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A Review on Augmentation of Voltage Stability Using Optimization Technique

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Abstract: Present day power systems are being operated closer to their stability limits due to economic constraints. 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. This paper presents review of LP Technique and PSO algorithm for system parameters development for improving voltage stability and voltage profile improvement. The different optimization techniques for improving voltage stability are studied. The advanced Particle Swarm Optimization algorithm is 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, Fast Decoupled Load Flow, L-Index

I. 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 [4]. To optimize we use different techniques like PSO, Genetic Algorithm, Fuzzy Logic, Linear Programming, etc [2].

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 [3]. 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 [2].

In this paper, the aim is to evaluate, improve and enhance voltage profile and hence voltage stability of the power system. This paper presents PSO based approach for reactive power control. The problem is formulated by using the relation between L-index value of each load bus and controlling ability of controlling devices such as switchable VAR compensators, OLTC transformers and generator excitations. The objective function preferred is voltage profile improvement which is to minimize the sum of the squares of the L-index values of the load buses. The proposed PSO algorithm is tested on an IEEE 39 node system. The results of the PSO algorithm are compared with conventional LP optimization technique.

II. 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. L-index gives an indication of how far the system is from voltage collapse [5].

A. L-Index Calculations

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 [7][8] is computed as

$$L_j = \left| 1 - \sum_{i=1}^g F_{ji} \frac{V_i}{V_j} \right| \quad (1)$$

Where j = g+1 ... n.

The values F_{ji} are obtained from the Y bus matrix as follows [1]:

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

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

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

Where $F_{LG} = [Y_{LL}]^{-1}[Y_{LG}]$ 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 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 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 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].

B. 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:

$$V_L = \sum_{j=g+1}^n L_j^2 \quad (4)$$

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

III. EVALUATION OF SYSTEM PARAMETERS

A. Constraint Equations for power and control variables

1) *Equality Constraints:* A 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]:

$$P_i = |V_i| \sum_{j=1}^n |V_j| (G_{ij} \cos \delta_{ij} + B_{ij} \sin \delta_{ij}) \quad (5)$$

$$Q_i = |V_i| \sum_{j=1}^n |V_j| (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) \quad (6)$$

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]:

$$\begin{aligned} \Delta V_{G_i}^{\min} &\leq \Delta V_{G_i} \leq \Delta V_{G_i}^{\max} \\ \Delta T_i^{\min} &\leq \Delta T_i \leq \Delta T_i^{\max} \\ \Delta Q_i^{\min} &\leq \Delta Q_i \leq \Delta Q_i^{\max} \end{aligned} \quad (7)$$

- ΔV_{G_i} = change Generator output Voltage,
- ΔT_i = change Transformer tap position,
- ΔQ_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,
- ΔT_i^{min} = Minimum tap position of Transformer,
- ΔT_i^{max} = Maximum tap position of Transformer,
- ΔQ_i^{min} = Minimum output of SVC's,
- ΔQ_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:

$$\begin{aligned} \Delta V_i^{min} \leq \Delta V_i \leq \Delta V_i^{max} \\ \Delta Q_{G_i}^{min} \leq \Delta Q_{G_i} \leq \Delta Q_{G_i}^{max} \end{aligned} \quad (8)$$

- ΔV_i^{min} = Lower limit of load voltage at any bus i,
- ΔV_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,
- ΔV_i = change Bus Voltage at any bus i,
- ΔQ_{G_i} = Reactive power generation at any bus i.

B. Error (V_e), $V_{stability}$ (V_s) and Power loss (P_{loss})

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. [7].

$$V_e = \sum_{j=g+1}^N (V_d - V_j)^2 \quad (9)$$

$$V_s = \sum_{j=g+1}^N L_j^2 \quad (10)$$

$$P_{loss} = \sum_{k=1}^L G_k [V_i^2 + V_j^2 - 2V_i V_j \cos(\epsilon_i - \epsilon_j)] \quad (11)$$

C. Reactive Power Output

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

$$Q_i = |V_i| \sum_{j=1}^N |V_j| (G_{ij} \sin \delta_{ij} - B_{ij} \cos \delta_{ij}) \quad (12)$$

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 k^{th} transmission line, l is total no. of transmission lines [7].

IV. FORMULATION FOR OPTIMIZATION

The problem considered for voltage profile improvement is to minimize the sum of the squares of the L-index values of the load buses and it is given by equation (4). Rewriting $V_{stability}$ (V_L) as,

$$V_L = \sum_{j=g+1}^N L_j^2 \quad (13)$$

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 the net reactive power change at any node due to change in transformer tap settings and the voltage magnitudes can be written as [4][7][8]

$$\begin{bmatrix} \Delta Q_G \\ \Delta Q_S \\ \Delta Q_r \end{bmatrix} = \begin{bmatrix} A_1 & A_2 & A_3 & A_4 \\ A_5 & A_6 & A_7 & A_8 \\ A_9 & A_{10} & A_{11} & A_{12} \end{bmatrix} \begin{bmatrix} \Delta T_m \\ \Delta V_G \\ \Delta V_S \\ \Delta V_r \end{bmatrix} \quad (14)$$

Transforming all the control variables to the RHS and dependent variables to the LHS, rearranging we get

$$\begin{bmatrix} \Delta Q_G \\ \Delta V_G \\ \Delta V_T \end{bmatrix} = [S] \begin{bmatrix} \Delta T_m \\ \Delta V_G \\ \Delta Q_S \end{bmatrix} \tag{15}$$

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. Then 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 [4][7][8]:

$$f = [H][\Delta T_1 \dots \Delta T_T \ \Delta V_1 \dots \Delta V_G \ \Delta Q_{G+1} \dots \Delta Q_{G+S}]^T \tag{16}$$

Using the Load flow Analysis the sensitivities of the above equation are calculated. The load flow analysis is done by Newton Raphson Method. The equation for the above is given as

$$\begin{bmatrix} \Delta P_2 \\ \vdots \\ \Delta P_n \\ \Delta Q_2 \\ \vdots \\ \Delta Q_n \end{bmatrix} = [J] \begin{bmatrix} \Delta \delta_2 \\ \vdots \\ \Delta \delta_n \\ \Delta |V_2| \\ \vdots \\ \Delta |V_n| \end{bmatrix}$$

Where n is total number of bus and [J] is Jacobian Matrix, which is divided into submatrices as

$$[J] = \begin{bmatrix} J_1 & J_2 \\ J_3 & J_4 \end{bmatrix}$$

For Fast Decoupled Load Flow method J_2 and J_3 are equal to zero. Therefore J_1 and J_4 are given as:

$$[J_1] = \begin{bmatrix} \frac{\partial P_2}{\partial \delta_2} & \dots & \frac{\partial P_2}{\partial \delta_n} \\ \vdots & \ddots & \vdots \\ \frac{\partial P_n}{\partial \delta_2} & \dots & \frac{\partial P_n}{\partial \delta_n} \end{bmatrix} \quad [J_4] = \begin{bmatrix} |V_2| \frac{\partial Q_2}{\partial |V_2|} & \dots & |V_n| \frac{\partial Q_2}{\partial |V_n|} \\ \vdots & \ddots & \vdots \\ |V_2| \frac{\partial Q_n}{\partial |V_2|} & \dots & |V_n| \frac{\partial Q_n}{\partial |V_n|} \end{bmatrix}$$

Using the above matrices the sensitivities i.e. the matrix [H] is calculated.

To calculate [H]: Sensitivities of voltage stability V_L with respect to real and reactive power injections at all load buses except swing

bus i.e. $\frac{\partial V_L}{\partial P_2}, \dots, \frac{\partial V_L}{\partial P_n}, \frac{\partial V_L}{\partial Q_2}, \dots, \frac{\partial V_L}{\partial Q_n}$ using equations:

$$\begin{bmatrix} \frac{\partial V_L}{\partial P_2} \\ \vdots \\ \frac{\partial V_L}{\partial P_n} \end{bmatrix} = [J_1]^{-1} \begin{bmatrix} \frac{\partial V_L}{\partial \delta_2} \\ \vdots \\ \frac{\partial V_L}{\partial \delta_n} \end{bmatrix} \quad \text{and} \quad \begin{bmatrix} \frac{\partial V_L}{\partial Q_2} \\ \vdots \\ \frac{\partial V_L}{\partial Q_n} \end{bmatrix} = [J_4]^{-1} \begin{bmatrix} \frac{\partial V_L}{\partial |V_2|} \\ \vdots \\ \frac{\partial V_L}{\partial |V_n|} \end{bmatrix}$$

By knowing above values objective function sensitivities with respect to control variables i.e. $\frac{\partial V_L}{\partial T_m}, \frac{\partial V_L}{\partial V_k}, \frac{\partial V_L}{\partial V_1}, \frac{\partial V_L}{\partial Q_{SVC}}$ can be estimated [4][7][8].

V. PROPOSED OPTIMIZATION TECHNIQUES

A. Approach for LP Technique in Power System

Linear programming is adaptive and more flexibility to analyse 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. 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[2][7][8]. The flow chart of LP technique is shown in fig 1.

B. Algorithm for PSO method in Power System

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. 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 [3][6]. The flowchart of PSO algorithm is shown in fig. 2.

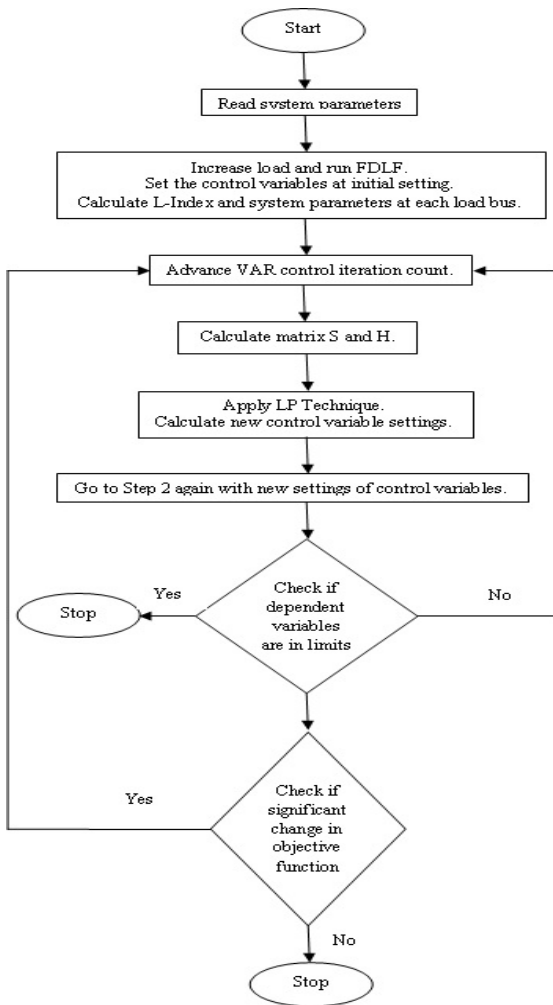


Fig. 1 Flowchart of LP Technique

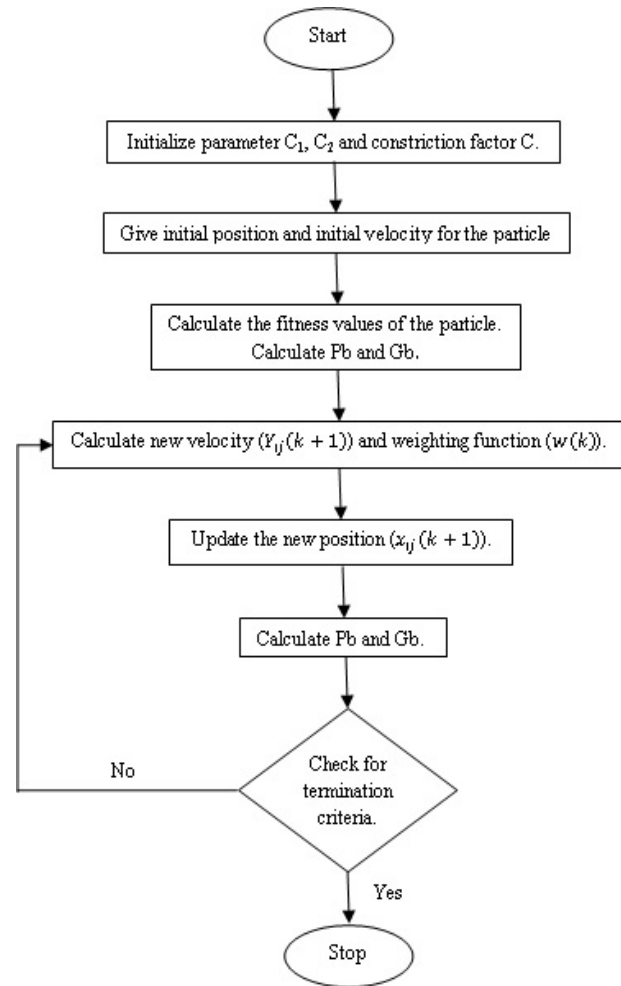


Fig. 2 Flowchart of PSO Algorithm

Following are the steps required to perform PSO Algorithm [7]

- 1) Initialize parameter C_1 , C_2 and constriction factor C .
- 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

$$Y_{ij}(k+1) = w(k)Y_{ij}(k) + C_1r_1(Pb_{ij}(k) - x_{ij}(k)) + C_2r_2(Gb_{ij}(k) - x_{ij}(k))$$

Where $w(k)$ is known as the weighting function and is written as:

$$w(k) = w_{max} - \frac{(w_{max} - w_{min}) * iter}{max\ iter}$$

Where $max\ iter$ = maximum iteration given by user.

$x_{ij}(k)$ = 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.

- 5) Now update the position using

$$x_{ij}(k+1) = x_{ij}(k) + Y_{ij}(k+1)$$
- 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.

VI. CONCLUSION

In this paper two methods are proposed for the analysis of voltage stability in power system. Both the methods help in the enhancement of voltage profile. Traditionally LP Technique was used to improve the stability of the power system when load was increased or decreased. But LP technique had many drawbacks such as this method is time consuming, it can be used only for linear problems, it take many iteration to converge, etc. therefore new methods for optimization are used. One of those methods is proposed in this paper. PSO algorithm is based on the behaviour of swarms. For better results the parameters and weighting function in the PSO algorithm are varied by user. This method is used to optimize the objective function (ΣL^2) for IEEE 39 bus system. In the proposed paper calculation for the optimized setting of control variables like OLTC transformer, Generator excitation and Switchable VAR devices, is performed using proposed Algorithms. The analysis shows that PSO algorithm is more efficient and better than LP technique. Different parameters like control variable setting, L-Index, Verror and power loss, are also observed for the better understanding of the system.

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