International Journal on Emerging Technologies **11**(4): 292-298(2020)

ISSN No. (Print): 0975-8364
ISSN No. (Online): 2249-3255

Design of CC-3DOF-PD Controller for Load Frequency Control of Multi Area Multi Source System using TLBO Algorithm

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(Received 15 May 2020, Revised 22 June 2020, Accepted 02 July 2020)
(Published by Research Trend, Website: www.researchtrend.net)

ABSTRACT: This study delivers the design of cascaded-three degree of freedom- proportional derivative (CC-3DOF-PD) controller for three area multi source load frequency control (LFC) system. Multi source of LFC are thermal unit for area 1, area2 and hydro units for area 3 providing unified power systems. Different secondary controllers such as proportional integral derivative (PID), two degree of freedom PID (2DOF-PID), three degree of freedom PID (3DOF-PID) controller have studied here individually to control the frequency and tie line power. In this proposed CC-3DOF-PD controller, 3DOF (PID) controller serves as master controller to control frequency and tie line power deviations and PD controller serves as slave controller to maintain balance between real power generation and demand. A heuristic algorithm teaching learning based optimization (TLBO) is applied here for optimizing the controlled parameters. The error function integral time absolute error (ITAE) is taken as objective function for this optimization process. Superiority of proposed CC-3DOF-PD controller over other secondary controllers is performed through numerous simulations. The effectiveness of controller parameters optimized by both TLBO and differential evolution particle swarm optimization (DEPSO) algorithm through extensive simulations using MATLAB/SIMULINK and finally dynamic performances results are compared.

Keywords: Load frequency Control (LFC), Degree of Freedom (DOF), Generation Rate Constraint (GRC), Step Load Perturbation (SLP), Teaching Learning Based Optimization (TLBO).

Nomenclature:
i Subscript referred to area i (1,2,3).
f System frequency (Hz)
D Damping of area, p.u. (MW/Hz)
B_i Frequency bias constant of area i
T_{Gi} Speed governor time constant of area i(s)
T_{CHi} Non reheat turbine time constant of area i
M_i Inertia constant of area i
R_i Speed regulation constant of area i
Rt Speed regulation constant of transient droop
T_r Hydro turbine speed governor reset time (s)
T_W Nominal starting time of water in penstock (s)
Δf_i Frequency deviation of area i (Hz)
Δf_{tiei-j} Tie-line power deviation between area i and j
T_i Synchronizing power coefficient

I. INTRODUCTION

Increasing demand of electricity causes a mismatch between the power system generation and loading of interconnected system. This unbalance causes deviation in system frequency and tie-line power overcome by the closed control of active powers with suitable secondary controllers. The literature review reveals that the investigation in the pitch of load frequency control is happening by Concordia [1]. The chief intention of LFC is to preserve the frequency into scheduled value and controlling the tie-line power exchange in this interconnected system [2]. Automatic generation control (AGC) of interconnected two equal areas, three and five unequal-areas thermal systems is proposed by Saikia, *et al.,* [3]. Two area LFC systems for multi sources like thermal-hydro and gas units are described in paper [4]. Daood *et al.,* [5] delivers LFC of three area system using artificial neural network (ANN) based controller. In preceding works many academics detailed the improved performance of LFC but few of these linked with the system nonlinearities allowing for appropriate GRC and governor dead band (GDB). Tan. W, Chang describes the effect system nonlinearities for frequency control [6].

Nonlinear nature of LFC can be solved by designing suitable secondary controllers. Various researchers have already discussed about these secondary controllers such as classical [3], fuzzy logic, ANN [5]. Simple structure and robustness characteristics of PID controller [7-8] make it popular feedback control in the process industry applications. But it may causes saviour damage in the system performance due to peak overshoot and large settling time in transient period. Fuzzy Logic PID Control for LFC has better robustness as compared to conventional PID [9-10]. However such methods suffer limitations of large computational time due to design process of membership function. Through multiple control loops, control action is achieved which are basically called as degrees of freedom (DOF). In order to enhance the control action, multi degree of freedom PID controllers (MDFPID) like 2DOF-PID and

3DOF-PID controllers are suggested for frequency control by Patel, N.C. [11]. Concept of 2DOF PID controller has discussed which has better response characteristics as compared to conventional PID controller. AGC of multi area system using 2DOF-PID controller is used as secondary controller with GDB has discussed. They propose the LFC of multi area system using 2DOF of PID controller [12-15]. However when the tuning knobs present in a controller are more, the dynamic performances is improved in LFC which needs further investigation. Hence three degree of freedom PID (3DOF-PID) controller is effectively used in the proposed system [16-19]. Rahman *et al*., describes the dish stirling solar system for restructured LFC system using 3DOF-POD controller [18]. The dynamic assessment of 3DOF-PID controller is superior as compared to 2DOF-PID and conventional PID controller is analysed [19]. However few works related to the effect of both primary and secondary controller present in LFC system has not described elaborately. This needs more investigation for the researchers.

Moreover, the conventional controller can jump to take corrective accomplishment in contradiction of arbitrary perturbation only after the adequate eccentricity of controlled output from the reference input. Controller initiates any control action after the disturbances are sensed by plant. Hence a feed-forward controller is taken to solve these issues. However, feed-forward controller requires direct measurement of disturbances and known power system model before to calculate the suitable controlled output. This causes major problem for feed-forward controller. Therefore, cascade controller can be used as a better substitute to improve the performance of the closed-loop system by retaining secondary measurement and secondary feedback organization. In [20] LFC issue of an interconnected four-area power system using a coordinated PI–PD controller is proposed by Dash et al. The aids of using cascade controllers over single-loop controllers have been recognized [21]. Proposed 2DOF-CC, the combination of 2DOF proportional-integral-derivative (2DOF-PID) and 2DOF proportional-derivative (2DOF-PD) controllers is discussed [22].

In this period of computational uprising, more and more heuristic approaches for optimisation are growing. Several grounds of revisions have been discovered with these types of optimization techniques. In LFC different techniques such as bacterial foraging optimization (BFO) [3], differential evolution (DE) [4, 12], flower pollination algorithm (FPA) [8, 20], differential evolution particle swarm optimization (DEPSO) [10],grey wolf optimization (GWO) [11], symbiotic organism search (SOS) [15], biogeography based optimization (BBO) [17, 18], bat algorithm (BA) [21] and teaching learning based optimization TLBO [9, 19, 23-25] are used for optimization of controller variables. In [9] fuzzy PID controller applied to two area system optimized by TLBO was delivered by B.K. Sahu for optimization. It is very necessary to tune the controller parameters properly because improper tuning may causes to either increase of computational time or reaches to local optimum. Considering this fact a new optimization technique is introduced which doesn't require algorithm specific parameters only requires controlling parameters. Since this algorithm carries parameter free optimization, simple in nature and more effective with faster convergence characteristics has widely motivated by researchers to use their areas. Addition of DC link to the existing AC tie line has greater stability to mitigate the frequency deviations [27-28]. High voltage direct current (HVDC) has lower frequency oscillations, improved transient stability and less conduction loss as compared to AC link

This work reveals a practicable model of LFC for harmonizing power generation and load demand.

— Modelling of three area thermal hydro system considering GRC

— The effectiveness of controlling and feasibility of CC-3DOF-PD over 3DOF, 2DOF and PID controller.

— Application of TLBO has been explicated for getting optimum CC-3DOF-PD gain parameters.

— The controller parameters are optimised using TLBO and DEPSO method and the results are compared simultaneously.

II. THREE-AREA POWER SYSTEM MODEL

In this paper thermal units considered for area 1 and 2 and hydro unit is taken in area 3. Each control areas are connected through tie lines. Fig. 1 shows the structural diagram of three area LFC systems. Area control error (ACE) is the summation of frequency deviation with biasing coefficient (B) and tie-line power flow fluctuation. Area control error can be expressed as in equation (1, 2 and 3) [29]:

$$ACE_1 = \Delta P_{12} + B_1 \Delta w_1 \quad (1)$$

$$ACE_2 = \Delta P_{21} + B_2 \Delta w_2 \quad (2)$$

$$ACE_3 = \Delta P_{31} + B_3 \Delta w_3 \quad (3)$$

$\Delta P_{12}, \Delta P_{21}, \Delta P_{31}$ are the tie-line power fluctuations of respective areas

B_1, B_2, B_3 are the frequency biasing coefficient of respective areas

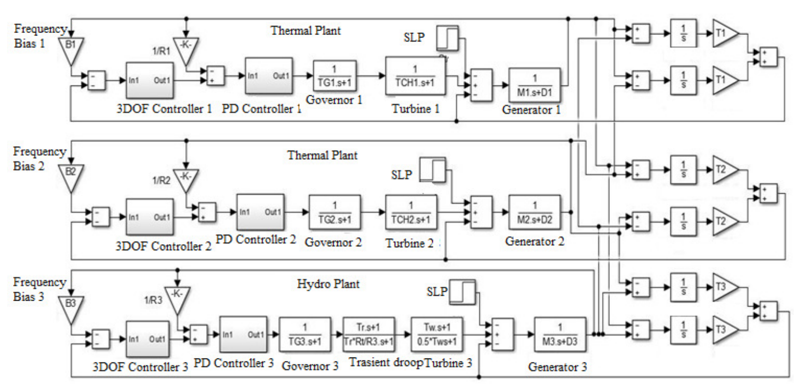

Fig. 1. Transfer function model for three area power system using 3DOF-PID controller cascaded with PD controller.

A. Controller Design
At first a three area thermal-hydro LFC system is modelled with PID controller where area control error (ACE) is taken as input in control area. In this there are three parameters to be optimized (K_P, K_I, K_D). Though PID controller is simple to design, it has severe oscillations with peak overshoot and large settling time causes damage in the system performance. Control action can be achieved by multiple control loops which are basically called as degrees of freedom. So a 2DOF-PID then 3DOF-PID controllers are implemented individually for this system with two control loops R(s), Y(s) and three loops R(s), Y(s) and D(s) respectively. Therefore when the tuning knobs are more in a controller, the performance of the latter is better in AGC. In Fig. 2 [17] 3DOF-PID controller contains three control loops to enhance the stability of the system, proper response curves and exclusion of disorder in the power system due to the extra loop D(S) in 3DOF-PID controller.

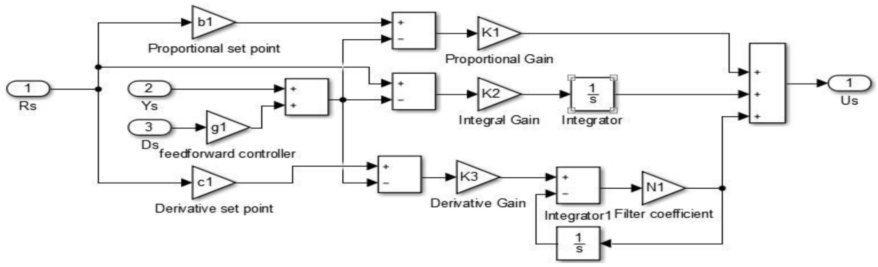

Fig. 2 Basic structure diagram for 3DOF-PID controller

After that a PD controller as primary action again used in cascaded with the 3DOF-PID controller to enhance the stability, faster response and minimize the ACE effectively.

B. Optimization Technique
Teaching Learning based optimization is a teaching learning process inspired algorithm where teacher's influence depends on learner's output. There are two elementary means of learning) through teacher known as teacher phase ii) through interaction with the other learners known as learner phase. Different steps involved in TLBO algorithm are:
(a) Initialization: randomly generating the population size Np and dimension D in order of $[Np \times D]$.
(b) Teacher phase: Calculating the mean value of the subjects that has assigned to a teacher in the class room. For particular subject mean result of learners is
$X_{mean} = [m_1, m_2, \ldots .. m_D]$ (4)
Teacher is assigned as the best learner. r is the random number within [0, 1]. The difference between learner's mean result and corresponding teacher result for a particular subject can be expressed as
$X_{diff} = r.(X_{teacher} - (T_F X_{mean}))$ (5)
T_F, is the teaching factor to be changed 1 or 2 randomly and be represented as
$T_F = round[1 + rand(0,1)]$ (6)
Then the updated value of existing population can be expressed as
$X_{new} = X + X_{diff}$ (7)
If X_{new} is better than X then accepted the elements of X_{new} otherwise accepted the elements of X.

C. Learner phase
In this stage a learner increase his or her knowledge by interacting with other experienced learners. Then randomly selected two learners named as X_p and X_q such that $p \neq q$.

$$X_{new} = \begin{cases} X_p + r(X_p - X_q) & f(X_p) < f(X_q) \\ X_p + r(X_q - p) & \text{otherwise} \end{cases} \quad (8)$$

where $f(X)$ is the value of objective function. This the end of learner phase.

III. RESULT ANALYSIS

In this paper a 3DOF-PID controller cascaded with PD controller is applied to the three area hybrid power system which simulation results can be prepared by MATLAB/SIMULINK through numerous simulations. For this at first, PID with 3 parameters then 2DOF- PID controller in which extra two control loops R(s) and Y(s) is taken with six parameters are optimized for one area. After that a 3DOF-PID controller is used in which three control loops are taken in addition of disturbance D(s) with seven parameters are optimized. Finally a 3DOF-PID controller as secondary controller is cascaded with PD controller as primary action where nine parameters are optimized for one area through simulations. Then a comparison is made among all the above controllers in which later one has better stability as well as improved performance in terms of settling time, undershoot and overshoot. The performance of these controllers is depicted in Table 1.

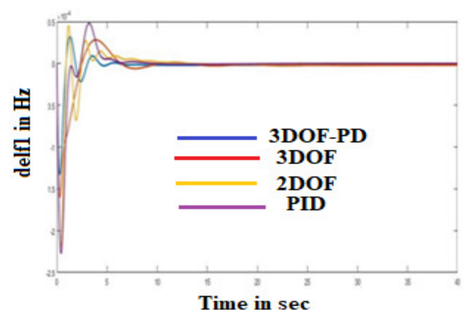

Fig. 3. System frequency deviation for area1 with all controllers.

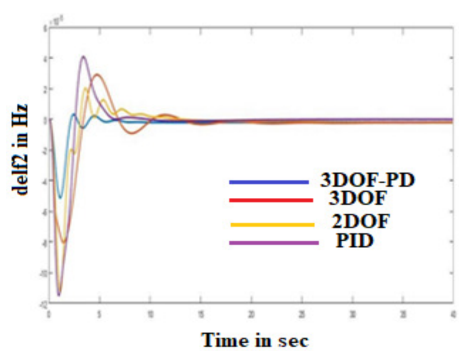

Fig. 4. System frequency deviation for area 2 with all controllers.

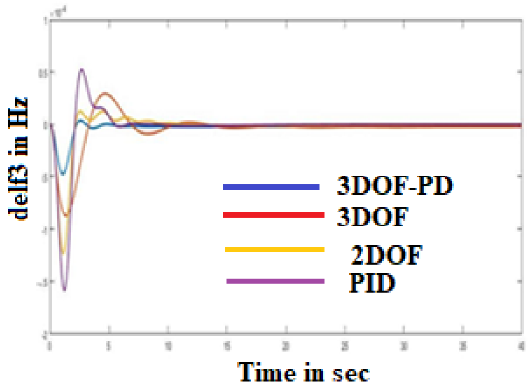

Fig. 5. System frequency deviation for area3 with all controllers.

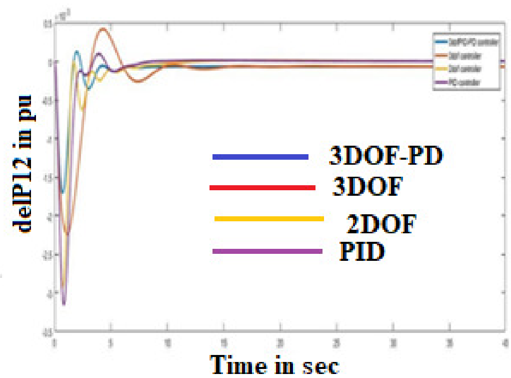

Fig. 6. Tie-line interchanging power for area1 with all controllers.

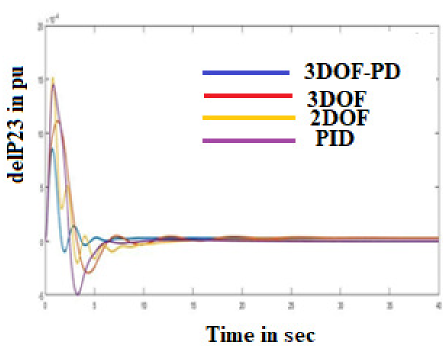

Fig. 7. Tie-line interchanging power for area2 with all controllers.

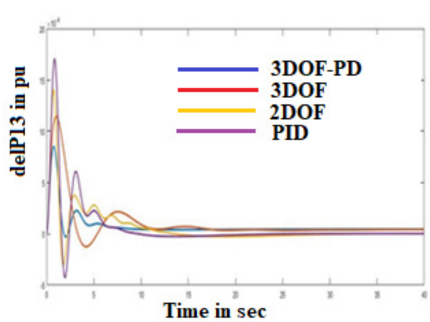

Fig. 8 Tie-line interchanging power for area3 with all controllers.

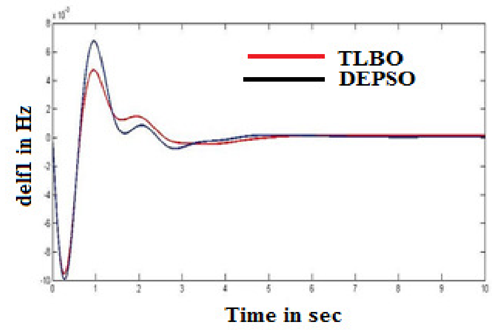

Fig. 9 Frequency deviation for area 1.

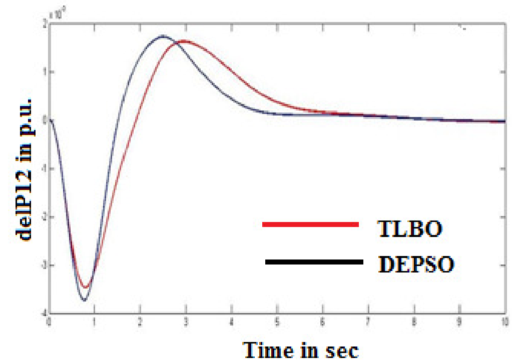

Fig. 10. Tie line power deviation.

Comparison performance of different controllers such as PID, 2DOF-PID and 3DOF-PID are done individually through numerous simulations. The gain parameters of these controllers are optimized by TLBO algorithm. PID controller has three gain parameters such asK_p, K_i and K_d which is simpler in nature. 2DOF controller has five gain parameters such asK_p,K_i, K_d, $b_1$and c_1.This controller has extra two tuning parameters which improves the transient behaviours of the system. 3DOF-PID controller has six controller parameters such asK_p,K_i,K_d,b_1,c_1 anddisturbance factor (d_s).

This controller has more tuning parameters as compared to previous PID and 2DOF-PID controller, hence stability of dynamic performances are superior as compared to other. Cascade of 3DOf-PID controller with more tuning parameters and PD controller with faster transient response makes the system superior as compared to individual secondary controllers. From the simulation results Fig. 3-8 that the cascade of 3DOF-PD controller has less settling time with small oscillations in terms of overshoot and undershoot.

Since TLBO algorithm is free from other parameters it has faster convergence characteristics as compared to DEPSO algorithm. The frequency deviation and tie line power deviation of TLBO based and DEPSO based controller is compared in the simulation results in Fig. 9, 10. The optimized controller parameters are tabulated in Table 2.

Table 1: Output results of settling time, overshoot and undershoot for all the controllers.

	Settling Time (T_s) in s				Undershoot (U_{sh}) in pu				Overshoot (O_{sh}) in pu			
	PID	2DOF	3DOF [19]	3DOF-PD	PID	2DOF	3DOF [19]	3DOF-PD	PID	2DOF	3DOF [19]	3DOF-PD
Δf_1	18.84	12.76	9.82	7.95	-0.2276	-0.2194	-0.1600	-0.1328	0.0486	0.0453	0.0282	0.0326
Δf_2	24.48	13.74	10.56	8.50	-0.1148	-0.1123	-0.0803	-0.0511	0.0408	0.0203	0.0291	0.0033
Δf_3	25.05	14.8	11.22	9.85	-0.1583	-0.1232	-0.0867	-0.0474	0.0529	0.0124	0.0293	0.0037
ΔP_{12}	25.73	15.22	13.78	10.09	-3.1625	-2.9150	-2.2375	-1.7090	0.0971	0.0148	0.4173	0.1258
ΔP_{23}	26.02	16.96	14.53	10.64	-0.4946	-0.2938	-0.2012	-0.0968	1.4533	1.5153	1.1135	0.8590
ΔP_{31}	27.77	18.77	16.52	12.07	-0.4265	-0.3024	-0.1263	-0.0314	1.7092	1.4025	1.1461	0.8500

Table 2: Controller gain parameters of three area system optimized by TLBO algorithm.

Gain parameters	3DOF-PD controller	3DOF controller [19]	2DOF controller	PID controller
K_1	0.0100	0.3260	2.0000	0.7924
K_2	2.0000	2.0000	2.0000	2.0000
K_3	0.0100	1.2173	0.3216	0.6479
b_1	0.3315	2.0000	0.8434	—
c_1	1.8953	1.2492	1.7969	—
Gf_1	0.0100	0.0100	—	—
N_1	100.0000	100.0000	300.0000	—
Kp_1	2.0000	—	—	—
Kd_1	1.6690	—	—	—
K_4	1.8404	0.0100	0.9292	2.0000
K_5	0.2721	2.0000	1.0903	1.1671
K_6	0.0100	0.9427	1.9177	1.2854
b_2	2.0000	0.5173	1.3401	—
c_2	2.0000	2.0000	0.1051	—
Gf_2	0.0100	0.0100	—	—
N_2	163.2779	100.0000	118.4932	—
Kp_2	0.1026	—	—	—
Kd_2	0.0100	—	—	—
K_7	1.1065	1.7371	1.4811	0.1000
K_8	0.0100	0.9704	1.0859	2.0000
K_9	1.5651	2.0000	0.1000	0.1000
b_3	1.7726	1.8982	0.1000	—
c_3	0.0100	0.4975	0.1163	—
Gf_3	1.1079	1.2651	—	—
N_3	100.0000	199.4876	218.8336	—
Kp_3	0.0100	—	—	—
Kd_3	2.0000	—	—	—

Performances of controllers in terms of bar diagram are presented in Fig. 11-13. From that 3DOF-PD controller is finer to others. Fig. 14 shows the convergence graph of TLBO algorithm.

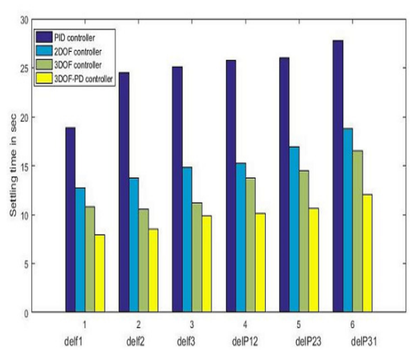

Fig. 11. Bar diagram of settling times for all controller.

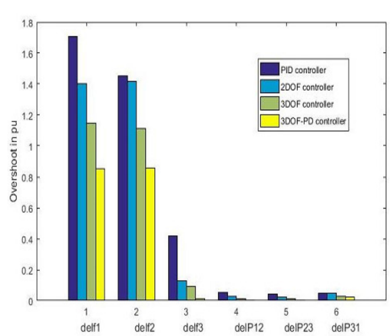

Fig. 12. Bar diagram of overshoots for all controller.

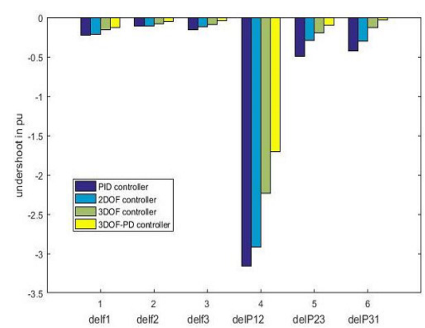

Fig. 13. Bar diagram of undershoots for all controller.

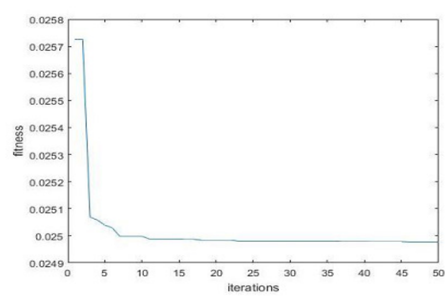

Fig. 14. Convergence graph of TLBO algorithm.

IV. CONCLUSION

A cascade implementation of 3DOF as secondary controller and PD as primary controller is functional for three area LFC system. The controller parameters are optimized by a heuristic optimization technique TLBO. This technique has better convergence characteristics as compared to DEPSO optimized parameters. The performance of CC-3DOF-PD is compared with all other the controllers PID, 2DOF and 3DOF controller. The cascade controller has better stability criteria and also better dynamic performances such as less overshoot and undershoots with less settling time. This proposed system further extended to four area system with renewable energy resources using fractional order controller.

ACKNOWLEDGMENT

This research was supported by Sunita Pahadasingh I cannot express enough thanks to my colleagues for their continued support and encouragement. Foremost I would like to express my sincere gratitude to my guide Asst. Prof. Dr. Chitralekha Jena and Co-guide Prof. Chinmoy Kumar Panigrahi for their continuous support of my research work. I also acknowledge with a deep sense of reverence and gratitude towards my family members who has always supported me morally as well as economically.

APPENDIX

D1=1, D2=1, D3=1, M1=10, M2=10, M3=6, TG1=0.1, TG2=0.1, TG3=0.2,TCH1=0.3, TCH2=0.3, Tr=5, Tw=1, R1=0.08, R2=0.08, R3=0.05, Rt=0.38, B1= (1/R1) +D1, B2= (1/R2) +D2, B3= (1/R3) +D3, T1=15, T2=15, T3=15,T12=0.06, T13=0.08, T21=0.06, T23=0.06, T31=0.08, T32=0.06

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How to cite this article: Pahadasingh, S., Jena, C. and Panigrahi, C. K. (2020). Design of CC-3DOF-PD Controller for Load Frequency Control of Multi Area Multi Source System Using TLBO Algorithm. *International Journal on Emerging Technologies*, *11*(4): 292–298.