The Journal of CPRI,
Vol. 12, No. 4, December 2016 pp. 655-663

Application of Ant Colony Optimization Algorithm for Voltage profile Improvement

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Minimization of voltage deviations and power loss can be controlled by Optimal Reactive power Dispatch (ORPD) for voltage stability of the system. This paper presents a real ant colonies foraging behavior procedure for solving the ORPD problem using Ant Colony Optimization (ACO) algorithm. The objective of this paper is to minimize the voltage deviations at load buses using control and dependent variable constraints with proposed sensitivity parameters of reactive power. The On-Load Tap Changing Transformers (OLTC), Generator Exciters, Switchable VAR sources are used as control variables for improvement of system parameters like Voltage deviations, L-index and Power loss. The effectiveness of the proposed method is demonstrated on New England 39-bus system for near optimal solutions. The performance of the proposed method is compared with conventional optimization technique and presented for illustration purpose.

Keywords: *Optimal Reactive Power Dispatch, Voltage deviation, Voltage Stability, L-index, Ant colony optimization; Linear Programming.*

1.0 INTRODUCTION

Optimal reactive power dispatch problem is the major concern issue in power systems focusing from past decades. The unmatched generation and transmission capacity expansion, voltage uncertainty is creating the system to ensure about the system security, reliability and quality of supply is restricting it to a permissible limit of operation. Whereas overloading, voltage collapse and voltage stability are concerned as major problems in power system. Such that the voltage stability is to be enhanced by rearrangement of reactive power generations, switchable VAR sources, generator exciters, possible adjustments of transformer taps settings for best near optimal values. For these problems many artificial intelligence techniques like artificial bee colony, particle swarm optimization, bat Algorithm and genetic algorithm techniques based on their biological behaviour have been introduced by the researcher teams.

R. D. Chenoweth *et al*., [1] explained a method which employs linearized sensitivity relationships of power systems to establish system performance sensitivities relating dependent and control variables for the objective functions of voltage deviations and power loss by simultaneously satisfying the operating constraints. He finds the method for optimal reactive power distribution in the system using dual linear programming technique when applied on 30 bus system. R. C. Mamandur, [2] developed a method of calculating under-voltages, and violations of reactive power limits of generators. The proposed method considers all VAR control variables and minimizes the overall adjustments to be performed on the control variables like generator excitations

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and on load-tap changing transformers which would be useful for the system operator voltage control applications in emergency. D Thukaram *et al.*, [3] described reactive power optimization problem formulated without inversion of large matrices using iterative scheme of successive power flow method using linear programming method with only upper bound limits on state variables. Kessel and Glavitsch [4] demonstrated a method for the testing of power system stability aiming at calculation of voltage instabilities. For this purpose authors used an indicator known as L-index which ranges between 0 and 1. This indicator is used to detect proximity of voltage collapse. Qiu and Shahidehpour [5] proposed a new method for improving voltage profile and reducing transmission losses by adjusting all the control variables like on-load tap changing transformers and VAR sources without any matrix inversion. Kenji Iba [6] proposed an approach to optimal reactive power planning based on genetic algorithm which is a kind of search algorithm based on the mechanics of natural selection and genetics. Bansilal, D Thukaram and K Parthasarathy [7] presented an algorithm for monitoring and improving voltage stability in power systems based on L-index of load buses. John G.Vlachogiannis *et al.,* [8] presented a ant colony system (ACS) method for network constrained optimization problem and it consist of mapping of the solution space, expressed by an objective function of the constrained load flow on the space of control variables, that ants walk. Thukaram, *et al.,* [9] explained fuzzy set theory for reactive power control aiming to improve voltage stability of the power system by minimizing voltage deviations from pre-desired values of all the load buses. Voltage deviations and controlling variables are translated into fuzzy set notations. The performance of the fuzzy system is compared with linear programming technique by considering different test systems. Thukaram Dhadbanjan *et al.,* [10] illustrated and proposed algorithms for reactive power optimization with different objective functions like aiming to minimize the sum of the squares of the voltage deviations of the load buses, minimization of sum of squares of voltage stability L-indices of load buses algorithm, and also the objective of system real power loss minimization with conventional Linear Programming(LP) technique. Vaisakh et al., [11] presented a Differential Evolution based approach for solving optimal reactive power dispatch for voltage stability enhancement. The monitoring methodology for voltage stability is based on the L-index of load buses. The objective is to minimize the sum of squares of the L-indices subjected to limits on generator real and reactive power outputs, bus voltages, transformer taps and shunt power control devices such as SVCs. Devaraj *et al.,* [12] described a technique based on the minimization of the maximum of L-indices of load buses by considering Generator voltages, switchable VAR sources and transformer tap changers as controlled variables. Worawat Nakawiro and Istvan Erlich, [13] proposed a modified ant colony optimization method for solving voltage stability constrained optimal reactive power dispatch problem. This paper proposes ACO approach for reactive power control for the purpose of estimation and enhancement of voltage profile in power system. The problem is formulated with the relation between voltage deviations and controlling ability of controlling devices. Control variables considered are switchable VAR compensators, OLTC transformers and generator excitations with the objective selected is voltage profile improvement which is to minimize the sum of the squares of the voltage deviations of the load buses. The proposed ACO is demonstrated on New England 39 bus power system and the performance is compared with conventional optimization technique like LP and satisfactory results are obtained.

2.0. L- INDEX METHOD AND VOLTAGE STABILITY ANALYSIS

2.1 L-Index Method

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, G+S+2… G+S+N, the remaining busses (R = N-G-S) and T = Number of on load- Tap changing (OLTC) Transformers. l = No. of Transmission lines.

The L-index obtained from load flow or output of the state estimation is calculated as

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

where j = G+1, G+2.... N and all the terms within the sigma on the Right Hand Side of (1) are complex quantities.

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

Where I_G, I_L and V_G, V_L represents currents and voltages at the generator nodes and load nodes rearranging, equation (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 $F_{LG} = -Y_{LG} Z_{LL}$

are the required values. The stability margin is obtained as the distance of L from a unit value i.e. (1-L).For stability of the system, (the maximum condition=1) should not be violated for any of the busses j. An L-index value close to zero and away from 1 tells that system security is improved. Voltage magnitudes and phase angles will change as the load or generation increases on the network. L_j values of all load busses will come close to 1, at maximum power transfer condition, tells that system is nearer to voltage collapse.

3.0. OBJECTIVE FUNCTION AND SYSTEM PARAMETERS

3.1. Objective Function

The objective selected for voltage profile improvement is to minimize the sum of the squares of the voltage deviations of the load buses and is as follows:

$$V_e = \sum_{j=G+1}^{N} (V_d - V_j)^2 \qquad ...(4)$$

where V_d is the desired value of the voltage magnitude at the j^{th} load bus and is usually set to 1.0 p.u.

3.2 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

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

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

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.

3.3 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,

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

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

$$\Delta Q_i^{\min} \le \Delta Q_i \le \Delta Q_i^{\max} \qquad ...(7)$$

ΔV_{G_i} = change Generator output Voltage,

ΔT_i = change Transformer tap position,

ΔQ_i = change SVC setting positions,

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

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

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

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

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

$Q_i^{\max}$ = Maximum output of SVC's. As the voltage of load bus and value of generator reactive power can be obtained after the power flow calculation, they are treated as state variables generally. The state variable constraints are given by

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

$$\Delta Q_{G_i}^{\min} \le \Delta Q_{G_i} \le \Delta Q_{G_i}^{\max} \quad ...(8)$$

ΔV_i = change Bus Voltage at any bus i,

ΔQ_{G_i} = Reactive power generation at any bus i,

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

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

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

$Q_{G_i}^{\max}$ = Upper limits of generator output of Reactive power.

3.4 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} (Ve), $V_{stability}$ (V_s) and power loss ($P_{loss)}$ respectively.

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

$$V_S = \sum_{j=G+1}^{N} L_j^2 \quad ...(10)$$

$$P_{Loss} = \sum_{k=1}^{l} G_k \left[V_i^2 + V_j^2 - 2V_iV_j \cos(\delta_i - \delta_j) \right] \quad ...(11)$$

3.5 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

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

Where, G_{ij} = conductance & B_{ij}= susceptance between buses 'i' and 'j', V_i and 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.

4.0 PROBLEM FORMULATION AND METHODOLOGY

The problem considered for voltage profile improvement is to minimize the sum of the squares of the voltage deviations of the load buses and it is given by equation (4), and rewriting V_{error} (Ve) as

$$V_e = \sum_{j=G+1}^{N} (V_d - V_j)^2 \quad ...(13)$$

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

$$\begin{bmatrix} \Delta Q_g \\ \Delta Q_s \\ \Delta Q_r \end{bmatrix} = \begin{bmatrix} A_1 & A_2 & A_3 & A_4 \\ A_5 & A_6 & A_7 & A_8 \\ A_9 & A_{10} & A_{11} & A_{12} \end{bmatrix} \begin{bmatrix} \Delta T_m \\ \Delta V_g \\ \Delta V_s \\ \Delta V_r \end{bmatrix} \quad ...(14)$$

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

$$\begin{bmatrix} \Delta Q_g \\ \Delta V_S \\ \Delta V_r \end{bmatrix} = [S] \begin{bmatrix} \Delta T_m \\ \Delta V_g \\ \Delta Q_s \end{bmatrix} \quad ...(15)$$

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 expressed by the following matrix.

$$\left[\Delta V_{G+1} \;\; \Delta V_{G+2} \;\; .. \;\; \Delta V_{N-1} \;\; \Delta V_N\right]^T =$$

$$[S]\left[\Delta T_1 \;\; .. \;\; \Delta T_T \;\; \Delta V_1 \;\; .. \;\; \Delta V_G \;\; \Delta Q_{G+1} \;\; .. \;\; \Delta Q_{G+S}\right]^T \quad ...(16)$$

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

$$\left[\Delta V_{G+1}^{correct} \quad \Delta V_{G+2}^{correct} \quad .. \quad \Delta V_{N-1}^{correct} \quad \Delta V_{N}^{correct}\right]^T =$$
$$\left[H\right]\left[\Delta T_1 \quad .. \quad \Delta T_T \quad \Delta V_1 \quad .. \quad \Delta V_G \quad \Delta Q_{G+1} \quad .. \quad \Delta Q_{G+S}\right]^T \qquad ...(17)$$

where $\Delta V_{G+1}^{correct} \quad \Delta V_{G+2}^{correct} \quad .. \quad \Delta V_{N-1}^{correct} \quad \Delta V_{N}^{correct}$ are the voltage deviations to be corrected for all load buses. And the elements of the 'H' matrix can be derived from the equations (18) to (20)

$$\frac{\partial V_e}{\partial T_m} = \sum_{j=G+1}^{N} 2\times(V_d - V_j)\times(-\frac{\partial V_j}{\partial T_m}) \qquad ...(18)$$

Where $\frac{\partial V_j}{\partial T_m} = S_{jm}$

, which is element of sensitivity matrix. Where j=load bus and m=1toT

$$\frac{\partial V_e}{\partial V_m} = \sum_{j=G+1}^{N} 2\times(V_d - V_j)\times(-\frac{\partial V_j}{\partial V_m}) \qquad ...(19)$$

Where $\frac{\partial V_j}{\partial V_m} = S_{jm}$

, which is element of sensitivity matrix S. where j=load bus and m=T+1 to T+G.

$$\frac{\partial V_e}{\partial Q_m} = \sum_{j=G+} 2\times(V_d - V_j)\times(-\frac{\partial V_j}{\partial Q_m}) \qquad ...(20)$$

Where $\frac{\partial V_j}{\partial Q_m} = S_{jm}$

, which is element of sensitivity matrix S. where j = load bus and m = T+G+1 to T+G+S.

5.0 PROPOSED LP AND ACO ALGORITHM APPROACH

5.1 Computational procedure for power system operation with LP Technique .

Step 01: Read the system data for the proposed system.

Step 02: Increase the load demand by 20% and run the load flow using Fast Decoupled Load Flow (FDLF) method with initial settings of the control variables of the problem and calculate the values of L-Index at each load bus and system parameters like Ve, $\sum L^2$, P_{loss} from equations (9), (10) and (11).

Step 03: Advance the VAR control iteration count.

Step 04: Calculate the sensitivity matrix (S) which is relating dependent and control variables of the system from equation (15)

Step 05: Calculate the coefficients of the voltage deviation

Sensitivities (H) with respect to control variables from equation (17)

Step 06: Apply LP Technique and calculate new settings of the control variables.

Step 07: Perform operational load flow again by replacing initial control variables with new (optimum) control variables and find the value of objective function and system parameters

Step 08: If the dependent variables, at each load bus are with in limits then stop, otherwise repeat Step 3

Step 09: Check the significant changes in the objective function in the system, if yes go to step3

Step 10: Obtain all system parameters, L-Index and Print the results.

5.2 Proposed Ant colony optimization (ACO) Algorithm

ACO algorithm is inspired by the behaviour of the real ant colonies and is used to solve combinatorial optimization problem. The following are the steps for ACO algorithm.

Initialize the no of ants as 20, maximum iterations 100, the parameters $\alpha = 0.1$, $\beta = 2$ and evaporation constant $\rho = 0.6$.

Generating the possible set of solutions containing the control variables and is given by $X_{ij} = (ub_i - lb_i) \times rand + lb_i$ ...(21)

lb_i = lower limit of i^th control variable.

ub_i = upper limit of i^th control variable.

Step 01 Each ant selects the first node by generating random number based on uniform distribution, ranging from 1 to 100.

Step 02 Ant k applies a probabilistic transition rule in order to decide which node to be visited next. The probabilistic transition rule is given by

$$P_{ij}^{k}(t) = \frac{\left[\tau_{ij}(t)\right]^{\alpha}\left[\eta_{ij}(t)\right]^{\beta}}{\sum_{q}\left[\tau_{iq}(t)\right]^{\alpha}\left[\eta_{iq}(t)\right]^{\beta}} \qquad j \in N_i^k, q \in N_i^k \qquad ...(22)$$

where, τ_{ij} is Pheromone trail deposited between path i and j. $\eta_{ij} = \frac{1}{d_{ij}}$. d_{ij} is distance of the path between i and j.

Step 03: Update the pheromone to the visited paths during the process. The amount of pheromones can be updated as

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \rho\Delta\tau_{ij} \qquad ...(23)$$

where, $\Delta\tau_{ij}$ Incremental value of pheromone trail in the path. This local updating rule will shuffle the tours, so that the early nodes in the ant's tour may be explored later in other ant's tours.

Step 04: Check, if ant visited all control variables or not. If not go to Step 4 otherwise Step 7.

Step 05: Calculate the fitness value and select the best tour.

Step 06: Check for termination criteria, if yes go to Step 10. Otherwise go to Step 03 after completing Step 09.

Step 07: Apply global updating rule. Only one ant is allowed to update the amount of pheromone which determines the best fitness. After all ants completed their tours, update the pheromones using equation

$$\tau_{ij}(t+1) = (1-\rho)\tau_{ij}(t) + \varepsilon\tau_0 \qquad ...(24)$$

where ε is best path weighting constant in the [0 1], τ_0 is Pheromone trail in the best path.

Step 08: Print the results

6.0 TEST SYSTEM RESULTS AND DISCUSSION

The proposed ACO approach has been tested and verified on a New England 39-bus power system. The outputs and results obtained are compared with conventional optimization technique like LP in terms of Voltage deviations, ∑L2 and Power loss. A typical set of results of 39-bus power system network are presented. Table I shows details of the proposed test system.

TABLE 1

39 BUS SYSTEM DATA

System components	39 bus system
No. of Generators	7
No. of Regulating Transformers	2
No. of Non-Regulating ransformers	10
No. of Transmission lines	46
P-Generation in MW	6182
P-Load in MW	6125
Q-Load in MVAR	1594
No. of SVC buses	2

TABLE 2

39 BUS SYSTEM-CONTROLLER SETTINGS

Control Variables	Initial	LP opt. tech	AC opt. tech
T_{14-13}	1.0000	0.9875	0.9238
T_{14-11}	1.0000	1.0238	1.0309
V_1	1.0000	1.0141	1.0320
V_2	1.0000	1.0143	1.0217
V_3	1.0000	1.0141	1.0376
V_4	1.0000	1.0139	1.0201
V_5	1.0000	1.0142	1.0235
V_6	1.0000	1.0140	1.0247
V_7	1.0000	1.0142	1.0117
V_8	1.0000	1.0142	1.0208
V_9	1.0000	1.0147	1.0287
V_{10}	1.0000	1.0140	1.0274
SVC_{11}(MVAR)	0.0000	3.7700	2.2800
SVC_{12}(MVAR)	0.0000	3.9700	3.1900

The proposed ACO Algorithm focuses more on nodes where voltage deviations are high, suggesting measures so as to minimize these voltage deviations and thus improve power system voltage profile and hence voltage stability. The Values of Controller settings and system parameters for the given loading conditions of the 39-node power system for ACO and LP techniques are given in Table 2 and Table 3 respectively. Voltage magnitude values at all selected buses and the corresponding L-Index values before and after optimization with ACO and LP techniques are given in Table 3.

TABLE 3

39 BUS SYSTEM-VOLTAGE AND L-INDEX VALUES AT ALL SELECTED LOAD BUSES

Bus no	Voltage Magnitudes (p.u)			L-Index Values		
	Initial	LP opt. tech	AC opt. tech	Initial	LP opt. tech	AC opt. tech
V_{11}	0.9474	0.9629	0.9772	0.1509	0.1456	0.1405
V_{12}	0.9398	0.9563	0.9706	0.1904	0.1836	0.1778
V_{13}	0.9477	0.9654	0.9853	0.1455	0.1404	0.1355
V_{14}	0.9226	0.9443	0.9301	0.1666	0.1605	0.1548
V_{15}	**0.9354**	**0.9521**	**0.9641**	**0.2267**	**0.2187**	**0.2129**
V_{16}	0.9531	0.9695	0.9803	0.2002	0.1934	0.1886
V_{17}	0.9562	0.9728	0.9845	0.2085	0.2013	0.1961
V_{18}	0.9548	0.9713	0.9835	0.2107	0.2035	0.1980
V_{19}	0.9759	0.9909	0.9995	0.0904	0.0875	0.0857
V_{20}	0.9719	0.9869	0.9959	0.1043	0.1011	0.0991
V_{21}	0.9504	0.9666	0.9767	0.1736	0.1677	0.1638
V_{22}	0.9719	0.9873	0.9962	0.0958	0.0927	0.0907
V_{23}	0.9678	0.9834	0.9901	0.1099	0.1062	0.1042
V_{24}	0.9598	0.9761	0.9862	0.2016	0.1948	0.1902
V_{25}	0.9921	1.0075	1.0184	0.0989	0.0955	0.0930
V_{26}	0.9800	0.9966	1.0094	0.1789	0.1726	0.1678
V_{27}	**0.9612**	**0.9780**	**0.9904**	**0.2196**	**0.2119**	**0.2062**
V_{28}	0.9841	1.0006	1.0146	0.1502	0.1451	0.1408
V_{29}	0.9880	1.0041	1.0182	0.1073	0.1037	0.1007
V_{30}	0.9530	0.9694	0.9872	0.1331	0.1284	0.1238
V_{31}	1.0024	1.0173	1.0266	0.0350	0.0338	0.0329
V_{32}	0.9574	0.9737	0.9867	0.1892	0.1827	0.1776
V_{33}	**0.9308**	**0.9478**	**0.9634**	**0.2197**	**0.2119**	**0.2050**
V_{34}	0.9386	0.9558	0.9736	0.1804	0.1740	0.1680
V_{35}	0.9424	0.9596	0.9778	0.1661	0.1602	0.1546
V_{36}	0.9297	0.9471	0.9649	0.2039	0.1965	0.1896
V_{37}	0.9289	0.9464	0.9638	0.2082	0.2007	0.1937
V_{38}	0.9826	0.9984	1.0100	0.0812	0.0784	0.0761
V_{39}	0.9811	0.9965	1.0083	0.0937	0.0906	0.0883

From the results indicated in Table 3, the voltages V_{15}, V_{27} and V_{33} are the most critical load buses of the proposed test power system. The minimum voltage V_{15} of the system improves from an initial voltage of 0.9354 p.u to 0.9521 p.u in LP and to 0.9641 p.u in proposed ACO algorithm. The minimum voltage V_{27} of the system improves from initial voltage of 0.9612 p.u to 0.9780 p.u in LP and to 0.9904 p.u in proposed ACO algorithm. Similarly voltage V_{33} improves from an initial voltage of 0.9308 p.u to 0.9478p.u in LP and to 0.9634 p.u in proposed ACO algorithm. The corresponding voltage magnitudes along with other critical load buses are shown in Figure 1. The initial L-Index values at all selected buses and the corresponding L-Index values after optimization with LP and ACO techniques are indicated in Table III for the proposed objective function. As reported in table III at the most critical load bus V_{15}, the L-index value decreases from initial value of 0.2267 to 0.2187 in LP and to 0.2129 in proposed ACO. Also initial L-index value of 0.2196 at bus V_{27} decreases to 0.2119 in LP and to 0.2062 in proposed ACO algorithm. Similarly initial L-index value of 0.2197 at bus V_{33} decreases to 0.2119 in LP and to 0.2050 in proposed ACO. The corresponding L-index values along with other critical load buses are shown in Figure 2. As indicated in Table IV The sum squared voltage deviations of all load buses (Ve) decreases from an initial value of 0.0617 to 0.0292 in LP and to 0.0169 in ACO algorithm. Also the sum squared L-index ($\sum$L2) of all buses reduced from an initial value of 0.7859 to 0.7321 in LP and to 0.6899 in ACO algorithm. Similarly power system losses decreased from an initial value of 49.65 MW to 48.22 MW in LP and to 47.67 MW in proposed ACO algorithm. Improvement of System parameters of 39-bus are shown Figure 3 with conventional LP technique and Proposed ACO approach.

TABLE 4			
39 BUS SYSTEM-SYSTEM PARAMETERS			
System parameters	Initial values	LP opt. tech values	AC opt. tech values
Ve	0.0617	0.0292	0.0169
$\sum L^2$	0.7859	0.7321	0.6899
Ploss(MW)	49.65	48.22	47.67

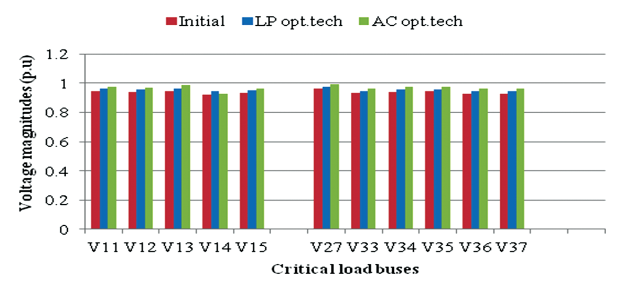

FIG. 1. 39 BUS SYSTEM-VOLTAGE PROFILE FOR CRITICAL LOAD BUSES

The improvement of voltage profiles and their corresponding L-Index values are given in Table III for all load buses but in Figure 1 and Figure 2 only critical buses are considered for illustration purpose.

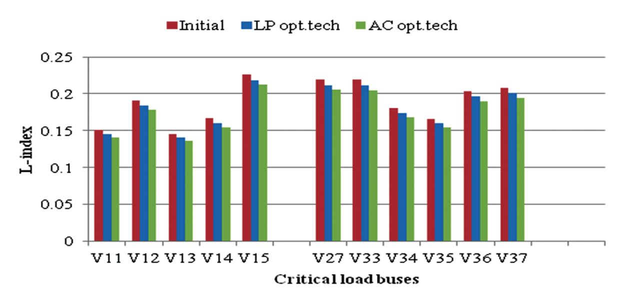

FIG. 2. 39 BUS SYSTEM- L-INDEX VALUES FOR CRITICAL LOAD BUSES

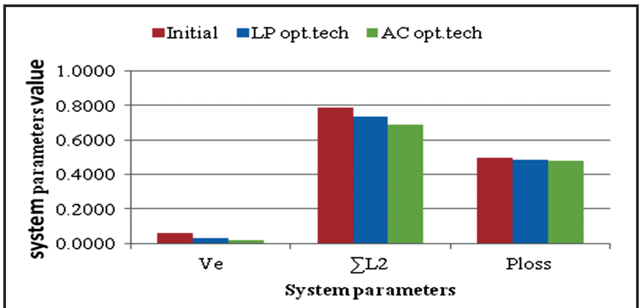

FIG. 3. 39 BUS SYSTEM- SYSTEM PARAMETERS

7.0 CONCLUSIONS

ACO Algorithm has been proposed for voltage profile enhancement in this paper. This Algorithm is formulated using foraging behaviour and coordination of real ants for the voltage deviation problem. The ACO technique is illustrated to give inspiring results for New England 39-bus system. The results obtained are compared with conventional Linear Programming technique for near optimal values. Results Clearly shows the ACO approach is effective in enhancing voltage stability and simultaneously lowering system parameters like Voltage error, $\sum L2$ and power loss.

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