

LOAD SHEDDING ALGORITHM FOR AVOIDING VOLTAGE COLLAPSE IN DISTRIBUTION SYSTEMS

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Abstract: A simple load shedding algorithm that uses voltage stability indicator for averting voltage collapse is proposed in this article. This method identifies the weakest bus and uses an analytical procedure to compute the sheddable load; and serves to improve the bus voltage profile, in addition to enhancing voltage stability. The method developed is tested on two distribution systems with satisfactory results.

Key words: distribution systems, voltage stability, voltage stability index, load shedding.

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
$P_{L-m}^o + jQ_{L-m}^o$	real and reactive power load at node- m before load shedding
$P_{S-m} + jQ_{S-m}$	net real and reactive power load to be shed at node- m
$r_m + jx_m$	resistance and reactance of branch- m connected between nodes- k and m

S_m	apparent power at the receiving end of branch- m
S_{net}	net apparent power load in the system in KVA
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
Ψ	set of branches leaving node- m
Φ_m	power factor angle of the power at the receiving end of branch- m
η	weighting factor in the range of 0 to 1
ΔL_m	$L^t - L_m$, mismatch of VSI at node- m
$\Delta P_m + j\Delta Q_m$	additional real and reactive powers of load to be shed at node- m
ΔS_m	additional apparent power of load to be shed at node- m

1.0 Introduction

Modern power systems are more heavily loaded than ever before to meet the growing demand and one of the major problems associated with such a stressed system is voltage collapse or voltage instability. Voltage collapse is characterized by a slow variation in system operating point due to increase in loads in such a way that the voltage magnitude gradually decreases until a sharp accelerated change occurs. The problem of voltage collapse may simply be explained as the inability of

the power system to supply the required reactive power or because of an excessive absorption of the reactive power by the system itself [1-2]. The problem of voltage instability or collapse has become a matter of great concern to the utilities in view of its prediction, prevention and necessary corrections to ensure stable operation. In recent years, the load demand in distribution systems are sharply increasing due to economical and environmental pressures. The operating conditions are thus closer to the voltage stability boundaries. In addition, distribution networks experience distinct load changes everyday. 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 have 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 [4-8].

However, when the operating state is near instability, the main objective is prevention of voltage collapse. If the different control strategies such as generation and energy transfer rescheduling, bringing standby generators on-line, switching capacitor banks, reduction of MV set point and other reactive power controls are exhausted, the only alternative way is load curtailment at some weak buses to avoid voltage collapse. Insufficient load shedding will not eliminate voltage instability problem. On the other hand, excessive load shedding will end up with an imminent power outage problem. Though extensive research is underway on under-frequency load shedding, [9-14], relatively a little contribution is reported on the effect of load shedding on transmission systems to avoid voltage instability [15-22] and hardly any work is carried out on load shedding for voltage stability enhancement of distribution systems. There is thus a need to

device better techniques to identify the optimal locations and determine the minimum sheddable load to avoid voltage instability of distribution systems.

A new algorithm that uses the VSI suggested in [8] for identifying the optimal locations and determining the minimum sheddable load to avoid voltage collapse in radial distribution system is proposed in this article. This method improves the voltage profile in addition to enhancing voltage stability. The algorithm is tested on 33- and 69-node radial distribution systems and the results are presented.

2.0 Proposed Load Shedding Algorithm

The method uses VSI suggested in [8], identifies the weaker buses and determines the minimum amount of load to be shed in distribution systems to improve VSI values towards a fixed threshold value, which is chosen based on the system configuration and the operating state.

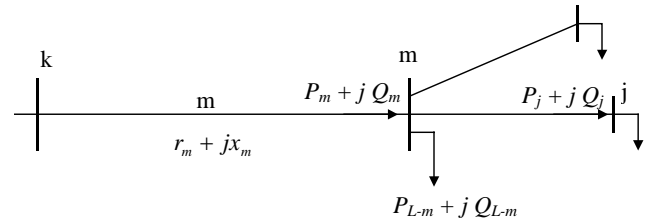


Fig. 1 Sample Distribution Line

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

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

Replacing P_m and Q_m in terms of the apparent power S_m in Eq. (1) as,

$$L_m = V_k^4 - 4S_m^2 \left\{ x_m^2 \cos^2 \Phi_m - r_m^2 \sin^2 \Phi_m \right\} - 2x_m r_m \cos \Phi_m \sin \Phi_m - 4S_m \{ r_m \cos \Phi_m + x_m \sin \Phi_m \} V_k^2 \quad (2)$$

Linearising Eq. (2) by treating S_m as the control variable and neglecting the higher order terms

$$\Delta L_m = \frac{\partial L_m}{\partial S_m} \Delta S_m \quad (3)$$

where

$$\frac{\partial L_m}{\partial S_m} = -4S_m \left\{ x_m^2 \cos^2 \Phi_m - r_m^2 \sin^2 \Phi_m \right\} - 4\{ r_m \cos \Phi_m + x_m \sin \Phi_m \} V_k^2 \quad (4)$$

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 load shedding; else the nodes, whose VSI values are lower than the threshold value, are chosen as the candidate nodes for load shedding. However, the node having the lowest VSI value is chosen as the optimal node- m for load shedding and the apparent power of load to be shed, ΔS_m , at this node can be obtained by solving Eq. (3). As the real and reactive components of the load are proportionately related, the load power factor is assumed to be constant at each node and the real and reactive parts of load to be shed at node- m can be computed using

$$\begin{aligned} \Delta P_m &= \eta \Delta S_m \cos \Phi_m \\ \Delta Q_m &= \eta \Delta S_m \sin \Phi_m \end{aligned} \quad (5)$$

After curtailing the portion of load, ΔP_m and ΔQ_m at node- m , distribution power flow is carried out and the above process is continued till all the VSI values exceed the threshold limit or all the candidate

nodes reach the load shedding limit, which is usually taken as 80% of the initial load. The flow of the proposed algorithm is shown in Fig.2

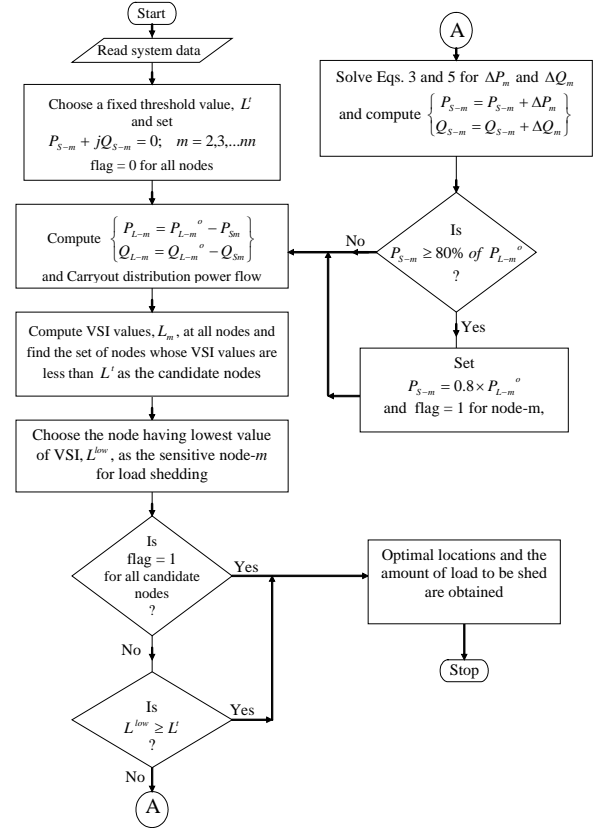


Fig.2 Flow chart of the proposed method

3.0 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 [23] and [24]. The power flow suggested in [25] is used in this study. The load factor used in this approach is a multiplier by which the active and reactive load powers of each node are increased in steps. The threshold value for VSI is taken as 0.70 and 0.68 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 high, it does not ensure that the power system will be maintained in a stable state. If this value is fixed too low, the loads to be shed will be too excessive. The results for different load factors are obtained for both the systems.

The optimal nodes for load shedding, the net real and reactive power to be shed, $P_{S-m} + jQ_{S-m}$ and the percentage sheddable load obtained by the PM at different load factors for 33- and 69-node systems are given in Table-1. The minimum value of VM, V^{low} and the lower value of VSI, L^{low} before and after load shedding, at different load factors are also

given for 33- and 69-node systems in the table. Analyzing these results, it is very clear that the PM improves the system voltage profile and brings the system far away from the region of voltage instability. This method is suitable for distribution systems of any size and for practical implementations.

Table 1 Summary of results of the PA

Test system	Load Factor	Optimal nodes for load shedding	$P_{S-m} + jQ_{S-m}$	% Sheddable loads	L^{low}		V^{low}	
					BLS	ALS	BLS	ALS
33 node	1.00	16,17	87.66+j31.70	2.13	0.667	0.694	0.904	0.913
	1.20	14,16,17,18,32,33	438.04+j190.56	9.11	0.606	0.696	0.882	0.913
	1.50	12,13,15,16,17,18,30,31,32,33	975.12+j470.31	16.52	0.517	0.676	0.848	0.907
	1.70	11,13,14,15,16,17,18,30,31,32,33	1310.96+j865.26	21.15	0.460	0.685	0.824	0.910
	1.90	10,11,12,13,14,15,16,17,18,30,31,32,33	1674.34+j1192.96	24.76	0.405	0.676	0.798	0.907
	2.30	9,10,11,12,13,14,15,16,17,18,29,30,31,32,33	2375.62+j1839.98	29.90	0.300	0.668	0.740	0.904
	2.70	8,11,12,13,14,15,16,17,18,29,30,31,32,33	3046.24+j2641.26	34.18	0.203	0.644	0.671	0.896
	3.00	8,10,11,12,13,14,15,16,17,18,29,30,31,32,33	3683.79+j3112.97	36.79	0.133	0.645	0.604	0.896
	3.30	8,9,10,11,12,13,14,15,16,17,18,28,29,30,31,32,33	4273.70+j3517.56	38.39	0.063	0.640	0.501	0.895
	3.40	8,9,10,11,12,13,14,15,16,17,18,28,29,30,31,32,33	4472.40+j3680.38	38.99	0.031	0.636	0.420	0.893
69 node	1.00	---	0.00+j0.00	0.00	0.758	0.758	0.933	0.933
	1.30	64	176.53+j125.91	3.58	0.631	0.677	0.891	0.907
	1.50	61,62,64,65	509.19+j363.47	6.40	0.550	0.675	0.861	0.906
	1.70	61,62,64,65	872.94+j623.13	13.54	0.470	0.676	0.828	0.907
	1.90	61,62,64,65	1237.34+j883.25	17.17	0.393	0.675	0.791	0.907
	2.00	61,62,64,65	1419.59+j1013.34	18.71	0.354	0.675	0.772	0.907
	2.20	61,62,64,65	1784.42+j1273.84	21.38	0.278	0.675	0.726	0.906
	2.40	61,62,64,65	2149.69+j1534.57	23.61	0.202	0.674	0.670	0.906
	2.60	61,62,65,65	2515.46+j1795.68	25.51	0.117	0.674	0.585	0.906
	2.67	61,62,65,65	2643.61+j1887.16	26.10	0.070	0.673	0.514	0.906

4.0 Conclusion

A novel load shedding algorithm for avoiding voltage collapse has been presented in this article. This approach identifies the weakest bus and uses an analytical procedure to compute the sheddable load; and serves to improve the bus voltage profile, in addition to avoiding voltage collapse. The simulation study indicates that this method is ideally suitable for practical implementation.

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References

1. C.W. Taylor, Power System Voltage Stability, McGraw-Hill, Inc., 1994.
2. Kundur. P, Power system stability and control, McGraw-Hill, Inc., 1993

3. R.B. Prada and L.J. Souza, Voltage stability and thermal limit: constraints on the maximum loading of electrical energy distribution feeders, IEE Proc. Gen. Trans and Dist., vol. 45 (5), pp. 573-77, 1998.
4. A.K. Sinha and D. Hazarika, A comparative study of voltage stability indices in a power system, Electrical Power and Energy Systems, vol. 22(1), pp. 589-596, 2000.
5. Bedoya. D.B, Castro. C.A, Da Silva. L.C.P, A method for computing minimum voltage stability margins of power systems, IET Gener. Transm. Distrib., vol. 2(5), pp. 676-689, 2008.
6. Berizzi. A, Bovo. C, Crio. D, Delfanti. M, Merlo. M and Pozzi. M, Online fuzzy voltage collapse risk quantification, Electric Power System Research, vol. 79 (5), pp. 740-749, 2009.
7. Wang. Y, Wenyuan Li, Jiping Lu, A new node voltage stability index based on local voltage phasors, Electric Power System Research, vol. 79(1), pp. 265-271, 2009.
8. M. Chakravorty and D. Das, 2001, "Voltage stability analysis of radial distribution networks," International Journal of Electrical Power and Energy Systems, Vol. 23(2), pp. 129-135.
9. V.N. Chuvychin, N.S. Gurov, S.S. Venkata and R.E. Brown, "An adoptive approach to load shedding and spinning reserve control during underfrequency conditions", IEEE Trans. on Power Systems, vol. 11(4), pp. 1805-1810, 1996.
10. D. Kottick., "Neural-networks for predicting the operation of an under-frequency load shedding system", IEEE Trans. on Power Systems, vol.11 (3), pp. 1350-1358, 1996.
11. S.-J. Huang, C.-C. Huang, "An adoptive load shedding method with time-based design for isolated power systems", Electrical Power and Energy Systems, vol. 22 (1), pp. 51-58, 2000.
12. H. You, "Self-healing in power systems: an approach using islanding and rate of frequency decline-based load shedding", IEEE Trans. on Power Systems, vol. 18 (1), pp. 174-181, 2003.
13. D. Mingchui, L. Chinwang and W. Chikong, Adaptive under-frequency load shedding, Tsinghua Science and Technology, vol. 13 (6), 823-828, 2008.
14. C.T. Hsu, H.J. Chuang and C.S. Chen, Artificial neural network based adaptive load shedding for an industrial cogeneration facility, Industry Applications Society Annual Meeting-IAS'08, pp. 1-8, 5-9 Oct 2008
15. T. Quoc Tuan, J. Fandino, N. Hadjsaid, J.C. Sabonnadiere and H. Vu, "Emergency load shedding to avoid risks of voltage instability using indicators", IEEE Trans. on Power Systems, vol. 9 (1), pp. 341-351, 1994.
16. S. Arnborg, D.J. Hill and I.A. Hiskens, "On undervoltage load shedding in power systems", Electrical Power and Energy Systems, vol. 19 (2), pp. 141-149, 1997.
17. Z. Feng, V. Ajjarapu and D.J. Maratukulam, "A practical minimum load shedding strategy to mitigate voltage collapse", IEEE Trans. on Power Systems, vol.13 (4), pp. 1285-90, 1998.
18. M.Z. El-Sadek, G.A. Mahmoud, M.M. Dessouky and W.I. Rashed "Optimum load shedding for avoiding steady state voltage instability", Elect Power System Research, vol. 50 (2), pp. 119-123, 1999.
19. L.D. Arya, V.S. Pande and D.P. Kothari, A technique for load-shedding based on voltage stability consideration, Electrical Power and Energy Systems, vol. 27 (7), pp. 506-517, 2005.

20. F.M. Echavarren, E. Lobato and L. Rouco, A corrective load shedding scheme to mitigate voltage collapse, *Electrical Power and Energy Systems*, vol. 28 (1), pp. 58-64, 2006.
21. B. Otomega, M. Glavic and T.V. Custem, Distributed undervoltage load shedding, *IEEE Trans. on Power Systems*, vol. 22 (4), pp. 2283-2285, 2007.
22. N. Sadati, T. Amraee and A.M. Ranjbar, A global particle swarm based simulated annealing optimization technique for under-voltage load shedding problem, *Applied Soft Computing*, vol.9 (2), pp. 652-657, 2009.
23. B. Venkatesh and R. Ranjan, "Optimal radial distribution system reconfiguration using fuzzy adaptation of evolutionary programming", *Journal of Electrical Power and Energy Systems*, vol. 25 (10), pp. 775-780, 2003.
24. S. Sivanagaraju, N. Visali, V. Sankar and T. Ramana, " Enhancing voltage stability of radial distribution systems by network reconfiguration", *Electric power components and systems*, vol. 33(5), pp. 539-50, 2004.
25. P. Aravindhababu and R. Ashokkumar, A fast decoupled power flow for distribution systems, *Electric Power Components and Systems*, vol. 36(9), pp. 932-940, 2008.