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Voltage Stability Assessment Using LVSI Under (N-m) Contingency

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ABSTRACT

Voltage instability is an incident that can occur in a power system due to a stress condition. The occurrence of voltage instability will lead to a total blackout of the whole power system. Thus, an assessment of voltage instability due to the stress condition or other disturbances needs to be carried out. Disturbances can be in the form of line outage or generator outage. The assessment is to identify the line that has the highest effects on voltage stability when there is an outage occurrence. The highest rank of contingency shows that the line of the system contributes to system instability. This paper presents the assessment of voltage stability using line voltage stability index (LVSI) under (N-m) contingency. In this case, N is the total components in a system, while m is the total components undergoing outages either line or generator. This is to trace the state of the voltage stability condition and the values of the line indices are ranked to emulate the contingency. The proposed contingency ranking technique was tested on the IEEE 30-Bus Reliability Test System (RTS).

Key words : Voltage collapse, contingency ranking, voltage stability.

1. INTRODUCTION

Voltage stability is defined as the ability of all buses in a system to maintain the voltage in a certain or acceptable value after the system has been subjected to a disturbance from the normal working condition [1]–[3]. Voltage stability condition is also evaluated to show the capability of the power system to keep or re-establish the balance between the load demand and supply. During the voltage instability [4]–[8], voltage decreases or increases at several buss can be spotted. Load loss from some areas, tripping on the transmission line, or other elements in the protection system which contributes to cascading are some of the factors that will lead to voltage instability. The loss of generator synchronization can also lead to outages. Voltage stability is also known as load stability. Voltage instability is a non-linear phenomenon. Voltage instability could be caused by the stressed load and unpredictable incidents in the system termed as contingencies. When the system has a heavy load along with environmental limits, it becomes a serious problem for voltage instability and the loading system will operate close to the limit [9]–[11]. Voltage instability has become a major concern in the secure operation of many power systems. There are various causes that can start a power system outage. The inability of the power system to supply the reactive power or to absorb the reactive power has become the main cause for the voltage collapse. During the last decade, voltage instability has occurred in some countries. Voltage instability will occur when the system is heavily loaded and incapable of maintaining its generation and transmission schedule, observed by an unexpected failure or wide voltage sag in the system. The procedure for the prediction of voltage collapse and contingency analysis is similar to the line outage simulation. When the voltage changes rapidly, the control devices might not take corrective procedures quickly to avoid power failure. This voltage stability needs to be observed. Therefore, it is crucial for the operators and planners to know the limit point of voltage instability. Thus, the important assignment for voltage stability studies is to find the voltage stability index. The purpose of voltage stability indices is to detect the system loadability. These indices will provide reliable data about the proximity of voltage instability in the system. Their value usually changes from 0 (no load) to 1 (voltage collapse). A literature review [12]–[14] of techniques reveals that many methods for critical line identification such as parameter optimization, busbars identification, and stability boundary detection and system stability studies, etc. have been proposed to detect voltage instability . The condition of voltage stability in a system can be decided using the voltage stability index. The system analysis of voltage stability for a power system is affected with double aspects: (1) A suitable voltage stability index defines how the system is close to voltage instability, (2) what are the stability weak buses and which areas are included. Voltage stability can be analyzed by using two types of approaches [15], [16], either a dynamic or a static approach. By using the static method, the aspect of the voltage stability problem can be analyzed effectively. This is because the dynamic analysis approach needs additional computational time, but the static analysis approach summarizes the snapshots of the network at different time frames [17], [18]. The significant outcome of the early investigation work is based on repeated power flow using PV and QV curves [19], [20]. These methods need to repeat the power flow solution where it will take a long time to solve it. Therefore, voltage stability indices-based methods were developed. These methods have a faster approximation of voltage stability for the systems. These voltage stability indices calculate the numerical value of the power flow solution which shows the state of the system's voltage stability.

This paper presents a pre-developed about Voltage Stability Assessment formed as LVSI under (N-m) Contingency. The on-line voltage stability index is proposed from the viewpoint of the relationship among the active power and the line of the bus voltage [21]–[26], When the resistance of the transmission line in the power system is equal to zero, the index will fail. The voltage stability and contingency analyses were conducted on the IEEE 30-Bus RTS and produced promising results. The results obtained from the study indicate that LVSI is reliable to detect the voltage stability condition in a power system.

2. VOLTAGE STABILITY INDEX FORMULATION

A voltage stability study can be conducted on a system by calculating and estimating the voltage stability index. In this study, the voltage stability index refers to a line.

2.1 Line Stability Index (Lmn)

Lmn or line stability index was proposed by M. Moghavvemi et al.[20] based on the power flow in the line of a power system. It is used to measure the voltage stability for each line. The line becomes unstable when the value of Lmn is high. To obtain the real roots of the voltage, the root discriminant of the voltage quadratic equation is set to zero. The voltage instability occurs when the discriminant is less than zero, as a result the root will become imaginary.

Figure 1 shows a two bus system which is the interconnection network of a line where 'R' is characterized as the receiving end and 'S' characterized as the sending end. The stability index can be written as:

$$Lmn = \frac{4XQ_R}{[V_s \sin(\theta - \delta)]^2} \quad (1)$$

where:
X = Line reactance,
Q_R = Receiving end reactive power,
V_s = Voltage at sending end,
θ = Line impedance angle, and
δ = The angle difference between the supply voltage and the receiving voltage.

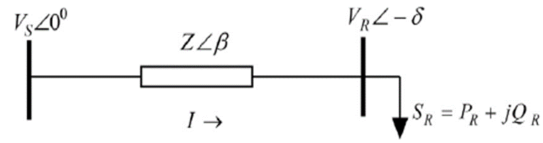

Figure 1: Two bus system delivering load over a transmission line

2.2 Line Stability Factor (LQP)

LQP was proposed by A. Mohammed et al.[19] who derived a line stability factor based on a power transmission theory in a single line. An index was extracted in order to prove it since LQP is the most suitable one. The formulation starts with the power equation in a power system.

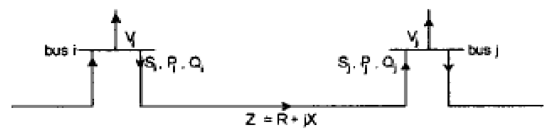

Figure 2: Single line of power transmission concept

The line stability factor can be shown as:

$$LQP = \frac{4X}{V_s^2}\left[\frac{XP_s^2}{V_s^2} + Q_R\right] \quad (2)$$

where:
X = Reactance,
V_s = Sending end voltage,
P_s = Sending end power, and
Q_R = Receiving end of reactive power.

In order to maintain stability, the LQP must be less than 1.00.

2.3 Fast Voltage Stability Index (FVSI)

The fast voltage stability index (FVSI) was introduced in [19]. It shows the voltage stability index of a line. For a typical transmission line, the index is:

$$FVSI = \frac{4Z^2Q_R}{V_s{}^2X} \quad (3)$$

where:
Z = Line impedance,
X = Line reactance,
Q_R = Reactive power at the receiving end, and
V_s = Voltage at sending end.

An index that is near to 1.00 shows that the line is a stressed line in the power system. This index is used to determine the network voltage weak line. If FVSI exceeds 1.00, the buses connected to the line will undergo an unexpected voltage drop that will lead to power system failure.

2.4 Line Voltage Stability Index (LVSI)

The line voltage stability index was proposed by Naishan et al. [19] and deals with the relationship between the line active power and the line of the bus voltage. If the resistance of the transmission line in the power system is equal to 0, the index will fail. The index is written as:

$$LVSI = \frac{P_R r}{[V_s \cos(\theta - \delta)]^2} \leq 1.0 \quad (4)$$

Where:
P_R = Receiving end power,
r = Resistance,
V_s = Voltage at sending end,
θ = Line impedance angle, and
δ = The angle difference between the supply voltage and the receiving voltage.

Its range is from 0 to 1 where 0 indicates a stable system and 1 indicates an unstable system.

3. VOLTAGE STABILITY ANALYSIS

There are several methods that have been proposed in the literature for conducting a voltage stability analysis. Examples of these methods are the usage of P-V curves, Q-V curves, minimum singular value, modal analysis, sensitivity analysis, and artificial intelligence. The result of the analysis of voltage stability is to identify the nearest instability point of the system, the weakest bus that is close to the maximum allowable load, and the line that is responsible for the voltage instability of the whole system. Voltage stability can be analysed by using two types of approaches i.e. a dynamic or static approach. By using a static method, the aspect of the voltage stability problem can be analysed effectively. This is because the dynamic analysis approach needs additional computational time, but the static analysis method summarizes the snapshots of the network at different time frames.

Figure 3 shows the flow chart of the LVSI. It starts with calling the data bus and the line bus of the IEEE 30-Bus RTS. To do a line or generator outage, the line or generator in the system needs to be removed. Next, the load flow is run and the LVSI is calculated. The range of LVSI is from 0 to 1. If the result of LVSI is 0, it shows that the system is stable while a result of 1 shows that the system is unstable. If the line is stable, it will calculate the value of LVSI for the next line. If the system is unstable, the identification of the stressed line needs to be done.

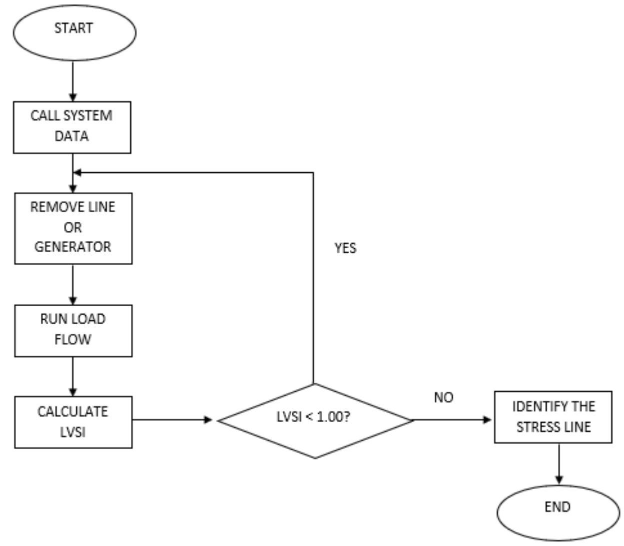

Figure 3: Flowchart of FVSI

4. AC POWER FLOW

Ac power flow is an important part of the voltage stability index specifically in the preparation of the upcoming power system enlargement and to run the present power system optimally. The power flow calculation of the voltage stability index could be incorporated into the load flow program which will give the result of a complete voltage stability study process.

5. RESULTS AND DISCUSSION

A test on the IEEE 30-Bus RTS has been conducted. This power system has five generator bus, one slack bus, and twenty-four load bus with forty-one interconnected branches. One load bus was randomly selected in order to investigate the real power loading and reactive power loading on LVSI. The real power loading and reactive power loading at Bus 7 were steadily increased from the base case. This was to see whether the real power loading or reactive power loading would affect the LVSI. The LVSI values were evaluated for each line in the power system for every load increase.

The graphs in Figure 4 show the corresponding LVSI profiles versus real load variations at Bus 7. Figure 4 shows the results of theLVSI profile with respect to the increment of real load at Bus 7. This increment has caused the LVSI values of lines 2 and 5 to experience a gradual increase with respect to the increment of Pd_7. Apparently, lines 2 and 5 are the two lines affected by the Pd_7 increment. This shows that the LVSI is sensitive to real power. A further increase in the real power loading would cause the indices to exceed 1.00 and this can cause the whole power system to experience voltage instability.

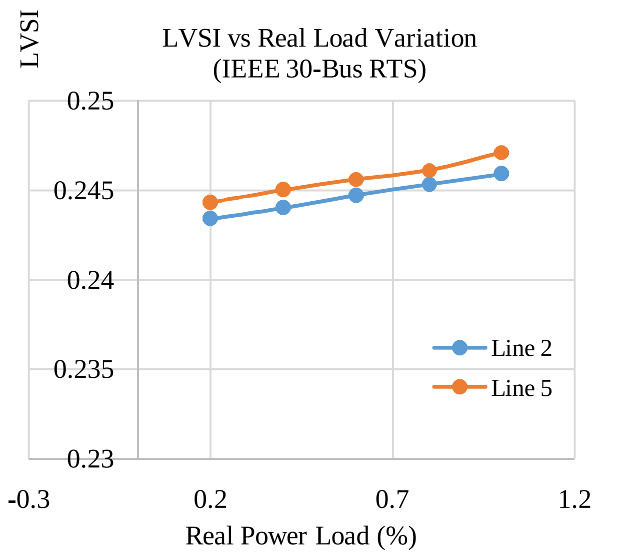

Figure 4: LVSI versus the real load variation

Figure 5 shows the effect of the reactive power loading increment on LVSI. From the graph, the reactive power loading is slow to affect the LVSI. This is because LVSI is more sensitive to real power loading.

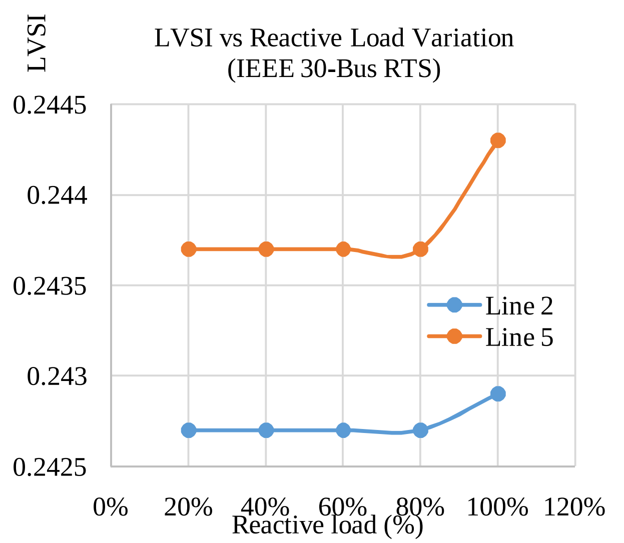

Figure 5: LVSI versus reactive load variation at Bus 7

Figure 6 shows that the indices for line 2 and line 5 are rapidly increasing. This happens because the indices are sensitive to the real power loading but at the same time the reactive power loading helps the reactive loading to affect the indices but at a slower rate. When the real and reactive power loading increase at the same time, the indices will rapidly increase. If the reactive and real power loading keep increasing, the indices will keep increasing and exceed the indices limit which could lead to voltage instability.

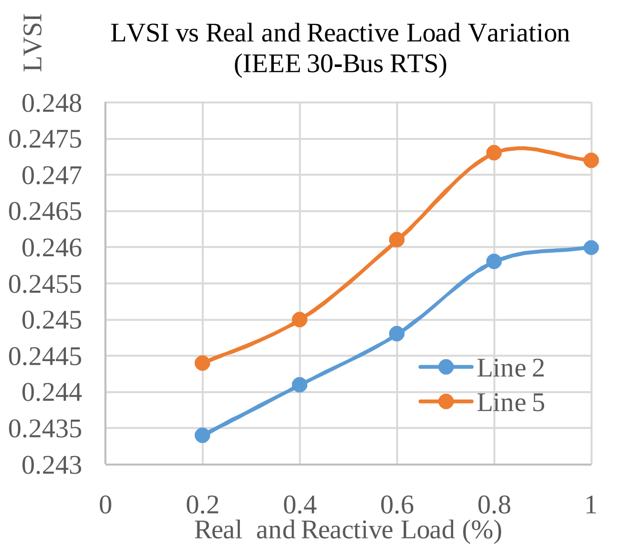

Figure 6: LVSI versus real and reactive load variation

5. CONCLUSIONS

An investigation into the effect of real power loading and reactive power loading was carried out and tested on the IEEE 30-Bus RTS. The results presented that the indices determine the voltage instability which refers to a bus which is the weakest bus in the power system. The LVSI range is from 0 to 1 where 0 indicates a stable system while 1 shows an unstable power system. The result shows that the LVSI is sensitive to the real power loading compared to reactive power loading. If the real power loading and the reactive power loading increase at the same time, it will increase the indices much faster. This could lead to a much faster voltage instability in the system.

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REFERENCES

1 R. S. S. Reddy and T. G. Manohar. **Literature Review on Voltage stability phenomenon and Importance of FACTS Controllers In power system Environment**,*Glob. J. Res. Eng.*, Vol. 12, no. 3-F, 2012.

2 P. Kundur, N. J. Balu, and M. G. Lauby, ***Power system stability and control***, Vol. 7. New York: McGraw-hill, 1994.

3 J. Hu, Y. Huang, D. Wang, H. Yuan, and X. Yuan. **Modeling of grid-connected DFIG-based wind turbines for dc-link voltage stability analysis**, *IEEE Trans. Sustain. Energy*, Vol. 6, no. 4, pp. 1325–1336, 2015, doi: 10.1109/TSTE.2015.2432062.

4 Y. Huang, X. Yuan, J. Hu, P. Zhou, and D. Wang. **DC-Bus Voltage Control Stability Affected by AC-Bus Voltage Control in VSCs Connected to Weak**

AC Grids,*IEEE J. Emerg. Sel. Top. Power Electron.*, Vol. 4, no. 2, pp. 445–457, 2016. https://doi.org/10.1109/JESTPE.2015.2480859

5 K. Kawabe and K. Tanaka. **Analytical method for short-term voltage stability using the stability boundary in the P-V plane**,*IEEE Trans. Power Syst.*, Vol. 29, no. 6, pp. 3041–3047, 2014. https://doi.org/10.1109/TPWRS.2014.2313152

6 T. V. S. Babu and B. A. Kumar. **Power Saving and Reducing Transmission Delay in WSN using DMP Scheme**,*Int. J. Adv. Trends Comput. Sci. Eng.*, Vol. 3, no. 5, pp. 54–59, 2014.

7 I. Patel, S. Alekhya, D. Aarti, and R. Kulkarni. **Sensible heat storage for power generation**,*Int. J. Adv. Trends Comput. Sci. Eng.*, Vol. 3, no. 5, pp. 13–17, 2013.

8 M. H. Mansor *et al.*. **A hybrid optimization technique for solving economic dispatch problem**,*J. Phys. Conf. Ser.*, Vol. 1049, no. 1, 2018.

9 S. Ratra, R. Tiwari, and K. R. Niazi. **Voltage stability assessment in power systems using line voltage stability index**,*Comput. Electr. Eng.*, Vol. 70, pp. 199–211, 2018.

10 B. Singh, N. K. Sharma, and A. N. Tiwari. **Prevention of voltage instability by using FACTS controllers in power systems: a literature survey**,*Int. J. Eng. Sci. Technol.*, Vol. 2, no. 5, pp. 980–992, 2010.

11 R. Tiwari, K. R. Niazi, and V. Gupta. **Line collapse proximity index for prediction of voltage collapse in power systems**,*Int. J. Electr. Power Energy Syst.*, Vol. 41, no. 1, pp. 105–111, 2012. https://doi.org/10.1016/j.ijepes.2012.03.022

12 M. V Suganyadevia and C. K. Babulalb. **Estimating of loadability margin of a power system by comparing Voltage Stability Indices**,*2009 International Conference on Control, Automation, Communication and Energy Conservation*, pp. 1–4, 2009.

13 T. Van Cutsem and C. Vournas.**Voltage stability of electric power systems**,*Springer Science & Business Media*, 2007.

14 M. Aldeen, S. Saha, T. Alpcan, and R. J. Evans. **New online voltage stability margins and risk assessment for multi-bus smart power grids**,*Int. J. Control*, Vol. 88, no. 7, pp. 1338–1352, 2015.

15 T. Moger and T. Dhadbanjan. **A novel index for identification of weak nodes for reactive compensation to improve voltage stability**,*IET Gener. Transm. Distrib.*, Vol. 9, no. 14, pp. 1826–1834, 2015.

16 B. H. Chowdhury and C. W. Taylor. **Voltage stability analysis: VQ power flow simulation versus dynamic simulation**, *IEEE Trans. Power Syst.*, Vol. 15, no. 4, pp. 1354–1359, 2000. https://doi.org/10.1109/59.898112

17 V. Ajjarapu and C. Christy. **The continuation power flow: a tool for steady state voltage stability analysis**,*1991 Power Industry Computer Application Conference*, pp. 304–311, 1991.

18 D. Devaraj and J. P. Roselyn. **On-line voltage stability assessment using radial basis function network model with reduced input features**,*Int. J. Electr. Power Energy Syst.*, Vol. 33, no. 9, pp. 1550–1555, 2011.

19 I. Musirin and T. K. A. Rahman. **On-line voltage stability based contingency ranking using fast voltage stability index (FVSI)**, *IEEE/PES Transmission and Distribution Conference and Exhibition*, Vol. 2, pp. 1118–1123, 2002.

20 M. Moghavvemi and F. M. Omar. **Technique for contingency monitoring and voltage collapse prediction**, *IEE Proceedings-Generation, Transm. Distrib.*, Vol. 145, no. 6, pp. 634–640, 1998. https://doi.org/10.1049/ip-gtd:19982355

21 A. R. Phadke, M. Fozdar, K. R. Niazi, R. C. Bansal, and N. Mithulananthan. **On-line monitoring of proximity to voltage collapse using a new index based on local signals**,*Electr. Power Components Syst.*, Vol. 38, no. 13, pp. 1498–1512, 2010.

22 W. A. Mittelstadt, B. H. Chowdhury, and C. W. Taylor. **Voltage stability analysis: VQ power flow simulation versus dynamic simulation [discussion and closure]**," *IEEE Trans. Power Syst.*, Vol. 16, no. 4, pp. 931–932, 2001.

23 A. Mohamed, G. B. Jasmon, and S. Yusoff. **A static voltage collapse indicator using line stability factors**,*J. Ind. Technol.*, Vol. 7, no. 1, pp. 73–85, 1989.

24 I. Musirin and T. K. A. Rahman. **Novel fast voltage stability index (FVSI) for voltage stability analysis in power transmission system**, *Student Conference on Research and Development*, pp. 265–268, 2002.

25 N. S. Hang, T. Xu, Q. H. Liao, and Z. Q. Lu. **The analysis of abundance index of voltage stability based circuit theory**,*Guangxi Electr. Power*, Vol. 2, p. 2, 2006.

26 N. Ainna, S. Abas, I. Musirin, S. Jelani, M. H. Mansor, and M. S. Naeem. **Integrated monte carlo-evolutionary programming technique for distributed generation studies in distribution system**, *Bull. Electr. Eng. Informatics*, vol. 8, no. 3, pp. 1074–1080, 2019. https://doi.org/10.11591/eei.v8i3.1631