Optimal Reactive Power Dispatch Using Teaching Learning Based Optimization Algorithm with Consideration of FACTS Device “STATCOM”

Khaled N. Nusair Muwaffaq I. Alomoush

***Abstract*— this paper shows solution of optimal reactive power dispatch (ORPD) problem using a Teaching Learning Based Optimization Algorithm (TLBO) with consideration of flexible alternating current transmission systems (FACTS) device “STATCOM”. The target is to minimize the transmission losses, enhance the voltage profile, determine the optimal value of control variables such as generator voltage magnitudes, tap setting of the transformer and number of compensation devices and also maintain a reasonable system performance in terms of limits on generator real power and reactive power outputs, bus voltages and power flow of transmission lines. In order to reduce the total active power loss, improve power system voltage, enhance reliability and increase power transfer limits. We propose also the optimization of the placement of FACTS devices in the power system (STATCOM). The proposed method is examined on IEEE 14-bus and modified IEEE 30-bus power systems. The results of this technique is compared with previous results obtained by particle swarm optimization ,Differential evolution (DE) , Modified Hybrid PSO (MHPSO) , Mutated PSO (MPSO) , Self adaptive real coded genetic algorithm (SARGA) , Genetic Search (GS) ,Comprehensive learning PSO , Control schemes of the strategy parameters (CSSPs) , Evolutionary programming (EP) ,Sequential quadratic programming (SQP) ,Particle swarm optimization–Cauchy mutation (PSO-CM) , Particle swarm optimization –Adaptive mutation (PSO-AM) , Hybrid algorithm of differential evolutionary programming (DEEP) .**

***Index Terms*– Active Power Loss, Optimal Reactive Power Dispatch (ORPD), Teaching Learning Based Optimization Algorithm (TLBO), Flexible Alternating Current Transmission Systems (FACTS), Static Synchronous Compensator (STATCOM).**

I. Introduction

THE Optimal reactive power dispatch aims to reduce the active power loss, enhance the fineness of voltage, while fulfilling a set of operational and physical constraints. It determines controllable variables like generator voltage magnitudes, tap setting of the transformer and number of compensation devices, etc. ORPD is a complex combinatorial optimization problem, which includes nonlinear functions, and has various Local minima and nonlinear and discontinuous constraints [1].since optimal power flow was first discussed by carpentier in 1962 [2].many optimization methods have been used in this area. Various classical methods have been applied for solving the problem like dual linear programming [3], P-Q decomposition approach [4], Quadratic programming [5], united approach [6], two level hierarchical approach for optimum allocation of Var sources [7], and penalty function linear programming technique [8]. Recently, artificial intelligence methods have become widespread for solving the reactive power optimization problem due to their advantages such as no need of derivative information, ability to not get stuck in a local minimum and ability to cope with large scale non-linear problems. Different artificial intelligence methods have been applied for solving the problem such as genetic algorithm [9,10], evolutionary programming [11],particle swarm optimization[12],improved hybrid evolutionary programming [13],multi-agent particle swarm optimization [14],hybrid genetic algorithm [15], seeker optimization algorithm [16],etc.these artificial intelligence techniques can enhance optimal solutions for the reactive power optimization problem compared to the classical methods but with proportionally slow implementation.

The Static Synchronous Compensator (STATCOM) is a member of the group of Flexible Alternating Current Transmission Systems (FACTS) with very attractive features such as compensation the reactive power in a grid, stabilization the grid voltage and improvement the power transfer capability of the system [17].

Teaching Learning Based Optimization Algorithm is a new kind of population based global optimization method, which was first proposed by Rao et al in 2011 [18].As in other population population-based algorithms, in TLBO, The basic idea of TLBO is that the teacher is considered as the most knowledgeable person in a class who shares his/her knowledge with the students to improve the output (i.e., grades or marks) of the class. The quality of the learners is

Manuscript received february 28, 2017.

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evaluated by the mean value of the student's grade in class. Furthermore, learners also learn from interaction between themselves, which also helps in their results. [18]

TLBO algorithm has been used in many application in electrical power system such as optimization of PID controller [19], Impact of PEVs on automatic generation control [20], solution of price based unit commitment [21], dynamic economic emission dispatch [22], tuning of PID controller for linear motor [23], coordination of directional over current relays in presence of distributed generation [24] and loss allocation in radial distribution system with multiple DG [25].

The purpose of this paper is to develop an algorithm to find the minimization of the active power loss, maintain a reasonable system performance in terms of limits on real power generation, reactive power generation and power flow of transmission lines. This problem is solved using TLBO and Newton Raphson load flow method. It is examined on IEEE 14-bus and IEEE 30-bus power systems. and the obtained results are compared to those from particle swarm optimization [26],Differential evolution (DE) [27], Modified Hybrid PSO (MHPSO) [28], Mutated PSO (MPSO) [29], Self adaptive real coded genetic algorithm (SARGA) [30], Genetic Search (GS) [31],Comprehensive learning PSO [32], Control schemes of the strategy parameters (CSSPs) [32], Evolutionary programming (EP) [34],Sequential quadratic programming (SQP) [35],Particle swarm optimization–Cauchy mutation (PSO-CM) [29], Particle swarm optimization –Adaptive mutation (PSO-AM) [29], Hybrid algorithm of differential evolutionary programming (DEEP) [34].

II. Formulation of The Optimization Problem

The aim The aim of the reactive power optimization problem is to optimize the objective function while fulfilling various equality and inequality constraints.

The objective function can be described as follows:

$$Min\, P_{Loss} = \sum_{k=1}^{Nl} g_k [V_i^2 + V_j^2 - 2V_iV_j \cos(\delta_i - \delta_j)] \qquad (1)$$

where P_{loss} denotes active power loss of the power system, gk is the conductance of branch k, N_B is the total number of bus V_i and V_j are the voltage of bus i and j respectively, N_k and N_c are the number of tap changing transformers and shunt VAR compensators respectively, N_g and N_l are the number of generators and transmission lines respectively ,V_g is the terminal voltages at the voltage controlled bus, T is the tap ratio of the tap changing transformers and Q_c is the output of shunt VAR compensators, P_{Gi} and Q_{Gi} are the injected active and reactive power, P_{Di} and Q_{Di} are the active and reactive power demand at bus i; G_{ij} and B_{ij} are the transfer conductance and susceptance between bus i and j, δ_{ij} is the phase angle difference between the voltages at bus i and j.

The above objective function is subjected to the equality and inequality constraints as follows:

1) Equality constraints

The equality constraints are power flow equations and these constraints search to find the group of voltages that fulfill the system conditions

a) Real and Reactive power flow equations at each bus:

$$P_{Gi} - P_{Di} = \sum_{j=1}^{Nb} V_iV_j [G_{ij}\cos(\delta_i - \delta_j) + B_{ij}\sin(\delta_i - \delta_j)] \;\; ; i = 1,2,...,Nb \qquad (2)$$

$$Q_{Gi} - Q_{Di} = \sum_{j=1}^{Nb} V_iV_j [G_{ij}\sin(\delta_i - \delta_j) + B_{ij}\cos(\delta_i - \delta_j)] \;\; ; i = 1,2,...,Nb \qquad (3)$$

2) Inequality constraints

a) Voltage limits at generation buses:

The target of determining bus voltage limits are to keep the buses working between desirable per unit voltage limits and specify the reactive power output related to the voltage profile. Bus voltages are state variables originated from the solution of the power flow problem. These constraints with regard to the bus voltage limits are defined as:

$$V_i^{\min} \le V_i \le V_i^{\max} \;\; ; \; i = 1,2,...,Nb \qquad (4)$$

b) Capacity limits for switchable capacitor banks:

Capacitor banks can modify capacity by switching/removing some of the capacitors. These have a zone of operation with lower and upper limits and defined as:

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max} \;\; ; \; i = 1,2,...,Nc \qquad (5)$$

c) Transformer tap setting constraints:

There are transformers that are capable of supplying small modification to the output voltage by changing their taps. Transformers that can accomplish this operation while energized are called on-load-tap-changing transformers. These taps can be varied within a domain usually of ±10%. These limits can be defined as:

$$t_k^{\min} \le t_k \le t_k^{\max} \;\; ; \; k = 1,2,...,Nk \qquad (6)$$

d) Security constraints for transmission lines:

The thermal limit of an overhead transmission line is reached when the electric current flow heats the conductor material up to a temperature above which the conductor material gradually loses mechanical strength, and the MVA thermal capacity can be defined as:

$$| \boldsymbol{S}_i | \leq \boldsymbol{S}_i^{max} \;\; ; \; i = 1,2,\ldots,Nl \qquad (7)$$

III. MODELING OF STATCOM

STATCOM is a shunt connected FACTS device which allows simultaneous supply inductive and capacitive reactive power to transmission network [17].

A simpler schematic representation of STATCOM is shown in figure 1 with its equivalent circuit in figure 2.

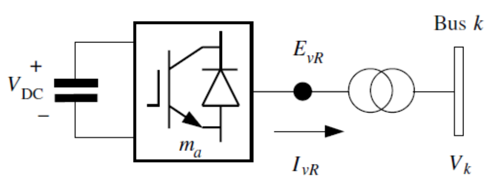

Figure1. STATCOM Schematic Diagram

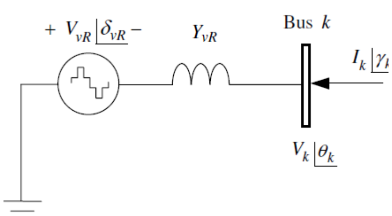

Figure2. STATCOM Equivalent Circuit

In a power flow calculation, a STATCOM is typically considered as a shunt reactive power controller assuming that it can correct its injected reactive power to control the voltage at the Statcom terminal bus, the below equations show the voltage source, the apparent power, Active and reactive power and Jacobian matrix of statcom [17] .

- The voltage source of statcom

$$E_{vR} = V_{vR}\,(Cos\,\delta_{vR} + j\,Sin\,\delta_{vR}) \qquad (8)$$

- The apparent power of statcom

$$S_{vR} = V_{vR}\, I^*_{vR} = V_{vR}\, Y_{vR}^*\,(V_{vR}^* - V_k^*) \qquad (9)$$

- Active and reactive power of statcom

$$P_{vR} = V_{vR}^2\, G_{vR} + V_{vR}\, V_k\,[G_{vR}\, Cos\,(\delta_{vR} - \theta_k) + B_{vR}\, Sin\,(\delta_{vR} - \theta_k)]$$
$$Q_{vR} = -V_{vR}^2\, B_{vR} + V_{vR}\, V_k\,[B_{vR}\, Cos\,(\delta_{vR} - \theta_k) + G_{vR}\, Sin\,(\delta_{vR} - \theta_k)]$$

$$P_k = V_k^2\, G_{vR} + V_{vR}\, V_k\,[G_{vR}\, Cos\,(\theta_k - \delta_{vR}) + B_{vR}\, Sin\,(\theta_k - \delta_{vR})]$$

$$Q_k = -V_k^2\, B_{vR} + V_{vR}\, V_k\,[G_{vR}\, Sin\,(\theta_k - \delta_{vR}) - B_{vR}\, Cos\,(\theta_k - \delta_{vR})] \qquad (10)$$

- Jacobian matrix of statcom

$$\begin{bmatrix} \Delta P_k \\ \Delta Q_k \\ \Delta P_{vR} \\ \Delta Q_{vR} \end{bmatrix} \begin{bmatrix} \frac{\partial P_k}{\partial \theta_k} & \frac{\partial P_k}{\partial V_k} V_k & \frac{\partial P_k}{\partial \delta_{vR}} & \frac{\partial P_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_k}{\partial \theta_k} & \frac{\partial Q_k}{\partial V_k} V_k & \frac{\partial Q_k}{\partial \delta_{vR}} & \frac{\partial Q_k}{\partial V_{vR}} V_{vR} \\ \frac{\partial P_{vR}}{\partial \theta_k} & \frac{\partial P_{vR}}{\partial V_k} V_k & \frac{\partial P_{vR}}{\partial \delta_{vR}} & \frac{\partial P_{vR}}{\partial V_{vR}} V_{vR} \\ \frac{\partial Q_{vR}}{\partial \theta_k} & \frac{\partial Q_{vR}}{\partial V_k} V_k & \frac{\partial Q_{vR}}{\partial \delta_{vR}} & \frac{\partial Q_{vR}}{\partial V_{vR}} V_{vR} \end{bmatrix} \begin{bmatrix} \Delta \theta_k \\ \frac{\Delta V_k}{V_k} \\ \Delta \delta_{vR} \\ \frac{\Delta V_{vR}}{V_{vR}} \end{bmatrix} \qquad (11)$$

IV. TEACHING LEARNING BASED OPTIMIZATION

The TLBO is a powerful and dynamic search algorithm. this algorithm was first proposed by Rao et al. TLBO mimics the philosophy of teaching and learning in a class, this optimization method is based on the impact of the effect of a teacher on the outcome of learners in a class. It is a population based technique and similar to other population based methods it employs a population of solutions to proceed to the best solution. A group of learners comprise the population in TLBO. In any optimization algorithms there are numbers of different control variables. The different control variables in TLBO are similar to different subjects given to learners and the learners' outcome is similar to the fitness, as in other population-based optimization techniques. As the teacher is considered the most learned person in the class, the optimal solution so far is similar to Teacher in TLBO. The procedure of TLBO is divided into two parts. The first part consists of the "Teacher Phase" and the second part consists of the "Learner Phase". The "Teacher Phase" means learning from the teacher and the "Learner Phase" means learning through the interaction between learners. TLBO searches for the global optimum mainly through two steps: teacher phase and learner phase.

1) Teacher phase:

The learner with the minimum objective function value is known as the teacher (X_{best}) for respective iteration. The Teacher phase makes the algorithm proceed by shifting the mean of the learners towards its teacher. To obtain a new group of enhanced learners a random weighted differential vector is composed from the current mean and the desirable mean parameters and joined to the present population of learners.

In this phase each teacher attempts to enhance the mean outcome of a class in the topic assigned to him. As the teacher practices the learners, therefore, the teacher is considered as the best learner.

The mean value of the marks gained by different students for each topic is founded as

$$M_d = [m_1, m_2, m_3, ..., m_D] \tag{12}$$

The difference between the mean outcomes in a particular topic and the result of corresponding teacher is given by

$$M_{diff} = rand\,(0,1)[X_{best} - T_f M_d] \tag{13}$$

Teaching factor (TF) is taken as either 1 or 2 and is decided randomly using Eq. (14)

$$Tf = round\,[1 + rand\,(0,1)] \tag{14}$$

The existing population is updated using Eq. (15)

$$X_{new} = X + M_{diff} \tag{15}$$

2) Learner phase:

In this phase the interaction of learners with one another takes place. The process of mutual interaction tends to increase the knowledge of the learner. The random inter- action among learners improves his or her knowledge.

In this stage a teacher choose a student randomly and tries to enhance his information and knowledge by means of interaction. A teacher reinforces his knowledge by interaction if the other learner has gained more knowledge than him. the learning process in this stage is as follows :

$$X_{new} = X_i + rand\,(0,1)[X_i - X_j] \quad if \;\; f(X_j) \geq f(X_i)$$

$$X_{new} = X_i + rand\,(0,1)[X_j - X_i] \quad if \;\; f(X_i) \geq f(X_j) \tag{16}$$

V. Numerical Examples and Simulation Results

TLBO algorithm has been applied for minimization of active power loss in three different test systems, viz., IEEE 14-bus and IEEE 30-bus power systems. Programs have been written in matlab language. After a number of experimentation, following optimum values of TLBO parameters have finally been settled for all cases: maximum iteration =50, population size=30 and teaching factor is a random number 1 or 2. To demonstrate the effectiveness of the proposed approach four cases to be discussed:

Case 1: Solution of ORPD on IEEE 14-bus system

The IEEE 14-bus system consists of five generators at buses (1, 2, 3,6and 8), 20 transmission lines and 3 transformer are shown in figure 3. In addition, shunt VAR compensating devices are connected at bus 9 and 14.

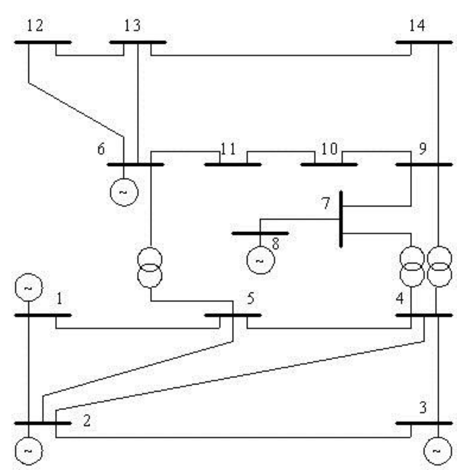

Fig.3. Structure of the tested IEEE 14 Bus System

The active and reactive power for loads and generators are given in the table (1) .the transmission line data are described in the table (2).

TABLE 1

The load and generation power for IEEE 14 -Bus system

Bus i	Generation		Load	
	P_{G_i} (MW)	Q_{G_i} (MVAR)	P_{D_i} (MW)	Q_{D_i} (MVAR)
1	232.4	-16.9	0.0	0.0
2	40.0	42.4	21.7	12.7
3	0.0	23.0	94.2	19.0
4	0.0	0.0	47.8	-3.9
5	0.0	0.0	7.6	1.6
6	0.0	12.2	11.2	7.5
7	0.0	0.0	0.0	0.0
8	0.0	17.4	0.0	0.0
9	0.0	0.0	29.5	16.6
10	0.0	0.0	9.0	5.8
11	0.0	0.0	3.5	1.8
12	0.0	0.0	6.1	1.6
13	0.0	0.0	13.5	5.8
14	0.0	0.0	14.9	5.0

TABLE 2

The Line data of IEEE 14 -Bus system

$N_{L\,(i)}$	**(i-j)**	**Line Impedance**		$B_{ij/2}$	t_K
		R (p.u)	**X** (p.u)	**(p.u)**	
1	1-2	0.01938	0.059	0.0264	1.0
2	2-3	0.04669	0.198	0.0219	1.0
3	2-4	0.05811	0.176	0.0187	1.0
4	1-5	0.055403	0.223	0.0246	1.0
5	2-5	0.05695	0.173	0.0170	1.0
6	3-4	0.06701	0.171	0.0173	1.0
7	4-5	0.01335	0.042	0.006	1.0
8	5-6	0.0	0.252	0.0	0.970
9	4-7	0.0	0.209	0.0	0.940
10	7-8	0.0	0.176	0.0	1.0
11	4-9	0.0	0.556	0.0	0.930
12	7-9	0. 0	0.119	0. 0	1.0
13	9-10	0.03181	0.085	0.0	1.0
14	6-11	0.09498	0.198	0.0	1.0
15	6-12	0.12291	0.255	0.0	1.0
16	6-13	0.06615	0.130	0.0	1.0
17	9-14	0.12711	0.270	0.0	1.0
18	10-11	0.08205	0.192	0. 0	1.0
19	12-13	0.22092	0.119	0.0	1.0
20	13-14	0.17093	0.348	0.0	1.0

The total active load in the system was 259 MW.The initial real power loss was 13.49 MW, the minimum and maximum voltage of generator buses and load buses are 0.9 and 1.1 p.u respectively. The upper and lower transformer tap settings are set between 0.95 and 1.1 p.u , the upper and lower of the capacitor bank limits are set between 18 MVAR and 0 MVAR. From the table 3, it is seen that TLBO is able to reduce the active power loss with respect to the base case by 8.41 % .fig 4 shows the convergence of TLBO for minimization power loss. TLBO obtains 6.5% , 6.66% , 6.84% , 6.87% , 6.97% , 6.67% , 6.72% ,7.23% more loss reduction than of SARGA,PSO-AM ,PSO-CM , MHPSO ,MPSO, DE ,SQP and PSO respectively .the obtained best results from the proposed TLBO method are compared to SARGA , PSO AM ,PSO-CM ,MHPSO , MPSO ,DE ,SQP and PSO for power loss minimization as given in table 3,the optimum control parameter settings of proposed approach are given in table 4.

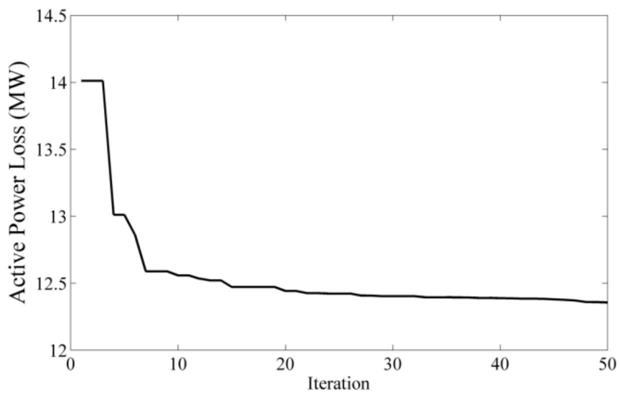

Fig.4. Convergence characteristics of TLBO for IEEE 14 bus system

TABLE 3

Comparison of performance of TLBO with other techniques for IEEE 14 bus system

Method	Min. Loss Value (MW)	Real Power Saving Compared with Base Case (%)
PSO [26]	13.3227	1.240178
SQP [35]	13.2460	1.808747
DE [27]	13.2390	1.860638
MPSO [29]	13.28120	1.547813
MHPSO [28]	13.2684	1.642698
PSO-CM [29]	13.2634	1.679763
PSO-AM [29]	13.2371	1.874722
SARGA [30]	13. 21642	2.075612
TLBO	**12.356**	**8.406227**

TABLE 4

Control variables value for IEEE 14 bus system

Control Variable Setting (p.u)	TLBO
V_1	1.1000
V_2	1.0877
V_3	1.0603
V_6	1.0900
V_8	1.0999
TAP_8	0.9679
TAP_9	0.9974
TAP_{10}	1.0172
Q_{c9}	.17702
Q_{c14}	.069534
Active Power Loss (MW)	12.356

Case 2: Solution of ORPD on IEEE 14-bus system including STATCOM

In this case IEEE 14-bus system has been considered to identify the optimal location and parameter of the STATCOM to minimize the real power loss. The minimum and maximum voltage of STATCOM buses are 0.95 and 1.1 p.u respectively, the upper and lower bounds on the STATCOM phase angles -18 deg are 0 deg, the upper and lower bounds on the reactive power of STATCOMs are 18 MVAR and 0 MVAR. the Simulation are carried out for different location of STATCOM, the proposed approach with optimal installation of STATCOM at bus 14 given better results than without STATCOM installation. For example with installation of STATCOM, active power loss 12.1833 MW which is better compared with the results found at the base case 13.49 MW. Figure (5) shows the real power loss with STATCOM at bus 14, the optimum control parameter setting of the voltage, phase angle and reactive power of STATCOM are 1 p.u,-18 deg and -10 MVAR respectively, the real power loss for various location of STATCOM are presented in table (5).

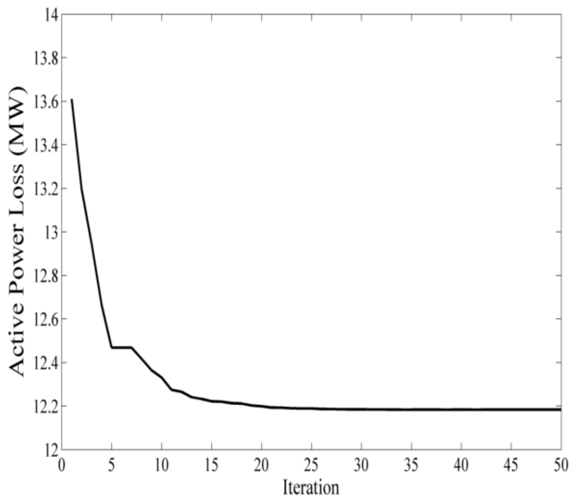

Fig.5. Convergence characteristics of TLBO for IEEE 14 bus system including STATCOM at Bus 14

TABLE 5

Comparison of real power loss for various location of STATCOM for IEEE 14 bus system

Location of STATCOM (Bus i)	Min Loss Value (MW)
11	12.2678
12	12.2494
13	12.2144
14	**12.1833**

Case 3: Solution of ORPD on IEEE 30-bus system

The IEEE 30-bus system consists of five generators at buses (1, 2, 5, 8,11and 13), 41 transmission lines and 4 transformer are shown in figure 6. In addition, shunt VAR compensating devices are connected at bus 10 and 24.

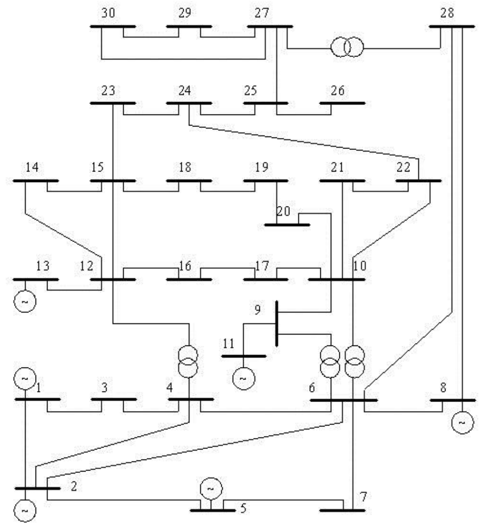

Fig.6. Structure of the tested IEEE 30 Bus System

The active and reactive power for loads and generators are given in table 6 .the transmission line data are given in table7.

TABLE 6

The load and generation power for IEEE 30 -Bus system

	Generation		**Load**	
Bus *i*	P_{G_i}	Q_{G_i}	P_{D_i}	Q_{D_i}
1	0	0	0	0
2	80	27.65	21.7	12.7
3	0	0	2.4	1.2
4	0	0	7.6	1.6
5	50	21.54	94.2	19
6	0	0	0	0
7	0	0	22.8	10.9
8	20	22.93	30	30
9	0	0	0	0
10	0	0	5.8	2

11	20	38.58	0	0
12	0	0	11.2	7.5
13	20	40.34	0	0
14	0	0	6.2	1.6
15	0	0	8.2	2.5
16	0	0	3.5	1.8
17	0	0	9	5.8
18	0	0	3.2	.9
19	0	0	9.5	3.4
20	0	0	2.2	.7
21	0	0	17.5	11.2
22	0	0	0	0
23	0	0	3.2	1.6
24	0	0	8.7	6.7
25	0	0	0	0
26	0	0	3.5	2.3
27	0	0	0	0
28	0	0	0	0
29	0	0	2.4	.9
30	0	0	10.6	1.9

TABLE 7

The Line data of IEEE 30 -Bus system

$N_{L\ (i)}$	**(i-j)**	Line Impedance		$\mathbf{B_{ij/2}}$	t_K
		R (p.u)	X (p.u)	**(p.u)**	
1	1-2	.0192	.0575	.0264	1
2	1-3	.0452	.1852	.0204	1
3	2-4	.0570	.1737	.0184	1
4	3-4	.0132	.0379	.0042	1
5	2-5	.0472	.1983	.0209	1
6	2-6	.0581	.1763	.0187	1
7	4-6	.0119	.0414	.0045	1
8	5-7	.0460	.1160	.0102	1
9	6-7	.0267	.0820	.0085	1
10	6-8	.0120	.0420	.0045	1
11	6-9	0	.2080	0	1.078
12	6-10	0	.5560	0	1.069
13	9-11	0	.2080	0	1
14	9-10	0	.1100	0	1
15	4-12	0	.2560	0	1.032
16	12-13	0	.1400	0	1
17	12-14	.1231	.2559	0	1
18	12-15	.0662	.1304	0	1
19	12-16	.0945	.1987	0	1
20	14-15	.2210	.1997	0	1
21	16-17	.824	.1923	0	1
22	15-18	.1073	.2185	0	1
23	18-19	.0639	.1292	0	1
24	19-20	.0340	.0680	0	1
25	10-20	.0936	.2090	0	1
26	10-17	.0324	.0845	0	1
27	10-21	.0348	.0749	0	1
28	10-22	.0727	.1499	0	1
29	21-22	.0116	.0236	0	1
30	15-23	.1000	.2020	0	1
31	22-24	.1150	.1790	0	1
32	23-24	.1320	.2700	0	1
33	24-25	.1885	.3292	0	1

34	25-26	.2544	.3800	0	1
35	25-27	.1093	.2087	0	1
36	28-27	0	.3960	0	1.068
37	27-29	.2198	.4153	0	1
38	27-30	.3202	.6027	0	1
39	29-30	.2399	.4533	0	1
40	8-28	.0636	.2000	.0214	1
41	6-28	.0169	.0599	.0650	1

The total active load in the system was 283.4 MW.the initial real power loss was 17.56 MW, the minimum and maximum voltage of generator buses and load buses are 0.9 and 1.1 p.u respectively. The upper and lower transformer tap settings are set between 0.95 and 1.1 p.u, the upper and lower capacitor limits are set between 5 MVAR and 0 MVAR. From the table 8, it is seen that TLBO is able to reduce the active power loss with respect to the base case by 8.5 % .fig 7 shows the convergence of TLBO for minimization power loss. TLBO obtains 1.3% ,1.6% ,1.67% ,1.92% ,2.13% ,1.94% ,2% ,2.5% ,2.56% ,2.58% ,3.56% ,3.94% more loss reduction than of PSO-AM ,PSO-CM ,MHPSO ,MPSO ,Classical PSO , CSSP4 ,CSSP3 ,CSSP2 , DE , DEEP , EP and CSSP1 respectively .the obtained best results from the proposed TLBO method are compared to PSO-AM ,PSO-CM , MHPSO , MPSO , Classical PSO , CSSP4 , CSSP3 , CSSP2 , DE , DEEP , EP and CSSP1 for power loss minimization as given in table 14,the optimum control parameter settings of proposed approach are given in table 9.

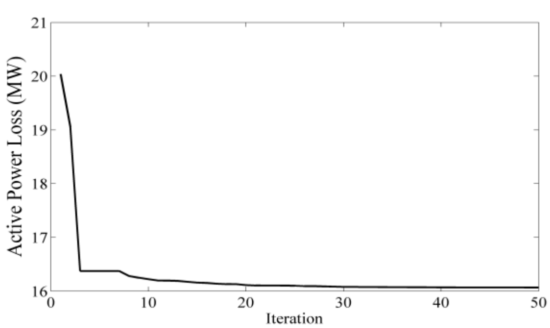

Fig.7. Convergence characteristics of TLBO for IEEE 30 bus system

TABLE 8

Comparison of performance of TLBO with other techniques for IEEE 30 bus system

Method	Min. Loss Value (MW)	Real Power Saving Compared with Base Case (%)
CSSP1 [33]	16.7272	4.742597
EP [34]	16.6759	5.034738
DEEP [36]	16.4922	6.080866
DE [27]	16.4898	6.094533
CSSP 2 [33]	16.4791	6.155467
CSSP 3 [33]	16.3941	6.639522
CSSP 4 [33]	16.3861	6.68508
Classical PSO [30]	16.4177	6.505125
MPSO [29]	16.3823	6.70672
MHPSO [28]	16.3397	6.949317
PSO-CM [29]	16.3210	7.055809
TLBO	**16.0667**	**8.503986**

TABLE 9

Control variables value for IEEE 30 bus system

Control Variable Setting (p.u)	TLBO
V_1	1.1
V_2	1.0846
V_5	1.0523
V_8	1.0589
V_{11}	1.1
V_{13}	1.1

TAP_{11}	1.0341
TAP_{12}	0.95
TAP_{15}	1.043
TAP_{36}	0.9785.
Q_{c10}	.049993
Q_{c24}	.049988
Active Power Loss (MW)	16.0667

Case 4: Solution of ORPD on IEEE 30-bus system including STATCOM

In this case IEEE 30-bus system has been considered to identify the optimal location and parameter of the STATCOM to minimize the real power loss. The minimum and maximum voltage of STATCOM buses are 0.95 and 1.1 p.u respectively, the upper and lower bounds on the STATCOM phase angles are -18 deg and 0 deg, the upper and lower bounds on the reactive power of STATCOMs are -30 MVAR and 30 MVAR, the Simulation are carried out for different location of STATCOM, the proposed approach with optimal installation of STATCOM given better results than without STATCOM installation. For example with installation of STATCOM at bus 30, active power loss 15.764 MW which is better compared with the results found at the base case 17.56 MW. Figure (8) shows the real power loss with STATCOM at bus (30), the optimum control parameter setting of the voltage, phase angle and reactive power of STATCOM are 1 p.u,-17.86 deg and -25.85 MVAR respectively, the real power loss for various location of STATCOM are presented in table (10).

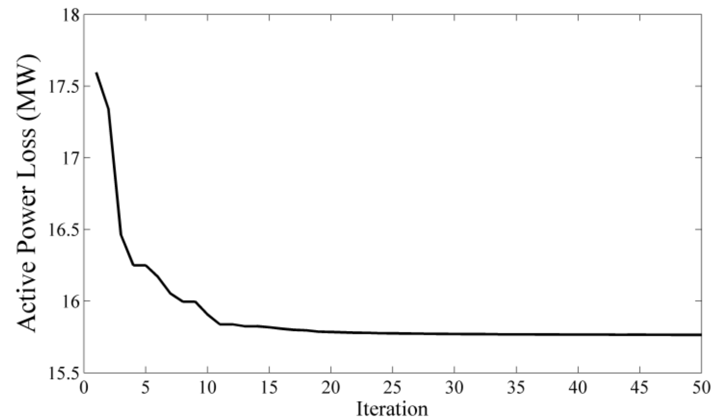

Fig.8. Convergence characteristics of TLBO for IEEE 30 bus system including STATCOM at Bus 30

TABLE 10

Comparison of real power loss for various location of STATCOM for IEEE 30 bus system

Location of STATCOM (Bus i)	Min Loss Value (MW)
7	15.857
14	15.857
18	15.8658
22	15.9043
25	15.8861
29	15.8323
30	**15.764**

VI. CONCLUSION

In this paper, the TLBO has been successfully performed to solve optimal reactive power dispatch including STATCOM for reducing of active power loss. This approach has been checked and proved on three IEEE 14-bus and IEEE 30-bus systems to manifest its performance. The results obtained from the TLBO approach were compared to those reported in the recent literature. It has been observed here, that TLBO has the efficiency to reduce the active power loss reasonably without violating any constraints. Moreover, TLBO owns excellent convergence characteristics compared to BFGS, MPSP, PSO-CM and other techniques. Therefore .from the simulation results it may be concluded that TLBO is superior to the other algorithms.

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