Efficient Distribution System Realization Using Equivalent Voltage Stability Indicator

Partha Kayal, *Member, IACSIT,* C. K. Chanda, and Tamal Dutta

***Abstract*—Distribution system should be operated in minimum active and reactive power loss condition for efficient distribution and improvement of reliability of the system. In this paper a new voltage stability indicator is presented to measure voltage stability level of network. An IEEE 30-bus system has reconfigured here for minimization of total system losses and enhancement of voltage stability. Reconfiguration is a modern methodology of modification the topology structure of network which is done here by changing the switching status of additional power lines with the existing network. Considering the different switching combination, configuration which generates minimum value of proposed Equivalent voltage stability indicator (VSIeqv), is selected as optimal network configuration. Simulation results have shown that after reconfiguration voltage stability is improved significantly. From different case studies with random selection of loads, satisfactory results of voltage stability indicators have been obtained to realize the efficient distribution system properly. A strong connection between VSIeqv and active and reactive losses is established in which decreasing value of the VSIeqv indicates reduction of total distribution losses. So, improved distributions can possible reconfiguring the network using developed VSIeqv without any additional voltage regulation hardware installation.**

***Index Terms*—Equivalent two-bus system, switching option, equivalent voltage stability indicator, active and reactive losses.**

I. Introduction

Distribution system reconfiguration can be considered as an operational problem and it is realized by changing the status of sectionalizing and tie switches. Under normal operating conditions, the main aim of network reconfiguration [1, 3, 11] is reduction of system losses and improvement of stability of the system. The reduction of system losses have taken into account very seriously due to the high cost of electrical energy. Besides economic considerations, by minimizing the power losses, voltage stability of the system can be increased and reliability of the system can be maximized [1, 2, 7, 9]. Voltage stability of a network damages when the power system faces the problem of heavy transmission line loading and insufficient local reactive power supply. The level of voltage stability of a system can be measured using Equivalent voltage stability indicator (VSIeqv). Improvement of voltage stability involves study of different tie and sectionalizing switching combinations. The best switching option can be implemented by choosing each successive operation that minimizes the value of voltage stability indicator [4, 6, 10] most, without violating the constraints such as voltage constraints, capacity constraints of line and transformers and reliability constraints.

In the last few years, interest has grown on distribution system reconfiguration for improvement of voltage stability with many publications where new heuristic algorithms were applied to the problem given in [5, 8]. In network reconfiguration, a solution method consists of a search over radial configuration for load balancing and loss minimization has proposed by Baran and Wu [11]. Many techniques have been suggested to find the suitable pair of switches in order to achieve optimal configuration of interconnected network. A new approach of switching search has given by M. A. Kashem et al for enhancement of voltage stability [1, 5]. M. A. Kashem et al have used a voltage stability index derived by Jasmon and Lee for realization of voltage stability [7, 8].

In this paper Equivalent voltage stability indicator has been derived. The developed voltage stability indicator is then applied to different switching combination of the network to assess voltage stability after reducing them into their corresponding equivalent two-bus system. This paper also shows a relationship between voltage stability and total system loss in which it is shown that voltage stability is maximized when total system loss is minimized. We have studied different case studies here with changing system loads randomly to obtain best switching option by network reconfiguration.

II. Calculation of Equivalent Two-Bus Network

An interconnected network can be reduced to an equivalent two-bus network by network equivalencing technique. In this technique, P_S and Q_S are considered as source power and connected with receiving end power P_R and Q_R by an equivalent impedance of Z_{eq} .

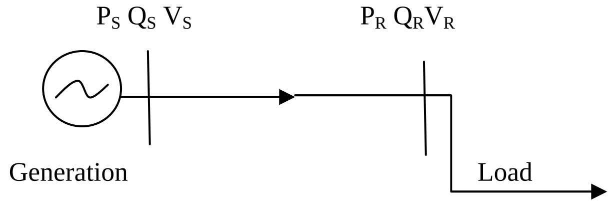

Fig. 1. Equivalent two-bus system.

The power flow equation for the equivalent two-bus system can be shown as

Manuscript received April 5, 2012; revised May 1, 2012.

P. Kayal and T. Dutta are with the Department of Electrical Engineering, Fututre Institute of Engineering and Management, Kolkata, India (e-mail: partha_kayal@yahoo.co.in, tamaldutta95@yahoo.com).

C. K. Chanda is with the Department of Electrical Engineering, Bengal Engineering and Science University, Howrah, India (e-mail: ckc_math@yahoo.com).

$$P_S = P_L + P_R \quad (1)$$

$$Q_S = Q_L + Q_R \quad (2)$$

The real power loss P_L and reactive power loss Q_L for the equivalent system can be represented by

$$P_L = r_{eq}(\frac{P_S^2 + Q_S^2}{V_S^2}) \quad (3)$$

$$Q_L = x_{eq}(\frac{P_S^2 + Q_S^2}{V_S^2}) \quad (4)$$

where r_{eq} and x_{eq} are the equivalent resistance and reactance of the system. Here V_S is the sending end voltage.
The equivalent impedance of the system is given by

$$Z_{eq} = r_{eq} + jx_{eq} \quad (5)$$

$$r_{eq} = \frac{P_L}{\left(P_S^2 + Q_S^2\right)} \quad (6)$$

$$x_{eq} = \frac{Q_L}{\left(P_S^2 + Q_S^2\right)} \quad (7)$$

The sending end voltage V_S being assumed to be at nominal value (V_S = 1.0 p.u). The receiving end voltage V_R can be calculated easily as given below

$$V_R = V_S - Z_{eq}.\frac{\left(P_S - j\,Q_S\right)}{V_S} \quad (8)$$

The total transmission loss (including real and reactive power loss) is obtained from the load-flow solution of the original interconnected system.

III. Proposed Equivalent Voltage Stability Indicator

A new voltage stability indicator of the system is developed here. The proposed indicator is given below considering a line of impedance $r + jx$ is connected between two nodes as shown in the following Fig. 2.

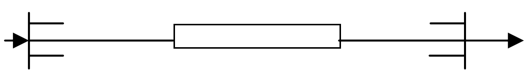

Fig. 2. SLD of two-bus segment of distribution system.

As reactive power and voltage are strongly coupled and active power and voltage are weakly coupled, so for the implementation of Equivalent voltage stability indicator active power is taken as constant. V_1 is considered as the reference bus voltage.
From the general power flow equation,

$$Q_2 = Q_1 - Q_L \quad (9)$$

$$Q_L = x(\frac{P_1^2 + Q_1^2}{V_1^2}) \quad (10)$$

$$Q_1 V_1^2 = Q_2 V_1^2 + x\left(P_1^2 + Q_1^2\right) \quad (11)$$

Derivative of the above equation with respect to Q_1 yields,

$$V_1^2 = V_1^2 \frac{dQ_2}{dQ_1} + 2Q_1 x \quad (12)$$

$$\frac{dQ_1}{dQ_2} = \frac{V_1^2}{\left(V_1^2 - 2Q_1\,x\right)} \quad (13)$$

Again, $$Q_L = x\frac{\left(P_2^2 + Q_2^2\right)}{V_2^2} \quad (14)$$

From Eqn(14) and Eqn(9),

$$Q_1 V_2^2 = Q_2 V_2^2 + x\left(P_2^2 + Q_2^2\right) \quad (15)$$

Derivative of Eqn(15) with respect to Q_2 generates,

$$V_2^2 \frac{dQ_1}{dQ_2} + 2Q_1 V_2 \frac{dV_2}{dQ_2} = V_2^2 + 2Q_2 V_2 \frac{dV_2}{dQ_2} + 2Q_2 x \quad (16)$$

Using the value of $\frac{dQ_1}{dQ_2}$ from Eqn(13) and Q_L from Eqn(9) in Eqn(16), proposed voltage stability indicator is obtained as, $L = \frac{dV_2}{dQ_2} = \frac{Q_2 x}{V_2 Q_L} - \frac{x V_2 Q_1}{Q_L\left(V_1^2 - 2x\,Q_1\right)}$ (17)

From the concept of equivalent two-bus network, Equivalent voltage stability indicator is given by

$$L_{eqv} = \frac{Q_R x_{eq}}{V_R Q_L} - \frac{x_{eq} V_R Q_S}{Q_L\left(1 - 2x_{eq}\,Q_S\right)} \quad (18)$$

The more the value of the indicator nearer to zero, the system is more stable.

IV. Network Reconfiguration Scheme

Reconfiguration of distribution network is determined by different switching options for enhancement of voltage stability under a given loading condition. Improvement of voltage stability is realized by addition or deletion of power lines with original interconnected system which can be achieved by placing line interconnection switches (S) into the network. ‘0’ indicates switch is open and ‘1’ indicates switch is closed. N number of switches in a network generates 2^N possible switching combinations. Study of network reconfiguration involves identification of best switching option which minimizes active and reactive power losses among different switching combinations.

In our study, we have taken an IEEE 30-bus system with addition of four power lines for reconfiguration. There will be sixteen switching combination for four switches in four power lines. Additional four power lines data are given in Table I below.

TABLE I: LINE DATA OF ADDITIONAL POWER LINES

Power line	Starting bus	End bus	R (p.u)	X (p.u)	B/2 (p.u)	Tap setting value
L1	2	7	0.0012	0.1762	0.0	1
L2	5	16	0.1229	0.2558	0.0	1
L3	9	19	0.1168	0.2246	0.0	1
L4	13	23	0.1247	0.2615	0.0	1

V. SOLUTION TECHNIQUE USING PROPOSED VSIEQV

The steps for calculation of best switching option using developed VSI_{eqv} for improvement of distribution efficiency are as follows:

1) Select the additional power lines using switching states '0' or '1' of switch S with the existing network.
2) Run a standard load flow solution program and calculate bus voltages, total generation power ($P_S + jQ_S$), total load power ($P_R + jQ_R$) and total active and reactive losses (P_L and Q_L) of the system.
3) Reduce the multi-bus network into an equivalent two-bus network using equivalent resistance r_{eq} , equivalent reactance x_{eq} and equivalent receiving end voltage $V_R = 1 - Z_{eq} . \frac{(P_S - jQ_S)}{V_S}$.
4) Calculate the value of L_{eqv} using equation $L_{eqv} = \frac{Q_R x_{eq}}{V_R Q_L} - \frac{x_{eq} V_R Q_S}{Q_L (1 - 2x_{eq} Q_S)}$.
5) Repeat the previous steps with different switching status of additional power lines.
6) Search the minimum value of L_{eqv} to obtain best voltage stable and minimum power loss system.

VI. SIMULATION RESULTS AND DISCUSSIONS

An IEEE 30-bus system has been reconfigured considering $2^4 = 16$ different switching combinations for the four switches in additional lines. All switches open yields normal operating condition. Each switching combination has been studied separately and given a reference configuration number. At normal loading condition calculated value of voltage stability indicators, active and reactive power losses are given below Table.

TABLE II: DIFFERENT SWITCHING COMBINATIONS FOR MODIFICATION THE EXISTING NETWORK

Configuration no	S1 (2-7)	S2 (5-16)	S3 (9-19)	S4(13-23)
0	0	0	0	0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
10	1	0	1	0
11	1	0	1	1
12	1	1	0	0
13	1	1	0	1
14	1	1	1	0
15	1	1	1	1

TABLE III: CALCULATED VALUES OF LEQV, ACTIVE, REACTIVE AND TOTAL LOSSES FOR DIFFERENT CONFIGURATIONS

Configuration no	Value of Leqv	Active power loss (MW)	Reactive power loss (MVar)	Total system loss (MVA)
0	0.0363	23.726	50.778	56.048
1	0.0373	23.832	49.147	54.620
2	0.0378	23.654	49.446	54.813
3	0.0365	23.749	47.969	53.526
4	0.0334	23.669	43.057	49.134
5	0.0323	23.765	41.755	48.044
6	0.0327	23.506	42.080	48.200
7	0.0317	23.616	40.827	47.165
8	0.0346	21.229	44.287	49.112
9	0.0332	21.326	42.660	47.694
10	0.0336	21.146	42.944	47.868
11	0.0323	21.235	41.469	46.589
12	0.0300	21.539	38.033	43.709
13	0.0289	21.610	36.720	42.607
14	0.0293	21.368	37.049	42.769
15	**0.0283**	**21.433**	**35.851**	**41.769**

From the previous table it is seen that the value of Leqv and total system loss is minimum at configuration no.15. The lowest value of Leqv indicates the system is most voltage stable. So, after studying each switching combination, last combination i.e. all switches closed is estimated as the best switching option.

In this paper we have done different case studies with changing the system loads randomly to reconfigure the network. In every case the minimum value of Leqv and minimum power loss are calculated.

Case1: In this case load is increased 50% at buses 8, 16, 30 and load is decreased 50% at buses 19 and 26 of their original loadings. Considering each switching combination it is seen that best switching option is obtained with all additional power lines closed.

TABLE IV: VALUES OF LEQV, ACTIVE, REACTIVE AND TOTAL LOSSES BEFORE AND AFTER RECONFIGURATION FOR CSAE1

	Value of Leqv	Active power loss (MW)	Reactive power loss (MVar)	Total system loss (MVA)
Before configuration	0.0459	27.691	63.212	69.011
After reconfiguration	0.0352	24.848	46.375	52.612

Case2: For this case study 50% load is increased at buses 23 and 50% load is decreased at buses 7, 16 and 19 of their original loadings. In this case also best result for reconfiguration is obtained at configuration no.15.

TABLE V: VALUES OF LEQV, ACTIVE, REACTIVE AND TOTAL LOSSES BEFORE AND AFTER RECONFIGURATION FOR CSAE2

	Value of Leqv	Active power loss (MW)	Reactive power loss (MVar)	Total system loss (MVA)
Before configuration	0.0299	19.919	36.473	41.557
After reconfiguration	0.0214	18.683	25.762	31.823

Case3: With 50% increase of load at buses 7, 16, 19 and 50% decrease of load at bus 23, we have found that all switch status '1' generate lowest value of Leqv .

TABLE VI: VALUES OF LEQV, ACTIVE, REACTIVE AND TOTAL LOSSES BEFORE AND AFTER RECONFIGURATION FOR CSAE3

	Value of Leqv	Active power loss (MW)	Reactive power loss (MVar)	Total system loss (MVA)
Before configuration	0.0448	27.101	62.979	68.563
After reconfiguration	0.0351	24.672	47.416	53.450

The following graphs show changing of proposed indicator values for different configurations and variation of total system losses for different switching combinations for different cases.

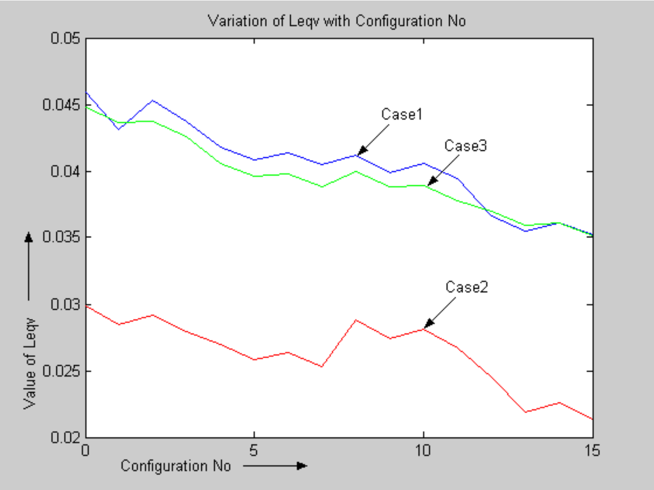

Fig. 3. Graph for variation of Leqv with different configurations

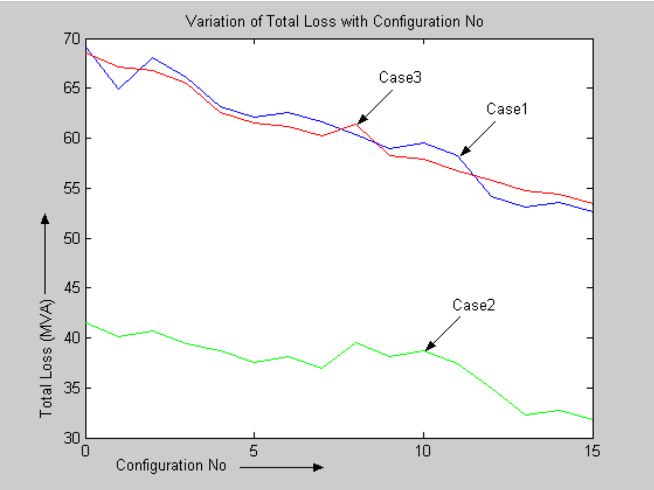

Fig. 4. Graph for variation of total loss with different configurations

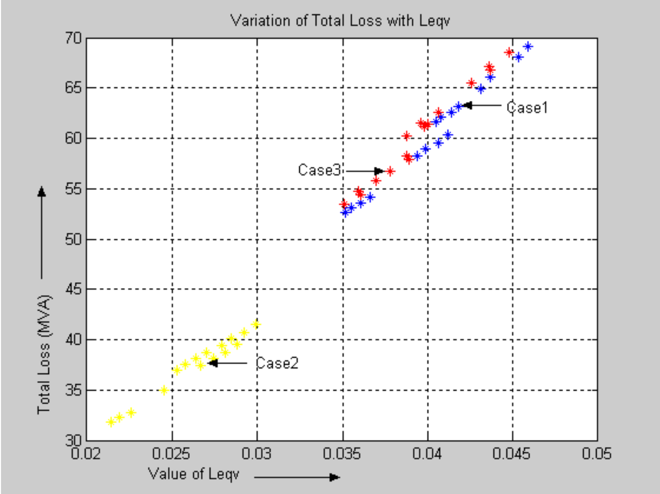

Fig. 5. Plot for variation of Total Loss with respect to Leqv

From all above results it could be observed that after reconfiguration both active and reactive power losses are reduced to considerable lower values. The proposed indicator values justify minimization of losses satisfactorily as they change proportional to system losses. It is seen from different case studies with random selection of load that configuration of network having switching status S1=1, S2=1, S3=1, S4=1 gives desired reconfiguration.

VII. CONCLUSION

In this paper a new voltage stability indicator has been derived from power flow equation of distribution system. Reconfiguration of a network is done here for minimization of active and reactive losses and improvement of voltage stability. It is clear from above discussions that there must be a switching option which can result best configuration for any loading and generation condition. The configuration which generates the minimum value of Equivalent indicator is considered to be the best voltage stable system. A relation between VSIeqv and system loss is presented here in which decreasing value of VSIeqv indicates reduction of active and reactive losses. So, efficient distribution system can be achieved reconfiguring the network using developed VSIeqv.

REFERENCES

[1] M. A.kashem, V. Ganapathy, and G. B. Jasmon, "A new approach of distribution system reconfiguration for loss minimization," *Elsevier (Electrical Power and System Research 22)*, 2000, pp. 269-276.

[2] C. K. Chanda, A. Chakraborti, and S. Dey, "Development of global voltage security indicator (VSI) and role of SVC on it in longitudinal power supply (LPS) system," *Elsevier (Electrical Power and System Research 68)*, 2004, pp.1-9.

[3] 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, pp. 539-550, 2005, copy right Taylor and Francis.

[4] C. K. Chanda and A. Chakrabarti et al, "Development of a Unique Network Equivalencing Technique for Determining Voltage Stable states in a Multi-bus Longitudinal Power System using Load Flow Analysis," *IE(I) Journal-EL*, vol. 85, pp. 196-202, March 2005.

[5] M. A. Kashem and Mahmoud Moghavveni, "Maximizing Radial Voltage Stability and Load Balancing via Loss Minimization in Distribution Networks," IEEE catalogue No: 98EX137, 0-7803-4495-2/98/ 1998 IEEE.

[6] T. K. Abdul and G. B. Jasmon, "A New Technique for Voltage Stability Analysis in a Power system and Improved Load Flow Algorithm for Distribution Network," IEEE Catalogue no 95TH8130.

[7] G. B. Jasmon and Lee, "Maximizing voltage stability in distribution networks via loss minimization," J. Electr. Power Energy System, 1991, pp. 148-152.

[8] M. A. kashem, V. Ganapathy and G. B. Jasmon, "Network Reconfiguration for enhancement of voltage stability in distribution systems," *IEE Proc.-Gener Trunsm Dislrib*., vol. 147, no. 3, May 2000.

[9] S. K. Goswami and S. K. Basu, "Direct solution of distribution systems," *IEE Proc. C*, vol. 138, no. 1, pp. 78-88, 1991.

[10] F. Gubina and B. Strmcnik, "A simple approach to voltage stability assessment in radial network," *IEEE Trans. on PS*, vol. 12, no. 3, pp. 1121-1128, 1997.

[11] M. E. Baran and F. F. Wu, "Network Reconfiguration in Distribution Systems for Loss Reduction and Load Balancing," *IEEE Transactions on Power Delivery*, vol. 4, no. 2, April, 1989.