Comparison of Loss Sensitivity Factor & Index Vector methods in Determining Optimal Capacitor Locations in Agricultural Distribution

K.V.S. Ramachandra Murthy, M. Ramalinga Raju, G. Govinda Rao, K. Narasimha Rao

Abstract **: Utilization of fixed capacitors is one of the most important methods in loss reduction and improving the voltage profile of distribution systems. In this paper, suitable capacitor locations are obtained based on index vector method and loss sensitivity factor method. Both the methods are based on power loss. The correctness of the locations is checked by obtaining optimal sizes of capacitors. Optimal sizes of the fixed capacitors are given by Index Vector method and particle swarm optimization method respectively. The distribution networks with balanced loading and radial configuration is considered for analysis. Finally, these methods are tested on a region of the distribution network of the Andhra Pradesh Eastern Power Distribution Corporation consisting of 22 buses. It is observed that Loss sensitivity factor method is more effective.**

I. INTRODUCTION

One of the most effective and useful methods in reducing the power losses in distribution networks is utilization of optimal capacitor placement. Capacitors are installed in distribution systems for reactive power compensation. The Capacitor placement problem is the process of determination of the location, size and number of the capacitor to be placed in a radial distribution system. The objectives are to reduce the losses in the system and to maintain good voltage profile within the limits. Various techniques have been implemented by researchers for optimal capacitor placement problem. Integer programming method was used by Wang J. et. al. [1]. Nonlinear programming method was implemented in [2, 3], Sensitivity analysis method is used by Huang [4], Gallego et. al. [5], The equal area criterion for selecting the sites of fixed capacitors was used by Grainger [6], Delfanti used dynamic programming method [7] for solving the capacitor placement problem. Simple and Efficient method of distribution load flow was developed by D.Das et. al [8]. Topology based approach was introduced by J. H. Teng [9]. Index Vector method was used by Sydulu et. al in [10]. Loss Sensitivity factors were obtained for obtaining optimal capacitor locations and Particle Swarm Optimization was used for obtaining optimal sizes of capacitors in [11].

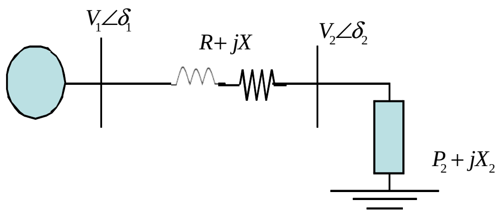
K.V.S. Ramachandra Murthy is working as Associate Professor, G.V.P. College of Engineering., Visakhapatnam.
Mail: murthykvs2000@yahoo.co.in

M. Ramalinga Raju is Professor and Head of the Department of E.E.E. at University college of Engineering, JNTU, Kakinada, India.
Mail : rajumanyala@rediffmail.com

G.Govinda Rao and K. Narasimha Rao are working as Professor, G.V.P. College of Engineering., Visakhapatnam.

In this paper, the objective is to find the optimal location for keeping fixed capacitors in distribution networks by using index vector, Loss sensitivity factor methods. Particle swarm optimization method is used to obtain the size of capacitor units in the locations given by loss sensitivity factor method.

II. DISTRIBUTION LOAD FLOW EQUATIONS



P_2 and Q_2 are effective active and reactive powers supplied beyond node 2. Formulae have been derived in [8]. The simple and efficient method of load flow was developped by Das and Kothari.

$$A[j] = P_2R[j] + Q_2X[j] - \frac{V_1^2}{2} \quad (1)$$

$$B[j] = \sqrt{[A[j]^2 - (P_2^2 + Q_2^2)(R[j]^2 + X[j]^2)]} \quad (2)$$

$$V_2 = \sqrt{[B[j] - A[j]]} \quad (3)$$

$$P_{loss}[j] = R[j] * \left[\frac{P_2^{\ 2} + Q_2^{\ 2}}{V_2^{\ 2}}\right] \quad (4)$$

$$Q_{loss}[j] = X[j] * \left[\frac{P_2^{\ 2} + Q_2^{\ 2}}{V_2^{\ 2}}\right] \quad (5)$$

III. INDEX VECTOR METHOD FOR OPTIMAL CAPACITOR PLACEMENT

1. Objective Function

The Objective function in the capacitor placement problem comprises of the minimization of the total real power losses in the given Radial Distribution System. The Objective function is given by:

$$Min\ P_{loss} = R[k]\left[\frac{P[k]^2 + Q[k]^2}{V[n]^2}\right] \quad (6)$$

where

P[k], Q[k] =Real and reactive power in the Branch k
V[n] =Voltage at node n
R[k] =Resistance of the branch k

2. Index Vector Based Method

Index Vector based method is the conventional approach for optimal capacitor placement[22]. Index Vector is formulated by running the base case load flow on a given radial distribution network, and calculating reactive component of current in the branches and reactive power load concentration at each node. Based on the elements of the Index Vector, this method identifies a sequence of nodes to be compensated. The sequence of priority of the nodes is mainly determined by the Index-Vector.

The Index-Vector for bus n is given by

$$Index\,[n] = \frac{1}{V_n^{\,2}} + \frac{I_q[k]}{I_p[k]} + \frac{Q_{eff}[n]}{totalQ} \qquad (7)$$

where

Index[n] =”Index” for n^{th} bus
V[n] = Voltage at n^{th} bus
$I_q[k]$ = Imaginary component of current in k^{th} branch
$I_p[k]$ = Real component of current in k^{th} branch
Qeff[n] = Effective load at n^{th} bus
TotalQ = Total reactive load of the given Distribution system

After formulating the Index Vector multiply the index value by the load reactive power at that bus to estimate the size of the capacitor to be placed. Thus, the potential location and size of the capacitor to be placed are obtained directly. Arrange the Index vector in descending order so that highest priority bus will come first and the lowest priority bus will come at end. Now place the capacitor at the first potential location and run the load flow and estimate the losses .Then assume capacitors at first two potential locations and perform load flow again evaluate the corresponding losses. It may be observed that the loss will reduce. Repeat this with estimated capacitors at first “n” busses till losses reduce to minimum and for the first (n+1) potential locations the loss start increasing Then the estimated capacitors at first n potential locations will give optimal location and size for the given radial distribution system.

IV. SENSITIVITY ANALYSIS

Loss sensitivity factors are calculated for determining the candidate nodes for placement of capacitors. Estimation of these sensitive nodes helps in reducing the search space.

$$\frac{\partial P_{loss}}{\partial Q_2} = \frac{2 * Q_2 * R[j]}{V_2^{\,2}} \qquad (8)$$

$$\frac{\partial Q_{loss}}{\partial Q_2} = \frac{2 * Q_2 * X[j]}{V_2^{\,2}} \qquad (9)$$

Loss sensitivity factors, $\frac{\partial P_{loss}}{\partial Q_2}$ are calculated using load flow, and values are arranged in descending order for all the lines. Normalized voltage magnitudes are calculated for all the buses. by the following formula.

$$Norm\,[i] = \frac{V[i]}{0.95} \qquad (10)$$

Buses, whose normalized values are less than 1.01 are considered as candidate nodes requiring compensation. Loss Sensitivity factors decide the sequence of in which buses are to be considered for compensation placement and the normalized values of voltages decide, whether a particular bus needs compensation or not.

V. PARTICLE SWARM OPTIMIZATION

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Eberhart and Dr. Kennedy in 1995. This method is based on the social behavior of bird flocking or fish schooling . PSO has many similarities with evolutionary computation techniques like Genetic Algorithms (GA). The system is initialized with a population of random solutions and searches for optimal solution by updating generations in different iterations. However, unlike GA, PSO has no evolution operators such as crossover and mutation. In every iteration, each particle is updated by following two "*best*" values. The first one is the best solution (fitness) it has achieved so far. This value is called *pbest*. Another "*best*" value that is tracked by the particle swarm optimizer is the best value, obtained so far by any particle in the population. This best value is a global best and called *gbest*.

Velocity Updation: ith particle velocity is updated by the eqn,

v[i][j] =K*(w* v[i][j]+ c_1*rand( )*(pbestx[i][j] - x[i][j]) + c_2*rand( )*(gbestx[i][j] - x[i][j])) (11)

x[i][j] = x[i][j] + v[i][j] Equation for updating the position of the particle :
K is called constriction factor = 0.7259
c1, c2 weight factors= 2.05
w inertia weight parameter=1.2
‘i’ particle number,
‘j’ control variable.

There are eight capacitors required. In each row, six capacitor values are assumed. Particle[i] = [q1 q2 q3 q4 q5 q6 q7 q78] Initially 20 particles are randomly selected. Velocities are also randomly selected and then updated by the given formulae.

Capmin, minimum capacitor rating = 0 kvar and

Capmax, maximum capacitor rating = 150 kvar is assumed.

$$Vmax = (Capmax - Capmin)/n. \quad (12)$$

If the velocity violates the limits (-vmax, vmax), it is set to the limit it violates. Particle position is updated by adding velocity to it. Iterations are continued till 6 iterations.

The techniques discussed were applied for the part of the network of APEPDCL, which is modeled as a 22 bus system. Data of the feeder is presented in Table I. Load data is given in Table II.

TABLE I
SYSTEM DATA OF THE FEEDER

Line No.	From Bus	To Bus	Resistance (ohm)	Reactance (ohm)
1	1	2	0.3664	0.1807
2	2	3	0.0547	0.0282
3	2	4	0.5416	0.2789
4	4	5	0.193	0.099
5	4	9	0.7431	0.3827
6	5	6	1.3110	0.6752
7	6	7	0.0598	0.0308
8	6	8	0.2905	0.1496
9	9	10	0.0547	0.0282
10	9	11	0.675	0.3481
11	11	12	0.0547	0.0282
12	11	13	0.3942	0.203
13	13	14	1.0460	0.5388
14	14	15	0.022	0.0116
15	14	16	0.0547	0.0282
16	16	17	0.3212	0.1654
17	17	18	0.0949	0.0488
18	17	19	0.574	0.2959
19	19	20	0.1292	0.066
20	20	21	0.0871	0.045
21	20	22	0.5329	0.2744

VI. RESULTS

Optimal capacitor locations and sizes given by index vector method are presented in Table III. Optimal capacitor locations given by sensitivity analysis given in Table IV along with the sizes of capacitors given by PSO. It is interesting to note that the locations given by the two methods are not same. They differ because of the different mathematical formulations. LSF method gives priority nodes based on the rate of change of real power loss with respect to reactive power consumed at that node. Index Vector method determines the priority nodes based on the three components discussed in Section III.

TABLE II
LOAD DATA OF THE FEEDER

Bus No.	Real Power(Kw)	Reactive Power(Kvar)
1	0	0
2	16.78	20.91
3	16.78	20.91
4	33.80	37.32
5	14.56	12.52
6	19.31	25.87
7	10.49	14.21
8	8.821	11.66
9	14.35	18.59
10	14.35	18.59
11	16.27	19.48
12	16.27	19.48
13	82.13	71.65
14	34.71	30.12
15	34.71	30.12
16	80.31	70.12
17	49.62	47.82
18	49.62	47.82
19	43.77	38.93
20	37.32	35.96
21	37.32	35.96
22	31.02	29.36

Voltage magnitudes and angles are compared before and after compensation using index vector method are presented in Table V. Angle values are positive before compensation and they are found to be negative after compensation. Voltage magnitude without compensation, with compensation using Index Vector method and with PSO are presented in VII. . The results are promising. They are almost very nearer to each other and in acceptable voltage limits. Comparison of real and reactive power loss before and after placement of capacitors between Index-Vector method and Loss sensitivity factor method is presented in table VI.

TABLE III
OPTIMAL LOCATION AND CAPACITOR SIZE GIVEN BY INDEX VECTOR METHOD

Optimal Location (Bus No) given by Index Vector method	Optimal Capacitor sizes (kVAr) given by Index Vector method
13	137.71
16	120.90
4	79.58
17	76.99
18	63.03
19	57.43
14	54.80
6	51.85
TOTAL	**642.29**

TABLE IV
OPTIMAL LOCATION GIVEN BY LOSS SENSITIVITY FACTOR METHOD AND CAPACITOR SIZES GIVEN BY PSO

Optimal Location (Bus No.) given by Loss Sensitivity Factor method	Optimal Capacitor sizes (kVAr) given by P.S.O.
14	136.63
9	25.34
4	104.67
11	58.39
2	10.89
13	79.25
19	100.67
17	110.84
Total KVAR	**626.68**

VII. CONCLUSIONS

Optimal location and size for capacitors is given by index method in the first case. In the second case, locations are given by loss sensitivity factor method and size of the capacitor is given by particle swarm optimization method. The sizes of capacitors, voltages, and power losses are compared. The results are very promising. In the second case, loss reduction is same but, the amount of reactive power requirement is less than the first method. Though the voltages obtained in the second case (LSF and PSO) method are slightly lower, they are in acceptable limits and reasonably good. It is interesting to find that the locations are not same given by two methods and the sizes are also different in both the methods. But, total reactive power used for compensation is almost nearer to each other. Q compensation is equal to 642.29 kVAr in the Index Vector method and 626.68 kVAr in the second case. The maximum reduction in active and reactive power loss is also same for the given system.

TABLE. V
COMPARISON OF VOLTAGES AND ANGLES WITH AND WITHOUT COMPENSATION BY INDEX VECTOR METHOD

Bus No	Voltage p.u without compensation	Voltage p.u with compensation	Voltage angles	
			Before compensation	After compensation
1	1	1	0	0
2	0.9969	0.9979	0.0572	- 0.0515
3	0.9969	0.9979	0.0572	- 0.0515
4	0.9926	0.9951	0.1317	- 0.1432
5	0.9925	0.995	0.1375	- 0.1432
6	0.9918	0.9946	0.1546	- 0.1604
7	0.9917	0.9946	0.1546	- 0.1604
8	0.9917	0.9946	0.1604	- 0.1604
9	0.9875	0.9917	0.2177	- 0.2406
10	0.9875	0.9917	0.2177	- 0.2406
11	0.9832	0.9889	0.2864	- 0.3380
12	0.9832	0.9889	0.2864	- 0.3380
13	0.9808	0.9874	0.3265	- 0.4010
14	0.9756	0.984	0.4067	- 0.5099
15	0.9756	0.984	0.4067	- 0.5099
16	0.9754	0.9838	0.4125	- 0.5156
17	0.9744	0.9831	0.4297	- 0.5271
18	0.9743	0.9831	0.4297	- 0.5328
19	0.9733	0.9822	0.4469	- 0.5271
20	0.9731	0.982	0.4526	- 0.5213
21	0.9731	0.982	0.4526	- 0.5213
22	0.9729	0.9818	0.4526	- 0.5213

TABLE VI
COMPARISION OF LOSSES

Loss	Total loss before placement of capacitors	Total loss after placement of Capacitors using index vector method	Total loss using Loss sensitivity Factor method
Real Power Loss (KW)	17.69	9.22	9.22
Reactive Power Loss(Kvar)	9.05	4.72	4.72
Total real power loss reduction(KW)		8.47	8.47
Total reactive power loss rduction(KVAR)		4.33	4.33

REFERENCES

[1] WANG, J., CHIANG, H., NAN MINU, K., DARLING, G., "Capacitor Placement and Real Time Control in Large-Scale Un- balanced Distribution Systems:" Part I & II, *IEEE Trans. On Power Delivery* 12 ,1997, 953–964.

[2] CARPINELLI, G., VARILONE, P, Di VITO, V., ABUR, A. : Capacitor Placement in Three-phase Distribution Systems with Nonlinear and Unbalanced Loads, *IEE Proc.-Gener. Trans. Distrib*, 152 No. 1, 2005, pp. 47–52.

[3] CHIANG, H., WANG, J., DARLING, G. "Optimal Capacitor Placement, Replacement and Control in Large-Scale Unbalanced Distribution Systems:" Part I & II, IEEE Trans. On Power Systems 10 , 1995, pp. 356–369.

TABLE VII
COMPARISON OF VOLTAGE MAGNITUDES

Bus No	Voltage p.u without compensation	Voltage p.u with compensation using index vector method	Voltages with compensation using Loss sensitivity factor method and PSO
1	1	1	1
2	0.9969	0.9979	0.9979
3	0.9969	0.9979	0.9979
4	0.9926	0.9951	0.995
5	0.9925	0.995	0.9949
6	0.9918	0.9946	0.9942
7	0.9917	0.9946	0.9942
8	0.9917	0.9946	0.9942
9	0.9875	0.9917	0.9916
10	0.9875	0.9917	0.9916
11	0.9832	0.9889	0.9888
12	0.9832	0.9889	0.9887
13	0.9808	0.9874	0.9871
14	0.9756	0.984	0.9836
15	0.9756	0.984	0.9835
16	0.9754	0.9838	0.9834
17	0.9744	0.9831	0.9827
18	0.9743	0.9831	0.9826
19	0.9733	0.9822	0.9819
20	0.9731	0.982	0.9817
21	0.9731	0.982	0.9816
22	0.9729	0.9818	0.9815

[4] HUANG, Y. C.—YANG, H. T.—HUANG, C. L. : Solving the Capacitor Placement Problem in a Radial Distribution System Using Tabu Search Application, IEEE Trans. On Power Systems 11 (1996), 1868– 1873.

[5] GALLEGO, R. A., MONTICELLI, A. J., ROMERO, R. : Optimal Capacitor Placement in Radial Distribution Networks, IEEE Trans. On Power Systems 16 (2001), 630–637.

[6] GRAINGER, J. J. LEE, S. H., "Optimum Size and Location of Shunt Capacitors for Reduction of Losses on Distribution Feeders", *IEEE Trans. On Power Appar*. A. Syst.", PAS-100, 1981, pp. 1105–1118.

[7] DLFANTI, M.—GRANELLI, G. P.—MARANNINIO, P. : Optimal Capacitor Placement Using Deterministic and Genetic Algorithm, IEEE Trans. On Power Systems 15 (2000), 1041–1046.

[8] D. Das, D.P. Kothari, A Kalam "Simple and effcient method for load flow Solution of radial distribution networks"., *Journal of Electrical Power and Energy Systems,* Vol 17, No.5, pp335 – 346,1995.

[9] Jen-Hao Teng, "A Network- Topology based Three-Phase Load flow for Distribution systems", *Proceedings of the National Science Council*, ROC(A), Vol.24, No.4, 2000, Pp. 259-264.

[10] V.V. K. Reddy and M. Sydulu, " Index and GA based Optimal Location and Sizing of Distribution System Capacitors", Power Engineering Society General Meeting, June, 2007, Tampa, FL, pp1-4.

[11] K. Prakash, M. Sydulu, "Particle Swarm Optimization Based Capacitor Placement on Radial Distribution Systems", Power Engineering Society General Meeting, June, 2007, Tampa, FL, pp1-4.

BIOGRAPHIES

K. V. S .Ramachandra Murthy did his graduation in Electrical Engineering and M. Tech in Power Systems from R.I.T., Jamshedpur in 1994 and 2002 respectively. He is pursuing his Ph.D. from J.N.T.U., Hyderabad, India. He had four years of industrial experience and eight years of Teaching Experience. He is currently employed as Associate Professor in Electrical Engineering Department in G. V. P. College of Engineering, Visakhapatnam, India. His research interests are in the Management of Electrical Energy.

M. Ramalinga Raju did his B. Tech in Electrical Engineering from J.N.T.U. College of Engineering, Kakinada in 1986 and M. Tech in Electrical Machines and Industrial Drives from Regional Engineering College, Warangal, India in 1989. He did his Ph.D. from J.N.T.U., Hyderabad, India in the year 2004. Presently he is Professor & Head ' Department of Electrical and Electronics Engineering, University College of Engineering, Kakinada ,JNTU Kakinada, India. His areas of interest are Energy Management, Power Electronics.

G. Govinda Rao was born in Srikakulam, Andhra Pradesh, India on January 19th, 1939. He graduated in Electrical Engineering from the College of Engineering, Kakinada, affiliated to Andhra University in 1959. He obtained his M.E. Degree from Andhra University in 1966 and Ph.D. from I.I.Sc, Bangalore in 1981. He had his teaching career at Andhra University college of Engineering for four decades and is currently employed in Gayatri Vidya Parishad College of Engineering, Visakhapatnam, India. Govinda Rao received the Best Teacher Award from the A.P. State Govt. in 1996 and is a Felllow of Institute of Engineers, India and a Member of the Indian Society of Technical Education. His research interests are in the areas of Fundamentals of Circuit Analysis and Power System Analysis and Stability.

K. Narasimha Rao has obtained degree in Electrical Engineering from the Institute of Engineers (INDIA), Kolkata in summer 1996 and Post Graduation M. Tech. in IT Power Engineering from Jawaharlal Nehru Technological University, Hyderabad in December, 2002 and Ph. D. from JNT University, Hyderabad, India in the year 2009. He is having 14 years of experience in teaching and presently working as Professor with GVP College of Engineering, Visakhapatnam, AP, India. He is a Life member of ISTE, New Delhi and Member of Institute of Engineers (India), Kolkata. His research of interests includes Power System Security, Application of Neural Networks & Fuzzy in power system.