FOPID DESIGN FOR LOAD-FREQUENCY CONTROL USING GENETIC ALGORITHM

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ABSTRACT: *A fractional order PID (FOPID) for a load frequency control (LFC) is presented in a three-area power system. FOPID controllers are designed the same way as PID controllers are, with the difference that FOPID controllers have five parameters in the controller that should be determined. That is why they have two more degrees of freedom for better tuning the dynamical characteristics of the controller compared to PID controllers. Once the FOPID is designed using Genetic Algorithm (GA), a comparison is made between this approach and FOPID controllers that are designed with other optimization methods such as Imperialist Competitive Algorithm (ICA). Then, the results of the frequency change and transferred power change of each area by FOPID are compared in comparison the PID controller designed using GA. The results indicate that FOPID controllers tail better characteristics compared to the PID controllers. It is also revealed that FOPID controllers designed using GA have better characteristics compared to those designed using other optimization methods such as ICA.*

Keywords: *EOPID, LFC, GA, Controller*

1. INTRODUCTION

Many researchers are used different search algorithms and technical software for solving power system problems [1-7]. Controlling the generated power of the output is one of the most important control objectives in the power system so that the transferred frequency and power would remain in their nominal value and experience minimum fluctuation. When the load varies, there are abrupt changes in the transferred frequency and power. For this reason, an LFC controller controls these variations of transferred frequency and power and restores frequency to its nominal value.

In the recent years, designing controllers using FOPIDs has been of great interest. In [8], a hybrid Firefly Algorithm optimized fuzzy PID controller for Load Frequency Control. In [9], parameters of the PI controller are controlled by genetic algorithm optimization. PI controller design for multi-area interconnected power systems has been used by Dual Mode Bat algorithm in [10]. Bacterial Foraging Optimization Algorithm for load frequency control in the power system is proposed in [11]. For achieving Load Frequency Control on a two area interconnected power system, performance of Artificial Bee Colony algorithm as a multi objective based optimization, has been studied in [12]. Noise-tolerable PID feedback is used for a load frequency control in the power system in [13]. Load Frequency Control is investigated in [14] by unified PID tuning method which uses internal model control.

FOPID controller is used in [15] for Load Frequency Control, in [16] for Automatic Voltage Regulator system, in [17] for network delay and in [18] for chopper fed DC motor drive.

An FOPID and a PID are designed for an LFC using GA method and they are then compared. Finally, the results of FOPID designed using GA are compared to those designed using other methods.

2. FRACTIONAL ORDER PID

To study FOPID, there are several definitions for fractional order. The first is by Riemann-Liouville [19]:

$$\alpha D_t^q = \frac{1}{\Gamma(m-\alpha)}\left(\frac{d}{dt}\right)^m \int_\alpha^t \frac{f(\tau)}{(t-\tau)^{1-(m-\alpha)}} \qquad (1)$$

Another definition is by Grunwald-Letnikov:

$$\alpha D_t^\alpha f(t) = \lim_{h\to 0} \frac{1}{\Gamma(\alpha)h^\alpha} \sum_{k=0}^{\frac{t-\alpha}{h}} \frac{\Gamma(\alpha+k)}{\Gamma(k+1)} f(t-kh) \qquad (2)$$

It is demonstrated in [20] that the Laplace transform of the n-th derivative of a signal x (t) at t=0 is given by $L\left\{D^n x(t)\right\} = s^n x(s)$. Therefore, the differential equation of the fractional order would be as follows:

$$G(s) = \frac{a_1 s^{\alpha_1} + a_2 s^{\alpha_2} + \dots + a_{m_A} s^{\alpha_{m_A}}}{b_1 s^{\beta_1} + b_2 s^{\beta_2} + \dots + b_{m_B} s^{\beta_{m_B}}} \qquad (3)$$

The general form of FOPID is presented in [21]:

$$G(s) = K_p + \frac{K_I}{s^\lambda} + K_D s^\mu \qquad (4)$$

$$0 \le \lambda, \mu \le 1$$

PID and FOPIDs are compared in terms of different μ and λ in the figure 1.

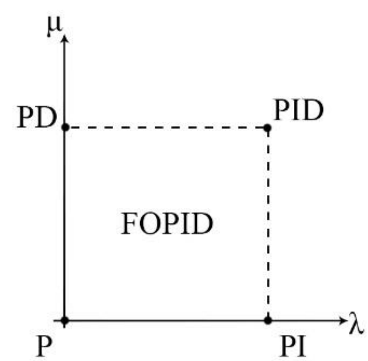

Figure. 1. Comparing PID and FOPID.

3. GENETIC ALGORITHM

Genetic algorithm uses Darwinian selection principles to find an optimal formula for prediction or pattern matching. The attraction of this method lies in the fact that it encompasses higher speed and reliability. Genetic algorithm includes three major operators: Selection, Crossover, and Mutation [22]. Genetic algorithm flowchart is shown in figure 2.

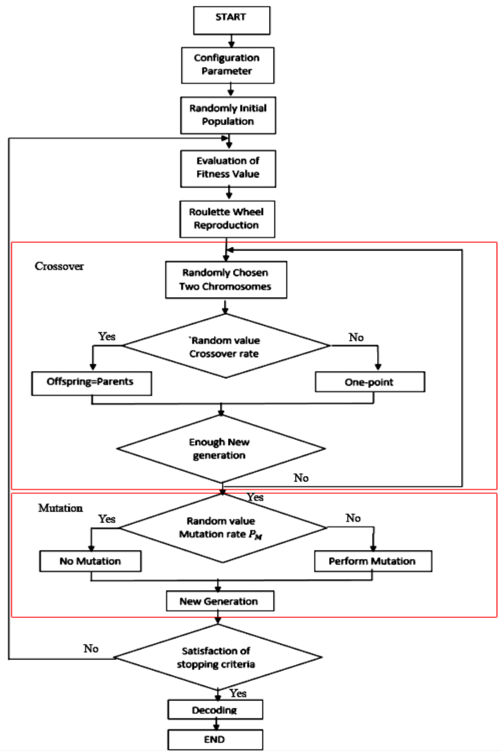

Figure. 2. GA flowchart for tuning the FOPID controller.

3.1. SELECTION

The strings in the current population is permitted to inherit their genetic material to the following generation by the selection operator [23].

3.2. CROSSOVER

Crossover is the recombination of genetic information among chromosomes. This operator causes the parents' characteristics to be combined in order for a better chromosome to be generated. The main task of this operator is to improve population fitness. There are several types of crossovers: one-point crossover, N-point crossover, uniform crossover.

3.3. MUTATION

This operator makes for a new solution. A number of obtained chromosomes are changed using mutation operator. In doing so, new chromosomes come into being that did not probably exist in the entire population.

4. FOPID DESIGN USING GA

FOPID and PID differ in that FOPIDs have two more controllable parameters in order for them to possess better dynamical characteristics. The general form of FOPID is as follows:

$$K = K_p + \frac{K_I}{s^{\lambda}} + K_D s^{\mu} \qquad (5)$$

To use this function in GA, limitations for each control constant should be taken into consideration as follows:

$$-1 \le K_P, K_I, K_D \le 1$$

Maximum overshoot and settling time are taken into account upon designing this controller.

5. SIMULATION RESULTS

This optimization aimed at designing FOPID, thus improving the control system and exhibiting better results compared to PID and other optimization methods such as ICA. Table 1 shows controllers' parameters and Table 2 shows compared values between FOPID and PID. Table 3 demonstrates comparison results between FOPID designed using GA and ICA. FOPID designed using ICA in [24]. As the diagrams and the table show, the results of FOPID controller designed using GA are far better than those designed using ICA and maximum overshoot and settling time have been decreased. Three area power system showed in figure 3 and power system parameters in table 4 [24]. Four cases of disturbances have been investigated. In the first case, disturbance exists only in the first area, i.e. $P_{D_1} = 0.1, P_{D_2} = P_{D_3} = 0$, for this case, for compare PID and FOPID, change in the frequency of area 1 showed in figure 4 and for compare FOPID designed using GA and ICA [24], change in the frequency of area 1 and area 2 showed in figure 5 , Change in the frequency of area 3 showed in figure 6 and change in the Ptie of area 1 showed in figure 7, the results show, FOPID designed using GA has lower maximum overshoot and settling time . In the second case, disturbance exists only in the second area, i.e. $P_{D_2} = 0.1, P_{D_1} = P_{D_3} = 0$, for this case , for compare FOPID and PID ,change in the frequency of area 2 showed in figure 8 and for compare FOPID designed using GA and ICA[24], change in the frequency of area 1 and area 2 showed in figure 9, change in the frequency of area 3 showed in figure 10 and change in the Ptie of area 2 showed in figure 11, the results show, FOPID designed using GA improved dynamic behavior of the system. In the third case, disturbance exists only in the third area, i.e. $P_{D_3} = 0.1, P_{D_2} = P_{D_1} = 0$, in this case, for compare PID and FOPID ,change in the frequency of area 3 showed in figure 12 and for compare FOPID designed using GA and ICA[24], change in the frequency of area 1 and area 2 showed in figure 13, change in the frequency of area 3 showed in figure 14 and change in the Ptie of area 3 showed in figure 15, the results show ,FOPID designed using GA improved oscillation rate .In the fourth case, disturbance exists in all areas, i.e. $P_{D_1} = P_{D_2} = P_{D_3} = 0.1$, in this case , for compare FOPID and PID ,change in the frequency of area 1 and area 2 showed in figure 16 , change in the frequency of area 3 showed in figure 17 and for compare FOPID designed using GA and ICA [24], change in the frequency of area 1 and area 2 showed in figure 18 , change in the frequency of area 3 showed in figure 19 , Change in the Ptie of area 1 and area 2 showed in figure 20 and change in the Ptie of area 3 showed in figure 21.The designed FOPID properly controls disturbance in all cases, restoring transferred frequency and power to their nominal values at the right time.

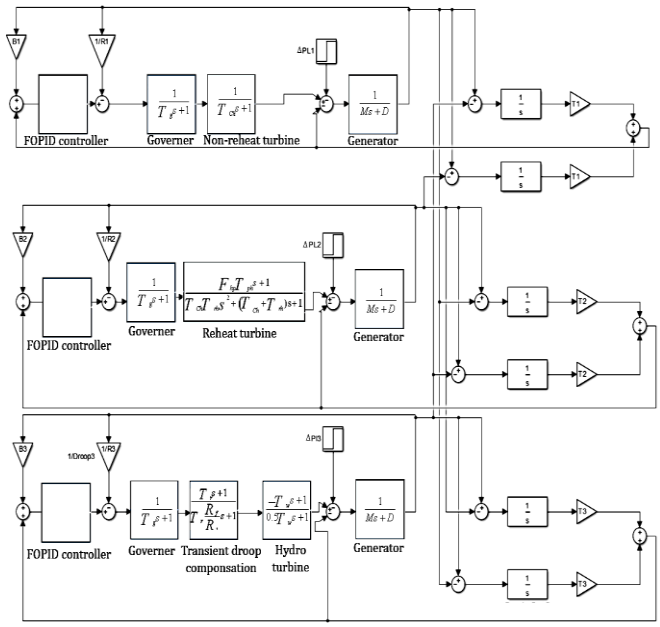

Figure. 3. Three area power system with different generating units.

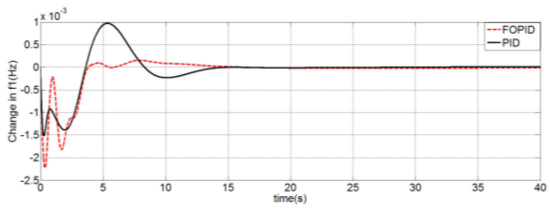

Figure. 4. Change in the frequency of area 1 for step increase in demand of area 1.

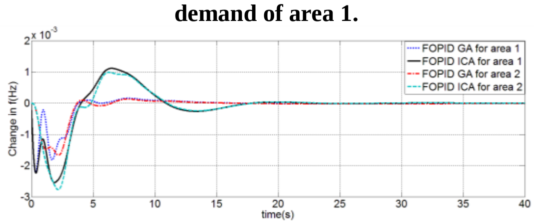

Figure. 5. Change in the frequency of area 1 and area 2 for step increase in demand of area 1.

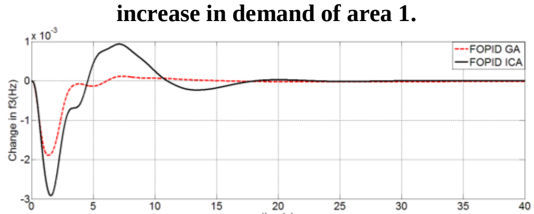

Figure. 6. Change in the frequency of area 3 for step increase in demand of area 1.

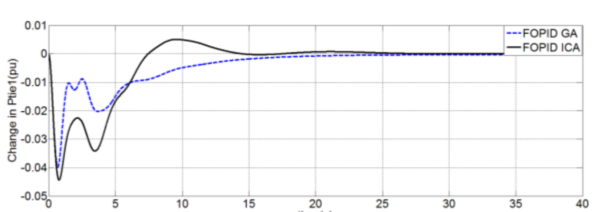

Figure. 7. Change in the Ptie of area 1 for step increase in demand of area 1.

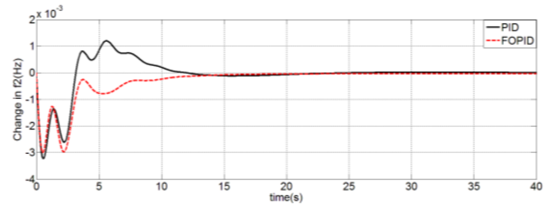

Figure. 8. Change in the frequency of area 2 for step increase in demand of area 2.

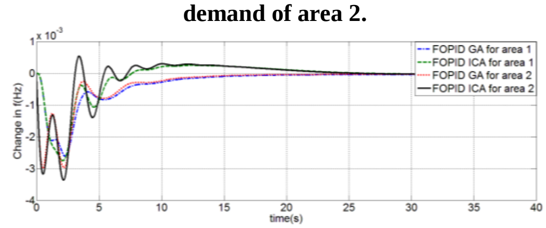

Figure. 9. Change in the frequency of area 1 and area 2 for step increase in demand of area 2.

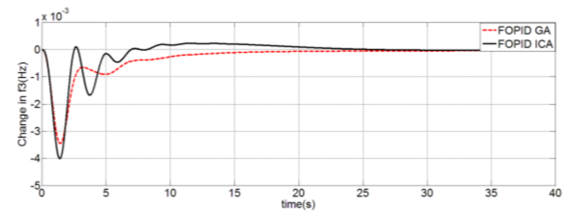

Figure. 10. Change in the frequency of area 3 for step increase in demand of area 2.

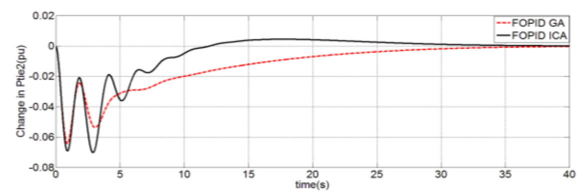

Figure. 11. Change in the Ptie of area 2 for step increase in demand of area 2.

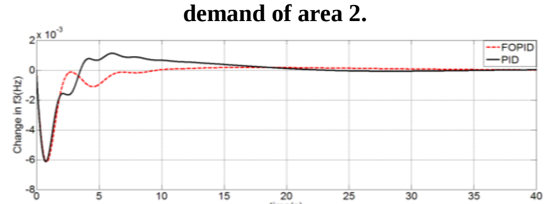

Figure. 12. Change in the frequency of area 3 for step increase in demand of area 3.

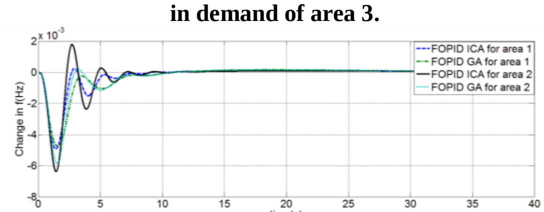

Figure. 13. Change in the frequency of area 1 and area 2 for step increase in demand of area 3.

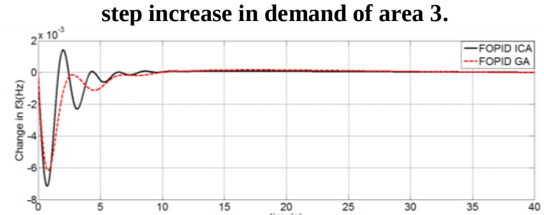

Figure. 14. Change in the frequency of area 3 for step increase in demand of area 3.

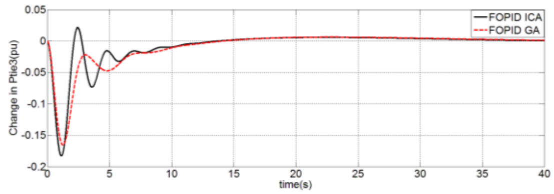

Figure. 15. Change in the Ptie of area 3 for step increase in demand of area 3.

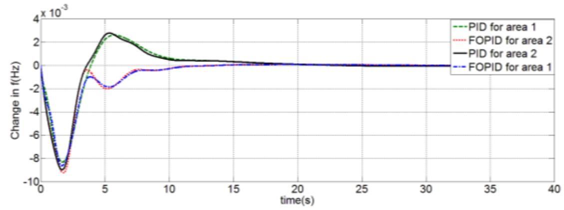

Figure. 16. Change in the frequency of area 1 and area 2 for step increase in demand of all areas.

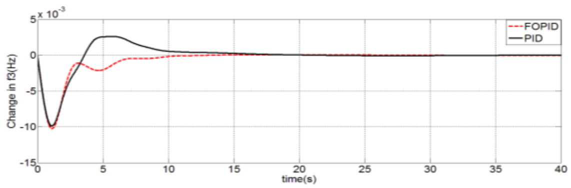

Figure. 17. Change in the frequency of area 3 for step increase in demand of all areas.

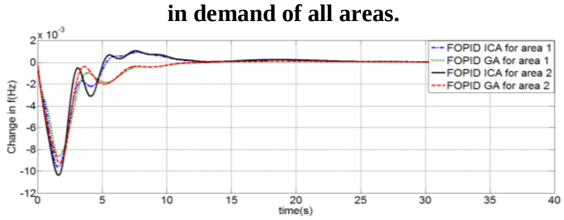

Figure. 18. Change in the frequency of area 1 and area 2 for step increase in demand of all areas.

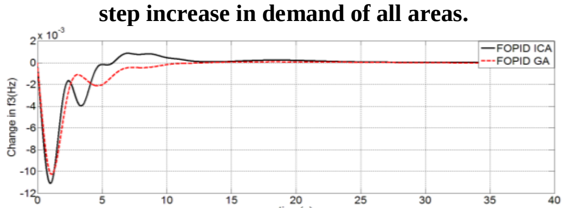

Figure. 19. Change in the frequency of area 3 for step increase in demand of all areas.

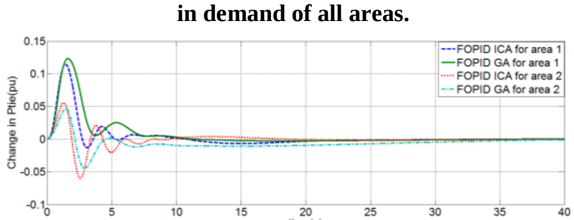

Figure. 20. Change in the Ptie of area 1 and area 2 for step increase in demand of all areas.

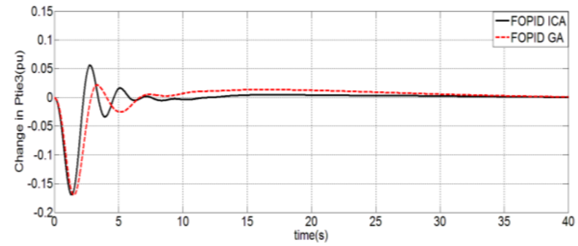

Figure. 21. Change in the Ptie of area 3 for step increase in demand of all areas.

TABLE 1.
CONTROLLERS' PARAMETERS

Controller parameters		K_P	K_I	K_D	λ	μ
Area1	PID	-0.2447	-0.863	-0.993	1	1
	FOPID	-0.3287	-0.584	-0.739	0.9246	0.6698
Area2	PID	-0.3893	-0.6944	-0.7573	1	1
	FOPID	-0.7575	-0.139	-0.97	0.9944	0.9863
Area3	PID	-0.0528	-1	0.4097	1	1
	FOPID	-0.1528	-1	0.5853	0.643	0.962

6. CONCLUSION

An FOPID for an LFC is put forward in a three-area power system using genetic algorithm. Simulation results suggest that the presented controller entails better characteristics compared to PID and FOPID designed using ICA. In most cases, FOPID designed using GA has lower maximum overshoot and settling time; however, in few results, PID or FOPID designed using ICA has lower maximum overshoot and settling time. As can be seen, the results are not ideal for the designed FOPID and PID controllers and there is still room for improvement. Furthermore, dynamic behavior of the low-frequency controller has been improved and lower oscillation rate has been achieved. Also, this controller has smoother response time in comparison to the PID or FOPID designed by ICA and this improved response time causes frequency oscillation of the abrupt change in the load to damp easily.

TABLE 2.
SETTLING TIME AND MAXIMUM DEVIATION OF SYSTEM RESPONSES TO DISTURBANCES, COMPARING PID AND FOPID CONTROLLERS.

	Max. deviation						Settling time					
Parameters	f_1	f_2	f_3	P_{tie1}	P_{tie2}	P_{tie3}	f_1	f_2	f_3	P_{tie1}	P_{tie2}	P_{tie3}
PID												
Disturbance in area 1	0.0015	0.0016	0.0018	0.028	0.019	0.0135	13.68	13.19	13.28	14.21	24.76	27.31
Disturbance in area 2	0.0025	0.0032	0.0038	0.05	0.07	0.031	21.2	20.44	18.76	21.24	20.81	36.42
Disturbance in area 3	0.0045	0.058	0.0061	0.09	0.079	0.162	21.47	21.17	19.45	30.81	35.42	34.33
Disturbance in all area	0.0083	0.0089	0.0098	0.1213	0.0369	0.1551	17.54	17.63	15.88	18.83	36.19	32.51
FOPID												
Disturbance in area 1	0.0022	0.0016	0.0018	0.039	0.022	0.017	12.6	12.63	12.14	20.16	13.06	23.7
Disturbance in area 2	0.0026	0.003	0.0034	0.052	0.064	0.03	22.85	17.12	20.27	25.04	32.7	31.54
Disturbance in area 3	0.0047	0.0058	0.0061	0.0902	0.08	0.1654	27.28	24.51	23.75	28.14	36.02	32.55
Disturbance in all area	0.0086	0.0092	0.0102	0.1234	0.047	0.1695	10.76	10.51	9.92	21.92	39.9	33.3

TABLE 3.
SETTLING TIME AND MAXIMUM DEVIATION OF SYSTEM RESPONSES TO DISTURBANCES, COMPARING FOPID DESIGNED USING ICA [23] AND FOPID DESIGNED USING GA.

	Max. deviation						Settling time					
Parameters	f_1	f_2	f_3	P_{tie1}	P_{tie2}	P_{tie3}	f_1	f_2	f_3	P_{tie1}	P_{tie2}	P_{tie3}
FOPID ICA												
Disturbance in area 1	0.0027	0.0029	0.0029	0.0448	0.0349	0.0256	19.6	19.5	19.55	16.42	20.33	20.44
Disturbance in area 2	0.0027	0.0033	0.0039	0.0546	0.0965	0.0437	21.87	20.74	20.15	21.96	29.11	34.62
Disturbance in area 3	0.0047	0.0062	0.0068	0.0938	0.0855	0.1758	21.78	8.11	15.2	22.48	32.33	30.23
Disturbance in all area	0.0095	0.0101	0.0108	0.1105	0.0525	0.1618	13.58	13.66	13.65	22.71	30.17	24.48
FOPID GA												
Disturbance in area 1	0.0022	0.0016	0.0018	0.039	0.022	0.017	12.6	12.63	12.14	20.16	13.06	23.7
Disturbance in area 2	0.0026	0.003	0.0034	0.052	0.064	0.03	22.85	17.12	20.27	25.04	32.7	31.54
Disturbance in area 3	0.0047	0.0058	0.0061	0.0902	0.08	0.1654	27.28	24.51	23.75	28.14	36.02	32.55
Disturbance in all area	0.0086	0.0092	0.0102	0.1234	0.047	0.1695	10.76	10.51	9.92	21.92	39.9	33.3

TABLE 4.
THREE AREA POWER SYSTEMS' PARAMETERS.

Non-reheat		**Reheat**		**Hydraulic**	
$M_1(pu\,s)$	10	$M_2(pu\,s)$	10	$M_3(pu\,s)$	6
$D_1(pu/Hz)$	1	$D_2(pu/Hz)$	1	$D_3(pu/Hz)$	1
$T_{Ch1}(s)$	0.3	$T_{Ch2}(s)$	0.3	$T_{G3}(s)$	0.2
$T_{G1}(s)$	0.1	F_{hp}	0.3	$T_r(s)$	5
$R_1(Hz/pu)$	0.05	$T_{rh}(s)$	7	$R_t(Hz/pu)$	0.38
$B_1(pu/Hz)$	21	$T_{G2}(s)$	0.2	$R_3(Hz/pu)$	0.05
$T_1(pu/rad)$	22.6	$R_2(Hz/pu)$	0.05	$B_3(pu/Hz)$	21
		$B_2(pu/Hz)$	21	$T_w(s)$	1
		$T_2(pu/rad)$	22.6	$T_3(pu/rad)$	22.6

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