



vol. 17 / 2023



The 7th International Conference on Science Technology

organized by
Faculty of Social Science and
Law Universitas Negeri Manado and
Consortium of International Conference
on Science and Technology

The Innovation Breakthrough in Digital and Disruptive Era

Analysis of the Voltage Stability of Power Using L-Index Voltage Stability

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Abstract

Voltage stability is highly dependent on the ability of the system to maintain voltage conditions throughout the bus, both under normal conditions and after a disturbance. One static analysis tool often used is the power flow completion method to determine the voltage magnitude at several points under review. This paper presents static voltage stability analysis for heavy and light load conditions on the load bus. Voltage stability analysis is performed on the IEEE-14 power system bus using the L-index voltage stability method. L-index values ranging from 0 – 1, buses with L-index voltage stability values close to 1.0 are identified as critical buses.

Keyword: *Voltage Stability, Static Voltage Stability, L-index Voltage Stability,*

Introduction

In recent years, finding new landlines to build high-voltage transmission lines to deliver energy to load centers has been difficult. Increased load will result in system equipment being loaded to near its limits. These conditions will become vulnerable if large-capacity plants cannot operate, so the voltage in some buses drops far below normal conditions. For an electric power system to operate safely and reliably, all situations that may cause unstable system operation must be accurately identified [1, 2].

An electric power system is said to be stable if all its variables are stable, either bus voltage, generator angle, or system frequency. Stability issues depend largely on the system's ability to maintain steady voltage conditions on the entire bus, both under normal operating conditions and after a disruption. A system is said to be in an unstable voltage condition when there is a change in the system either due to interference or an increase in load beyond the forecast, where the voltage drops rapidly and uncontrollably. Voltage stability usually occurs in heavily overloaded systems due to interruptions or unexpected load increases. The occurrence of voltage failure as a series of previous fault events is influenced by various factors, mainly due to weaknesses in the system itself, namely the strength of the transmission network and the level of power delivery. Other factors that contribute to voltage failure are generator voltage/reactive power control limits, load characteristics, reactive power compensation equipment, action of voltage control equipment such as *Transformer Under Load Tap Changers (ULTC)*[3].

Several studies have been conducted previously to estimate voltage stability in electric power systems and the likelihood of voltage failure. Voltage stability studies using indices such as V-Q sensitivity or MSV neglect the dynamic behaviour of the system[4], The development of Artificial Neural Network for voltage stability monitoring[5]. Practical short-term voltage stability index based on voltage curves ([4, 6], new VSI of an Islanded Microgrids IMG[7]. New Line Voltage Stability Index (BVSI) for Voltage Stability Assessment in Power System [8]. The analysis in this paper is static stress stability analysis using the popular L-index [9. 10] instability measurement indicator method. This index provides a fairly accurate and practical way of rating and can reveal stability analysis quickly and simply.

The phenomenon of voltage instability and the consequences it causes is a dynamic process and can be analyzed dynamically or statically. One static analysis tool often used is the power flow completion method to determine the voltage magnitude at several points under review. In this study, voltage stability will be evaluated, namely determining the voltage stability index with the L index conducted by [11-12].

The L value is a quantitative measure for estimating the distance from the actual state of the system to the voltage stability limit. L-index stability is one measure or method to determine whether a power system is stable. The L value is a scalar value from 0 to 1. 0 means the system is not overloaded, and 1 means the system has a voltage collapse. The system is said to be stable when the L value is close to 0 and unstable when the L value is close to 1.

If a system is known where n is the total number of buses with 1,2,...,g generator buses, g+1, g+2, . . . , n load buses. The power flow result is used to calculate the L-index as follows:

$$L_j = \left| 1 - \sum_{i=1}^{l=g} F_{ji} (V_i/V_j) \right| \frac{S_j}{Y_{jj} V_j}$$

Where $j = g+1, \dots, n$ and all quantities in sigma in the above equation are complex quantities. The F_{ji} value is obtained from the Y bus matrix as follows:

$$\begin{bmatrix} I_G \\ I_L \end{bmatrix} = \begin{bmatrix} Y_{GG} & Y_{GL} \\ Y_{LG} & Y_{LL} \end{bmatrix} \begin{bmatrix} V_G \\ V_L \end{bmatrix}$$

With I_G, I_L, V_G, V_L express the current and voltage at the generator and load nodes. Equation (32) is rearranged, obtained:

$$\begin{bmatrix} V_L \\ I_G \end{bmatrix} = \begin{bmatrix} Z_{LL} & F_{LG} \\ K_{GL} & Y_{GG} \end{bmatrix} \begin{bmatrix} I_L \\ V_G \end{bmatrix}$$

where $F_{LG} = - [Y_{LL}]^{-1} [Y_{LG}]$ is the desired value

The value of the L indicator is a quantitative measure for estimating the distance from the system's actual state to the stability limits. The local indicator L_j can determine which buses are experiencing voltage collapse. This given theory is appropriate when both conditions are met, i.e. the stability limit is reached for $L = 1$. First, all generator voltages must not change in either magnitude or phase angle. Second, the current of the bus I_j directly responds proportionally to the consideration of the voltage V_j on the bus j .

Methods

This voltage stability analysis was performed by simulating the MATLAB computer program on the IEEE-14 bus electric power system, as shown in Figure 1. This 14-bus system consists of 5 generator buses and 11 load buses. This simulation determines the L-index value of voltage stability and stress profile when the system is heavy and light load. Based on the results obtained, it will be known that weak load buses cause voltage instability in the electric power system.

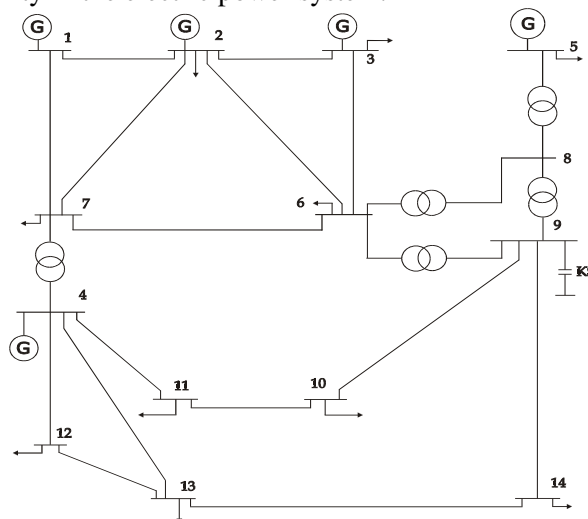


Fig 1. Single Line Diagram Power System IEEE-14 bus

Network data as shown in Tables 1 and 2 below.

Table 1. Generation and load data as well as voltage at the initial conditions of the IEEE-14 bus system

Bus number	Generation		Load		Voltage	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)	pu	Deg.
1		-16.90	0.00	0.00	1.0600	0.0000
2	232.40	42.40	21.70	12.70	1.0450	-4.9800
3		23.40	94.20	19.00	1.0100	-12.7200
4	40.00	12.20	11.20	7.50	1.0700	-14.2200
5	0.00	17.40	0.00	0.00	1.0900	-13.3600
6	0.00		47.80	3.90	1.0190	-10.3300
7			7.60	1.60	1.0200	-8.7000
8	0.00		0.00	0.00	1.0620	-13.3700
9			29.50	16.60	1.0560	-14.9400
10	0.00		9.00	5.80	1.0510	-15.1000
11			3.50	1.80	1.0570	-14.7900
12			6.10	1.60	1.0550	-15.0700
13			13.50	5.80	1.0500	-15.1600
14			14.90	5.00	1.0360	-16.0400

Table 2. Line Data of the IEEE-14 bus System

From Bus	To Bus	Line Impedance			Trafo Ratio
		Resistance (pu)	Reactance (pu)	Suseptance (pu)	
1	2	0.01938	0.05917	0.05280	1.000
1	7	0.05403	0.22304	0.04920	1.000
2	3	0.04699	0.19797	0.04380	1.000
2	6	0.05811	0.17632	0.03740	1.000
2	7	0.05695	0.17388	0.03400	1.000
3	6	0.06701	0.17103	0.03460	0.932
4	7	0.00000	0.25202	0.00000	1.000
4	11	0.09498	0.19890	0.00000	1.000
4	12	0.12291	0.25581	0.00000	1.000
4	13	0.06615	0.13027	0.00000	1.000
5	8	0.00000	0.17615	0.00000	1.000
6	7	0.01335	0.04211	0.00000	0.978
6	8	0.00000	0.20912	0.00000	0.969
6	9	0.00000	0.55618	0.00000	1.000
8	9	0.00000	0.11001	0.00000	1.000
9	10	0.03181	0.8450	0.00000	1.000
9	14	0.12711	0.27308	0.00000	1.000
10	11	0.08205	0.19207	0.00000	1.000
12	13	0.22092	0.19988	0.00000	1.000
13	14	0.17093	0.34802	0.00000	1.000

The analysis steps are shown in Figure 2 below.

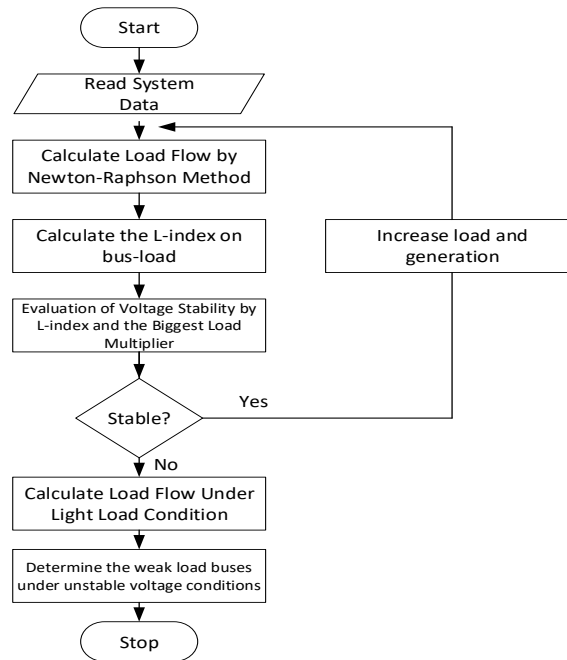


Fig 5. Flowchart of Voltage Stability Analysis

Results and Discussion

Simulation under *heavy load conditions*

As a basic case, it is taken on the state of the system with a heavy load obtained by multiplying the XL (load factor) on each load both on the generator bus and the load bus. The results of calculating the L index and stress under *heavy load conditions* (with a load multiplier factor of 3.9281) are shown in Table 3. The largest L index value sorts bus numbers.

Table 3. Results of voltage and L-index calculations under *heavy load conditions*

Bus number	L_{max}	V (pu)
14	0,505	0,774
9	0,417	0,815
10	0,393	0,822
8	0,212	0,899
11	0,198	0,928
13	0,164	0,949
6	0,158	0,864
12	0,115	0,988
7	0,106	0,877

In this case, bus 14 and bus 9 have the largest L index values of 0.505 pu and 0.417 pu, respectively and voltage values of 0.774 and 0.815, respectively.

Simulation under *light load conditions*

This case is carried out at *light load conditions* (60% of normal). The power flow analysis results show that some load buses are experiencing overvoltage (voltage above 1.05 pu).

Table 4. Results of voltage and L-index calculations under light load conditions

Bus number	Lmin	V (pu)
6	0,018	1,023
7	0,012	1,025
8	0,023	1,061
9	0,040	1,050
10	0,038	1,049
11	0,021	1,058
12	0,014	1,060
13	0,019	1,057
14	0,045	1,043

In this case, buses 14 and 9 have small L-index values close to zero of 0.040 and 0.45 and voltages of 1.050 pu and 1.043 pu, respectively.

The simulation results on the heavy load showed two very weak buses, each bus 14 and 9. This can be observed from the value of the stability index and the voltage magnitude, where these two buses have the largest stability index value, and the voltage profile is very low compared to other load buses. The largest L value on bus 14 and bus 9 indicates that these two buses have high sensitivity when a voltage rises above normal. Thus, these two load buses are recommended to install compensators.

While in the simulation with *light load conditions*, with a load of 60% of normal conditions. The simulation results show that the system is *overvoltage*, with a maximum voltage of 1.0605 pu on buses 12, 9, and 14.

Thus, both load buses 9 and 14 are recommended to install compensators.

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