Voltage Stability Enhancement based on Voltage Stability Indices using FACTS Controllers

Million Alemayehu Bedasso
Department of Electrical Engineering
Visakhapatnam, india

Dr. R. Srinu Naik
Department of Electrical Engineering
Visakhapatnam, India

Abstract—**This Increased load demand (mostly reactive load) and inadequate sources of generation have led to the operation of the power system near its voltage uncertainty point. The issue of determining voltage stability prior to voltage failure has become an exciting subject for many researchers. Therefore, to calculate the distance of the power system from voltage failure, many voltage stability indices have been suggested.**

In this article, two-line indices of voltage stability have been carried out. The index of line stability (L_{mn}) and the index of rapid voltage stability are (FVSI). They were used to govern the weakest bus in the IEEE 30-bus test process. Then, three kinds of FACTS compensation, shunt, series and hybrid (shunt and series) were used to assist voltage stabilization. The results indicate that shunt compensation is more effective than the other two forms

Keywords— *Voltage Stability Indices, FACTS Compensators, Line Stability Index L_{mn}, Fast Voltage Stability Index FVSI, Voltage Stability Enhancement, IEEE 30 bus system.*

I. INTRODUCTION

Voltage Collapse is the mechanism by which voltage instability in a significant part of the device results in voltage loss [3]. Adding extra reactive power by implementing reactive power sources is the best method to improve the voltage stability boundary, i.e., FACTS controllers at the right venue. FACTS devices are made up of shunt, sequence, and hybrid parts. To defined system voltage stability problem, the component's correct choice will restore the system's voltage stability [1].

In voltage stability analysis, scalar magnitudes that can be tracked as device parameters change are useful for estimating power systems' voltage stability using voltage stability indices (VSI). Operators can use this index to know how close the device is to the voltage failure in an accepted way and respond accordingly [7]. The application of two voltage stability indices to an IEEE 30 bus test system is described in this paper. For the identification of the weakest bus in the scheme, the efficacy of these indexes was compared [2]. Moreover, the addition of shunt compensation to the weakest bus is helped by comparison the voltage profile of the system and steady- Margin for State Voltage Stability. The paper also includes shunt, set, and hybrid FACTS compensators (shunt and series).

This paper's structure is as follows: Mathematical formulation, simulation tools used for the analysis, then finally results and conclusion.

II. MATHEMATICAL FORMULATION OF THE INDICES

In up-to-date power systems, voltage stability indices can show the voltage stability state of a power system. These indices were used to locate the power system's critical bus, or to measure the voltage stability margins of the system [11]. Two-line voltage stability indexes are described briefly in this section and are used to evaluate system stability.

A. Index of line stability (L_{mn}) The index of line stability (L_{mn}) was introduced in 1998 by M.Moghavvemi and F.M.Omar [10]. It is based on the principle of power transmission on a single line. The application of this index can provide the ranking of the tested system buses. This index's lower value means higher stability. As the index's value rises to reach unity, it should be said that the line is closer to its instability [6]. A single line of a unified network is shown in Figure 1, where (L_{mn}) is derived from Figure 1.
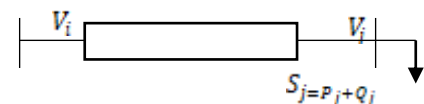
is derived from Figure 1.

Fig. 1. Two bus system

In this model, the line stability index is defined as:

$$L_{mn} = \frac{4xQ_j}{[V_i \sin(\theta - \delta)]^2}$$

Where:
line reactance is X
The reactive power at the receiving is Qi.
The sending end voltage is Vi.
θ is the line impedance angle, and δ is the angle difference between the sending end and the receiving end voltage.

In [5], Lines that displays values of L_{mn} near to 1, specifiethat those lines are closer to their unpredictability points. However, the L_{mn} the index should be less than one to maintain a safe condition.

III. FAST VOLTAGE STABILITY INDEX (FVSI)

Quick voltage stability index FVSI as proposed in 2002 by I.Musirin and T.K.A.Rahman[12]. The features of this index can provide the rating of the tested system buses. Similarly, smaller value of the index indicates greater stability of the voltage. As this index's value rises to reach unity, this indicates that the line is closer to its point of instability [8,4].

The index of stability is determined by: $FVSI_{ij} = \frac{4z^2 Q_j}{V_i^2 X}$

Where:

Z, is the line impedance.
X, is the line reactance.
Qj, is the reactive power flow at the receiving end and
Vi is the sending end voltage.

The line that gives an index value close to one would be the crucial line for the bus. It also contributes to the instability of the entire system. It is possible to use the measured FVSI to evaluate the weakest bus in the system. The concept of the weakest bus depends on the maximum allowable load on the bus. The most vulnerable bus in the scheme is the bus with the lowest overall permissible load [9].

IV. SIMULATION TOOLS

The IEEE 30 bus test system is the system studied in this article. Figure 2 [10] displays a single-line diagram of the test system. The system is composed of five generator buses, 24 load buses and 41 interconnected lines. The details of the test system are given in [5]. Gauss-Seidel is the load flow process, which is an easy and unnecessary amount of computing time. Using MatLab M-file, the load flow programmers were completed.

V. RESULTS

A. Rank determination of the Weakest bus

The rank of the system buses needs to be determined by improving voltage stability. The weakest bus in the system, which has the lowest maximum reactive capacity, is given this rank. Figure 3 displays the flow chart of the software to assess the weakest bus and the load bus range based on the two FVSI & L_{mn} indices. Moreover, the maximum reactive power of all the load buses corresponding to the two indices is calculated. Running the load flow software is the first step. The device parameter that was obtained was used for the index calculation. The freight buses are checked one at a time. In each stage, the reactive power on the tested bus is gradually raised by 0.01 MVAR. When the index reaches one, the programmer progresses to a new bus, only the reactive power on each load bus is modified incrementally. The key explanation for the voltage failure may be that the power system cannot supply the reactive power or an intemperate absorption of the system's reactive power [8].

Figure 4 illustration the margin of all the load buses' reactive capacity in the IEEE 30 bus test system corresponding to FVSI index. The same results are presented in tables 1&2 below where the load buses are ranked relative to the maximum reactive power.

Figure 4 and the first row of table 1 show that bus 30 is ranked 1 with the smallest maximum reactive power (25.9 MVAR), which indicates that bus 30 is the weakest bus of the system. The FVSI value is 0.9634 corresponding to the line (27-30), while bus 7 has the highest maximum reactive capacity, the last bus in the rank (170.9 MVAR). That implies that Bus 7 is the system's healthiest bus.
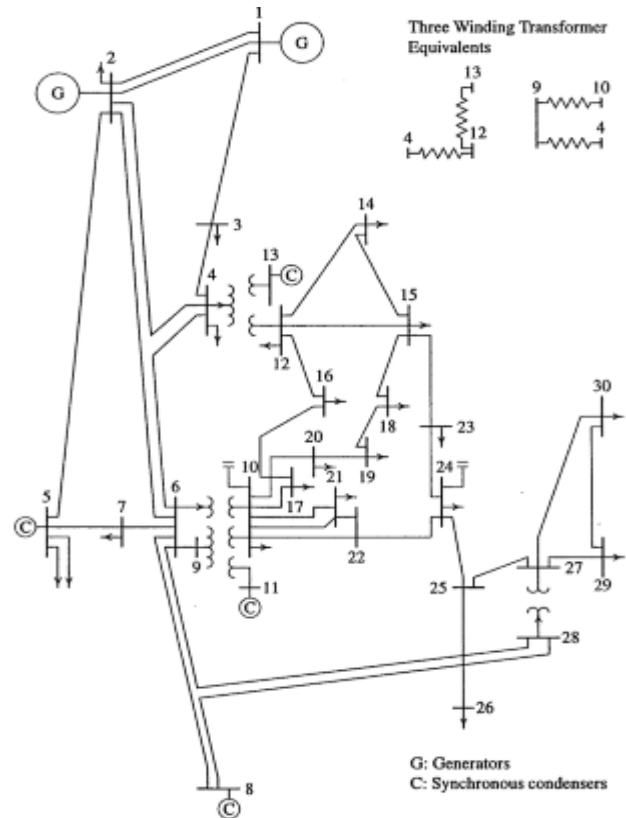

Fig 2. Single line diagram of IEEE 30 bus system.

Table 2, on the other hand, indicates outcomes dependent on Lmn. Oh, index. This table shows exactly the same results as Table 1, i.e., the bus ranking begins with bus 30, the weakest bus, finishes with bus 7, the safe bus, and the lowest maximum reactive power (25.9 MVAR), and the highest is (161.9 MVAR).
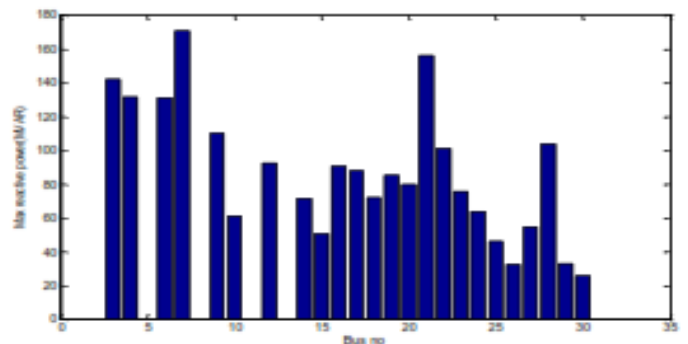

Fig. 4. Margin of reactive power of all the load buses in IEEE 30 bus test system corresponding to FVSI index.
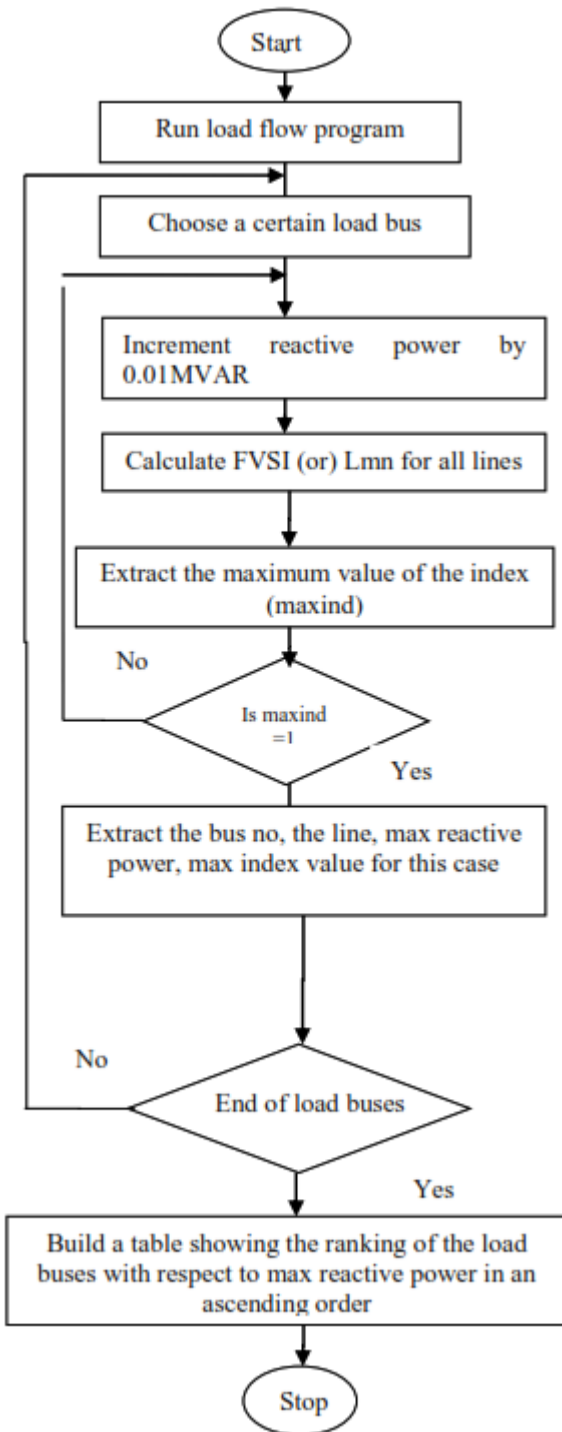
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Fig 3. A general flowchart for obtaining bus ranking corresponding

Using the L_{mn} index for bus ranking confirms bus ranking outcomes using the FVSI index, as is evident from the above discussion. The FVSI index bus rankings result in this analysis are verified by the results of the previous study [12], which can be considered a confirmation of the results.

Figure 5 shows the voltage profile with increasing reactive power on bus 30, the weakest bus, and the variation of the FVSI indices of the two lines connected to bus 30.

Table 2 Bus ranking with Lmn values

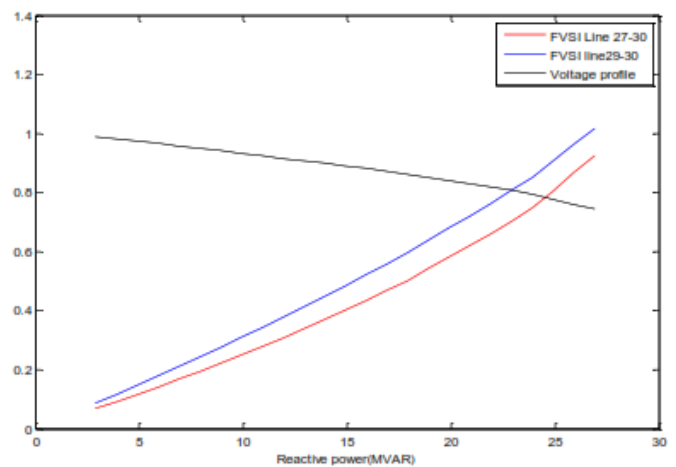| Rank	Bus no	Qmax	from	to	Lmn
1	30	25.9	27	30	0.97591
2	26	29.3	25	26	0.98521
3	29	32.9	27	29	0.99941
4	25	45.0	24	25	0.97201
5	15	49.5	14	15	0.98841
6	27	55	28	27	0.99011
7	10	62	6	10	0.98331
8	24	63.7	23	24	097961
9	14	68.6	12	14	0.99031
10	18	70.9	15	18	0.99741
11	23	73.6	15	23	0.98361
12	20	78.7	10	20	0.98441
13	19	85.4	18	19	0.97871
14	16	88.8	12	16	0.99621
15	17	89.8	16	17	0.99681
16	12	92.5	4	12	0.99561
17	22	102.0	10	22	0.99271
18	28	103.0	8	28	0.99631
19	9	111.0	6	9	0.99521
20	4	136.0	2	4	0.99531
21	6	138.0	2	6	0.99431
22	3	149.2	1	3	0.99811
23	21	157.2	10	21	0.98621
24	7	161.9	5	7	0.99471

Fig 5. Variation of voltage and FVSI indices with reactive power load at bus

From Figure 5, as is obvious, the bus voltage decreases with increasing reactive power. Also, as reactive power increases, the value of the indices of the two lines increases. Also, line 29-30's FVSI hits its limit, 1, at 25.9 MVAR.

B. Constant power factor load changes

In practical power systems, the actual and reactive load generally differs from the same percentage; this means constant power. It is, therefore, assumed that as the load increases, the power factor remains constant. The index of voltage stability is determined by increasing all load buses to a constant power factor [9,3]. The loads are raised in steps before the system's load flow diverges. The system's voltage profile for the base case and 1.5 load factor is shown in

Figure 6. From this statistic, it was evident that bus 30 is the weakest bus, as seen in the previous section. The figure demonstrates that at heavy loading conditions, the voltage at bus 30 decreased to 0.89.
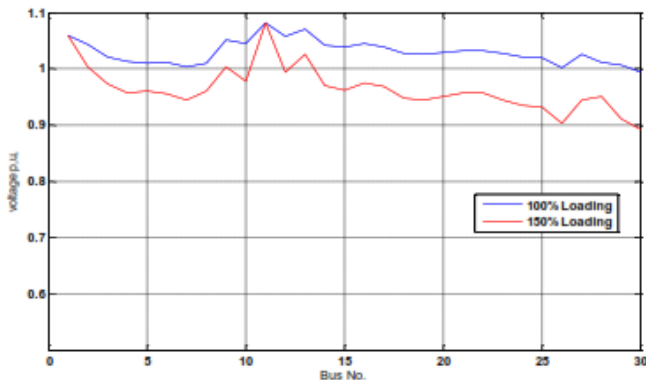

Fig.6. Voltage profile of the system for base load and 150% loading

The variance of FVSI indices of the two lines linked to bus 30 with the loading factor is shown in Figure 7. Until the load flow solution no longer converges, the index increases with the loading factor. The values of the indexes are within the boundaries of equilibrium.
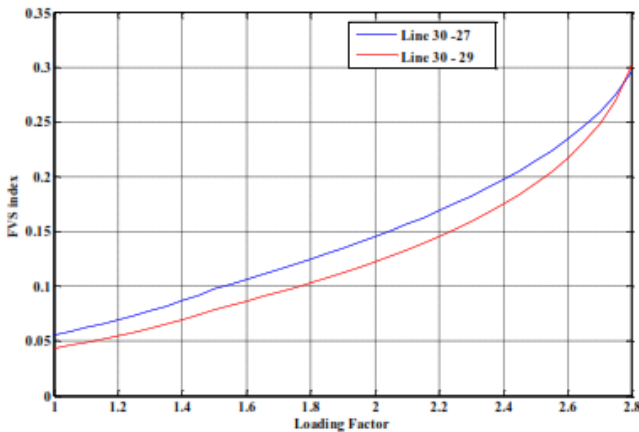

Fig .7. variation of FVSI indices with loading factor at bus 30

C. With different FACTS compensators comparison system performance

1. The best location for the addition of shunt compensator Bus 30 (the weakest bus) is Providing reactive support for shunt. For different values of reactive power compensation at bus 30 with full reactive power load, Table 3 represents FVSI and per unit bus voltage (25.9MVAR).

2. The thyristor-controlled series compensator (TCSC) is added to the series compensator, To the 27-30 line, which is the best position for series reimbursement. Different TCSC values, table 4 reflects FVSI and per unit bus voltage.

3. Shunt compensation on 30 bus is added on all shunt and sequence compensators. In addition to that, series compensation is applied to line 27-30. For different series values and shunt compensation, table 5 represents FVSI and per unit bus voltage.

Table. 4.FVSI and pre unit bus voltage with shunt compensation.

$Q_{comp\,(MVAR)}$	FVSI	V(p.u)
2	0.851	0.7591
4	0.763	0.8181
6	0.680	0.8391
8	0.596	0.8621
10	0.520	0.8811
12	0.447	0.8991
14	0.377	0.9161

Table 5. FVSI and per unit voltage difference of TCSC

X_{TCSC}	FVSI	V(p.u)
0.1Xline	0.901	0.7751
0.2Xline	0.852	0.7871
0.3Xline	0.813	0.7981
0.4Xline	0.778	0.8141
0.5Xline	0.771	0.8251
0.6Xline	0.798	0.8371
0.7Xline	0.892	0.8481

Table 6. FVSI and per unit voltage for different values of series & shunt compensation

QShunt (MVAR)	X TCSC	FVSI	V (p.u.)
2	0.1Xline	0.803	0.8041
4	0.2Xline	0.683	0.8341
6	0.3Xline	0.582	0.8601
8	0.4Xline	0.495	0.8861
10	0.5Xline	0.430	0.9061
12	0.6Xline	0.384	0.9241
14	0.7Xline	0.363	0.9401

Table 3 illustrations that shunt FACTS are very useful, resulting in a rapid improvement of the FVSI. While table 4 shows that 0.771, which is relatively high, is the best value obtained. The voltage of the bus is also still low at 0.848 p.u. No noticeable difference in the FVSI and Bus voltage values is shown in Table 5 compared to Table 3. Enhancement in FVSI and bus voltage is also largely due to shunt compensation.

D. with shunt FACTS controller system performance

Clearly, at bus 30, the weakest bus in the system, the appropriate place to have shunt reactive backup is. The shunt FACTS controller's capabilities can be calculated by adding such reactive power increments before the voltage on this bus becomes 1PU. It has been determined as 15MVAR at 1.5 loading factor, for instance. The voltage profile of the device at 1.5 loading factor with and without shunt FACTS is shown in figure 8.
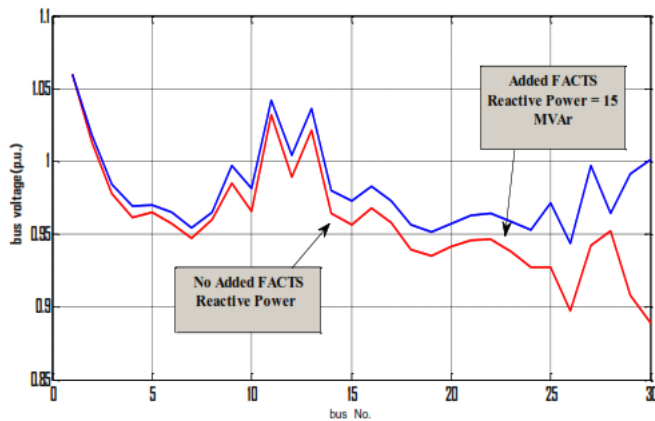
Fig 8. Voltage profile of the system at 1.5 loading factor with and without shunt FACTs

V. CONCLUSION

Recently, several voltage stabilities indexes have been presented. These indices are used to show the collapse distance of the voltage stabilization form. To discovery the weakest bus in the IEEE 30-bus test system, two of these indices, the line voltage stability index (Lmn) and the FVSI fast voltage stability index, are used. The findings suggest that the worst bus is Bus 30. This bus is the best shunt recompense spot.

In the first test, A FACT involves a shunt to increase bus voltage and series to reduce line tension. In the first test, FACTS compensators are linked to the weakest bus. The FACTS part is linked to the weakest line in the second test. The FACTS components in the third test are related to the weakest bus and the weakest line. The results show that the best improvement in voltage stability is given by shunt compensation.

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