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Design of Fractional Order Controller Integrated with Renewable Resource in Multi Area Islanded Microgrid

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***Abstract*— This paper presents on designing of fractional order controller, integrated with renewable energy sources in multi-area islanded micro grid. For automatic generation control (AGC), thermal plants in each area with solar thermal power plant (STPP) in area-1 are implemented here. The generating ratios of areas are 1:2:4. Area -1 consists of STPP and thermal plant. Appropriate generation rate constant (GRC) is taken for all the three areas. Hybrid proportional integral derivative (PID) with filter via fractional order integral derivative (PIDN-FOID) controller is considered. Multi verse optimizer (MVO) optimisation technique is used to tune the controller gains. It is observed from simulation results that proposed hybrid PIDN-FOID outperforms as compared to conventional controller. Sensitivity analysis has been performed to test the robustness of suggested approach.**

Keywords*— Multi-Area Islanded Micro grid, Automatic Generation Control, Multi Verse Optimizer, Fractional Order Controller

I. INTRODUCTION

In the area of power grid, inspired by the ever-diminishing conventional energy source like fossil fuel, the alternative sources have received high attention to be applied in the field of micro grid. To overcome the environmental issues renewable energy sources (RESs) such as solar, wind, diesel, fuel cell, hydro and geothermal are currently used by the engineers. We mostly use these non-conventional energy sources because of their several benefits like producing energy which minimize greenhouse gas emissions and reduce air pollution diversifying energy supply and lowers dependency on Fuels. A micro grid is a small-scale power grid that can actuate in independent manner or in cooperative manner with the main power grids. A micro grid is a distributed and de-centralized localized power grid which consists of distributed energy sources (DER) especially the above renewable energy sources, energy storage systems such as battery energy storage system and fuel energy storage system and other equipment that is needed in the MG infrastructure. Throughout heavy load, Micro-grid operates in connected mode or can boost the rating of the main power grid. In the Course of a blackout, it can operate autonomously in islanded mode. The natural disturbance like weather factors makes the renewable sources especially photovoltaic (PV) and wind unsteady and to diverge rapidly. So these sources are not considered for secondary control [1]. Simultaneously, now a day's consumer demand fluctuates at a high rate. It is essential to satisfy the consumer by balancing the supply and load demand.

This is required to continue the tie-line power of the system and frequency within their predefined nominal value for reliable and economic operation of the existing plant. The deviation in frequency from nominal value and tie-line power variation because of alteration in demand and due to other unusual situation, these variations should be kept as minimum as possible. Automatic generation control (AGC) is use to retain the system frequency and tie-line power trade within their supposed value. To cancel out the frequency variation rapidly and in order to continue the tie-line power exchange within predefined rate, AGC approach is implemented [2-4]. Solar energy can be considered as alternative source of energy. Concentrated solar power (CSP) can be converted in to the form of thermal energy and it can be stored. Electricity can be produced from the stored thermal energy without solar radiation. [5] have studied the conception related to “of solar concerted grid linked ocean thermal power conversion system”. But in case of AGC problem same concept can't be applied in an interconnected power system. Though idea of integrating of STPP for case of AGC learning was first introduced by [6].

In the present work, Multi verse optimizer (MVO) algorithm is used to tune the hybrid proportional integral derivative (PID) with filter via fractional order integral derivative (PIDN-FOID) controller for the frequency regulation of interconnected power system.

The main contribution of this present work are, (a)Three-area thermal power plant with STPP is used, (b) MVO technique is implemented for the optimization of controller parameter, (c) The advantages of proposed PIDN-FOID controller is compared with I, PI, PID controller, (d) Sensitivity analysis done to check the healthiness of the proposed approach in presence of STPP.

The novelties of this research work are (a) Reliability of the system is increased while STPP is added to the proposed system i.e. three are thermal power plant (b) Dynamic performance of the whole system is increased by using a novel controller i.e. PIDN-FOID.(c) Due to the addition of fractional controller, the robustness of proposed controller is increased as compared to the conventional controller.

The section wise description of this paper is as follows: (a) Section 1 highlights the overview of the problem, literature review, objective of work and novelties, (b) Section 2 enlightens the modelling of proposed system, Multi verse optimizer (MVO) technique, designing of proposed controller, (c) Section 3 contains results and discussion, (d) Section 4 draws the conclusion.

II. System Modelling

A three-area unequal model consist of solar integrated with thermal plant in all area with STPP is considered in area-1 [3,5,7]. The capacity is in ratio of 1:2:4. area-1 consist of STPP and thermal plant. GRC of 3% minute is taken for all the three area. The parameters value of thermal power plant are taken from [3] and for STPP[5,7]. The conventional controllers like I, PI and PID [16-20] are optimized by using MVO technique. The system dynamics is studied by taking 1% SLP in area-1. Transfer function representation of purposed arrangement is given in Fig.1. The type of performance index usually considered while designing the controller are “The Integral of Time multiplied Absolute Error (ITAE), Integral of Squared Error (ISE), Integral of Time multiplied Squared Error (ITSE) and Integral of Absolute Error (IAE)” [19].

Here all the gains of the controller along with all other parameters value are optimized with MVO technique. and cost function which is used for the optimization is, ISE given by Eqn. 1

$$Objective\ Function = \int_0^{\tau}\left[\left(\Delta f_i\right)^2 + \left(\Delta P_{tiei-j}\right)^2\right]dt \qquad (1)$$

where, i, j use to represent area i=1,2 ,and j=2,3($j \neq i$)

A. Solar Thermal Power Plant (STPP)

Solar energy is considered as huge potential of energy source. Photovoltaic (PV) system and CSP is the system which are capable of, for the production of electrical energy from solar system. CSP system consists of broad area of collector field [7] have given a relative study of STPP with taking into consideration a large numbers of flat plate type collector, parabolic plate type collector. Collectors are used for the purpose of focusing the solar radiation on the pipes in which working fluids like water and molten salt are present. Steam in heat exchangers is produced by this hot working fluid. This turbine is driven by the steam. Heat storage technology is to be incorporated because of changing weather condition and regular change of day, night, in order to supply energy continuously. High heat oil, molten salt and water these area 3 heat storage mediums. The model was purposed by Buzás [1]. The rate at which output changes with temperature can represented given by Eqn. 2.

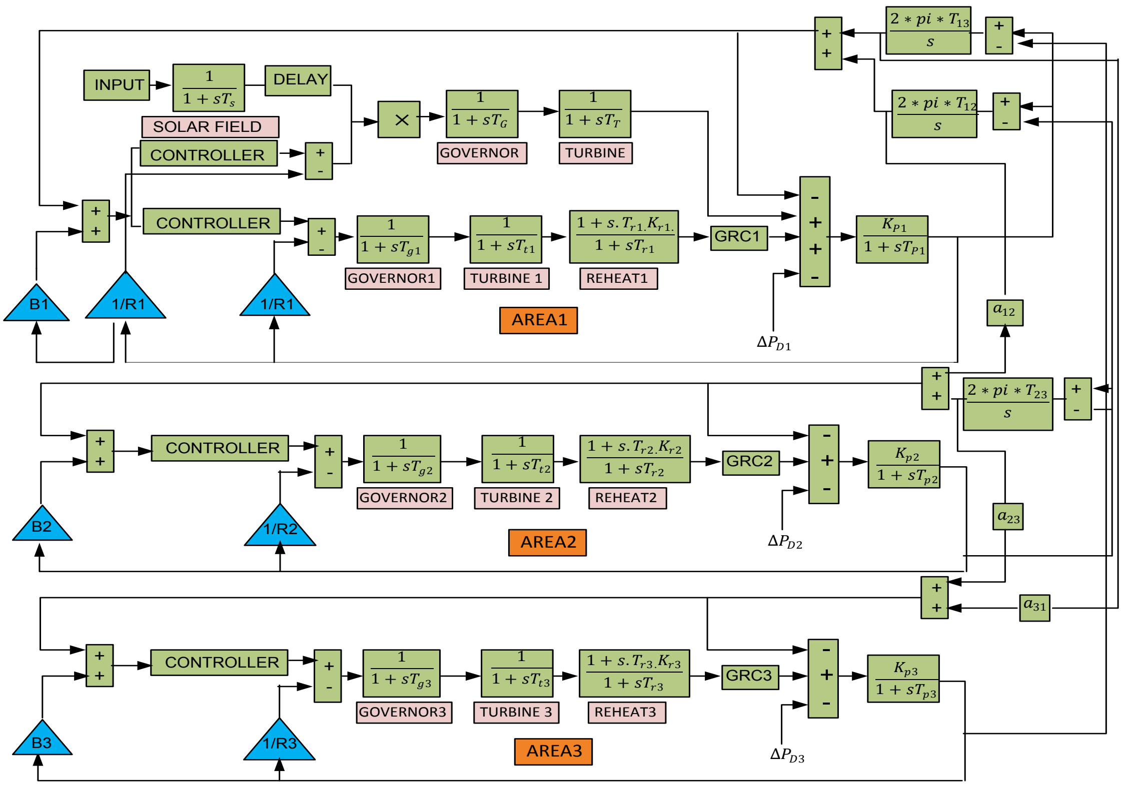


Fig.1 Matlab Simulink model of a three area system considering STPP in area-1.

$$\frac{dT_o(t)}{dt} = \frac{A\eta_o}{C} I(t) - \frac{U_L}{A}\left[T_a(t) - T_e(t)\right] + \frac{v_t}{V}\left[T_i(t) - T_o(t)\right] \qquad (2)$$

Where $T_a(t) = \dfrac{T_i(t) - T_o(t)}{2}$

Transfer function representation of solar field in respect to solar radiation is written by Eq (3)

$$G(s) = \frac{K_s}{1+T_s} \qquad (3)$$

Here Ks is treated as gain for solar field and the steam that is formed in heat exchangers is used to drives the turbine.

B.

B. Multi verse Optimizer (MVO) Algorithm

This algorithm mimics the multi verse theory that believes the presence of multiple universe and deals with their interaction through black hole, white hole and worm hole. It is a stochastic optimization technique. Like other population based algorithm, it also starts optimization by generating random solutions. Phases of optimization exploration achieved by black whole and white hole. Warm hole assists to exploit the target along the search space. It is supposed that the variable in a problem are the object present in each universe and the main idea behind this technique is that the fitness value of a problem is proportional to the inflammation rate.

Black hole and white hole play the role of a tunnel for the mechanism of exchanging objects between universes. White hole universes are the source of objects and black hole universes are the destination of objects. The rate of changing position of the solutions are calculated by two vital parameters i.e. warm hole existence probability (WEP), travelling distance rate (TDR).

$$WEP = min + l \times \left(\frac{\min - \max}{L} \right) \tag{4}$$

'min' is for minimum iteration set and 'max' is for maximum iteration set. 'l' is the present iteration and 'L' is the utmost allowed iteration.

$TDR = 1 - \dfrac{l^{\frac{1}{q}}}{L^{\frac{1}{q}}}$, '$q$' is the exploitation accuracy.

C. Designing of Controller

Multi verse Optimizer technique, although simple, is an effective and potential method for the realization of optimization of actual parameters. This optimization method when integrated through a FOPID (Saha A, 2018) controller an exceptional optimization technique is obtained which can be used to minimize any deviation in the frequency. A Proportional-Integral-Derivative & Fractional Order Integral Derivative is achieved when an Integral Order (IO) and Fractional Order(FO) are combined in cascade. Unlike other controllers with three parameters, this proposed controller has five parameters instead, namely as The Proportionality Constant and as Integral Constant, as Derivative Constant, and as Derivative Order and Integral Order. The controller structure of proposed PIDN-FOID controller is shown in Fig2.The parameters values of I, PI, PID, TIDF and proposed PIDN-FOID controller are demonstrated in Table I.

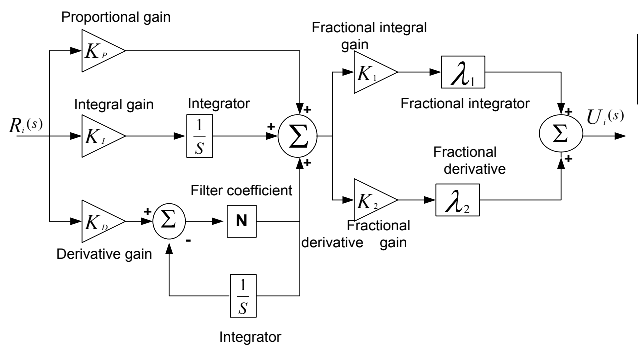


Fig.2. Control arrangement of PIDN-FOID controller

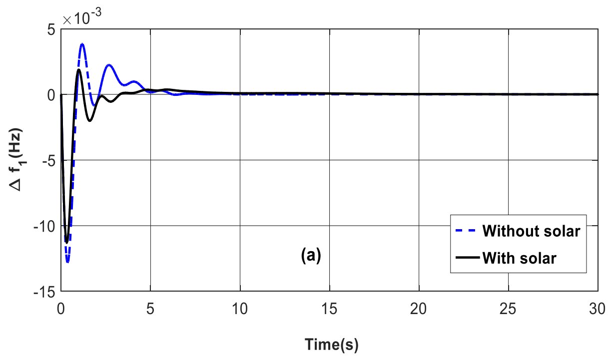
TABLE I. Optimun gain value of the different controller

Contro-ller	paramet ers	Controll er1	Controll er2	Controll er3	Controll er4
I	K_I	1.3941	0.4146	0.3746	0.7458
PI	K_P K_I	0.8582 0.4735	0.1499 0.2455	0.2052; 0.0568	0.4610; 0.4655
PID	K_P K_I K_D	1.6622 1.8560 0.3390	1.7675 0.7757 0.7651	0.5429 1.7358 1.4830	0.8957 1.4193 1.8887
TIDF	K_P K_I K_D N_1 K_d	0.9168 0.4308 0.2661 0.5726 261.7284	0.6751 1.6662 0.8145 0.3406 125.0158	0.8943 1.4567 1.2677 0.2156 177.9589	1.0927 0.6949 0.2661 0.2580 231.6839
PIDN-FOID	K_P K_I K_D N K_1 K_2 λ_1 λ_2	0.0515 1.5495 0.7044 99.0321 1.3788 0.4241 0.1115 0.9425	1.7103 1.7256 0.2517 114.7456 1.6888 1.6137 0.2765 0.3112	0.7612 0.8370 0.1319 473.5747 1.5805 1.3043 0.9750 0.1307	1.0317 1.0636 0.2637 322.0663 0.8146 1.3834 0.6953 0.3018

III. SIMULATION RESULTS AND DISCUSSIONS

A three unequal area system consist of thermal plant within each area with solar thermal plant in one area is considered. And generating ratio of area are 1:2:4. Area one consist of STPP and thermal plant. GRC of 3% per minute is taken for all the three area. All the supposed value for thermal plant is considered from [8, 1] and for STPP from [9] and [10]. A number of conventional controllers like I, PI and PID have were optimized as secondary controllers [16-20]. In order to study the dynamics of the system is done by considering 1% SLP in one area. Fig1. Shows the Simulink TF model of the purposed system. The actual gains of the controller and all remaining parameters value are optimized with MVO method.

The cascaded controller(PIDN-FOID) is optimized using differential evolution technique And the system's dynamic response is compared with the presence of STPP and without incorporating STPP and the simulation is done with the help of MATLAB 2016-a



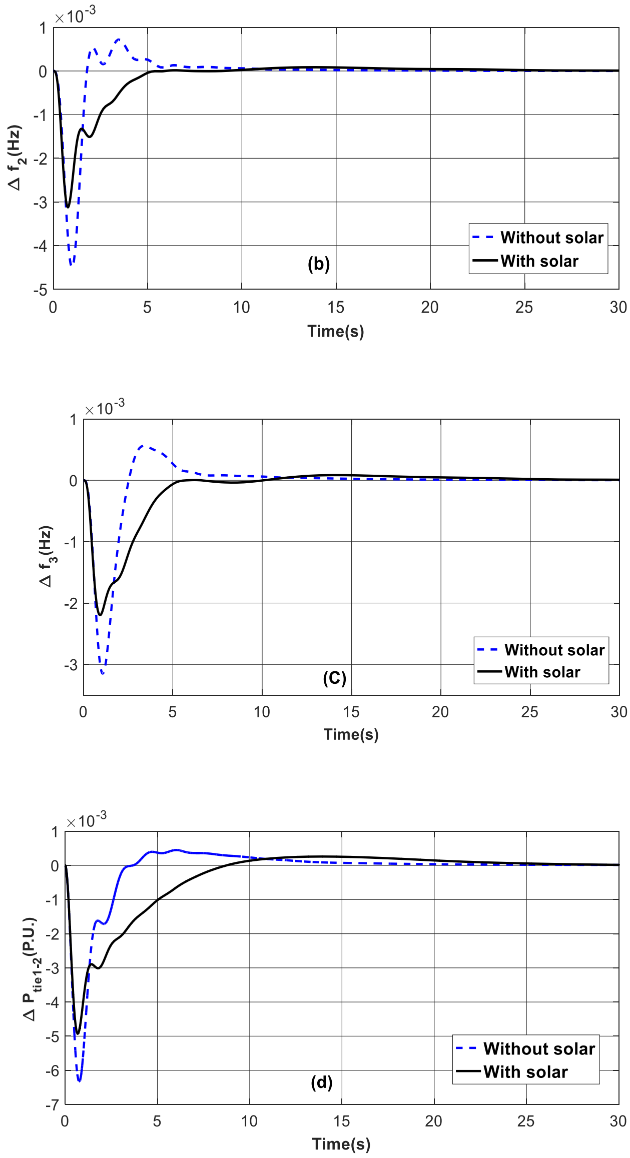
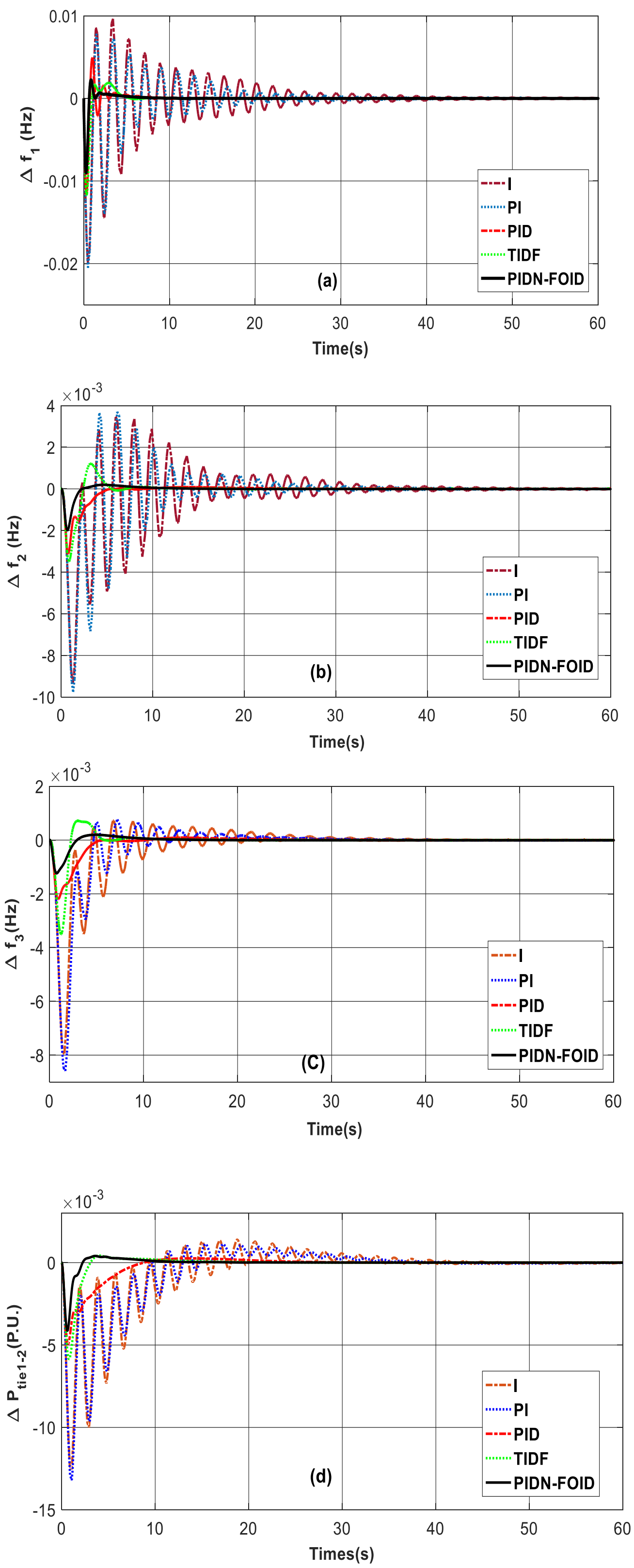


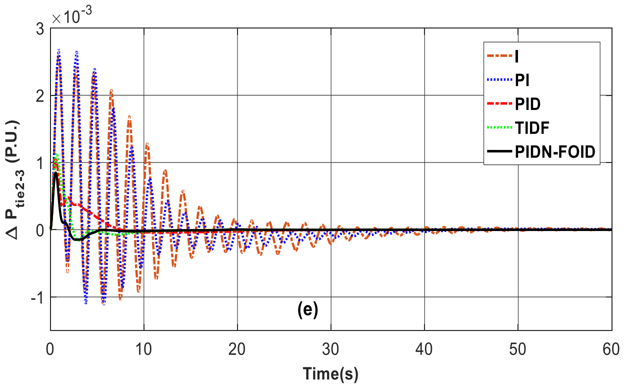
Fig.3 System response (a) Δf_1 vs time, (b)Δf_2 vs time(c) Δf_3 vs Time (d) $\Delta P_{(tie1\text{-}2)}$ for 1% SLP in area1

TABLE. II. Settling time and overshoot values with solar and without Solar

parameters	Settling time(sec)		Peak overshoot	
	Without STPP	With STPP	Without STPP	With STPP
Δf_1	1.3900	1.4900	0.0038	0.0019
Δf_2	1.3600	1.2400	0.0007	0.0001
Δf_3	1.3600	1.2500	0.0006	0.0001
$\Delta P_{tie\ 1\text{-}2}$	1.9300	1.7400	0.0005	0.0003

From the above result Fig.3 and Table II, it can be analyzed that with the presence of STPP in area one and the PID is considered as secondary controller for all area overall dynamic response for the system improves in comparison to system without incorporating STPP.





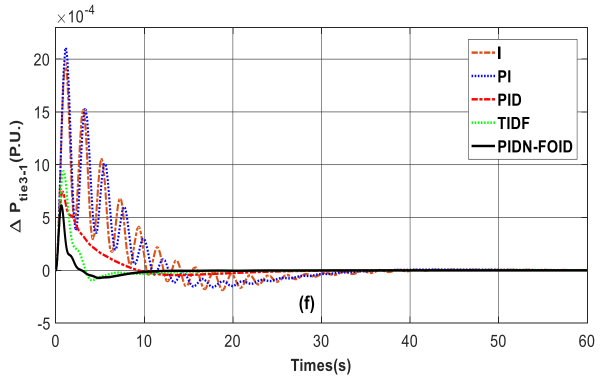


Fig. 4. System response (a)Δf_1 (b)Δf_2 (c)Δf_3(d)$\Delta P_{(tie1-2)}$

(e) $\Delta P_{(tie2-3)}$(f))$\Delta P_{(tiel-2)}$ with 1% SLP in area 1

A. *Sensitivity Analysis*

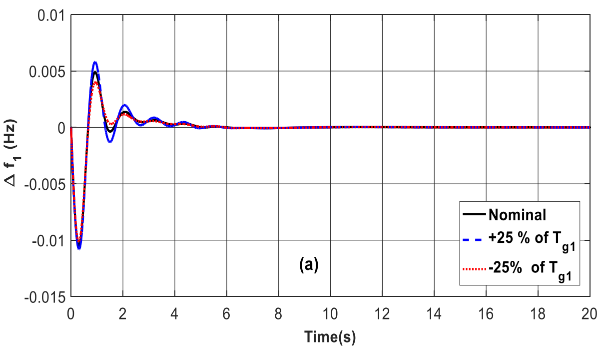


Fig.5 System response (a) Δf_1 vs time 1% SLP in area 1 with variation of Tg_1

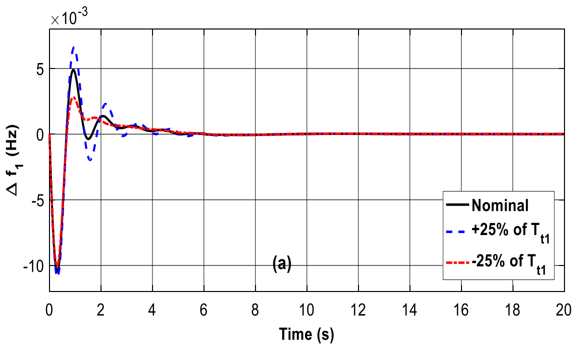


Fig.6 System response (a) Δf_1 vs time 1% SLP in area 1 with variation of Tt_1

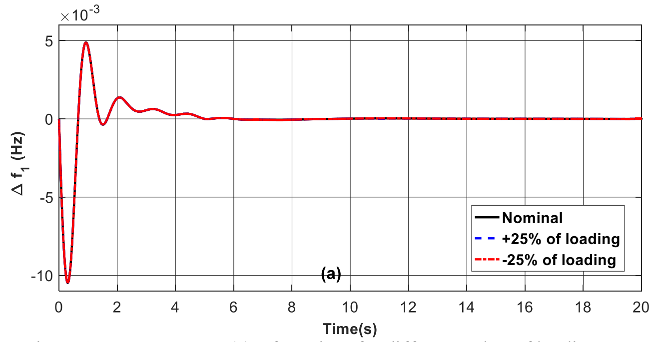


Fig. 7. System response (a) Δf_1 vs time for different value of loading

TABLE III. Eigen values and minimum damping ratio of the system with different secondary controllers

Controller	I	PI	PID	TIDF	PIDN-FOID
System mode	-3.3333 -0.0500 -0.5556 -2.3810i -12.5000 -0.025 ±2.381i -0.025 ±2.8659i	-0.1000 -3.3333 -12.500 -1.0000 -0.5556 -0.0500 -0.025 ± 2.381i -0.025 ±2.8459i	-0.1000 -3.3300 -0.5600 -0.3300 -0.0500; -12.500 -100. 0 -12.5000 -0.030 ±2.39i -0.030 ± 2.86i -0.02 ±2.38i	-500.00 -261.70 -3.3000 -500.00 -125.00 -16.700 -464.400 -178.000 -231.700 -537.600 -307.80 -0.5000 ; -0.4000 -579.5 ± 02.8i ±02.4i	-1000.0 -3.3000 -12.500 -0.5000 -5.8000 -3.5000 -12.400 -0.2000 -0.6000 -17.100 -59.900 -71.400 -250.700 -880.300 -322.7 -191.100 -2.9000 -10.0000 -35.2000 - 59.900 -123.7 -26.2000 -322.7 - 59.9000 -0.400±434.20i -20.300±0.0035i -0.00 ± 02.8i -0.0000 ±02.4i

In this section, in order to study the stability of the given system Eigen value analysis is carried out in a controlled manner, that is with the existence of secondary controller. The system is considered with altered secondary controllers like I, PI, PID, an PIDN-FOID separately, and Eigen value analysis is done. In this system, in all areas identical controller is applied. The Eigen values are given in Table III (column 2). Investigation of these values says that with I, PI, and PID as secondary controllers, there is a chance where condition possibly will occur that the given system might loose stability because as there are some values with zero real part as a result the system becomes marginally stable. But whenever the PIDN-FOID is used as a secondary controller in the given system, it can be observed that all Eigen values have a -ve real part, so that the system becomes is totally stable. Here MVO technique is used for optimization of various type of traditional controllers like I, PI, PID and also with PIDN-FOID controller. When the cascaded controller is used as secondary controller it outperforms as compare to that of conventional controller. And from Table I it can be analyzed that with the presence of STPP in area one and the PID is considered as secondary controller in all areas overall dynamic response of the system improves in comparison to system without incorporating STPP. Sensitivity analysis is carried out in order to check the healthiness of system and this is found that there is negligible variation in frequency variation and tie-line power for a large variant in system situation. That is, no need to change the system parameter and to reset the controller for large variation in system condition. Bode plot analysis is done, and it is observed that the phase margin and gain margin of system is positive and the system is stable even for the large change in system parameter.

IV. CONCLUSION

A simplified model of renewable energy is integrated in a three area AGC system. MVO technique is used for optimization of fractional order controller. Here, the model that we have taken in to consideration, a three area system with renewable energy i.e., STPP system in one of the area and thermal in all area is optimized using MVO technique for various type of traditional controllers like I, PI PID and also with proposed PIDN-FOID controller. When the cascaded controller is treated as secondary controller it outperforms as compare to that of conventional controller. It can be analyzed from Table 1 that with the presence of STPP in area one and the PID is considered as secondary controller in each area. It may be concluded that the overall dynamic response of the system enhances in comparison to system without incorporating STPP. Sensitivity analysis is done by checking the healthiness of the system. It is seen that there is negligible variation of frequency deviation and tie-line power with large changing of system condition.

APPENDIX

Nominal parameters of the system are

f = 60 Hz;
T_{gs} = 1.0 s;
T_{g1}, T_{g2}, T_{g3} = 0.08 s;
T_{ts} = 3.0s;
T_{t1}, T_{t2}, T_{t3} = 0.3 s;
T_{ri} = 10 s;
K_{ri} = 0.5;
K_{pi} = 120 Hz/pu MW;
T_{pi} = 20 s;
T_{12} = T_{23} = T_{13} = 0.086 pu MW/rad;
H_i = 5 s;
D_i = 8.33*10^{-3} pu MW/Hz;
B_i = 0.425 pu MW/Hz;
R_i = 2.4 Hz/pu

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