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POWER SYSTEM STABILITY IMPROVEMENT OF MULTIMACHINE SYSTEM USING TLBO OPTIMIZATION TECHNIQUE

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ABSTRACT: In this paper, power system stabilizer (PSS) is carried out using a new Meta heuristic Teaching Learning based algorithm (TLBO) to optimize the parameters. The design of proposed controller is considered with an objective function based on eigenvalue shifting to guarantee the stability of nonlinear system for a wide range of conditions using TLBO. The TLBO optimized PSS controller is applied to the standard two area four machine & IEEE ten-machine thirty nine-bus test power system model and the performance is compared with a robust GSA algorithm. The robustness is tested by considering different fault conditions with change of different loading and operating at different buses of the power system to establish, the superior performance with TLBOPSS over the GSAPSS.

KEYWORDS: Two Area Four Machine;New England System; Power System Stabilizer (PSS); Teaching Learning Based Algorithm (TLBO); Eigen-Value Analysis.

I. INTRODUCTION

The stability of the small signal (SSS) is generally “a slow phenomenon which is characterized by low frequency” vibrations (LFO) in the frequency variety from 0.2 Hz to 3.0 Hz [1]. If not damped properly then it is very undesirable for system. Since they endanger security & integrity of electrical network, it could become even more serious today if the connections to the electrical network become very important [2]. In addition, these vibrations can also shorten the life of the machines in the fuel system. In such fragile conditions, even a minor malfunction, if left unresolved, can compromise system security and, furthermore, an interruption in power supply can lead to system failure and therefore economic loss.

The LFO creates oscillatory unpredictability and causes organization separation if the system is not sufficiently damped. So, the damping of the power supply system plays a significant role in refining the power transmission capacity and stabilizes the structure [3]. PSS is primarily used to dampen and improve the SSS of the SMIB system (Single Machine Infinite Bus) and the MMPS (Multi Machine Power System)[4]. Simple function of the PSS is to recompense for the phase shift error a mid“the excitation input and the electrical torque and to generate a torque component on the rotor.”

Many examination ventures have been completed in field of PSS plan [5]. In earlier years, traditional force framework stabilizer (CPSS) with fixed boundaries was commonly utilized because of its basic idea and structure [6]. The dynamic conduct of a cutting edge power gracefully framework is altogether different under various working conditions. The CPSS which have been produced for certain working conditions may no longer give agreeable outcomes if the working conditions are changed [7]. These exploration endeavors referenced in the writing have prompted the advancement of different methods, for example, customary control strategies: old style control [8], present day control [9], versatile control [10], hearty control [11] and non-direct control [12] for the synchronous change of PSS - Parameters in various working states of the SMIB and MMPS framework. In any case, it is exceptionally hard to apply both recurrence space approach & time area recreation strategy to the assessment of online dependability in the working of the framework. Alleviate the weaknesses of these customary techniques; Many calculations dependent on enhancement have been proposed. The techniques accessible in the writing are no-no exploration [13], the development calculation [14], the differential advancement calculation (DE) [15], reenacted toughening [16], the hereditary calculation [17], fluffy rationale [18], the kind of stretch - 2 Fuzzy rationale [19], counterfeit honey bee state (ABC) [20], improvement of the molecule swarm [21], search calculation d 'agreement [22]. The above streamlining strategies function admirably, however come up short, the target work being very epistic with an enormous number of boundaries. For such a goal work, these techniques can give weakened outcomes extraordinary computational exertion. The principle points of interest of these meta-heuristic strategies are that they are without induction and can look for the ideal or practically ideal answer for the streamlining issue. This article looks at two mainstream meta-heuristic procedures, GSA and TLBO, for the powerful structure of PSS boundaries for MMPS. The PSS structure strategy utilizes an objective capacity

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dependent on eigen values, which incorporates damping factor & ratio, so as to move the marginally damped and/or shaky eigen values in a D-moulded zone in the left 50% of plane S [23]. Different chose streamlining methods are utilized to plan the controls for a two-zone four-zone framework and a New England Power System (NEPS) with 10 machines and 39 transports. Orders planned with GSA and TLBO are called GSAPSS or TLBOPSS. The exploration specialist based GSA is an assortment of masses that communicate with one another dependent on Newtonian gravity, and the Motion of Motion and TLBO calculation depends on the effect of effect of an educator on understudy execution in a class. The principle bit of leeway of the TLBO strategy is that no working boundary is required for its activity, except for the populace size and the greatest number of cycles. Also, the calculation is anything but difficult to actualize and requires less computational memory contrasted with all the calculations referenced better than as GA, PSO, GSA [31] and so forth. TLBO innovation is actualized for some issues with power flexibly frameworks [24]. The effectiveness of different controllers is watched and looked at by an Eigen value examination, time space recreations and execution records for various working conditions in various extreme unsettling influence situations. The strength of all PSS controls planned is additionally inspected by testing and looking at them under imperceptible working conditions.SSS moderation and improvement execution utilizing TLBOPSS is better than GSAPSS.

II. PROBLEM FORMULATION

The goal of this article is to exploit the unrivaled presentation of the TLBO calculation for blending with power frameworks. In this manner, EPS components, for example, generators, the excitation framework and the PSS must be displayed. A target work is important to finish the democratic procedure and must be characterized to get good outcomes. Subsequently, the framework model and an objective capacity utilized during the time spent setting the PSS boundaries for multi-machine taking care of frameworks must be created.

(A) Test Power System

It is a complex and multi structured system. It can be expressed and analyzed via. The differential equations. Expecting that state vector and the info vector are spoken to by X and U separately, the force framework can be appeared as in equ. (1)

$$\dot{X} = f(X, U) \tag{1}$$

A non-linear power system can be linearized taking into account a small disturbance around an operating point. It is easy to design PSS for such a linearized model of a power system [25]. That by Eq. (1) can be determined by equations of state as in the equation. (2).

$$\dot{X} = A\Delta X + BU \tag{2}$$

(a) Two Area Four Machine Test System

The first test system under study is a 10-bus, two-surface power supply system with 4 machines [26]. The system block diagram is illustrated in Fig. 1. Improvement of 0020 minor sign model of a multi-machine taking care of framework is clarified in detail in [27]. It tends to be spoken to by countless differential and logarithmic conditions. Taking N as the quantity of generators in a multi-machine system, with N_{pss} the number of PSS linked in decentralized way to generators. State archetypal container be denoted as in Eqn. (2), where A is the system matrix with instruction 4N × 4N (16 × 16) and is assumed by, δf/δX while B is the input matrix through order 4N × N_{pss} (16 × 4) and is given by δf δU. The order of state vector ΔX is 4N × 1 (16 × 1), and the order of ΔX is N_{pss} × 1 (4 × 1).

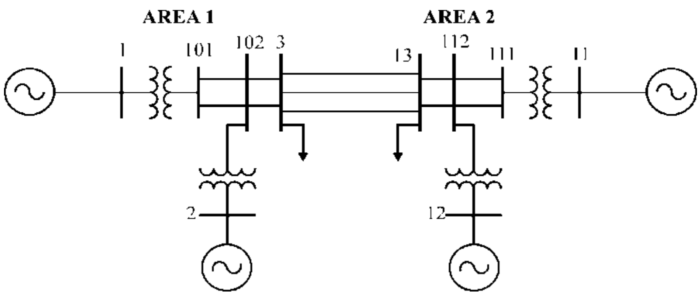

Fig.1 Single Line Diagram of Two Area Four Machine System

(b) New England 10 Machine 39-Bus Test System

The state equations to the power system, involving of N, the quantity of generators, and N_{pss}, the quantity by PSS, be able to be carved as in Eqn (2). Now here, A is the system matrix of the instruction 4N × 4N (40 × 40) and B is the input matrix with the instruction 4N × N_{pss} (40 × 10). The instruction of state vector ΔX is 4N × 1(40 × 1), and the order of ΔU is N_{pss} × 1 (10 × 1). The single-line diagram of IEEE 39-bus power system is presented in fig.2.

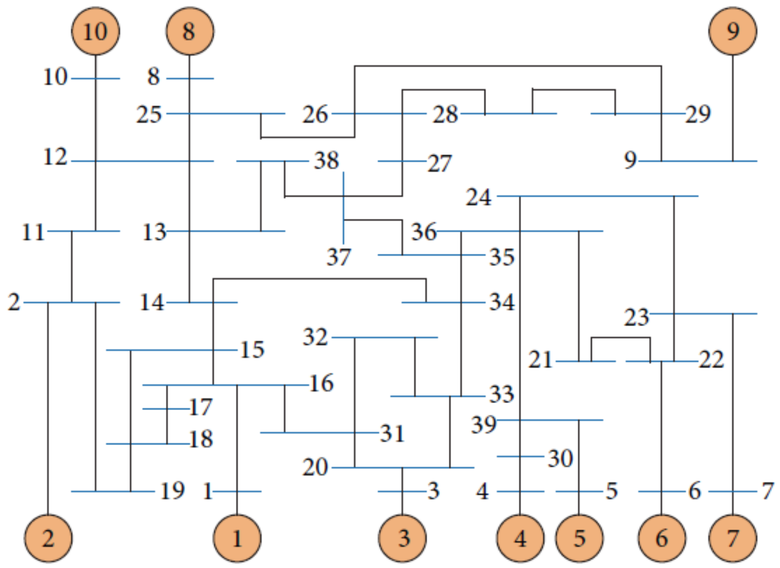

Fig.2 Single Line Diagram of New England System [30]

(B) Objective Function

To ensure stability and obtain improved damping for local and inter-zone oscillations, PSS constraints can be selected so that the following objective function is minimized:

$$J = \sum_{j=1}^{NP} \sum_{\sigma_{ji} \geq \sigma_o} (\sigma_o - \sigma_{ij})^2 + \alpha \times \sum_{j=1}^{NP} \sum_{\xi_{ji} \geq \xi_o} (\xi_o - \zeta_{ij})^2 \qquad (3)$$

Consequently, the Eigen values of the closed-loop system are classified in the D-shaped sector, which is characterized by the system for four machines and ten machines shown in Figures 3 and 4.

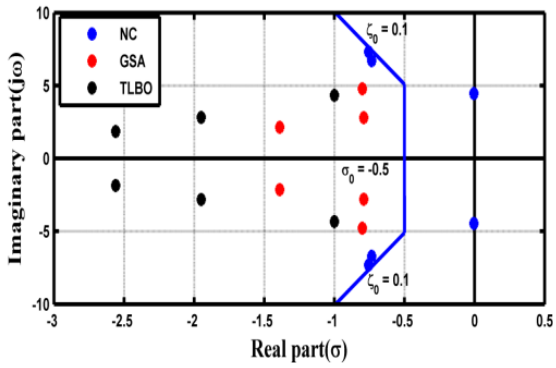

Fig.3 D-Sector Shape for Four Machine System

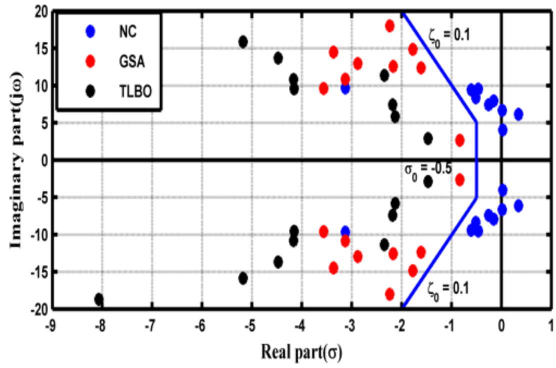

Fig.4 D-Sector Shape for New England System

Where, NP characterizes the whole quantity of functioning points identified in the design difficult, In this paper, $\sigma_0 = -0.5$ and $\xi_0 = 0.1$ are set as correspondingly. Created on objective function J optimized difficult can be stated as:

Minimize J subject to:

$$K_i^{min} \leq K_i \leq K_i^{max} \tag{4}$$

$$T_{1i}^{min} \leq T_{1i} \leq T_{1i}^{max} \tag{5}$$

$$T_{3i}^{min} \leq T_{3i} \leq T_{3i}^{max} \tag{6}$$

III. REVIEW OF TLBO ALGORITHM

The occupied of TLBO is separated into 2 part, “Teacher phase” & “Learner phase”. Their roles and operation is specified below[24].

(A) Teacher Phase

It is initial segment of calculation wherein students gain from the educator. During this stage, an educator attempts to expand the normal aftereffect of the class in the subject he instructs as indicated by his aptitudes. At any emphasis I, acknowledge that there are 'm' amount of subjects (i.e. design variables), ‘n’ quantity of apprentices (i.e. population size, k=1,2,…,n) and $M_{j,i}$ be the mean result of the beginners in a specific subject ‘j’ (j=1,2,…,m) The best generally result $X_{total\text{-}kbest,I}$seeing all the subjects together found in the entire population of learners can be considered as the result of best learner $kbest$. But, since teacher is generally measured to be a extremely qualified person who trains learners to perform better, the algorithm is considered to be the learner best identified by the teacher as the teacher [28] The contrast amid the normal outcome current for every subject & comparing consequence of educator for each subject is:

$$\text{Difference\_Mean}_{j,k,i} = r_i(X_{j,kbest,i} - T_F Z M_{j,i}), \tag{7}$$

Where, $X_{j,kbest,i}$ is consequence of greatest learner in topic j. T_F is teaching issue which chooses worth of mean to be different, & r_i is random-number in choice [0, 1]. Worth of T_F may be also 1 or 2. The worth of T_F is definite randomly through equivalent probability as,

$$T_F = \text{round}[1 + \text{rand}(0,1)\{2-1\}, \tag{8}$$

Where T_F isn't a boundary of the TLBO algorithm estimation of T_F is not assumed as an input to algorithm &it’s worth is randomly obvious by algorithm by eq. (8). Subsequent to leading various tests on numerous benchmark capacities, it is inferred that calculation performs improved if worth of T_F is amid 1 & 2. In any case, calculation is establish to achieve greatly improved if the worth of T_F is each 1 or 2 & hence to normally algorithm, teaching problem is recommended to proceeds each 1 or 2 conditional on the rounding up criteria assumed through eq. (8). Founded on the $\text{Difference\_Mean}_{j,k,i}$, the current resolution is updated in the teacher phase rendering to following appearance.

$$X'_{j,k,i} = X_{j,k,i} + \text{Difference\_Mean}_{j,k,i} \tag{9}$$

Where, $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$. $X'_{j,k,i}$ is recognized if it provides improved occupation worth. All the utility worth recognized at end of teacher's phase are kept and these worth develop input for learning phase. Learning phase be contingent on the teacher's phase [28].

(B) Learner Phase

This is 2^{nd} phase of algorithm in which learners magnify their information through interrelating with every other. A learner relates casually with other learners to expand their information. The expansion of lA learner learns different effects if the other learner has extra information than him or her [29]. Seeing a population size of ‘n’, randomly choice 2-learners P and Q such that $X'_{total-P,i} \neq X'_{total-Q,i}$ (where, $X'_{total-P,i}$ and $X'_{total-Q,i}$ are the efficient function worth of $X_{total-P,i}$ and $X_{total-Q,i}$ of P and Q separately at end of teacher phase)

$$X''_{j,P,i} = X'_{j,P,i} + r_i(X'_{j,P,i} - X'_{j,Q,i}), \text{if } X'_{total-P,i} \le X'_{total-Q,i} \tag{10}$$

$$X''_{j,P,i} = X'_{j,P,i} + r_i(X'_{j,Q,i} - X'_{j,P,i}), \text{if } X'_{total-Q,i} \le X'_{total-P,i} \tag{11}$$

Where, $X''_{j,P,i}$ is accepted if it gives a better function value. The eq. (10) and eq. (11) are for minimization problems. In the case of maximization problems, the eqs. (12-13) are used .

$$X''_{j,P,i} = X'_{j,P,i} + r_i(X'_{j,P,i} - X'_{j,Q,i}), \text{if } X'_{total-Q,i} \le X'_{total-P,i} \tag{12}$$

$$X''_{j,P,i} = X'_{j,P,i} + r_i(X'_{j,Q,i} - X'_{j,P,i}), \text{if } X'_{total-P,i} \le X'_{total-Q,i} \tag{13}$$

(C) Application of TLBO to PSS Design

PSS restrictions are optimized by TLBO algorithm. The objective occupation and TLBO and PSS parameters works as same platform and that is define by fig.5.

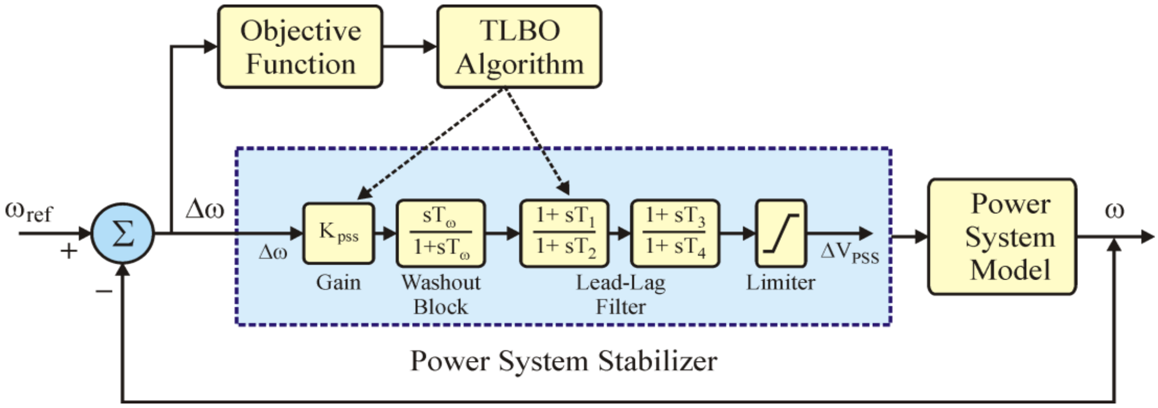

Fig.5PSS Design with TLBO

IV. RESULT & DISCUSSION

(A) Two Area Four Machine System

(a) System Creation for Simulation

Single line diagram of system is defined by fig.1. Main aim the damp out the oscillation is very quickly. The proposed model use PSS controller and controller parameters optimized by TLBO and GSA algorithm. System simulation is running in MATLAB environment and in MATLAB platform the load flow analysis is perform by MATPOWER tool box. The various fault and loading condition is applied to the system. Table 1 is defining different PSS parameters optimized by TLBO and GSA algorithm.Table-2 define the various cases and fault applied in the system.Table-3 define the Eigen value analysis. The Eigen value analysis indicates complete stability of the system. Through participation factor analysis we have find out number of PSS. The proposed system requires three PSS and they install on generator 1, 2& 4.

Algorithm	Gen no.	K	T_1	T_3	Performance Index
GSA	G_1	35.1587	0.3333	0.2028	5.0410
	G_2	32.5147	0.1128	0.4352	
	G_4	21.7456	0.2188	0.2489	
TLBO	G_1	52.7380	0.1862	0.1241	1.0135
	G_2	32.4498	0.1253	0.3491	
	G_4	29.3654	0.0101	0.2536	

Table 1: Optimal PSSs Parameters and Performance Index

Fig. 6 shows graph between best cost v/s iteration graphs of the system. The graph define the TLBO shows better performance than GSA algorithm

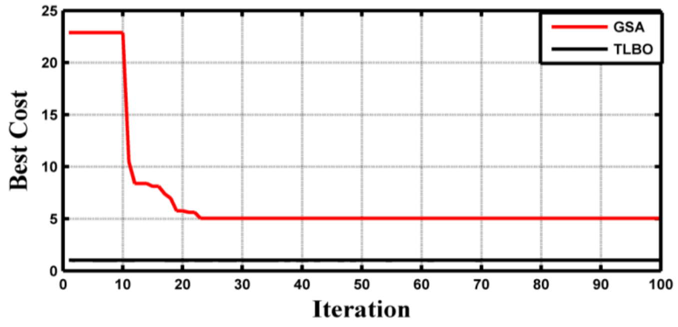

Fig.6 Fitness Function Graph of Both Algorithm

Condition	Fault Condition
Scenario-1	Symmetrical 3-Phase,6-Cycle Fault at Bus 7 at the Starting of Line 7-8 @ 1sec and 20% Step Increase in Mechanical Torque Input of G1 @ 5sec.
Scenario-2	Loss of Single Line A mid Bus 7 and Bus 8
Scenario-3	Loss of Double Line Amid Bus 7 and Bus 8

Table 2: Fault Cases of Two Area Four Machine System

Algorithms	Without PSSs			With GSA		With TLBO	
Fault conditions	**Eigen Values**	**Damp. Factor**	**Frequency**	**Eigen Values**	**Damp. Factor**	**Eigen Values**	**Damp. Factor**
Scenario-1	-0.7553±j7.3158	0.1027	1.1644	-1.39±j2.14	0.5453	-2.56±j1.85	0.8093
	-0.7336±j6.7108	0.1087	1.0681	-0.8±j4.79	0.1647	-1.0±j4.33	0.2252
	-0.0042±j4.4565	0.001	0.7093	-0.79±j2.80	0.2732	-1.95±j2.81	0.5693
Scenario-2	-0.7520±j7.2896	0.1026	1.1602	-1.38±j2.18	0.5365	-2.55±j1.91	0.8008
	-0.7251±j6.6913	0.1077	1.0650	-0.87±j4.76	0.1791	-1.29±j4.22	0.2933
	-0.0125±j3.9193	-0.0032	0.6238	-0.68±j2.55	0.2584	-1.54±j2.69	0.4968
Scenario-3	-0.7445±j7.2561	0.1021	1.1548	-1.37±j2.22	0.5255	-2.53±j1.97	0.7887
	-0.7060±j6.6704	0.1052	1.0616	-0.93±j4.77	0.1917	-1.61±j4.38	0.3444
	-0.0267±j2.8972	-0.0092	0.4611	-0.59±j1.94	0.2903	-1.11±j1.95	0.4937

Table 3: Eigen Value of Two Area Four Machine System

(b) Speed Response Analysis

Fig.7 to 12 shows various speed response at various fault conditions. The system response recorded with without control, with GSA and TLBO algorithm applied the proposed test system. Every fault condition TLBO tuned PSS controller shows superior response than GSA. The system is attenuated low frequency oscillation very quickly. The Eigen value analysis define in table-2 and Eigen value plot in fig.3 prove that Eigen value shift left half of s plane & damping factor is improved when parameters of proposed controller tuned with TLBO algorithm. Finally the stability of system is improved.

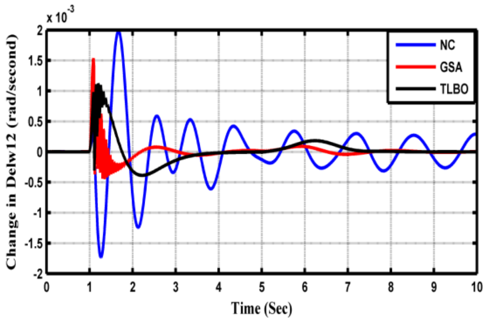

Fig. 7 Change in$\Delta\omega_{12}$(rad/Sec) at Scenario-1

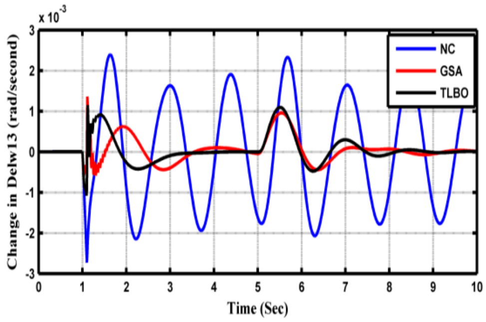

Fig. 8Change in$\Delta\omega_{13}$(rad/Sec) at Scenario-1

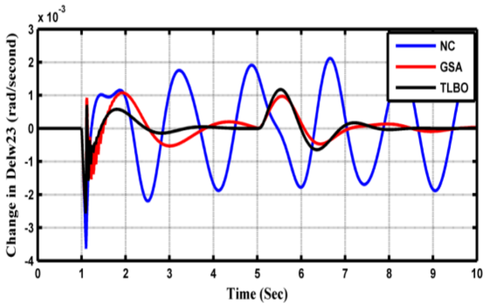

Fig. 9Change in$\Delta\omega_{23}$(rad/Sec) at Scenario-2

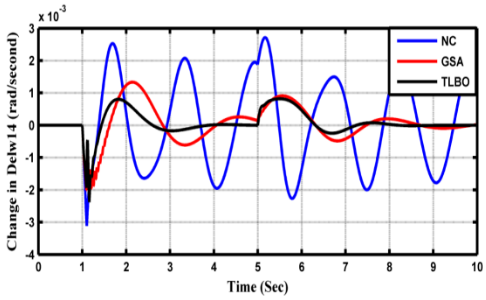

Fig. 10Change in$\Delta\omega_{14}$(rad/Sec) at Scenario-2

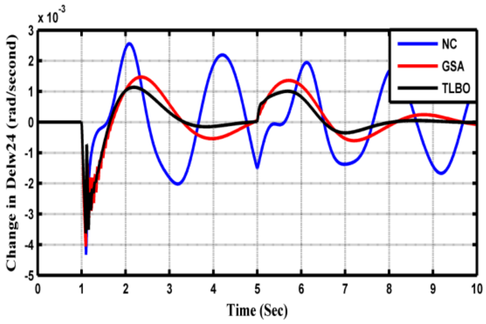

Fig. 10Change in$\Delta\omega_{24}$(rad/Sec) at Scenario-3

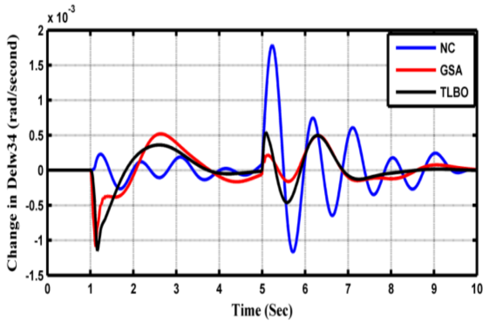

Fig. 11Change in$\Delta\omega_{34}$(rad/Sec) at Scenario-3

B.NEW ENGLAND SYSTEM

(a) System Creation for Simulation

Single line diagram of system is defined by fig.2.The system contain 10 machine 39 bus system. The simulation result is defining the robustness of the system. The controller PSS parameters are optimized by TLBO and GSA algorithm. The load flow analysis is done by MATPOWER tool box[33]. The various fault and contingency analysis is applied the system. Table-3 is shows PSS parameters optimized by TLBO and GSA algorithm. Table-4 shows the various fault applied in the system.Table-5represents the Eigen value represent the stability of the system and number of PSS defines by using participation factor. The nine PSS requirement of the system and they install on generator 1, 3 to 10.

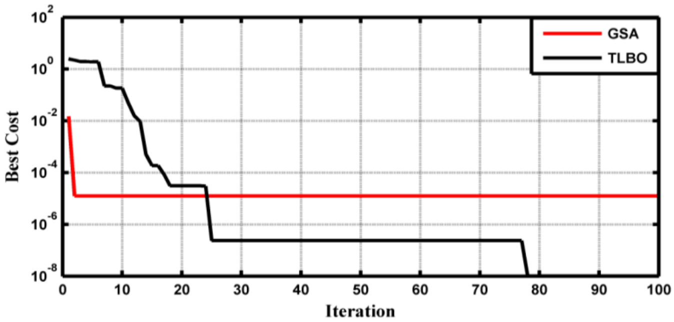

Fig. 12 GSA & TLBO Perfomance Graph

Gen no.	GSA			TLBO		
	K	T_1	T_3	K	T_1	T_3
G_1	59.3718	0.4834	0.02859	13.6479	0.1364	0.3619
G_3	51.6664	0.02594	0.3517	57.1279	0.1251	0.2662
G_4	30.1446	0.4146	0.04606	18.6327	0.127	0.2127
G_5	13.8328	0.3641	0.02363	37.7665	0.2876	0.0794
G_6	27.5312	0.409	0.02322	42.5659	0.0894	0.3245
G_7	66.7979	0.3807	0.04089	48.5865	0.1119	0.0621
G_8	18.6885	0.4223	0.04424	38.5577	0.1807	0.0944
G_9	30.392	0.49	0.01034	13.9823	0.1873	0.2355
G_{10}	32.6304	0.4232	0.01386	24.6817	0.0378	0.3268

Table 4: Optimal PSSs Parameters of New England System

Condition	Fault Condition
Scenario-1	A Symmetrical 3-phase,6-cycle Fault at Bus 29 at the end of Line 26-29 @ 1sec without Tripping the Line 26-29
Scenario-2	Outage of Line 21-22
Scenario-3	Outage of Line 2-19

Table 5: Various Faults on New England System

Algorithms	Without Controller			With GSA		With TLBO	
Fault Conditions	Eigen Values	Damp. Factor	Frequency	Eigen Values	Damp. Factor	Eigen Values	Damp. Factor
Scenario-1	-0.1537±j7.9431	0.0193	1.2642	-1.7751±j14.8486	0.1187	-2.1801±j7.4173	0.2820
	0.0287±j4.0382	-0.0071	0.6427	-0.8334±j2.6620	0.2988	-1.4708±j2.8807	0.4547
	0.0164±j6.6610	-0.0025	1.0601	-2.1695±j12.5764	0.1700	-8.0675±j18.7014	0.3961
	-0.2556±j7.4176	0.0344	1.1805	-2.8782±j12.9474	0.2170	-4.1547±j9.5580	0.3986
	-0.4611±j9.5254	0.0483	1.5160	-3.5624±j9.6124	0.3475	-5.1781±j15.8793	0.3100
	-0.6060±j9.4132	0.0643	1.4982	-2.2366±j18.0274	0.1231	-2.3455±j11.3667	0.2021
	-0.5123±j8.3664	0.0611	1.3316	-3.1301±j10.8497	0.2772	-4.1662±j10.8175	0.3594
	0.3427±j6.1312	-0.0558	0.9758	-1.6110±j12.3775	0.1291	-2.1284±j5.8152	0.3437
	-3.1281±j9.6765	0.30761	1.5401	-3.3639±j14.4842	0.2262	-4.4734±j13.6827	0.3108
Scenario-2	-0.1562±j7.9794	0.0196	1.27	-1.7986+j14.7584	0.1210	-2.1297±j7.2980	0.2801
	0.1244±j3.7235	-0.0334	0.5926	-0.7202±j2.6474	0.2625	-1.1439±j2.8121	0.3768
	0.1748±j6.2824	-0.0278	0.9999	-2.2164±j12.4305	0.1755	-8.2392±j18.4081	0.4085
	-0.08±j6.8011	0.0118	1.0824	-2.8517±j12.7805	0.2178	-2.8076±j7.6395	0.3449
	-0.5376±j9.5502	0.0562	1.52	-2.5625±j9.9981	0.2483	-5.2177±j15.2627	0.3235

	-0.6027±j9.4424	0.0637	1.5028	-2.3403±j17.3844	0.1334	-2.8808±j12.0495	0.2325
	-0.5501±j8.3022	0.0661	1.3213	-3.5107±j10.8106	0.3089	-0.3.6759±j10.2984	0.3362
	0.2261±j5.7203	-0.0 395	0.9104	-1.6504±j12.3254	0.1327	-1.8647±j6.6306	0.3144
	-3.0613±j9.5863	0.3042	1.5257	-3.4814±j14.2389	0.2375	-4.4645±j13.5234	0.3135
Scenario-3	-0.1699±j8.0003	0.0212	1.2733	-1.8422±j14.5290	0.1258	-2.266±j7.3065	0.2915
	0.0247±j3.1567	-0.0078	0.5024	-0.5033±j2.0320	0.2404	-0.7213±j2.0318	0.3346
	0.02±j6.4711	-0.0031	1.0299	-2.3654±j12.3766	0.1877	-8.2888±j18.4323	0.4101
	-0.2580±j7.4124	0.0348	1.1797	-2.8793±j12.9291	0.2174	-4.1508±j9.4560	0.4019
	-0.4655±j9.5306	0.0488	1.5168	-3.3652±j9.7907	0.3250	-5.1779±j15.8345	0.3108
	-0.6111±j9.4171	0.0648	1.4988	-2.2481±j18.0020	0.1239	-2.3401±j11.3595	0.2018
	-0.5231±j8.3579	0.0625	1.3302	-3.2920±j10.8901	0.2894	-4.1076±j10.7861	0.3559
	0.3591±j6.0962	-0.0588	0.9702	-1.6172±j12.3678	0.1297	-1.9101±j5.7998	0.3128
	-3.1095±j9.6536	0.3066	1.5384	-3.4431±j14.3847	0.2328	-4.4611±j13.6351	0.3110

Table 6: Eigen Value of NEPS

(b) Speed Response Analysis

Fig. 13 to 18 shows various speed deviation of generator 8 & 9.The system performance compare with GSA and TLBO algorithm. The time domain simulation defines with three scenarios. When PSS parameters tuned with TLBO algorithm the system attenuated low frequency oscillation is very quickly. The both condition Eigen value analysis and time domain simulation system shows satisfactory result and dam pout oscillation with minimum time at different fault.

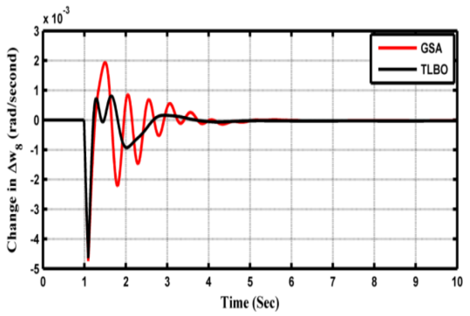

Fig. 13 Change in$\Delta\omega_8$ (rad/second) at Scenario-1

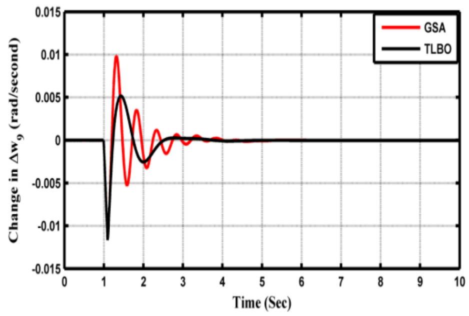

Fig. 14 Change in$\Delta\omega_9$ (rad/second) at Scenario-1

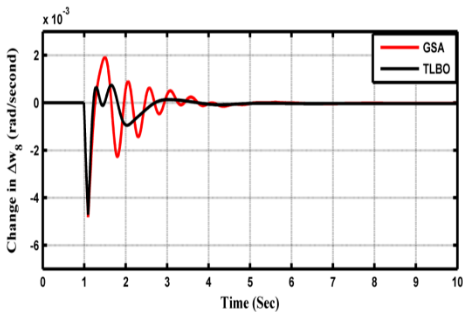

Fig. 15 Change in$\Delta\omega_8$ (rad/second) at Scenario-2

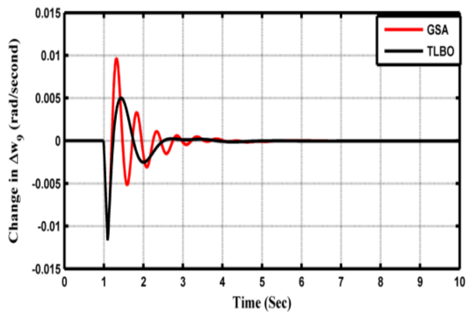

Fig. 16 Change in $\Delta\omega_9$(rad/second) at Scenario-2

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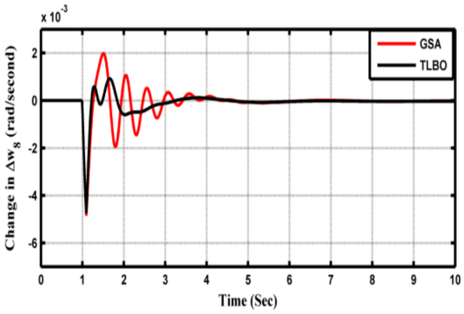

Fig. 17 Change in$\Delta\omega_8$ (rad/second) at Scenario-3

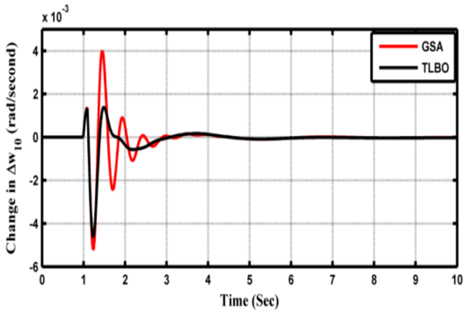

Fig. 18 Change in$\Delta\omega_9$(rad/second) at Scenario-3

V. CONCLUSION:

This paper proposed PSS controller is optimized by TLBO technique. The parameters of PSSs design are successfully applied to multimachine power system. The eigen value based objective function applied to the system. The D sector shape and eigen value assessment define the robustness of the system. The various graphs are presented graphical and tabular form that defines effectiveness of the proposed system. Finally TLBOPSS system shows superior response than GSAPSSs for different fault conditions.

Appendix-A

Machine models [1]

$$\dot{\delta}_i = \omega_b(\omega_i - 1) \tag{A.1}$$

$$\dot{\omega}_i = \frac{1}{M_i}(P_{mi} - P_{ei} - D_i(\omega_i - 1)) \tag{A.2}$$

$$\dot{E}'_{qi} = \frac{1}{T'_{doi}}(E_{fdi} - (x_{di} - x'_{di})i_{di} - E'_{qi}) \tag{A.3}$$

$$\dot{E}_{fdi} = \frac{1}{T_{Ai}}(K_{Ai}(\upsilon_{refi} - \upsilon_i + u_i) - E_{fdi}) \tag{A.4}$$

$$T_{ei} = E'_{qi}i_{qi} - (x_{qi} - x'_{di})i_{di}i_{qi} \tag{A.5}$$

Whereδ=rotor angle;ω= rotor speed; P_m and P_e=mechanical and electrical power;υ =terminal voltage; T_e=elecric torque; T'_{do} =excitation circuit time constant

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