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Load Frequency Control of Multi-Area Multi-Source Power System using Teaching Learning Optimization Technique

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Abstract: Interconnecting two generating areas is very beneficial in respect of increased stability, lower generation cost, sharing of load, reducing congestion in transmission and a backup system. In present context too two area interconnected system is being considered. For stable operation it is required that the deviation in frequency and tie line power exchange should almost be zero. To ensure this in each of the system Automatic Generation Control (AGC) is implemented for Load frequency control (LFC) for each area. For this AGC continuously observe the difference in the amount of power i.e. demanded and actual power generated by the units. This difference is termed as Area Control Error which in turn is fed back to LFC loop so as to adjust the generation of units as according to the power demanded. In the present case each area consists of three different power generation sources namely thermal, hydro and gas. Hence, it is a multi unit power source system and it is necessary to coordinate the LFC of each source efficiently in both the areas. To further improvise the performance of LFC loop Proportional Integral Derivative (PID) Controller is included in it, to which ACE act as the input. To give the optimal output from PID controller it was optimized using a new technique Teaching Learning Based Optimization (TLBO).

The given two area system is analysed with two different cases i.e. with AC tie line and then with AC tie line in parallel with HVDC parallel link. To verify the effectiveness of present scheme it was examined and compared with the system employing newly published optimal output feedback controller with DE Algorithm. It was tested with different performance measures such as settling time and standard error criteria of frequency and tie-line power deviation causing a step load perturbation (SLP). It was observed that with the TLBO tuned PID the given system dynamic performance is better and its designed system is tough not affected by variation in loading conditions, system parameters or size of SLP.

Keywords: Automatic Generation Control; TLBO; Load Frequency Control;AC Tie Line;AC-DC Tie Line

I. INTRODUCTION

A. Introduction

Power system is requiring operating stable and maintaining frequency all condition at different types of load. The load frequency control is a best method to achieve this condition. The load frequency control is used for controlling the real power and frequency. It consists of two loop first is primary loop and second secondary loop. We achieve many objectives by Automatic Generation Control(AGC) as maintain frequency, generation as required system and maintain power exchanges through tie lines[5].

The load frequency control applies single area system and also multi area system. Past year load frequency control implemented without controller and optimization technique. Today we apply modern control technique of load frequency control. Modern technique maintains frequency when any change of load. To achieve this many controller such as PI, PID controller and many optimization technique as particle swarm optimization technique, genetic algorithm, fuzzy logic controller, artificial neural network, differential evolution etc. are used.

Since the last few years Teaching learning based optimization(TLBO) is preferred by researchers for optimization problems Teaching learning based optimization(TLBO) offers many advantages over differential evolution like simple algorithm can be easily implemented and it uses few parameters[3].

The proposed Teaching learning based optimization(TLBO) is used to tuned proportional integral derivative (PID) frequency controller. In this we apply as hydro-thermal-gas work based on different conditions. The system performance analysis with tie line bias control, control parameters based on Ziegler-Nichols tuning and control parameters based on the Teaching learning based optimization(TLBO). This comparison shows that Teaching learning based optimization(TLBO) allow efficient operation and compares the result with the differential evolution and improves the result.

B. Objective Function

The aim of this work is to use genetic algorithm to obtain the optimal PID controller parameters for a two-area system. Any adjustment of the regulator represents a particle in the search space, the proportionality of its parameters, K_p, K_i and K_d changes in order to minimize the error function (objective function in this case). The error function used here is the integral time of the absolute errors (ITAE), Integral. The equation are

$$J = \int_0^{t_1}(|\Delta F|).t.dt \tag{1}$$

Hence the design problem of PID controller is stated as

Minimize J subjected to

$$K_{Pmin} \le K_P \le K_{Pmax}, K_{Imin} \le K_I \le K_{Imax}, K_{Dmin} \le K_D \le K_{Dmax} \tag{2}$$

II. SYSTEM MODEL

A. AGC in a Multi Area System

In a nonstop (multi-extend) framework there for each control region of an ALFC loop (situated in the EDC of this range). They are appeared in fig.1 for the related working framework. For an aggregate change in the load demand of ΔP_D the steady state frequency deviation is given in both zones by means of

$$\Delta f = \Delta w_1 = \Delta w_2 = \frac{-\Delta P_D}{\beta_1 + \beta_2} \tag{3}$$

Where

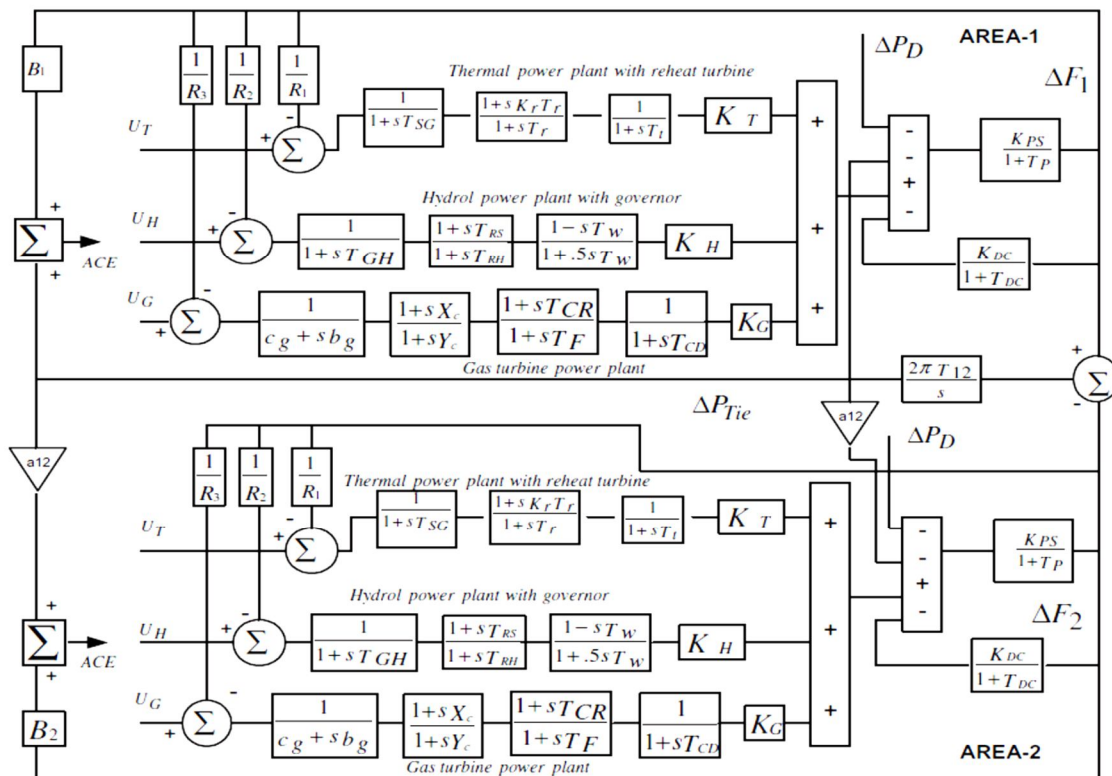$$\beta_1 = (D_1 + 1/R_1) \text{ and } \beta_2 = (D_2 + 1/R_2)$$

Fig.1 AGC for A Multi-Area Operation with AC-DC Parallel Tie Line..

The present piece of work has been discussed and analysed in two cases based on the nature of line. Here, first, the system has been analysed for AC tie line only, then for the second case it was replaced with the AC-DC parallel tie lines as shown in the figure 4.12 and 4.13 respectively. The advantage of using HVDC link in parallel with existing AC tie line is in the stabilization of AC system frequency oscillations. Overall it enhances the system active performances. Also, it provides controlled transmit of power between

two stations. One of the significant applications of HVDC transmission is to maneuver a DC link in parallel with an AC link interconnecting two control areas to get an enhanced system performance with better stability under small system disturbances.The system has been tested for these two particular cases with small load perturbation (SLP) in respect of settling time and frequency deviation.

B. Expression For Tie-Line Flow In A Two-Area Interconnected System

Consider an adjustment in load ΔP_{D1} in area-1. The unfaltering state frequency deviation Δf is the same for both the areas. That is $\Delta f = \Delta f_1 = \Delta f_2$. In this way, for area-1, we have

$$\Delta P_{m1} - \Delta P_{D1} - \Delta P_{12} = D_1 \Delta f \tag{4}$$

Where, ΔP_{12} is the tie line power flow from area_1 to area_2 and for area_2

$$\Delta P_{m2} + \Delta P_{12} = D_2 \Delta f \tag{5}$$

The mechanical power depends on regulation. Hence

$$\Delta P_{m1} = -\frac{\Delta f}{R_1} \text{and} \qquad \Delta P_{m2} = -\frac{\Delta f}{R_2}$$

Substituting these equations, yields

$$(\frac{1}{R_1} + D_1)\Delta f = -\Delta P_{12} - \Delta P_{D1} \text{and} \quad (\frac{1}{R_2} + D_2)\Delta f = \Delta P_{12} \tag{6}$$

Solving for Δf, we get

$$\Delta f = \frac{-\Delta P_{D1}}{\left(\frac{1}{R_1}+D_1\right)+\left(\frac{1}{R_2}+D_2\right)} = \frac{-\Delta P_{D1}}{\beta_1 + \beta_2} \tag{7}$$

and $\qquad \Delta P_{12} = \dfrac{-\Delta P_{D1}\beta_2}{\beta_1 + \beta_2} \tag{8}$

Where β_1 and β_2 are the characteristic composite of area1 or area-2 of frequency response respectively. An increase in the load of area1 ΔP_{D1}(change in load demand of area1) results in a reduction of the frequency in the two zones and a tie line flow of $\Delta P12$. A positive $\Delta P12$ (change in tie line power) indicates the flow from zone-1 to zone-2, while a negative $\Delta P12$, a flow from zone-2 to the zone-1. Similar $\Delta PD2$ change in load area-2, then change in frequency due to change in load demand of area-2 are

$$\Delta f = \frac{-\Delta P_{D2}}{\beta_1 + \beta_2} \tag{9}$$

And

$$\Delta P_{12} = \Delta P_{21} = \frac{-\Delta P_{D2}\beta_2}{\beta_1 + \beta_2} \tag{10}$$

III. TLBO TUNED PID CONTROLLER

A. Teaching Learning Optimization Technique

TLBO is the new kind of optimization algorithm for getting the more optimal operation of the problems, which have been previously, solved using other techniques. It is a very simple concept containing two important parts, one is a Teaching and other is learning.

It simulates the exact environment of a class room where a teacher is imparting knowledge to the students (learner). This is one way of learning as teacher knowledge is always more than the students. Then comes the second way, after teacher left the class room students start discussing the topic taught. Students will share with each their parts understanding of the topic that means interaction among them.

TLBO algorithm follows the same basic concept to find out the best possible solution in two parts,

1) Teacher (best solution) to students (learners)

2) Interaction among learners.

M(i)=mean

T(i)=teacher (best solution point)

Now T(i) will always works to move M(i) close to the value which it has. Therefore, now mean changes to Mnew.

The new solution will be the difference of old and new mean.

$$\text{Mean}(i) = r(i) [\text{Mnew} \; TF \times M(i)] \tag{11}$$

r(i)=random no. (0 to 1)

TF =teaching factor (1 or 2 random selection). TF is responsible for the mean value change.

Therefore, new solution is,

$$\text{Xnew,}(i) = \text{Xold,}(i) + \text{Difference Mean}(i) \tag{12}$$

This is one part of learning directly via teacher. In other part learner learns via interaction among them. Learner learns from another learner only if the other has more knowledge. This update is given as,

I= no. of iteration

For I = 1:Pn

Xi and Xj selected randomly I is not equal to j

If $f(Xi) < f(Xj)$ Xnew(i) = Xold(i) + ri(Xi − Xj)   (13)

Else Xnew(i) = Xold(i) + ri(Xj − Xi)   (14)

Accept Xnew if it gives a better function value.

Algorithm,

Fig.2 shows TLBO algorithm diagram.

a) Statement of problem which is to be optimized. Initialization of parameters of it

Size of population =Pn

Generation number= Gn

No. of Design Variables= Dn its limit (UL, LL).

Ex.

Minimize f (X). Subject to $Xi \in xi = 1, 2. . . Dn$

f (X) =objective function, X = vector for design variables ($LL \leq x(i) \leq UL$)

b) Starting P (Population).

Random generation of population depending on Pn and Dn.

Here, Pn => learners

Dn => Subjects

It is expressed as

$$P = \begin{bmatrix} X_{1,1} & X_{1,2} & \dots & X_{1,D} \\ X_{2,1} & X_{2,2} & \dots & X_{2,D} \\ \dots & \dots & \dots & \dots \\ X_{Pn,1} & X_{Pn,1} & \dots & X_{Pn,D} \end{bmatrix}$$

c) Teacher phase.

Mean calculation P column wise giving mean of each subject.

M,D = [m1,m2, . . . ,mD]

For a iteration best solution is,

Xteaxher=Xf (X)=min

Teacher efforts is to move M, D to Xteacher. This the new mean for the iteration.

Mean Difference (i)= r(i) [Mnew TF×M(i)]

r(i) = random number $(0 \leq r(i) \leq 1)$

TF= teacher factor (0 to 1) decide new mean value

Then the new solution is,

Xnew, (i)= Xold, (i)+ Mean Difference (i)

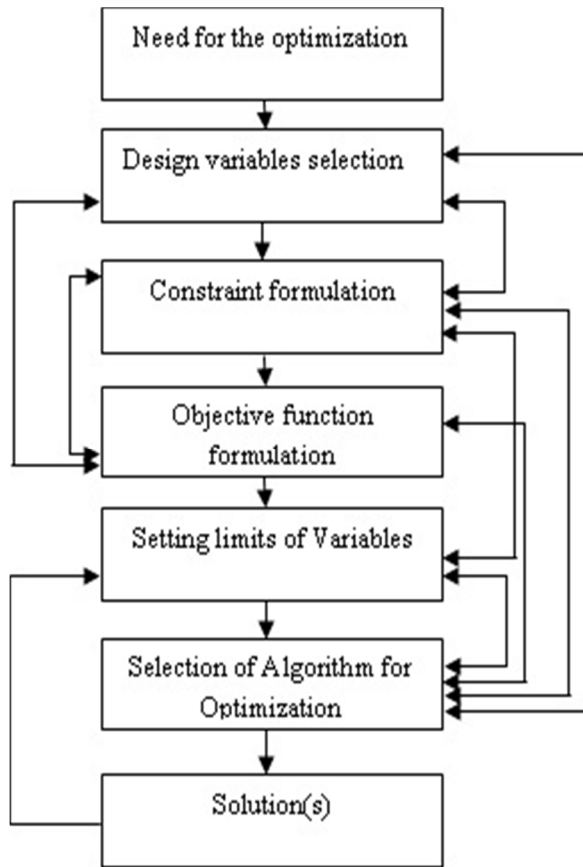If function value is better accept Xnew.

Fig. 2: TLBO Algorithm lock Diagram

d) Learner phase. learners increase their knowledge with the help of their mutual interaction
e) Termination criterion.

The given iteration will stop when Pn=maximum, otherwise goes to step 3.
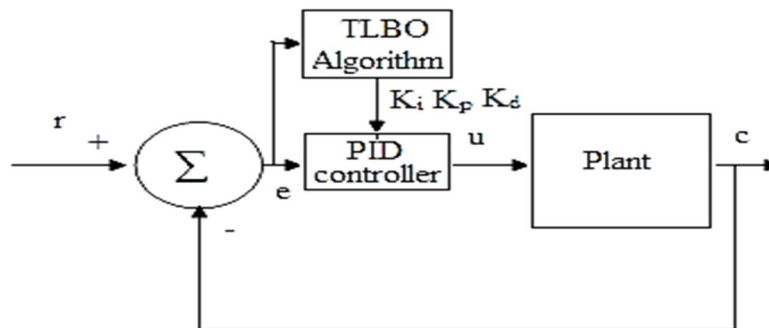
B. TLBO Tuned PID controller

Fig. 3: TLBO Tuned PID

Fig.3 shows TLBO tuned PID controller show.Based on teacher learner relationship PID controller parameters are modified. These modifications in the parameters depend upon the performance index. The performance index must be of minimum value. In a teacher learner relation teachers imparts knowledge of the subject to learners. The subject here are the parameters of controller which should have value close to or nearly equal to the best possible value i.e. optimal solution. There are namely three parameters K_p, K_i and K_d gain of PID controller.

IV.   RESULT AND DISCUSSIONS

This result presents a utility of the novel artificial intelligent search approach to discover the parameter optimization of load frequency control (LFC) considering proportional Integral Derivative Controller (PID) for a power system. A multi-area multi-source power system comprising hydro, thermal with reheat turbine and gas turbine. The linearized models of governors, reheat turbines, hydro turbines, gas turbines are used for simulation and LFC study of the power system. The contrast of Teaching Learning based Optimization Algorithm (TLBO) and Differential Evolution (DE) is employed to look for optimum controller parameters to reduce the time domain objective feature. The overall performance of the proposed approach has been evaluated with two conditions as AC tie lines and AC-DC parallel tie lines. The system parameters optimized by two algorithms by means of contrast with the TLBO and DE algorithm, the effectiveness of the proposed TLBO are verified over different running situations, and device parameter variations.

A.   Matlab/Simulink Implementation Of Block Diagram Of Two Area (Thermal-Hydro-Gas System With No Reheat Turbine) Load Frequency Control

Fig.4 shows a MATLAB/SIMULINK model of multi-area multi-source power system. Each area comprises reheat thermal, hydro and gas generating units. The system operated with two conditions as AC tie lines and AC-DC parallel tie lines. The R_1, R_2, R_3 are the regulation parameters of thermal, hydro and gas units respectively, U_T, U_H and U_G are the control outputs for of thermal, hydro and gas units respectively, K_T, K_H and K_G are the participation factors of thermal, hydro and gas generating units, respectively, T_{SG} is speed governor time constant of thermal unit in sec, T_T is steam turbine time constant in sec, K_r is the steam turbine reheat constant, T_r is the steam turbine reheat time constant in sec, T_w is nominal starting time of water in penstock in sec, T_{RS} is the hydro turbine speed governor reset time in sec, T_{RH} is hydro turbine speed governor transient droop time constant in sec, T_{GH} is hydro turbine speed governor main servo time constant in sec, X_C is the lead time constant of gas turbine speed governor in sec, Y_C is the lag time constant of gas turbine speed governor in sec, c_g is the gas turbine valve positioner, b_g is the gas turbine constant of valve positioner, T_F is the gas turbine fuel time constant in sec, T_{CR} is the gas turbine combustion reaction time delay in sec T_{CD} is the gas turbine compressor discharge volume-time constant in sec, K_{PS} power system gain in Hz/puMW, T_{PS} is the power system time constant in sec, ΔF is the incremental change in frequency and ΔP_D incremental load change.
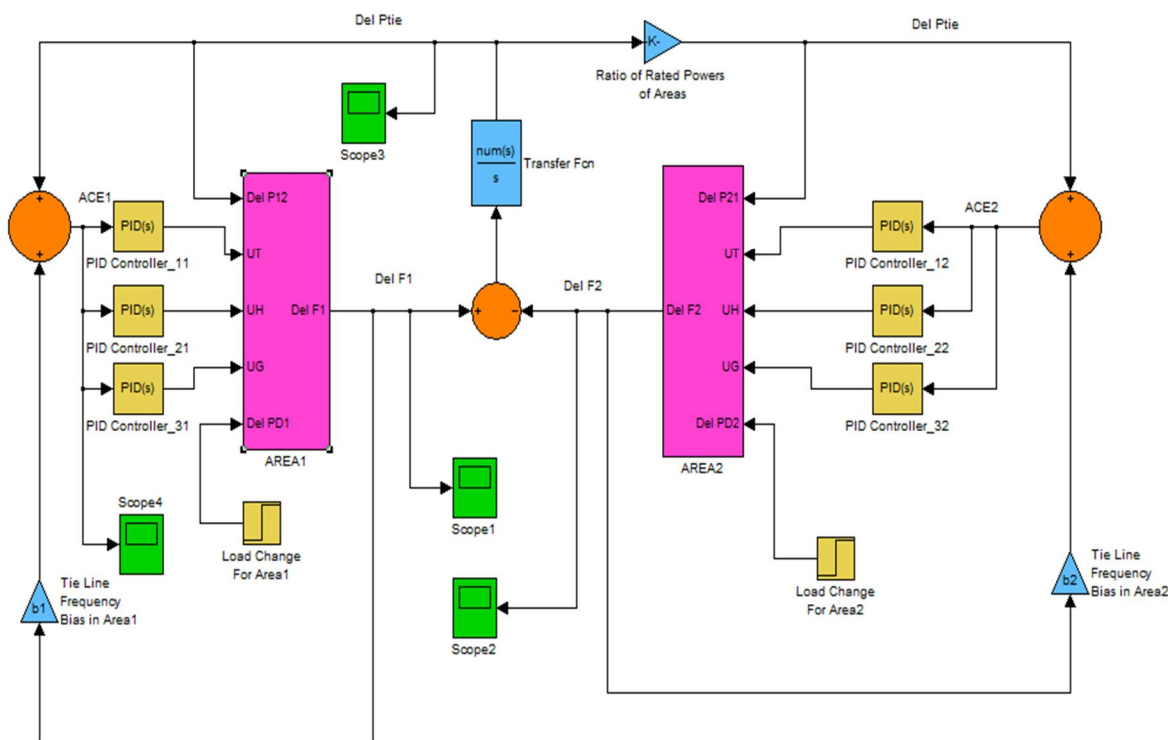

Fig. 4: MATLAB/SIMULINK Model of Multi-Area Multi-Source Power System

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B.   Result Of Tlbo Pid Optimization

Table 1 & Table 2 shows optimized PID parameters with AC & AC-DC Tie line

Table 1: Optimized PID Parameter With AC Tie Only

S.No.	Parameter	DE Optimized PID Controller			TLBO Optimized PID Controller		
		Thermal	Hydro	GAS	Thermal	Hydro	GAS
	ITAE	.004474			0.0103		
1	K_P	0.779	0.5805	0.5023	4.5005	1.4059	1
2	K_I	0.2762	0.2291	0.9529	1.0366	0.3261	9.9981
3	K_D	0.6894	0.7079	0.6569	10	9.3309	1

Table 2: Optimized PID Parameter with AC-DC Tie Line Only

S.No.	Parameter	DE Optimized PID Controller			TLBO Optimized PID Controller		
		Thermal	Hydro	GAS	Thermal	Hydro	GAS
	ITAE	0.1987			0.0143		
1	K_P	1.6929	1.77731	0.9094	9.7138	9.9381	1
2	K_I	1.9923	0.7091	1.9425	1.3423	0.1212	9.8381
3	K_D	0.8269	0.4355	0.2513	3.1984	1.000	1.0007

1)   Case-1: 1% Step Load Change in Area1 with AC Tie Line & AC-DC Tie Line

Fig. 5 to 10 shows frequency deviation of area-1, 2, tie line power deviation and changes in area control error of 1% step load change in area-1. To study the effective behavior of the system with TLBO optimized controllers, a 1% step load perturbation (SLP) is applied at t = 0 s. To show the dominance of the proposed approach, the results are compared with a newly published DE optimized controller for the same power system. It can be seen proposed TLBO optimized PID controller gives superior dynamic response having comparably smaller peak overshoot and lesser settling time as compared to the DE optimized PID controller. The designed controllers are emphatic and carry out the satisfactory operation when employs TLBO PID controller.
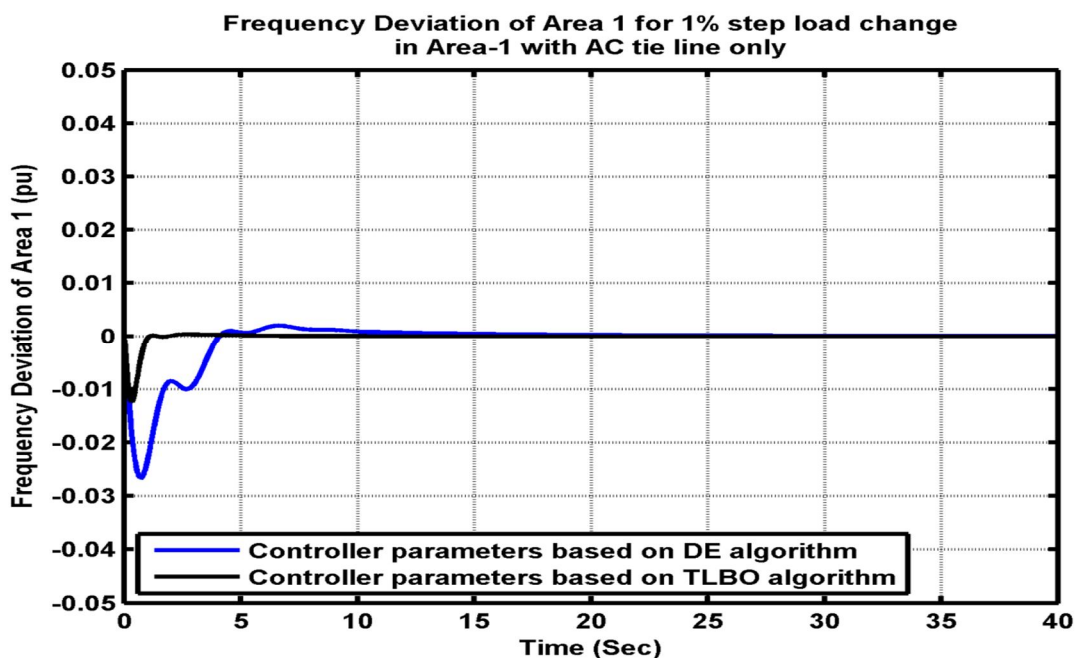

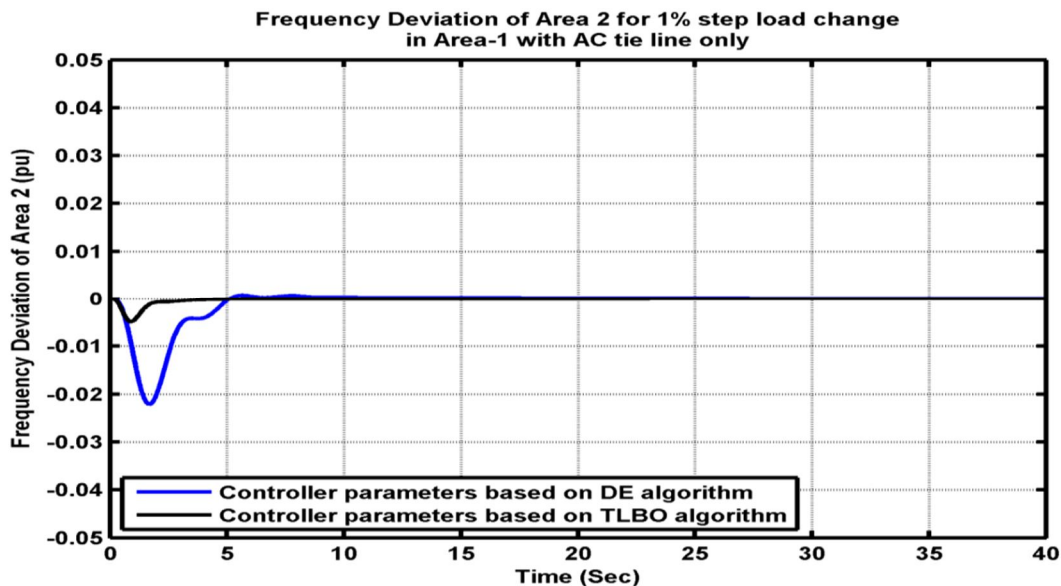Fig. 5. Frequency Deviation of Area-1 for 1% Step Load Change in Area-1with AC Tie line

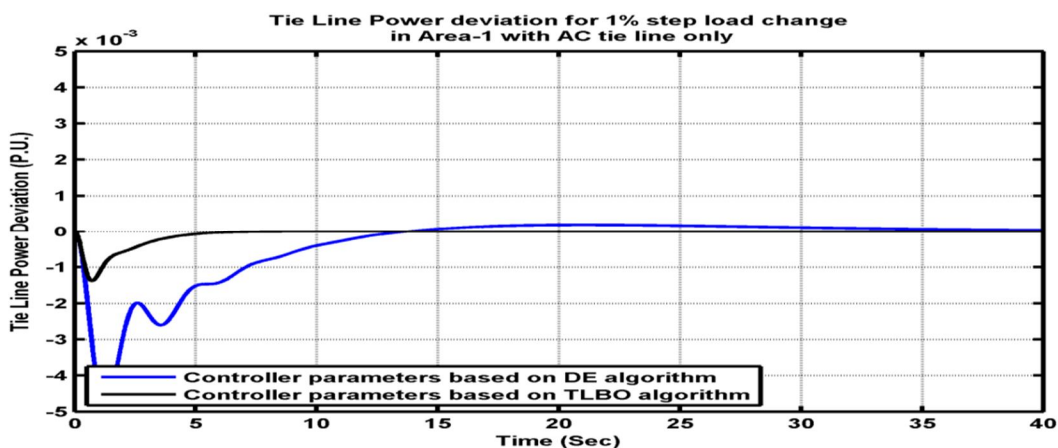Fig. 6 Frequency Deviation of Area-2 for 1% Step Load Change In Area-1 with AC Tie line

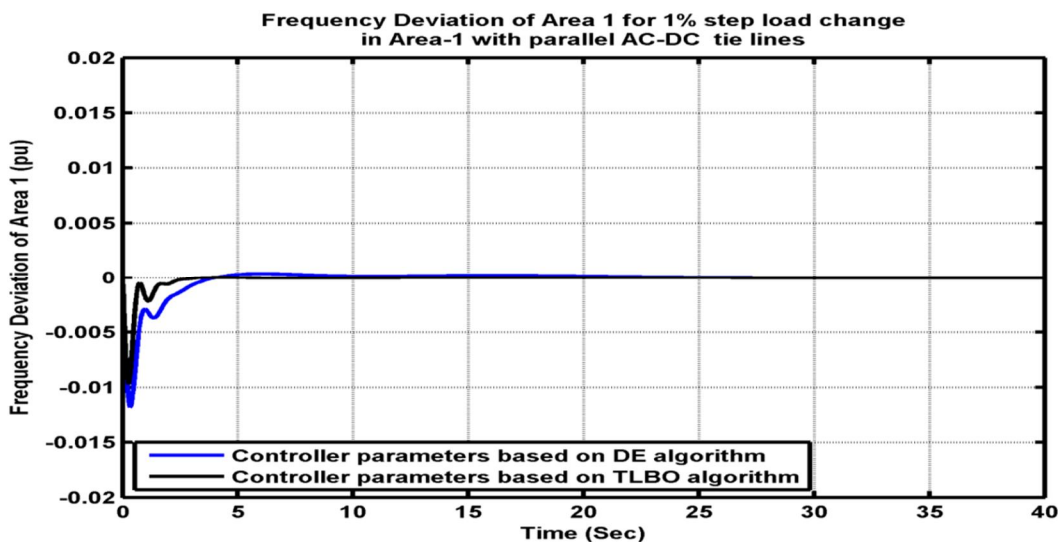Fig. 7 Tie Line Power Deviation for 1% Step Load Change in Area-1 with AC Tie line

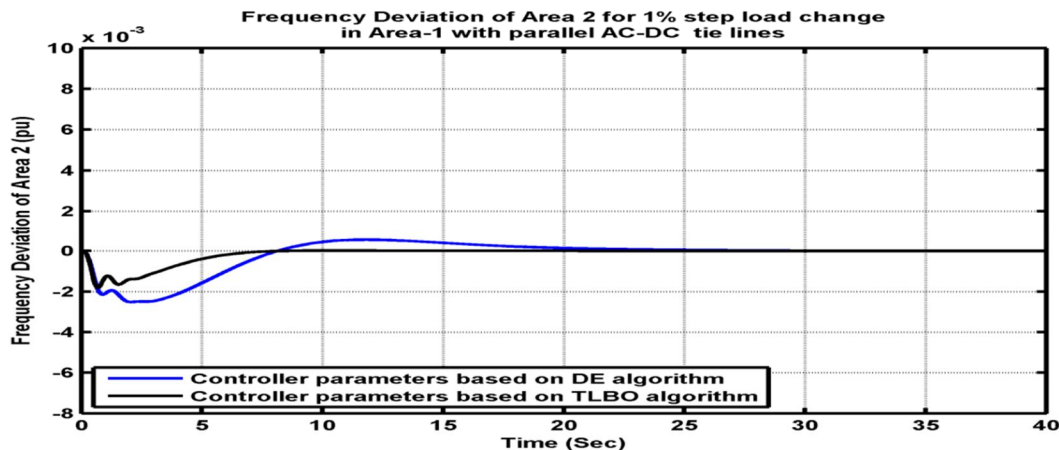Fig.8. Frequency Deviation of Area-1 for 1% Step Load Change in Area-1 with AC-DC Tie Line

Fig. 9 Frequency Deviation of Area-2 for 1% Step Load Change In Area-1 with AC-DC Tie Line
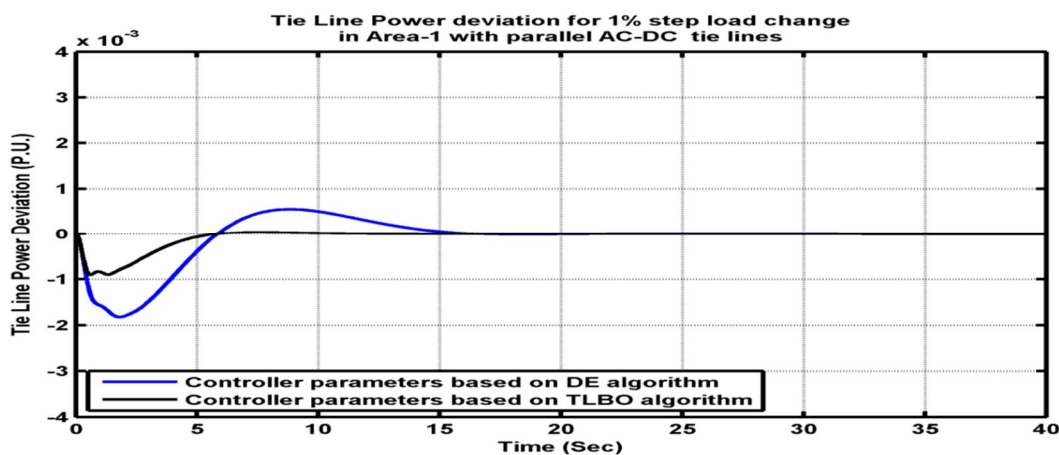

Fig. 10 Tie Line Power Deviation for 1% Step Load Change in Area-1 with AC-DC Tie Line

2)   Case-2 : 1-3 % Step Load Change in Area-1 with AC-DC Tie Line

Fig. 10 to 12 shows frequency deviation of area-1, 2, tie line power deviation and changes in area control error of 1% step load change in area-1. To study the effective behavior of the system with TLBO optimized controllers, a 1% step load perturbation (SLP) is applied at t = 0 s. To show the dominance of the proposed approach, the results are compared with a newly published DE optimized controller for the same power system. It can be seen that proposed TLBO optimized PID controller gives superior dynamic response having comparably smaller peak overshoot and lesser settling time as compared to the DE optimized PID controller. The designed controllers are emphatic and carry out the satisfactory operation when employs TLBO PID controller. . The comparison of different settling time both techniques are shown in table 3.
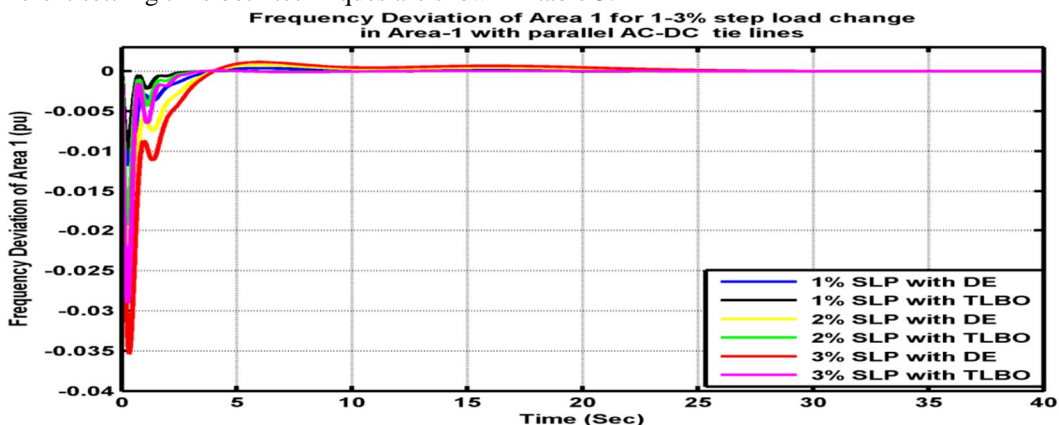

Fig. 10. Frequency Deviation of Area-1 for 1-3% Step Load change in area-1 with AC-DC Tie Line
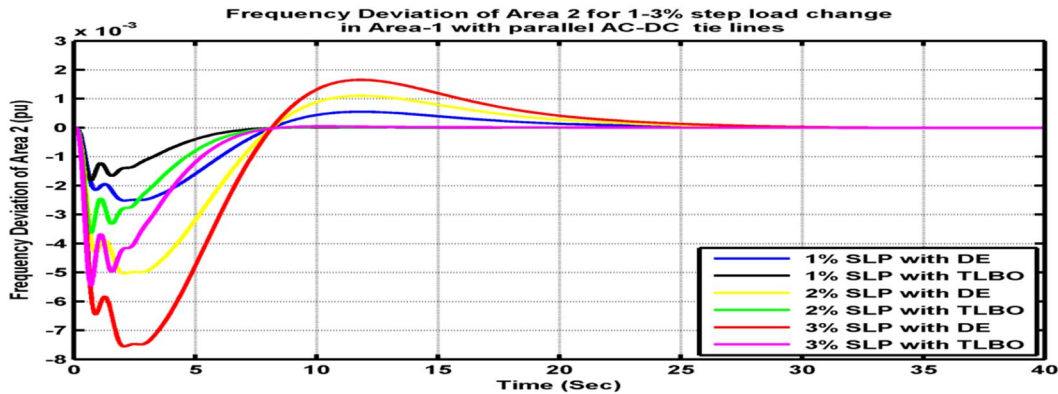
Fig. 11. Frequency Deviation of Area-2 1-3% Step Load change in area-1 with AC-DC Tie Line
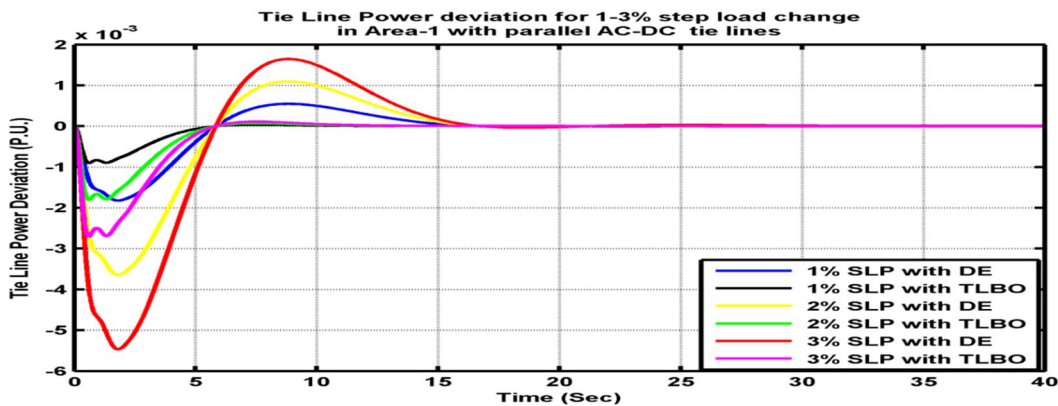

Fig. 12. Tie Line Power Deviation for 1-3% Step Load change in area-1 with AC-DC Tie Line

Table3 1-3% Step Load change in area-1 with AC-DC Tie Line

Frequency Deviation	% SLP	DE Optimized PID (Settling time) (Second)	TLBO Optimized PID (Settling time) (Second)
Area-1	1%	8.3551	2.4806
	2%	8.3351	2.4806
	3%	8.3351	2.4806
Area-2	1%	24.4512	7.4988
	2%	24.4512	7.4988
	3%	24.4512	7.4988
Tie line power deviation	1%	15.3859	10.1171
	2%	15.3859	10.1171
	3%	15.3859	10.1171

V. CONCLUSIONS

Load Frequency Control (LFC) of multi-unit source power system having different sources of power generation like thermal, hydro and gas power plants is given in this paper. The controller parameters are optimized using Teaching Learning Based Optimization (TLBO) optimization technique. System study with two cases first multi-area multi-source power system and second an HVDC link is also designed in parallel with the existing AC tie line for the interconnection of two areas. The parameters of Integral (I), Proportional Integral (PI) and Proportional Integral Derivative (PID) are optimized utilize tuned TLBO algorithm. The excellence of the proposed approach has been shown by comparing the results with newly published optimal output feedback controller for the same power systems by using various performance measures like settling time and standard error criteria of frequency and tie-line power deviation resulting a step load perturbation (SLP). It is observed that, the dynamic performance of proposed controller is improved than an optimal output feedback controller. Moreover, it is also seen that the designed system is tough and is not affected by changes in the loading condition, system parameters and size of SLP.

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