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Minimization of Real Power Loss using TLBO Algorithm in Transmission Systems

M.Priyanka[1], P.Jyoshna[2], Dr. Ch.Chengaiah[3]

[1]Department of EEE, M.TECH Student , Sri Venkateswara University College of Engineering, Tirupati,INDIA,
[2]Department of EEE, Research Scholar ,Sri Venkateswara University College of Engineering, Tirupati, INDIA,
[3]Department of EEE, Professor , Sri Venkateswara University College of Engineering, Tirupati, INDIA,

Abstract:- ***Electrical power losses is considered as important factor for the operation of power systems. There are various methods which are used for reducing real power losses in transmission system. These methods helps to reduce real power losses and improve the voltage profile of the system. The proposed method is used for the optimal location and sizing of FACTS devices such as SVC and UPFC using Teaching and Learning Based Algorithm The main objective is to minimize real power losses while keeping the voltage profiles in the network within specified limits. The proposed technique is tested to IEEE 14 Bus system.***

Keywords— Teaching and learning based algorithm, real power losses, transmission loss.

I. INTRODUCTION

The primary objective of Power Systems design is to operate the systems economically at maximum efficiency and supply power on demand to various load centres with high reliability. The rising electric power demand in the 21st-century, has called for re-structuring of the electric power system. Due to increasing of load demand losses also increases and reduce the voltage profile of the system With the advancement in Power electronics, FACTS devices are being utilized to achieve many objectives in an electric power system [1],[2]. Facts Technology opens up new opportunities for controlling line power flows, minimizing losses and maintaining bus voltages at desired level in a power system network. These are done by controlling one or more of the interrelated system parameters including series impedance, shunt impedance, current, voltage, phase angle etc. with the insertion of facts controllers in a power system network. This paper presents the real power loss minimisation problem, with the best utilisation of the existing generator bus voltage magnitudes, transformer tap settings and also with the optimal location and setting of FACTS devices so as to minimise the loss and to enhance the voltage stability of the system. The real power minimisation is a significant tool in the planning and maintaining of the power systems. It involves solving nonlinear and multiobjective optimization problems with a mixture of discrete and continuous variables.

Optimal load flow solution is a very demanding non-linear programming problem, due to large number of variables and in particular to the much larger number and type of constraints which define the boundaries of technical feasibility [3].Many conventional techniques such as gradient-based search algorithms and various mathematical programming methods has been proposed to reduce the real power losses [4].

Many conventional methods are used to reduce real power losses, such as Newton Raphson method[5] and linear programming proposed by E.Hobson[6-7]. The gradient and Newton Raphson methods have failed to deal with inequality constraints. In recent years, several biological and natural processes have been increasingly used in science and technology methodologies. Particle Swarm Optimization proposed byKennedy,j.,Eberhart[8], artificial immune systems proposed by Dasgupta., D.[9], Ant Colony Optimization proposed by Dorigo[10].These algorithms have been applied to many engineering optimization problems and proved effective to solve some specific kind of problems.

The main limitation of all the above algorithms that different parameters are required for proper working of these algorithms. Proper selection of the parameters is essential for the searching of the optimum solution by all algorithms. Rao et al was recently proposed the Teaching-Learning Based Optimization (TLBO) algorithm. It does not require any specific parameter to be tuned, which facilitates its implementation and use and also reduce the real power losses.

The performance of these proposed method is investigated on an IEEE 14-bus system to solve the load flow problem for minimizing the real power losses in electrical transmission system.

II. PROBLEM FORMULATION

In this paper, a real power loss minimization problem is tackled which may be stated as an optimization problem where objective functions are minimized, while satisfying the number of equality and inequality constraints. The following objective function is minimized by using FACTS devices.

Where V_i and V_j are the sending and receiving voltages, respectively.

- X_i is the line reactance.
- I_i is the current through the transmission line.

Therefore, the objective function for the real power losses is expressed as

$$P_{loss} = \sum_{i=1}^{nl} g_k (v_i^{\,2} + v_j^2 - 2 v_i v_j \cos\theta_{ij}) \tag{2.1}$$

where n_l is the number of lines.

Reducing the real power losses enables more active power to be transferred over a single line.

2.1. EQUALITY CONSTRAINTS:

The power flow equations as follows:

$$P_{Gi} - P_{Di} = V_i \sum_{j=1}^{nb} (G_{ij}\cos\theta_{ij} + B_{ij}\sin\theta_{ij}) \tag{2.2}$$

$$Q_{Gi} - Q_{Di} = V_i \sum_{j=1}^{nb} (G_{ij}\sin\theta_{ij} - B_{ij}\cos\theta_{ij}) \tag{2.3}$$

where i=1,2,3,4,………………..nb

- nb is the number of buses.
- P_{Gi} and Q_{Gi} are the active power and reactive powers generated at the i^{th} bus.
- P_{Di} and Q_{Di} are the active power and reactive power demands at the i^{th} bus respectively.
- V_i is the voltage magnitude at the i^{th} bus.
- θ_{ij} is the voltage angle difference between buses i and j.
- G_{ij} and B_{ij} are the Mutual conductance and susceptance between buses i and j respectively.

2.2. INEQUALITY CONSTRAINTS:

Generator constraints: Generator real power outputs and voltage magnitudes are restricted by their upper and lower limits as follows:

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max} \quad \text{for i=1,2,……ng} \tag{2.4}$$

$$V_{Gi}^{\min} \le V_{Gi} \le V_{Gi}^{\max} \quad \text{for i=1,2,……ng} \tag{2.5}$$

where ng is the number of generating units.

Transformer's tap setting constraints: Transformer taps are bounded by their related minimum and maximum limits as follows

$$T_{Gi}^{\min} \le T_{Gi} \le T_{Gi}^{\max} \quad \text{for i=1,2,……ng} \tag{2.6}$$

Shunt VAR compensator constraints: The setting of the shunt VAR compensation devices is restricted as follows

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max} \quad \text{for i=1,2,……ng} \tag{2.7}$$

2.3. DECISION VARIABLES

The decision variables include the generator voltages V_g, and the tap changing ratio of the transformers (T)

$$x = [V_{g1}, V_{g2}, ...V_{gn}, T_1, T_2, ...T_n] \tag{2.8}$$

Where V_g is the generated voltage.

It is worth noting that the decision variables are self constrained by the optimization algorithm.

2.4. MODELLING OF FACTS DEVICES:

Several facts devices are available in the field of power system those are out of which in this paper

1. Series compensators
2. Series and shunt compensators

2.5 SERIES COMPENSATORS

2.5.1 .STATIC VAR COMPENSATOR (SVC):

The Static VAR Compensator (SVC) is a FACTS shunt connected controller whose main function is to control the voltage of a given bus by controlling its reactance. It is essentially a fixed condenser (FC) and a thyristor-controlled reactor (TCR).SVC is a shunt compensator, uses reactors (usually in the form of Thyristor-Controlled Reactors) to consume VARs from the system, lowering the system voltage. Under inductive (lagging) conditions, the capacitor banks are automatically switched in, thus providing a higher system voltage. SVCs with an auxiliary injection of a suitable signal can considerably improve the dynamic stability performance of a power system.

In this paper, Static VAR compensator (SVC) is considered as simple injecting the reactive power into the transmission line as shown in the fig.1. In the present work the SVC is modelled as an ideal reactive power injection at bus i. The reactive power changes at bus i given by the formula as shown in below eq (2.9).

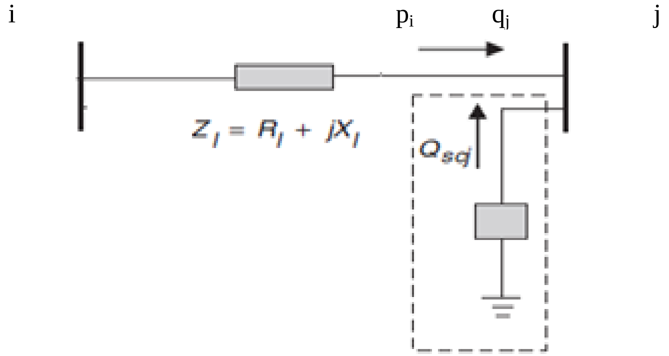


Fig.1 Modelling of SVC

$$\Delta Q_i = Q_{SVC} \tag{2.9}$$

2.6 SERIES AND SHUNT COMPENSATORS

2.6.1UNIFIED POWER FLOW CONTROLLER (UPFC) :

A Unified Power Flow Controller (UPFC) is an electrical device to provide high -voltage electricity transmission networks with rapid reactive power compensation. It uses a pair of Three - Phase controllable bridges to produce a current that is injected with a series transformer into a transmission line. In a transmission line, the controller can control the active and reactive power flow.

UPFC can provide reactive power but also active power with the presence of the two converters. UPFC device have been selected to place in suitable location to reduce the losses and improve the voltage profiles in power system. UPFC circuit is shown in Fig.2.Power flow through the transmission line depend on line reactance, bus voltage magnitudes, and phase angle between sending and receiving end buses .This is expressed by

$$P_{ij} = \frac{V_i V_j}{X_{ij}} \sin(\delta_i - \delta_j) \tag{2.10}$$

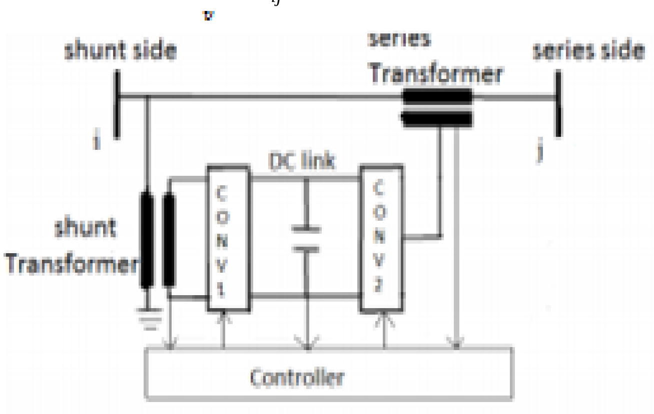
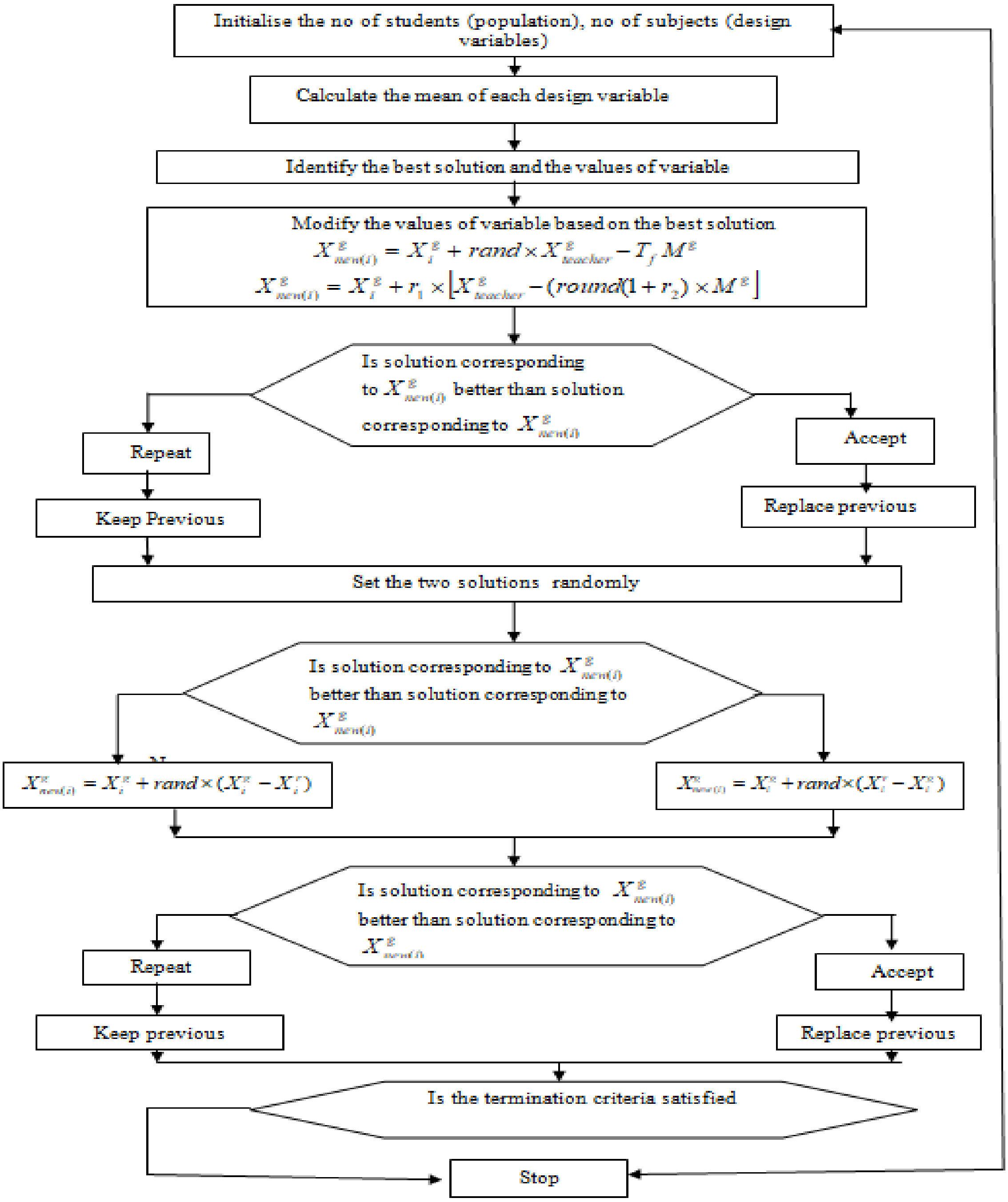


Fig.2.Modelling of UPFC

III.PROPOSED METHOD

The proposed method i.e TLBO is used for reducing the losses and for improving the voltage profile of the system. It is a new efficient population based algorithm developed by Rao et al. The algorithm mimics the teaching-learning ability of the teacher and learners in a classroom. In this method, a group of students in a class is considered as a population and design variables are the subjects offered to the student's. A students result is analogous to fitness value and the value of objective function represents the knowledge of a particular students. As the teacher is considered the most learned person in the society, the best solution so far is analogous to Teacher in TLBO. The process 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. In the sub-sections below we briefly discuss The TLBO is implemented in a flow chart,which is discussed as

Fig.3 Flow chart of TLBO:



3.1ALGORITHM OF TLBO:

The TLBO algorithm that is introduced here is shown in the flow chart of figure 3. The following steps give explanations to the TLBO algorithm.

Step 1 :Initialize the population size or number of students in the class (N), number of generations (G), number of design variables or subjects (courses) offered which coincides with the number of units to place in the distribution system (D) and limits of design variables (upper, U L and lower, LL of each case). Define the optimization problem as: Minimize f (X) , where f (X) is the objective function, X is a vector for design variables such that $LL \leq X \leq UL$.

Step 2: Generate a random population according to the number of students in the class (N) and number of subjects offered (D).

Step3: Evaluate the average grade of each subject offered in the class. The average grade of the j subject at generation g is given by

$$M^{g} = mean(X_{1,j}, X_{2,j}, ...X_{i,j}) \quad (3.1)$$

Step 4: Based on the grade point (objective value) sort the students (population) from best to worst. The best solution is considered as teacher and is given by

$$X_{teacher} = X\Big|_{F(x)\min} \quad (3.2)$$

Step 5: Modify the grade point of each subject (control variables) of each of the individual student. Modified grade point of the j^{th} subject of the i^{th} student is given by

$$X^{g}_{new(i)} = X^{g}_{i} + rand \times X^{g}_{teacher} - T_{f} M^{g} \quad (3.3)$$

$$X^{g}_{new(i)} = X^{g}_{i} + r_{1} \times \left[X^{g}_{teacher} - (round(1+r_{2}) \times M^{g}\right] \quad (3.5)$$

Step 6 : Every learner improves grade point of each subject through the mutual interaction with the other learners. Each learner interacts randomly with other learners and hence facilitates knowledge sharing. For a given learner, X^{g}_{i} another learner X^{r}_{g} is randomly selected ($i \neq r$). The grade point of the j_{t}^{h} subject of the i^{th} learner is modified by

$$X^{g}_{new(i)} = X^{g}_{i} + rand \times (X^{g}_{i} - X^{r}_{i}) \quad (3.6)$$

IV. SIMULATION RESULTS

From the result analysis of section-II – section-III, the proposed method istesting on IEEE-14 bus system, is illustrated to minimize the real power losses with TLBO optimization algorithms using MATLAB Environment. The IEEE-14 bus system consists of 5 generator buses, 9 load buses and 20 branches, and having a total capacity of 273MW and 76MVAr. The results of proposed IEEE-14Bus system are discussed as follows.

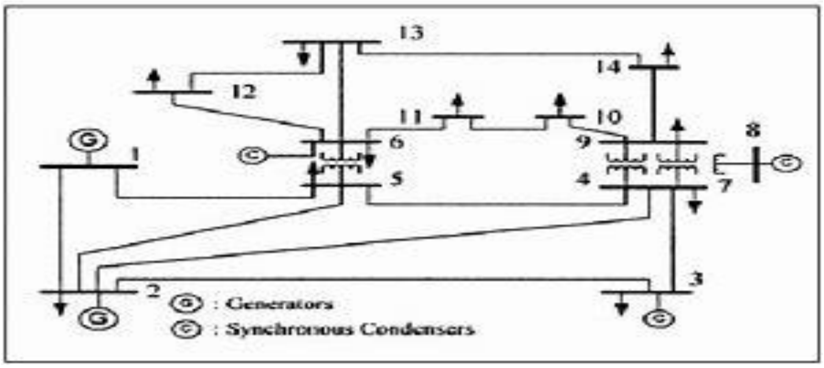


Fig.4.single line diagram of IEEE 14 bus system

Table.1. Control Limits

Limits of Generation of Reactive Power					
Bus	1	2	3	6	8
Q_G^{max} Q_G^{min}	0 0	50 -40	40 0	24 -6	24 -6
Limits of Voltage and Tap settings					
V_G^{max} V_G^{min} V_{PQ}^{max} V_{PQ}^{min} T_k^{max} T_k^{min} 1.1 0.95 1.1 0.95 1.05 0.95					
Limits of FACTS devices					
SVC Q_{ci}^{max} Q_{ci}^{min} 0.40 -0.06					
UPFC V_{nUPFC} δ_{nUPFC}^{max} δ_{nUPFC}^{min} 1.0 360^0 0^0					

The TLBO optimization algorithm for this IEEE-14 bus system the number of Teachers are taken as 10, number of learners100, and maximum iterations as 100. The system is tested with the different FACTS devices such as SVC and UPFC and the results are discussed as follows.

The standard IEEE 14 bus system has been tested by using Newton Raphson method with facts devices and TLBO algorithm with FACTS devices. Compared to Newton Raphson method the voltage profile has been improved by using FACTS devices.

Table 2: Voltage profile for IEEE 14 bus system

Bus No.	voltage (without facts devices)	voltage (with SVC)	voltage (with UPFC)
1	1.060	1.050	1.050
2	1.045	1.046	1.045
3	1.0100	1.019	1.020
4	1.0166	1.015	1.019
5	1.0201	1.014	1.017
6	1.0700	1.028	1.013
7	1.0514	1.025	1.007
8	1.0900	1.025	1.007
9	1.0347	1.028	1.011
10	1.0334	1.021	1.004
11	1.086	1.021	1.005
12	1.0479	1.011	1.001
13	1.0536	1.012	0.998
14	1.0473	1.003	1.000

Table 3: Control variables of SVC

Control Variables	TLBO
V1	1.1000
V2	1.08000
V3	1.0567
V6	1.08
V8	1.0275
V13	1.0557
T6-9	1.0298
T6-10	1.0287
T4-12	1.0354
Optimal bus	7
Reactive Power	0.04p.u.

From table 3 and 4 it is clear that the SVC is placed on bus number 7. Which is optimal bus obtained by applying TLBO with SVC. The optimal reactive power injected by SVC at this bus is 27.36MVAr. The UPFC is placed on bus number 4, the optimal reactive power injected by UPFC is 35.22MVAr.

Table.4 Control variables of UPFC

Control Variables	TLBO
V1	1.1
V2	1.1
V5	1.0487
V8	1.1
V11	1.09
V13	1.0907
T6-9	1.0500
T6-10	0.9545
T4-12	1.0913
T28-27	0.9553
Optimal bus	4
Reactive power	0.06p.u.
R Optimal X_{new} Between the Buses	-0.436 0.05043 3 – 4
Power Angle(^{0})	287.773

Table. 5Power flow Profile of Newton Raphson method

From bus	To bus	Real power (P) MW	Reactive power (Q) MVAr	Real power loss (Mw)	Reactive power loss (MVAr)
1	2	155.879	32.180	4.2983	-0.455
2	3	73.380	-4.832	2.3223	-1.209
2	4	55.731	-6.310	1.6677	-4.089
1	5	75.528	-5.530	2.7760	-1.102
2	5	41.071	-5.548	0.9105	-5.482
3	4	-22.950	4.853	0.3785	-6.964
4	5	-62.506	4.443	0.4828	-1.474
5	6	42.673	-0.177	-0.000	3.826
4	7	29.637	11.922	0.0000	1.691
7	8	0.100	1.605	0.0000	0.004
4	9	15.973	-6.769	0.0000	1.503
7	9	29.537	8.627	0.0000	0.857
9	10	6.012	5.711	0.0061	0.049
6	11	6.549	2.030	0.1081	0.077
6	12	7.632	2.312	0.0791	0.134
6	13	17.292	6.394	0.2445	0.366
9	14	9.998	4.549	0.0921	0.272
10	11	-3.006	0.138	0.0421	0.015
12	13	1.467	0.578	0.0101	0.004
13	14	5.069	0.802	0.0943	0.078
Total losses				13.509	6.582

Table 5 shows the power flow profiles of IEEE 14 Bus system by using conventional NR method.

Table 6.Power flow Profile of SVC

From Bus	To bus	Real power (P) MW	Reactive power (Q) MVAr	Real power loss (Mw)	Reactive power loss (MVAr)
1	2	155.93	32.180	3.977	-0.500
2	3	72.909	-4.832	2.128	-1.069
2	4	56.100	-6.310	1.544	-3.967
1	5	75.514	-5.530	2.549	-1.056
2	5	41.253	-5.548	0.818	-5.414
3	4	-23.419	4.853	0.338	-6.873
4	5	-63.223	4.443	0.475	-1.411
5	6	45.102	-0.177	0.000	4.312
4	7	29.727	11.922	0.000	1.381
7	8	0.100	1.605	0.000	0.807
4	9	16.493	-6.769	0.000	1.381
7	9	29.627	8.627	0.000	1.381
9	10	5.990	5.711	0.018	0.048
6	11	6.584	2.030	0.048	0.100
6	12	7.464	2.312	0.071	0147
6	13	16.854	6.394	0.197	0.388
9	14	10.631	4.549	0.142	0.303
10	11	-3.028	-0.138	0.008	0.020
12	13	1.293	0.578	0.004	0.003
13	14	4.449	-0.810	0.900	0.099
Total losses				12.639	0.009

Table 7.Power flow profile of UPFC

From bus	To bus	Real power (P) MW	Reactive power (Q) MVAr	Real power loss (Mw)	Reactive power loss (MVAr)
1	2	155.98	-29.053	3.261	-0.500
2	3	72.909	1.792	1.954	-1.069
2	4	56.100	-4.649	1.225	-3.967
1	5	75.514	-3.665	2.445	-1.056
2	5	41.253	-4.279	0.566	-5.414
3	4	-23.419	-0.628	0.304	-6.873
4	5	-63.223	2.838	0.5600	-1.411
5	6	45.102	1.175	1.026	4.312
4	7	29.727	1.075	0.0962	1.381
7	8	0.100	-22.100	0.000	0.807
4	9	16.493	1.650	-0.014	1.381
7	9	29.627	21.440	0.071	1.381
9	10	5.990	4.746	0.0204	0.048
6	11	6.584	3.022	0	0.100
6	12	7.464	2.016	0	0147
6	13	16.854	5..110	0.017	0.388
9	14	10.631	-1.121	0.134	0.303
10	11	-3.028	-1.102	0.072	0.020
12	13	1.293	0.269	0.002	0.003
13	14	4.446	-0.812	0.800	0.099
Total losses				12.123	0.242

As the SVC is a shunt FACTS device it cannot be placed on the generator buses. For the IEEE-14 Bus system SVC can be placed on bus numbers 4, 5, 7, 9and 14. The optimal placement of SVC is 7.The real power losses are reduced with SVC is p_{loss}=12.639MW. With the optimal placement of UPFC in bus numbers , the losses are reduced to 12.123MW.

V. CONCLUSIONS

From p_{loss}=12.639MW the result analysis, compared to N-R method the real power loss is reduced from 13.509 to 12.639MW, 12.123MW with the usage of TLBO Algorithm for the placement of FACTS devices such as SVC and UPFC.The real power losses are reduced and voltage profile is improved for IEEE 14 bus system.With the optimal placement of SVC the losses are reduced from 13.509 to 12.639MW and with optimal placement of UPFC the losses are reduced from 13.509 to 12.123Mw. .So the proposed method has proved better results compared to conventional methods.

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