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Application of AHP Method for Optimal Placement of Statcom Device Using TLBO

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Abstract

The concept of FACTS (Flexible Alternating Current Transmission System) refers to a family of power electronics-based devices able to enhance AC system controllability and stability and to increase power transfer capability. The ability of these FACTS devices for power flow control at normal/steady state condition and device with AHP method using Teacher Learning Based Optimization (TLBO) method is examined. The objective is to minimize the fuel cost of generation, voltage deviation, transmission real power losses, and to determine the optimal value of control variables such as generator real power, 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. The proposed method is examined and implemented on IEEE 30-bus power system.

Keywords: *FACTS, TLBO, STATCOM*

1. Introduction

Over the past two decades, electric power systems have experienced a continuous increase in power demand without a matching expansion of the transmission and generation facilities. This discrepancy has resulted in increased system vulnerabilities to voltage disturbance and instabilities have been observed in the power networks throughout the world. Worldwide transmission systems are undergoing continuous change due to steady growth in demand for electric power, much of which has to be transmitted over long distances. However, public concern over the environmental impact of power generation and transmission, coupled with problems related to the cost and right-of-way issues, have hindered addition of new plants to meet this increased demand. The deregulation has pushed the industry to promote advanced technologies for the transmission congestion because of shortage of transmission line capacity. Besides the impact from the Blackout, the continuous technical advances in power electronics, such as Static Var Compensators (SVC), Static Synchronous Compensators (STATCOM), DVAR, SuperVAR, etc, make the application of large amount of VAR compensation more efficient, affordable, and attractive. Power electronics based equipment, or FACTS, provide proven technical solutions to voltage stability problems. Especially, due to the increasing need for fast response for power quality and voltage stability, the shunt dynamic Var compensators such as SVC and STATCOM have become feasible alternatives to a fixed reactive source. FACTS stands for the ‘flexible AC transmission system(FACTS) are “alternating current transmission systems incorporating power electronics based and other static controllers to enhance controllability and PTC of transmission lines. FACTS devices control power flow through a transmission network by obeying the command of the control center. These devices also facilitate the operation of transmission lines closer to their maximum thermal limits and the control over the line impedances of a transmission system, the voltage magnitude, and the phase angle of buses. They also help in reducing the flow in heavily loaded lines, resulting in the increase in power flow transfer capability of the transmission systems, to enhance continuous control over the voltage profile and/ or to damp power system oscillations. The ability to control power rapidly can increase the stability margins as well as the damping of the power system, to minimize losses, reduced cost of production, to work within the thermal limits range, etc. FACTS devices provide control facilities, both in steady state power flow control and dynamic stability control. The optimal operation of the power system networks have been based on economic criterion. The shunt FACTS devices can be very helpful in the optimal operation of power system networks. Both the power system performance and the power system stability can be enhanced by utilizing FACTS devices. To a large extent, proper location of STATCOM device can make great enhancement to power system performance/voltage stability. VSC type STATCOM device has self-commutated DC to AC converters, using GTO thyristors, which can internally generate capacitive and inductive reactive power for transmission line compensation, without the use of capacitor or reactor banks. Thus, this leads to improve the security and stability of the power system.

2. Mathematical Model of OPF Problem

2.1 Objectives

The optimal power problem seeks to find an optimal profile of active and reactive power generations along with voltage magnitudes in such a manner as to minimize the total operating costs of a thermal electric power system, while satisfying networks security constraints. The constraint minimization problem can be transformed into an unconstrained one by augmenting the load flow constraints into the objective function. Some well-known four types of objective functions of OPF problem are identified as below:

Objective Function I: Min $f_1 = F(pg) = \sum_{i=1}^{ng} (a_i P_{gi}^2 + b_i P_{gi} + c_i)$ is total generation cost function

Objective Function II: Min $f_2 = P_L = \sum_{i=1}^{N_1} g_k [V_i^2 + V_j^2 - 2V_i V_j \cos(\delta_i - \delta_J)]$ is total real power loss

Objective Function III: Min $f_3 = Lj2s = \sum_{j=g+1}^{nb} L_j^2$ is the sum of squared voltage stability index

Objective Function IV: Min $f_4 = VD = \sum_{i=1}^{nb} \left(|V_i - 1| \right)^2$ is the total voltage deviation.

2.2 Constraints

The OPF problem has two categories of constraints

2.2.1 Equality Constraints These are the sets of nonlinear power flow equations that govern the power system, i.e., Load flow constraints:

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (1)$$

$$Q_{Gi} - Q_{Di} + \sum_{j=1}^{n} |V_i||V_j||Y_{ij}| \sin(\theta_{ij} - \delta_i + \delta_j) = 0 \quad (2)$$

where P_{Gi} and Q_{Gi} are the real and reactive power outputs injected at bus i respectively, the load demand at the same bus is represented by P_{Di} and Q_{Di}, and elements of the bus admittance matrix are represented by $|Y_{ij}|$ and θ_{ij}.

2.2.2Inequality Constraints These are the set of constraints that represent the system operational and security limits like the bounds on the following:

- Generators real and reactive power outputs

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1, \ldots, ng \quad (3)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, i = 1, \ldots, ng \quad (4)$$

- Voltage magnitudes at each bus in the network

$$V_i^{\min} \le V_i \le V_i^{\max}, i = 1, \ldots, NL \quad (5)$$

Where NL is the number of load buses

- Transformer tap settings

$$T_i^{\min} \le T_i \le T_i^{\max}, i = 1, \ldots, nt \quad (6)$$

where nt is the number of tap changing transformers

- Reactive power injections due to capacitor banks

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max}, i = 1, \ldots, cs \quad (7)$$

where cs is the number of shunt capacitor

- Transmission lines loading

$$S_i \le S_i^{\max}, i = 1, \ldots, nl \quad (8)$$

where nl is the number of transmission lines

- Voltage stability index

$$L_j \le L_j^{\max}, \qquad j = 1, \ldots, NL \quad (9)$$

- FACTS device constraint

$$V_{vR}^{\min} \le V_{vR} \le V_{vR}^{\max} \quad \text{STATCOM voltage magnitude} \quad (10)$$

$$\delta_{vR}^{\min} \le \delta_{vR} \le \delta_{vR}^{\max} \quad \text{STATCOM voltage angle} \quad (11)$$

The equality constraints are satisfied by running the power flow program. The generator bus real power generations

(P_{gi}), generator terminal voltages (V_{gi}), transformer tap settings (T_i), the reactive power compensation (Q_{Ci}) are the control variables and they are self-restricted by the representation itself. The active power generation at the slack bus (P_{gs}), load bus voltages (V_{Li}) and reactive power generation (Q_{gi}), line flows (S_i), and voltage stability (L_j)-index are state variables which are restricted through penalty function approach.

3. Modeling of STATCOM

The STATCOM is a FACTS controller based on voltage sourced converter. A VSC generate a synchronous voltage of fundamental frequency, controllable magnitude and phase angle. If a VSC is shunt-connected to a system via a coupling transformer as shown in Figure 1.1 the resulting STATCOM can inject or absorb reactive power to or from the bus to which it is connected and thus regulate the bus voltage magnitude. This STATCOM model is known as Power Injection Model (PIM) or Voltage Source Model (VSM). Steady state modeling of STATCOM within the Newton-Raphson method in polar co-ordinates is carried out as follows:

The Thevenin equivalent circuit representing the fundamental frequency operation of the switched-mode voltage sourced converter and its transformer is shown in Figure 1.2

$$V_{vR} = V_k + Z_{vR} I_{vR} \tag{12}$$

Is expressed in Norton equivalent form

$$I_{vR} = I_N - Y_{vR} V_{vR} \tag{13}$$

Where $I_N = Y_{vR} V_{vR}$

In these expressions, V_k represents bus k voltage and V_{vR} represents the voltage source inverter. I_N is the Norton's current while I_{vR} is the inverter's current. Also, Z_{vR} and Y_{vR} are the transformer's impedance and short-circuit admittance respectively.

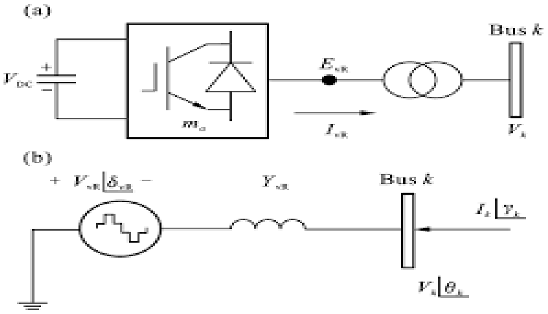


Figure 1.1 Static compensator (STATCOM) system: (a) voltage source converter(VSC) connected to the AC network via shunt-connected transformer; (b) shunt solid-state voltage source

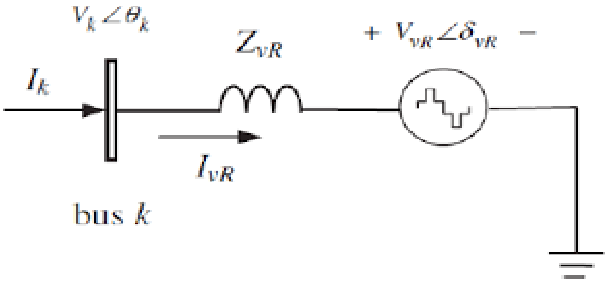


Figure 1.2 STATCOM equivalent circuit

The STATCOM voltage injection V_{vR} bound constraint is as follows:

$$V_{vR\min} \le V_{vR} \le V_{vR\max} \tag{14}$$

Where $V_{vR\min}$ and $V_{vR\max}$ are the STATCOM's minimum and maximum voltages.

The current expression in is transformed into a power expression by the VSC and power injection into bus k as shown in equations (15) and (16) respectively.

$$S_{vR} = V_{vR} I_{vR}^* = V_{vR}^2 Y_{vR}^* - V_{vR} Y_{vR}^* V_k^* \tag{15}$$

$$S_k = V_k I_{vR}^* = V_{vR} Y_{vR}^* V_k^* - V_k^2 Y_{vR}^* \tag{16}$$

Where $|V_{vR}|$ and δ_{vR} are the STATCOM voltage magnitude and angle respectively.

The active and reactive power equations for the STATCOM and bus k, respectively:

$$P_{vR} = V_{vR}^2 G_{vR} + V_{vR} V_k [G_{vR} \cos(\delta_{vR} - \theta_k) + B_{vR} \sin(\delta_{vR} - \theta_k)], \tag{17}$$

$$Q_{vR} = -V_{vR}^2 B_{vR} + V_{vR} V_k [G_{vR} \sin(\delta_{vR} - \theta_k) - B_{vR} \cos(\delta_{vR} - \theta_k)] \tag{18}$$

$$P_k = V_k^2 G_{vR} + V_k V_{vR} [G_{vR} \cos(\theta_k - \delta_{vR}) + B_{vR} \sin(\theta_k - \delta_{vR})], \tag{19}$$

$$Q_k = -V_k^2 B_{vR} + V_k V_{vR} [G_{vR} \sin(\theta_k - \delta_{vR}) - B_{vR} \cos(\theta_k - \delta_{vR})] \tag{20}$$

Using these power equations, the linearized STATCOM model is included in the load flow solution, where the voltage magnitude V_{vR} and phase angle δ_{vR} are taken to be the state variables.

4 Algorithm of AHP Method

AHP is a decision-making tool, which helps in finding goals or objectives among alternative. It is a systematic method for comparing a list of objectives and the alternative solutions satisfying respective objectives. Some mathematical steps involved in AHP method are as follows.

Step 1: selection and evaluation of attributes

Step 2: selection of alternatives

Step 3: Formation of decision matrix

The entire MADM problem can be easily expressed in matrix format. A decision matrix **A** is an (M × N) matrix in which element aij indicates the performance of alternative Ai when it is evaluated in terms of decision criterion Cj, (for i = 1,2,3,..., M, and j = 1,2,3,..., N). This decision matrix is taken as an input to all the MADM methods.

$$\begin{array}{cccccc}
 & & & \text{Criteria} & & \\
\underline{\text{Alternatives}} & \underline{C1} & \underline{C2} & \underline{C3} & \underline{\dots} & \underline{C_N} \\
A_1 & a_{11} & a_{12} & a_{13} & \dots & a_{1N} \\
A_2 & a_{21} & a_{22} & a_{23} & \dots & a_{2N} \\
A_3 & a_{31} & a_{32} & a_{33} & \dots & a_{3N} \\
.. & . & . & . & \dots & . \\
.. & . & . & . & \dots & . \\
.. & . & . & . & \dots & . \\
A_M & a_{M1} & a_{M2} & a_{M3} & \dots & a_{MN}
\end{array} \qquad (21)$$

Step 4: construction of pair wise comparison matrix

The number of comparison is the combination of a number of attributes to be compared. The number of pair wise comparisons is shown in Table 1.1

Table 1.1
Number of comparisons

Number of elements	1	2	3	4	5	6	7	n
Number of comparison	0	1	3	6	10	15	21	$\frac{n(n-1)}{2}$

The scaling is not necessary 1 to 9 but for qualitative data such as preference, ranking and subjective opinions, it is suggested to use scale 1 to 9. The values of the pair wise comparisons in the MADM methods are determined according to the scale introduced by Saaty (1980). According to the scale, the available values for the pair wise comparisons are members of the set: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9} and is shown in Table 1.2

Table 1.2
Scale of Relative Importance (according to Saaty (1980))

Intensity of Importance	Definition
1	Objectives are of equally importance
3	objective is weakly more important than other objective
5	objective is strongly more important than other objective
7	objective is very strongly more important than other objective
9	Objective extremely more important than other objective
2,4,6,8	Intermediate values between the two adjacent judgments
Reciprocals of above non zero	If activity one objective has one of the above nonzero numbers assigned to it when compared with activity, then other objective has the reciprocal value

For ‘N’ number of objectives, the size of the comparison matrix is N xN. The diagonal elements of the matrix are always 1 and the upper diagonal has to fill based on preference values using the following rules:

1. If the judgment value is on the right side of 1, put the actual judgment value.
2. If the judgment value is on the left side of 1, put the reciprocal value.

If *bij* is the element of row i column j of the matrix, then the lower diagonal is filled using this formula as

$$b_{ji} = \frac{1}{b_{ij}} \tag{22}$$

Thus this is complete comparison matrix. All the elements in the comparison matrix are positive or b_{ji}>0. The pair wise comparison matrix of objectives is shown in Table 1.2.

obj1	obj2	obj3	… objN	Priority
obj1	b11	b12	… b1N	p1
obj2	b21	b22	… b2N	p2
.	.	.	… .	.
.	.	.	… .	.
objN	bN1	bn2	… bNN	Pn

(23)

Step 5: Find the relative normalized weight

Find the relative normalized weight (W_j, $j = 1, 2, 3, ...N$) of each attribute by (i) calculating geometric mean of the i^{th} row and (ii) normalizing the geometric means of rows in the comparison matrix. This can be represented as

$$GM_j = \left(\prod_{j}^{M} b_{ij} \right)^{\frac{1}{M}} \tag{24}$$

$$W_j = \frac{GM_j}{\sum_{j=1}^{M} GM_j} \tag{25}$$

The geometric mean method of MADM methods is commonly used to determine the relative normalized weights of the attributes, because of its simplicity, easy determination of the maximum Eigen value, and reduction in inconsistency of the judgments.

Later steps involved in the four methods are

Step6: Calculate matrices $A3$ and $A4$ such that $A3 = A1 * A2$ and $A4 = A3 / A2$, where $A1$ is pair wise comparison matrix, $A2 = \left(W_1, W_2, W_3 .... W_j\right)^T$.

Step7: Determine the maximum Eigen value $\lambda_{\max}$ that is the average of matrix A_4.

Step8: Calculate the consistency index $CI = {}^{(\lambda_{\max} - M)}\!\big/_{M-1}$. The smaller the value of CI, the smaller is the deviation from the consistency.

Table 1.3

RCI values for different values of N

N	1	2	3	4	5	6	7	8	9	10	
RCI	0	0	0.58	0.89	1.12	1.24	1.32	1.41	1.45	1.49	

Step10: Calculate the consistency ratio $CR = CI / RI$ Usually CR of 0.1 or less is considered as acceptable and it reflects an informed judgment attributable to the knowledge of the analyst regarding the problem under study.

Step11: The overall performance score of the alternatives is obtained by multiplying the relative normalized weight (W_j) of each attribute with its corresponding normalized weight value for each alternative and summing over the attributes for each alternative.

5 Teaching Learning Based Optimization

The demonstration or working of TLBO Algorithm is divided into two parts:

- ‘Teacher phase’.
- ‘Learner phase’.

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.

5.1 Teacher Phase

It is the first part of the algorithm where learners learn through the teacher. During this phase, a teacher tries to increase the mean result of the class in the subject taught by him or her depending on his or her capability. At any iteration i, assume that there are ‘m’ number of subjects (i.e., design variables), ‘n’ number of learners (i.e., population size, k=1,2,…,n) and $M_{j,i}$ be the mean result of the learners in a particular subject ‘j’ (j=1,2,….,m). The best overall result $X_{total-kbest,i}$ considering all the subjects together obtained in the entire population of learners can be considered as the result of best learner kbest. The difference between the existing mean result of each subject and the corresponding result of the teacher for each subject is given by,

$$\text{Difference\_}mean_{j,k,i}=r_i(X_{j,kbest,i}-TFM_{ji}) \tag{26}$$

Where, $X_{j,kbest,i}$ is the result of the best learner in subject j. TF is the teaching factor which decides the value of mean to be changed, and TF is the random number in the range [0,1]. Value of TF can be either 1 or 2. The value of TF is decided randomly with equal probability as,

$$TF = \text{round } [l + \text{rand } (0,1)\{2-1\}] \tag{27}$$

TF is not a parameter of the TLBO algorithm. The value of TF is not given as an input to the algorithm and its value is randomly decided by the algorithm using Eq. (27). After conducting a number of experiments on many benchmark functions it is conducted that the algorithm performs better if the value of TF is between 1 and 2. However, the algorithm is found to perform much better if the value of TF is either 1 or 2 and hence to simplify the algorithm, the teaching factor is suggested to take either 1 or 2 depending on the rounding up criteria given by Eq. (27). Based on the Difference_$mean_{j,k,i}$, the existing solution is updated in the teacher phase according to the following expression.

$$X_{j,k,i} = X_{j,k,i} + \text{Difference\_}mean_{j,k,i} \tag{28}$$

$X_{j,k,i}$ is accepted if it gives better function value. All the accepted function values at the end of the teacher phase are maintained and these values become the input to the learner phase. The learner phase depends upon the teacher phase.

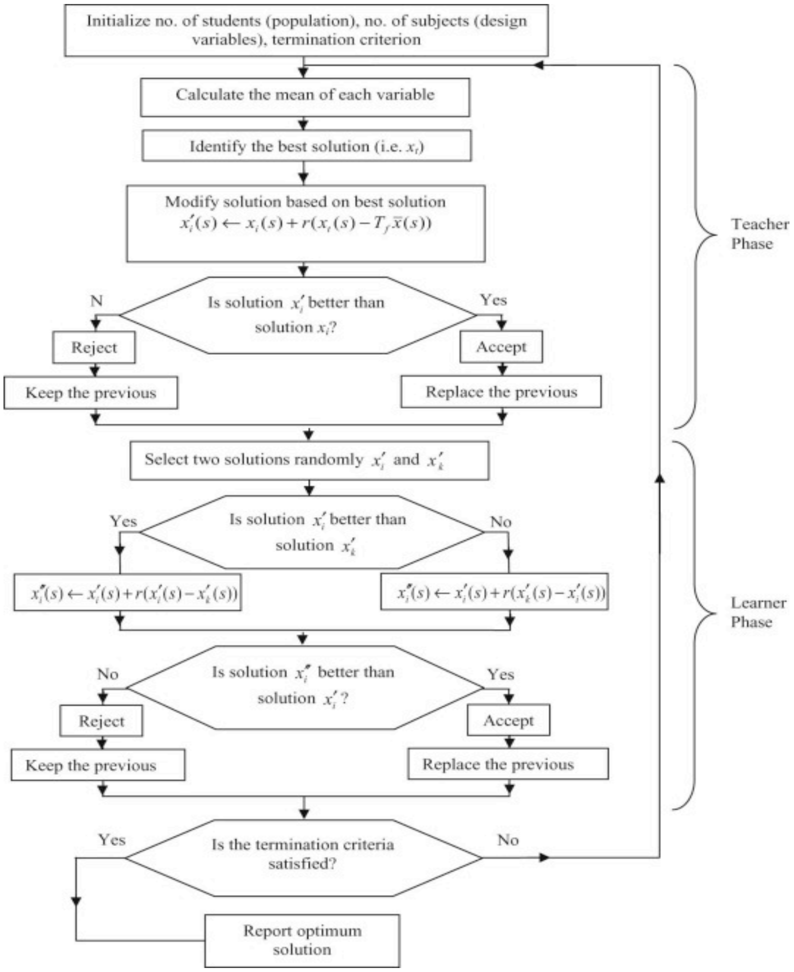
5.2 Learner Phase

It is the second part of the algorithm where learners increase their knowledge by interacting among themselves. A learner interacts randomly with other learners for enhancing his or her knowledge. 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. A learner learns new things if the other learner has more knowledge than him or her. Considering a population size of ‘n’, the learning phenomenon of this phase is explained below. Randomly select two 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 updated function values of $X'_{total-P,i}$ and $X'_{total-Q,i}$ are the updated function values of $X'_{total-P,i}$ and $X'_{total-Q,i}$ of P and Q, respectively, at the end of teacher phase). Teaching-learning -based optimization (TLBO) is a population-based algorithm which simulates the teaching-learning process of the classroom. This algorithm requires only the common control parameters such as the population size and the number of generations and does not require any algorithm- specific control parameters.

$$X''_{j,P,i} = X'_{j,P,i} + r_i\left(X'_{j,P,i} - X'_{j,Q,i}\right), If\ X'_{total} - P, i < X'_{total-Q,i} \quad (29)$$

$$X''_{j,P,i} = X'_{j,P,i} + r_i\left(X'_{j,Q,i} - X'_{j,P,i}\right), If\ X'_{total} - Q, i < X'_{total-P,i} \quad (30)$$

5.3 FLOWCHART OF TEACHING LEARNING BASED OPTIMIZATION ALGORITHM (TLBO):



6 Results and Discussion

6.1. IEEE 30-bus system results

This section presents the details of the study carried out on IEEE 30-bus system for power system performance enhancement. The maximum and minimum values for the generator voltage and tap changing transformer control variables are 1.1 and 0.9 in per unit respectively. The maximum and minimum voltages for the load buses are considered to be 1.05 and 0.95 in per unit. The case studies for simulation study are as follows:

Case I: Single-objective optimization with STATCOM device at the selected locations.

Case II: Application of MADM methods for determination of optimal location of STATCOM

Case I: Single-objective optimization with STATCOM device at the selected locations

In the present power system operation, the utilities need to operate their power transmission system much more effectively, increasing their utilization degree. Reducing the effective reactance of lines by series compensation is a direct approach to increase transmission capability. However, power transfer capability of long transmission lines is limited by stability considerations. Because of the power electronic switching capabilities in terms of control and high speed, more advantages have been done in areas of FACTS devices and presence of these devices improve the performance of the power system. The proposed TLBO algorithm is applied for solving the optimal power flow problems subjected to different equality and inequality constraints with STATCOM device in the selected locations. The selected locations of STATCOM are at buses 9,10,12,14 and 16. These locations are taken based on first five maximum voltage deviations of load buses from steady state values of load buses. The TLBO algorithm is applied for solving the OPF problem with four different objective functions. In each case study, four sets of 10 test runs were performed for solving the OPF problems under three operating conditions. All the solution satisfies the constraints on reactive power generation limits and line flow limits. Figures 1.3(a)-1.3(d) shows the convergence characteristics of fuel cost of generation, total real power loss, sum of squared voltage stability index and voltage deviation with STATCOM located at different locations of optimal value under three operating conditions. From these figures it can be observed that the TLBO algorithm reaches the best solution within 150 iterations under all the operating conditions. Table 1.4 shows the OPF results with STATCOM device located in the selected lines with respect to different objective functions. Table 1.4 shows four different attributes (objectives) such as total fuel cost of generation, total real power loss, sum of squared voltage stability index and voltage deviation with five different alternatives (different lines)such as 9,10,12,14 and 16 buses has being taken for STATCOM device installation.

Also from the Table 1.4, it can be observed that under normal condition the optimal value for cost of generation is 798.5024 $/hr at bus 12, the optimal value for power loss is 0.0306 p.u at bus 9, the optimal value for voltage stability index is 0.1018 at bus 9 and optimal value for voltage deviation is 0.0007 at buses 10 and 12. With this one can say that optimal values of four attributes are obtained at different alternatives.

Case II: Application of MADM methods for determination of optimal location of STATCOM

In this section, in order to differentiate the best alternative out of five considered alternatives 9,10,12,14 and 16 MADM method is applied. The decision making method considered for determination of best location of STATCOM is AHP. The same preference matrix given in Table 1.5 is also considered here. This matrix is based on the preferences given to the four attributes i.e. the pair wise comparisons determines the preference of each attribute over another. Table 1.6 also used as priority vector of the attributes. Priority vector shows relative weights among the attributes that are used for comparison. Table 1.4gives the OPF results with STATCOM device located at buses with respect to different objective functions and are used as decision table for MADM methods. The considered decision matrix of MADM methods for the system consists of 5 alternatives (different buses)such as 9,10,12,14 and 16, 4 attributes(objectives) such as total fuel cost of generation, total real power loss, sum of squared voltage stability index and voltage deviation. This decision matrix is given as an input to all the methods. The element in this matrix indicates the performance of alternative when it is evaluated in terms of decision criterion.

Table 1.4
Decision table for MADM Methods

ATTRIBUTES	WITHOUT DEVICE	WITH STATCOM (ALTERNATIVES)				
		9	10	12	14	16
Fuel Cost	798.8986	799.4301	798.6667	798.5024	799.5416	798.7870
Power loss	0.0316	0.0301	0.0310	0.0322	0.0333	0.0306

Voltage stability index	0.1057	0.1018	0.1034	0.1029	0.1037	0.1044
Voltage deviation	0.0008	0.0008	0.0007	0.0007	0.0009	0.0008

Table 1.5
Pair Wise Comparison Matrix for Attributes

Attributes	Attributes			
	Fuel Cost	Power Loss	Voltage Stability Index	Voltage Deviation
Fuel Cost	1	2	3	3
Power Loss	1/2	1	3	5
Voltage stability index	1/3	1/3	1	2
Voltage deviation	1/3	1/5	1/2	1

Table 1.6
Weight Matrix and value of attributes

Attributes	Weight-age	Subjective measure of attribute	Assigned Value
Fuel Cost	0.4266	Eigen value	4.1548
Power loss	0.3427	Consistency index	0.0516
Voltage stability index	0.1422	Consistency ratio	0.0580
Voltage deviation	0.0885		

Table 1.7
Relative Ranking of Alternatives under different operating conditions MADM methods

Alternatives	AHP
9	2
10	1
12	5
14	3
16	4

Table 1.7 shows that relative ranking of alternatives under different operations by MADM methods. From the Table 1.7 it is observed that AHP method gives rank one for alternative 10. From this it is can say that AHP method gives rank one to the alternative 10 for the STATCOM location and so it is considered as a best choice for the location of STATCOM device among the buses considered for the system and this gives highest benefits to the power system operation in terms of performance parameters. Figure 1.4(a)-1.4(d) shows the convergence characteristics of fuel cost of generation, total real power loss, sum of squared voltage stability index and voltage deviation with STATCOM located at optimal bus 10. Tables 1.4(a)-1.4(b) shows that the optimal control variables settings for OPF without and with STATCOM device located at the optimal bus10. From figure 1.4(a)-1.4(d), it is observed that the convergence characteristics of the four objectives obtained are better when compared to without STATCOM device and at optimal location 10 STATCOM gives better performance compared to other locations.

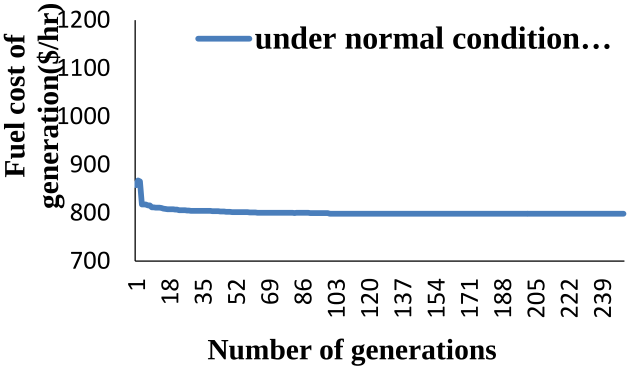


Figure 1.3(a) Convergence of fuel cost of generation

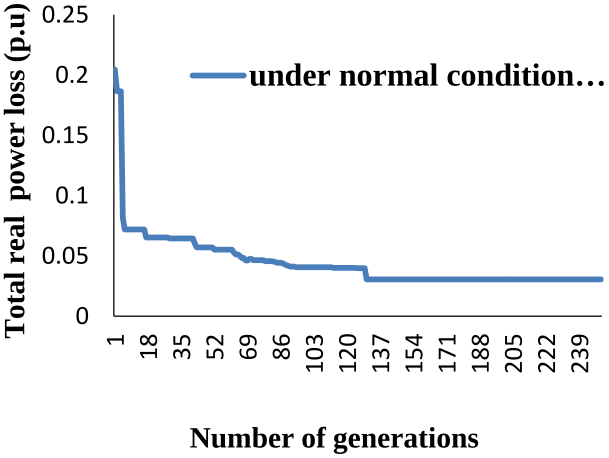


Figure 1.3(b) Convergence of total power loss

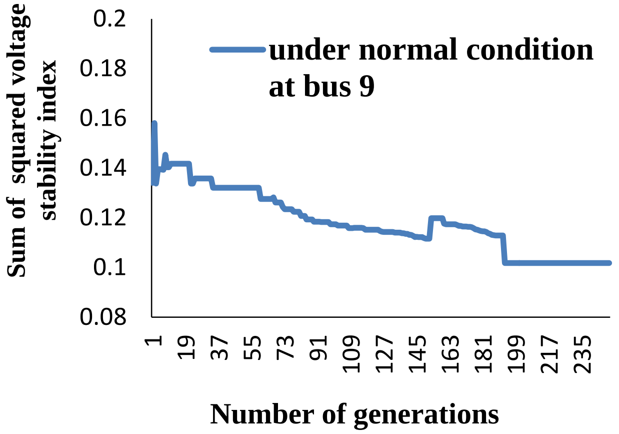


Figure 1.3(c) Convergence of voltage stability index

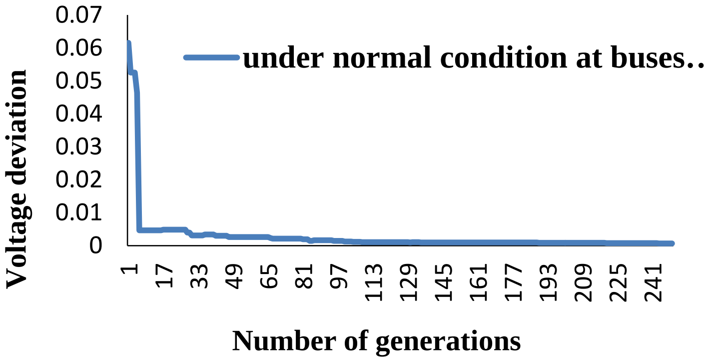


Figure 1.3(d) Convergence of voltage deviation

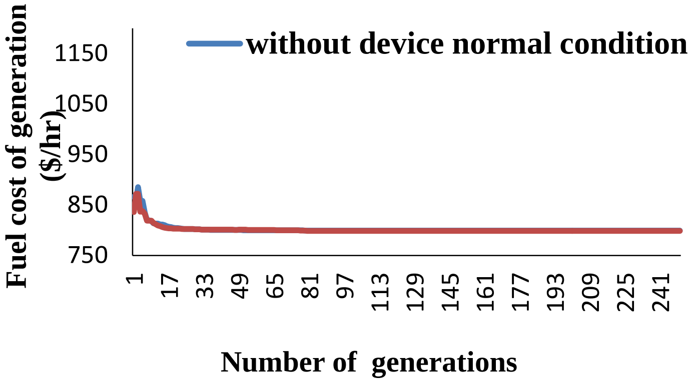


Figure 1.4 (a) Convergence of fuel cost of generation of IEEE30 bus system with optimal location of STATCOM

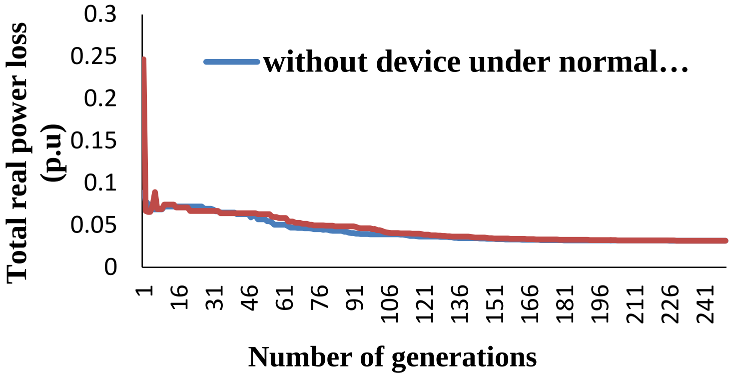


Figure 1.4(b) Convergence of power loss of IEEE 30-bus system with optimal location of STATCOM

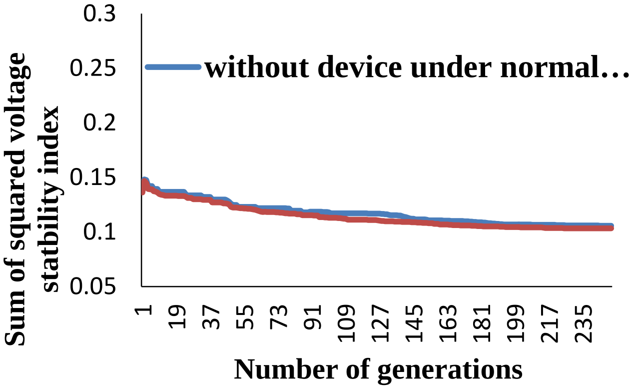


Figure 1.4(c) Convergence of voltage stability index of IEEE 30-bus system with optimal location of STATCOM

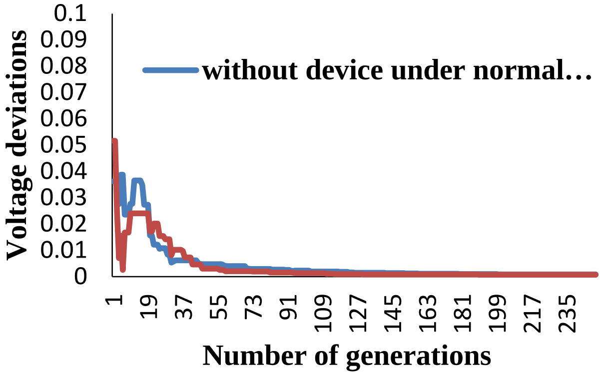


Figure 1.4(d) Convergence of voltage deviation of IEEE 30-bus system with optimal location of STATCOM

7. CONCLUSION

In this paper, the TLBO has been successfully performed to solve optimal placement of STATCOM for reducing the active power loss, enhancing voltage stability index, improvement in voltage deviations and reducing the cost. 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. Therefore .from the simulation results it may be concluded that TLBO is superior to the other algorithms. Simulation results for IEEE 30 bus system are analyzed and graphs are generated for the optimal placement of STATCOM in the transmission line using TLBO optimization technique based on the AHP method. Graphs are generated for convergence for cost of generator, power loss, and voltage stability index (VSI) and voltage deviation with and without STATCOM FACTS device.

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