Power System Technology
ISSN:1000-3673

Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

Stability Assessment of Multi-Bus Power Networks for Predicting System Collapse

Manish Parihar[1], Dr. M.K. Bhaskar[2], Dr. Dharmendra Jain

[1,3] Ph. D scholar, Department of Electrical Engineering, M.B.M University, Air Force, Area, Jodhpur, 342011, Rajasthan, India.

[2]Professor, Department of Electrical Engineering, M.B.M University, Air Force, Area, Jodhpur, 342011, Rajasthan, India.

Corresponding author(s). E-mail(s): [1]manish.pariharee@gmail.com;

Abstract: Voltage stability is an important consideration in power system operation, and the development of voltage stability indices is a key aspect of ensuring the reliability and security of the power grid. In this work, newly constructed voltage stability indices have been discussed that are designed to predict the closeness of a multibus system to voltage collapse. These stability indices are based on the analytical expression of complex power, which allows for a more accurate characterization of the system's voltage stability. By using these indices, operators can gain a better understanding of the system's stability and take appropriate actions to prevent collapse. To test the effectiveness of the newly developed index, it was applied to the IEEE bus system. The results showed that the index was able to accurately predict voltage instability or the proximity of a collapse. This is an important step in improving the reliability and security of the power grid, as it allows operators to take preemptive measures to avoid voltage collapse. Overall, the development of these new voltage stability indices is a positive step towards improving the performance of power systems. By providing a more accurate and reliable prediction of voltage instability, these indices can help prevent costly and potentially dangerous system failures.

Keywords: Voltage collapse, Voltage stability indexes, weakest bus, Power system networks, Blackout, Voltage instability

Introduction:

Power system interconnections have become more widespread in recent years, resulting in increased reliability and the ability to balance energy generation and demand. However, there is an increased danger of system disruptions and cascade failures with the rise in demand, which can lead to blackouts. To avoid system blackouts, the power system must be analyzed in terms of voltage stability under a wide range of system circumstances. As evident in the literature,

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

the primary goal of voltage stability analysis is to determine the system's maximum load-ability limit and the reasons for voltage instability (Reddy (2011)). Whenever electricity fails, the importance of electrical power becomes apparent (Matthewman and Byrd (2014)). If the power system fails to deliver electricity, millions of people are left without power for an unknown period of time known as power failure, power outages, or blackouts. The blackouts mostly happened due to voltage collapse conditions (Kulkarniirlekar (2015); Parihar and Bhaskar (2018)). When a line trips, the rest of the lines must carry the power, thus consuming more reactive power and reducing the voltage at the load center without affecting the frequency. Shortage of reactive power causes more voltage drop at stressed line loading conditions. Therefore, the voltage becomes as a key stress indicator of the power system (Chakrabarti et al (2010); Sauer (2005)). It is necessary to do a power system study in terms of voltage stability. Many alternative analytical approaches have been proposed in earlier research works, to provide a better knowledge of the phenomena, evaluate the systems in operating scenarios, and develop appropriate control measures to prevent voltage instability situations (Khan (2008);Basu (2000)). There are varieties of tools available for assessing whether a system is voltage stable or not and how close the system is to instability. These tools are called voltage stability indices. These indices help the system planner and operators to know the condition of voltage stability in a power system. In the past literature, various voltage stability indices have been proposed for assessing voltage stability over the last decade(Danish et al (2019); Elemary et al (2022)).Several strategies for mitigating voltage instability have recently been developed (Mokred et al (2023); Parihar et. al. (2024)). Voltage collapse can be avoided or mitigated if a thorough study is conducted to identify the weak bus or node where reactive power compensation (RPC) can be installed. FACTS Controllers have been around for a long time and play an important role in power systems (Gadal et al (2023)). To improve power factor and control voltage level flexible alternating current transmission systems (FACTS) devices are utilized. To reduce instability in power systems, evolution algorithms such as PSO, artificial intelligence, genetic algorithms (GA), artificial neural networks (ANN), bee colonies, and others have been widely used (Gupta and Mallik (2023)). This paper presents an alternate stability index used to predict the occurrence of voltage collapse. The voltage stability study was performed sequentially on the IEEE 5-bus test system, IEEE 14 bus, IEEE 30 bus system and showed promising results. In the stability analysis, the line that gives the indices value close to unity will be taken as the most critical line or bus that may lead to instability of the whole system. At this point, maximum of power system loading is achieved. Power system becomes unstable at this point. This point is known as maximum loading point/critical point/ voltage collapse point. The suggested technique was validated by studying the test system using the power voltage curve (P-V curve) analysis method. The results showed that the established stability index is a helpful tool for forecasting voltage collapse by ranking the weakest buses and critical lines of the network. Furthermore, it is compared with other established indices to

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

check its performance. 2 Methodology The development of new stability indices for predicting voltage collapse is an important area of research in power systems. By providing more accurate and reliable predictions of voltage instability, these indices can help prevent costly and potentially dangerous system failures. The stability index developed in this paper is derived by first obtaining the current equation through a line in a 2-bus system as shown in below figure 1. Consider a transmission line in which a generator with sending-end bus voltage |Vi | ∠δi , supplying complex power Sj to a receiving-end voltage |Vj | ∠δj through a transmission line represented by its ABCD parameters.

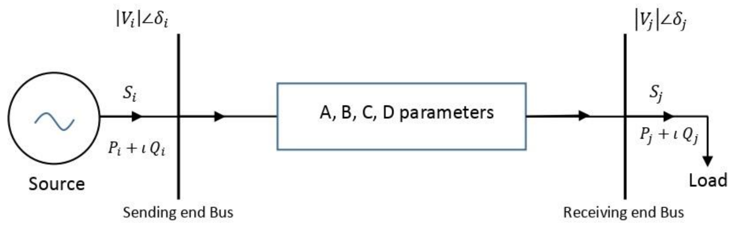


Fig. 1 Single line diagram of a two-bus system

The important considerations in the design and operation of a transmission line are the determination of voltage drops, line losses, and efficiency of transmission. These values are greatly influenced by the line parameters namely, resistance (R), inductance (L), and capacitance(C) of the transmission line. In recent years, many methods have been developed that calculate voltage regulation, power transfer, and efficiency of transmission lines, etc. These methods provide an opportunity to understand the effect of the parameters of the line on bus voltage and the flow of power, and secondly, this helps develop an overall understanding of what is occurring in the electric power system (Saadat (1999)).

An analytical expression for complex power, real power has been formulated using exact representation of a transmission line with ABCD parameters using elementary mathematics and receiving end circle diagram. These ABCD parameters are useful in the determination of line performance and its calculation, values of generalized circuit constant known as ABCD parameters can be determined by using line parameters. Let the generalized line constants be expressed as A∠α, B∠β, C∠c, D∠Δ. The complex power at the receiving end is given by the expression:

$$S_j = P_j + \iota Q_j = V_j I_j^* \quad (1)$$

Where I_j^* is the conjugate of the receiving end current I_j . In a two-port representation of a transmission line, the sending end voltage and current are expressed in terms of the receiving end voltage and current for the network as

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

$V_i = AV_j + \ BI_j$ (2)

$I_i = CV_j + \ DI_j$ (3)

Thus receiving end current for k^th^ iteration can be expressed as

$$\mathrm{I_j} = \frac{V_i^{(k)} - \mathrm{A}\, V_j^{(k)}}{\mathrm{B}} = \frac{\left|V_i^{(k)}\right| \angle\delta_i^{(k)} - \mathrm{A}\angle\alpha\ V_j^{(k)} \angle\delta_j^{(k)}}{\mathrm{B}\angle\beta} = \left(\frac{\left|V_i^{(k)}\right|}{\mathrm{B}}\angle\delta^k - \beta\right) - \left(\frac{A}{\mathrm{B}} V_j^{(k)} \angle\alpha - \beta\right) \quad (4)$$

So conjugate of I_j,

$$I_j^* = \left(\frac{V_i^{(k)}}{\mathrm{B}}\angle\beta - \delta^k\right) - \left(\frac{A}{\mathrm{B}} V_j^{(k)} \angle\beta - \alpha\right) \quad (5)$$

When the value of I ∗ j in equation (1) is substituted, the receiving end complex power is:

$$S_j = P_j + jQ_j = \left(\frac{V_j^{(k)} V_i^{(k)}}{\mathrm{B}}\angle\beta - \delta^k\right) - \left(\frac{A}{B} V_j^{2(k)} \angle\beta - \alpha\right) \quad (6)$$

Real power and reactive power at the receiving end can be determined by separating the real and reactive components.

$$P_j = \left(\frac{V_j^{(k)} V_i^{(k)}}{\mathrm{B}} \cos\beta - \delta^k\right) - \left(\frac{A}{B} V_j^{2(k)} \cos\beta - \alpha\right) \quad (7)$$

$$Q_j = \left(\frac{V_j^{(k)} V_i^{(k)}}{\mathrm{B}} \sin\beta - \delta^k\right) - \left(\frac{A}{B} V_j^{2(k)} \sin\beta - \alpha\right) \quad (8)$$

The transmission lines are usually operated with constant sending end and receiving end voltages, so one component of each of receiving and sending end powers is a fixed phasor while the other component is a phasor of constant magnitude and variable angle. The loci of complex powers at receiving Sj and sending end Si are, therefore, circles drawn from the tip of constant phasors or radius. The circle drawn with receiving end real and reactive power components as the horizontal and vertical axis coordinates is called the receiving end power circle diagram. The above equations (7) and (8) can be rewritten as:

$$P_j + \left(\frac{A}{B} V_j^{2(k)} \cos\beta - \alpha\right) = \left(\frac{V_j^{(k)} V_i^{(k)}}{\mathrm{B}} \cos\beta - \delta^k\right) \quad (9)$$

$$Q_j + \left(\frac{A}{B} V_j^{2(k)} \sin\beta - \alpha\right) = \left(\frac{V_j^{(k)} V_i^{(k)}}{\mathrm{B}} \sin\beta - \delta^k\right) \quad (10)$$

Squaring and adding equations (9) and (10) we have

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

$$[\,P_j + \left(\frac{A}{B}V_j^{2(k)}\cos\beta-\alpha\right)]^2 + \left[Q_j + \left(\frac{A}{B}V_j^{2(k)}\sin\beta-\alpha\right)\right]^2$$
$$= \left[\frac{V_j^{(k)}V_i^{(k)}}{\mathrm{B}}\right]^2 [\cos^2(\beta-\delta^k)+\sin^2(\beta-\delta^k)]$$

Or,

$$[P_j + \left(\frac{A}{B}V_j^{2(k)}\cos\beta-\alpha\right)]^2 + \left[Q_j + \left(\frac{A}{B}V_j^{2(k)}\sin\beta-\alpha\right)\right]^2 = \left[\frac{V_j^{(k)}V_i^{(k)}}{\mathrm{B}}\right]^2$$

The above equation represents the equation of circle $(x-h)^2 + (y-g)^2] = r^2$. Where, x-coordinate of the center of circle is (h) = $-\left(\frac{A}{B}V_j^{2(k)}\cos\beta-\alpha\right)$ and y-coordinate of the center of circle (g)= $-\left(\frac{A}{B}V_j^{2(k)}\sin\beta-\alpha\right)$, radius of the circle= $\frac{V_j^{(k)}V_i^{(k)}}{\mathrm{B}}$. As we know complex power at receiving end is given by:

$$S_j = P_j + jQ_j = \left(\frac{V_j^{(k)}V_i^{(k)}}{\mathrm{B}}\angle\beta-\delta^k\right) - \left(\frac{A}{B}V_j^{2(k)}\angle\beta-\alpha\right) \quad (11)$$

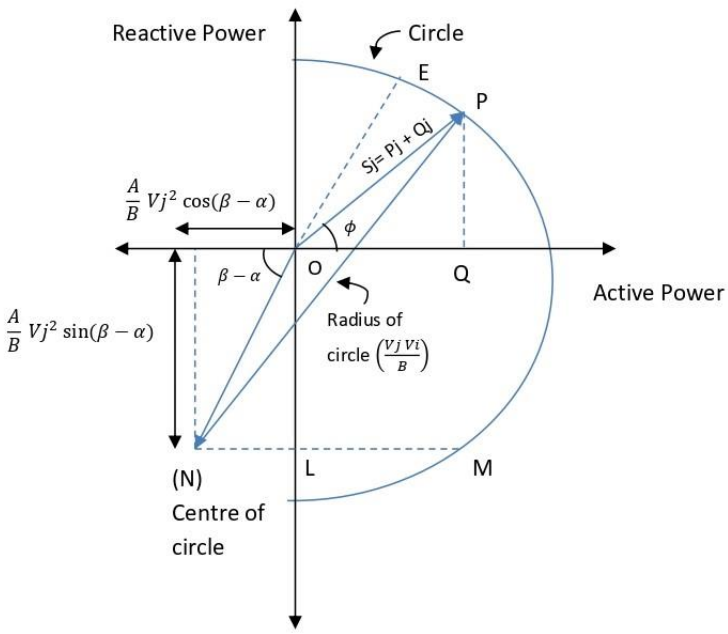


Fig. 2: Receiving end circle diagram

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

The equation 11 represents a circle for the varying value of δ^k with position of center indicated by $-\left(\frac{A}{B}V_j^{2(k)}\angle\beta-\alpha\right)$ and radius by $\frac{V_j^{(k)}V_i^{(k)}}{B}$, where A, B, C, D are generalised line constant and δ^k is power angle as shown in figure 2. By analysing figure 2, it is noted that:

$\mathrm{ON}=\frac{A}{B}V_j^{2(k)}$; $\mathrm{OP}=S_j$; $\mathrm{NP}=\frac{V_j^{(k)}V_i^{(k)}}{B}$, and

$$\delta' = \delta^k-\alpha \quad ; \quad \phi' = 180^\circ-(\beta-\alpha)+\phi \tag{12}$$

Φ is the power factor angle, is positive for lagging power factor and negative for leading power factor. In ΔONP

$$\frac{OP}{\sin\delta'} = \frac{NP}{\sin\phi'} = \frac{ON}{\sin\theta} \tag{13}$$

Solving the preceding equations yields:

$$S_j = \frac{V_i^{2(k)}\sin\theta\sin\delta'}{AB\sin^2\phi'} \tag{14}$$

Also from △ ONP $\theta = 180^\circ-(\phi'+\delta')$ Therefore,

$$S_j = \frac{V_i^{2(k)}\sin(\phi'+\delta')\sin\delta'}{AB\ \sin^2\phi'} \tag{15}$$

Thus for receiving end apparent power to be maximum put $(dS_j/d\delta^k) = (dS_j/d\delta') = 0$. Solution of equation 15 provides a critical value of power angle δ, critical value of voltage, and maximum value of complex power.

$$\delta'_{cr} = 90^\circ-\frac{\phi'}{2}, \text{ and } \quad \delta_{cr} = 90^\circ-\frac{\phi'}{2}+\alpha \tag{16}$$

$$S_{jmax} = \frac{V_i^{2(k)}}{4\,AB\sin^2\frac{\phi'}{2}} \tag{17}$$

$$V_{jcr} = \frac{V_i^{(k)}}{2A\sin\frac{\phi'}{2}} \tag{18}$$

Hence, the stability index SPVI (Stability Prediction Voltage Index) and SPPI (Stability Prediction Power Index) can be defined as:

$$SPVI = \left[1-\frac{V_j^{(k)}-\frac{V_i^{(k)}}{2A\sin\frac{\phi'}{2}}}{\frac{V_i^{(k)}}{2A\sin\frac{\phi'}{2}}}\right]$$

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

$$SPPI = \left[1 - \frac{\frac{V_i^{2(k)}}{4\, AB \sin^2 \frac{\phi'}{2}} - S_i}{\frac{V_i^{2(k)}}{4\, AB \sin^2 \frac{\phi'}{2}}} \right]$$

For stable operation values of the stability index discussed above should be less than unity i.e. SP V I < 1 and SP P I < 1. It must not be violated for any of the nodes and lines of the network. Violation in the above condition may lead to voltage collapse in the entire system.

Simulation Results and Discussion The IEEE 5-bus test system was utilized to investigate the applicability of the suggested index. The IEEE 5-bus network consists of two generators, G1 and G2, placed on buses 1 and 4, respectively, three load buses located on buses 2, 3, and 5, and seven transmission lines. Power systems analysis is a critical part of any transmission or distribution system. Load flow calculations on a 5-bus system is done using Newton Raphson method and the output of load flow analysis is used for calculating the proposed SPPI and SPVI index.

Table 1 Stability prediction power index values for different loading conditions

Loading at node 3 P(p.u.)	Line 1-2	Line 1-4	Line 2-3	Line 4-3	Line 4-5	Line 5-3	Line 4-2
0	0.173	0.089	0.0059	0.082	0.158	0.082	0.088
.1	0.495	0.226	0.091	0.398	0.273	0.198	0.330
1.50	0.712	0.369	0.178	0.598	0.366	0.355	0.490
1.70	0.808	0.445	0.232	0.700	0.421	0.447	0.576
1.90	0.930	0.558	0.330	0.840	0.512	0.594	0.707
1.95	0.967	0.621	0.398	0.909	0.569	0.686	0.781
2.00	0.980	0.646	0.427	0.932	0.592	0.721	0.809

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

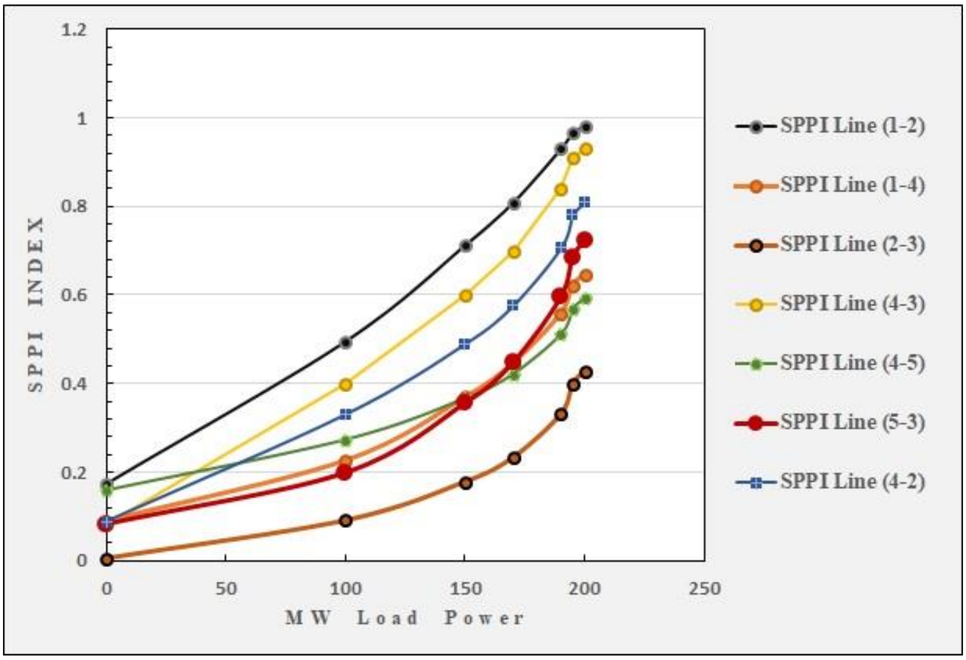


Fig. 3 SPPI Index variation with load

The stability indexes are calculated using the base case scenario. Now, gradually increase the system load from the base load case to the peak load case and calculate the stability index value. The load has been changed at one particular node Bus 3 at a time and all the other nodes in the system fixed at their base values. The value of stability indices presented in Table 1 and Table 2 increases with increased loading. SPPI gives information related to the weakest and strongest transmission lines in the network. Both real and reactive power are varied in the same proportion. As the load increases on bus 3, power flow increases in the line, and values of proposed indices vary. At 2.00 p.u. active power loading SPPI value for the transmission line between bus 1 to bus 2 is .98, thus at heavy lagging load line 1-2 is the most critical line and line 4-3 is the second most critical line as depicted in figure 3.

Table 2 Stability Prediction Voltage index values for different loading conditions

Loading at node 3 P (p.u.)	Bus1	Bus2	Bus3	Bus4	Bus5
0	0.300	0.307	0.158	0.333	0.351
.1	0.3002	0.471	0.388	0.381	0.453
1.50	0.3007	0.619	0.583	0.458	0.568
1.70	0.3007	0.701	0.689	0.501	0.634
1.90	0.3007	0.849	0.866	0.571	0.741
1.95	0.3007	0.931	0.972	0.615	0.808
2.00	0.3007	0.964	1.008	0.632	0.834

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

SPVI helps identify the weakest and most stable bus in the power system network. At heavy loading, bus 3 SPVI value is 1.008 indicating the point of voltage collapse is reached. If the further load is incremented, then the system will enter into an unstable state. Bus 3 is the weakest node and bus 2 is the second weakest node as shown in figure 4.

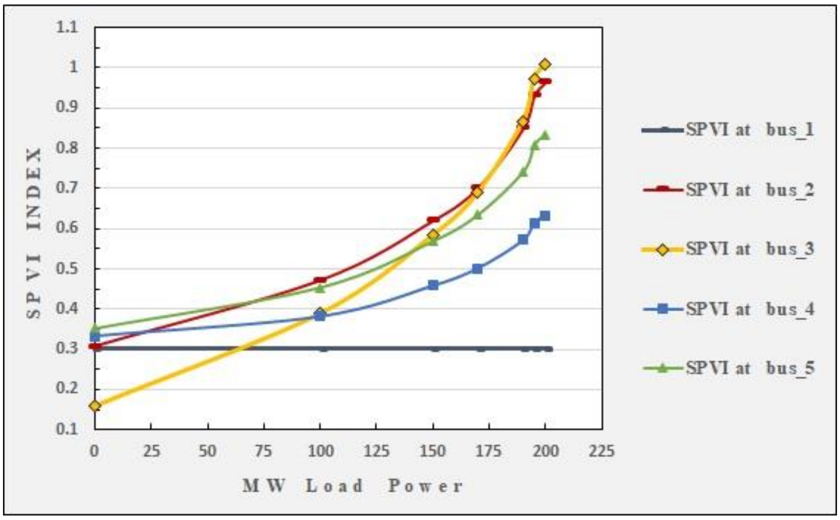


Fig. 4 SPVI Index variation with load

To study the loadability of the interconnected network. The power voltage curve is drawn at the lagging power factor angle. As the load increases from zero, the powervoltage point travels from the top left part of the curve to the tip of the curve. It is observed that as the power increases, the voltage drops. The tip corresponds to the maximum power that can be delivered to the load. On further addition, load will cause the system to collapse. Bus 1 shows a flat voltage profile, whereas Bus 3 and Bus 2 show a higher drop in voltage.

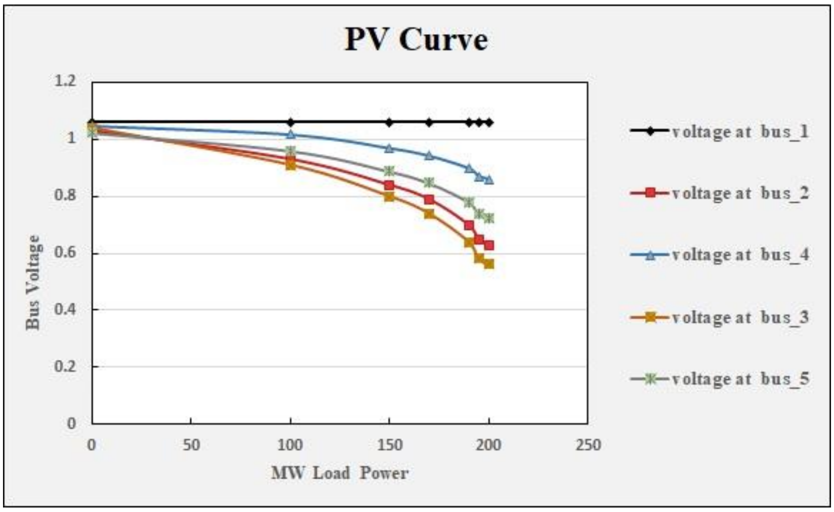


Fig. 5 Variation of bus voltage with load variation (PV-Curve)

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

PV curve results are compared with the stability index discussed in the previous section, and it is concluded that as the operating point moves towards the tip of the curve, the index value approaches unity and bus voltage decreases as indicated in figure 5. Table 3 gives the values of $\boldsymbol{\phi'}$, δcri, critical value of voltage, maximum value of complex power, maximum real power and limiting values of reactive power by using equation 17 and 18 for heavy lagging load power factor angle.

Table 3 Maximum Complex Power, Critical Angle and Voltage of Transmission Lines

Line from - to	ϕ' Degree	δ_cri degree	S_{j_max}	P_{j_max}	Q_{j_Lim}	V_{j_cr}
1-2	147.2040	16.513	1.2137	0.9478	0.75815	0.619462
1-4	149.9819	15.1243	4.769	3.5757	3.155963	0.628148
2-3	152.3133	13.958	3.331	2.4062	2.304494	0.52445
4-3	149.3567	15.436	1.048	0.7940	0.685526	0.605016
4-5	139.0733	20.578	1.664	1.4337	0.845339	0.620087
5-3	164.1445	8.043	0.529	0.2990	0.436648	0.620033
4-2	151.9034	14.163	1.036	0.7539	0.711791	0.59775

To validate the effectiveness of the above-proposed method, the results are also compared with other stability indicators, namely the Line Collapse Proximity Index (LCPI) (Tiwari et al (2012)) and the Fast Voltage Stability Index (FVSI) (Musirin and Rahman (2002)), as shown in Table 4.

Table 4 Line stability indices for 5 bus test system with heavy lagging load

Line	LCPI	FVSI	SPPI	Remark
1-2	0.951818	0.705542	0.980317	Critically stressed
1-4	0.606419	0.484253	0.646533	
2-3	0.402739	0.330858	0.427704	
4-3	0.89735	0.693337	0.932795	stressed
4-5	0.517817	0.361757	0.592094	
5-3	0.710469	0.643625	0.721609	
4-2	0.77286	0.624491	0.809182	

By analyzing the data values presented in Table 4, it is observed that the proposed index presents an accurate instrument for voltage instability prediction. The line that connects bus 1 to bus 2 is the most critical line. The line from bus 2 to bus 3 is the most stable line in the

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

network. The values of SPPI index is higher than LCPI and FVSI. FVSI cannot give reliable proof of voltage instability since it ignores the impacts of real power as well as line resistance, shunt parameters, and power angle. Whereas LCPI is derived using ABCD parameters of the transmission line, and its value is calculated by utilizing the discriminant of the roots of the receiving end voltage quadratic equation for a given operating condition.

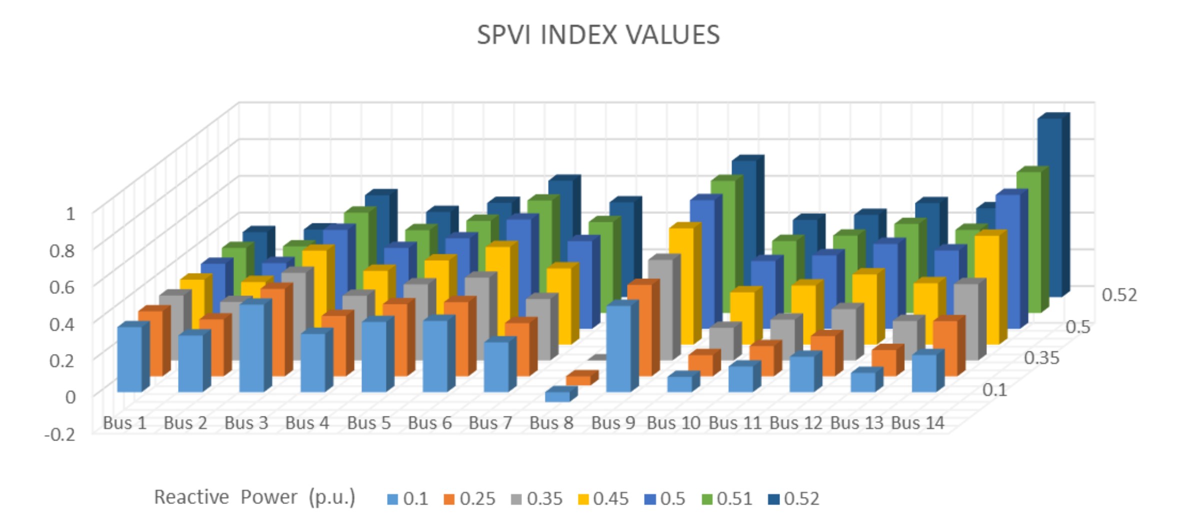


Fig. 6 SPVI Index variation with reactive power

Thus, the LCPI index is close to SPPI index values, but the overall performance of the proposed index is better than that of the LCPI and FVSI indicators. Additionally, the suggested index's adaptability has been tested on the IEEE 14 bus system. The SPVI index varies as the reactive loading on the candidate bus rises, as evident in Figure 6. When there is a significant reactive load of 0.5191 p.u. at node 14, the index SPVI rises to 0.97139 for bus 14 and 0.74189 for bus 9. It implies that node 9 is the second weakest bus in the network and node 14 is the most crucial bus. The results of the analysis are presented in Table 5.

Table 5 Line stability indices for 14 bus test system with lagging load

Bus loading at node 14	**Line From-to**	**LCPI**	**FVSI**	**SPPI**	**Remark**
Q= 0.25 p.u.	1-5	0.159341	0.009247	0.405698	
	3-4	0.111937	0.062661	0.137208	
	4-9	0.019758	0.019587	0.208036	
	5-6	0.088405	0.08736	0.29917	
	6-13	0.116299	0.084025	0.127989	
	7-8	0.153695	0.153695	0.147928	
	7-9	0.053648	0.053592	0.096791	

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

	9-10	0.011675	0.007217	0.014372	
	9-14	0.220069	0.181508	0.241394	
	13-14	0.20044	0.168413	0.216207	
Q= 0.45 p.u.	1-5	0.272656	0.10928	0.516194	
	3-4	0.176125	0.146758	0.181077	
	4-9	0.196422	0.192795	0.409581	
	5-6	0.236945	0.231586	0.491597	
	6-13	0.203902	0.157928	0.225435	
	7-8	0.178939	0.178939	0.171478	
	7-9	0.12135	0.121064	0.17813	
	9-10	0.009668	0.004798	0.013056	
	9-14	0.487749	0.40452	0.586191	
	13-14	0.438547	0.363703	0.514525	
Q= 0.519 p.u.	1-5	0.376084	0.207632	0.614403	4
	3-4	0.207806	0.186572	0.210124	13
	4-9	0.326137	0.31684	0.576442	5
	5-6	0.350024	0.338378	0.647638	3
	6-13	0.274412	0.21826	0.30813	11
	7-8	0.204131	0.204131	0.194769	14
	7-9	0.178103	0.177416	0.248412	12
	9-10	0.008643	0.003087	0.012691	20
	9-14	0.66887	0.552914	0.872465	1
	13-14	0.610321	0.505095	0.770813	2

The IEEE 14 bus system has 14 buses, 5 generators, and 11 loads. Only a few of the buses' application outcomes are shown in this table because of space restrictions. Identify the weak buses in the system by progressively raising the reactive load at the specified node bus until voltage collapse occurs.

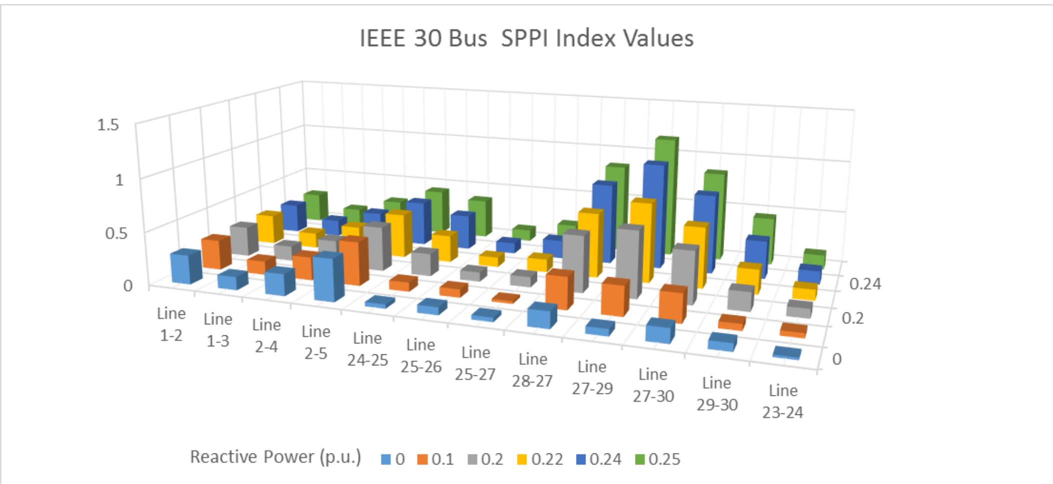
Reactive power demand increases are reflected in voltage stability indicators. For transmission from bus 9 to bus 14, the proposed index and other indices have the maximum value. As a result, the system's most vulnerable branch is 9–14. It demonstrates that the proposed strategy is consistent with earlier approaches to identify the system's most susceptible branch. Taking into consideration both line resistance and shunt admittance, the results of the previous case studies corroborate the conclusion that the proposed index performs better and more accurately than existing indices in predicting the stressed state of a transmission line. The stressed state of a line is indicated by how close the suggested index is to unity

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

Table 6 Line stability indices for IEEE 30 bus test system with heavy lagging load

Bus loading at node 29	Line From-to	LCPI	FVSI	SPPI	Remark
Q= 0.25 p.u.	1-2	0.138279	0.006143	0.286838	
	1-3	0.092239	0.075224	0.161381	
	2-4	0.188306	0.086191	0.286532	
	2-5	0.181033	0.023466	0.439883	
	24-25	0.328777	0.261977	0.382946	
	25-26	0.104013	0.074606	0.111354	
	25-27	0.182687	0.147351	0.205916	
	28-27	0.556549	0.539433	0.854252	weak
	27-29	0.811405	0.625598	1.164625	critical
	27-30	0.636696	0.429445	0.858747	stressed
	29-30	0.492019	0.4918	0.454438	

Higher index values imply that lines are over stressed and will collapse with increasing load, whereas smaller index nodes and branches are assumed to have sufficient voltage stability margins. The application outcomes of the suggested index for assessing the voltage stability of the IEEE 30 bus system are shown. The suggested index is computed under high loading circumstances in order to show how well it can identify weak buses and unstable areas. In general, reactive power flow has a significant impact on voltage stability. The reactive load is progressively increased to the point of voltage collapse at a certain node, while the loads at other nodes stay constant. Table 6 presents the case studies of a few branches. At node 29, the reactive power is progressively rising to 0.25 p.u. A system blackout was triggered by additional load added to node 29, indicating that loading is critical and approaching the voltage collapse point. The transmission line between bus 27 to bus 29 becomes most critical with the proposed index showing a value of 1.164625.



Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

However, the FVSI is determined to be significantly less than unity, and the LCPI displays a value of 0.8114. It would be feasible to determine that the proposed index precisely reflects the voltage stability of the system by comparing it with the LCPI and FVSI. Figure 7's bar chart illustrates how the SPPI index varies with load reactive power. Weak branches and areas can be recognised using this chart. It has been determined that Branches 27–29, 27–30, and 28–27 represent vulnerable locations within the system.

Conclusion

This paper discusses two indicators to prevent voltage instability in the system. Voltage stability analysis aims to anticipate the point of voltage collapse using the proposed stability indexes (SPPI and SPVI). To begin, a load flow program was created to achieve the power flow solution in the system. The load flow computation results are used to compute the stability index values for each line or bus in the system. Starting with the base case, the load flow computation is steadily raised until it stops converging. The values of the stability indices SPPI and SPVI are shown in Tables 1 and 2. To accurately measure overall system performance, all load buses in the system are tested sequentially. The results of this experiment indicate the system's voltage stability condition, weak bus, and crucial line. The voltage stability condition and the critical line referred to for particular buses and lines are determined by the SPPI and SPVI values close to 1.00. Similar results were obtained when the system was analyzed using the PV curve analysis technique as implied in the figure 5. When the point of singularity is reached or the value of the Jacobian matrix's determinant is zero, the system fails to converge around the voltage collapse point. The values of ϕ', δcri, critical value of voltage, maximum value of complex power, maximum real power and limiting values of reactive power for heavy lagging load power factor angle are presented in Table 3. After doing a comparative study with two other voltage stability indices (FVSI and LCPI), the results of the study showed that the new stability index was effective in predicting the occurrence of voltage collapse and identifying potential instability issues in the system. The results of this comparative analysis are indicated in Table 4. This is an important step in improving the reliability and security of power systems, as it allows operators to take preemptive measures to prevent voltage collapse and blackouts.

References

1. C. M. Reddy, "Power System Voltage Stability Analysis", Department of Electrical Engineering IIT Hyderabad, June 2011.
2. Steve Matthewman, "Blackouts: a sociology of electrical power failure", socialspace journal.eu. June 2013
3. Sudeep Dattatraya Kulkarniirlekar, "Blackouts in The Power System", International Journal of Electrical And Electronics Research, Vol. 3, Issue 4, Pp: (1-7), Month: October - December 2015.

Power System Technology
ISSN:1000-3673
Received: 06-11-2024 Revised: 15-12-2024 Accepted: 05-01-2025

4. Manish Parihar, M.K. Bhaskar "Review of Power System Blackout" International Journal of Research and Innovation in Applied Science -IJRIAS vol.3 issue 6 June 2018, pp.08-13
5. Abhijit Chakrabarti, de Abhinandan, Mukhopadhyay A.K.,Kothari D.P., 2010, An Introduction to Reactive Power Control and Voltage Stability in Power Transmission Systems, PHI Learning Pvt. Ltd.
6. Peter W. Sauer, University of Illinois at Urbana-Champaign, Reactive Power and Voltage Control Issues in Electric Power System.
7. Asfar Ali khan, “PV Curves for Radial Transmission Lines”. Accepted for Publication in The Proceedings of National Systems Conference 2007 to be Held at Manipal Institute of Technology from 14-15 Dec.2007.
8. Basu, K. P., “Power Transfer Capability of Transmission Line Limited by Voltage Stability: Simple Analytical Expressions” IEEE Power Engineering Review, September 2000, pp 46-47.
9. Danish, M.S.S.; Senjyu, T.; Danish, S.M.S.; Sabory, N.R.; K, N.; Mandal, P. A Recap of Voltage Stability Indices in the Past Three Decades. Energies 2019, 12, 1544. https://doi.org/10.3390/en12081544.
10. Atef A. Elemary , M.M.R Ahmed , Ebtisam M. Saied , Mohamed A. Hamdy, 2022, Power System Voltage Stability Index, International Journal Of Engineering Research & Technology (Ijert) Volume 11, Issue 09 (September 2022).
11. Mokred, S., Wang, Y., & Chen, T. (2023). A novel collapse prediction index for voltage stability analysis and contingency ranking in power systems. Protection and Control of Modern Power Systems, 8(1), 7.
12. Parihar, Manish, and Dharmendra Jain. "Quantitative Analysis of the Impact of Phantom Power on Voltage Stability in Electrical Power System Networks." JOURNAL OF TECHNICAL EDUCATION: 310. https://www.researchgate.net/publication/381109529_Quantitative_Analysis_of_the_Impact_of_Phantom_Power_on_Voltage_Stability_in_Electrical_Power_System_Networks
13. Gadal, R., Oukennou, A., El Mariami, F., Belfqih, A., & Agouzoul, N. (2023). Voltage Stability Assessment and Control Using Indices and FACTS: A Comparative Review. Journal of Electrical and Computer Engineering, 2023.
14. Gupta, S. K., & Mallik, S. K. (2023). Fast assessment of the voltage stability using reconfigured power system network and artificial neural network approaches. Engineering Research Express, 5(3), 035047.
15. Saadat, Hadi, 2002.Power System Analysis, 2nd ed., New York: McGraw-Hill.
16. Tiwari, R., Niazi, K. R., & Gupta, V. (2012). Line collapse proximity index for prediction of voltage collapse in power systems. International Journal of Electrical Power & Energy Systems, 41(1), 105-111.
17. Musirin, I., & Rahman, T. A. (2002, July). Novel fast voltage stability index (FVSI) for voltage stability analysis in power transmission system. In Student conference on research and development (pp. 265-268). IEEE.