A Multi Degree of Freedom Based Hybrid Fractional Order Controllers for Load Frequency Control in Hybrid Systems

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Abstract. In isolated and linked power systems, load frequency control (LFC) is critical in delivering high-quality power. The LFC must be resilient to the system's parameter uncertainties and have a strong disturbance elimination capacity to maintain high-quality power. In the presence of wind Power generation and a dynamic Model of Electric vehicles, this study offers a unique load frequency control (LFC) approach for an integrated two-area thermal power system. To regulate the power outputs of the Thermal, wind generators, and EV, a Multi-degree of flexibility (MDOF)-based Fractional order controller named MDOF-control by hybrid is created as a supplementary controller in LFC. The suggested controller's dynamic pursuance is also assessed. This paper describes a hybrid controller composed of a fractional order controller and a tilt-integral-derivative controller. Under various circumstances, the suggested MDOF-Hybrid controller's dynamic effects as the LFC's intermediate controller are contrasted to that of the PID, FOPID, and FOTID controllers. A susceptibility evaluation is also performed to demonstrate the suggested controller's resilience in the face of parameter variations. Simulation investigations on a two-area system are conducted to assess the benefits of the proposed LFC design. To examine the controllers, different results are shown, including area frequencies, tie-line power flow, and Tie line Frequencies. The findings show that the suggested LFC system outperforms others in dynamic efficiency.

Keywords: Multi-degree of flexibility (MDOF) · IOC (Integral order control) · FOC (Fractional order control · TID (Tilt angle Derivative) · EV (Electric Vehicle) · Real Boundary (RB) · Complex Boundary (CB) · TPP (Thermal Power plant)

1 Introduction

The intricacy of power systems is rising as a result of i) increased integration of renewable energy, (ii) adoption of new technologies such as smart grids, and (iii) automation of power system control relying on insecure communication technologies. The above causes directly affect power system functioning, stability, and safety. Because of its significance, frequency regulation in power systems has recently gotten much attention Towards LFC.

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Load frequency management is a technique that effectively researches the fluctuation of power output versus load profile by focusing on a linked power system of two areas. The three frequency management levels are referred to as fundamental, auxiliary, and tertiary regulation levels. The fundamental frequency loop is in charge of detecting frequency declines well before frequency protective relays are triggered. The governor droop is commonly used for primary frequency regulation, resulting in consistently reported errors. Secondary frequency control, also known as load frequency control (LFC), regulates the frequency in power systems with two objectives: i) Limiting the frequency to an acceptable limit; and (ii) governing the interconnect power through significant tie-lines between the various control regions [1–4]. After a severe disruption, the primary responsibility of the tertiary control level is to re-dispatch generating units and auxiliary reserves.

Recently, some control strategies centred on computational inertia management have been introduced to optimize Grid frequency stability [5–8]. [5] Recommends using a derivative controller-based immersive inertia to improve the frequency consistency of the linked grid [6, 7] proposes a fuzzy controller for implementing a virtual inertial control to maintain Grid frequency stability. In [8], a reliable H-infinity approach built on virtual momentum is provided for analysing frequency stability when the EVs are at a reasonable degree. To offset the high infiltration level of EVs in Grid [9], proposes a predictive control (PC) for a virtualized inertial controlled system.

In [10], virtual inertia-based control increases system stability by piercing strong wind power via a technique of predicting frequency sensitivity. Because of its numerous advantages, such as cheap cost and flexibility, PID or PI controller is regarded as among the most frequent forms of frequency control research [11]. Furthermore, due to interruptions or changes in system characteristics, it has failed to deliver dependable results (system uncertainties). Several control techniques for LFC have previously been proposed, notably fuzzy control [12, 13], Multi degree-of-freedom (MDOF) control [14–17], FOCs [18, 19], inner model control [11], sliding mode control [20], and predictive control (PC). The Fuzzy controller is designed for a certain system situation and may lack efficacy in other settings. In terms of strong efficacy in predefined monitoring and adjusting in the face of disruption inputs, MDOF controllers outperform traditional 1-DOF controllers.

This research offers a unique MDOF-based Hybrid controller for EV-WT-integrated Two-area power systems that combines the benefits of TID and FOPID controllers. Furthermore, this work aims to investigate the aforementioned relationship in linked power systems.

2 System Description

The schematic diagram and transfer function model of a grid-Integrated system are shown in Figs. 1 and 2 which includes traditional thermal power plants, scattered generation such as wind power plants, EVs, and ramped loads. In conventional energy networks, frequency regulation is mainly determined by generated power and consumption equivalency. If an imbalance arises, frequency control may be accomplished in three methods. The first is the primary control, which achieves frequency control by varying the speed

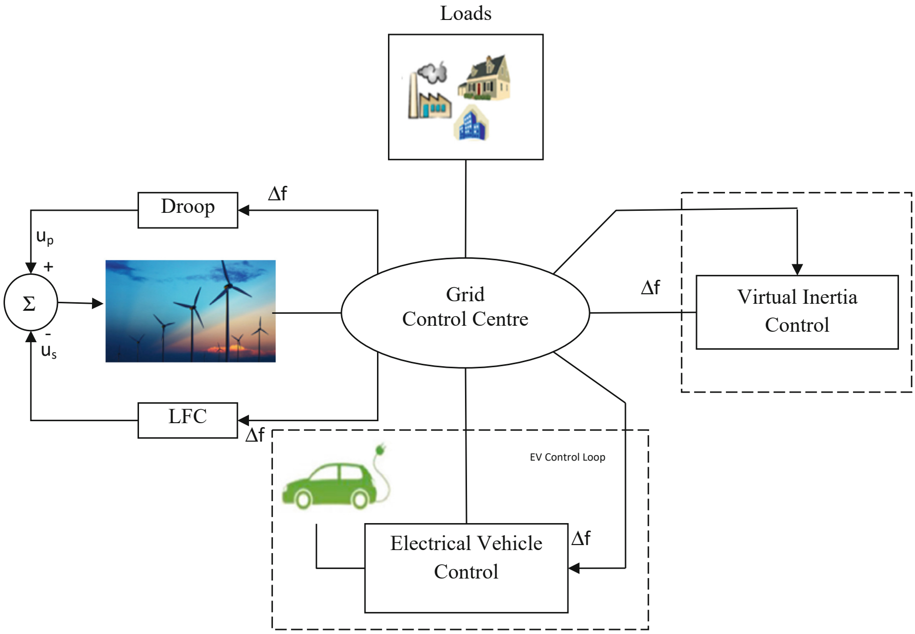


Fig. 1. Schematic Diagram of proposed controller

regulation constant. In secondary control, auxiliary controllers are used to stabilizing the frequency. In inertia control, the inertia provided by the synchronous generator is used to adjust the speed in response to changes in power demand. This clearly describes the distributed generating systems that are involved in standard grid connection.

3 Design of Multi-Degree of Flexibility (MDOF)-Based Fractional Order Hybrid Controller

FOPID and TID controllers offer greater levels of freedom and versatility than IOCs. As a result, they can increase the efficacy of integrated control systems with a wide variety of dynamics. It was found that FOCs outperform IOCs in terms of boosting dynamic stability. The FOPID, TID, and PID controllers' transfer functions are expressed as follows.

$$PID = k_p + \frac{k_I}{s} + k_d s$$

$$PI^{\lambda}D^{\mu} = k_p + \frac{k_I}{s^{\lambda}} + k_d s^{\mu} \tag{1}$$

$$TID(s) = K_T s^{(-1/n)} + \frac{K_I}{s} + K_D s$$

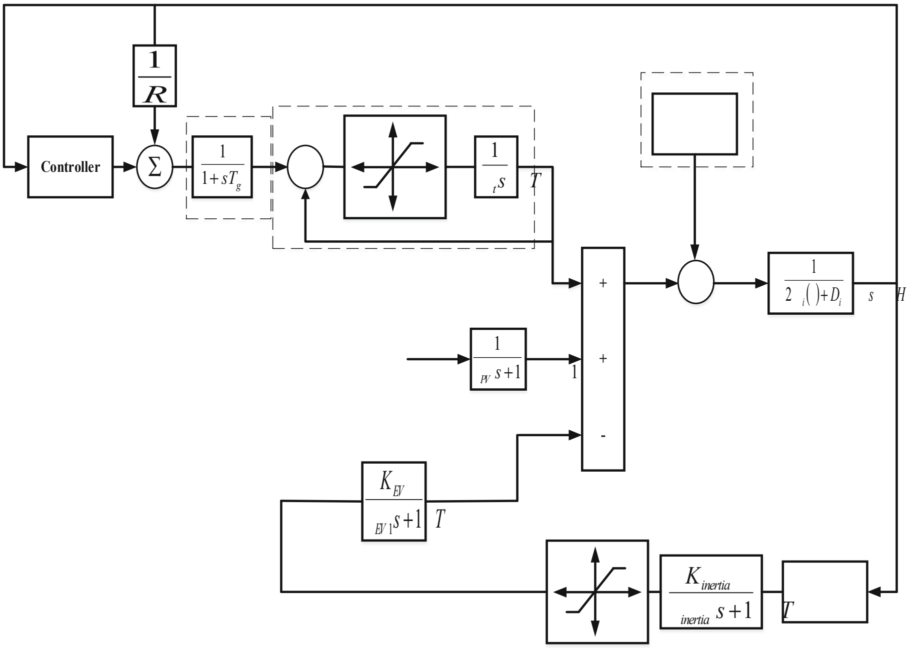


Fig. 2. Transfer Function Model of proposed System

where K_p, K_I, K_d, and K_t are the proportional, integral, derivative, and tilt variables, Gains. The fractional-order operators vary in the range of (0, 1). Also, n is the TID controller's fractional-order operator, which is usually set between 2 and 3 before optimizing other coefficients

DOF is the autonomous adjustment of the amount of closed-loop transfer functions in a control system. Compared to 1DOF-based controllers, control systems that rely on MDOF provide benefits such as versatility in achieving high efficacy in predefined surveillance and correction in the context of disturbance inputs [11, 12]. In Fig. 3, r(s) symbolizes the input reference signal, y(s) represents feedback from the evaluated system output, U(s) defines the output signal, f(s) operates as a pre-filter on the r(s), d(s) denotes the load perturbation, and c(s) defines the 1-DOF controller. The MDOF-based controller provides an output signal, which is the difference between a reference signal and a measured signal, as illustrated in Fig. 3 the mathematical equation governing the closed-loop of the MDOF control system is written as

$$u(s) = C_r(s)r(s) - C_y(s)y(s) \tag{2}$$

where $C_r(s) = K_C\left[\beta + \frac{1}{T_i s}\right]$ predefined controller transfer function

$$C_y(s) = K_C\left[1 + \frac{1}{T_i s} + T_d s\right] \tag{3}$$

Is Feed Back controller transfer function.

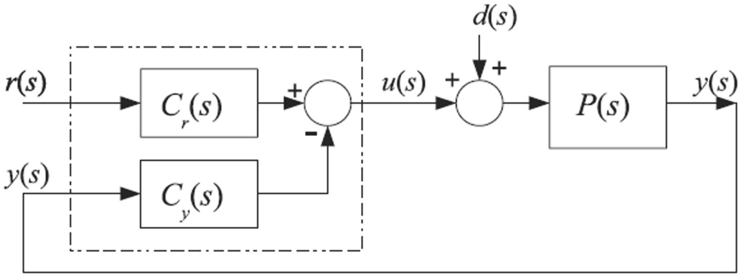


Fig. 3. MDOF-based Hybrid Controller

This controller creates a balanced difference signal for each proportional, integral, and derivative term based on the preset point values. The controller output is the total of the proportional, integral, and derivative actions on the appropriate difference signals. Each action is weighted based on the gain settings used. Using FOCs based on MDOF as auxiliary frequency controllers of the power system has a practical effect on increasing the power system frequency performance, corresponding to the preceding formulations.

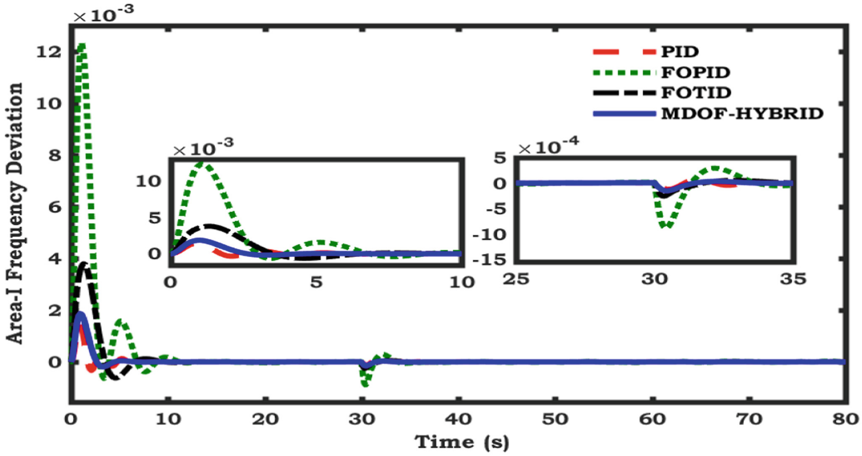
4 Results and Discussion

MATLAB/Simulink is used to execute time-domain simulations and parametric perturbations under high infiltration of RESs, EVs, and loads. The suggested MDOF-Hybrid controller is compared with the PID, FOPID & FOTID controllers to determine its efficiency. With the help of petite signal modeling, the designer can consider modeling mistakes and desired performance, as well as disturbance rejection and reference tracking against system variation and modeling errors. To evaluate the dynamic efficacy of the suggested controller within the AGC loop, a connected two-area power system with TPP, wind farm, and electric vehicle can be investigated.

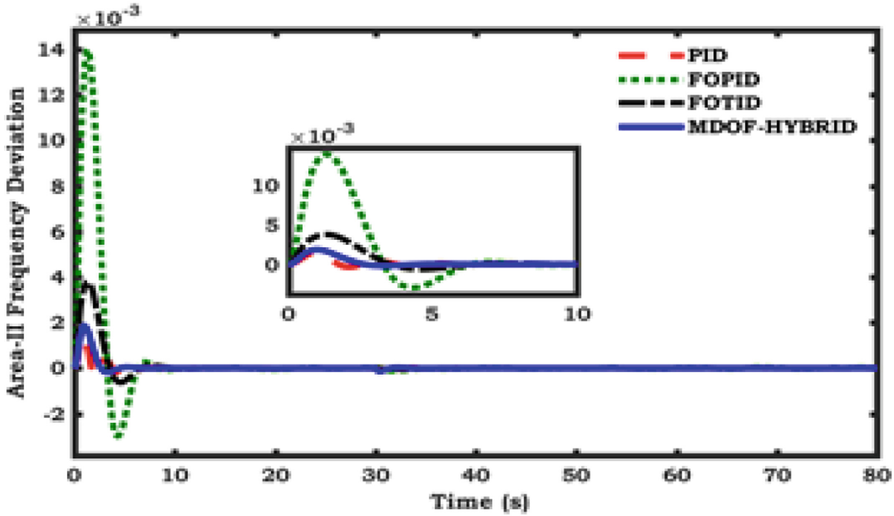
Case: I Two Area System with Wind power Source & Electric Vehicle (Controlled case with all Proposed Controllers)

The load frequency control in this scenario involves two-area system with a wind turbine and an electric Vehicle. The EV model provided in this paper is a virtual inertia-based electric vehicle model, in which the virtual inertia is estimated from the TPP model. The results obtained in this situation, as shown in Fig. 4, clearly demonstrate the MDOF hybrid controller's strong dynamic effectiveness in terms of time domain indices. Table 1 lists all of the controllers' specifications, allowing us to conclude that MDOF hybrid controller provides better settling time, overshoot, and peak number.

Case: II Two Area System with 50% Increase in Turbine Time Constant (T_T)
The sensitivity of MDOF hybrid controller towards uncertainties in parameters of power system is considered in this case. Specifically the turbine constant T_t was considered as 0.4s in the regular model but to create perturbation the turbine time constant is increased by 50% of its original value. Theoretically when turbine time constant is increased then



(a)



(b)

Fig. 4. **(a)** Area-I Frequency deviation **(b)** Area-II Frequency Deviation

it will reflect in the speed of generator in thermal power plant which directly affects the system frequency, but the proposed robust MDOF hybrid controller gains are designed based on the integral error methods is effectively damping out the frequency oscillations, which can be observed from Fig. 5, it is evident that the settling time, peak overshot and number of peaks are very less under ambiguity in turbine time constant, which can be also observed from the Table 2.

Table 1 .

Controller	Signal	T_S	M_p %		No. of Peaks
			+ve	−ve	
PID	Δf1	20	0.556	7.21	3
	Δf_2	20	0.556	7.23	3
	ΔP_{12}	20	1	2.0	3
FOPID	Δf_1	12	0.575	1.99	2
	Δf_2	12	0.575	1.8	2
	ΔP_{12}	12	0.521	2	2
FOTID	Δf_1	7	0.5	1.2	2
	Δf_2	7	0.52	2	2
	ΔP_{12}	7	0.51	1.9	2
MDOF-HYBRID	Δf_1	5	0.32	1.1	2
	Δf_2	5	0.41	0.9	2
	ΔP_{12}	5	0.41	1.6	2

Case: III Two Area System with 50% Decrease in Governor Constant (T_G)
In this case there is a reduction of governor time constant by 50% which proportionately effect the system frequency, from Fig. 6 area 1 frequency is reaching to steady state with in very less when compared to other controllers. However, the overshoot, undershoot and number of peaks obtained are very less with MDOF Hybrid controller which can be observed from the below Figures (Table 3).

Case: IV Two Area System with 50% Decrease in Governor Constant (T_G)
In this case there is a reduction of governor time constant by 50% which proportionately effect the system frequency, from the Fig. 7 area 1 frequency is reaching to steady state with in very less when compared to other controllers. However, the overshoot, undershoot and number of peaks obtained are very less with MDOF Hybrid controller which can be observed from the above Figures.

Case: V Two Area System with Change in Turbine Synchronizing Power Coefficient (T_{12})
Synchronizing power coefficient plays important role in stabilizing the frequency under variation in the load demand but in this case we have made an attempt to increase T_{12} by 50%. As MDOF Hybrid controller response been recorded in Fig. 8 which directly says frequency is stabilized very rapidly with less settling time overshoot, number of peaks with respect to other controller.

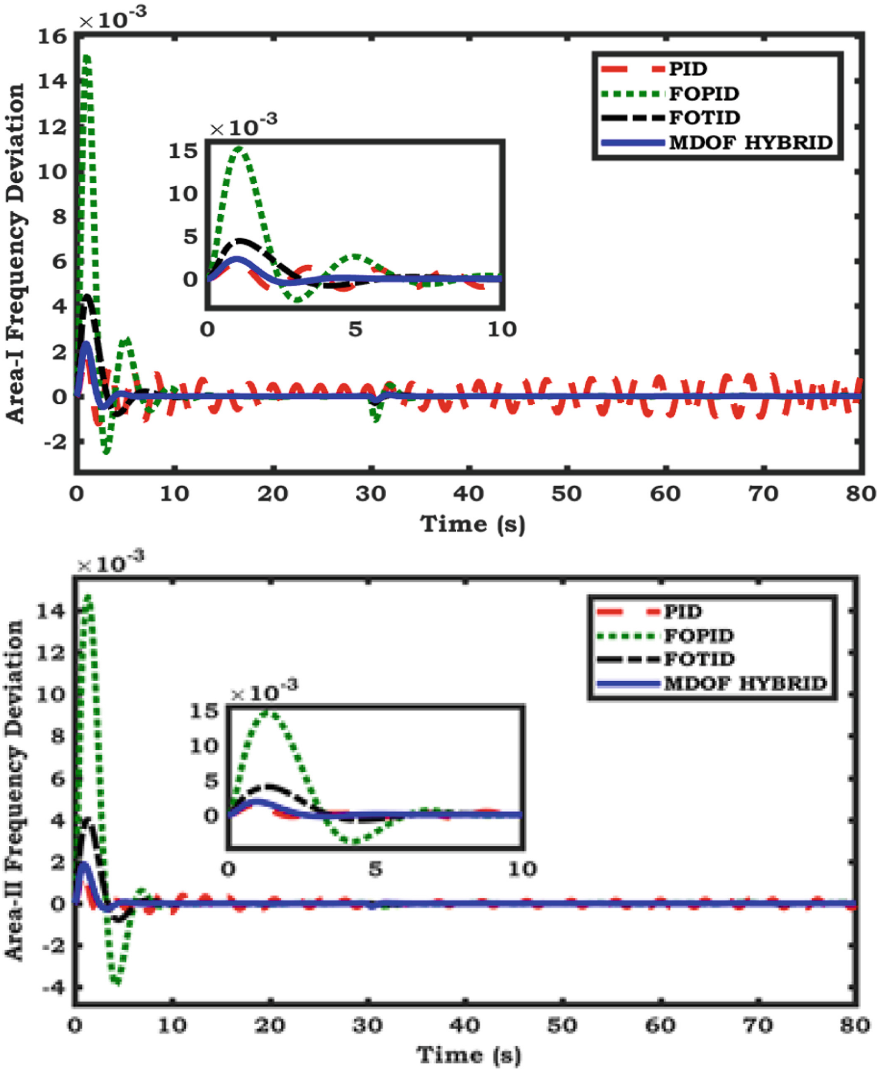


Fig. 5. Frequency deviation of Area-1 & Area-2

Table 2 .

Controller	Signal	T_S	M_p %		No. of Peaks
			+ve	**−ve**	
PID	$\Delta f1$	22.7	0.595	27.91	3
	Δf_2	22.7	0.556	13.67	3
	ΔP_{12}	22.7	116.8	1.98	3
FOPID	Δf_1	10.2	0.581	2.38	2
	Δf_2	10.2	0.581	2.38	2
	ΔP_{12}	12.2	0.515	2	2
FOTID	Δf_1	8	0.575	2.5	2
	Δf_2	8	0.575	2.5	2
	ΔP_{12}	8	0.515	1.99	2
MDOF Hybrid	Δf_1	4	0.32	1.4	2
	Δf_2	4	0.32	1.4	2
	ΔP_{12}	4	0.4	1.2	2

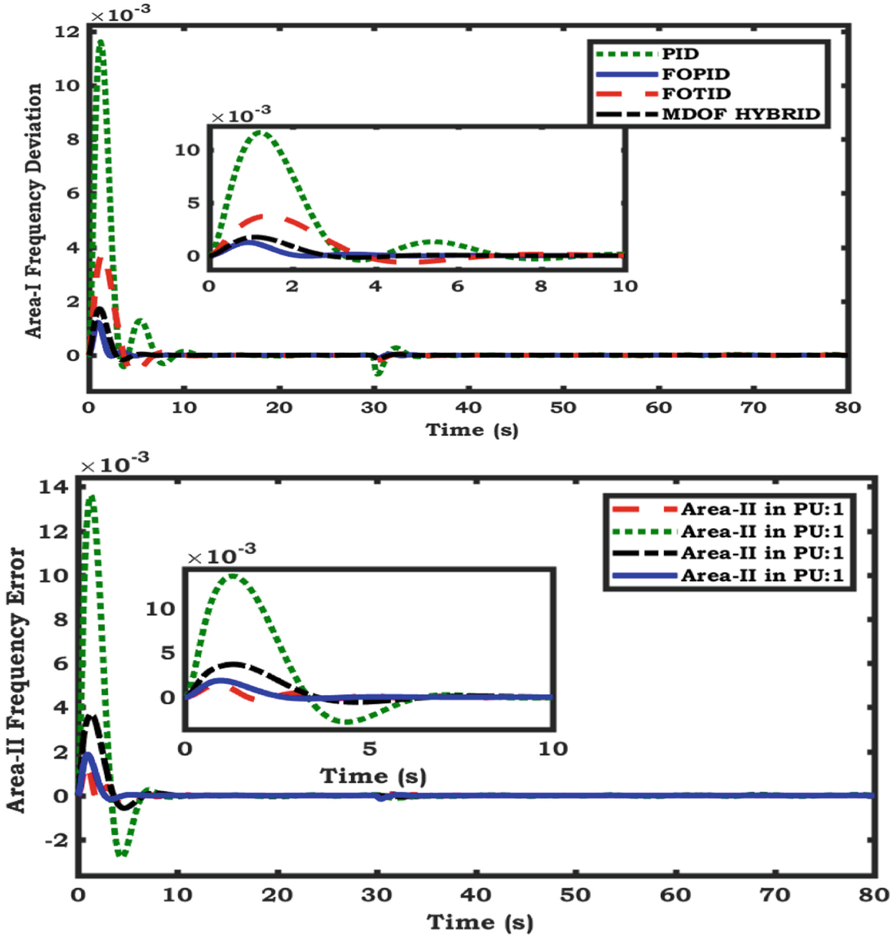


Fig. 6. Frequency deviation of Area-1 & Area-II

Table 3 .

Controller	Signal	T_S	M_p %		No. of Peaks
			+ve	−ve	
PID	Δf1	14	0.505	2	3
	Δf_2	14	0.505	2	3
	ΔP_{12}	14	0.505	2	3
FOPID	Δf_1	10	0.52	2.2	2
	Δf_2	10	0.52	2.2	2
	ΔP_{12}	10	0.54	2.4	2
FOTID	Δf_1	9	0.562	2	2
	Δf_2	9	0.562	2	2
	ΔP_{12}	9	0.521	2	2
FOTID	Δf_1	4	0.45	1.1	2
	Δf_2	4	0.45	1.1	2
	ΔP_{12}	4	0.5	1.5	2

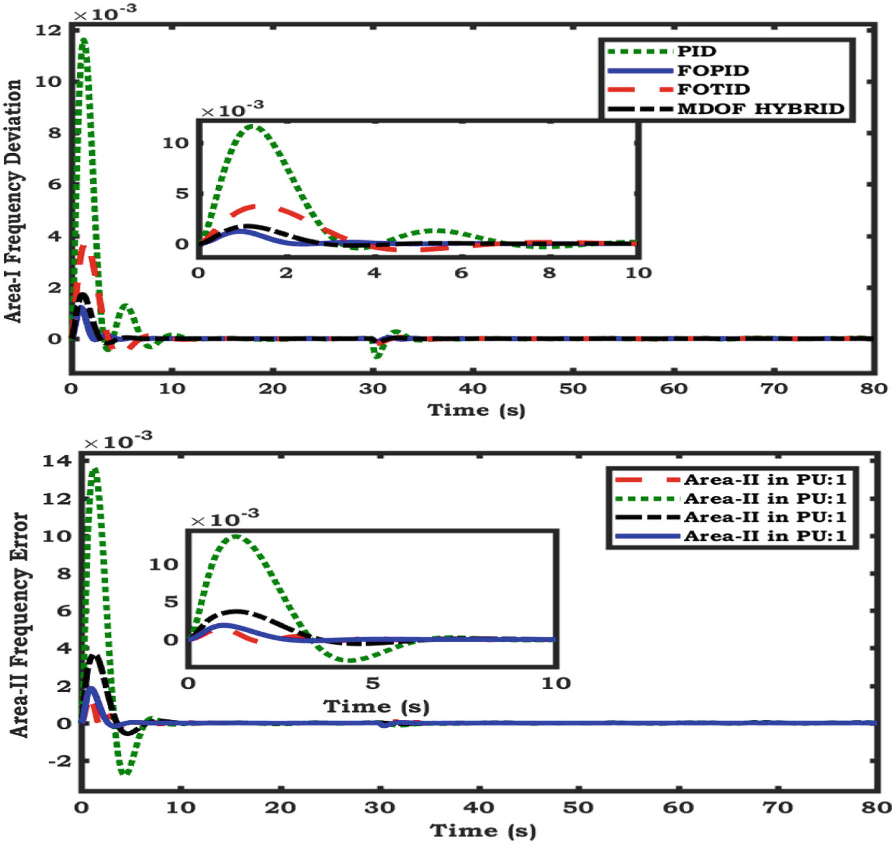


Fig. 7. Frequency deviation of Area-1 & Area-II

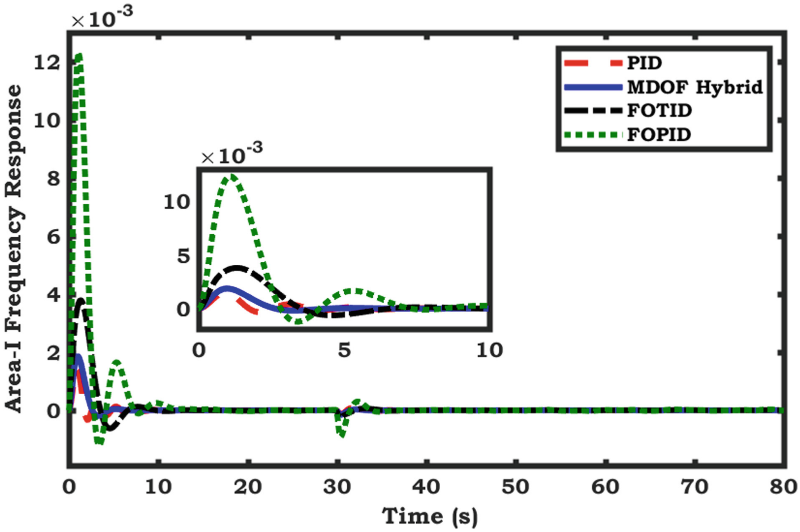


Fig. 8. Tie Line power in pu, MW

5 Conclusion

With the ever-growing demands of electrical energy, there is a great need to have an efficient LFC system that can handle the system parameter ambiguity. A Load Frequency Control design technique based on the concept of fractional order control has been provided in this study. The FOPID controller's resilience against parametric unpredictability has also been assessed. Finally, the suggested approach's performance is compared to that of the newly proposed MDOF-Hybrid controller. The performance of the MDOF-Hybrid controller is significantly superior to that of fractional order and integral order 1DOF controllers in settling time, overshoot, and oscillations in frequency. The findings also reveal that the suggested MDOF Hybrid controller has a strong capacity for disturbance rejection and handling parametric uncertainty, making it well suited to the LFC problem. The results of several controls are listed for easy reference. According to all tabular statistics, the MDOF Hybrid controller performs admirably in dynamic situations. With all controllers, the susceptibility of the controller to parameter uncertainty such as (Turbine time constant (Tt), Governor time constant (Tg), and synchronizing power coefficient) is examined. Finally, with precise inspection, the MDOF Hybrid controller provides efficient execution with a complex model.

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