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Minimization of L-index using Genetic Algorithm for Improvement of Voltage profile in Power Systems

J. Vanishree*, V. Ramesh and Abhishek Verma

School of Electrical Engineering, VIT University, Vellore – 632014, Tamil Nadu, India; j.vanishree@vit.ac.in, vramesh@vit.ac.in, abhishek21kt@gmail.com

Abstract

Objectives: The objective is to identify weakest buses using L-index method and to reduce the maximum value of L-index using Genetic Algorithm so as to maintain the voltage profile. **Methods/Statistical Analysis**: Among the various existing voltage stability indices, L-index is implemented in this paper since it involves simple calculation with high accuracy and reliability. Hence on identifying buses with maximum L-index, it becomes essential to minimize the L-index to maintain the system stability. Genetic Algorithm is chosen since it is faster and more accurate when implemented for power system problems in particular to optimize the voltage. **Findings**: The variations to be adopted for the control variables which are thus obtained for IEEE 30 bus system by using Genetic Algorithm are highly important to reduce L-index value. The voltage profile is improved better when Static Var Compensator is placed at the first weakest bus rather than the improvement in the voltage profile on employing a compensator in the next weakest buses which indicates the importance in identification of weakest buses. The significance of weakest buses are still emphasised on considering normal condition and contingency condition which shows that under contingency it is the weakest buses which is much more affected and hence driving the entire system towards voltage collapse. **Application/Improvements:** Hence by identifying the weakest buses using L-index and by minimizing the maximum value of L-index using Genetic Algorithm along with reactive power compensator improves the voltage profile better.

Keywords: Genetic Algorithm, L-Index, Reactive Power, Voltage Profile

1. Introduction

In recent years, power shortage continues to be a major cause of concern. With the growth in the economy, demand for the power has increased to a greater extent. Hence the power sector needs to compensate the difference between demand and the supply through sufficient power generation as well as through efficient transmission[1,2]. In order to avoid the cost requirement for the establishment of new lines and to operate with the existing power plant facilities as well as to meet the required power demand, the transmission lines are operated closer to their maximum limit. This leads to an inadequacy in reactive power with a result of voltage instability in the system and if preventive measures are not performed which in turn results in a blackout. Many such blackouts were witnessed due to voltage collapse incidents in past few decades[3–6].

Hence it has become essential to perform the voltage stability analysis so as to determine the distance of system voltage to the collapse point. This is considered by means of active power flow, load level and with available reactive power reserve. In order to measure these terms certain types of indices are followed which are called Voltage Stability Indices (VSI)[7,8]. These indices measure the proximity by means of load flow parameters such as load voltage, line current, real and reactive power and so on. There are various types of Voltage Stability Indices such as P-V and Q-V curves, L-index, V/V_o index, Line Stability Index (LSI) and Fast Voltage Stability Index (FVSI). As L-index is based on maximum loadability, it provides accurate information regarding the stability conditions. Hence it is best suited for analysing the proximity of voltage collapse. A comparison of various Voltage Stability Indices was performed and has concluded that L-index has greater accuracy and better

**Author for correspondence*

reliability[9]. Hence optimization of the L-index values can be performed using various techniques such as Memetic algorithm, Differential evolution, Genetic Algorithm and so on. Each optimization technique has its own benefits in different areas. Genetic Algorithm proves to be faster and more accurate when implemented in power system problem for optimization of the required parameter. On identification of weakest buses the FACTS devices can be employed for meeting the reactive power demand and to improve the voltage profile far better with effective transmission of active power[10–16].

This paper is mainly concerned with analysis and maintenance of voltage profile by minimizing the value of L-index using Genetic algorithm. The weakest buses are identified using L-index formulation. From the obtained voltage profile, it is observed that the values are not within the nominal limit in particular for the weakest buses. These are the buses which are much prone to cause a voltage collapse. Hence to maintain a stable operation it is essential to minimize the L-index value. The minimization of L-index value is achieved using Genetic Algorithm and the implementation results on IEEE 30 bus system show an efficient maintenance in voltage profile both under normal and contingency conditions. In this paper mathematical background of L-index is given in Section 2. Section 3 explains the objective function and its constraints. Section 4 gives the general description of Genetic algorithm. Section 5 shows the implementation details and its results for load flow analysis and L-index calculation for IEEE 30 bus system. Section 6 reveals significance of Genetic Algorithm in reducing the L-index value. Section 7 discusses the results observed. Section 8 gives the conclusion.

2. Mathematical Formulation of L-Index

Many methods are existing to determine Voltage Stability Index. L-index is one among those techniques in the literature[17]. It is formulated on the basis of power flow. L-index value varies from 0 to 1. If it is closer to 1 then it predicts that the system is moving towards the collapse point and is safe if the value is approaching towards 0. The buses which are responsible for voltage collapse are considered to be the weakest buses in the given system. Discussion of L-index calculation is as follows:

Consider an N-bus system. As per the kirchhoff current law generator voltage and load voltage can be related to their respective currents in terms of elements of admittance matrix and is given below:

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_G & Y_G \\ Y_G & Y_L \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix} \tag{1}$$

Where,

I_G : Current at generator buses.
I_L : Current at load buses.
V_G : Voltage at generator buses.
V_L : Voltage at the load buses.

Above Equation can also be written as:

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & E_{LG} \\ M_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix}_s \tag{2}$$

where

$$E_{LG} = -\left[Y_{LL}\right]^{-1}\left[Y_{LG}\right] \tag{3}$$

Expression for the L-index of the nth node is,

$$L_n = \left| 1 - \sum_{m=1}^{N_g} E_m \frac{V_m}{V_n} \angle(\phi_m + \gamma_m - \gamma_n) \right| \tag{4}$$

Where,

V_m, V_n voltage value of mth generator and nth node respectively,

ϕ_m angle of the term E_{nm},

γ_m, γ_n voltage angle of mth generator and nth node respectively.

3. Problem Statement

The main objective is to maintain the voltage within the nominal limit both under normal and contingency condition. This is obtained by reducing the L_{max} value by means of adjusting the reactive power control variables subjected to system constraints.

3.1 Constraints considered for improvement of voltage profile are as follows:

- Generator bus voltage bound.

$$V_{gm}^{\min} \le V_{gm} \le V_{gm}^{\max} \qquad m \in N_B$$

- Bound on active power generation of Slack bus.

$$P_S^{\min} \le P_S \le P_S^{\max}$$

- Bound on power flow.

$$S_l \le S_l^{\max} \qquad l \in N_l$$

- Bound on reactive generation.

$$Q_{gm}^{\min} \le Q_{gm} \le Q_{gm}^{\max} \qquad m \in N_{PV}$$

Where

P_s active power generation of slack bus.
V_{gm} voltage value at m^{th} generator.
N_l total of transmission lines.
N_{PV} total of generator buses.
N_B total of buses.

4. Genetic Algorithm

Genetic algorithm[18] is a hunt algorithm stimulated by natural genetics. This algorithm is initialized by manipulating the data available in existing residents to replace the members of old generation by using the process of reproduction, crossover and mutation. Assessment is carried for the individuals through computing the objective function so as to obtain the fittest chromosomes for the consecutive iterations to proceed until an optimal result is achieved.

4.1 Selection

Selection is a genetic operator and its main goal is to select the fittest solution to reproduce and eliminate the bad solution. There are various types of proposed selection operators[19] available out of which tournament operator is used for the given problem and the size is 2. As Genetic Algorithm is implemented on 30 bus system, population of the system is 30. In this type of selection, say 'n' numbers of individuals are selected randomly. In order to proceed with the consecutive processes the fittest among the present residents are included till the matting pool is completely occupied.

4.2 Crossover

Crossover is the process by means of which the characteristics of the parents are inherited to their resultants. Generally the range is from 0.6 to 1 for the probability of selection. For the given problem crossover rate is 0.9. There are varieties of crossover operators proposed and two point technique is implemented for the given problem. In case of two points, new gene is formed by the genes taken from the parents from 1 to q such that one parent genes is considered from any less than p and another between p+1 to q and considering the genes more than q from the one considered initially.

4.3 Mutation

Mutation provides wider universe to hunt by means of introducing arbitrary variations in personalities present in the residents. There are varieties of mutations, out of which uniform mutation with rate of mutation = 0.1 is used in the implementation.

5. Load Flow Studies and Calculation of L-Index

Implementation is carried on IEEE 30 bus system and its diagram is in Figure 1. Power flow analysis is implemented on the considered network under normal and contingency condition and comparative results were shown in Table 1. L-index were calculated for the load buses under normal and contingency condition using the data obtained from load flow analysis and their results in Table 2 were compared. From Table 3, it has been witnessed voltage instability is resulted due to supplementary increase in L-index value of weakest buses. Hence it is essential to reduce the L-index value in order to safeguard the system from voltage fall. Necessary reduction in L-index is done using GA and its flow is given in Figure 2.

5.1 Minimization of L-Index using Genetic Algorithm

Objective function is given by:

$$\min f = L^{\max} + SP + \sum_{n=1}^{N_{PQ}} VP_n + \sum_{n=1}^{N_g} QP_n + \sum_{n=1}^{N_l} LP_n \qquad (5)$$

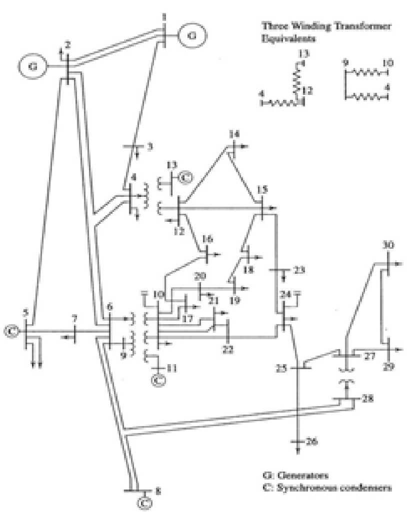

Figure 1. Single line diagram of IEEE 30-bus system.

Table 1. Voltages of buses under normal and contingency condition

Bus number	Voltage under normal condition	Voltage under contingency condition (line outage in 29-30)
1	1.0600	1.0600
2	1.0430	1.0330
3	1.0215	1.0211
4	1.0129	1.0124
5	1.0100	1.0100
6	1.0121	1.0116
7	1.0034	1.0031
8	1.0100	1.0100
9	1.0510	1.0506
10	1.0444	1.0438
11	1.0820	1.0820
12	1.0574	1.0571
13	1.0710	1.0710
14	1.0424	1.0421
15	1.0378	1.0372
16	1.0447	1.0443
17	1.0391	1.0386
18	1.0279	1.0274
19	1.0253	1.0247
20	1.0293	1.0287
21	1.0321	1.0314
22	1.0327	1.0319
23	1.0272	1.0261
24	1.0216	1.0198
25	1.0189	1.0146
26	1.0012	0.9969
27	1.0257	1.0200
28	1.0107	1.0094
29	1.0059	0.9948
30	0.9945	0.9802

Here,
SP: Reference bus real power violation penalty.
VPj: Penalty term for load bus voltage limit violation.
QPj: Penalty term for reactive power violation.
LPj: Power flow limit.

The penalty terms can be formed by including penalty factors with each parameter of the respective terms.

Table 2. L-index of buses under normal and contingency condition

Bus number	L-index (under normal condition)	L-index (under contingency condition)
6	0.0785	0.0780
7	0.0581	0.0562
8	0.0384	0.0361
9	0.0145	0.0131
10	0.0003	0.0002
11	0.0485	0.0479
12	0.0202	0.0194
13	0.0785	0.0780
14	0.0455	0.0447
15	0.0467	0.0462
16	0.0364	0.0357
17	0.0385	0.0379
18	0.0526	0.0520
19	0.0536	0.0531
20	0.0490	0.0484
21	0.0461	0.0456
22	0.0457	0.0454
23	0.0555	0.0555
24	0.0601	0.0607
25	0.0728	0.0760
26	0.0917	0.0951
27	0.0730	0.0776
28	0.0610	0.0609
29	0.0941	0.1049
30	0.1066	0.1214

Table 3. Weakest buses among 24 load buses

S. no	Bus number	L-index (under normal condition)	L-index (under contingency condition)
1	30	0.1066	0.1214
2	29	0.0941	0.1049
3	26	0.0917	0.0951
4	6	0.0785	0.0780
5	27	0.0730	0.0776

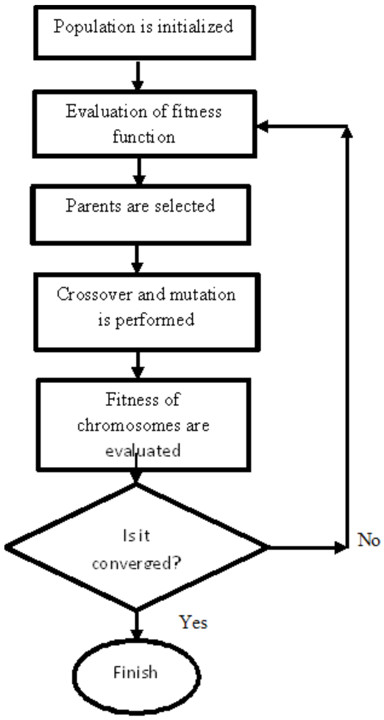

Figure 2. Flow chart of Genetic Algorithm.

$$SP = \begin{cases} R_S(P_S - P_S^{\max})^2 \, if P_S \geq P_S^{\max} \\ R_S(P_S - P_S^{\min})^2 \, if P_S \leq P_S^{\min} \\ 0 \, otherwise \end{cases}$$

$$VP_n = \begin{cases} R_V(V_n - V_n^{\max})^2 \, if V_n \geq V_n^{\max} \\ R_v(V_n - V_n^{\min})^2 \, if V_n \leq V_n^{\min} \\ 0 \, otherwise \end{cases}$$

$$QP_n = \begin{cases} R_q(Q_n - Q_n^{\max})^2 \, if Q_n \geq Q_n^{\max} \\ R_q(Q_n - Q_n^{\min})^2 \, if Q_n \leq Q_n^{\min} \\ 0 \, otherwise \end{cases}$$

$$LP_n = \begin{cases} R_l(L_n - L_n^{\max})^2 \, if L_n \geq L_n^{\max} \\ 0 \, otherwise \end{cases}$$

in which R_s, R_v, R_q and R_l are penalty elements.

As Genetic Algorithm maximizes function, reduction of the objective function f is considered as maximization function where 100 is the value of R.

$$fitnessfunction = \frac{R}{f}$$

The required settings adopted for implementation are shown below:

Population → 30
Crossover → Two Point (rate = 0.9)
Selection → Tournament (size = 2)
Mutation → Uniform (rate = 0.1)
Number of Generation → 100

The values of the control variables for normal and contingency condition before and after the implementation of Genetic Algorithm were shown in Table 4 and Table 5 respectively.

From the tables it has been observed that the value of L-index have reduced under both the conditions (normal and contingency) hence it is possible to maintain the system within the stable condition.

6. Results and Discussion

The graphs are shown for the fitness function for both regular and contingency conditions in Figures 3 and 4 respectively. From the graphs it is clear that fitness value starts reducing from a value of 2 to 0.12 between 10th and 45th generations and then settles finally at a value of 0.1166 at 51st generation. On observing the graph

Table 4. Control variables under normal condition

S. No.	Control variable	Initial setting	Optimal setting
1.	V1	1.06	1.06
2	V2	1.043	1.0153
3	V3	1.01	1.0063
4	V4	1.082	1.0635
5	V5	1.01	1.0116
6	V6	1.071	1.0976
7	t 1	0.978	1.05
8	t 2	0.969	0.9
9	t 3	0.932	0.925
10	t 4	0.968	0.95
11	Q30	0	5
12	Q29	0	5
13	Q26	0	5
14	Q6	0	1
15	Q27	0	3
16	P loss	17.599	17.28
17	L max	0.1066	0.10114

Table 5. Control variables under 125% loaded condition

S. No.	Control variable	Initial setting	Optimal setting
1	V1	1.06	1.06
2	V2	1.033	1.0106
3	V3	1.01	1.0054
4	V4	1.082	1.0442
5	V5	1.01	1.0094
6	V6	1.071	1.0953
7	t 1	0.978	1.05
8	t 2	0.969	0.9
9	t 3	0.932	0.925
10	t 4	0.968	0.95
11	Q30	0	5
12	Q29	0	5
13	Q26	0	5
14	Q6	0	1
15	Q27	0	3
	P loss	18.128	17.634
	L max	0.1214	0.11665

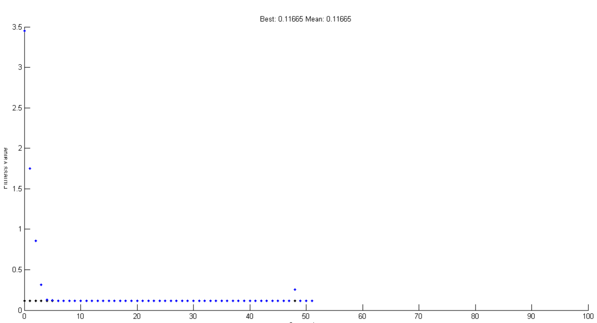

Figure 3. Best fitness value under normal condition.

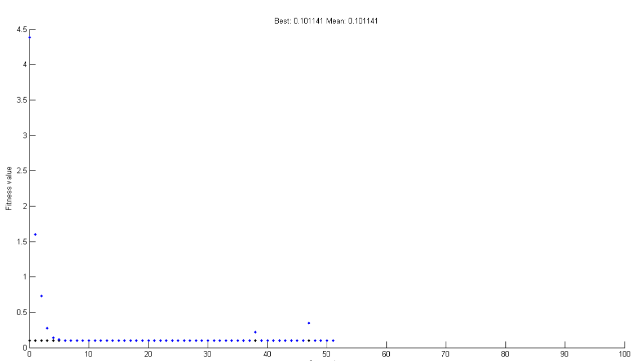

Figure 4. Best fitness function under contigency condition,

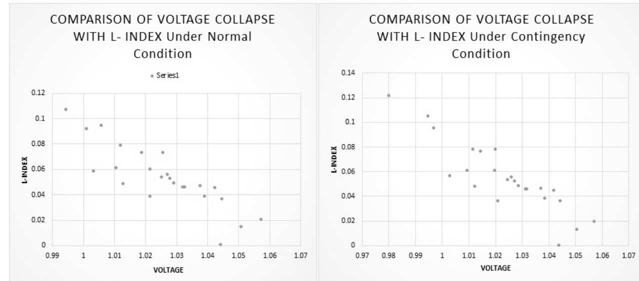

Figure 5. Comparison of voltage with L-index under normal and contingency condition.

under contingency condition, it is clear that the fitness value reduces from a value of 2 to almost a value of 0.11 at around 10th generation and reduces still further to a value of 0.10114 at 46th generation. Hence the fitness function value decreases under contingency condition when compared with normal condition of the system.

From the graphs it has been observed that the L-index value under normal condition of the system is slightly with lesser value as compared with the contingency condition. The voltage decline is more in contingency condition with greater increase in L-index when compared with increase in L-index value under normal condition. This denotes instability condition to happen readily for system. Hence reduction in L-index value at overloaded bus becomes essential, which is obtained by the optimization using Genetic Algorithm. The graphs plot between L-index and voltage are shown in Figure 5 for normal and contingency condition. The significance of the optimization algorithm in minimizing the value of L-index is clear from Table 4 and Table 5.

7. Conclusion

Voltage stability analysis in terms of L-index value was performed on IEEE 30 bus system. On obtaining the result, 30th bus was witnessed as first weakest bus followed by 29th and 26th buses. The obtained results were validated by introducing a contingency on 30th bus by means of a overload of about 125%. It was inferred that this contingency resulted in an outage of the line 29-30, with a further increase in its L-index value. If this impact is not cleared by means of reducing the L-index, it might result in a cascading effect which may lead to a blackout. Hence GA is employed for identifying the variations to be implemented in the control parameters and thus L-index value is reduced as desired.

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