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Research paper

Effect of reactive power loading on the stability of power network bus voltage and transmission line

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Abstract

Increased loading results in the instability of bus voltages and power transmission lines, which results in the outage of power transmission lines. For stable operation, finding the maximum loading limit of buses is needed. This paper introduces newly proposed modified voltage stability index (MVSI) and line stability index (L_{st}) that are used to rank buses and lines, respectively, based on the severity of load contingency. Thus, to account for the effect of inductive load on bus voltage and line stability, only load reactive power is increased up to its *maximum* stability limit. The MVSI and L_{st} are determined using Newton Raphson power flow. Buses and lines are then ranked using MVSI and L_{st} based on the severity of bus loading. The effectiveness of the new stability indices is evaluated against conventional stability indices based on the IEEE-14 bus standard systems and tested on the Ethiopian 230 KV power network. Results show that the proposed indices perform better in ranking buses and lines.

Keywords: *Bus Loading; Bus and Line Ranking; Ethiopian 230 KV Power Network; Line Stability Index; Modified Voltage Stability Index.*

1. Introduction

Voltage stability is the ability of power system to maintain steady state voltage at all buses before and after the power system network is subjected to contingencies. A contingency comprises unplanned outages of power transmission lines, tripping of generators, transformer outage and unexpected load changes. Power utility companies are highly concerned about increased voltage stability problems associated with the recent exponential growth in energy demand. The maximum loading limit of power substations, thermal limit of power transmission lines and the rating of controlling mechanisms associated with excessive loading are the main constraints which affect the bus voltage stability [1], [2].

Excessive loading, especially inductive loading, results in bus voltage instability and further loading beyond the maximum stability limit of bus may lead to partial or total power blackout. Due to the higher initial and operating costs in constructing new power plants and new transmission lines, power companies are forced to connect additional loads to existing buses up to their maximum stability limits[3].

Increased loading also leads to power transmission line outages when their thermal limits are reached [4]. Excessive reactive power loading not only affects load bus voltage stability but also affects the overall network stability. Thus, as inductive load demand increases, the line reactive power and current flow through the line increase so as to meet the customer demand as per the energy conservation principle. Further, over-loading of bus results in excessive heating on power transmission lines followed by energizing and opening of circuit protective devices and hence, line outage [5].

In general, this unplanned line outage due to the load contingency leads to unexpected changes in the power system parameters such as; bus voltage and its phase angle, line MVA limit, and bus real and reactive power flow [6], [7].

In recent research, different approaches have been used for identifying and ranking voltage unstable buses and lines based on the severity of load contingency. Commonly used techniques are; Fast voltage stability indices FVSI [8], Voltage Collapse Point Indicators (VCPI) [9], voltage stability evaluation index (VSE) [10], Revamp Voltage Stability Indicator (RVSI) [11], optimal power planning using Differential Evolution (DE) [12] and line instability indices [13], [14]. Most of these conventional bus and line voltage stability indices have been developed based on radially connected two-bus power networks. In addition, each of these stability indices is developed as a function of load reactive power, sending end bus voltage and line admittance between two buses. Accordingly, if the stability index approaches unity, the affected bus or line is deemed to be entering into an unstable region.

Conventional techniques have been found to perform fairly well in ranking radially connected networks. However, since the modern power network is highly meshed, formulating the voltage stability index using two-bus radial connected power network is not feasible. In addition, the bus voltage stability of an interconnected power network not only depends on sending end bus voltage and impedance between two buses but also depends on the entire network admittances and bus voltages. Therefore, to overcome these problems, a new voltage stability index is proposed in this paper.

Additionally, for a highly meshed modern power network, formulation of line stability index as a function of load reactive power based on two-bus radial systems is not feasible. From load flow solution, for buses connected through two or more power transmission lines, the load power is equal to the sum of line flow entering into the buses. Thus, for meshed power network, since line flow is always less or equal to the load power, transmission lines reach the stability limit for line power flow less than the bus-end load power. Thus, line stability analysis is more feasible when line reactive power flow is used instead of load power. This also necessitates formulation of a new line stability index.

This paper proposes two new stability indices, that is, Modified Voltage Stability Index (MVSI) and Line stability index (L_{st}) for ranking buses and lines, respectively, based on the severity of load contingency.

2. Problem formulation

Excessive bus loading affects the stability of bus voltages and power transmission lines. Thus, identifying and ranking buses and lines using stability indices based on the severity of load contingency is needed to recommend the stability improvement on the network.

2.1. Developing modified voltage stability indices (MVSI)

Assuming an N-bus power system, the current, I, based on current, voltage and admittance relationship is given as;

$$\begin{vmatrix} I_1 \\ \vdots \\ I_k \\ \vdots \\ I_N \end{vmatrix} = \begin{vmatrix} Y_{11}\cdots Y_{1k}\cdots Y_{1N} \\ \vdots \\ Y_{k,1}\cdots Y_{k,k}\cdots Y_{k,N} \\ \vdots \\ Y_{N1}\cdots Y_{N,k}\cdots Y_{NN} \end{vmatrix} \begin{vmatrix} V_1 \\ \vdots \\ V_k \\ \vdots \\ V_N \end{vmatrix} \tag{1}$$

where, k is a load bus within the network.

The current entering bus k, I_k, is given as;

$$I_k = \sum_{i=1, i\neq k}^{N} (Y_{ki} V_i) + Y_{kk} V_k \tag{2}$$

where V_i and V_k are voltage at bus i and load bus k, Y_{ki} is the transfer admittance between bus-k and i, and Y_{kk} is the self-admittance at bus k given by;

$$V_i = |V_i| e^{j\delta_i} \tag{3}$$

$$V_k = |V_k| e^{j\delta_k} \tag{4}$$

$$Y_{ki} = |Y_{ki}| e^{j\theta_{ki}} \quad (5) \quad Y_{kk} = |Y_{kk}| e^{j\theta_{kk}} \tag{6}$$

where, δ_i and δ_k are the sending and receiving end bus voltage phase angles, θ_{ki} is the line transfer admittance angle between bus i and k and θ_{kk} is the line self-admittance phase angle at bus k.

The apparent power at load bus k is given by;

$$P_k + jQ_k = V_k I_k^* \tag{7}$$

Conjugating both sides;

$$I_k = \frac{P_k - jQ_k}{V_k^*} \tag{8}$$

Using equations (2) and (8), the load apparent power is expressed as;

$$P_k - jQ_k = |V_k|^2 |Y_{kk}| e^{j\theta_{kk}} + |V_k| e^{-j\delta_k} \sum_{i=1, i\neq k}^{N} (|V_i| e^{j\delta_i} |Y_{ik}| e^{j\theta_{ki}}) \tag{9}$$

Decomposing into real and imaginary parts;

$$P_k = |V_k|^2 |Y_{kk}| \cos\theta_{kk} + \sum_{i=1, i\neq k}^{N} |V_k||V_i||Y_{ki}| \cos(-\delta_k + \delta_i + \theta_{ki}) \tag{10}$$

$$-Q_k = |V_k|^2 |Y_{kk}| \sin\theta_{kk} + \sum_{i=1, i\neq k}^{N} |V_k||V_i||Y_{ki}| \sin(-\delta_k + \delta_i + \theta_{ki}) \tag{11}$$

Letting $\delta = \delta_i - \delta_k$, where the difference is very small in magnitude and using cosine and sine trigonometric relationships;

$$\cos(\delta - \theta_{ki}) = \cos\delta\cos\theta_{ki} + \sin\delta\sin\theta_{ki} \tag{12}$$

$$\sin(\delta - \theta_{ki}) = \sin\delta\cos\theta_{ki} - \cos\delta\sin\theta_{ki} \tag{13}$$

Since $\delta = \delta_i - \delta_k$ is small in magnitude, equations (12) and (13) can be approximated as;

$$\cos\delta\cos\theta_{ki} + \sin\delta\sin\theta_{ki} \approx \cos\theta_{ki} \tag{14}$$

and

$$\sin\delta\cos\theta_{ki} - \cos\delta\sin\theta_{ki} \approx -\sin\theta_{ki} \tag{15}$$

Thus, equations (10) and (11) simplify to equations (16) and (17), respectively:

$$P_K = |V_k|^2 |Y_{kk}| \cos\theta_{kk} + \sum_{i=1, i\neq k}^{N} |V_k||V_i||Y_{ki}| \cos\theta_{ki} \tag{16}$$

$$-Q_k = |V_k|^2 |Y_{kk}| \sin\theta_{kk} - \sum_{i=1, i\neq k}^{N} |V_k||V|_i |Y_{ik}| \sin\theta_{ki} \tag{17}$$

Considering only the reactive power due to its adverse effect on voltage stability, equation (17) is transformed into the following quadratic equation of the load bus voltage as shown in equation (18):

$$|V_k|^2 - \frac{|V_k|}{|Y_{kk}|\sin\theta_{kk}} \sum_{i=1, i\neq k}^{N} |V_i||Y_{ki}| \sin\theta_{kk} + \frac{Q_k}{|Y_{kk}|\sin\theta_{kk}} = 0 \tag{18}$$

$$V_k = \frac{\frac{1}{|Y_{kk}|}\sum_{i=1, i\neq k}^{N} |V_i||Y_{ki}| \pm \sqrt{\left(\left(\frac{1}{|Y_{kk}|}\sum_{i=1, i\neq k}^{N} |V_i||Y_{ki}|\right)^2 - 4\left(\frac{Q_k}{|Y_{kk}|\sin\theta_{kk}}\right)\right)}}{2} \tag{19}$$

To have real and stable voltage at load bus k in equation (19), the discriminant should be greater or equal to zero [15]. Thus;

$$\left(\frac{1}{|Y_{kk}|}\sum_{i=1, i\neq k}^{N} |V_i||Y_{ki}|\right)^2 - 4\frac{Q_k}{|Y_{kk}|\sin\theta_{kk}} \geq 0 \tag{20}$$

Therefore, the ratio $MVSI_k$ that defines the user-modified stability indices is given as;

$$MVSI_k = \frac{4(Q_k |Y_{kk}| \sin\theta_{kk})}{(\sum_{i=1, i\neq k}^{N} |V_i||Y_{ki}|)^2} \leq 1 \tag{21}$$

where Q_k is load reactive power.

From equation (21), for stable operation, the load bus reactive power should be increased up to maximum of;

$$Q_k \leq \frac{(\sum_{i=1, i\neq k}^{N} |V|_i |Y_{ki}|)^2}{(4|Y_{kk}|\sin\theta_{kk})} \tag{22}$$

Thus, if $MVSI_k$ approaches unity or greater, the corresponding load bus is said to be voltage unstable.

2.2. Developing new line stability index (L_{st})

Consider N-bus power network and a load bus k which is connected between buses i and j through two transmission lines, line-*i, k* and *j, k*. The apparent power and current at load bus k are then given by;

$$S_k = V_k I_k^* \tag{23}$$

$$I_k = I_{ik} + I_{jk} \tag{24}$$

where I_{ik} and I_{jk} are the line current flow between bus i and k, and bus j and k, respectively.
Using equation (23) in (24) gives.

$$S_k = V_k I_{ik}^* + V_k I_{jk}^* \tag{25}$$

Considering only line apparent power flow, the line stability index for line-ik is derived as;

$$S_{ik} = V_k I_{ik}^* \tag{26}$$

where the current I_{ik} is given by;

$$I_{ik} = \left[\frac{|V_i| e^{j\delta_i} - |V_k| e^{j\delta_k}}{|Z_{ik}| e^{j\theta_{ik}}} \right] \tag{27}$$

Considering equation (27), equation (26) is rewritten as

$$S_{ik} = |V_k| e^{j\delta_k} \left[\frac{|V_i| e^{j\delta_i} - |V_k| e^{j\delta_k}}{|Z_{ik}| e^{j\theta_{ik}}} \right]^* \tag{28}$$

Decomposing into real and reactive power;

$$P_{ik} = -|V_k|^2 |Y_{ik}| \cos\theta_{ik} + |V_k||V_i||Y_{ik}| \cos(\delta_k - \delta_i + \theta_{ik}) \tag{29}$$

$$Q_{ik} = -|V_k|^2 |Y_{ik}| \sin\theta_{ik} + |V_k||V_i||Y_{ik}| \sin(\delta_k - \delta_i + \theta_{ik}) \tag{30}$$

where P_{ik} is the line real power and Q_{ik} is line reactive power. Considering the reactive part only due to its adverse effect on bus voltage and line stability, the quadratic equation for the bus voltage at the receiving end is;

$$|V_k|^2 - \frac{|V_k||V_i| \sin(\delta_k - \delta_i + \theta_{ik})}{\sin\theta_{ik}} + \frac{Q_{ik}}{|Y_{ik}| \sin\theta_{ik}} = 0 \tag{31}$$

From the general quadratic equation, voltage at bus k is given as;

$$|V_k| = \frac{\dfrac{|V_i| \sin(\delta_k - \delta_i + \theta_{ik})}{\sin\theta_{ik}} \pm \sqrt{\left[\dfrac{|V_i| \sin(\delta_k - \delta_i + \theta_{ik})}{\sin\theta_{ik}} \right]^2 - 4\left[\dfrac{Q_{ik}}{|Y_{ik}| \sin\theta_{ik}} \right]}}{2} \tag{32}$$

For stable and non-imaginary voltage at the load bus, the discriminant should be greater or equal to zero and is given as;

$$\left[\frac{|V_i| \sin(\delta_k - \delta_i + \theta_{ik})}{\sin\theta_{ik}} \right]^2 - 4\left[\frac{Q_{ik}}{|Y_{ik}| \sin\theta_{ik}} \right] \geq 0 \tag{33}$$

The line stability index L_{st} at bus k is thus given by

$$L_{st} = \left[\frac{4 Q_{ik} \sin\theta_{ik}}{\left(|Y_{ik}| \left[|V_i| \sin(\delta_k - \delta_i + \theta_{ik}) \right]^2 \right)} \leq 1 \right] \tag{34}$$

For stable operation, the line stability index should be less or equal to unity. The lines are identified and ranked based on the severity of bus loading. If L_{st} approaches or equals unity, the line is considered as unstable and more prone to the outages.

3. Methodology

In this paper, MATLAB is used to determine the proposed modified voltage stability index and line stability index under load contingency, based on IEEE-14 and Ethiopian Electric Power Corporation (EEPCO)-230 KV power transmission network [15]. The steady-state condition of the networks is checked using Newton Raphson (NR) power flow solution. Considering the adverse effect of inductive loading on bus voltage and line stability, only the load reactive power is increased up to its maximum stability limit and the stability indices are determined. Buses and lines are then ranked using MVSI and L_{st} based on the severity of load contingency. The effectiveness of the proposed indices is validated by comparing the proposed methods with conventional techniques. The algorithm for contingency ranking using MVSI and L_{st} is given by Fig.1.

Step 1: Read line, bus, transformer and generation data,
Step 2: Run Newton Raphson power (NR) power flow for base-case load and observe the steady-state condition of the network,
Step 3: Increase reactive power demand (Q_d) at a load bus up to the maximum stability limit and run NR power flow again,
Step 4: Find the line stability indices MVSI and L_{st}
Step 5: Repeat steps 3 and 4 for another load bus,
Step 6: Rank buses and lines using the MVSI and L_{st} respectively based on the severity loading
Step 7: Summarize the result

Fig. 1: Algorithm for Ranking Buses and Lines Using Stability Indices.

4. Results and discussions

The ranking of buses and lines using the proposed modified voltage stability index and line stability index based on the severity of load contingency is presented in this section with its full discussions.

4.1. Evaluation of the modified voltage stability index against conventional techniques

IEEE-14 bus standard test system was used for the validation and evaluation of the MVSI technique against conventional voltage stability indices from the literature such as; L_{mn}, VSE and FVSI and the results is given in Table 1. The results in Table 1 show the bus ranking of IEEE-14 bus standard system based on the severity of inductive loading. It is shown that both the conventional and proposed techniques are effective in ranking unstable buses. As observed from the results in Table 1 and hence their comparison given in Fig.2, the top-ranked unstable bus is the same in both conventional and MVSI cases. However, buses attain the maximum stability limit at different reactive power loadings as observed in Fig.3. The variation in loading is as a result of considering meshed N bus network voltage and line impedance effect on the stability of bus voltage in case of the proposed voltage stability index instead of using two-bus radially connected network in conventional stability indices formulation. In addition, applying line stability index (L_{mn}) for bus voltage stability analysis in case of conventional technique is not feasible.
As observed in Table 1, the reactive power in bus-9, 10 and 13 can be increased to some higher magnitude using the proposed voltage stability index compared to the conventional voltage stability index. On the other hand, the reactive power in bus-12 and 14 can be increased to lower magnitude using the proposed technique compared to the convention stability index. Thus, the proposed voltage stability index performs better in ranking the buses of highly meshed

recent network based on the severity of load contingency than conventional voltage stability indices.

Table 1: Ranking IEEE 14 Bus Network Using User- Modified and Conventional Stability Indices

Bus	Bus ID.	Ranking using conventional techniques: L_{mn}			FVSI			VSE			Ranking using MVSI: MVSI		
		Q_d	L_{mn}	rank	Q_d	FVSI	Rank	Q_d	VSE	rank	Q_d	MVSI	Rank
5	1	0.45	0.161	7	0.45	0.161	7	0.45	0.081	7	0.45	0.000	7
9	2	0.54	0.925	3	0.73	0.829	3	1.06	0.738	3	1.66	0.843	3
10	3	0.84	0.773	4	0.84	0.553	4	1.62	0.626	4	1.62	0.498	5
11	4	0.51	0.447	6	0.51	0.320	6	0.51	0.189	6	0.51	0.268	6
12	5	0.26	0.945	2	0.45	0.334	5	0.45	0.371	5	0.16	0.915	2
13	6	0.25	0.588	5	0.58	0.877	2	0.84	0.789	2	0.84	0.785	4
14	7	0.47	0.993	1	0.73	0.982	1	1.18	0.986	1	0.50	0.956	1

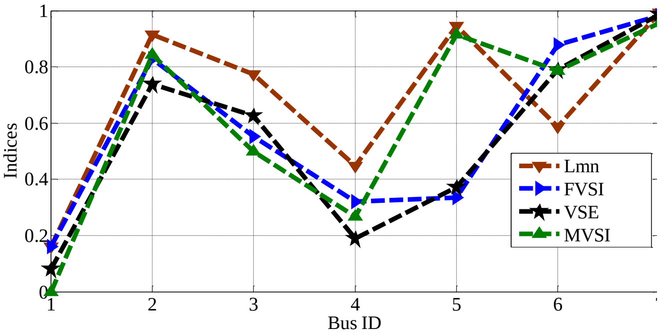

Fig. 2: Comparing MVSI with Conventional Indices for IEEE-14 Bus Standard System.

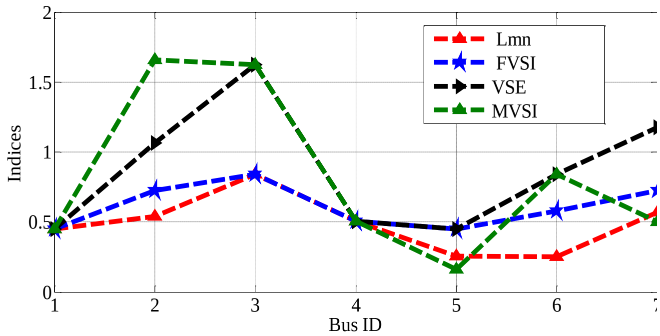

Fig. 3: Comparing Maximum Reactive Power Demand (Q_d) Loading in Case Of MVSI and Conventional Stability Indices.

The proposed voltage stability index is then used for ranking EEPCO-230 K V transmission network test system buses based on the severity of load contingency. The results in Table 2 show the ranking of Ethiopian 230 KV power network buses using MVSI based on the severity of bus loading.

Table 2: Ranking of EEPCO-230 KV Transmission Network Using MVSI

Bus No.	Bus name	V	Q_d	MVSI	Rank
37	2307	0.8718	-0.6969	1.0101	1
28	2349	0.7948	0.7121	0.9707	2
14	2312	0.9613	-1.1575	0.9659	3
17	2326	0.9394	-0.9465	0.965	4
33	2303	0.8669	-0.6544	0.9485	5
11	2309	1.0000	1.9064	0.945	6
24	2321	0.7893	-0.8220	0.9206	7
7	2325	0.8067	-0.8573	0.9182	8
35	2304	0.8667	-0.6843	0.9107	9
36	2379	0.8584	0.85836	0.8419	10
16	2317	1.0000	5.1778	0.7982	11
2	2361	0.8660	-0.5457	0.7906	12
27	2347	0.4597	-0.2807	0.4107	13
9	2311	1.1068	-0.2828	0.4088	14
8	2308	1.0000	0.27992	0.4044	15
32	2316	0.8617	-0.2209	0.3191	16
21	2320	0.6476	-0.2131	0.3085	17
10	2310	1.0497	-0.1688	0.2441	18
31	2350	1.0761	-0.1447	0.2092	19
29	2376	0.8484	-0.1432	0.2079	20
23	2380	0.9933	-0.1434	0.2072	21
19	2346	0.7458	-0.1429	0.2071	22
12	2302	0.9303	-0.1244	0.1796	23
34	2360	0.9920	-0.1079	0.1559	24
26	2351	1.0541	-0.0990	0.1431	25
20	2375	0.8511	0.0536	0.1417	26
15	2342	0.9829	-0.0724	0.1045	27
3	2329	0.9164	-0.0724	0.1045	28
6	2400	0.9401	-0.0546	0.0789	29
13	2313	1.1341	-0.0089	0.0128	30
30	2348	0.9755	-0.0009	0.0013	31

Accordingly, buses are ranked in parallel with the bus voltage and its maximum reactive power loading. Thus, the most severely affected buses are ranked at the top whereas the least severely affected buses are ranked at the bottom.

4.2. Ranking power transmission lines using the line stability indices

In this section the ranking of power transmission lines using the proposed line stability index is presented. The line stability index is used to rank lines based on the severity of load contingency. The feasibility of proposed line stability index is tested first in small IEEE-14 bus standard system by comparing its effectiveness with the conventional line stability index. The results in Table 3 show the line ranking of IEEE-14 bus standard system based on the severity of bus loading.

The results show that both the conventional and proposed techniques are effective in ranking unstable lines. The top-ranked unstable line is the same in both cases though lines attain stability limit at lower maximum reactive power

Table 3: Ranking IEEE-14 Buses Using the Proposed Line Stability Index (L_{st}) and Conventional Technique (L_{mn})

Ranking using the proposed line stability indices					Ranking using conventional line stability index				
Line [i, j]	Line ID	Q_{ij}	L_{st}	Rank	Line [i, j]	Line ID	Q_d	L_{mn}	Rank
4,9	6	0.278	0.644	1	4,9	6	2.160	5.358	1
1,5	1	0.675	0.568	2	12, 13	12	0.585	1.281	2

13,14	14	0.242	0.475	3	7,9	11	2.160	1.114	3
12,13	12	0.222	0.443	4	13,14	14	0.256	0.961	4
2,4	2	0.491	0.366	5	6,13	13	0.585	0.765	5
2,5	3	0.36	0.264	6	9,14	10	0.256	0.744	6
7,9	11	0.497	0.233	7	3,4	4	0.233	0.527	7
3,4	4	0.286	0.230	8	2,4	2	0.233	0.411	8
9,14	10	0.098	0.144	9	9,10	9	0.136	0.290	9
4,5	5	0.599	0.116	10	6,12	7	0.063	0.167	10
6,13	13	0.116	0.083	11	10,11	15	0.06	0.142	11
10,11	15	0.071	0.073	12	6,11	8	0.041	0.126	12
6,12	7	0.053	0.072	13	1,5	1	0.036	0.079	13
9,10	9	0.109	0.047	14	2,5	3	0.036	0.067	14
6,11	8	0.041	0.044	15	4,5	5	0.036	0.024	15

Loadings under the proposed line stability index This is due to using the line reactive power flow over the line-end terminal load bus reactive power which is used in conventional line stability indices for ranking lines. Thus, the line flow is always less than

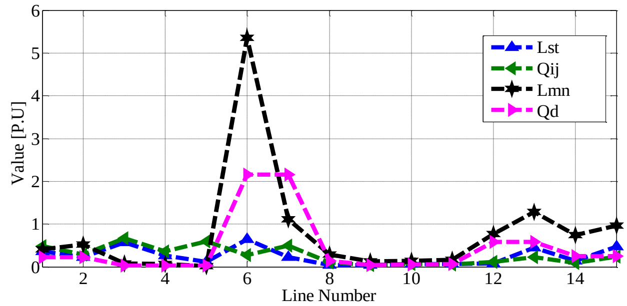

Fig. 4: IEEE-14 Bus Q_{ij} Vs Q_d in Case of L_{st} and L_{mn} Stability Indices.

The reactive power loading at the bus-end of the lines for the meshed network, that is, load reactive power at a bus is equal to the sum of line flows.

The new line stability index which uses line flow instead of load reactive power performs well in ranking meshed power network lines. The stability indices and maximum loading limits are also compared in Fig. 4. From the result, it can be observed that top-ranked lines reach their stability limits at lower maximum reactive power in case of the proposed line stability index compared to the conventional line stability index.

The effectiveness of the proposed line stability index is validated and its advantage over conventional stability index is checked, then the line ranking of EEPCO-230 KV system using L_{st} based on the severity of load contingency is given in Table 4.

The results in Table 4 show line ranking of EEPCO-230 KV transmission line network using the proposed line stability index.

From the results, the most severely affected lines are identified and ranked at the top whereas the least severely affected lines are ranked at the bottom.

Table 4: Ranking EEPCO-230 KV Using Proposed Line Stability Index

Line [i, j]	Q_{ij}	V	Lst	Rank
22,7	0.376	0.8564	10.380	1
32,15	0.024	0.8937	9.214	2
12,33	0.259	0.8615	8.766	3
16,15	0.024	0.8937	6.851	4
12,34	0.023	0.9922	5.674	5
21,22	0.029	0.9911	4.752	6
35,3	0.027	0.9412	3.886	7
1,12	0.046	0.9365	3.673	8
37,6	0.002	0.9899	2.884	9
18,19	0.046	0.9742	2.717	10
21,19	0.046	0.9742	2.629	11
8,6	0.002	0.9899	2.190	12
3,34	0.023	0.9922	1.733	13
35,37	0.273	0.8756	1.722	14
37,7	0.376	0.8564	1.211	15
9,14	0.293	0.9763	1.112	16
17,28	0.323	0.9721	0.921	17
33,35	0.868	0.0312	0.791	18
8,10	0.031	0.9981	0.371	19
14,13	0.002	0.9899	0.339	20
22,27	0.094	0.8652	0.306	21
9,13	0.002	0.9899	0.234	22
31,26	0.033	0.9951	0.171	23
33,36	0.358	0.8594	0.129	24
25,26	0.033	0.9951	0.125	25
5,34	0.023	0.9922	0.093	26
35,2	0.991	0.0225	0.063	27
19,29	0.038	0.9742	0.001	28
18,20	0.025	0.9718	0.001	29
27,30	0.001	0.8652	0.001	30

The results show that over-loading the end terminal bus of top-ranked lines results in the worst line stability problems compared to loading the end terminal bus of bottom-ranked lines.

5. Conclusion

In this paper, Modified Voltage Stability Index (MVSI) and a new line stability index (L_{st}) are presented. The MVSI and L_{st} are used for ranking buses and lines, respectively, based on the severity of load contingency. The two indices are developed so as to overcome the drawback of conventional voltage and line stability indices in ranking buses and lines. Thus, considering the adverse effect of inductive loading on the bus voltage and line stability indices, only load reactive power is increased up to maximum stability limit and the proposed stability indices are determined. The network buses and lines are then ranked using MVSI and L_{st} based on the severity of load contingency on bus voltage and power transmission line stability. The results show that the modified voltage stability index and the newly developed line stability index perform well in ranking buses and lines compared to conventional techniques, which is observed from IEEE-14 bus standard and EEPCO-230 KV networks test systems results. The large computational time required in the proposed stability indices and its accuracy can be further improved if the proposed techniques are used in combination with the artificial intelligent system.

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