International Journal of Management, IT & Engineering
Vol. 9 Issue 7, July 2019,
ISSN: 2249-0558 Impact Factor: 7.119
Journal Homepage: http://www.ijmra.us, Email: editorijmie@gmail.com
Double-Blind Peer Reviewed Refereed Open Access International Journal - Included in the International Serial Directories Indexed & Listed at: Ulrich's Periodicals Directory ©, U.S.A., Open J-Gage as well as in Cabell's Directories of Publishing Opportunities, U.S.A

A COMPARATIVE STUDY OF OPTIMIZATION TECHNIQUES FOR VOLTAGE STABILITY OF POWER SYSTEM

Dhruvi Chopra*

Prof. Y. D. Shahakar**

Abstract

Present day power systems are being operated closer to their stability limits due to economic constraints. In today's scenario, as the development is taking place simultaneously the demand for the electricity in the world is also increasing. Operation and planning of large interconnected power systems are becoming more and more complex. In power system, voltage stability plays a very important role. Voltage instability may cause blackouts and collapse of the power system. Maintaining a stable and secure operation of a power system is therefore very important and challenging issue. Many traditional and advanced optimization techniques have been proposed for reactive power dispatch to improve voltage stability of the power system. In this paper, the importance of voltage stability and optimal reactive power dispatch are discussed and analysis of voltage stability is carried out using L–index method. The different optimization techniques for improving voltage stability are studied. This paper presents LP and PSO algorithm for system parameters development for enhancing voltage stability and voltage profile improvement. All algorithms are tested in IEEE 39 bus system. The performance of PSO is compared with conventional linear programming methods.

Keywords:

Voltage Stability;

Linear Programming;

PSO;

Voltage Profile Improvement;

L-index.

---

[*] M.E. (EPS), P.R.Pote COE & M, Amravati

[**] Assistant Professor, Department of Electrical Engineering, P.R. Pote COE & M, Amravati

1. Introduction

Voltage stability refers to the ability of power system to maintain steady voltages at all the buses in the system after being subjected to a disturbance from a given initial operating point. The system state enters the voltage instability region when a disturbance or an increase in load demand or alteration in system state results in an uncontrollable and continuous drop in system voltage. Enhancing the voltage stability indirectly means reactive power control. Any changes in either power demand or system configuration implies increase or decrease in voltage. These changes can lead to system instability which can be improved through reactive power allocation. Reactive power allocation can be done by (a) tap changing transformer (b) changing generator voltages (c) switchable var sources. The optimal reactive power control problem can be stated as the problem of finding the correct value control variables so that the loss can be decreased. The main advantages of reactive power control are decrease in transmission losses, increase in power transmission capability, improved voltage profile and improved system stability. To obtain optimized reactive power control different objective functions are optimized like to minimize the sum of square of the voltage deviations of the load buses, minimization of sum of squares of voltage stability L indices of load buses, real power loss minimization, etc. To optimize we use different techniques like PSO, Genetic Algorithm, Fuzzy Logic, Linear Programming, etc. The process of improving something than its current condition is called as Optimization. It is the process of adjusting inputs, mathematical process or device characteristics to get the required output. This process is called as fitness function, objective function or cost function. Particle Swarm Optimization is inspired by behaviour of bird flocking. This algorithm consists of swarm of particles i.e. group of random particles where each single solution is a bird (particle) in the search space. Optimized solution for every particle is determined by fitness function. PSO is based on birds swarm searching for optimal food sources in which direction of birds movement is influenced by its current movement. Linear programming is a simple technique where we depict complex relationships through linear functions and then find the optimum points. The real relationships might be much more complex – but we can simplify them to linear relationships. Linear programming is used for obtaining the most optimal solution for a problem with given constraints. In linear programming, we formulate our real life problem into a mathematical model. It involves an objective function, linear inequalities with subject to constraints.

Linear programming is adaptive and more flexibility to analyze the problems. The main advantage of linear programming is its simplicity and easy way of understanding. Linear Programming (LP) is a technique for optimization of a linear objective function, subject to linear equality and linear inequality constraints. The linear programming approach is based on an assumption that the world is linear. In the real world, this is not always the case. Therefore LP Technique cannot be used as efficient method of optimization. Particle Swarm Optimization characterized into the domain of Artificial Intelligence. The term 'Artificial Intelligence' or 'Artificial Life' refers to the theory of simulating human behaviour through computation. It involves designing such computer systems which are able to execute tasks which require human intelligence. PSO technique allows greater diversity and exploration over a single population. Classical optimization techniques such as LP and NLP are efficient approaches that can be used to solve special cases of optimization problem in power system applications. As the complexities of the problem increase, especially with the introduction of uncertainties to the system, more complicated optimization techniques, such as stochastic programming have to be used. Particle Swarm Optimization (PSO) technique can be an alternative solution for these complex problems. PSO is characterized as simple in concept easy to implement, and computationally efficient. PSO has a flexible and well-balanced mechanism to enhance and adapt to the global and local exploration abilities. Moreover it allows faster convergence and requires least computation time. Therefore in this paper the main objective is to prove that PSO is best optimization method compared to traditional LP Technique.

In this paper a mathematical model is developed for optimization techniques and minute changes in the system are observed after the increment of load. The voltage stability is enhanced by performing optimization in objective functions. This optimization will help to find the suitable control variables settings for the power system. The results obtain are compared with traditional and advanced technique.

2. L-index method and voltage stability analysis

The objectives in the proposed system is to minimize the sum of squares of voltage stability L-indices of load buses (ΣL^2) and analysis of this objective function is presented to illustrate the advantages [17]. The various calculations are performed in the programming and their formulas are represented as follows:

2.1 L-index

Consider a system where, n=total number of busses, with 1, 2... g generator busses (g), g+1, g+2... g+s SVC busses (s), g+s+1... n the remaining busses (r= n-g-s) and t = number of OLTC transformers.

A load flow result is obtained for a given system operating condition, which is otherwise available from the output of an on-line state estimator. Using the load flow results, the L-index [1] is computed as

$$L_j = \left| 1 - \sum_{i=1}^{g} \mathrm{F}_{\mathrm{ji}} \frac{\mathrm{V_i}}{\mathrm{V_j}} \right| \qquad (1)$$

Where $j = g+1... n$.

The values F_{ji} are obtained from the Y bus matrix as follows

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \qquad (2)$$

Where I_G, I_L and V_G, V_L represent currents and voltages at the generator nodes and load nodes. Rearranging (2) we get

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix} \qquad (3)$$

Where $\mathrm{F}_{\mathrm{LG}} = [Y_{LL}]^{-1}[Y_{LG}]$ are the required values. The L-indices for a given load condition are computed for all load busses. For stability, the bound on the index $\mathrm{L_j}$ must not be violated (maximum limit=1) for any of the nodes j. Hence, the global indicator L describing the stability of the complete subsystem is given by L= maximum of $\mathrm{L_j}$ for all j (load buses). An L-index value away from 1 and close to zero indicates an improved system security. For a given network, as the load/generation increases, the voltage magnitude and angles change, and for near maximum power transfer condition, the voltage stability index $\mathrm{L_j}$ values for load buses tend to close to 1, indicating that the system is close to voltage collapse. The stability margin is obtained as the distance of L from a unit value i.e. (1-L) [4] [7].

2.2 Objective Function

The objective selected for voltage profile improvement is to minimize the sum of the squares of the voltage stability indices (L-index) of all load buses in the system and is as follows[19]:

$$V_L = \sum_{j=G+1}^{N} L_j^2 \tag{4}$$

where L_j is L-index value at load bus j whose value is given in the equation (1).

2.3 System Parameters

To check the effectiveness of the proposed method, the overall performance of the system has been analyzed in terms of the following system parameters V_{error} (V_e), $V_{stability}$ (V_s) and power loss (P_{loss}) respectively. V_d is desired value set as 1.0 p.u [1] [4].

$$V_e = \sum_{j=G+1}^{N} \left(V_d - V_j\right)^2 \tag{5}$$

$$V_S = \sum_{j=G+1}^{N} L_j^2 \tag{6}$$

$$P_{Loss} = \sum_{k=1}^{l} G_k \left[V_i^2 + V_j^2 - 2V_i V_j \cos\left(\delta_i - \delta_j\right)\right] \tag{7}$$

2.4 Reactive Power Output of the Generators

From the load flow studies, we can calculate the reactive power 'Q' at generator bus 'i' is given by,

$$Q_i = |V_i| \sum_{j=1}^{N} |V_j| \left(G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}\right) \tag{8}$$

Where, G_{ij} = conductance & B_{ij} = susceptance between buses 'i' & 'j', V_i & V_j are the voltages at bus i and j,

δ_{ij} is the phase angle difference of voltage from bus i to j.

G_k is conductance of kth transmission line,

l is total no. of transmission lines.

2.5 Problem Formulation

The model selected for the enhancement of voltage stability uses linearized sensitivity relationships to define the optimization problem. The three objectives considered are [19]:

1. Minimize the sum of the squares of the voltage deviations from desired voltages at all load buses.
2. Minimization of sum of the squares of the voltage stability L – indices of all the load buses.
3. Minimization of total real power losses in the system.

For all these three objectives the constraints are the linearized network performance equations relating the control and dependent variables and the limits on the control and dependent variables. The control variables are:

- The transformer tap settings (ΔT)
- The generator excitation settings (ΔV)
- The Switchable VAR Compensator (SVC) settings (ΔQ)

These variables have their upper and lower limits. Changes in these variables affect the distribution of the reactive power and therefore change the reactive power at generators, the voltage profile and thus the voltage stability of the system.

The dependent variables are:

- The reactive power outputs of the generators (ΔQ)
- The voltage magnitude of the buses other than the generator buses (ΔV)

These variables also have their upper and lower limits. In mathematical form, the problem is expressed as:

$$\text{Minimize} \quad \mathrm{V}_e = Cx \qquad (9)$$

$$\text{Subject to} \quad b_{\min} \leq b = Sx \leq b_{\max} \qquad (10)$$

$$\text{And} \quad x_{\min} \leq x \leq x_{\max} \qquad (11)$$

Where C is the row matrix of the linearized objective function sensitivity coefficients, S the linearized sensitivity matrix relating the dependent and control variables, b the column matrix of linearized dependent variables, x the column matrix of the linearized control variables, b_{max} and b_{min} are the column matrices of the linearized upper and lower limits on the dependent variables and x_{max} and x_{min} are the column matrices of linearized upper and lower limits on the control variables [5]. In the NR load-flow method, the Jacobian is formed relating real and reactive power injections to changes in bus voltages and angles. The inverse of the Jacobian matrix is called the sensitivity matrix. Required elements of the sensitivity matrix are determined using the triangular matrix factors of the Jacobian matrix. Using these values of the sensitivity elements, the method establishes the linearized objective function and linearized network performance constraints in terms of state variables. Then, it employs the Linear Programming technique to evaluate the new status for the state variables.

Consider a system where, K = Total number of control variables with 1,2…T number of OLTC transformers,T+1, T+2…T+G generator excitations and T+G+1…K SVCs, (K=T+G+S).The relation between all the control variables (RHS) and dependent variables (LHS), is given as [27]

$$\begin{bmatrix} \Delta Q_g \\ \Delta V_s \\ \Delta V_r \end{bmatrix} = [S] \begin{bmatrix} \Delta T_m \\ \Delta V_g \\ \Delta Q_s \end{bmatrix} \quad (12)$$

Where 'S' is sensitivity matrix which relates dependent and control variables. So by adjusting the controlling device, the quantity of voltage improvement of load buses can be controlled, also L-index values of the load buses. Therefore here the equation (12) is used to get the optimized value of control variables such that the dependent variable does not cross the threshold values. Also the sensitivities of voltage deviation function of all the load buses with respect to control variables from equation (4) can be expressed by the given matrix [28]

$$f = [H][\Delta T_1 \quad .. \quad \Delta T_T \quad \Delta V_1 \quad .. \quad \Delta V_G \quad \Delta Q_{G+1} \quad .. \quad \Delta Q_{G+S}]^T \quad (13)$$

With the constrains for the equation (12) as

1. Equality Constraints*:* Equality constraints of reactive power optimization are the power flow equations. Each node in the system has active and reactive power functions, which are given by [7][8][2]:

$$P_i = |V_i| \sum_{j=1}^{N} |V_j| \left(G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}\right) \quad (14)$$

$$Q_i = |V_i| \sum_{j=1}^{N} |V_j| \left(G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}\right) \quad (15)$$

In the above equations, V_i and V_j are the voltages at bus i and j. G_{ij} and B_{ij} are the conductance and

susceptance of the line connecting bus i and j. δ_{ij} is the phase angle difference of voltage from bus i to j.

2. Inequality Constraints: In the reactive power optimization, generator excitation, on load transformer taps and reactive power compensation capacity (SVC) are selected as control variables. So, the control variable constraints are given as [7][8]:

$$\Delta V_{G_i}^{min} \leq \Delta V_{G_i} \leq \Delta V_{G_i}^{max}$$

$$\Delta T_i^{min} \leq \Delta T_i \leq \Delta T_i^{max} \quad (16)$$

$$\Delta Q_i^{min} \leq \Delta Q_i \leq \Delta Q_i^{max}$$

Where,

$$\Delta V_{G_i} = change\ Generator\ output\ Voltage,$$

$$\Delta T_i = change\ Transformer\ tap\ position,$$

$\Delta Q_i = \ change\ SVC\ setting\ positions,$

$\Delta V_{G_i}^{min}\ = Minimum\ output\ Voltage\ of\ Generator,$

$\Delta V_{G_i}^{max}\ = Maximum\ output\ Voltage\ of\ Generator,$

$\Delta T_i^{min}\ =\ Minimum\ tap\ position\ of\ Transformer,$

$\Delta T_i^{max}\ =\ Maximum\ tap\ position\ of\ Transformer,$

$\Delta Q_i^{min}\ =\ \ Minimum\ output\ of\ SVC's,$

$\Delta Q_i^{max}\ =\ Maximum\ output\ of\ SVC's.$

The voltage of load bus and value of generator reactive power can be obtained after the PF calculation. They are treated as state variables generally. The state variables constraints are given by [1] [4] :

$$\Delta V_i^{min} \le \Delta V_i \le \Delta V_i^{max}$$

$$\Delta Q_{G_i}^{min} \le \Delta Q_{G_i} \le \Delta Q_{G_i}^{max} \qquad (17)$$

$\Delta V_i^{min}\ = Lower\ limit\ of\ load\ voltage\ at\ any\ bus\ i,$

$\Delta V_i^{max}\ = Upper\ limit\ of\ load\ voltage\ at\ any\ bus\ i,$

$\Delta Q_{G_i}^{min}\ = Lower\ limit\ of\ generator\ output\ of\ reactive\ power,$

$\Delta Q_{G_i}^{max}\ = Upper\ limit\ of\ generator\ output\ of\ reactive\ power,$

$\Delta V_i =\ change\ Bus\ Voltage\ at\ any\ bus\ i,$

$\Delta Q_{G_i} = Reactive\ power\ generation\ at\ any\ bus\ i.$

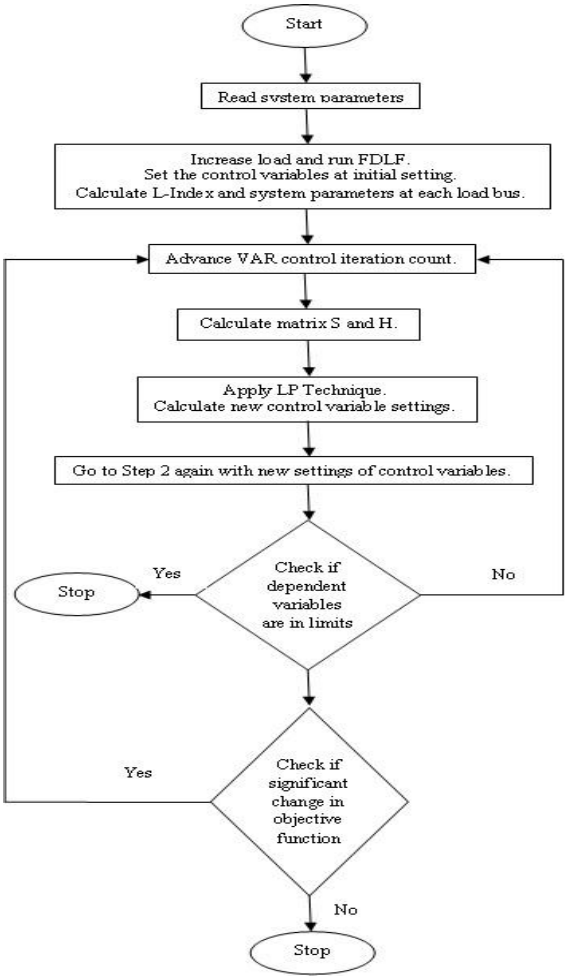
3. LP Technique

3.1 Approach for LP Technique in Power System

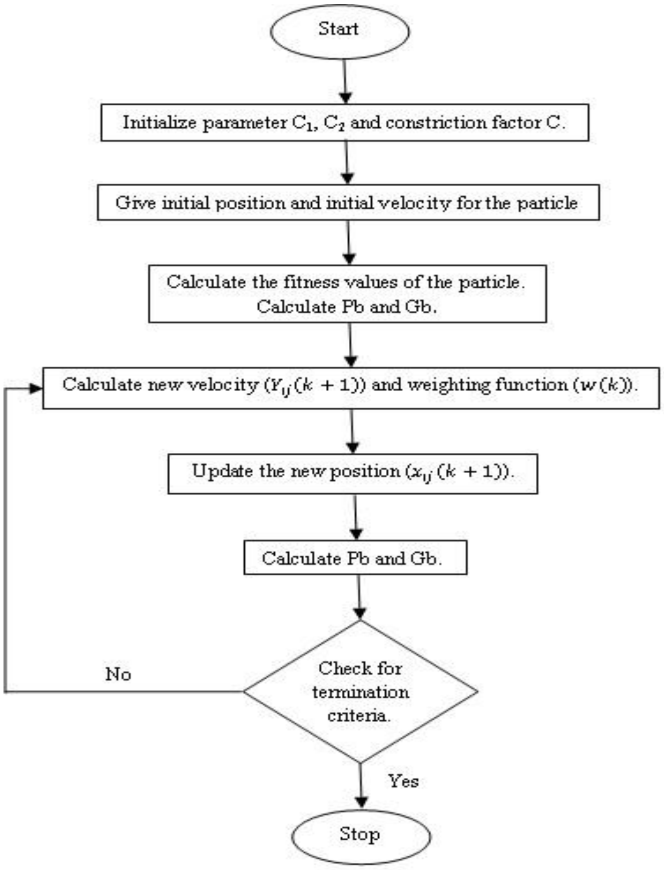
The flow chart of LP technique is shown in Flowchart 1[28]. Following are the steps required [25]:

1. Read the system data for IEEE 39 bus system.
2. Increase the load demand and run the load flow analysis using fast decoupled load flow method. Set the control variables at initial setting and calculate L-Index and system parameters at each load bus using equation (5), (6) and (7).
3. Advance VAR control iteration count.
4. Calculate matrix S and H in equation (12) (13).
5. Apply LP Technique and calculate new control variable settings.

6. Check if control variables are in given threshold.
7. Perform Step 2 again with new settings of control variables.
8. If dependent variables obtained from equation (12), at each load bus are within their constraints then stop otherwise go to step 3.
9. If there is significant change in objective function then go to step 3.
10. Calculate all system parameters, L-index and print result.



Flowchart 1. Flowchart of LP Technique



Flowchart 2. Flowchart of PSO Technique

4. Particle Swarm Optimization Algorithm

PSO is mathematically defined as [21][22]:

$$Y_{ij}(k+1) = WY_{ij}(k) + C_1 r_1 \left(Pb_{ij}(k) - x_{ij}(k)\right) + C_2 r_2 (Gb_{ij}(k) - x_{ij}(k)) \qquad (18)$$

$$x_{ij}(k+1) = x_{ij}(k) + Y_{ij}(k+1) \qquad (19)$$

Where,

W is known as the weighting function.

$x_{ij}(k)$ = previous position of the particle.

$Y_{ij}(k)$ = previous velocity of the particle.

Pb = best fitness of the particle so far.

Gb = best fitness of the swarm so far.

$C_1 = 2.1$, $C_2 = 2$, $W = 0.5$

4.1 Approach for PSO Technique in Power System

The flowchart of PSO algorithm is shown in flowchart 2[28]. Following are the steps required [6]:

1. Initialize parameter C_1, C_2 and W.
2. Give initial position and initial velocity for the particle of the swarm.
3. Calculate the fitness values of the particle. Calculate Pb and Gb.
4. Calculate the new velocity using equation(18)
5. Now update the position using (19)
6. Calculate the fitness values of the particle and update Pb and Gb.
7. If termination criteria are satisfied go to next step otherwise go to step 4.
8. Stop and print results.

5. Results and Analysis

MATPOWER is an open-source Matlab power system simulation package. It is used widely in research and education for AC and DC power flow and optimal power flow (OPF) simulations. MATPOWER consists of a set of Matlab M-files designed to give the best performance possible while keeping the code simple to understand and customize. Matlab has become a popular tool for scientific computing, combining a high-level language ideal for matrix and vector computations, a cross-platform runtime with robust math libraries, an integrated development environment and GUI with excellent visualization capabilities, and an active community of users and developers. As a high-level scientific computing language, it is well suited for the numerical computation typical of steady-state power system simulations. Owing to these advantages MATPOWER is used in this project for the system calculation. The results obtained after applying LP and PSO Techniques are shown in Table1, 2 and 3.

Table 1. 39 Bus System Controller Setting

Controller	**Controller Settings**		
	Initial	***LP***	***PSO***
V_{30}	1.0000	1.0150	1.0129
V_{31}	1.0000	1.0150	1.0344
V_{32}	1.0000	1.0150	1.0130
V_{33}	1.0000	1.0150	1.0073
V_{34}	1.0000	1.0150	0.9841
V_{35}	1.0000	1.0150	1.0195
V_{36}	1.0000	1.0150	0.9978
V_{37}	1.0000	1.0150	1.0319
V_{38}	1.0000	1.0150	1.0132
V_{39}	1.0000	1.0150	1.0411

The load flow analysis is done using fast decoupled load flow and load is increased by 30% in the system. After the load is increased the initial voltages and losses in the buses are calculated using load flow analysis. The values for the controller setting are obtained by applying optimization Technique in suitable equations with given constraints. The Linear Programming technique is applied using the mathematical model developed in the previous chapter. The control variables are evaluated by LP technique and the variables are set in the system. Thereafter system parameters are calculated. Similarly in Particle Swarm Optimization, the load is increased by 30% in the system then control variables are randomly selected and PSO is applied in the system. The control variables are selected for which the fitness function or objective function is minimized. For the selected set of control variables, bus voltages, L-index and system parameters are calculated. The results of control variables obtained after applying optimization techniques are shown in Table 1.

Bus No.	**Voltage Magnitudes (p.u.)**			**L-Index values**		
	Initial	***LP***	***PSO***	***Initial***	***LP***	***PSO***
1	1.0011	1.0173	1.0364	0.0284	0.0272	0.0262
2	1.0038	1.0209	1.0274	0.0478	0.0456	0.0448
3	0.9824	1.0010	1.0064	0.0864	0.0821	0.0808
4	0.9510	0.9712	0.9795	0.1302	0.1233	0.1204
5	0.9556	0.9761	0.9880	0.1241	0.1170	0.1134
6	0.9602	0.9807	0.9928	0.1188	0.1119	0.1083
7	**0.9447**	**0.9654**	**0.9787**	**0.1353**	**0.1277**	**0.1235**
8	**0.9436**	**0.9642**	**0.9779**	**0.1352**	**0.1276**	**0.1235**
9	1.0008	1.0181	1.0392	0.0389	0.0366	0.0352
10	0.9834	1.0029	1.0096	0.0941	0.0889	0.0868
11	0.9739	0.9938	1.0024	0.1045	0.0986	0.0960
12	**0.9542**	**0.9747**	**0.9825**	**0.1345**	**0.1273**	**0.1244**
13	0.9758	0.9955	1.0022	0.1032	0.0976	0.0954
14	0.9651	0.9850	0.9910	0.1156	0.1095	0.1073
15	0.9658	0.9852	0.9856	0.1107	0.1052	0.1045
16	0.9873	1.0059	1.0040	0.0819	0.0779	0.0778
17	0.9886	1.0073	1.0080	0.0843	0.0802	0.0797
18	0.9848	1.0035	1.0060	0.0876	0.0834	0.0825
19	1.0321	1.0344	1.0383	0.0349	0.0339	0.0337
20	0.9658	0.9678	0.9721	0.0322	0.0321	0.0319
21	0.9827	0.9988	0.9991	0.0753	0.0717	0.0717
22	0.9977	1.0127	1.0133	0.0435	0.0414	0.0414
23	0.9903	1.0014	1.0023	0.0478	0.0459	0.0458
24	0.9914	1.0067	1.0073	0.0742	0.0705	0.0704
25	1.0168	1.0338	1.0422	0.0304	0.0287	0.0282
26	1.0112	1.0294	1.0324	0.0628	0.0597	0.0592
27	0.9945	1.0131	1.0151	0.0819	0.0779	0.0774
28	1.0146	1.0321	1.0327	0.0481	0.0457	0.0455
29	1.0168	1.0338	1.0336	0.0342	0.0324	0.0323

5.2 Results of Voltage and L-Index Values

. When the load is increased to 30% the output results acquired are shown in Table 2 in which bus voltages and L-index for all buses are shown and compared with control variables for initial, LP Technique and PSO algorithm. In the Table 2, the voltages V_7, V_8 and V_{12} are seen to be the most critical load buses of the proposed 39 bus test power system. The proposed PSO algorithm focuses more on nodes, in which voltage deviation are high. The model in this project suggests measures to minimize voltage deviations. Thus improving the power system voltage profile and hence voltage stability. After applying LP Technique significant changes in the voltages and L-Index

values of the critical buses are observed. After applying PSO algorithm the results obtained are compared with the initial and classical LP technique. From the table II, it is observed that the minimum voltages enhances from an initial value of 0.9447 to 0.9654 in LP and to 0.9787 in PSO algorithm for the bus 7. Similarly the voltage magnitude value increases from an initial value of 0.9436 to 0.9642 in LP and to 0.9779 in PSO algorithm for the bus 8. Also for bus 12 the increment in voltage magnitude is observed as from initial value of 0.9542 to 0.9747 in LP and to 0.9825 in PSO algorithm. The L-index value declines from an initial value of 0.1353 to 0.1277 in LP and to 0.1235 in PSO algorithm for the bus 7. Similarly the L-index value declines from an initial value of 0.1352 to 0.1276 in LP and to 0.1235 in PSO algorithm for the bus 8. Also for bus 12 the decline in L-index is observed as from initial value of 0.1345 to 0.1273 in LP and to 0.1244 in PSO algorithm.

Table 2. 39-Bus System Voltage and L-index values at all selected load buses

5.3 Results of System Parameters For 39-Bus System

The system parameters are calculated after applying the control variables to the system. The system parameters are basically the three objective functions which are to be minimized after the increment of the load. In table III the system parameters calculation of the 39-bus system are shown. From the Table 3, the voltage error V_e, voltage stability V_L and power loss P_{loss} (MW) are observed to reduce significantly after performing optimization algorithms. From the results reported in Table 3, it is clearly observed that voltage deviation or voltage error Ve of the system is reduced from initial value of 0.0221 to 0.0138 in LP and 0.0137 in PSO technique. Similarly, the system power losses declines from initial value of 54.536MW to 52.466 MW in LP and to 52.029MW in PSO algorithm. The sum of squares of L-indices of system are reduced from initial value of 0.2234 to 0.2003 in LP and to 0.1925 in PSO technique. Therefore from the results we can conclude that the application of PSO technique to the system improves the voltage profile as well as reduces losses of the system.

Table 3. 39 Bus System – System Parameters

Name of the System Parameter	**System Parameters**		
	Initial	***LP***	***PSO***
V_e	0.0221	0.0138	0.0138
V_L	0.2234	0.2003	0.1925
P_{loss}(MW)	54.536	52.466	52.029

5.4 Graphical Representation of Results

The graphical illustration of Table 2 only for critical buses is shown in Figure 1 and 2. The improvement of voltage profile and their corresponding L-index values for critical buses are shown in graph in Figure 1 and Figure 2.

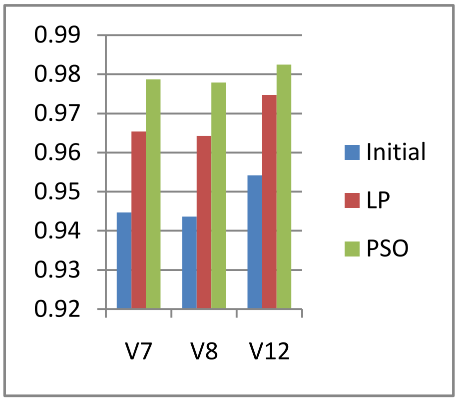


Figure 1. 39 bus system – Voltage profile for critical buses

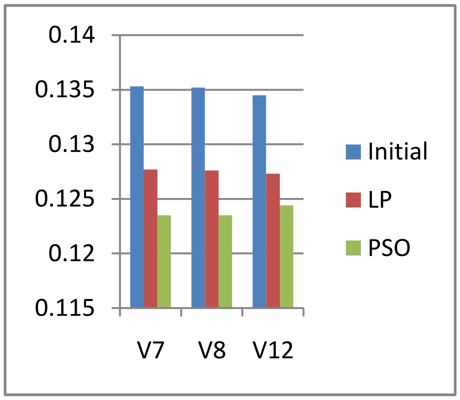


Figure 2. 39- bus system – L-index values for critical load buses

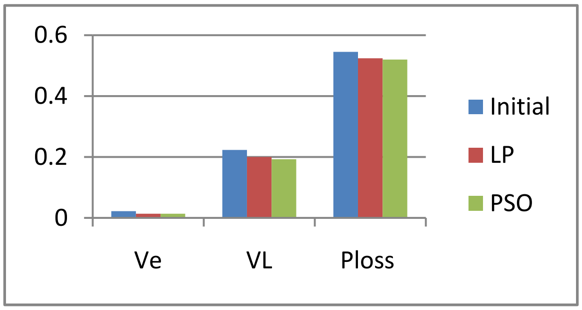


Figure 3. 39 bus system – System Parameters

The value of voltage magnitudes for each critical bus is compared for different optimization technique using the graphical representation Figure 1. Similarly, corresponding L-index values for each critical load bus is compared graphically for every optimization algorithm Figure 2. The graphical illustration of Table 3 is shown in Figure 3. The system parameters for each optimization algorithm are also represented in graph for comparison in Figure 3. The graphs of L-index and system parameters show a significant reduction in values after application of optimization techniques. Also in the graph of voltage magnitude, there is observed a significant enhancement in the values. This shows the effectiveness of the proposed algorithms for voltage stability enhancement. The objective functions considered are reduced significantly and are illustrated graphically in Figure 3.

6. Conclusion

Voltage stability is plays an important role in the security of the power system. Analysis of the system helps to prevent the voltage collapse and blackouts in the system. The proposed method has been tested on MATLAB software and examined with different system parameters to demonstrate its effectiveness and robustness. The indicator L-index is a quantitative measure for the estimation of the distance of the actual state of the system to the stability limit. For a given network, as the load/generation increases, the voltage magnitude and angles change, and for near maximum power transfer condition, the voltage stability index Lj values for load buses tend to close to 1, indicating that the system is close to voltage collapse. This feature of this indicator has been exploited in our proposed algorithms to evolve a voltage collapse margin.

The PSO was developed to help the system to reach to optimum value at faster rate and thus reducing the computational time. The results obtained from classical PSO are compared with traditional Linear Programming optimization technique for an IEEE NEW ENGLAND 39-bus system and it is verify that classical particle swarm optimization approach is effective in reducing values of system parameters and hence improving the voltage stability of the system than compared to Linear Programming technique.

REFERENCES

[1] K. Rayudu, G. Yesuratnam and A. Jayalaxmi, "Ant Colony Optimization Algorithm Based Optimal Reactive Power Dispatch to Improve Voltage Stability", 2017 International Conference on circuits Power and Computing Technologies [ICCPCT].

[2] Kaushik Paul and Niranjan Kumar, "Application of MATPOWER for the Analysis of Congestion in Power System Network and Determination of Generator Sensitivity Factor", International Journal of Applied Engineering Research ISSN 0973-4562 Volume 12, Number 6 (2017) pp.969-975.

[3] Sidnei do Nascimento and Maury M. Gouvêa Jr., "Voltage stability enhancement in power systems with automatic facts device allocation", 3rd International Conference on Energy and Environment Research, ICEER 2016, 7-11 September 2016, Barcelona, Spain.

[4] K. Rayudu, G. Yesuratnam, K. Surendhar and A. Jayalaxmi, “Voltage Stability Enhancement Based on Particle Swarm Optimization and LP Technique”, 2016 International Conference on Emerging Technological Trends [ICETT].

[5] Tejaswini A. Gawande, Komal Kaur Khokhar, Tushar Sahare, Naveen Verma, Naved Bakhtiyar and Dr. Altaf Badar, “Study of Different Methods of Voltage Stability Analysis”, International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, ISO 3297: 2007 Certified Organization, Vol. 4, Issue 11, November 2015.

[6] S. D. Chavan, Nisha P. Adgokar “An Overview on Particle Swarm Optimization: Basic Concepts and Modified Variants”, International Journal of Science and Research Volume 4 Issue 5, May 2015. pp 255-260.

[7] Elfadil.Z. Yahia, Mustafa A. Elsherif, Mahmoud N. Zaggout, “Detection of Proximity to Voltage Collapse by Using L –Index”, International Journal of Innovative Research in Science, Engineering and Technology, An ISO 3297: 2007 Certified Organization Vol. 4, Issue 3, March 2015.

[8] Pathak Smita and Prof. B.N.Vaidya, “Optimal Power Flow by Particle Swarm Optimization for Reactive Loss Minimization”, International Journal of Scientific & Technology Research Volume 1, Issue 1,Feb 2012, ISSN 2277.8616.

[9] Ray Daniel Zimmerman, Member IEEE, Carlos Edmundo Murillo-Sánchez, Member IEEE, and Robert John Thomas, Life Fellow IEEE, “MATPOWER: Steady-State Operations, Planning, and Analysis Tools for Power Systems Research and Education”, IEEE TRANSACTIONS ON POWER SYSTEMS, VOL. 26, NO. 1, FEBRUARY 2011.

[10] B. Singh, N. K. Sharma, and A. N. Tiwari. “Prevention of Voltage Instability by Using FACTS Controllers in Power Systems: A Literature Survey,” International Journal of Engineering Science and Technology, vol. 2, no. 5, pp. 980-992, 2010.

[11] Mudathir F. Akorede and Hashim Hizam, “Teaching Power System Analysis Course using MATPOWER”, 2009 International Conference on Engineering Education (lCEED 2009), December 7-8, 2009, Kuala Lumpur, Malaysia.

[12] J.K. Vis “Particle Swarm Optimizer for Finding Robust Optima”, 2009.

[13] K. Vaisakh, Member, IEEE, and P.Kanta Rao, “Optimum Reactive Power Dispatch Using Differential Evolution for Improvement of Voltage Stability”, 978-1-4244-1762-9/08/ C 2008 IEEE.

[14] C. Reis and F. P M. Barbosa “A comparison of voltage stability indices,” IEEE-MELECON, Benalmadena (Malaga), Spain, 2006.

[15] Dhadbanjan and Yesuratnam,“ Comparison of Optimum Reactive Power schedule with Different Objectives using LP Technique”, Int. Journal of Emerging Electrical Power Systems, Vol.7, no. 3, article.4, 2006, pp. 1-22.

[16] IEEE/CIGRE Joint Task Force on Stability Terms and Definitions, “Definition and Classification of Power System Stability,” IEEE Transactions. on Power Systems, vol. 19, no.3, pp. 1387-1401, 2004.

[17] M. A. Abido, “Optimal power flow using particle swarm optimization”, International Journal of Electrical Power & Energy Systems, vol. 24, no.7, 2002, pp 563-571.

[18] Hirotaka Yoshida and Yoshikazu Fukuyama, member, IEEE, “A Particle Swarm Optimization for Reactive Power and Voltage Control in Electric Power Systems Considering Voltage Security Assessment”, 0-7803-5731-0A9y$10.000 1999 IEEE.

[19] CIGRE Task Force 38.02.14 Rep., “Analysis and modeling needs of power systems under major frequency disturbances”, 1999.

[20] V. Ajjarapu, and C. Christy, “The continuation power flow A tool for steady state voltage stability analysis,” IEEE Transactions on Power Systems, vol. 7, no. 1. pp. 416-423, 1992.

[21] J.Qiu and S.M.Shahidehpour, “A new approach for minimizing power losses and improving voltage profile”, IEEE Trans. On Power Systems, vol. 2, no. 2, May 1987, pp. 287-295.

[22] Kessel. P and Glavitsch. H, “Estimating the Voltage Stability of a Power System”, IEEE Transactions on Power Delivery, vol.1, no.3, July 1986 pp. 346-354.

[23] K. R. C. Mamandur, Member, IEEE and R. D. Chenoweth, Senior Member, IEEE, “Optimal Control Of Reactive Power Flow For Improvements In Voltage Profiles And For Real Power Loss Minimization”, IEEE Transactions on Power Apparatus and Systems, Vol. PAS-I1O, No. 7 July 1981.

[24] L. H. Fink and K. Carlsen, “Operating under stress and strain,” IEEE Spectrum, vol. 15, no. 3, pp. 48-53, 1978.

[25] K. R. Padiyar, “Power System Dynamics Stability and Control”, Second edition by BS Publications.

[26] P. Kundur, “Power System Stability and Control”, McGraw-Hill, Inc.

[27] Achille Messac, “Optimization in Practice with MATLAB For Engineering Students and Professionals”, Cambridge University Press.

[28] Dhruvi Chopra and Prof. Y.D. Shahakar,” A Review on Augumentation of Voltage Stability Using Optimization Technique”, IJRASET, vol 7, Issue 1, Jan 2019, pp 786-791.