ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

OPTIMAL CAPACITOR PLACEMENT FOR VOLTAGE STABILITY ENHANCEMENT IN DISTRIBUTION SYSTEMS

Aravindhababu P. and Mohan G.
Department of Electrical Engineering, Annamalai University, Tamil Nadu, India
E-Mail: mohang_08@rediffmail.com

ABSTRACT

Voltage instability in power systems is characterised by a monotonic voltage drop, which is slow at first and becomes abrupt after some time; and occurs when the system is unable to meet the increasing power demand. The operating conditions of the present day distribution systems are closer to the voltage stability boundaries due to the ever increasing load demand. Capacitors are used in distribution systems to minimise line losses and improve the voltage profile. A new algorithm for optimal locations and sizing of static and/or switched shunt capacitors, with a view to enhance voltage stability is presented in this paper. The superiority of this approach is demonstrated by testing the algorithm on 33 and 69-node distribution systems.

Keywords: voltage stability, radial distribution systems, capacitor placement.

Nomenclature

L_m	VSI of node- m
L^t	Threshold value for VSI
L^{low}	Lowest value of VSI in the system
nn	Number of nodes in the system
PA	proposed algorithm
$P_m + jQ_m$	Real and reactive powers at the receiving end of branch-m
$P_{L-m} + jQ_{L-m}$	Real and reactive power load at node-*m*
$Q_m^{\ o}$	Value of Q_m before compensation
$Q_{L-\min}$ and $Q_{L-\max}$	system minimum and maximum reactive power demands respectively
Qc_m	Net reactive power compensation at node- m
$r_m + jx_m$	Resistance and reactance of branch-*m* connected between nodes-*k* and *m*
VM	voltage magnitude
VS	voltage stability
VSI	voltage stability index
V^{low}	Lowest value of VM in the system
V_k	voltage magnitude at node-k
δ_k	voltage angle at node-k
δ_{km}	$\delta_k - \delta_m$
Ψ	Set of branches leaving node-m
ΔL_m	$L^t - L_m$, mismatch of VSI at node- m
ΔQ_m	Additional reactive power compensation required at node- m

INTRODUCTION

The phenomenon of voltage instability in power systems is characterized by a progressive decline of voltage, which is caused due to the inability of the system to meet the ever increasing reactive power demand. In the recent years, the load demands are sharply increasing and the system operating states are found to be closer to voltage stability boundaries due to the economical and environmental pressures. The process of voltage instability is generally triggered by some form of disturbance or change in operating conditions that create an increased demand for reactive power, which is in excess of what the system is capable of supplying. The problem of voltage instability has thus become a matter of great concern to the utilities in view of its prediction, prevention and necessary corrections to ensure stable operation [1-2]. In certain industrial areas, it is observed that under certain critical loading conditions, the distribution system suffers from voltage collapse. In 1997, a voltage instability problem in a distribution network, which spread to a corresponding transmission system, had caused a major blackout in the S/SE Brazilian system [3]. Therefore over the years, voltage stability of distribution systems has received great attention with a need for both analysis and enhancement of the operating conditions. The voltage stability (VS) problem of radial distribution system from its single line equivalent has been investigated and the voltage stability index (VSI) for identifying the node that is most sensitive to voltage collapse has been developed [4-7].

Capacitors are commonly used to provide reactive power support in distribution systems. The amount of reactive compensation provided is very much related to the placement of capacitors in distribution feeders. The determination of the location, size, number and type of capacitors to be placed is of great significance, as it reduces power and energy losses, increases the available capacity of the feeders and improves the feeder voltage profile. Numerous methods for solving this problem in view of minimising losses have been suggested in the literature [8-13]. Algorithms for enhancing voltage stability of transmission systems by optimal capacitor placement have been discussed [14-15]. A relationship between voltage stability and loss minimisation has been developed and the concept of maximising voltage stability through loss minimisation has been outlined [16-17]. Algorithms for enhancing voltage stability of distribution

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

systems by network reconfiguration that alters the topological structure of the distribution feeders

By rearranging the status of switches have been suggested [18-21]. However, there is still a need to device better techniques of capacitor placement in order to enhance voltage stability in distribution systems.

A new algorithm that uses the VSI suggested in [6], for optimal placement of static and/or switched shunt capacitors in radial distribution system for voltage stability enhancement is proposed in this paper. This method improves the voltage profile and reduces system losses in addition to enhancing voltage stability. The method is tested on 33 and 69-node radial distribution systems and the results are presented.

PROPOSED CAPACITOR PLACEMENT ALGORITHM

The method uses VSI suggested in [6] and offers reactive power support at the candidate nodes to improve VSI values towards a fixed threshold value, which is chosen based on the system configuration and the operating state. The proposed algorithm (PA) determines the number, sizes, locations and types for capacitors to be placed on a distribution system in order to enhance voltage stability.

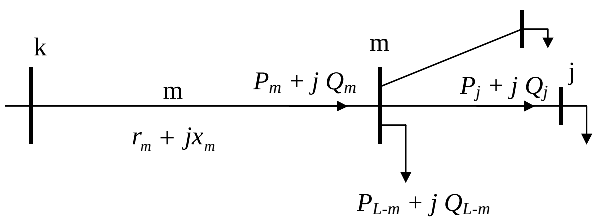

Figure-1. Sample Distribution Line.

The VSI that varies between unity at no load and zero at voltage collapse point at node-*m*, shown in Figure-1, can be determined by

$$L_m = V_k^{\,4} - 4\{P_m x_m - Q_m r_m\}^2 - 4\{P_m r_m + Q_m x_m\}V_k^{\,2} \quad (1)$$

The VS of the system can be improved by providing reactive power support at appropriate nodes. The placement of capacitor at node-*m* will obviously alter the reactive power flow in line-*m* and relieve the line from the burden of reactive power flow. As the required change in Q_m is a measure of amount of capacitor to be placed at node-*m*, it can be obtained by linearising Eq. (1) by treating Q_m as the control variable and neglecting the higher order terms

$$\Delta L_m = \frac{dL_m}{dQ_m}\Delta Q_m \quad (2)$$

where

$$\Delta L_m = L^t - L_m$$

$$\frac{dL_m}{dQ_m} = 8\left[P_m r_m x_m - Q_m r_m^{\,2} - 0.5 x_m V_k^{\,2}\right] \quad (3)$$

The VSI at all the nodes are computed using Eq. (1). If all these values are greater than a fixed threshold value, it indicates that the system is away from the voltage instability point and it does not require any reactive power compensation; else the nodes, whose VSI values are lower than the threshold value, are chosen as the candidate nodes for compensation. However, the node having the lowest VSI value is chosen as the optimal node-m for capacitor placement and the additional reactive power compensation, ΔQ_m, to be provided at this node can be obtained by solving Eq. (2). The calculated reactive power support is provided at node-m and the above procedure is continued till all the VSI values become less than the threshold value.

The maximum compensation at each node is limited to the initial reactive power delivered by the respective node prior to compensation for avoiding over-dimensioning of the capacitor banks as,

$$Qc_m \le Qm^o \quad (4)$$

The capacitor to be installed at a specific node may be either fixed or switched type, which is based on the system minimum and maximum reactive power demands, $Q_{L-\min}$ and $Q_{L-\max}$ in a defined period. They are chosen such that the reactive power is drawn from fixed capacitors when $\left\{\sum_{m=2}^{nn} Q_{L-m} \le Q_{L-\min}\right\}$ and switched capacitors when $\left\{Q_{L-\min} \le \sum_{m=2}^{nn} Q_{L-m} \le Q_{L-\max}\right\}$. The flow of the proposed method is shown in Figure-2.

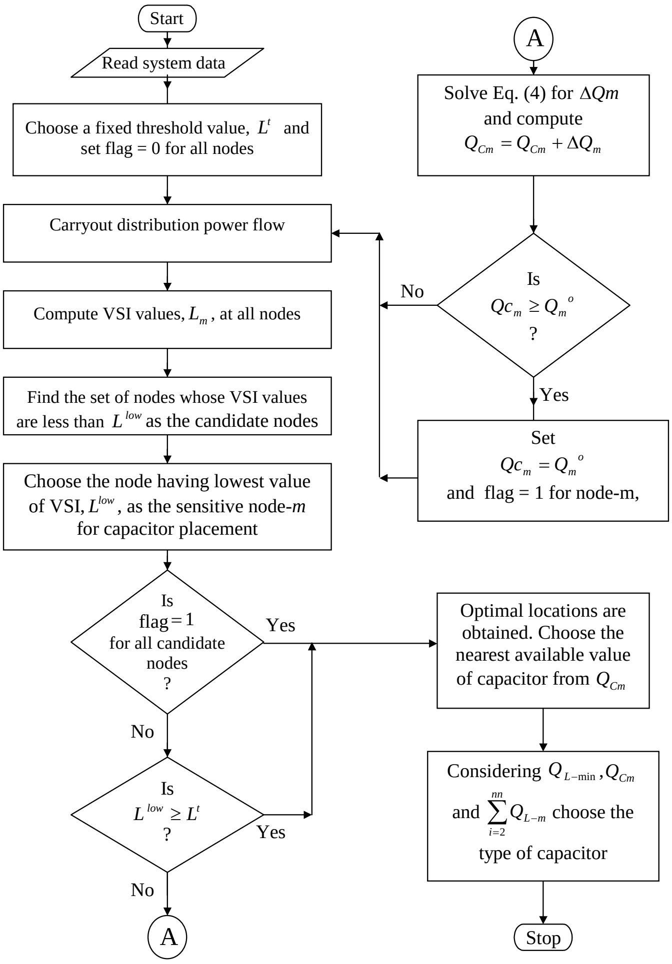

Figure-2. Flow chart of the proposed method.

SIMULATION

The proposed algorithm is tested on 33 and 69-node distribution systems. The line and load data for these two systems are obtained from the references [22] and [20]. The power flow suggested in [23] is used in this study. The size of the capacitor banks considered in this study is 150, 300, 450, 600 and 900 kVAR. The results are obtained for light, medium, full and over load conditions by multiplying the base-load by a factor 0.5, 0.8, 1.0 and 1.1 respectively. The threshold value for VSI is taken as 0.79 and 0.70 for 33 and 69-node systems respectively. The threshold value depends on the power system configuration and the operating state. If this value is fixed too low, it does not ensure that the power system will be maintained in a stable state. If this value is fixed too high, the reactive power to be provided will be too excessive.

33 node test system

The minimum reactive power compensation required to enhance voltage stability for different loading conditions for 33 node system are given in Table-1. The system minimum and maximum reactive power demands are 1150 kVAR and 2530 kVAR respectively. The size and type of capacitor banks required for 33 node system based on the variation of reactive power demands are given in Table-2. Four fixed type of capacitor banks with a net rating of 1050 kVAR are permanently connected at nodes-13, 14, 30 and 32 to supply reactive power at all loading conditions. Switched capacitor banks with a rating of 150 kVAR are connected at nodes-13, 15, 16, 30 and 31 as shown in Table-2 to offer additional reactive power. Table-3 compares L^{low}, V^{low} and the system losses before and after capacitor placement for different loading conditions. Analysis of this table clearly indicates that the optimal capacitor placement enhances voltage stability, improves voltage profile and reduces the system losses.

69 node system

The minimum and maximum reactive power demands for 69 node system are 1347 kVAR and 2964 kVAR respectively. The required reactive power compensation, size and type of capacitor banks, performance before and after capacitor placement are given in Tables-4, 5 and 6 respectively. These results also reveal that there is significant improvement in system performance in terms of voltage stability, voltage profile and system losses.

Table-1. Requirement of VAR compensation for 33 node system.

kVAR requirement								
Node No.		13	14	15	16	30	31	32
Load Level	Light	---	---	---	---	---	---	---
	Medium	---	150	---	---	---	---	150
	Full	150	150	150	150	750	150	150
	Overload	300	150	150	150	900	300	150

Table-2. Type and size of capacitor placed for 33 node system.

Node No.		13	14	15	16	30	31	32
Fixed	150 kVAR	1 No	1 No	---	---	---	---	1 No
	600 kVAR	---	---	---	---	1 No	---	---
Switched	150 kVAR	1 No	---	1 No	1 No	2 Nos	2 Nos	---

Table-3. Performance of the PA for 33 node system.

Load Level	**Before Capacitor Placement**			**After Capacitor Placement**		
	L^{low}	V^{low}	Loss (kW)	L^{low}	V^{low}	Loss (kW)
Light	0.828	0.954	48.78	0.897	0.973	36.25
Medium	0.730	0.924	130.71	0.797	0.945	89.14
Full	0.667	0.904	210.97	0.781	0.940	146.25
Over	0.636	0.893	259.64	0.777	0.939	178.53

Table-4. Requirement of VAR compensation for 69 node system.

kVAR requirement					
Node No.		61	62	63	64
Load Level	Light	---	---	---	---
	Medium	---	---	150	150
	Full	1050	300	150	150
	Over	1200	300	300	150

Table-5. Type and size of capacitor placed for 69 node system.

Node No.		61	62	63	64
Fixed	300 kVAR	---	1 No	1 No	---
	750 kVAR	1 No	---	---	---
Switched	150 kVAR	1 No	---	---	1 No
	300 kVAR	1 No	---	---	---

Table-6. Performance of the PA for 69 node system.

Load Level	**Before Capacitor Placement**			**After Capacitor Placement**		
	L^{low}	V^{low}	Loss (kW)	L^{low}	V^{low}	Loss (kW)
Light	0.787	0.942	70.20	0.879	0.968	71.39
Medium	0.665	0.903	192.88	0.755	0.932	134.30
Full	0.587	0.875	317.73	0.687	0.910	212.16
Over	0.549	0.861	395.50	0.673	0.906	272.20

CONCLUSIONS

A new algorithm for optimal locations and sizing of static and/or switched capacitor banks in order to enhance voltage stability of radial distribution system has been developed. This method improves the voltage profile and reduces the system losses in addition to enhancing voltage stability. The algorithm is suitable for practical implementation on systems of any size.

ARPN Journal of Engineering and Applied Sciences

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the authorities of Annamalai University for the facilities offered to carry out this work.

REFERENCES

[1] C. W. Taylor. 194. Power System Voltage Stability. McGraw-Hill, Inc.

[2] P. Kessel and M. Glavitch. 1986. Estimating the voltage stability of a power system IEEE Trans. Power Delivery. PWRD-I (3): 346-54.

[3] R. B. Prada., .L.J. Souza. 1998. Voltage stability and thermal limit: constraints on the maximum loading of electrical energy distribution feeders IEE Proc. Gen. Trans and Dist. 145(5): 573-77.

[4] G.B.Jasmon and L.H.C.C.Lee. 1991. Distribution network reduction for voltage stability analysis and load flow calculations International Journal of Electrical Power and Energy Systems. 13(1): 9-13.

[5] F. Gubina and B. Strmenik. 1997. A simple approach to voltage stability assessment in radial networks IEEE Trans. on Power Systems. 12(3): 1121-28.

[6] M. Chakravorty and D. Das. 2001. Voltage stability analysis of radial distribution networks International Journal of Electrical Power and Energy Systems. 23: 129-135.

[7] M. H. Haque. 2001. A linear voltage stability margin for radial distribution systems IEEE Trans. on Power Systems. 17(2): 876-83.

[8] M. E. Baran, F. F. Wu. 1989. Optimal capacitor placement on radial distribution systems IEEE Trans. on Power Systems. 4(1): 725-34.

[9] M. H. Haque. 1999. Capacitor placement in radial distribution systems for loss reduction IEE Proc. Gen. Trans and Dist. 146(5): 501-505.

[10] J. C. Carlisle and A. A. El-Keib. 2000. A graph search algorithm for optimal placement of fixed and switched capacitors on radial distribution systems IEEE Trans. on Power Delivery. 15(1): 423-428

[11] K. Prakash and M. Sydulu. 2006. A novel approach for optimal locations and sizing of capacitors on radial distribution systems using loss sensitivity factors and α-coefficients. IEEE PES, Power System Conference and Exposition. pp. 1910-1913.

[12] C. T. Su, C. F. Chang and J. P. Chiou. 2004. Optimal capacitor placement in distribution systems employing ant colony search algorithm. Electric Power Components and Systems. 33(8): 931-946

[13] B. Venkatesh and B. Ranjan. 2006. Fuzzy EP algorithm and dynamic data structure for optimal capacitor allocation in radial distribution systems IEE Proc. Gen. Trans and Dist. 153(5): 80-88.

[14] M. El Arini. 2000. Optimal capacitor placement incorporating voltage stability and system security ETEP. 10(5): 319-325.

[15] P. K. Satpathy, D. Das and P. B. Dutta Gupta. 2004. Critical switching of capacitors to prevent voltage collapse Electric Power Systems Research. pp. 11-20.

[16] B. Jasmon and L.H.C.C.Lee. 1991. Maximising voltage stability in distribution networks via loss minimisation Journal of Electrical Power and Energy Systems. 13(3): 148-152.

[17] M. A. Kashem and M. Moghaavvemi. March 1998. Maximising radial voltage stability and load balancing via loss minimisation in distribution networks Proceedings of Energy Management and Power Delivery. 1: 91-96.

[18] J. C. Wang, H. C. Chiang and G. R. Darling. 1996. An efficient algorithm for real-time network reconfiguration in large scale unbalanced distribution systems. IEEE Trans. on Power Systems. 11(1): 511-17.

[19] M. A. Kashem, V. Ganapathy and G. B. Jasmon. 2000. Network reconfiguration for enhancement of voltage stability in distribution networks IEE Proc. Gen. Trans and Dist. 147(3): 171-75

[20] S. Sivanagaraju, N. Visali, V. Sankar and T. Ramana. 2004. Enhancing voltage stability of radial distribution systems by network reconfiguration. Electric power components and systems. 33(5): 539-50.

[21] N. C. Sahoo and K. Prasad. 2006. A fuzzy genetic approach for network reconfiguration to enhance voltage stability in radial distribution systems Energy Conversion and Management. 47: 3288-306.

[22] B. Venkatesh and R. Ranjan. 2003. Optimal radial distribution system reconfiguration using fuzzy adaptation of evolutionary programming Journal of Electrical Power and Energy Systems. pp. 775-780.

[23] P. Aravindhababu, S. Ganapathy and K. R. Nayar. 2001. A novel technique for the analysis of radial distribution systems International Journal of Electrical Power and Energy Systems. pp. 167-171.