FRACTIONAL ORDER OBSERVER BASED CONTROLLER FOR LOAD FREQUENCY CONTROL IN MULTI AREA SMART DEREGULATED POWER SYSTEM

T.SanjeevaRao [1],*Dr. Brajesh Mohan Gupta*[2] and *Dr.T.Anil Kumar* [3]

[1]Reserachscholar, EE Department SSSUTMS Sehore, MP, India
[2]Professor, EE Department SSSUTMS Sehore, MP, India
[3]Professor, Dept of Electrical Engineering, Anurag UniversityHyderabad, India

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Abstract: Currently, Electric Vehicles (EV) and renewable energy sources are being integrated into the main grid to mitigate carbon emissions. Load Frequency Control (LFC) was a significant challenge in renewable and electric vehicle-integrated smart restructured power systems. This paper introduces a fractional order observer-based optimal state feedback controller (FROOSFC) during load frequency control within a two-area Smart Deregulated Power System (SDPS), incorporating thermal-wind resources in control area 1 and hydro-solar-thermal resources within control area 2, with electric vehicle aggregators integrated into each control area. The simulations are conducted employing the MATLAB simulation environment to simulate the bilateral contract scenario of SDPS. The efficacy of FROOSFC when compared with both the fractional order optimum state feedback controller including the FOPI controller within a potential bilateral contract context, addressing uncertainties and abrupt load variations.

Keywords— *Fractional Order Observer, State Feedback Control, LFC, Smart Deregulated power System.*

1. INTRODUCTION

Load frequency control is a noticeable problem in power system due to mismatch of generation with load demand, the LFC is more challenging in deregulated environment due to rapid deviation of load from one distribution company to another distribution company based on consumer load switching [1-5]. Now a day's integration of renewable energies causes frequency deviation in smart grids due to lack of potential of solar PV and new energy sources in smart grids [6]. Y R Prajapati et.al demonstrated the frequency response of two area system under different transaction scenario with integration of renewable energy system [7].Ashraf Khalil et.al presented a H-infinity controller with V-K iteration algorithm to address the uncertainties in the LFC model of restructured power system [8].

Muhammad Ahsan Zamee et.al presented a DE based PI controller on renewable energy based two area power system[9].Vijay Pratap Singh et.al presented a reinforcement based intelligent controller for LFC with event triggered communication topology demonstrated to improve dynamic performance of LFC in smart grid environment[10]. Sanjoy Debbarma et.al demonstrated the improvement of LFC response with participation of EVs in three area power system with gas turbine and thermal plants[11].Pushpa Gaur et.al presented a 2-DOF PID controller tuning with wind driven optimization presented to improve LFC response of STTP and V2G integrated power system[12].

Ark Dev et.al presented a Sliding mode super twisting controller for multi area LFC model under uncertainties and heavy load disturbances with chattering free robust performance [13].Ark Dev et.al presented a prediction based super twisting algorithm based disturbance observer demonstrated on three area power system[14].Abidemi Ajiborisha et.al presented a BESS used as an ancillary service with model predicative control is a potential candidate for diminishing LFC oscillations [15].Kamlesh Bharti et.al presented a LMI-LQR based controller with demand response integration in a renewable energy integrated smart grid with the effect of communication delay with pade approximation method[16].

Krishan Arora et.al presented a PI controller optimized with MFO algorithm is a promising optimizer to improve LFC response with demand response integration[17].Xing-Chen Shangguan et.al presented an event triggered communication delay method presented[18]. HH Ali et.al presented a Sooty Terns Algorithm with MPC-LFC for restricted renewables integrated power system[19].Ahmed Fathy presented a MVDA algorithm for optimizing gains[20].Mokhtar Shouran presented Bee algorithm for SMC[21]. 3-DOFPID tuning with seagull optimization algorithm with effect of communication delay presented[22].Authors suggested PID controller tuning with TDOF-LADRC and demand response integration for frequency regulation in smart grid [23].LPBO-PI-PD, AOA-PI-PD, and MPSO-PI-PD presented for LFC-AVR[24].

A satin-bowerbird optimization with ID-PD presented for geo-thermal, solar-thermal-power system [25]. IT2FLC for LFC of thermal-hydro-solar-diesel power system presented by authors[26],PID with GBO better performance than GBO-PID for four area IPS[27]. CFMPC-FOPID with STO suggested by authors for solar-PV and Wind integrated system[28].The authors advised an Adaptive-PI for solar PV,Wind,wave energy power system[29]. V2G for H-infinity with PSO for LFC in smart grid [30]. Mustafa Al-Tameemi et.al suggested virtual synchronous generator with M3C presented to reduce LFC oscillations using HVDC transmission [31]. Yiwen Xu et.al presented wind integrated power system with ultra-capacitor and battery energy storage system for improving LFC and nullifying the chattering effect [32]. HH Alhelou et.al presented a multi objective optimization technique with MPC for LFC with SMES introduced as an ancillary service with An integral sliding mode controller with modified PSO, adaptive sliding mode controller to improve transient behavior of integrated power system [33].

Farhad Farivar et.al presented a sliding mode observer with H-infinity feedback controller presented to better LFC of three area power system[34].Authors suggested a PID with GEO for parallel AC/HVDC [35].A HVDC link penetrated wind form with Fuzzy-PID controller suggested by Mehrdad Ahmadi Kamarposhti[36]. Babahajiani et.al presented RDR of with fuzzy-PI coordinated control suggested for AGC [37].Junaid Khalid et.al presented a PID control tuning with twin delayed deep deterministic policy gradient method for hybrid power system [38].An Fractional order intelligent controllers designed with prediction algorithms are giving feasible the load frequency control in deregulated power systems [39-41].

The smart deregulated power system affects with lack of load frequency control mechanism. In view of this fractional order control based observer is to give better controllability. The design of controller for smart deregulated power system and reveals the performance is given in following sections.

2. MATHEMATICAL MODELLING OF SMART DEREGULATED POWER SYSTEM

A. Mathematical modelling of DPS

Smart deregulated two area power systems deemed with control area-1 contains thermal-wind then EV aggregators and control area-2 set with hydro, solar, thermal and EV aggregators. Each area of Power system has two Distribution Companies (DISCOs) [5].

The multi-area power system's area control error[1-3]

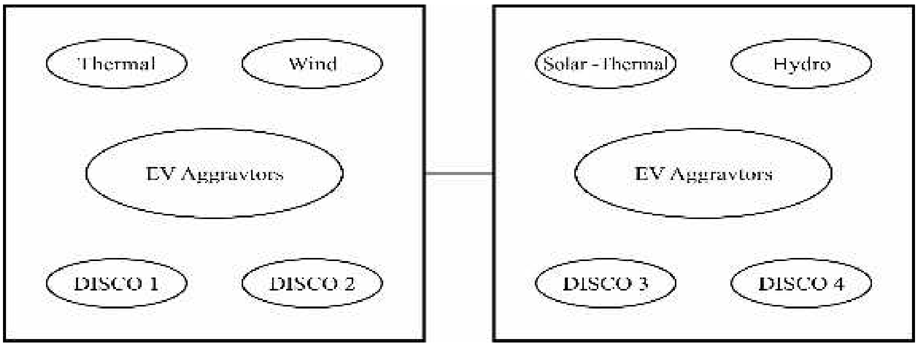

Fig-1: Block diagram model of deregulated power system

$$ACE=B\Delta f+\Delta P_{Tie} \quad (1)$$

The Area Contract Error Participation factor [1-3]

$$\sum_{j=1}^{n_i} apf_{ji}=1 \quad (2)$$

The total Load Demand

$$\Delta P_{Total} = \Delta P_{loc,i}+\Delta P_{di} \quad (3)$$

The contracted load demand

$$\Delta P_{loc,i} = \sum_{j=1}^{m_i} \Delta P_{Lj-i} \text{ local contracted demand} \quad (4)$$

The un contracted load demand

$$\Delta P_{di} = \sum_{j=1}^{m_i} \Delta P_{ULj-i} \quad (5)$$

Total un contracted demand

The deviation in scheduled tie- line power flow

$$\zeta_1 = \sum_{\substack{k=1 \\ i\neq k}}^{N} \Delta P_{Tie,ik,scheduled} \quad (6)$$

$$\Delta P_{Tie,ikscheduled} = \sum_{j=1}^{n_i}\sum_{t=1}^{m_k} apf_{(s_i+j)(s_k+i)}\Delta P_{Lt-k} - \sum_{t=1}^{n_k}\sum_{j=1}^{m_i} apf_{(s_k+i)(s_i+j)}\Delta P_{Lj-i} \quad (7)$$

$$\Delta P_{tie\ ,ikerror}=\Delta P_{tie,i,actual} - \zeta_1 \quad (8)$$

Generation of power of each GENCO

$$\Delta P_{m,k-i} = \rho_{ki}+apf_{ki}\sum_{j=1}^{m_i} \Delta P_{ULj-i}\text{ , k=1,2,….}n_i \quad (9)$$

ρ_{ki} is contracted load demand $GENCO_{k-i}$

$$\rho_{ki} = \sum_{j=1}^{N}\sum_{I=1}^{m_i} cpf_{(s_i+k)(s_j+t)}\,\Delta P_{Lj-i} \quad (10)$$

$$\int A\dot{C}E_1dt = \{B_1\Delta f_1 + \Delta P_{tie12} - (\textstyle\sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\Delta P_{Lj})\} \quad (11)$$

Similarly for the other area it is given by

$$\int A\dot{C}E_2dt = \{B_2\Delta f_2 + a_{12}\Delta P_{tie12} - a_{12}(\textstyle\sum_{i=1}^{2}\sum_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \sum_{i=3}^{4}\sum_{j=1}^{2} cpf_{ij}\Delta P_{Lj})\} \quad (12)$$

The DISCOM participation matrix in terms of contract participation factor (*cpf*)[5]

$$\text{DPM}=\begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \\ cpf_{51} & cpf_{52} & cpf_{53} & cpf_{54} \\ cpf_{61} & cpf_{62} & cpf_{63} & cpf_{64} \end{bmatrix} \quad (13)$$

B. Modelling of thermal plant:

The modelling of various components of thermal plant [30] given below

Governor model $G_g = \frac{K_g}{T_gs+1}$ (14)

Reheater model $G_r = \frac{K_{rT_rs+1}}{T_{rS+1}}$ (15)

Steam Turbine model$G_t = \frac{K_t}{T_{tS+1}}$ (16)

Generator model $G_{gen} = \frac{K_p}{T_{pS+1}}$ (17)

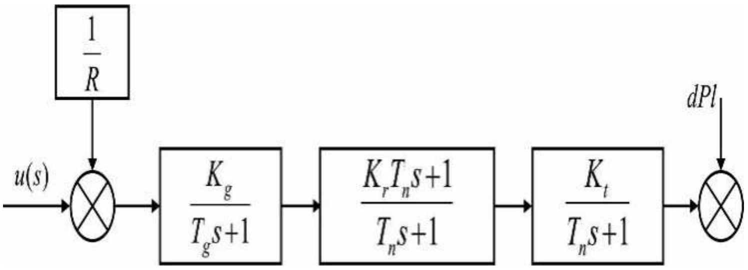

Fig-3: Block diagram model of thermal power system

C. Modelling of hydro plant:

The small signal transfer function model of hydro plant [30]

K_{gh} , T_{gh} are gain and time constants of turbine, G_t is the transfer function of governor andT_w is the normal start time of penstock.

$G_{MHG} = \frac{K_{gh}}{T_{gh}S+1}\frac{T_{Rs}S+1}{T_{Rh}S+1}$ (18)

$G_t = \frac{-T_wS+1}{0.5T_wS+1}$ (19)

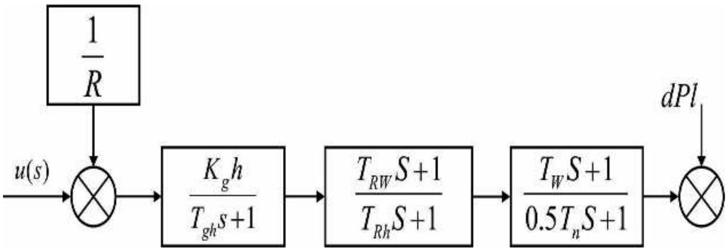

Fig-4: Block diagram model of hydropower system

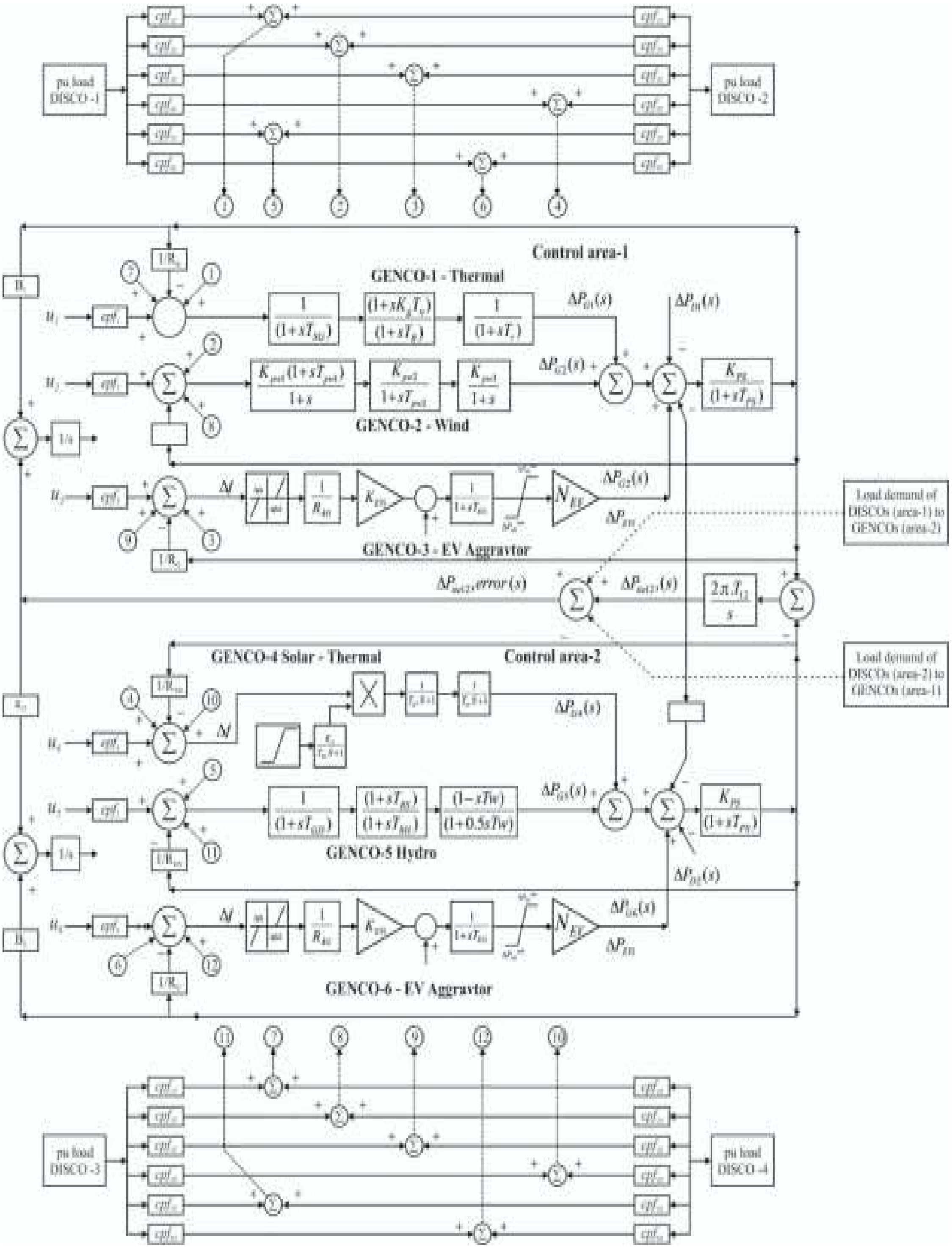

Fig-2: Schematic diagram of two area deregulated power system with the integration of EVs in each control area.

D. Modelling of wind turbine generator:

A DFIG model is considered, the output power of wind turbine generator given below [30]

$$C_p(\lambda,\beta) = 0.5\rho A C_p V_w^3 \tag{20}$$

$V_w$is the wind velocity,ρ is the air density and A is the area of the blade.

The small signal transfer function model of wind turbine generator given below

$$G_w = \frac{K_{pw1}(1+sT_{pw1})}{1+s} \times \frac{K_{pw2}}{1+sT_{pw2}} \times \frac{K_{pw3}}{1+s} \tag{21}$$

$K_{pw1,}K_{pw2,}K_{pw3}$ are the gains of wind turbine,T_{pw1},T_{pw2},$T_{pw3}$are time constants of wind turbine generator.

$$C_p(\lambda,\beta) = 0.44 - 0.0167\beta \sin\left(\frac{\pi(\lambda-2)}{15-0.3\beta}\right)\text{-}0.00184(\lambda\text{-}3) \tag{22}$$

λ is the tip speed ratio,β is the pitch angle.

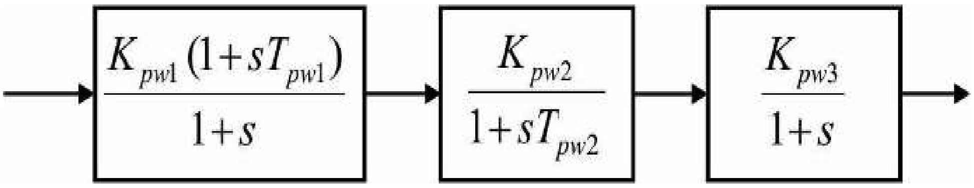

Fig-5: Block diagram model of hydropower system

E. Modelling of EV Aggregators:

The EV aggregator model depicts in fig.6. and the model consisting of battery charger, PFC and LFC. The power interchanges between grid and battery controlled by battery charger. To prevent unwanted actions when electric vehicles are not linked to the power grid, a dead band feature was implemented.This upper and lower limit'sdead band[Δf_{UL},Δf_{LL}] are [-10 mHZ, 10 mHz].That$K_{EV_i}$is a function for SOC deviation. The incremental change of EV Aggregator with maximum and minimum power delivered to the grid is depicted in equation 22&23[8, 9].

$$\Delta P_{AG}^{max} = [\frac{1}{N_{EV}} \times \Delta P_{EV_i}] \tag{23}$$

$$\Delta P_{AG}^{max} = -[\frac{1}{N_{EV}} \times \Delta P_{EV_i} \tag{24}$$

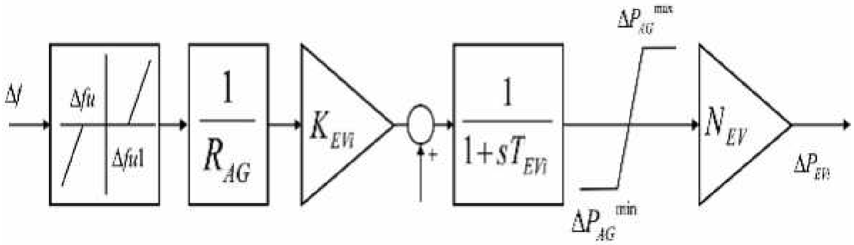

Fig-6: Block diagram model of EV aggregators

2 MATHEMATICAL MODELLING OF FRACTIONAL ORDER STATE FEEDBACK CONTROLLER

The fractional order calculus is a non-integer order operator($a^{D_t^{\gamma}}$).a, t are the boundaries of operation and γ is a real number [38,39].

$${}_aD_t^{\gamma} = \begin{cases} \dfrac{d^{\gamma}}{dt^{\gamma'}} & \gamma > 0, \\ 1 & \gamma = 0, \\ \int_a^t (d\tau)^{\gamma}, & \gamma < 0, \end{cases} \tag{25}$$

According to Grunwald–Letnikov (GL) the fractional order derivative defined as

$$ {}_{a}D_{t}^{\gamma} f(t) = \lim_{h \to 0} h^{-\gamma} \sum_{j=0}^{[(t-a)/h]} (-1)^{j} \binom{\gamma}{j} f(t - jh) \tag{26} $$

According to Riemann–Liouville (RL) the fractional order derivative define as

$$ \left(\frac{f}{j} \right) = \frac{\Gamma(\gamma + 1)}{\Gamma(j + 1)\,\Gamma(\gamma - j + 1)} \tag{27} $$

According to the Caputo definitions

$$ {}_{a}D_{t}^{\gamma} f(t) = \frac{1}{\Gamma(n - \gamma)} \frac{d^{n}}{dt^{n}} \int_{a}^{t} \frac{f^{(n)}(\tau)}{(t - \tau)^{\gamma - n + 1}} d\tau \quad for \;\; n - 1 < \gamma < n \tag{28} $$

The state space model of smart deregulated power system

$$ \begin{cases} \dot{x} = f(x) + g(x)u \\ y = H(x) \end{cases} \tag{29} $$

$$ \dot{z} = A.z + B.v_{n} \,| \tag{30} $$

The performance indexed minimised as

$$ \mathrm{J} = \frac{1}{2} \int_{0}^{\infty} \left(\mathrm{z}^{\mathrm{T}} \mathrm{Qz} + \alpha \mathrm{v}_{\mathrm{n}}^{2} \right) \mathrm{dt}, \left(\mathrm{Q} \in \mathrm{R}^{\mathrm{n\,X\,n}}, \alpha \in \mathrm{R} \right) \tag{31} $$

α Is a fractional order operator.

$$ A^{T}P + PA - \alpha^{-1}PB^{T}BP + Q = 0 \tag{32} $$

The control law obtained by soliving Matrix riccati equation by minimizing performance index where

$$ V_{n} = -\alpha^{-1} B^{T} P \tag{33} $$

3 MATHAMATICAL MODELLING OF FRACTIONAL ORDER OBSERVERR BASED OPTIMAL STATE FEEDBACK CONTROLLER (FROOSFC)

The nonlinear functional observer in state-space given as[40]

$$ \begin{cases} D^{\alpha}\eta(t) = Nx(t) + Jy(t) + Hu(t), \\ \hat{z}(t) = \eta(t) + Ey(t), \qquad\qquad 0 < \alpha < 2, \\ \eta(0) = \eta_{0}, \end{cases} \tag{34} $$

Where N is a observer system matrix,
α is a fractional order operator
The fractional order observer existence condition given below.

$$ \mathrm{D}^{\alpha} \mathrm{e(t)} = \mathrm{Ne(t)}\ \text{is asymptotically stable}, $$

$$ \mathrm{PA} - \mathrm{NP} - \mathrm{JC} = 0, \tag{35} $$

$$ \mathrm{PF} + \mathrm{NEG} - \mathrm{JG} = 0, \tag{36} $$

$$ \mathrm{H} = \mathrm{PB}, \tag{37} $$

$$ \mathrm{EG} = 0 \tag{38} $$

$$ \text{where}\ \mathrm{P} = \mathrm{L} - \mathrm{EC} \tag{39} $$

The fractional Order dynamics expressed in terms of error function, The error is a function of observer system matrix (N)[40].

$$D^{\alpha} e(t) = D^{\alpha} z(t) - D^{\alpha} \hat{z}(t) \tag{40}$$

$$\mathrm{NL} + \mathrm{ECA} + \mathrm{KC} = \mathrm{LA} \tag{41}$$

$$\mathrm{KG} + \mathrm{ECF} = \mathrm{LF} \tag{42}$$

If above condition satisfied then only fractional order nonlinear observer exists.

$$\begin{bmatrix} N & K & E \end{bmatrix} \sum_1 = \sum_2, \tag{43}$$

$$\sum_1 = \begin{bmatrix} L & 0 & 0 \\ C & G & 0 \\ CA & CF & G \end{bmatrix} \tag{44}$$

$$\sum_2 = \begin{bmatrix} LA & LF & 0 \end{bmatrix} \tag{45}$$

$$rank \begin{bmatrix} L & 0 & 0 \\ C & G & 0 \\ CA & CF & G \\ LA & LF & 0 \end{bmatrix} = rank \begin{bmatrix} L & 0 & 0 \\ C & G & 0 \\ CA & CF & G \end{bmatrix} \tag{46}$$

Test the nonlinear power system is observable or not using below conditions [40]

$$\begin{bmatrix} N & K & E \end{bmatrix} = \sum_2 \sum_1^{+} - Z(I - \sum 1 \sum_1^{+}), \tag{47}$$

$$N = A - ZB \tag{48}$$

Z is a arbitary matrix

$$A = \sum_2 \sum_1^{+} \begin{bmatrix} I \\ 0 \\ 0 \end{bmatrix} \tag{49}$$

$$B = \left(I - \sum_1 \sum_1^{+}\right) \begin{bmatrix} I \\ 0 \\ 0 \end{bmatrix} \tag{50}$$

$$J = K + NE, \tag{51}$$

$$\mathrm{H} = (\mathrm{L} - \mathrm{EC})\mathrm{B} \tag{52}$$

J, H matrices obtained from N,

K and E matrices.

The optimal state feedback gains obtained from below equation.

$$\mathrm{Z} = P_O^{-1} Q^T \tag{53}$$

4 SIMULATION RESULTS

Their DISCOs in both control area-1 and control area-2 get their electricity through a deregulated power system configuration, which includes a thermal-wind-EV aggregator including a hydro-solar thermal-EV aggregator. Every DISCO requires 0.1puMW of electricity. In every control region, there are three GENCOs that make up the ACE participation factor (apf), while the simulation runs under the assumption of a bilateral contract. The DPM matrix used in the computational investigations.

$$\mathrm{DPM}=\begin{bmatrix} 0.1 & 0.2 & 0.0 & 0.2 \\ 0.1 & 0.0 & 0.4 & 0.2 \\ 0.2 & 0.2 & 0.1 & 0.3 \\ 0.4 & 0.2 & 0.2 & 0.2 \\ 0.0 & 0.3 & 0.1 & 0.1 \\ 0.2 & 0.1 & 0.2 & 0.1 \end{bmatrix}$$

apf_1 = **0.3**	apf_2 = **0.4**	$apf_3 = 0.3$
apf_4 = **0.3**	apf_5 = **0.4**	$apf_6 = 0.3$

The generation of each GENCO expressed as

$$\Delta P_{mi} = \sum\nolimits_{i}^{j} cpf_{ij}\, \Delta P_{Lj}$$

$\Delta P_1 = 0.1(0.1) + 0.2(0.1) + 0.0(0.1) + 0.2(0.1) = 0.05$ puMW
$\Delta P_2 = 0.1(0.1) + 0.0(0.1) + 0.4(0.1) + 0.2(0.1) = 0.07$ puMW
$\Delta P_3 = 0.2(0.1) + 0.2(0.1) + 0.1(0.1) + 0.3(0.1) = 0.08$ puMW
$\Delta P_4 = 0.4(0.1) + 0.2(0.1) + 0.2(0.1) + 0.2(0.1) = 0.08$ puMW
$\Delta P_5 = 0.0(0.1) + 0.3(0.1) + 0.1(0.1) + 0.1(0.1) = 0.05$ puMW
$\Delta P_6 = 0.2(0.1) + 0.1(0.1) + 0.2(0.1) + 0.1(0.1) = 0.06$ puMW

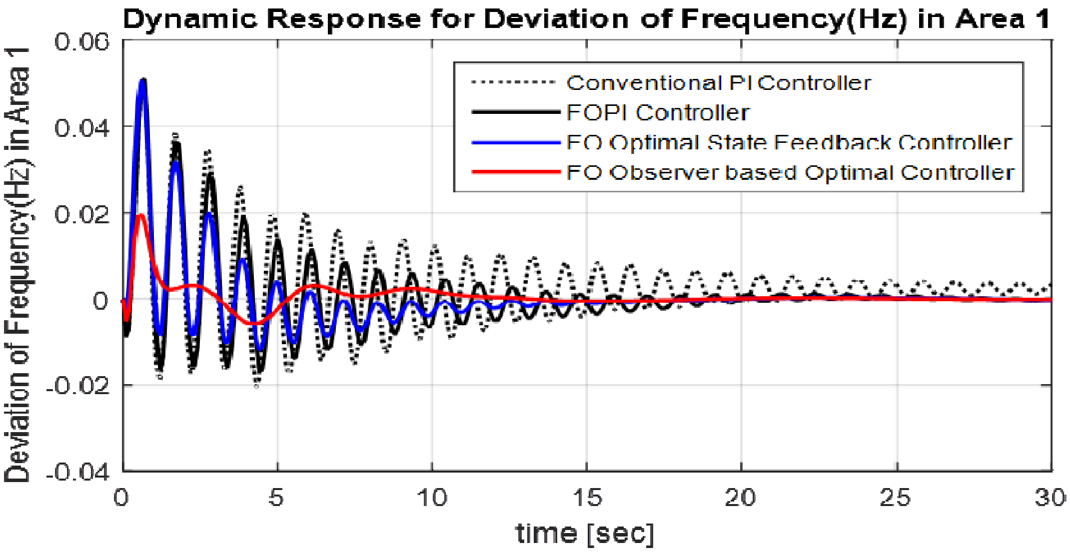

Fig-7: Frequency deviation of control area-1.

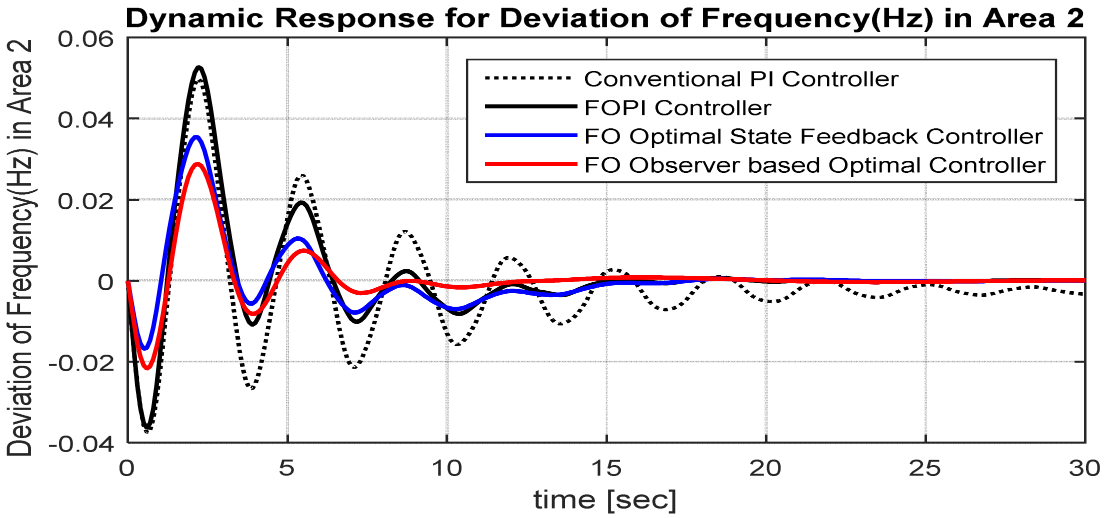

Fig-8: Frequency deviation of control area-2.

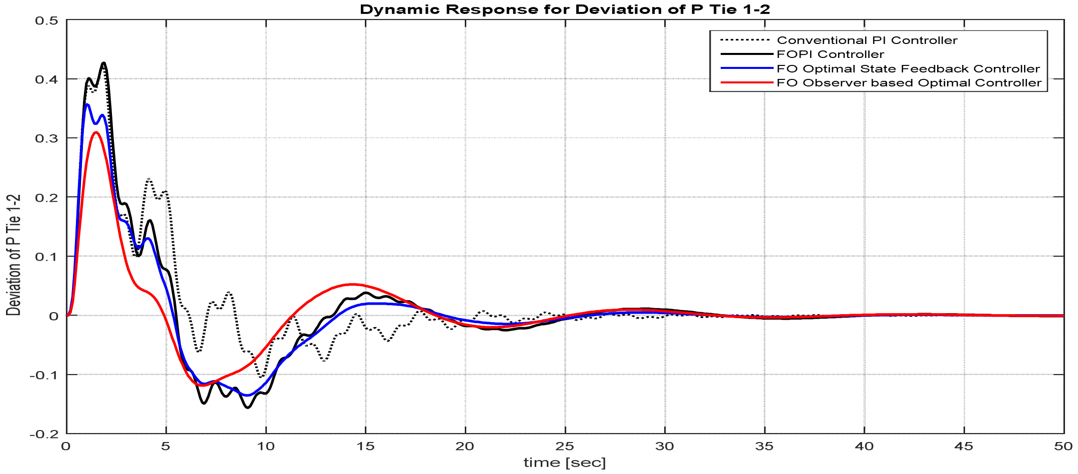

Fig-9: Tie line power flow deviation of control area-1&2.

Table-I: Dynamic Response of multi area power system Smart Deregulated Power System

Controller	**% of overshoot $-\Delta f_1$**	**% of overshoot -Δf_2**	**Settling time Δf_1(Sec)**	**Settling time Δf_2(Sec)**
Without any controller	38	24	Morethan 30	More than 30
FOPI	35	20	21	18
FOOSFC	30	15	15	15
FROOSFC	03	13	13	12.5

5 CONCLUSION

This study examines a two-area smart power system operating in a deregulated setting (SDPS). Within a bilateral contract scenario, this SDPS was evaluated and simulated using a fractional order

PI, a fractional order optimum state feedback controller, and an optimal controller determined by fractional order observers. In comparison to fractional order PI along with fractional order optimal state feedback controller, simulation results indicate that the dynamical performance of SDPS frequency deviations using a fractional order observer oriented optimum state feedback controller seems fairly excellent.

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