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Simple and efficient method for steady-state voltage stability assessment of radial distribution systems

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ABSTRACT

A new static voltage stability index of a radial distribution system is proposed to faithfully evaluate the severity of the loading situation, thereby predicting for voltage instability at definite load value. The proposed index includes different parameters which affect the steady-state voltage stability of distribution systems, therefore it gives accurate results. The maximum value of 1 of that index denotes the point where the system reaches the point of collapse whereas a minimum value of 0 shows the state of no load. The performance of the new index was tested on two radial distribution systems consisting of 33 and 85 buses. Comparison between the results of the new index and those of previous indices showed that the new index yielded reliable results in predicting voltage stability condition of the system. The new index overcomes the problem which faces many previous indices especially as the load approaches the critical point. Analysis of the two-bus equivalents of the test systems under different scenarios is also presented. A new *P*–*Q* plane of stability is introduced based on the equation of the proposed index. The active, reactive and apparent power margins are then directly determined from the voltage stability boundary.

1. Introduction

Voltage stability is considered to be one of the keen interests of industry and research sectors around the world since the power system is being operated closer to the limit whereas the network expansion is restricted due to many reasons such as lack of investment or serious concerns on environmental problems [1]. Distribution systems experience distinct change from a low to high load levels every day. In certain industrial areas, it was observed that under certain critical loading conditions, the distribution systems may experience voltage collapse [2]. Radial distribution systems have low reactance to resistance ratio (X/R). This causes considerable IR and IX voltage drops in these systems which may lead to voltage collapse. Therefore, they are categorized as ill conditioned systems [3]. The voltage stability problem has been investigated for some years but most of the investigations analyzed the problem for high voltage transmission systems. The influence of loads at distribution level might therefore not to be fully taken care by these investigations. So far, the researchers and the industries have paid very little attention to analyze the voltage stability problem for a distribution system [4].

Refs. [3,5] introduced different steady-state voltage stability indices for indicating the state of radial distribution systems while the load is increased at a certain bus. These indices can be used by reducing the actual radial system into a two-bus equivalent system using the method derived in [6]. Whereas Ref. [2] introduced a voltage stability index which can be evaluated at each bus of the radial distribution system. The index is derived from load flow equations given in [7]. Computing the value of this index needs a load flow solution and determining of the line losses for each line in the system. Ref. [8] presented a criteria for voltage stability analysis in radial distribution systems by a geometrically form using the load flow equations. The feasibility and uniqueness properties of load flow (using Newton–Raphson method) were tested by the circle diagram of synchronous generator and Jacobian matrix. Reducing the system into a two-bus equivalent system is used for testing these properties. In [4] a voltage stability margin of radial distribution systems was presented. This method was used to determine the distance to voltage collapse point.

An analytical approach to voltage collapse proximity determination based on voltage phasors was presented in [9]. The actual system is reduced into a two-bus equivalent system then the maximum active and reactive powers were computed.

Voltage stability problem is mainly a load stability aspect; the load bus voltage relations attribute a special importance. Two-bus power system can represent satisfactory the load bus performance in all its situations encountered in practice [10,11].

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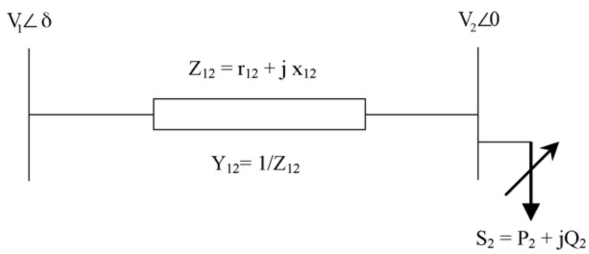

Fig. 1. Simple two-bus system.

The previous review showed that the existing indices need to be adjusted to include all parameters which contribute to voltage stability; therefore the problem which appears in the evaluation process especially as the load approaches the critical point can be solved.

This paper presents a new criterion (index) for more accurate evaluation of voltage stability in radial distribution systems. The proposed index is implemented for assessing the voltage stability in two distribution systems consisting of 33 and 85 buses. Through this paper the results obtained by applying the new proposed index were compared with those of two previous indices termed L_p and L which are introduced in Refs. [3,5], respectively. The equations of these two indices are given in Appendix A. Analysis of the two-bus equivalents of the studied systems with increasing the load at different buses with different power factors is also introduced.

A new method for evaluating the voltage stability limit is introduced based on the proposed index. This method gives the critical values of active and reactive power needed to plot the voltage stability boundary in the P–Q plane. This method enables powers engineers to determine and plot the critical active and reactive powers at any value of the power factors.

This paper is organized as follows: the next section describes the formulation of the new index. Then the generalization method which is used to implement the new index in N-bus distribution systems is introduced. The P–Q plane of stability is then presented. Details of the distribution test systems are presented before the results and discussion. Finally the conclusions of this paper are highlighted.

2. Formulation of the new index

A static voltage stability index is derived from Gauss–Seidel load flow equations, assuming that the radial distribution systems can be represented by their two-bus equivalent system. Line shunt capacitance is negligible which is valid with radial power distribution systems.

The equation of load flow using Gauss–Seidel method can be written as follows [12]:

$$V_i^{(k)} = \frac{1}{Y_{ii}}\left[\frac{P_{i,sch} - jQ_{i,sch}}{V_i^{*(k-1)}} - \sum_{j=1}^{i-1} Y_{ij}V_j^{(k)} - \sum_{j=i+1}^{N} Y_{ij}V_j^{(k-1)}\right] \quad (1)$$

Eq. (1) can be written for the two-bus system depicted in Fig. 1 as follows:

$$V_2 = \frac{1}{Y_{22}}\left[\frac{P_2 - jQ_2}{V_2^*} - Y_{12}V_1\right] \quad (2)$$

After some mathematical manipulation the following equation can be obtained:

$$V_2^2 - V_1V_2\cos\delta + \left[\frac{S_2}{Y_{22}}\cos(\theta+\varphi)\right] = 0 \quad (3)$$

where θ is the angle of Y_{22} and φ is the angle of the complex power (S_2).

Thus, the load voltage magnitude V_2 can be written as:

$$V_2 = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \quad (4)$$

Angle δ can be calculated from Eq. (5):

$$\delta = \cos^{-1}\left\{\frac{V_2^2 + (S_2/Y_{22})\cos(\theta+\varphi)}{V_1V_2}\right\} \quad (5)$$

Eq. (4) will give two values for V_2, the higher value of V_2 (V_2^H) is the stable voltage and the lower value of V_2 (V_2^L) is the unstable voltage. When the system operates within the voltage stability limit, the two values given by Eq. (4) are real and may be used to plot the conventional P–V curve of the system. As the load increases, the system will reach the critical point. At this point the values of (V_2^H) and (V_2^L) will be equal.

From Eq. (4), it can be observed that the system operates in the feasible operating region while the values of (V_2^H) and (V_2^L) are real positive, for such operation, the discriminant ($b^2 - 4ac$) of Eq. (4) is positive. While the load increases the value of (V_2^H) decreases and (V_2^L) increases until the two voltages reach critical point, at this point the value of the discriminant will be 0. For any load increase after this point the system collapses. In order to obtain real values of V_2 the following condition needs to be satisfied:

$$\left\{[V_1\cos\delta]^2 - \frac{4S_2}{Y_{22}}\cos(\theta+\varphi)\right\} \geq 0 \quad (6)$$

A new index is introduced based on this condition as follows:

$$L_v = \frac{[4S_2\cos(\theta+\varphi)]}{Y_{22}[V_1\cos\delta]^2} \quad (7)$$

where L_v is designated as the stability index that indicates the status of the system and approximately shows how close the operating point to the point of collapse. The voltage stability index L_v can be used to detect voltage stability in radial distribution systems. When the value of the index equals to 0 that means there is no load, and between 0 and 1 the system operates in the stable region and the values greater than 1 means that the system is unstable. As seen from Eq. (7) the value of the index depends on the load apparent power and power factor, also it depends on the value of the admittance of the line and the voltage at the sending end and its angle. The variables used in calculating this index combine several electrical quantities of the system, therefore it can be considered as a more representative of the system conditions and therefore its results will be more accurate as will be indicated.

3. Generalization of the proposed index for *n*-bus distribution systems

The three-phase radial distribution systems can be represented by their two-bus equivalent system and this is quite valid for 11 kV rural distribution feeders [7]. The method used to generalize the proposed index L_v depends on the reduction of the whole distribution system into an equivalent two-bus system by the two equations derived in [6], which compute the equivalent impedance of the line connecting the two buses as follows:

$$R_{eq} = \frac{P_{loss}}{(P_s^2 + Q_s^2)} \quad (8)$$

$$X_{eq} = \frac{Q_{loss}}{(P_s^2 + Q_s^2)} \quad (9)$$

where R_{eq}, X_{eq} are the equivalent resistance and reactance, P_{loss}, Q_{loss} are the total active and reactive power losses, and P_s, Q_s are the active and reactive power supplied to the whole system.

Table 1
Values of critical loading (kW) at different buses of the test systems.

Power factor	33-Bus system		85-Bus system	
	Bus 33	Bus 18	Bus 47	Bus 71
0.5	1290	710	1032	1252
0.7	1750	960	1365	1655
0.8	1990	1090	1532	1859
0.9	2270	1245	1710	2082

The radial distribution system will be reduced to an equivalent two-bus system similar to that shown in Fig. 1.

4. *P–Q* plane of stability

It is an established fact that the voltage collapse occurs when the system load (P and/or Q) increases beyond a certain limit. If the limiting values of P and Q are known, the voltage stability margin for a given operating point can directly be determined. This requires the plotting of voltage stability boundary of the system in P–Q plane using the limiting values of P and Q [13]. In this section, a new method for evaluating the values of the P and Q at the boundary of stability will be introduced. At the critical point, the value of L_v index equals to 1 and the following equation can be written as follows:

$$S_2^{cr} = \frac{Y_{22}(V_1 \cos\delta)^2}{4\cos(\theta+\varphi)} \tag{10}$$

Eq. (10) can be rewritten as follows:

$$P_2^2 + (P_2 \tan\varphi)^2 = \left[\frac{Y_{22}(V_1 \cos\delta)^2}{4\cos(\theta+\varphi)}\right]^2 \tag{11}$$

Then the active power at the critical point can be determined by the relation:

$$P_2^{cr} = \sqrt{\frac{1}{1+\tan^2\varphi}\left[\frac{Y_{22}(V_1 \cos\delta)^2}{4\cos(\theta+\varphi)}\right]^2} \tag{12}$$

Eq. (12) can be used to plot the voltage stability boundary at bus 2. Also; it can be used to compute the critical active and reactive power at any power factor. The voltage stability boundary in P–Q plane shows the relationship between the active and reactive power at the verge of voltage collapse.

5. Simulation results

5.1. *Implementation of the proposed index*

The effectiveness of the proposed index is tested on two radial distribution systems consisting of 33 and 85 buses which are presented in Refs. [14,7], respectively. First the power flow problems of the systems are solved for successively increased load condition at certain buses until the power flow algorithm fails to converge. The maximum load for which the power flow algorithm successfully converged is considered as the actual value of the critical load. Table 1 illustrates the critical loading for each bus at different power factors obtained from load flow solution of the two studied systems.

5.1.1. *The 33-bus system*

The 33-bus system used in this paper is depicted in Fig. 2. It is a balanced three-phase system that consists of 33 bus and 32 segments, operating at 11 kV voltage level. It is assumed that all the loads are fed from the substation located at bus 1. The system has 32 loads totalling 3.72 MW and 2.29 MVAr, real and reactive power loads, respectively. Table B1 in the Appendix B illustrates the lines and load data for this system. The simulation will be conducted on two buses of this system, bus 33 and bus 18.

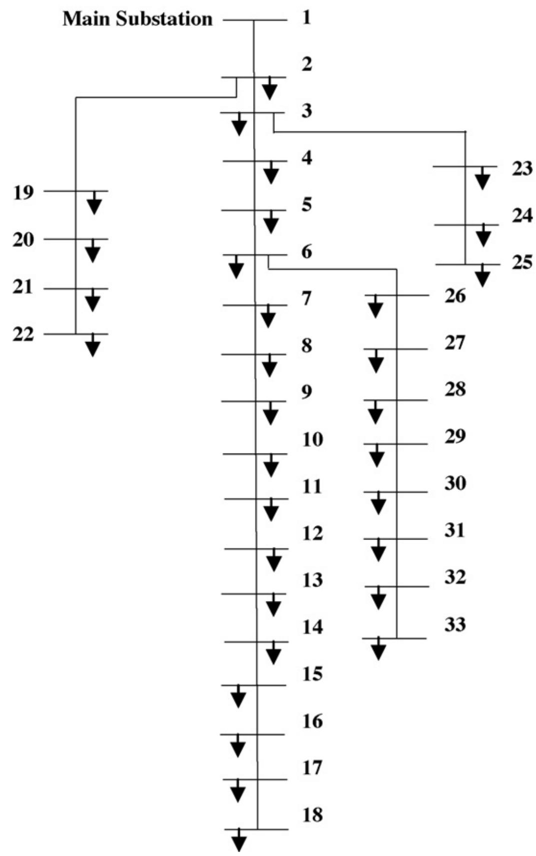

Fig. 2. 33-Bus distribution system.

A. *Increasing the load at bus 33*

The load at bus 33 is gradually increased from 100 kW in steps of 100 kW each at different power factors (0.5 and 0.8), while the loads at the other buses are maintained constant. The total active and reactive power load P_t and Q_t (sum of the individual loads at all buses in the whole system) will be changed according to the load increase at bus 33. The three indices (L_v, L and L_p) are calculated at each value of the total active and reactive power load and plotted versus the total active power (P_t) in p.u. (on 3.72 MW base power). Fig. 3 shows the variation of the three indices with the increase in total active power load (P_t) of the system at 0.5 and 0.8 power factors at bus 33. It can be seen that as the load at bus 33 increases the values of the three indices (L_v, L and L_p) increase. At the point of collapse, the proposed index gives more accurate value than those of the two indices (L and L_p) for all studied power factors when it compared to the critical values computed by load flow solution. Where L_p index gives a value less than 1 at 0.5 power factor lagging and a value larger than 1 at 0.8 power factor lagging. L index gives a value less than 1 at the point of collapse at all studied power factors.

B. *Increasing the load at bus 18*

The load at bus 18 is gradually increased with the same manner as in the previous section but for 0.7 and 0.9 power factors. The results are shown in Fig. 4. As seen from the results as the load

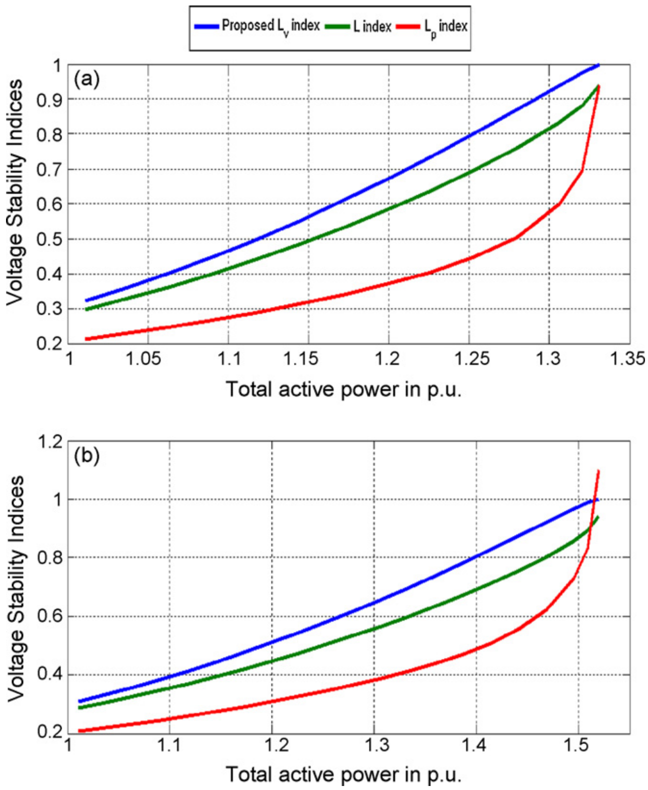

Fig. 3. Voltage stability indices with total active power increases at bus 33: (a) with 0.5 p.f. lagging, (b) with 0.8 p.f. lagging.

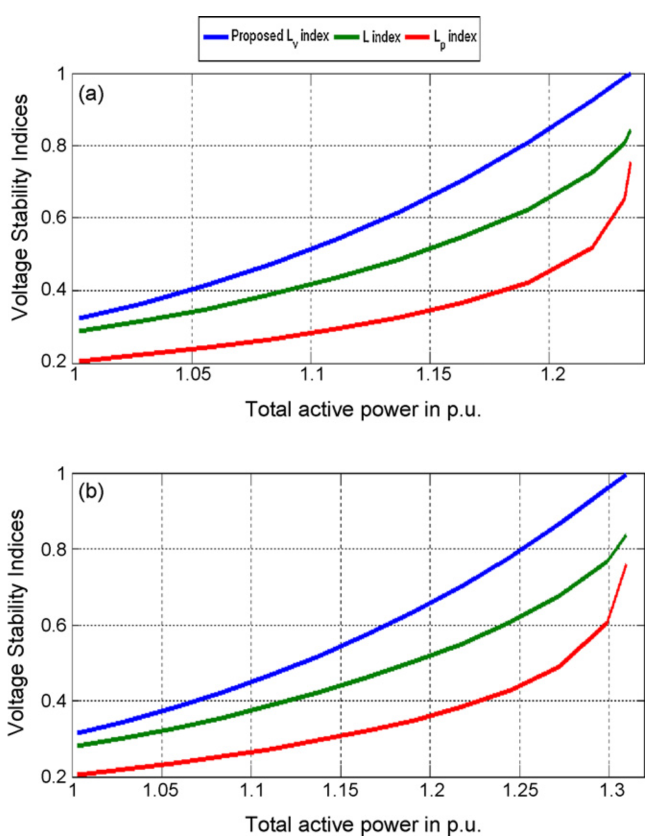

Fig. 4. Voltage stability indices with total active power increases at bus 18: (a) with 0.7 p.f. lagging, (b) with 0.9 p.f. lagging.

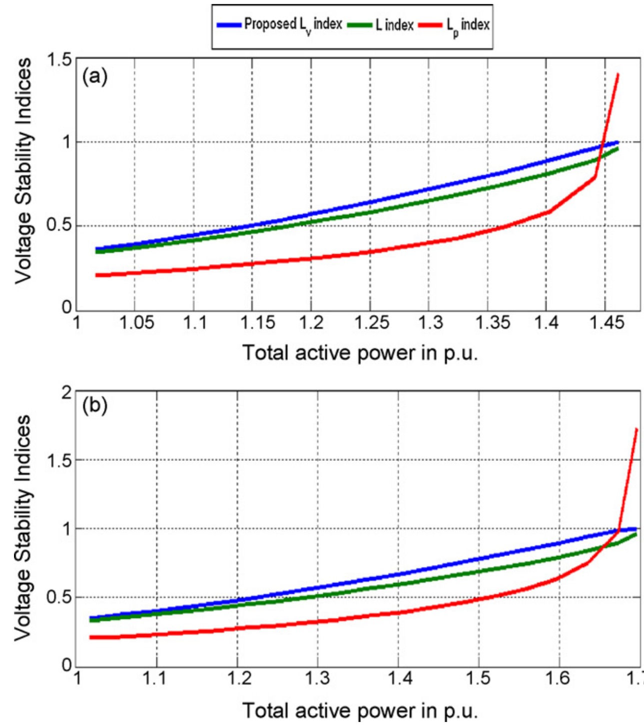

Fig. 5. Voltage stability indices with total active power increase at bus 71: (a) with 0.5 p.f. lagging, (b) with 0.8 p.f. lagging.

increases at different power factors at bus 18 the L_v index gives more accurate values which showing a good agreement with those values obtained by load flow solution. L_p and L indices give low values than those given by L_v index at different power factors.

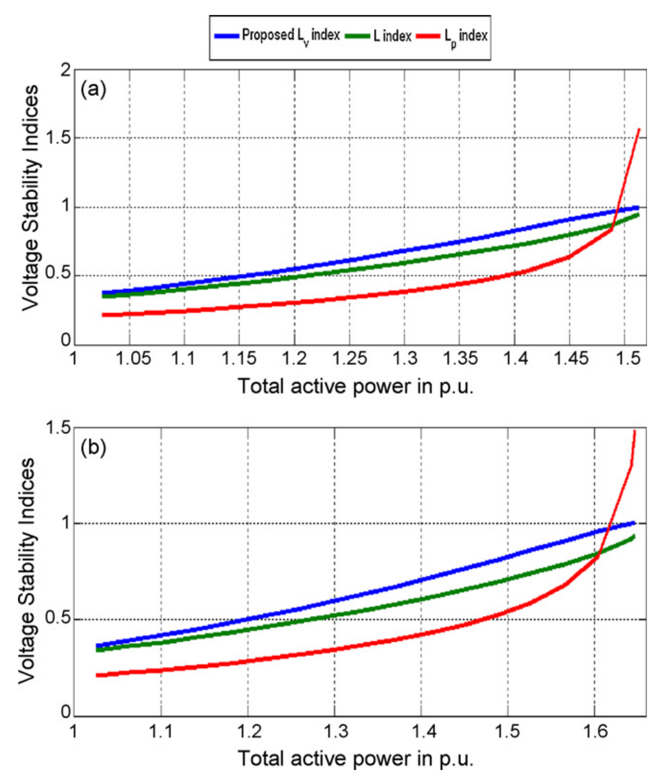

Fig. 6. Voltage stability indices with total active power increase at bus 47: (a) with 0.7 p.f. lagging, (b) with 0.9 p.f. lagging.

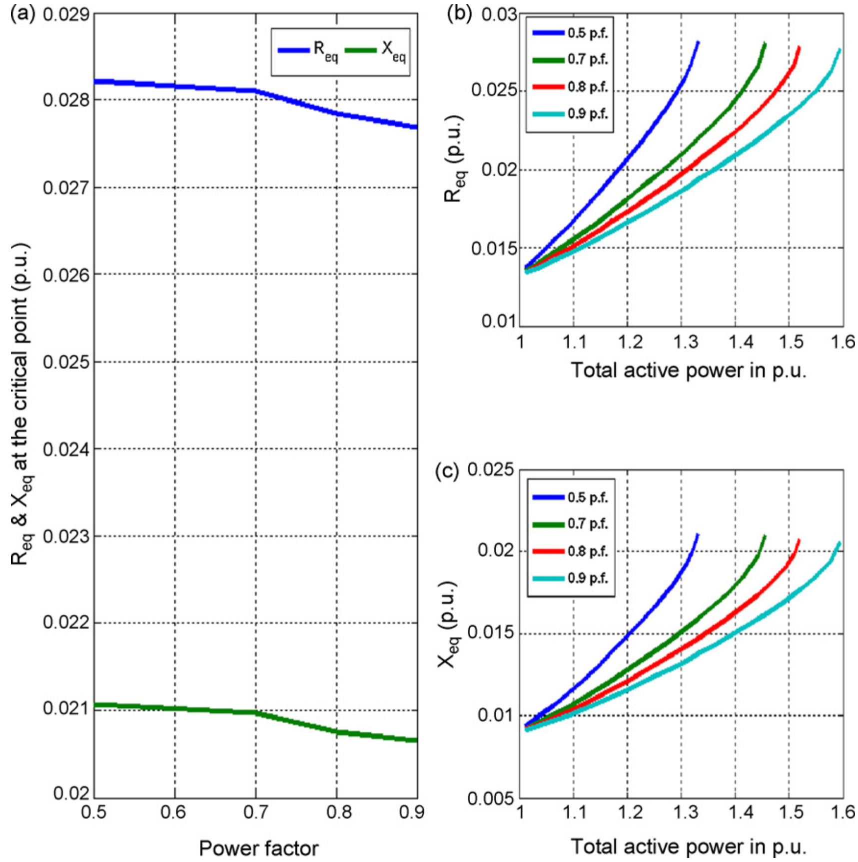

Fig. 7. Variation of R_{eq} and X_{eq} of the system with the load increases at bus 33: (a) R_{eq} and X_{eq} at the critical point at different power factors. (b) R_{eq} variation with total load increases at different power factors. (c) X_{eq} variation with total load increases at different power factors.

5.1.2. *The 85-bus system*

The 85-bus system is a balanced three-phase system that consists of 85 bus and 84 segments, operating at 11 kV voltage level. The system has 59 loads totalling 2.59 MW and 2.64 MVAr, real and reactive power loads, respectively. Table B2 in the Appendix B illustrates the lines and load data for this system.

A. *Increasing the load at bus 71*

The load at bus 71 is gradually increased from 100 kW in steps of 100 kW each at different power factors (0.5 and 0.8), while the loads at the other buses are maintained constant. The three indices L_v, L and L_p are calculated at each value of the total active and reactive power load and plotted versus the total active power (P_t) in p.u. (on 2.59 MW base power). Fig. 5 shows the variation of the three indices with the increase in total active power load (P_t) of the system at different values for the power factor. From these results it can be seen that the results obtained by using the proposed index matching with those obtained by load flow solution. The results obtained by using L_p index having an error especially at the point of collapse (critical point). Whereas L index gives low values than those of the proposed index at different power factors.

B. *Increasing the load at bus 47*

The load at bus 47 is increased from the base case while the loads at other buses are maintained constant. The three indices are evaluated at each load and the results obtained at each power factor (0.7 and 0.9) are shown in Fig. 6. It can be seen that the proposed index still gives more accurate results than those of the two previous indices.

5.2. *Analysis of the two-bus equivalents of the studied systems*

5.2.1. *The 33-bus system*

To obtain accurate results from the new index different equivalent two-bus system should be considered. That is because each value represents the current operating point. Also from this variation, the voltage stability phenomenon can be understood. Fig. 7(b) and (c) show the variation of R_{eq} and X_{eq} with the variation in total active power in p.u. (on 3.72 MW base) according to the load increase at bus 33 at different power factors. Fig. 7(a) shows the values of the R_{eq} and X_{eq} at the critical values at different power factors. It can be observed that the values of the R_{eq} and X_{eq} are approximately constant at the critical point while the load is increased at bus 33. From these results it can be observed that the voltage stability can be assessed while the load increase at bus 33 by evaluating the value of R_{eq} or X_{eq} of the system without considering the power factor of the load.

5.2.2. *The 85-bus system*

The variation of R_{eq} and X_{eq} with increasing the load at bus 71 of 85-bus system at different power factors are shown in Fig. 8(b) and (c). Fig. 8(a) shows the values of R_{eq} and X_{eq} at the critical loading at different power factors. It can be seen that the values of R_{eq} and X_{eq} are constant at different power factors. This means that the system will reach the point of collapse while the R_{eq} and X_{eq} reach a certain value while the load increases at bus 71.

5.3. *P–Q plane of stability results*

The proposed method for finding the voltage stability limit using the *P–Q* curve has been tested on the simple system of Fig. 1. The

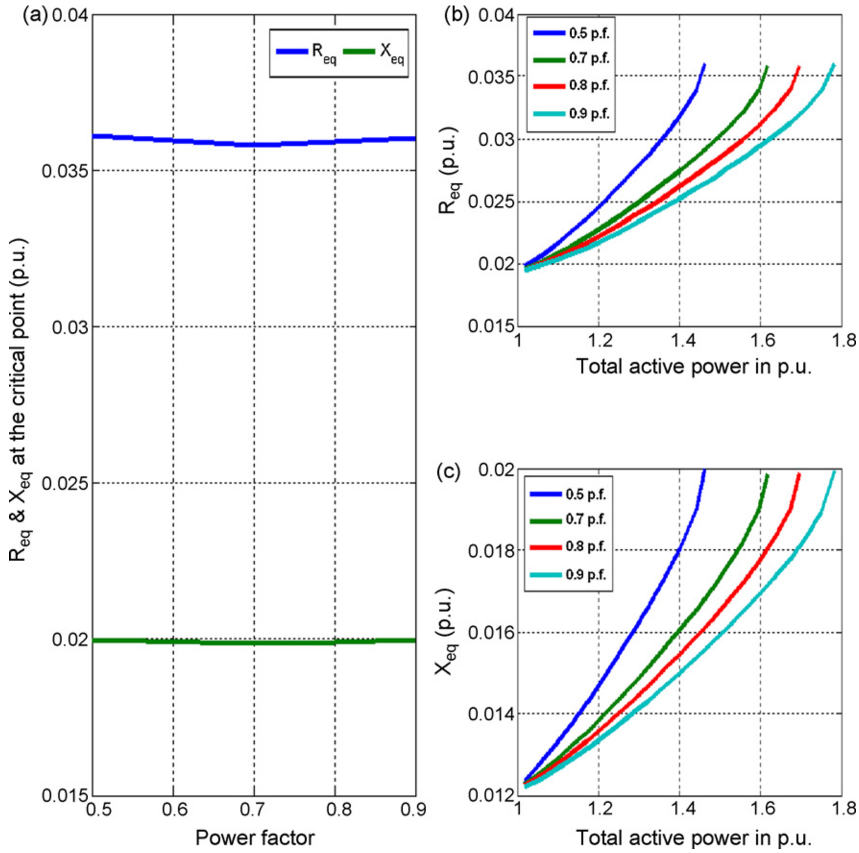

Fig. 8. Variation of R_{eq} and X_{eq} of the system with the load increases at bus 71: (a) R_{eq} and X_{eq} at the critical point at different power factors. (b) R_{eq} variation with total load increases at different power factors. (c) X_{eq} variation with total load increases at different power factors.

values of $r = 0.014027868$ p.u., $x = 0.01012377$ p.u. and $V_1 = 1$ p.u. on a base of 1 MVA, 11 kV. It can be seen that computing of the value of angle δ is a time consuming so that the values of the angle δ at 0 power factor, and at unity power factor are determined and between the two values the angle δ is estimated. Fig. 9 shows the variation of load reactive power against the load active power at the critical point. The region above the curve is considered to be an impossible operating region. The region below the curve is considered to be a normal operating region. The critical values of active and reactive power are plotted against the power factor in Fig. 10. For a given power factor, the maximum or critical load at the voltage collapse point can be determined from the point of intersection of the power factor line with the active or reactive power curves.

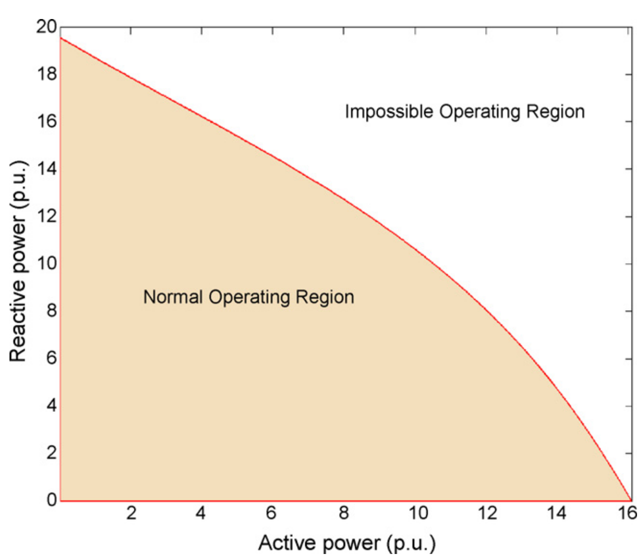

Fig. 9. P–Q plane of stability of the two-bus system.

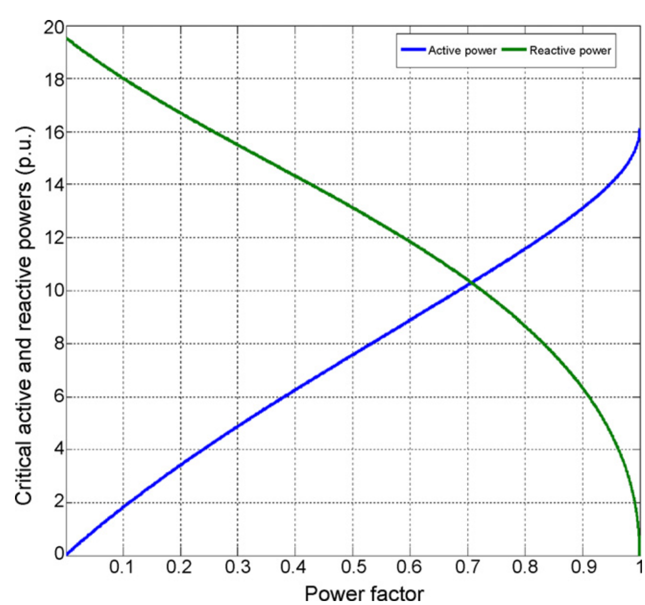

Fig. 10. Variation of critical active and reactive power with power factor of the two-bus system.

6. Conclusions

A simple and new voltage stability index of radial distribution system is proposed for assessing the stability of a certain loading condition. The effectiveness of the proposed index is tested on two relatively large distribution systems. The results of the proposed index are then compared with the actual values obtained from load flow and are found to be in a very good agreement. Then the results are compared with two previous indices and are found to be more accurate. For each loading condition for the studied system, different equivalent two-bus system should be considered. Taking fixed two-bus system for all loading conditions would not give accurate results. Improving the power factor at certain bus would increase system loadability, the equivalent two-bus system changes slightly in this case. A new method for determining the voltage stability limit using the *P*–*Q* plane is presented. In that method the boundary of the voltage stability region is first determined and then it is presented in the *P*–*Q* plane. The proposed method was tested on a simple two-bus system. The results of this method are easy to obtain and can give quick overview on the system voltage instability.

Appendix A.

A.1. L_p index [3]:

For the two-bus system shown in Fig. A1 the L_p index can be defined as follows:

$$L_p = \frac{4rP_r}{\{[V_s \cos(\theta-\delta)]^2\}} \quad \text{(A.1)}$$

$L_p = 0$, describes that no load at bus under study, and the case $L_p = 1$, describes that the system operates at the critical point and any value of L_p more than 1 means the system is unstable. The values of L_p between 0 and 1 describes the states of the system between the no load case and the critical point.

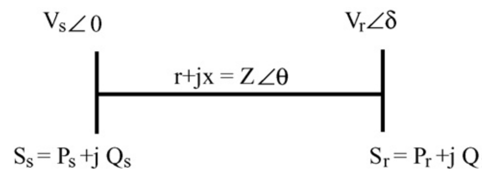

Fig. A1. Two-bus system.

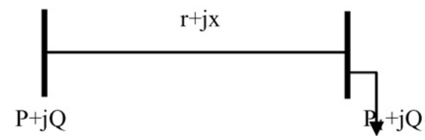

Fig. A2. Simple two-bus system.

A.2. L index [5]:

For the two-bus system shown in Fig. A2 the *L* index can be defined as follows:

$$L = 4\,((xP_1 - rQ_1)^2 + xQ_1 + rP_1) \quad \text{(A.2)}$$

When the value of *L* reaches 1 the system reaches the critical point, the value of *L* larger than 1 describe an unstable system.

Appendix B.

See Tables B1 and B2 .

Table B1
Data for 33-bus distribution system.

Line number	Sending bus	Receiving bus	Resistance (Ω)	Reactance (Ω)	Load at receiving end bus	
					Active power (kW)	Reactive power (kVAr)
1	1	2	0.0922	0.0477	100.0	60.0
2	2	3	0.4930	0.2511	90.00	40.00
3	3	4	0.3660	0.1864	120.0	80.00
4	4	5	0.3811	0.1941	60.00	30.00
5	5	6	0.8190	0.7070	60.00	20.00
6	6	7	0.1872	0.6188	200.0	100.0
7	7	8	1.7114	1.2351	200.0	100.0
8	8	9	1.0300	0.7400	60.00	20.00
9	9	10	1.0400	0.7400	60.00	20.00
10	10	11	0.1966	0.0650	45.00	30.00
11	11	12	0.3744	0.1238	60.00	35.00
12	12	13	1.4680	1.1550	60.00	35.00
13	13	14	0.5416	0.7129	120.0	80.00
14	14	15	0.5910	0.5260	60.00	10.00
15	15	16	0.7463	0.5450	60.00	20.00
16	16	17	1.2890	1.7210	60.00	20.00
17	17	18	0.7320	0.5740	90.00	40.00
18	2	19	0.1640	0.1565	90.00	40.00
19	19	20	1.5042	1.3554	90.00	40.00
20	20	21	0.4095	0.4784	90.00	40.00
21	21	22	0.7089	0.9373	90.00	40.00
22	3	23	0.4512	0.3083	90.00	50.00
23	23	24	0.8980	0.7091	420.0	200.0
24	24	25	0.8960	0.7011	420.0	200.0
25	6	26	0.2030	0.1034	60.00	25.00
26	26	27	0.2842	0.1447	60.00	25.00
27	27	28	1.0590	0.9337	60.00	20.00
28	28	29	0.8042	0.7006	120.0	70.00
29	29	30	0.5075	0.2585	200.0	600.0
30	30	31	0.9744	0.9630	150.0	70.00
31	31	32	0.3105	0.3619	210.0	100.0
32	32	33	0.3410	0.5302	60.00	40.00

Table B2
Data for 85-bus distribution system.

Line number	Sending bus	Receiving bus	Resistance (Ω)	Reactance (Ω)	kVA at receiving bus
1	1	2	0.108	0.075	0.000
2	2	3	0.163	0.112	0.000
3	3	4	0.217	0.149	56.00
4	4	5	0.108	0.074	0.000
5	5	6	0.435	0.298	0.000
6	6	7	0.272	0.186	0.000
7	7	8	1.197	0.820	35.28
8	8	9	0.108	0.074	0.000
9	9	10	0.598	0.410	0.000
10	10	11	0.544	0.373	56.00
11	11	12	0.544	0.373	0.000
12	12	13	0.598	0.410	0.000
13	13	14	0.272	0.186	35.28
14	14	15	0.326	0.223	35.28
15	2	16	0.728	0.302	35.28
16	3	17	0.455	0.189	112.0
17	5	18	0.820	0.340	56.00
18	18	19	0.637	0.264	56.00
19	19	20	0.455	0.189	35.28
20	20	21	0.819	0.340	35.28
21	2	22	1.548	0.642	35.28
22	19	23	0.182	0.075	56.00
23	7	24	0.910	0.378	35.28
24	8	25	0.455	0.189	35.28
25	25	26	0.364	0.151	56.00
26	26	27	0.546	0.226	0.000
27	27	28	0.273	0.113	56.00
28	28	29	0.546	0.226	0.000
29	29	30	0.546	0.226	35.28
30	30	31	0.273	0.113	35.28
31	31	32	0.182	0.075	0.000
32	32	33	0.182	0.075	14.00
33	33	34	0.819	0.340	0.000
34	34	35	0.637	0.264	0.000
35	35	36	0.182	0.075	35.28
36	26	37	0.364	0.151	56.00
37	27	38	1.002	0.416	56.00
38	29	39	0.546	0.226	56.00
39	32	40	0.455	0.189	35.28
40	40	41	1.002	0.416	0.000
41	41	42	0.273	0.113	35.28
42	41	43	0.455	0.189	35.28
43	34	44	1.002	0.416	35.28
44	44	45	0.911	0.378	35.28
45	45	46	0.911	0.378	35.28
46	46	47	0.546	0.226	14.00
47	35	48	0.637	0.264	0.000
48	48	49	0.182	0.075	0.000
49	49	50	0.364	0.151	36.28
50	50	51	0.455	0.189	56.00
51	48	52	1.366	0.567	0.000
52	52	53	0.455	0.189	35.28
53	53	54	0.546	0.226	56.00
54	52	55	0.546	0.226	56.00
55	49	56	0.546	0.226	14.00
56	9	57	0.273	0.113	56.00
57	57	58	0.819	0.340	0.000
58	58	59	0.182	0.075	56.00
59	58	60	0.546	0.226	56.00
60	60	61	0.728	0.302	56.00
61	61	62	1.002	0.415	56.00
62	60	63	0.182	0.075	14.00
63	63	64	0.728	0.302	0.000
64	64	65	0.182	0.075	0.000
65	65	66	0.182	0.075	56.00
66	64	67	0.455	0.189	0.000
67	67	68	0.910	0.378	0.000
68	68	69	1.092	0.453	56.00
69	69	70	0.455	0.189	0.000
70	70	71	0.546	0.226	35.28
71	67	72	0.182	0.075	56.00
72	68	73	1.184	0.491	0.000
73	73	74	0.273	0.113	56.00
74	73	75	1.002	0.416	35.28
75	70	76	0.546	0.226	56.00
76	65	77	0.091	0.037	14.00

Table B2 (*Continued*)

Line number	Sending bus	Receiving bus	Resistance (Ω)	Reactance (Ω)	kVA at receiving bus
77	10	78	0.637	0.264	56.00
78	67	79	0.546	0.226	35.28
79	12	80	0.728	0.302	56.00
80	80	81	0.364	0.151	0.000
81	81	82	0.091	0.037	56.00
82	81	83	1.092	0.453	35.28
83	83	84	1.002	0.340	14.00
84	13	85	0.819	0.340	35.28

Power factor of all loads is taken as p.f. = 0.7 lagging.

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