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Closed-Loop Tuning of Cascade Controller for Load Frequency Control of Multi-Area Distributed Generation Resources Optimized by ASOS Algorithm

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ABSTRACT

This paper provides closed-loop tuning of the cascaded-tilted integral derivative controller (CC-TID) for load frequency control (LFC) of a microgrid system. A microgrid system is the arrangement of distributed generation resources such as a wind turbine generator (WTG), fuel cell (FC), aqua electrolyzer (AE), diesel engine generator (DEG), and battery energy storage system (BESS). Different controllers such as proportional integral derivative (PID), two degrees of freedom (2DOFPID), three degrees of freedom (3DOFPID), and tilted integral derivative (TID) are used not only to sustain the disparity between real power generation and load demand but also accomplish zero steady-state error to enrich the frequency and tie power regulations. The anticipated controller encompasses both the value of cascade (CC) and fractional order (FO) controls for better elimination of system instabilities. In the proposed CC-3DOFPID-TID controller, the TID controller is cast-off as a slave controller, and the 3DOFPID controller aided the role of the dominant controller. The controlled parameters are optimized by an adaptive symbiotic organism search (ASOS) algorithm for keen results of difficulties in LFC. To persist in an ecosystem, symbiotic relations are predictable by an organism through imitators. Further, the dynamic behaviors of the controller optimized by ASOS, teaching learning-based optimization (TLBO), and differential evolution particle swarm optimization (DEPSO) are compared by extensive simulations in MATLAB/SIMULINK. Moreover, the supremacy of the proposed controller is performed through system dynamics comparison among PID, 2DOFPID, 3DOF-PID, and CC-3DOFPID-TID controllers. Finally, the sensitivity of the proposed controller has been proven through random load perturbation.

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1. INTRODUCTION

The power output of synchronous generators concerning random load demand can be delimited by LFC. The essential features of LFC are (i) to abolish the frequency error, (ii) to retain the steady power flow over transmission lines, and (iii) to uphold synchronization between the associated generators. The foremost concern of today's power system is to deliver eminence power against incessant load fluctuation, swift mounting load demand, interconnected large power networks, and dispersion of renewable energy sources [1-2]. From time to time, the foremost power production by thermal and hydro sources is not appropriate for challenging more power. Because, the presented fossil fuels have a very petite extent of time directed the researchers assimilate the non-conventional generations such as wind, solar, etc. to the prevailing power system [3-6]. Primary control is not adequate to alleviate and invalidate the steady-state error of the system sharply which imposes a secondary controller. The simple nature of the PID controller [7] is mostly used but it suffers from a poor transient response. Through multiple control loops, control action is achieved which are degrees of freedom. In [8] concept of a 2DOF PID controller has been discussed which has upgraded response as compared to a PID controller. The superiority of dynamic performances can be achieved by using more tuning factors than the conventional model. The effect of a three degree-of-freedom PID (3DOFPID) controller can also be experimented with for this proposed system [9]. A fractional-order controller has greater flexibility towards parameter variations as compared to a conventional controller [10-11]. In [12], load frequency control of multi-area system incorporated with distributed generation resources optimized tilted integral derivative controller has been discussed. Now, cascade controllers are mostly used in the power system to enlighten the frequency stability by engaging a secondary loop along with a feedback measurement loop. In [13], the design of a cascaded two-degree of freedom PID controller for the LFC of an interconnected power system has been discussed. Guha D, et al. [14] designate the CC-TID controller considering nonlinearity. However, the effect of an extra tuning factor on the PID controller in a cascade with the TID controller has not been discussed. Hence this needs further study. The controller structure itself is not enough for the power system progression. So, computational technique and proper objective function are essential to estimate the control parameters of the controllers. Hence many evolutionary optimization techniques are reconnoitered for this suggested LFC system. In LFC, various optimization techniques are analysed for tuning of controller parameters such as differential evolution particle swarm optimization (DEPSO) [7], teaching-learning based optimization TLBO [15], symbiotic organism search (SOS) [16], sine cosine algorithm [17], salp swarm algorithm (SSA), and adaptive symbiotic organism search (ASOS) [19]are used for the optimization of controller variables. A new optimization technique is presented here which gives advanced frequency stability. This algorithm is more operative in terms of reduced frequency fluctuation. So this algorithm is broadly inspired by the researchers to use in their areas. The core involvements of this paper are:

i) Implementation of DGR with conventional thermal hydro LFC system in Matlab/Simulink environment
ii) The sovereignty and feasibility of CC-3DOFPID-TID controller have been established over PID, 2DOFPID, 3DOFPID, and cascaded two loops 3DOFPID–PID, and 3DOFPID-TID controller.
iii) Solicitation of ASOS has been explicated for dynamic assessment of CC-3DOFPID-TID controller gains equated with SOS and TLBO algorithms.
iv) To uphold the worth of the CC-3DOFPID-TID controller, random load perturbation (RLP) for control areas is projected.

2. THREE-AREA POWER SYSTEM MODEL

This paper presents the LFC of the multi-area hybrid power system shown in Fig.5 [38]. This model presents a thermal unit for area1 and area2, a DGR system for area 1, and a hydropower unit for area 3. A step load perturbation (SLP) of 0.01 p.u. is applied only for control area1. Here the input of the controller in each area is the area control error (ACE). It is the summation of frequency deviation with biasing coefficient (B) and tie-line power flow fluctuation.

2.1. Controller Design

Control action can be achieved by multiple control loops which are called degrees of freedom. So a 2DOF controller [8] is implemented in this system which is preferable to a PID controller in terms of dynamic response. 2DOFPID controller contains two control loops that are optimized for this system. Therefore when the tuning knobs are more in a controller, the performance of the latter is better in AGC. The improvement of responses can be achieved by using the 3DOFPID controller [9] shown in Fig. 1 which contains three control loops to enhance the stability of the system, proper response curves, and eradication of instabilities happening in the power system due to the extra loop D(S) in 3DOF controller. After that a PID controller is used as primary control loop cascaded with the 3DOFPID controller as secondary control loop to enhance the permanence, faster response and minimize the ACE effectively. All these above conformist controllers don’t give a reasonable performance while execution of LFC with system nonlinearity. So fractional order controller is reflected here which offers superior system performance and flexibility in the direction of parameter disparities. TID controller [13] shown in Fig 2 entails proportional, integral, and derivative gain with the tilted component of transfer function$\frac{1}{s^n}$. The system frequency is fed back to achieve zero steady-state error. This controller is simpler to design and less prompted by parameter variations. Finally, the cascade connection of the 3DOF controller is taken as a master for secondary control action and the TID controller as a slave for primary control action. The transfer function model of DG resources is presented in Fig. 3 and the proposed power system is presented in Fig. 4.

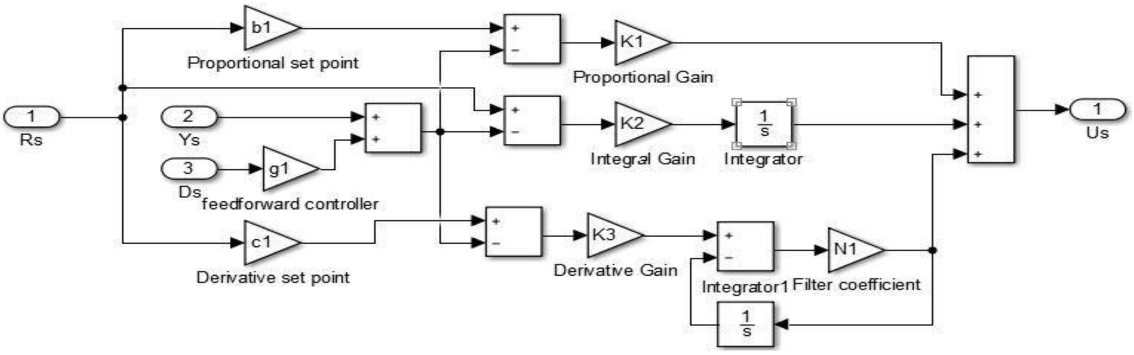

Figure 1. Basic structure of 3DOFPID Controller

Where R(s): is the input fed by the ACE signal.
Y(s): is the system output regarding frequency changes for each area.
D(s): is the system disturbance
The overall power provided to the load from the hybrid microgrid system is expressed in Eq. (2) [5]

$$P_s = P_{WTG} + P_{FC} + P_{AE} - P_{DEG} \pm P_{BESS} \qquad (2)$$

Where Ps: total power supplied

P_{WTG}: output power of wind turbine generator
P_{FC}: output power of fuel cell
P_{AE}: output power of aqua electrolyzer
P_{DEG}: output power of diesel generator
P_{BESS}: output power of battery energy storage system

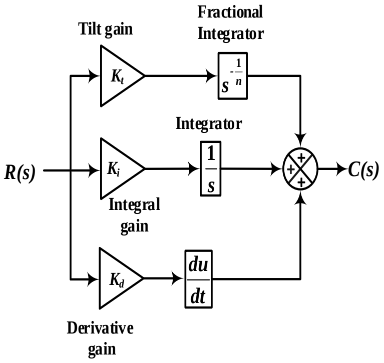

Figure 2. Model of TID controller

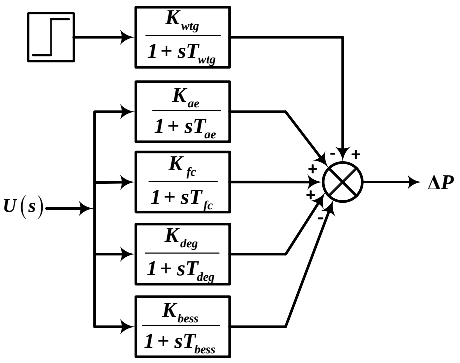

Figure 3. Model of DG resources

2.2. Objective Function

Performance of optimization process depended on the objective function generally used in time domain. Here integral of time multiplied absolute error (ITAE) is used as objective function because of small overshoot and oscillations.
Objective function (ITAE) is Minimize J, where

$$J = \int_0^t (|ACE_i|)t\,dt \quad (3) \qquad \text{and} \qquad ACE_i = \Delta P_{tie,i-j} + B_i \Delta F_i \quad (4)$$

Mathematical expression of ITAE function is

$$f = \int |\Delta F_1 + \Delta F_2 + \Delta F_3 + \Delta P_{tie}|.t.dt \qquad (5)$$

Where, dt is a very small time interval,ΔF_1,$\Delta F_2$and $\Delta F_3$are frequency deviations for area1, area2 and arae3 respectively. The tie line power deviation for control area isΔP_{tie}. In area1 step load perturbation is taken as 0.01 p.u.

2.3. Optimization Techniques: The biggest concern of control designer is to choose relevant parameters of controller by which the performance of controller can be enhanced to a greater extent. By selecting inappropriate parameters of controllers, the performance of the system may get divert from the desired responses. To overcome this dilemma, optimization/computational techniques are the most preferred tools to tune controllers. In recent decades, Optimization techniques are the most preferred tools to achieve desired responses by appropriately selecting controller parameters

2.3.1. Differential Evolution Particle Swarm Optimization: A hybrid technique, combination of PSO and DE, referred to as DEPSO has employed for LFC problems. This combined effect of both, improves the convergence characteristics as compared to individual. It also increases the system stability due to proper balance between exploration and exploitation**.**

- Initialize a random population of size$[N_P \times D]$ where population size is N_P and the dimension of particle id *D*, velocity and position of particle.
- First generate donor vectorV_i for DE operation

$$V_i = X_{i,r1} + F\left(X_{i,r2} - X_{i,r3}\right) \tag{6}$$

Wherer_1,r_2,r_3 are three distinct integers chosen between 1 and N_P and F , the scaling factor.

- Secondly generate the offspring vectorU_i with crossover rate CR

$$U_i = \begin{cases} V_i\,, rand(D,1) \leq CR \\ X_i,\ othrwise \end{cases} \tag{7}$$

- The target vector X_i has selected in selection process

$$X_i = X_i\ if\ f(X_i) \leq f(U_i)\ and\ \ X_i = U_i\ if\ f(U_i) \leq f(X_i) \tag{8}$$

Where, f is the function to be minimized.

- Finally detect the P_{best} and G_{best} value.
- For PSO operation, take X_i as initial population that obtained from DE operation.
- Then velocity and position of each swarm particle has updated

$$V_i^{k+1} = w.V_i^k + C_1 r_1\left(P_{i,best}^k - x_i^k\right) + C_2 r_2\left(P_{i,gbest}^k - x_i^k\right) \tag{9}$$

$$x_i^{k+1} = x_i + V_i^{k+1} \tag{10}$$

- Fitness function is evaluated and updated for next iterations.
- Repeat the steps until meet the stopping criteria

2.3.2. Teaching Learning based Optimization: TLBO algorithm has no computational parameter and gives excellent solutions in minimum time [22]. This algorithm exhibits two phases (i) Teacher Phase and (ii) Learner Phase. In teacher phase students (learners) learn from teachers and in learner phase students learn through interaction between learners (students). TLBO steps are

- Initially population x is generated randomly.
- The finest result x_{best} is assigned as teacher in teacher phase. The particular subject mean difference is mentioned as $m_{diff} = rand \times [x_{best} - T_f \times m_d]$ (11) and $T_f = round[1 + rand]$ (12)

where m_d is the mean value of every subject and T_f is the teaching factor.

- Updated the position by $x_{new} = x + m_{diff}$ (13)
- Evaluate and compared the fitness value and keep the best one.

- Then in learners phase students communicate with other by selecting two random vectors $x_i \ and \ x_j$ and updated the solutions.
- Better solution has identified and these process is continued up to the stopping criterion.

2.3.3. Adaptive Symbiotic Organisms Search (ASOS) Algorithm: This is the advanced meta-heuristic algorithm based on the population space ecosystem. New populations can be generated through biological interaction among organisms. In this case, the adaptive benefit factors (ABFs) are considered instead of benefit factors as in the SOS algorithm which assists in a better equilibrium between exploration and exploitation.

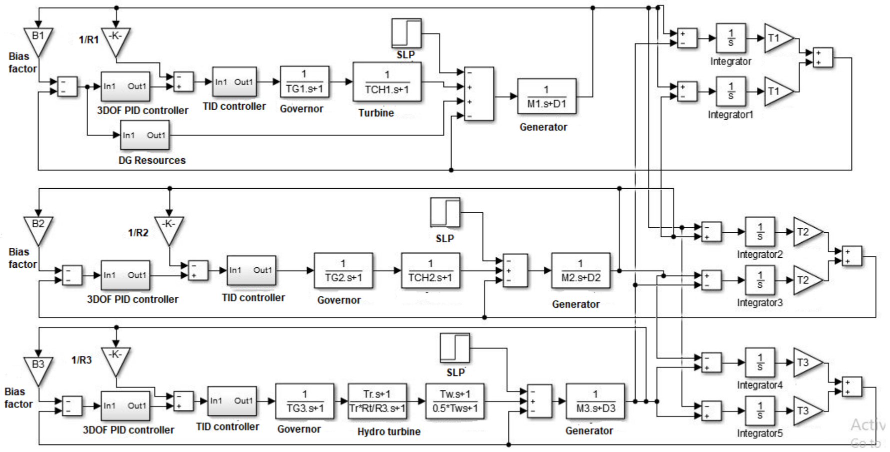

Figure 4.Transfer function model for three area power system using cascade loop controller

(i) Mutualism phase: This phase reveals the mutual benefit symbiotic relationship between two different species. In this phaseX_i and $X_j$are the two arbitrary organisms. The balance between exploration and exploitation can be achieved by modifying the benefit factors (BFs)as adaptive benefit factors (ABF) [19]

$$ABF_1 = \frac{f(X_i)}{f(X_{best})} \quad if \ f(X_{best}) \neq 0 \tag{14}$$

$$ABF_2 = \frac{f(X_j)}{f(X_{best})} \quad if \ f(X_{best}) \neq 0 \tag{15}$$

$$X_{i,new} = X_i + rand(0,1) * (X_{best} - Mutual\_vector * ABF_1) \tag{16}$$

$$X_{j,new} = X_j + rand(0,1) * (X_{best} - Mutual_{vector} * ABF_2) \tag{17}$$

$$\text{where} Mutual\_vector = \frac{X_i+X_j}{2} \tag{18}$$

(i) rand (0,1) is the random number and $BF_1, BF_2$are the benefit factor within the range of 1to 2. Both i^{th} and j^{th} organisms are restored by receiving aids from this interface with a possibility factor called benefit BF_1andBF_2. (ii) Commensalism phase: Two random organisms $X_i$and $X_j$from the ecosystem are permitted to interrelate in this phase. In this communication organism $X_i$assistances from the interaction, but organism $X_j$neither assistance nor writhes from the connection. The new updated value of $X_i$is calculated [19]

$$X_{i,new} = X_i + rand(-1,1) * (X_{best} - X_j) \tag{19}$$

(iii) Parasitism phase: In this phase one species get benefits from an ecosystem and the other is actively harmed. $X_j$is was selected as a host for parasite vectors from the ecosystem. This vector tries to replace $X_j$for survival in an ecosystem and the fitness values of both are calculated. If the parasite vector has a better fitness value then it will kill $X_j$from the ecosystem and consume this place. If $X_j$is better, then it gets immunity from the parasite vector. Now this PV will no longer be alive in the ecosystem.

3. RESULT ANALYSIS

Case 1: Comparison of performances for different algorithms

In this paper, the 3DOF-PID controller is considered a secondary loop of the power system, and the TID controller is considered a primary loop. The controller and gain parameters are optimized by optimization techniques to regulate the frequency oscillations. At first DEPSO algorithm is used with an objective function ITAE for 50 numbers of iterations. Then TLBO based controller has elaborated with the same objective functions and the number of iterations. After that adaptive symbiotic organism, search ASOS-based controller has taken for the dynamic performances of the controller. Of the above three optimization techniques, the latter one has improved dynamic performances as compared to others in terms of reduced oscillations, overshoots, and settling time. Simulations results from Fig. 5 and Fig. 6show the performances of a controller using DEPSO, TLBO, and ASOS algorithms for frequency and tie-line power deviations.

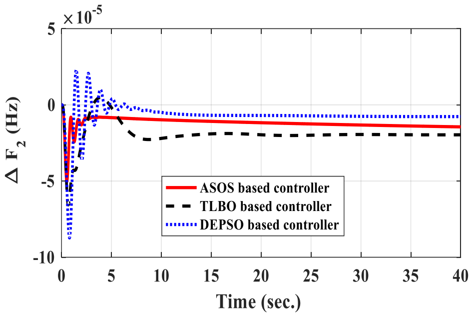

Figure 5. System frequency deviation for area 2

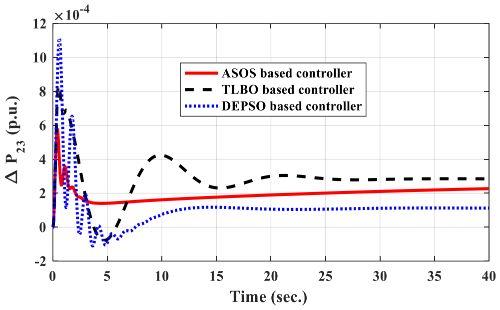

Figure 6. Power deviation between area1 and area 2

From Table 2, the ASOS-based 3DOF-TID controller has a minimum value of settling time (4.16 sec) as compared to TLBO-based (7.35 sec) and DEPSO-based (9.82 sec) methods. Similarly, the dynamic performances of the 3DOF-PID controller optimized by the ASOS algorithm have a minimum overshoot and undershoot than others. Dynamic assessments of all the above controllers are compared through numerous simulations using the ASOS method. To enhance the stability of the proposed system and for better dynamic responses an extra PID controller is cascaded with the 3DOF controller and for better flexibility towards parameter variations, the TID controller is cascaded with the 3DOF controller.

Table 2. Performance values of 3DOF-TID controller optimized by different algorithms

Performance	Algorithm	$\Delta f_1\ in\ Hz$	$\Delta f_2\ in\ Hz$	$\Delta f_3\ in\ Hz$	$\Delta P_{12}\ in\ pu$	$\Delta P_{23}\ in\ pu$	$\Delta P_{31}\ in\ pu$
Settling Time (T_s) in sec	ASOS	4.16	6.20	7.14	8.28	9.14	10.87
	TLBO [15]	7.35	8.79	9.25	11.37	13.46	14.56
	DEPSO [7]	9.82	10.42	11.12	12.68	14.33	15.25
Undersho3ot (U_{sh}) in pu	ASOS	-0.1742	-0.0592	-0.0481	-1.6213	-0.0000	-0.0000
	TLBO [15]	-0.1801	-0.0656	-0.0579	-1.7520	-0.0781	-0.0000
	DEPSO [7]	-0.2077	-0.0873	-0.0701	-2.2410	-0.1102	-0.0000
Overshoot (O_{sh}) in pu	ASOS	0.0000	0.0000	0.0000	0.0000	0.7749	0.8653
	TLBO [15]	0.0130	0.0048	0.0040	0.0000	0.8364	0.9356
	DEPSO [7]	0.0791	0.0231	0.0089	0.0000	1.1140	1.1317

Case 2: Comparison of dynamic performances for all controllers

At first PID, then 2DOFPID controller is used for this proposed system with two extra control loops R(s) and Y(s) are taken and six parameters are optimized for one area. After that, a 3DOFPID controller is used in which three control loops are taken in addition to disturbance D(s) to 2DOFPID where seven parameters are optimized. Then a 3DOFPID is considered as the master controller which is cascaded with a PID as a slave controller for this proposed system. Hence ten parameters are optimized for one area through simulations. Lastly, the cascade connection of 3DOF as a secondary controller and TID as a primary controller is considered. For the TID controller, the value of (n) is taken as 0.5 for each area.

The controller cascaded-three degree of freedom–tilted integral derivative (CC-3DOFPID-TID), in which 3DOFPID controller is used as a secondary loop and TID controller is used as a primary loop with governor action for this proposed three area LFC system. The controller parameters are optimized by the ASOS algorithm to diminish the frequency oscillations. Also, the cascade of two loops 3DOFPID and PID, 3DOFPID, 2DOFPID, and PID controllers are optimized by the ASOS algorithm. The dynamic assessments of all these controllers are compared through widespread simulations. From the simulation results Fig. 7 to Fig. 10, the cascaded two loops 3DOFPID-TID controller has reduced overshoot and undershoot as compared to others.

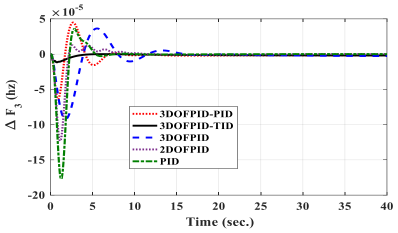

Figure 7. Frequency deviation for area3

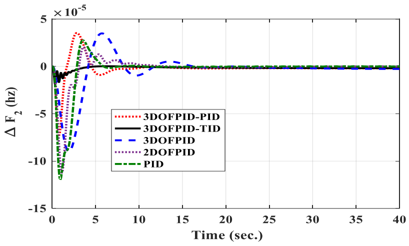

Figure 8. Frequency deviation for area2

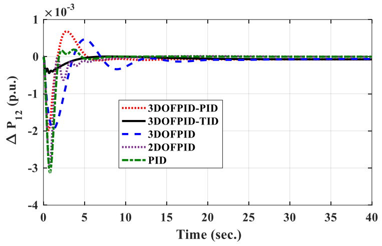

Figure 9. Power deviation between area1 and area 2

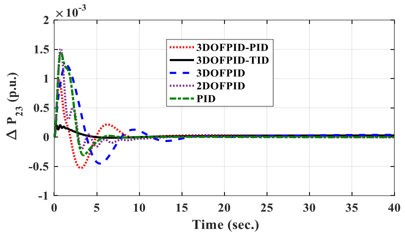

Figure 10. Power deviation between area 2 and area 3

The cascaded 3DOFPID-TID controller optimized by the ASOS algorithm settles quickly as compared to others. Further, the performance of these controllers tuned by the ASOS technique is mentioned in Table 3. Also, the gain parameters of all these controllers optimized by the ASOS algorithm are depicted in Table 4. There are 10 gain parameters such as $(K_1, K_2, K_3, b_1, c_1, Gf_1, N_1)$ for the 3DOFPID controller and (K_4, K_5, K_6) for the TID controller for each area. Hence for the three areas proposed system, 30 parameters are to be optimized by the ASOS algorithm.

Table 3. Output results of settling time, overshoot, and undershoot for all the controllers

Performance	Controller	Δf_1 *in Hz*	Δf_2 *in Hz*	Δf_3 *in Hz*	ΔP_{12} *in pu*	ΔP_{23} *in pu*	ΔP_{31} *in pu*
Settling Time (T_s) in s	3DOFPID-TID	4.46	7.20	8.14	9.82	10.41	11.70
	3DOFPID-PID	7.95	8.497	9.85	11.09	12.64	13.02
	3DOFPID [9]	10.82	10.56	11.22	13.78	14.53	16.52
	2DOFPID [4]	12.76	13.74	14.8	15.22	16.96	18.77
	PID	18.84	24.48	25.05	25.73	26.02	27.77
Undershoot (U_{sh}) in pu	3DOFPID-TID	-0.0838	-0.0184	-0.0116	-0.4412	-0.0107	-0.0006
	3DOFPID-PID	-0.1328	-0.0511	-0.0474	-1.7090	-0.0968	-0.0314
	3DOFPID [9]	-0.1600	-0.0803	-0.0867	-2.2375	-0.2938	-0.1263
	2DOFPID [4]	-0.2194	-0.1123	-0.1232	-2.9150	-0.2012	-0.3024
	PID	-0.2276	-0.1164	-0.1788	-3.1449	-0.3214	-1.0209
Overshoot (O_{sh}) in pu	3DOFPID-TID	0.0115	0.0002	0.0000	0.0053	0.2044	0.2370
	3DOFPID-PID	0.0326	0.0033	0.0037	0.1258	0.8590	0.8500
	3DOFPID [9]	0.0382	0.0291	0.0293	0.2013	1.1135	1.1461
	2DOFPID [4]	0.0453	0.0303	0.0324	0.2148	1.3113	1.4025
	PID	0.0486	0.0408	0.0529	0.2271	1.4701	1.6748

Case 3: Sensitivity Analysis

In this case, a random load form is considered a disturbance to the electrical system. Gains and other parameters of the cascaded 3DOFPID-TID controller are optimized using the ASOS technique. With acquired optimal standards, the dynamic responses for frequency and interchange power deviations are plotted and compared in Fig. 11 and Fig. 12. It is realized from the responses that the cascaded 3DOFPID-TID controller delivers the system responses with shortened fluctuations as compared to individual TID and 3DOFPID controllers.

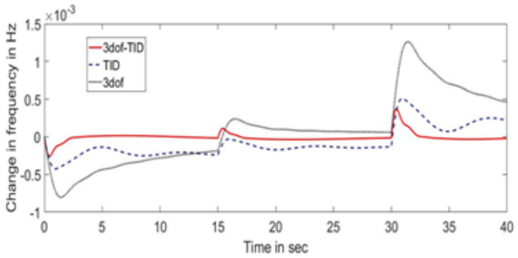

Figure 11. Effect of RLP for frequency deviation

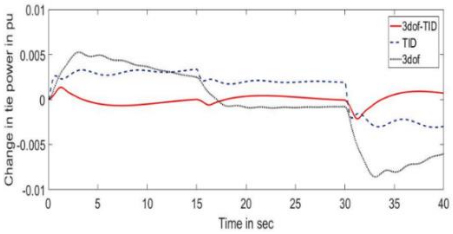

Figure 12. Effect of RLP for tie power deviation

Table 4. Gain values of controllers optimized by ASOS algorithm

Gain parameters	3DOF-TID controller	3DOF-PID controller	3DOF controller	2DOF controller	PID controller
K_1	1.6238	0.0100	0.3260	2.0000	0.7924
K_2	0.4076	2.0000	2.0000	2.0000	2.0000
K_3	1.6300	0.0100	1.2173	0.3216	0.6479
b_1	1.5560	0.3315	2.0000	0.8434	-------
c_1	1.3230	1.8953	1.2492	1.7969	-------
Gf_1	0.0102	0.0100	0.0100	-------	-------
N_1	139.6841	100.0000	100.0000	300.0000	-------
K_4	1.3794	2.0000	-------	-------	-------
K_5	1.6067	1.6690	-------	-------	-------
K_6	1.9611	1.8404	-------	--------	-------
K_7	0.4523	0.2721	0.0100	0.9292	2.0000
K_8	0.9993	0.0100	2.0000	1.0903	1.1671
K_9	0.5062	0.1001	0.9427	1.9177	1.2854
b_2	0.0277	2.0000	0.5173	1.3401	-------
c_2	0.8477	2.0000	2.0000	0.1051	-------
Gf_2	1.472	0.0100	0.0100	-------	-------
N_2	101.8638	163.2779	100.0000	118.4932	-------
K_{10}	0.5464	0.1026	-------	-------	-------
K_{11}	0.5084	0.0100	-------	-------	-------
K_{12}	1.0895	1.1065	-------	--------	--------
K_{13}	0.0100	0.0100	1.7371	1.4811	0.1000
K_{14}	0.4314	1.5651	0.9704	1.0859	2.0000
K_{15}	1.9773	0.4287	2.0000	0.1000	0.1000
b_3	0.1610	1.7726	1.8982	0.1000	-------
c_3	0.7965	0.0100	0.4975	0.1163	-------
Gf_3	1.7372	1.1079	1.2651	-------	-------
N_3	100.4908	100.0000	199.4876	218.8336	-------
K_{16}	0.7454	0.0100	-------	-------	-------
K_{17}	1.0331	2.0000	-------	-------	-------
K_{18}	1.2630	1.1527	-------	-------	-------

4. CONCLUSION

3DOFPID controller cascaded with TID controller is applied to three area hybrid power system. Hybrid power is the combination of conventional thermal and hydro with distributed generation resources. Here area 1, and area 2 are the thermal generating units, and area 3 is the hydro generating unit. DGR is applied to only area 1. The controller parameters are optimized by a recent heuristic ASOS optimization technique

This technique has improved dynamic response as compared to other algorithms such as TLBO and DEPSO algorithms. The ASOS-based controller has minimum oscillation and peak overshoot as compared to TLBO-based and DEPSO-based controllers. The dynamic performances of this proposed system have been compared with all the controllers like PID controller, 2DOFPID controller, 3DOFPID controller, cascaded two loops 3DOFPID and PID controller, and cascaded two loops 3DOFPID with TID controller. The latter one has better stability criteria and also better dynamic performances such as less overshoot and undershoots with less settling time. Sensitivity analysis also reveals that 3DOFPID-TID controller gains are quite reorganized for different loading conditions

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NOMENCLATURE

System parameters	Nominal values
Subscript referred to area i	1 to 4
System frequency (f)	50 Hz
Damping coefficient D_i	1 pu
Speed regulation (R_i)	0.08
Transient droop regulation (R_t)	0.38
Speed Governor for a thermal unit (T_g)	0.1 s
Speed Governor for a hydro unit (T_h)	0.2 s
Inertia constant (M) for thermal unit	10
Inertia constant (M) for hydro unit	6
Turbine time constant T_t	0.3 s
Reheat turbine time constant T_{ri}	10 s
Speed regulation constant R_i	2.4 pu
Reheat turbine gain K_{ri}	0.5 s
Reset time (T_r)	5 s
Frequency Bias coefficient (B)	0.425
Synchronizing power coefficient (T_i)	15 pu
Tie line power coefficient (ΔP_{tie})	0.06 MW/rad
Starting hydro time T_w	1 s
Gain and time constant of WTG (K_{WTG}, T_{WTG})	0.000833, 1.5 s
Gain and time constant of AE (K_{AE}, T_{AE})	0.01, 4 s
Gain and time constant of FC (K_{FC}, T_{FC})	0.02, 0.5 s
Gain and time constant of DEG (K_{DEG}, T_{DEG})	0.0003, 2 s
Gain and time constant of BESS (K_{BESS}, T_{BESS})	-0.0003, 0.1 s