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Dual-area power system fractional tri-parametric controller

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***Abstract*— This paper develops a three-parameter simple fractional-order controller to manage load frequency in a multi-area interconnected multisource power system (PS). The novel suggested controller has only three parameters to tune, like the classical PID structure. The suggested controller is tested in a two-area interconnected PS with thermal, gas, and hydraulic power plants and renewables (wind and solar power). The new controller's effectiveness is proven by comparing its performance to fractional-order proportional-integral controllers and tilted integral derivative controllers from the recent literature. The numerical findings show that the proposed controller considerably enhances system frequency stability under diverse load variations, uncertainties, fundamental limits, propagation delay, and high renewable energy source access.**

Keywords—Fractional-order controller, load frequency, two-area power system, nonlinearity.

I. Introduction

The electric grid industry is currently focused on energy with smaller carbon footprints as a result of the depletion of fossil resources. It has become crucial to implement renewable energy sources (RES). Due to load variability and the use of RESs to reduce typical power plant limitations, PSs are becoming more complicated. Wind and solar-type resources are in very high demand nowadays, affecting a system's inertia and stability. The growth of renewable energy sources and demand load and production imbalance present new difficulties to the current power grid. Additionally, these issues threaten electrical grid stability and security. Therefore, frequency control is essential to sustain grid frequency under normal and abnormal operating situations and govern power flow between PS sectors. Having found a solution for the stability in frequency and power in the whole grid system. The researchers have applied the technique to certain PSs and, further to that have improved the technique. The frequency stability issue has been addressed for different PS topologies, including two-area interconnected [1], single-area [3], multi-area [4], deregulated [5], [6], and complex interconnected areas with non-linearities [7], [8]. Also used are linear quadratic Gaussian approaches [9], model predictive control [10], fuzzy logic control [11], and artificial intelligence-aided PID [12]. Due to its benefits, researchers have focused on PID [13]. (i.e., it is easy to construct and reasonably priced). Choosing a PID controller by trial-n-error in the incidence of system flaws and non-linearities is difficult. As a result, significant work has gone into choosing the PID controller's ideal parameters. This has been achieved through different optimization algorithms developed due to the fact that not only one type of controller is suitable for many types of PSs. The drive has been shifted to deviate from conventional PID-based controllers. However, non-integer controller is growing rapidly due to their flexibility and freedom. Because it contains more poles, including hyper-damped poles, it gives more factors to alter. As a result, the stability region has grown, which gives more freedom when developing controllers. Consequently, academics are very interested in real-order controllers (ROCs). The ROCs have been applied in many PSs [14], [15], [16].

LFC now uses a tilting integrated controller. A two-area linked hybrid PS's LFC was controlled using a tilted integral derivative (TID) and ID-T controller structure [1]. It compared ID-T and TID controller efficiency to PID and FOPID controllers. The controller structure was assessed by a two-area hybrid PS with thermal, hydraulic, and gas power plants. IDT frequency control improved significantly under heavy load changes and parameters' modifications. Additionally, [17] saw numerous controller structures being implemented. The paper investigates PI, PID, PIDN, 2DOF/3DOF-PID, and TID controller architecture. The two connected-TID controller regulation with mix system is analysed in [17]. The different perturbation tests with load changes confirmed efficacy. Research focuses on simple, effective, and cost-efficient control structures. More research is integrating fractional order into control frameworks. Normal PID is most widely used. However, they are inefficient under these conditions. Advanced control methods like sliding mode controllers [18] and fuzzy decision [19], [20], [21] can address nonlinearities. Such systems are sometimes impractical and prone to chattering or complex tuning stages. Fractional calculus theory may develop a simple and robust method for classical PID. The real-order derivative and integral particular enhance heredity and memory systems. Fractional order systems have successfully implemented some control mechanisms [22] [23]. [24] analyses the design of a FOPID for AVR application for power system. There are better control components and tuning versatility. Overall, research shows that FOPID controller structure improves control techniques. FOPID can have differences from PID. 2DOF FOPI(D) was recently introduced for AVR [25]. FOPID is thoroughly explained in [26] and [27] for the LFC.

We seek to construct a primary yet effective multi-area PS LFC controller from the above works. The PS under consideration is integrated and uses thermal-gas-hydro units. This approach is practical since it accounts for uncertainties and non-linearity. The novel suggested structure has only three parameters to tweak [28], yet it performed better than recently investigated FOPID and TID fractional controllers for the same system.

II. MOTIVATIONS

Previous research has found that controller-expert-dependent LFC methods like H∞, MPC, and fuzzy can provide the necessary output. However, they also suffer from realization problems and demand much effort spent selecting control parameters. When it comes to handling system uncertainties, conventional PI and PID controllers have their own set of challenges. Previous publications mostly ignored important aspects of robustness analysis, such as the effects of system parameter fluctuations, nonlinearities, and flaws. Furthermore, the presence of system parameter fluctuations was not considered in most of the prior investigations. In light of these findings, this paper suggests a new structure $\mathrm{FOI}^{\lambda}\,\mathrm{D}^{1-\lambda}$controller in order to improve the frequency stability of the system while accounting for its integral uncertainties, nonlinearities, and numerous load perturbations. In addition the suggested $\mathrm{FOI}^{\lambda}\,\mathrm{D}^{1-\lambda}$ controller's characteristics have been chosen in light of the dual performance measures in order to preserve both frequency and overall plant stability in irregular circumstances.

Finally, the critical goals of the paper are listed below.

- Simple three-parameter type, namely $\mathrm{FOI}^{\lambda}\,\mathrm{D}^{1-\lambda}$ controller proposed instead of five parameter FOPID structure.
- $\mathrm{FOI}^{\lambda}\,\mathrm{D}^{1-\lambda}$ is simple to tune and improved than FOPID, TID and PID type structures.
- A dual-performance index is adopted in the optimization process.
- Effectiveness of the presented method is shown on the recent techniques with FOPID and TID.
- The suggested $FOI^{\lambda}\,D^{1-\lambda}$ is also poven better with system nonlinearities, uncertainties, and load fluctuations.

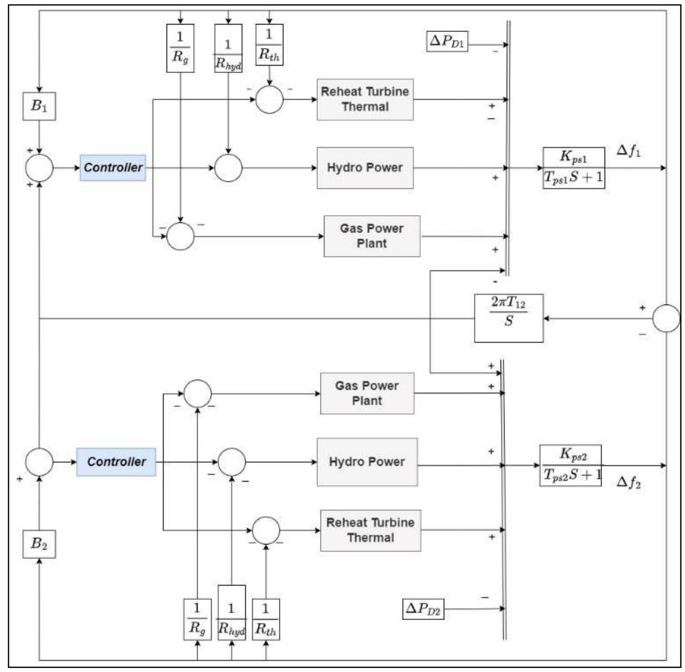

Fig. 1. Two-area multi-source PS under study

III. SYSTEM MODEL

The dual area linked mix power model is shown in Fig. 1. It has a reheat thermal turbine, hydro-power, and gas units in individual controlling areas. A similar system was studied in [1]. This system generates 1000 MW from thermal plant, 240 MW from gas and 500 MW from hydroelectric plant. Thus, 2000 MW is setup in production and 1740 MW nominal load. Note that nonlinearity in the system was 10% pu/minute, meaning a value of 0.0017 puMW/s as restricted by GRC. Same way, other nonlinearity values are 0.045 puMW/s and 0.06 puMW/s.

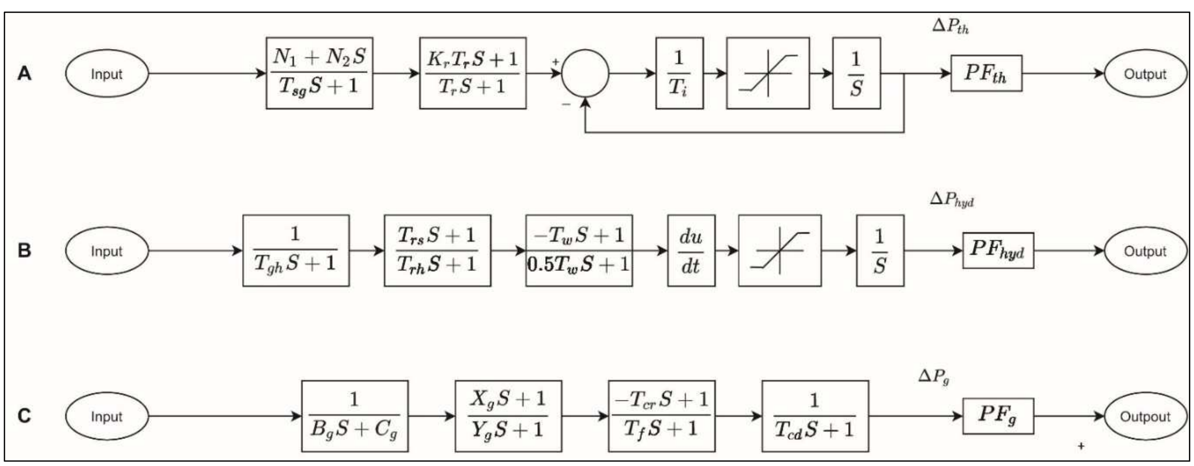

Fig. 2. Various areas as per plant stuided. (A): Reheat thermal, (B) Hydro and (C) Gas units

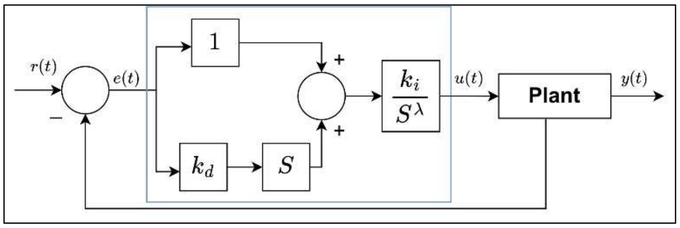

Fig. 3. $FOI^{\lambda} D^{1-\lambda}$ structure

GDB non-linearity equations are linearised for speed variation. The GDB model with 0.5% backlash is written as,

$$\frac{N_1 + N_2 s}{T_{sg} s + 1} \quad (1)$$

where $N_1 = 0.8$ and $N_2 = -0.2/\pi$. The individual system model is provided in Fig. 2.

IV. CONTROL METHODOLOGY AND PROBLEM FORMULATION

A new tri-parametric $FOI^{\lambda} D^{1-\lambda}$ controller is,

$$C(s) = \frac{k_i\,(1 + k_d s)}{s^{\lambda}} \quad (1)$$

where $\lambda \in (0, 1)$, and $(k_i\ , k_d)$ are controller gains. The structure can be visualized as in Fig. 3. Note that the large value λ may produce instability.

Interestingly, $FOI^{\lambda} D^{1-\lambda}$ structure is dual characteristics, as PD plus PI controller. Since λ is between 0 and 1, the controller acts between PD and PI behaviour. To compare with other fractional controllers (with more parameters), TID and FOPID controllers are used, those applied in [1]. Their structures can be visualised as Figs. 4 and 5, respectively. It is to clarify that TID is a sort of nonlinear controller that uses a P as tilted.

V. OPTIMAL FINDING OF PARAMETERS

To estimate the best controller values, a modified constraint whale optimization algorithm (cWOA) is used in this study [20]. The core algorithm is simulated in MATLAB® , and its main steps are provided using the simplified pseudo-code in Table I. In this optimization, a humpback whale discovers the position of the target and encircles around it. At this stage, the position of the optimal solution in the search space is uncertain; accordingly, cWOA algorithm the solution targets near to the optimal values. While the remaining search agents will try to modify their placements to the best results as per fitness value, computed as below.

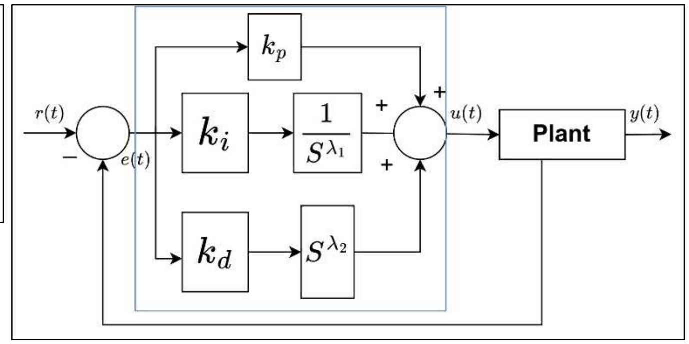

Fig. 4. $FOPID$ structure

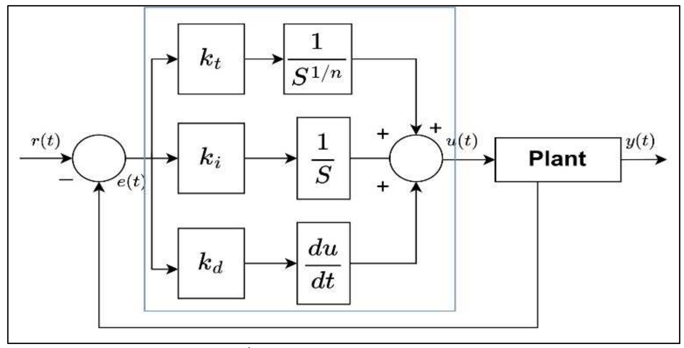

Fig. 5. TID structure

TABLE I. THE PSEUDO CODE FOR CONSTRAINT WOA (CWOA)

Initialize the whale's population
Set algorithm parameters
Set performance index
Calculate the fitness of all search agent
While (termination criteria not satisfied)
Encircle prey
Bubble net hunt
Search the prey
Compute the fitness value
End While
Return the best result
End

VI. PERFORMANCE INDEX

After installing the FO in the PI controller, the optimal parameter values must be determined. The target function should be such that the ideal parameter values produce a quick reaction, quicker settling time, and least overshoot for LFC in a two-area PS. Maintenance is expensive to counteract real-life situations of delayed performance and interruptions. Excessive PS operation may cause valve or actuator movement to wear or damage mechanical parts like springs or links [18]. Checking controller output variances during setting improvements is crucial. Dual performance measurements are used when cWOA calculates controller parameters. In this study, the $FOI^{\lambda} D^{1-\lambda}$ controller is created by minimising ISTE criteria. ISTE index findings are typically promising. We specify this index below for a suitable step reaction.

$$J_{ISTE(\eta)} = \int_0^{\infty} (t_e(\eta, t)^2)\,dt \quad (3)$$

where η is required to estimate. We add another condition to reduce the control input. The index is analytically as follows.

$$J_u = \min \eta \int_0^\infty \left|\frac{du}{du}\right| dt \quad (4)$$

We measure controller quality by smoothness, which reduces energy input and system maintenance costs. As per the two-area linked PSs in this study, the controller will be constructed to fulfil (3) and (4). Here are the new performance measurements for acquiring parameters.

$$J_{ISTE} = \min \eta * \int_0^\infty t((\Delta f_1)^2 + (\Delta f_2)^2 + (\Delta P_{tie})^2)dt \quad (4)$$

subject to $J_u = \min \eta * \int_0^\infty \left|\frac{du}{du}\right| dt$

where Δf and ΔP_{tie} are changes in frequency and tie-line power and η∗ is the selected settings from cWOA. The η∗ has k_{p1}, k_{t1}, k_{i1}, k_{d1}, λ_1, k_{p2}, k_{t2}, k_{i2}, k_{d2} and λ_2.

VII. VALIDATIONS

The system model is built in Simulink ® on a computer with an Intel core™ i7. The cWOA has 1 search agent and 50 iterations. These parameters are limited to -2 and 2. The controller parameters are the best solution from 50 optimization runs. The controller parameters are listed below.

To test the proposed method, various scenario is considering in the following subsection.

TABLE II. VARIOUS CONTROLLER FOR STUDIED SYSTEM

Settings	TID	FO-PID	$FOI^{\lambda} D^{1-\lambda}$
k_{t1}	0.1884	-	-
k_{p1}	-	0.760	-
k_{i1}	0.1200	1.860	-0.325
k_{d1}	-	1.990	-0.0288
λ_1	-	0.650	0.552
k_{t2}	0.1542	-	-
k_{p2}	-	0.041	-
k_{i2}	0.1130	-0.356	-1.012
k_{d2}	0.4990	1.648	-0.502
λ_2	-	0.400	0.452

A. Load Disturbance Approach – Scenario 1

A 1% demand increase is applied for Area 1. Figs. 6-8 show output responses. The comparison investigation shows that the offered technique outperforms fractional TID and FO-PID controllers. All techniques measure quantitative values in Table III. Both suggested structures have less overshoot, undershoot, and faster settling time than others.

TABLE III. SCENARIO 1 RESULTS

Schemes	Max overshoot (x 10^{-2})			Max undershoot (x 10^{-2})			Settlingtime s)		
	Δf_1	Δf_2	ΔP_{tie}	Δf_1	Δf_2	ΔP_{tie}	Δf_1	Δf_2	ΔP_{tie}
TID	1.612	1.740	0.016	-4.073	-5.186	-0.789	34.834	24.819	30.150
FOPID	0.989	0.933	0.103	-3.452	-3.323	-0.580	19.921	20.051	27.415
$FOI^{\lambda} D^{1-\lambda}$	0.052	0.624	0.382	-0.810	-1.688	-0.138	16.149	18.013	19.893

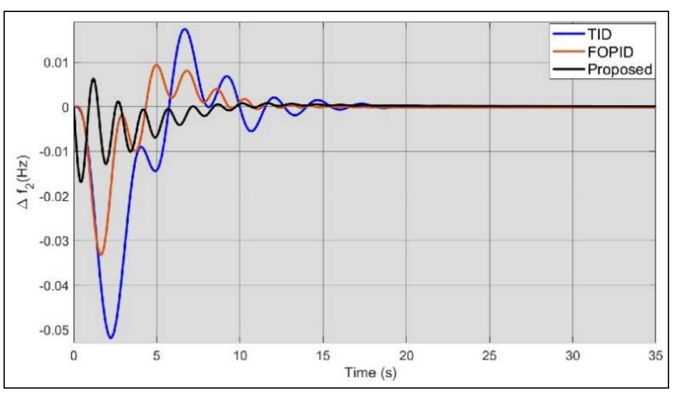

Fig. 6. A. Area One result

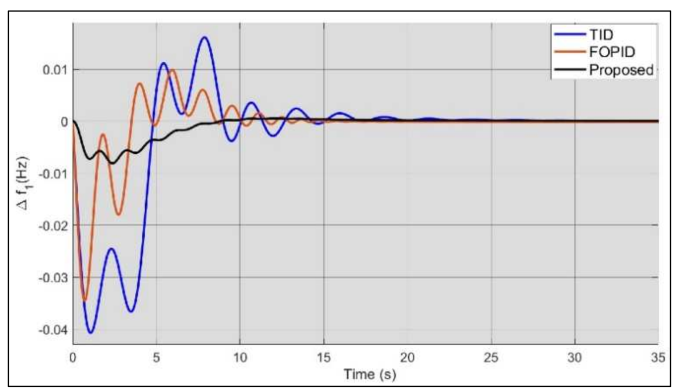

Fig. 7. A. Area two result

B. Parameter Perturbation Approach - Scenario 2

A step increase of one percent in Area 1's demand is used in conjunction with a reduction of 25 percent in the parameters. These parameters include the governor time constant, also known as T_g, the steam turbine reheat time constant, also known as T_r the hydro turbine time constant T_{gh}, and the gas turbine fuel time constant, also known as T_f. Figures 9–11 contain the output responses that were collected. The comparison analysis clearly shows that this strategy produced better outcomes than well-studied TID and FOPID controllers. It is worth mentioning that the approach outperforms FOPID, implying that this is superior to traditional PID.

TABLE IV. SCENARIO 2 RESULTS

Schemes	Max overshoot (x 10^{-2})			Max undershoot (x 10^{-2})			Settlingtime (s)		
	Δf_1	Δf_2	ΔP_{tie}	Δf_1	Δf_2	ΔP_{tie}	Δf_1	Δf_2	ΔP_{tie}
TID	0.069	0.797	-0.484	-4.449	-5.772	-0.768	N/A	N/A	N/A
FOPID	0.651	0.553	-0.007	-3.151	-2.893	-0.028	N/A	N/A	40.251
$FOI^{\lambda} D^{1-\lambda}$	**0.051**	**0.382**	**0.624**	**-0.810**	**-0.384**	**-1.688**	**17.623**	**11.250**	**30.193**

Table IV shows quantitative data from all techniques. Both suggested structures have less overshoot, undershoot, and faster settling time than others. Additionally, new structure is better.

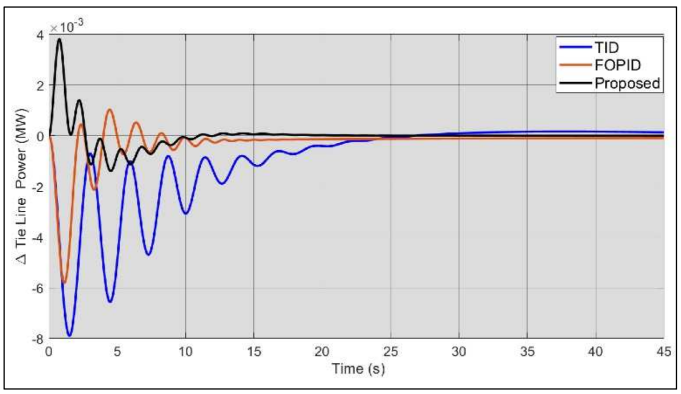

Fig. 8. A. Tie Line Power Change

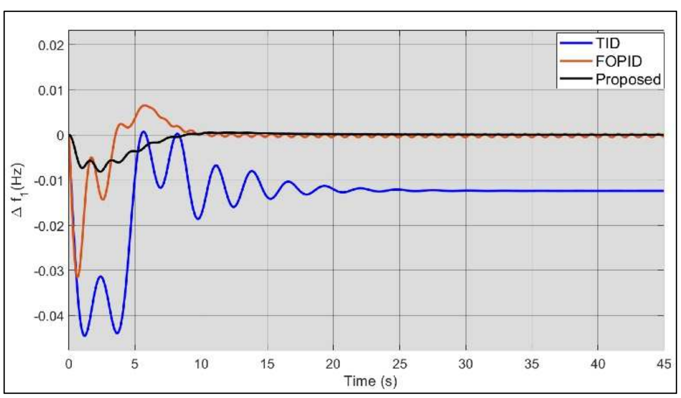

Fig. 9. B. Area one result

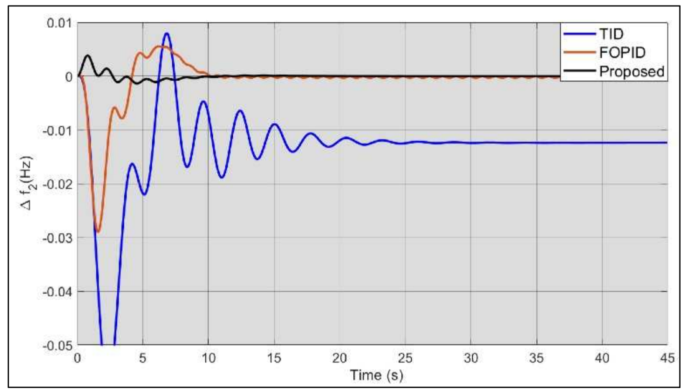

Fig. 10. B. Area Two result

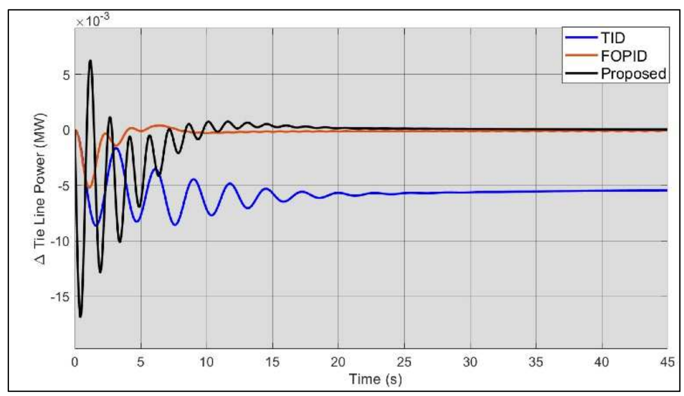

Fig. 11. B. Tie Line Power Change

VIII. CONCLUSIONS

A novel FOC type, $FOI^{\lambda}D^{(1-\lambda)}$, enhances power system performance in dual area power systems by reducing variationsa and instability due to demand changes. Due to its underutilization, a dynamic dual-area multisource plant was chosen. The WOA with ISTE performance criterion tunes the controllers. The fractional structure was better than other fractional structures like TID and FOPID, with less number of parameters. It provided the fastest settling time by 29%. Another practical consideration is frequency and power output response oscillations (over and undershoots). The strategy has reduced oscillations. Thus, fractional calculus and diverse architectures are good research areas for control systems and power systems. More investigations with various practical situations can be included in future analyses.

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