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Comparison of Stability Indices for Critical Line at Different Loading Conditions

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Abstract:- Modern power systems are operating under much stressed load conditions and also facing the problem of limited capacity of power generating sources. Voltage instability is a quite frequent phenomenon under such situation rendering degradation of power system performance. In order to avoid system voltage collapse and blackouts, power system is to be analyzed in view of voltage stability for a wide range of system conditions. This paper discusses the use of line voltage stability indices termed as fast voltage stability index (FVSI) and line stability index (Lmn) in order to determine the critical line. The line with least stability margin is ranked highest indices value is identified as theoretical line. The performances of the indices are investigated for the IEEE 14 - bus test system at different loading using MATLAB simulations.

Keywords*- Critical line, voltage collapse, Fast voltage stability index (FVSI), Line voltage index (LMN).*

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I. Introduction

Power system is one of the largest networks, which consist generation, transmission and distribution of electrical power. Since last decade many countries like India, France, Belgium, Germany, Japan, USA etc are facing the voltage instability problem due to overdrawn of load demand which leads to mismatch of reactive power. When overloading occurs in a power system, the voltage at a particular bus drops suddenly leading the system towards instability. For such a large network it is difficult to maintain voltage within safe limits. Voltage stability problem is significant since it affects the power system security and reliability. That’s why it is necessary to analyze critical line and find the proximity to voltage collapse.

P-V [25] and Q-V [26] curve methods were widely used as index to find the proximity to voltage collapse, but they have few disadvantages such as only one bus is considered for load variation at a time and it involves high computation time and convergence problem occurs in solving the power flow equation. In large complex networks Load-flow analysis is commonly used. Power-flow analysis and its application to voltage stability are very easy to implement. Based on power flow equations some indices are derived to find the proximity to voltage collapse. These indices are simple, easy to implement and computationally inexpensive. Voltage stability indices can be used for both online and offline studies.

Operation of power system is becoming difficult due to limited expansion of transmission network because of social and environmental burdens, lack of initiatives to replace the old voltage and power flow control mechanisms and imbalance in load-generation growth. As the system is operating close to the stability limit, a relatively small disturbance may cause the system to become unstable. The power system is normally an interconnected system, its operation and stability will be severely affected. It normally follows by a disturbance in the power system. As defined in [1], voltage stability is the ability of a power system to maintain steady and acceptable voltages at all buses in the system under normal operating conditions and after being subjected to a disturbance. The study of voltage stability can be analyzed under different approaches, but specially, the assessment of how close the system is to voltage collapse can be very useful for operators. This information on the proximity of voltage instability can be given in terms of Voltage Stability Indices. These indices can be used to enable the operators to take action or even to automate control actions to prevent voltage collapse and for the designing and planning purposes.

In this paper, voltage stability indices i.e. fast voltage stability index [12] and line stability index are analyzed for IEEE 14 bus. The capability of these indices to identify critical lines can be evaluated by keeping buses at different loading conditions. For each system, loading scenarios are base loading, load is increased by 30%, and load is increased by 50%. FVSI and Lmn indices are calculated for each loading scenario at each line. The most critical line is decided based on the results of indices.

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II. Voltage Stability Indices

The condition of voltage stability in a power system can be characterized by the use of voltage stability index. This index can either referred to a bus or a line. The broader classification proposed in this paper is based on [22] and [23], having adopted the notation of the Jacobian matrix based VSI and system variables based VSI. Jacobian matrix based VSI can calculate the voltage collapse point or maximum loadability limit and determine the voltage stability margin but the computation time is high and hence they are not suitable for online assessment. On the other hand, system variables based VSIs, which use the elements of the admittance matrix and some system variables such as bus voltages or power flow through lines, require fewer computations and, therefore, are adequate for online monitoring. The disadvantage of these indices is that they cannot accurately estimate the margin, so they can just present critical lines and buses. These indices are simple, easy to implement and computationally inexpensive.

(a) Fast Voltage Stability Index (FVSI)

The 2-bus power system model is shown in figure 1 and this is used to derive FVSI [12]. In the 2- bus power system model where bus 'k' is sending end bus and bus 'm' is receiving end bus. ($P_k + jQ_k$) and ($P_m + jQ_k$) are sending end and receiving end complex powers respectively.

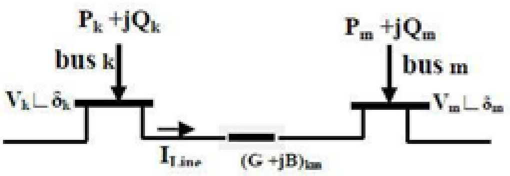

Figure1. 2-Bus power system

Where,
Vk,Vm are the sending and receiving end voltages
Pk,Pm are the sending and receiving end real power
Qk,Qm are the sending and receiving end reactive power
δk, δm are the sending and receiving end bus voltage angles
The Fast Voltage Stability Index (FVSI) for a line k-m is

$$FVSI_{km} = 4Z^2 Q_m / XV_k^2 \quad \ldots\ldots\ldots\ 1.$$

The value of FVSI index of a line when approaches unity it means that the line is approaching its stability limits. The FVSI of all the lines must be lower than 1 to assure the stability of power system.

(b) Line Stability Index (Lmn)

Moghavvemmiand F.M. Omar [13] derived a voltage stability index based on a power transmission concept in a single line. In figure 1, a 2- bus power system model is shown. The line stability index is given as

$$Lmn = \frac{4QmX}{\{Vk\sin(\theta-\delta)\}^2} \quad \ldots\ldots 2.$$

δ=δk−δm
X=Z. Sinθ, is the line reactance
θ is the line impedance angle
The value of Lmn index of a line when approaches to unity it means that the line is approaching its stability limits. The Lmn values of all the lines must be lower than 1 to assure the stability of power system.

III. Test result and discussion

For every test, the indices are investigated and compared regarding to scalar values. It shows that all indices have coherent performances relating to voltage stability. They are close to 0 when the system is stable, and increase towards 1 when the system is more critical.

Voltage stability analysis is carried out for determining loadability limits for IEEE standard 14bus power systems at 100 MVA base. Newton-Raphson method [16] is used for solving the power flow equations. MATLAB code is written for the used methods and indices.

For an IEEE 14 Bus test systems, MATLAB analysis has been carried out for different cases listed below:

1. Base Case: In this section IEEE standard system isused for the study.
2. 30% Increased load: IEEE standard system withincreased loading by 30% at each bus is used for the study.
3. 50% Increased load: In this case an IEEE standard system with increased loading by 50% at each bus isused for the study.

4. Line outage with increased load: IEEE system with increased loading by 50% at each bus along with line outage is considered for the study.

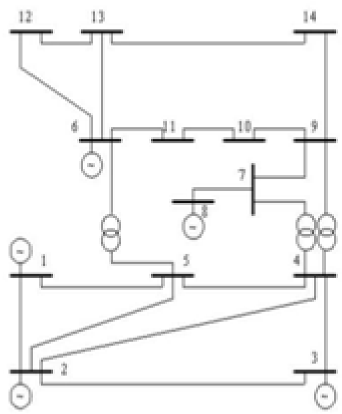

Figure 2. 14 -Bus IEEE standard test system

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IEEE standard 14-Bus test system consists of 5 generator buses (bus 1 is slack bus and 2,3,6 and 8 are PV buses), 9 load buses and 20 lines in which 3 lines (4-7, 4-9 and 5-6) are with tap changing transformers[17].

Table 1 : Voltage stability analysis based on FVSI and Lmn for Case 1

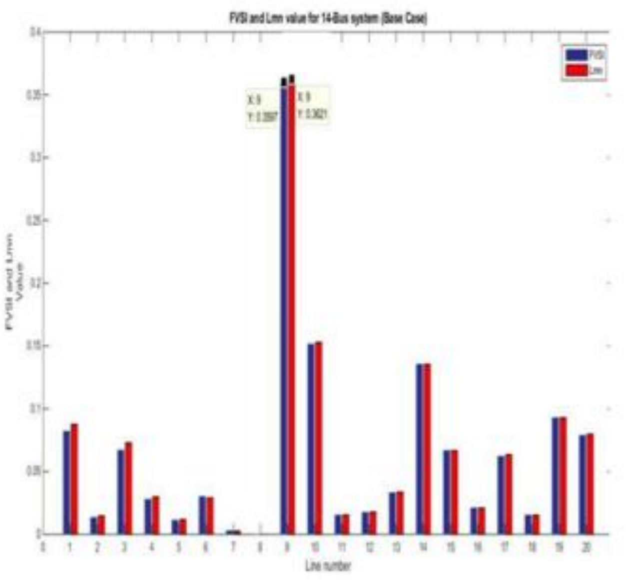
From Bus	To Bus	FVSI Value	Lmn Value
1	2	0.0822	0.0877
1	5	0.0134	0.0149
2	3	0.0671	0.0730
2	4	0.0279	0.0299
2	5	0.0113	0.0118
3	4	0.0302	0.0292
4	5	0.0029	0.0028
4	7	0.0000	0.0000
4	*9*	***0.3597***	***0.3621***
5	6	0.1515	0.1530
6	11	0.0154	0.0155
6	12	0.0176	0.0179
6	13	0.0332	0.0337
7	8	0.1355	0.1355
7	9	0.0668	0.0669
9	10	0.0211	0.0211
9	14	0.0622	0.0635
10	11	0.0154	0.0154
12	13	0.0929	0.0930
13	14	0.0789	0.0799

(1) Base case

Table 2 : Voltage stability analysis based on FVSI and Lmn for Case 2

From Bus	To Bus	FVSI Values	Lmn Values
1	2	0.1006	0.1106
1	5	0.0175	0.0203
2	3	0.0746	0.0847
2	4	0.0377	0.0417
2	5	0.0152	0.0163
3	4	0.0425	0.0407
4	5	0.0040	0.0039
4	7	0	0
4	*9*	***0.5021***	***0.5084***
5	6	0.2752	0.2805
6	11	0.0211	0.0213
6	12	0.0242	0.0247
6	13	0.0457	0.0467
7	8	0.1777	0.1777
7	9	0.0936	0.0938
9	10	0.0299	0.0300
9	14	0.0882	0.0910
10	11	0.0219	0.0218
12	13	0.1294	0.1297
13	14	0.1105	0.1126

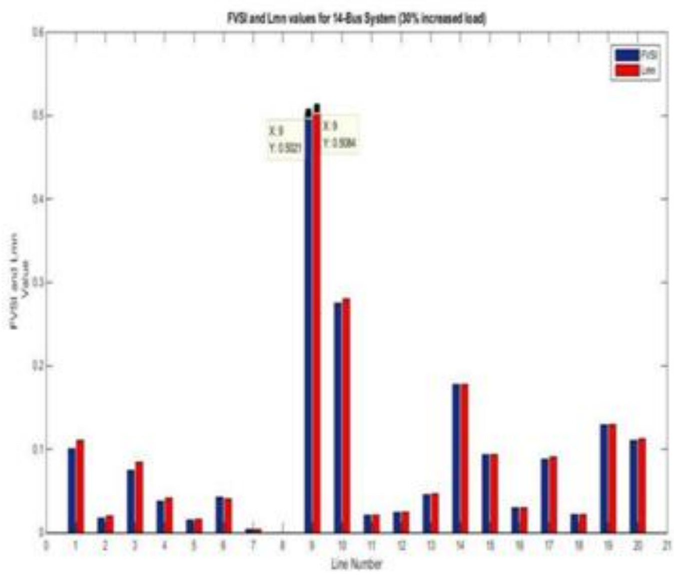
(2) 30 % increased loading



(Figure 1 - Base case)

The 9th line between buses 4 and 9 has the highest value of both Lmn and FVSI.

FVSI = 0.3597 Lmn = 0.3621



(Figure 2 - 30 % increased loading)

The 9th line between buses 4 and 9 has the highest value of both Lmn and FVSI.

FVSI = 0.5021 Lmn = 0.5084

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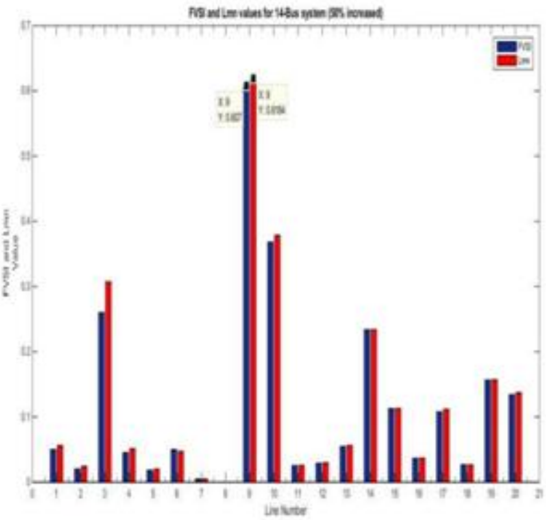
Table 3 : Voltage stability analysis based on FVSI and Lmn for Case 3

From Bus	To Bus	FVSI Values	Lmn Values
1	2	0.0499	0.0561
1	5	0.0202	0.0244
2	3	0.2603	0.3075
2	4	0.0453	0.0514
2	5	0.0183	0.0199
3	4	0.0501	0.0475
4	5	0.0049	0.0048
4	7	0.0000	0.0000
4	***9***	***0.6070***	***0.6184***
5	6	0.3682	0.3787
6	11	0.0254	0.0257
6	12	0.0291	0.0298
6	13	0.0548	0.0563
7	8	0.2340	0.2340
7	9	0.1128	0.1131
9	10	0.0365	0.0367
9	14	0.1077	0.1118
10	11	0.0268	0.0266
12	13	0.1566	0.1571
13	14	0.1342	0.1374

(3) 50% increased loading



(Figure 3 - 50% increased loading)

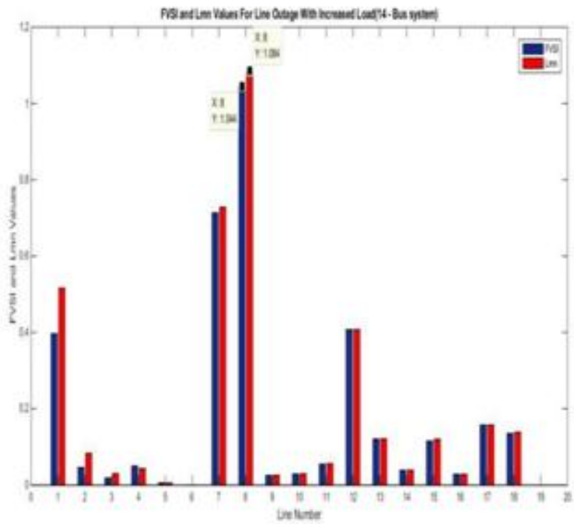
The 9th line between buses 4 and 9 has the highest value of both Lmn and FVSI.

FVSI = 0.6070 **Lmn = 0.6184**

Table 4 : Voltage stability analysis based on FVSI and Lmn for Case 4

From Bus	To Bus	FVSI Values	Lmn Values
1	2	0.3968	0.5165
1	5	×	×
2	3	×	×
2	4	0.0462	0.0835
2	5	0.0187	0.0301
3	4	0.0501	0.0435
4	5	0.0057	0.0055
4	7	0.0000	0.0000
4	9	0.7136	0.7285
5	***6***	***1.0439***	***1.0839***
6	11	0.0254	0.0256
6	12	0.0291	0.0298
6	13	0.0548	0.0563
7	8	0.4078	0.4078
7	9	0.1211	0.1214
9	10	0.0392	0.0394
9	14	0.1156	0.1203
10	11	0.0284	0.0283
12	13	0.1575	0.1576
13	14	0.1356	0.1389

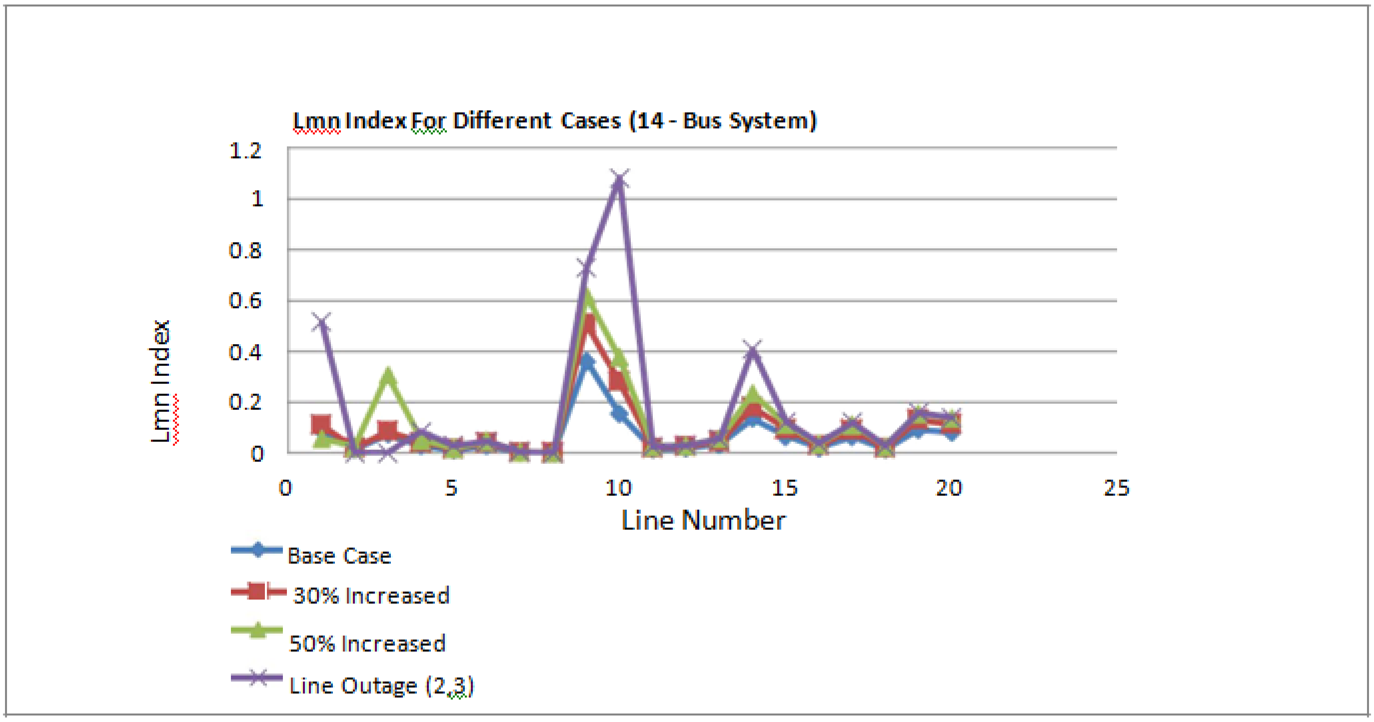
(4) 50 % load increased with line outage

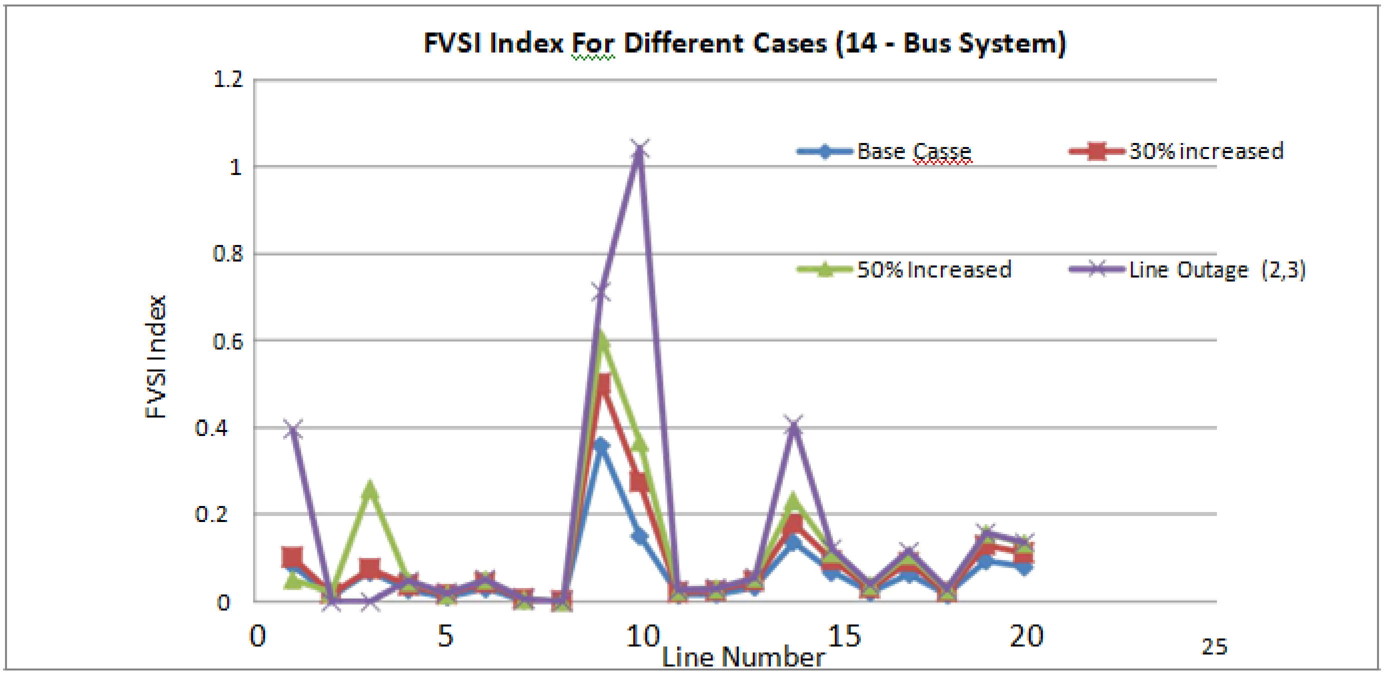


(Figure 4 - 50 % load increased with line outage)

10th line between buses 5 and 6 has the value of both Lmn and FVSI.

FVSI = 1.0439 **Lmn = 1.0839**





IV. Conclusion

In this paper two indices (FVSI and Lmn) are formulated to identify critical lines based on different loading conditions. The indices are simulated in a small 14-bus system using MATLAB simulation tool. This paper presents the methods to identify the critical lines. Voltage stability indices FVSI and Lmn are calculated and voltage instability is observed. The comparison of both indices is presented based on the different loading condition. Based on the analysis, it can be concluded that FVSI and Lmn are equivalent to each other. In terms of their general performance, both indices are coherent with their theoretical background. When the system is stable, these line indices present values near 0 and cross 1 at the voltage collapse point. This paper has four cases for each test system and their effects on stability of line. When we are moving from base load condition to 30% and 50% overloading the value of both indices also increases. The simulated results show that at 50% overloading with line outage both indices (FVSI and Lmn) crosses the value 1 and system becomes instable.

These indices give the information regarding critical bus or the weakest bus of the system so that operators of the power system maintain a margin for stability to avoid the

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voltage collapse. These indices are also useful for power system planning and operation.

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