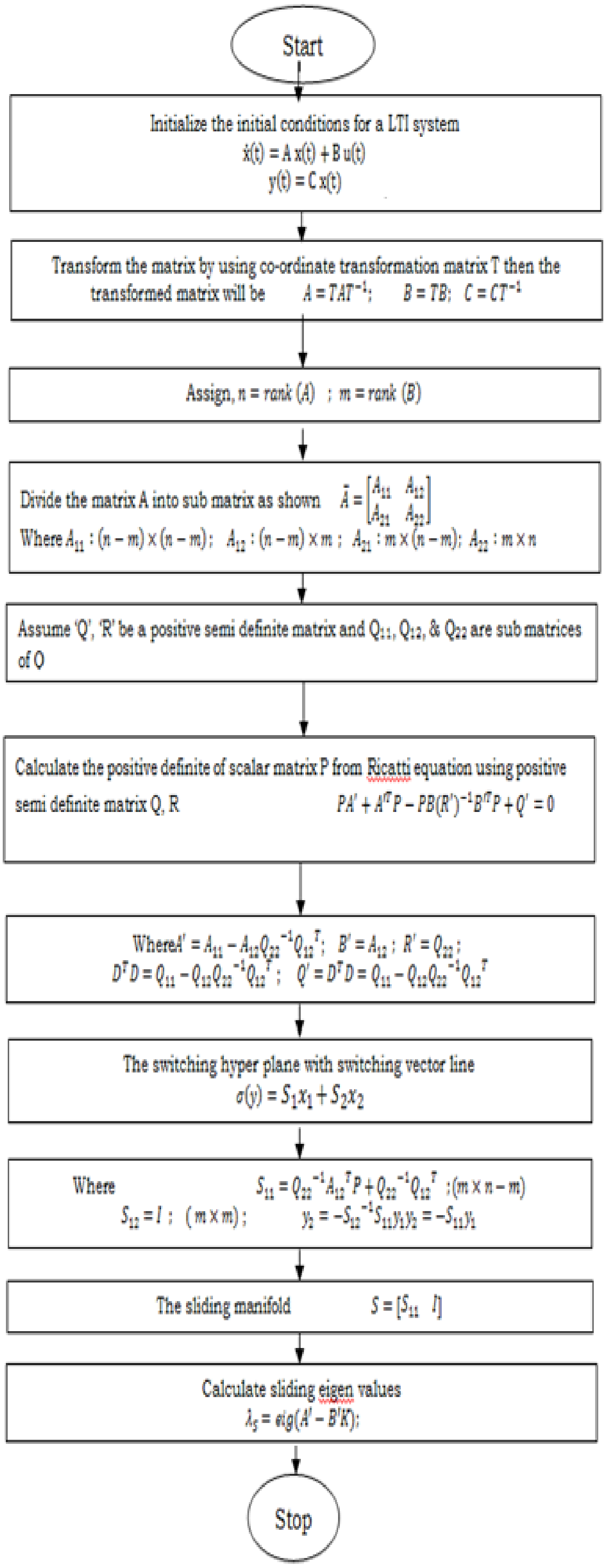


Figure 6: Flow Chart for Design of Sliding Poles

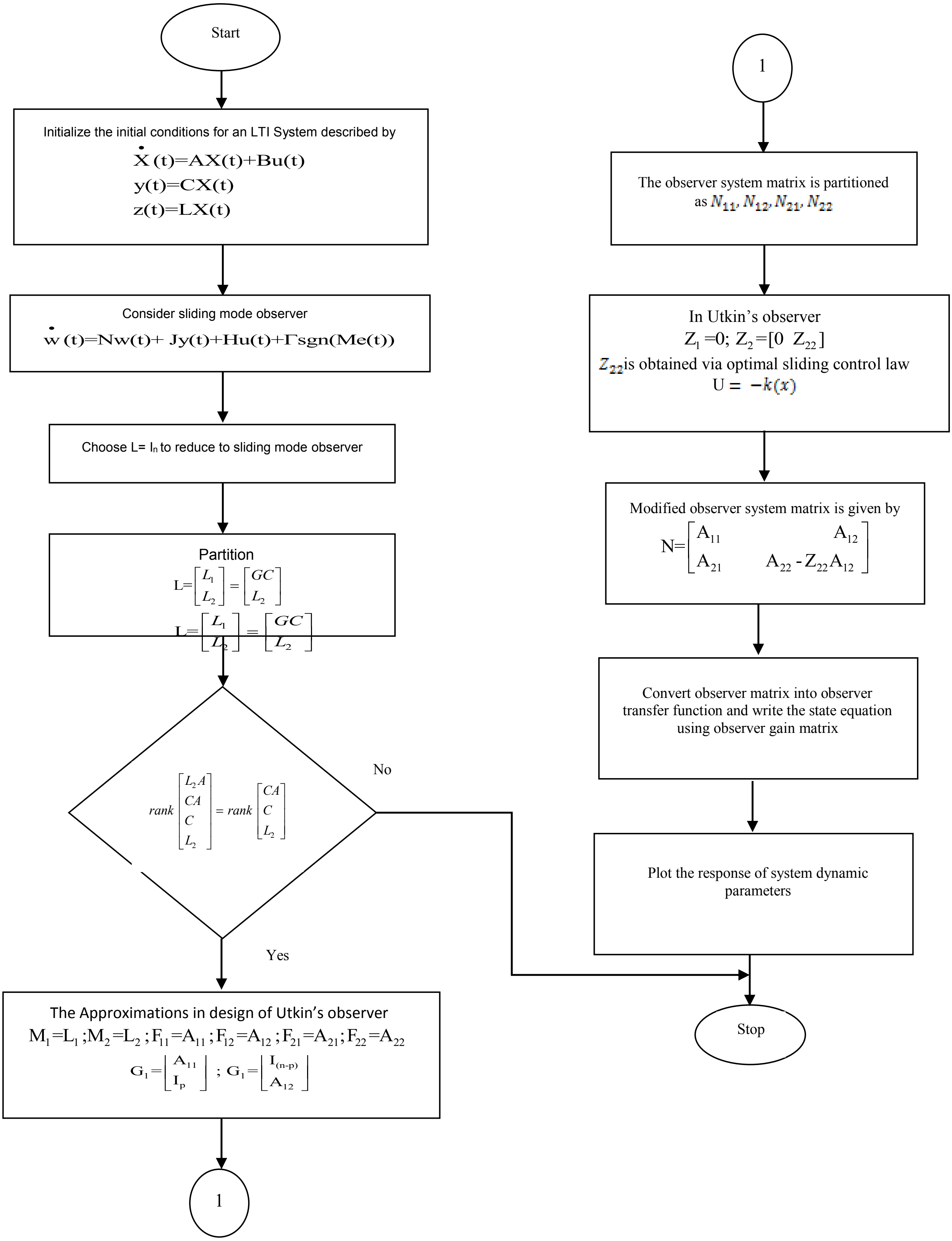


Figure 7: Flow Chart for Sliding Mode Observer based Optimal Controller.

SIMULATION RESULTS

Contract scenario:

In bilateral contract scenario, freedom will be there for the DISCOs to contract with GENCOs of same area or other area. The contracted power will be dispatched to the DISCOs based on the following DPM.

$$DPM = \begin{bmatrix} 0.2 & 0.3 & 0.5 & 0.0 \\ 0.3 & 0.2 & 0.0 & 0.7 \\ 0.5 & 0.0 & 0.2 & 0.1 \\ 0.0 & 0.5 & 0.3 & 0.2 \end{bmatrix}$$

It is considered that, each DISCO demands 0.1puMW power from the all other GENCOs. The GENCOs participates in AGC based on the following *ACEpfs.*

$\propto_1 = 0.6$, $\propto_2 = 1 - \propto_1 = 0.4$;$\propto_3 = 0.5$, $\propto_4 = 1 - \propto_3 = 0.5$

In steady state there should not be any mismatch between the generation of a GENCO and the load requirement of a DISCO in contract with it. It is expressed as

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

So, for this scenario we have

$\Delta P_1 = 0.2(0.1) + 0.3(0.1) + 0.5(0.1) + 0.0(0.1) = 0.1$puMW

$\Delta P_2 = 0.12$puMW; $\Delta P_3 = 0.08$puMW; $\Delta P_4 = 0.1$puMW;

The simulation results for the system under consideration i.e. Thermal – Thermal System were presented. Fig. 8 represents deviation of frequency in control area-1, Fig. 9 represents deviation of frequency in control area-2 and Fig.10 represents tie-line power exchange deviation.

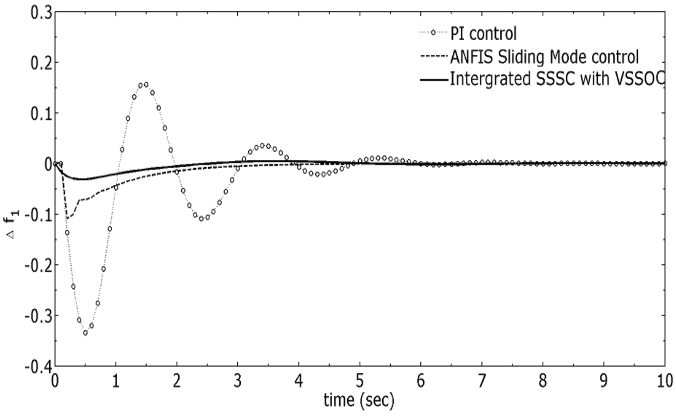


Figure 8: Deviation in Frequency in control area 1.

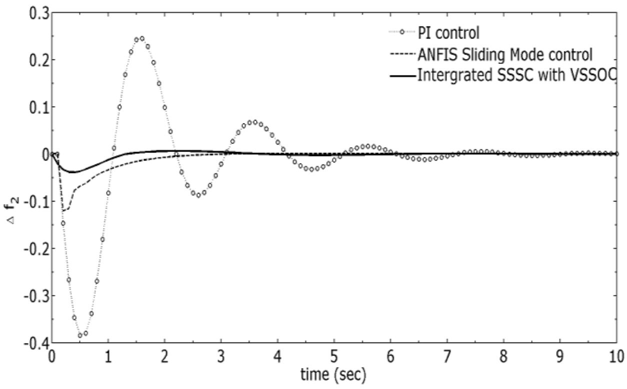


Figure 9: Deviation in Frequency in control areas 2.

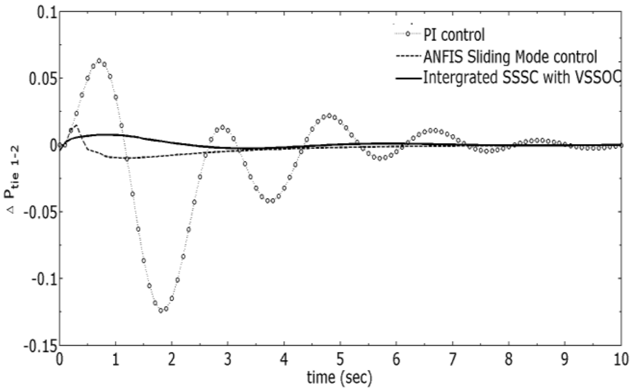


Figure 10: Tie - line power exchange Deviation.

Table-1: % of peak overshoots in change of frequency in CA-1, CA-2 after introducing different controllers.

Type of Controller	Percentage overshoot in Δf in Control Area-1	Percentage overshoot in Δf in Control Area-2
PI	100	100
NFSMC	30	30
VSSOC+SSSC	10	10

Table -2: The settling time of frequency deviations in CA-1 and CA-2

Type of Controller	Settling time of CA-1 (frequency change)	Settling time of CA-2 (frequency change)
PI	6sec	8sec
NFSMC	2sec	2sec
VSSOC+SSSC	< 2sec	< 2sec

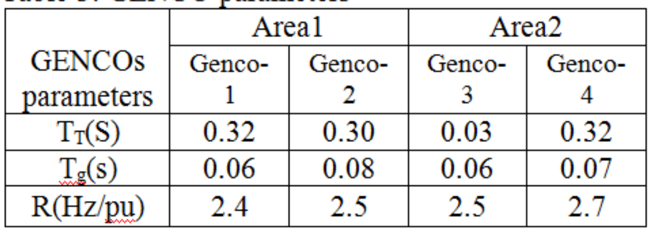
CONCLUSION

Variable structure observer based optimal controller is proposed to reduce tie-line power oscillations as well as to improve frequency response of two area thermal-thermal power system. The nonlinearities in power system model, unpredictable and uncertainty behavior of power system have overcome with this control strategy. The proven sliding mode control strategies are implemented. A Thermal-Thermal power system is considered for simulation study. SSSC is connected in series with tie line of the system. The low frequency oscillations of system are minimized by designing the gain of SSSC. The high frequency oscillations are minimized by designing observer based optimal controller. The performance of deregulated system with integrated control strategy (SSSC+ VSSO based Controller) is tested and simulation results are presented and compared to Neuro Fuzzy Sliding Mode Controller (NFSMC) and PI controller.

Appendix:

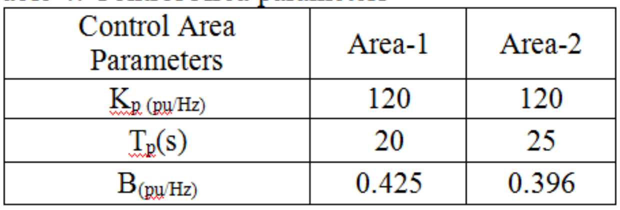
The power system parameter values are given in table 3 & 4 for Thermal – Thermal system.

Table 3: GENCO parameters



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 4: Control Area parameters



Control Area Parameters	Area-1	Area-2
K_p (pu/Hz)	120	120
T_p(s)	20	25
B(pu/Hz)	0.425	0.396

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