Analysis of continuous power flow method, Model analysis, Linear Regression and ANN for voltage stability assessment for different Loading conditions

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Abstract

This Paper presents voltage stability assessment through P-V curve and bus voltage sensitivity factor. Active power margin is used to measure the distance to instability. Analyses by using computational methods are used to obtain P-V curve of power system. Continuation power flow starting with initial operating point and increasing load to the maximum loading point and to reduce the size of the jacobian matrix modal analysis is adopted. A data statistics analysis tool is used to run linear regression. In this paper the linear regression method with ANN is compared with conventional methods and voltage stability is improved within less iterations.

Keywords: Regression analysis; MATLAB; Voltage stability; power flow; CPF; ANN; Loading conditions

1. Introduction

In general terms, voltage stability is defined as the ability of a power system to maintain steady voltages at all the buses in the system after being subjected to a disturbance from a given initial operating condition. It depends on the ability to maintain/restore equilibrium between load demand and load supply from the power system. Instability that may result appears in the form of a progressive fall or rise of voltages of some buses. Voltage stability problems mainly occur when the system is heavily stressed beyond its capability. While the disturbance leading to voltage collapse may be initiated by a variety of causes, the main problem is the inherent weakness in the power system.

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Many voltage stability indices are based on the Eigen value analysis or singular value decomposition of the system power flow Jacobian matrix. The prominent methods in voltage stability analysis are those that find system load margin, especially when system contingency is considered P--V curve and Q-V curve are most considerable method to find active power margin and reactive power margin. Network configurations and load distributions can also reflect using PV curve. The linear approach between the generator reactive power reserves and voltage stability margin is related to the system PV curves versus nodal VQ curves. Using this relationship, a systematic and practical method for determining the online voltage stability margin is proposed in.

In most of the research work the voltage stability has been considered as static phenomenon. This is due to slow variation of voltage over a long time observed in most of the incident until it reaches to the maximum loading point and then it decreases rapidly to the voltage collapse. Static voltage stability can be analyzed by using bifurcation theory. There are different types of bifurcation theory, in which saddle node bifurcation is used for static voltage stability analysis. This paper is concentrated on the steady state aspects of voltage stability. Indeed, numerous authors have proposed voltage stability indexes based on repeated power flow analysis. In this generally conventional load flow is used. The main difficulty in this method is that Jacobian of NR power flow become singular at voltage stability limit (critical point).

A power flow solution near the critical point prone to divergences and error. Singularity in the Jacobian can be avoided by slightly reformulating the power flow equations and applying a locally parameterized continuation technique. During the resulting —continuation power flow, the reformulated set of equations remains well-conditioned so that divergence and error due to a singular Jacobian are not encountered. The continuation power flow has some disadvantage of creating the jacobian matrix so linear regression analysis with ANN is done for voltage stability assessment.

2. 1.Linear regression

The characteristic of voltage stability are illustrated with IEEE 14-bus system. The generator produces active power, which is transferred through a transmission line to load. The reactive power capability of the generator is infinite. Thus the generator terminal voltage \( V_1 \) is constant.

![Fig. 1. Line diagram of IEEE 14 bus test system](image)

\[
V_2 = \sqrt{((V_1^2 - 2QX) \pm \sqrt{(V_1^4 - 4QX V_1^2 - 4PX^2)})/2}
\]

\[
P_i = \Sigma V_i V_j Y_{ij} \cos(\delta_i - \delta_{ij} Y_{ij})
\]

\[
Q_i = \Sigma V_i V_j Y_{ij} \sin(\delta_i - \delta_{ij} Y_{ij})
\]

For \( i, j = 1 \) to \( n \)
Simulation model

Fig2. Simulation model for IEEE 14-bus system
2.2. Modal Analysis:

Fig. 6: Eigenvalues of the reduced Jacobian matrix against load multiplication factor, K.
Table 1: Transmission lines data (r, x and b in pu on 100mva base) for the 14-bus test system

| End buses | R     | X     | B/2  |
|-----------|-------|-------|------|
| 1-2       | 0.01938 | 0.05917 | 0.0264 |
| 2-4       | 0.05811 | 0.17632 | 0.0170 |
| 12-13     | 0.22092 | 0.19988 | 0 |
| 13-14     | 0.17093 | 0.34802 | 0 |

Table 2: transformer data (r, x in pu on 100 mva base) for the 14-bus test system

| End buses | R   | X   |
|-----------|-----|-----|
| 3-8       | 0.0671 | 0.17173 |
| 7-9       | 0   | 0.11001 |
| 6-7       | 0   | 0.2522 |

Table 3: Shunt capacitor(r, x in pu on 100 mva base) for the 14-bus test system

| End buses | MVAR(pu) |
|-----------|---------|
| 4         | 0.191   |
| 5         | 0.016   |

Table 4: Base case load data (pu on 100 mva base) for the 14-bus test system

| Bus | P(MW) | QMVAR(pu) |
|-----|-------|-----------|
| 3   | 0.217 | 0.127     |
| 4   | 0.942 | 0.191     |
| 7   | 0.112 | 0.075     |
| 8   | 0.050 | 0         |
| 9   | 0.295 | 0.166     |
| 10  | 0.09  | 0.058     |
| 11  | 0.035 | 0.018     |
| 12  | 0.061 | 0.016     |
| 13  | 0.135 | 0.058     |
| 14  | 0.1499 | 0.050    |

Table 5: Base case generator data (pu on 100 mva base) for the 14-bus test system

| Bus | V(pu) |
|-----|-------|
| 1   | 1.06  |
| 2   | 1.045 |

Table 6: Eigen values of reduced Jacobian matrix (Pu on 100 MVA base) for the 14-bus test system

| K   | E1   | E2   | E3   | E4   |
|-----|------|------|------|------|
| 1.124 | 0.1861 | 0.3190 | 0.1361 | 0.5786 |

Table 7: Transformer data for different load levels (pu on 100 mva base) for the 14-bus test system

| End buses | R     | X     | Tap setting |
|-----------|-------|-------|-------------|
| 9-10      | 0.03181 | 0.08450 | 1           |
|           |        |       | 0.978       |
|           |        |       | 0.969       |
|           |        |       | 0.932       |
Table 8: Load data for different load levels (pu on 100 mva base) for the 14-bus test system

| Bus | P(pu)   | Q(pu)   | Load level |
|-----|---------|---------|------------|
| 4   | 0.942   | 0.191   | 1          |
|     | 0.931   | 0.185   | 0.978      |
|     | 0.928   | 0.189   | 0.969      |
|     | 0.940   | 0.172   | 0.932      |
| 5   | 0.478   | 0.197   | 1          |
|     | 0.435   | 0.192   | 0.978      |
|     | 0.241   | 0.188   | 0.969      |
|     | 0.448   | 0.179   | 0.932      |
| 9   | 0.295   | 0.166   | 1          |
|     | 0.285   | 0.164   | 0.978      |
|     | 0.274   | 0.158   | 0.969      |
|     | 0.286   | 0.149   | 0.932      |

Table 9: Generator data for different load levels (pu on 100 mva base) for the 14-bus test system

| Bus | P(pu)   | Voltage(pu) | Load level |
|-----|---------|-------------|------------|
| 4   | 0.035   | 1.06        | 1          |
|     | 0.061   |             | 0.978      |
|     | 0.135   |             | 0.969      |
|     | 0.1499  |             | 0.932      |
| 5   | 0.050   | 1.045       | 1          |
|     | 0.295   |             | 0.978      |
|     | 0.09    |             | 0.969      |
|     | 0.217   |             | 0.932      |
| 9   | 0.242   | 1.01        | 1          |
|     | 0.112   |             | 0.978      |
|     | 0.235   |             | 0.969      |
|     | 0.241   |             | 0.932      |

Table 10: Load voltages and reactive power outputs of generator 2 and 3 at load level 1 (pu on 100 mva base) for the 14-bus test system

| Contingency                  | V5  | V6  | QG3 | QG2 |
|------------------------------|-----|-----|-----|-----|
| Without outage, fixed tap   | 0.96| 1.11| 290 | -83 |
| Without outage, LTC active  | 0.99| 1.08| 227 | 144 |
| Line outage, fixed tap      | 0.91| 1.00| 200 | 224 |
| Line outage, LTC active     | 1.01| 1.09| 243 | 146 |

Table 11: Load voltages and reactive power outputs of generator 2 and 3 at load level 2 (pu on 100 mva base) for the 14-bus test system

| Contingency                  | V5  | V6  | QG3 | QG2 |
|------------------------------|-----|-----|-----|-----|
| Without outage, fixed tap   | 1.03| 1.11| 290 | -83 |
| Without outage, LTC active  | 0.99| 1.08| 227 | 144 |

Table 12: Load voltages and reactive power outputs of generator 2 and 3 at load level 3 (pu on 100 mva base) for the 14-bus test system

| Contingency                  | V5  | V6  | QG3 | QG2 |
|------------------------------|-----|-----|-----|-----|
| Without outage, fixed tap   | 1.02| 1.11| 401 | -81 |
| Without outage, LTC active  | 0.98| 1.07| 700 | 249 |
2.3. Continuation Power Flow Result (With Gen. Reactive Limit Constraint) and Linear Regression:
**Fig 11.** Forming the linear regression equation

**Fig 12.** Linear regression (Basic fitting) Analysis (K=1.146)

**Fig 13.** Data statistics of mean, standard deviation
Fig 14. Data statistics for input

Fig 15. Data statistics for output

Fig 16. Individual voltages variation (linear regression)

Fig 17. Modified power with linear regression
2.4. Neural network and regression analysis for MLP estimation:

**Step by step procedure:**
- With NN tool box
- Selecting data in NN
- Selecting the no. of hidden layers and network size
- Training the Network
3. CONCLUSION

Above all results shows that voltage stability margin can be found easily by linear regression with ANN. And P-V curve and max. Loading point can access. Only collapse point is not enough for voltage stability assessment. So, using tangent vector sensitivity analysis can be done. From voltage sensitivity factor weakest bus can identify. The Weakest bus identification is done by without excessive calculation. Placement of reactive power sources such as Fact devices, capacitor bank is known. This result is same accurate as to find Bus participation factor using QV modal analysis, continuation load flow and etc. This linear regression method and neural networks method is more accurate and simple for Voltage stability analysis.

4. REFERENCES

1. Venkataramana Ajjarapu —Computational Techniques for Voltage Stability Assessment and Control E-Book—Library of Congress Control Number: 2006926216, Iowa State University, Department of Electrical and Computer Engineering. 1122 Coover Hall, Ames Iowa 50011, U.S.A.
2. Varun Togiti —Pattern Recognition of Power System Voltage Stability using Statistical and Algorithmic Methods University of New Orleans ScholarWorks@UNO University of New Orleans 5-18-2012.
3. B. Gao, G. K. Morison, and P. Kundur, —Voltage stability evaluation using modal analysis, IEEE Trans. on Power Systems, vol. 7, no. 4, pp. 1529–1542, Nov. 1992.
4. P. A. Lof, T. Smed, G. Anderson, and D. J. Hill, —Fast calculation of a voltage stability index,IEEE Trans. on Power Systems, vol. 7, no. 1, pp. 54–64, Feb.1992.
5. L. Bao, Z. Huang, and W. Xu, —On-line voltage stability monitoring using var reserves, IEEE Trans. Power Syst., vol. 18, no. 4, pp.1461–1469, Nov. 2003.
6. Satish Joshi , —A Thesis on Voltage stability and contingency selection studies in electrical power system, Department of electrical engineering. Indian institute of technology Kanpur . December 1995.
7. P. Kundur, —Power System Stability and Control McGraw-Hill, 1994.
8. J. Paserba, V. Ajjarapu, G. Andersson, A. Bose, C. Canizares, N. Hatziargyriou, D. Hill, A. Stankovic, C. Taylor, T. Van Cutsem, V. Vital
9. P.Kundur, "Definition and Classification of Power System Stability," IEEE Trans. on Power Syst., vol. 19, no. 2, pp. 1387-1401, May 2004.