Methods for Preventing Voltage Collapse

Cláudia Reis[1], António Andrade[2], and F. P. Maciel Barbosa[3]

[1]Telecommunications Institute of Aveiro University, University Campus of Aveiro, Portugal
creis@av.it.pt
[2] Institute of Engineering of Porto, R: Dr. António Bernardino de Almeida, Portugal
ata@isep.ipp.pt
[3] Faculty of Engineering of Porto University, R: Dr. Roberto Frias, Portugal
fmb@fe.up.pt

Abstract

The condition of voltage stability in a power system can be characterized by the use of voltage stability indices.
The voltage stability analyses were conducted on the IEEE 14 and IEEE 57 reliability test system, using several different scenarios of load increase.
In this paper, a comparison of the performance of several indices is presented, with satisfactory results.
In this paper will also present New Index to Voltage Collapse (NIVCP). NIVCP is a system index and see the all power system.

1. Introduction

Electrical power systems are operating under heavily loaded conditions due to various economic, environmental and regulatory changes. So with the increased loading and exploitation of the power transmission system, the problem of voltage stability and voltage collapse has been attracting more attention and maintaining voltage stability has become a growing concern for electric power utilities [1,2].

Voltage stability is concerned with the ability of a electrical power system to maintain acceptable voltages at all buses of the system after being subjected to a disturbance from a given initial operation condition [3]. Therefore, a power system is said to have a situation of voltage instability when a disturbance causes a progressive and uncontrollable decrease in voltage level.

The development and use of accurate methods to predict incipient voltage instability is crucial in preventing such voltage collapse situations.

This paper investigates the effectiveness of five voltage stability indices known in the literature and they are computed for standard test power systems, under increasing reactive power conditions [4].

The value of voltage stability indices usually changes between 0 (no load) and 1 (voltage collapse).

The voltage stability indices will be tested on IEEE 14, and IEEE 57 busbar test system, and the results obtained will be compared and discussed.

2. Indices Formulation

In order to reveal the critical bus and to determine the point of collapse for detecting and predicting voltage collapse of an electrical power system, several stability indices have been proposed.

The indices used to examine the system stability are briefly described in this section.

2.1. Local load margin index

The local load margin index (P_{Lmg}) is based on the distance from the base case (P_{0i}, MW) to the point of voltage collapse (P_{CRi}, MW):

$$P_{Lmg} = \frac{P_{CRi} - P_{0i}}{P_{CRi}} \tag{1}$$

where P_{0i} is the active power at the base case of bus i and P_{CRi} is the maximum power transmitted in the node i.

The equation 1 indicates the local load margin for the PQ busbar. The local load margin index, P_{Lmg}, presents a value between 0 (voltage collapse) and 1 (no load).

2.2. L Index

Kessel *et al*. [5] developed a voltage stability index based on the solution of the power flow equations. The L index is a quantitative measure for the estimation of the distance of the actual state of the system to the stability limit.

The L index describes the stability of the complete system and is given by:

$$L = \max_{j \in \alpha_L} \{L_J\} = \max_{j \in \alpha_L} \left| 1 - \frac{\sum_{i \in \alpha_G} \underline{F}_{ji} \underline{V}_i}{\underline{V}_j} \right| \tag{2}$$

where α_L is the set of consumer nodes and α_G is the set of generator nodes.

L_j is a local indicator that determinates the busbar from where collapse may originate. The L index varies in a range between 0 (no load) and 1 (voltage collapse).

2.3. $\partial Q_i / \partial V_i$ Index

The power flow (PF) model [6] used is represented by equation

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = J \begin{bmatrix} \Delta \theta \\ \Delta V / V \end{bmatrix} \qquad (3)$$

where:

$$J = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \qquad (4)$$

is the jacobian matrix, J_{11} stands for the partial derivatives of the active power equation in relation to the phase angle, and J_{12} represents the multiplication of the partial derivatives of the active power equation in relation to the voltage level by the voltage level. J_{21} is the submatrix with the partial derivatives of the reactive power equation in relation to the phase angle, and J_{22} contains the multiplication of the partial derivatives of the reactive power equation in relation to voltage level by the voltage level.

2.4. P-V Curves

The P-V curves are used to determine the loading margin of a power system. To calculated P-V curves, the power system load is gradually increased and, at each increment, is necessary recompute power flows until the nose of the PV curve is reached. The margin between the voltage collapse point and the current operating point is used as voltage stability criterion [7].

2.5. NIVCP Index

António Andrade *et al.* [8-11] developed a New Index to Voltage Collapse Point (NIVCP). This new index is based on a new method for detecting the point of collapse FSQV - Full Sum $\partial Q_i / \partial V_i$ (diagonal elements).

The FSQV is calculated as:

$$FSQV = \sum_{i=1}^{n} \partial Q_i / \partial V_i \qquad (5)$$

where n is the number of buses of system.

The initial NIVCP value (corresponds to base case load) is zero and the final point NIVCP (correspond to the last FSQV point, until matrix J becomes singular) is 100 and a percentage of MLP.

3. Test Results and Discussion

The voltage stability analysis was performed on IEEE 14 busbar test system. This system has 5 generator busbars, 9 load busbars and 20 interconnected branches.

Figure 1 presents the values of the local load margin index, P_{Lmg}, for all PQ busbar of the IEEE 14 test system. To determine this index it was necessary draw P-V curves for each PQ busbar of this system.

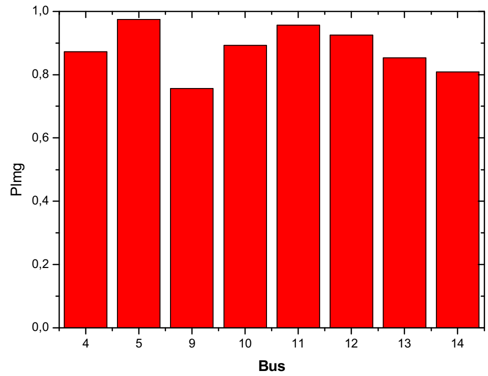

Fig. 1 Local load margin index for IEEE 14 busbar test system

As we can see in figure 1, the critical busbar of the IEEE 14 test system are the ones that present lower values of local load margin indices, such as bus 9 and bus 14.

Figure 2 shows the values of the local index L_j in the IEEE 14 busbar test system.

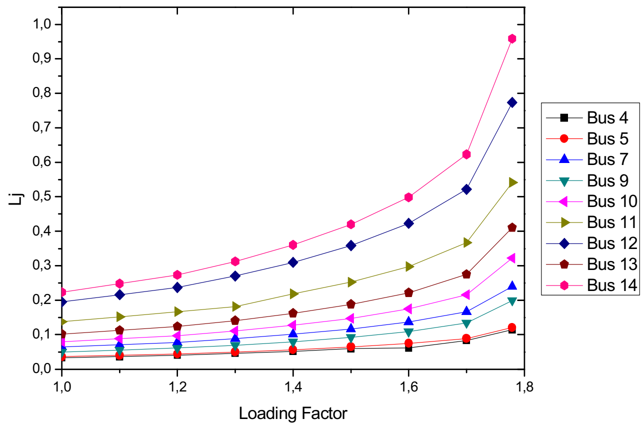

Fig. 2 Evaluation of L_j index versus load variation for IEEE 14 busbar test system

It can be seen that bus 14 exhibits the highest L_j index, which indicates that it is the most vulnerable bus on the system.

In Figure 3, L index and the voltage at bus 14 are plotted as a function of loading factor.

In the critical operating point L=0,958, so the voltage stability of this system is guaranteed. The stability limit is reached for L=1.

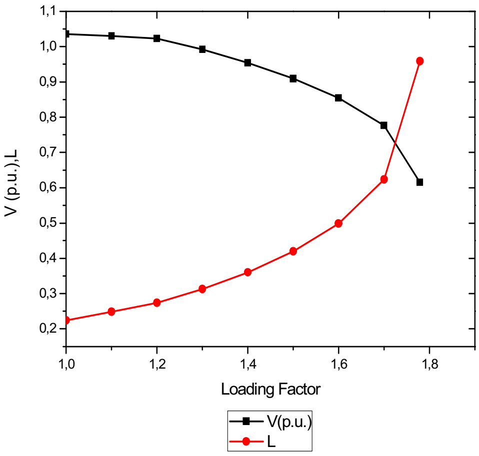

Fig. 3 Stability indicator L and its relation to the critical voltage of IEEE 14 busbar test system

The Jacobian submatriz J_{22} contains the multiplication of the partial derivatives of the reactive power equation in relation to voltage level bus by the voltage level bus. The diagonal elements $V_i\,\partial Q_i / \partial V_i$ are used to calculate $\partial Q_i / \partial V_i$ and to identify the critical bus. The first collapsed busbar have a smaller value. In Table I the critical busbar of IEEE 14 test system are identified using $\partial Q_i / \partial V_i$ index.

Table I - $\partial Q_i / \partial V_i$ Index for IEEE 14 test system

Bus	$\partial Q_i / \partial V_i$	Voltage (p.u.)
14	3,2	0,63
12	3,7	0,69
8	4,8	0,78
11	5,8	0,69
13	7	0,67

P-V curves show the bus voltage level as the loading factor λ increases.

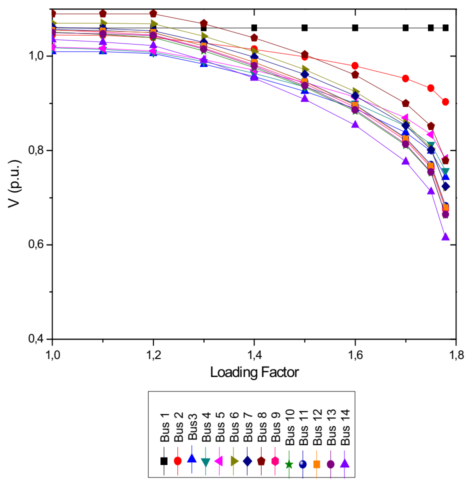

Fig. 4 P-V Curves for IEEE 14 busbar test system

Each point on the PV curves, shown in Figure 4, was obtained from load flow solution, using the conventional Newton-Raphson method.

As shown in Figure 4, the voltage stability margin of the IEEE 14 busbar test system is approximated 77,9%.

These tests were also carried out for IEEE 57 busbar test system.

The IEEE 57 busbar test system has 7 generator busbar, 50 load busbar and 80 interconnected branches.

For IEEE 57 busbar test system we also draw the P-V curves for each PQ busbar of the system and then we used the equation 1 to calculate the local load margin index.

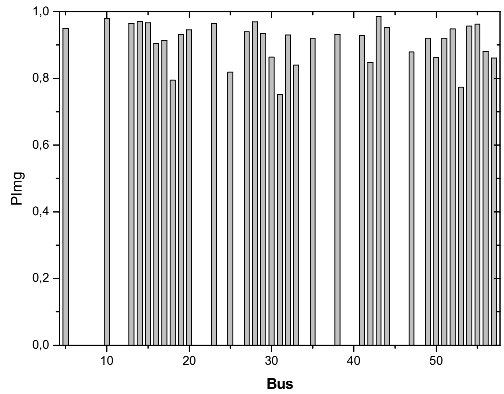

Fig. 5 Local load margin index for IEEE 57 busbar test system

As we can see in figure 5, bus 31 has the lowest value so it is the critical bus of the IEEE 57 busbar test system.

Table II shows the smaller $\partial Q_i / \partial V_i$ values and the voltage values until the power flow jacobian is singular for the IEEE 57 busbar system.

Table II - $\partial Q_i / \partial V_i$ Index for IEEE 57 test system

Bus	$\partial Q_i / \partial V_i$	Voltage (p.u.)
31	1,1526	0,5297
19	2,029	0,778
20	2,1792	0,7566
57	2,3095	0,6922
30	2,8031	0,5891
42	2,8882	0,7104

As we can see in Table II, the first bus that collapse is bus 31 because it has a smallest value. So bus 31 is the weakest bus of the IEEE 57 busbar test system.

The voltage stability margin of the IEEE 57 busbar system was calculated with P-V curves, as it can be seen in Figure 6.

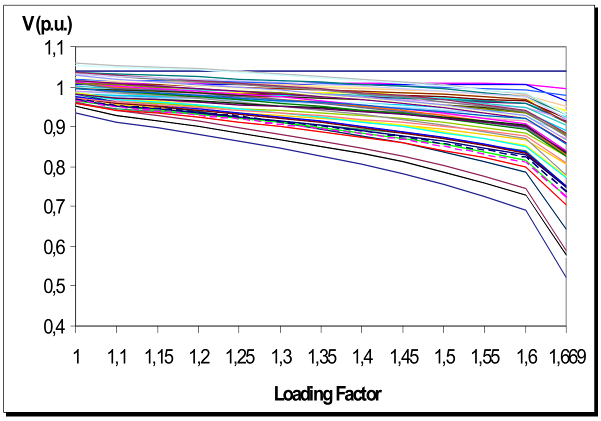

Fig. 6 P-V Curves for IEEE 57 busbar test system

Figure 6 shows that when the load was increased gradually, the voltages at all busbars decreased and it was observed that node 31 had the minimum voltage. Therefore, node 31 is more sensitive to voltage collapse.

The voltage stability margin of this system is approximated 66,9%.

Simulations with a constant loading factor (0.001) to increment the load and to calculate the FSQV values were made. Each bus system have characteristic FSQV values, initial and final (see table III).

The FSQV curves for IEEE 14 and 57 bus system are different and are presented in figures 7 and 8. In figures 7 and 8, point A corresponds to the Maximum Load Point (MLP), i. e. in these points jacobian matrix becomes singular and so corresponds to the voltage collapse points too.

TABLE III
THE FSQV VALUES

IEEE system	Initial	Final
14 bus	255.72	193.36
57 bus	1467.1	1213.8

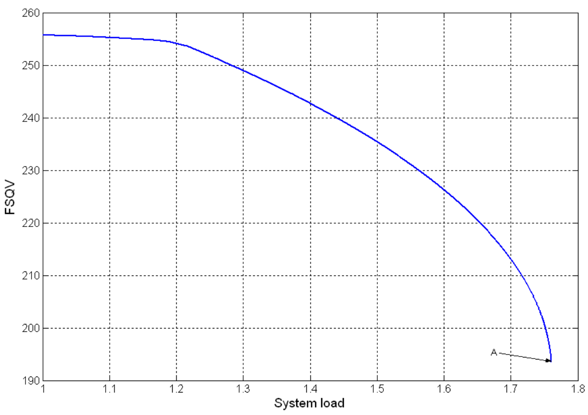

Fig. 7 FSQV curve for IEEE 14 bus system

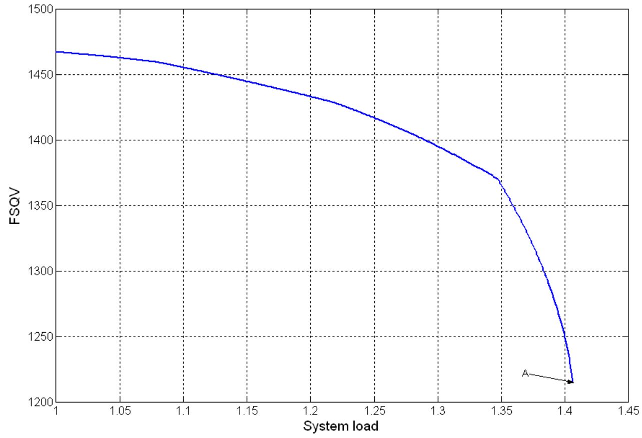

Fig. 8 FSQV curve for IEEE 57 bus system

The NIVCP for voltage collapse prevention control in power systems is presented in figure 9.

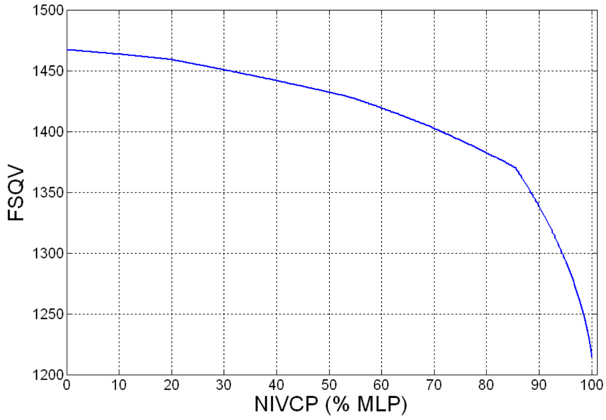

Fig. 9 – NIVCP curve for IEEE 57 bus system

4. Conclusions

The simulation results on IEEE 14 and IEEE 57 busbar test systems demonstrate the feasibility and effectiveness of the voltage stability indices.

The application of those indices gave accurate results and revealed the weakest bus of IEEE 14 and IEEE 57 power systems. The research showed an agreement between the different voltage stability indices.

We also concluded that taking in account FSQV values it is possible to use NIVCP index for voltage collapse prevention control in power systems. NIVCP index allows to know the distance to the MLP. At any time, knowing the FSQV values of a power system is possible to calculate the percentage and is even possible to increase the load.

5. References

[1] D.B. Bedoya, C.A. Castro, L.C.P. da Silva "A Method for Computing Minimum Voltage Stability Margins of Power Systems", Transm. Distrib., Vol. 2, No. 5, pp. 676–689, 2008.

[2] G. Y. Wu, C.Y. Chung, K. P. Wong, C. W. Yu "Voltage Stability Constrained Optimal Dispatch in Deregulated

Power Systems", IET Generation, Transmission & Distribution, Vol. 1, pp. 761-768, February 2007.
[3] IEEE/CIGRE Joint Task Force Report "Definition and Classification of Power System Stability", IEEE Trans. On Power Systems, Vol.19, No.2, pp. 1387-1401, May 2004.
[4] C. Reis, F.M. Barbosa "A Comparison of Voltage Stability Indices", 13th IEEE Mediterranean Electrotechnical Conference – Melecon2006, Málaga, Espanha, pp. 1007-1010, May 2006.
[5] P.Kessel, H.Glavitsch "Estimating the Voltage Stability of a Power System" IEEE, Transactions on Power Delivery, Vol.PWRD-1, N3, July 1986.
[6] J. J. Grainger and W. D. Stevenson, "Power System Analysis", New York, McGraw-Hill, 1994.
[7] Claudio Canizares "Voltage Stability Assessment: Concepts, Practices and Tools" IEEE/PES Power System Stability Subcommittee Special Publication, August 2002.
[8] António C. Andrade and F. P. Maciel Barbosa, "Voltage Collapse Preventive Control – A New Method", Melecon 2004 – The 12th Mediterranean Electro. Conf., Dubrovnik, Croatia, May 2004.
[9] António C. Andrade and F. P. Maciel Barbosa, "Voltage Collapse Preventive Control – A New Method and Tools", ICKEDS´2004 – The 1st International Conference on Engineering and Decision Support, Porto, Portugal, July 2004.
[10] António C. Andrade and F. P. Maciel Barbosa, "A New Method for Detecting the Point of Voltage Collapse", UPEC 2004 – 39th International Universities Power Engineering Conference, Bristol, England, September 2004.
[11] António C. Andrade and F. P. Maciel Barbosa, "Detection of the Point of Voltage Collapse Using the FSQV Method", PowerTech2005, St. Petersburg, Russia, June 2005.