Journal of Advanced Research in Applied Mechanics

Journal homepage: https://semarakilmu.com.my/journals/index.php/aram/index
ISSN: 2289-7895

Modal Analysis Method to Determine Voltage Stability in Electric Power Systems

Purwoharjono[1,*], Rudy Gianto[1], Zainal Abidin[1]

[1] Department of Electrical Engineering, Faculty of Engineering, Universitas Tanjungpura Pontianak, Indonesia

ARTICLE INFO

Article history:
Received 3 January 2025
Received in revised form 10 June 2025
Accepted 23 September 2025
Available online 10 December 2025

Keywords:
Modal Analysis; Voltage Stability; Eigenvalue; Bus Participation Factor

ABSTRACT

The modal analysis method is used to determine the stability of bus voltage in the electric power system based on the eigenvalue and participation factor of the bus. The Java-Bali 500 kV electrical system will be used as a sample for the research. This research begins with a power flow simulation to identify buses whose voltages are outside the specified tolerance value. Afterward, an assessment of the eigenvalue on each load bus is conducted, which can be used to determine the stability of each bus based on the weakest system mode. Then, the bus participation factors are assessed, to identify which buses have the lowest values. The result shows that all eigenvalues are positive, confirming the stability of the Java-Bali 500 kV electricity system.

1. Introduction

The increasing need for electrical energy for household and industrial services also impacts the improvement of good system stability to maintain the continuity of service operations. In such a situation, it can be said that the system is stable [1-5].

Unstable system conditions are undesirable because they may have a fatal impact on the failure (collapse) of operations in the electric power system and potentially lead to partial or total power outages for all electricity customers [6-8].

This situation is certainly not desired to occur, as it can result in disruptions to electricity service for consumers, which may harm many people. One of the factors that cause the instability in the electric power system is voltage collapse. [9-10].

The common issue in the electric power system is voltage collapse, which also often occurs in many other countries. This issue becomes very critical in the operation of electric power systems. The sudden overload issue happened due to loads exceeding the system capacity or the trip of one unit of the power plant. If this problem is not resolved immediately, it will cause voltage collapse, which endanger the electric power system [11-14].

One method that can be used to solve the problem above is the Modal Analysis method. This method is expected to provide a clear picture of the voltage stability in the power system. Stability

* *Corresponding author.*
E-mail address: purwo.harjono@ee.untan.ac.id

https://doi.org/10.37934/aram.144.1.7283

analysis is very needed for future planning when new loads will be added to the power system. The modal analysis method can determine system stability by starting by calculating the smallest eigenvalue of the Reduction Jacobian matrix, which the size of this eigenvalue then will provide a measure of the proximity of the system to collapse. Then by determining the value of the participation factor, we can identify the weak buses or nodes of the system under study [15-25].

2. Material and Method

In this method, the first step is to input the data for power flow from buses, namely active (P) and reactive (Q) power injection, voltage magnitude (V), and voltage phase angle (δ). The parameters of the line include resistance, reactance, transmission line length, and conductor. Newton-Raphson's method is used to determine the power flow equation and obtain the Jacobian matrix, which is used to analyze the voltage stability of the system.

Based on the equation and the substitution results, the Jacobian Reduction matrix is obtained and used to determine the eigenvalue values as a parameter of voltage stability from a system based on the Modal Analysis method.

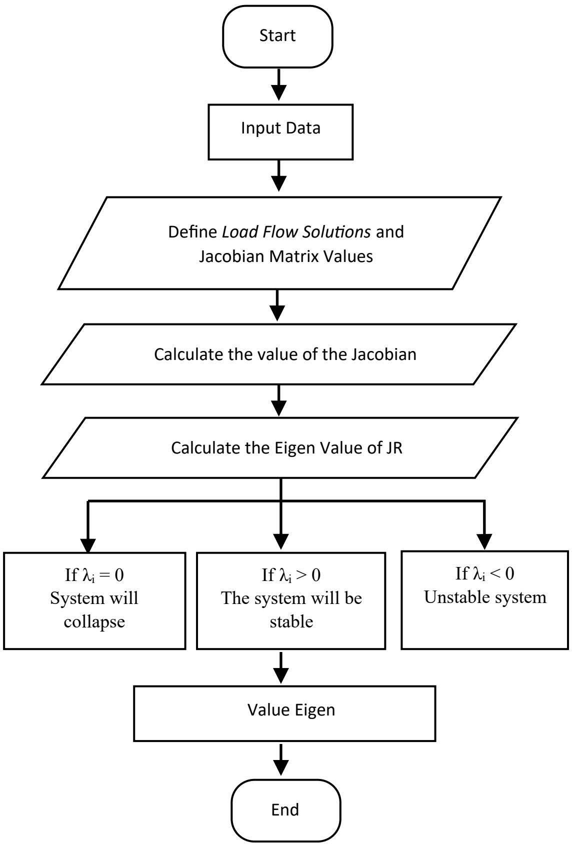

Fig. 1. Modal analysis method flow chart

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix} \begin{bmatrix} \Delta \theta \\ \Delta V \end{bmatrix} \quad (1)$$

Where:

$\begin{bmatrix} J_{11} & J_{12} \\ J_{21} & J_{22} \end{bmatrix}$ = Jacobian matrix

Assuming $\Delta P = 0$, then:

$$0 = J_{11}\Delta\theta + J_{12}\Delta V$$

$$\Delta\theta = -J_{11}^{-1} J_{12} \Delta V \quad (2)$$

$$\Delta Q = J_{21}\Delta\theta + J_{22}\Delta V \quad (3)$$

Substitutions (2) and (3) are obtained:

$$\Delta Q = J_R \Delta V \quad (4)$$

$$J_R = \lfloor J_{22} \quad - J_{21} \quad J_{11}^{-1} \quad J_{12} \quad \rfloor \quad (5)$$

J_R is a Jacobian matrix reduction system, such that equation (6):

$$\Delta V = J_R^{-1} \Delta Q \quad (6)$$

Voltage instability is seen from the eigenvalue of the JR matrix. Analysis of the results of the JR eigenvalue is as follows:

$$J_R = \xi \, \Delta \eta \quad (7)$$

Where:

ξ = vector eigen right J_R

Γ = vector eigen left J_R

η = diagonal eigenvalues J_R

By changing J_R become J_R^{-1} Retrieved:

$$J_R^{-1} = \xi \, \Delta^{-1} \, \eta \quad (8)$$

With $\Phi\Gamma = I$

Substitutions (5) and (8), then:

$$\Delta V = \xi \, \Delta^{-1} \, \eta \, \Delta Q \quad (9)$$

$$\Delta V = \sum_i \frac{\xi_i \, \eta_i}{\lambda_i} \, \Delta Q \quad (10)$$

Equation 6 is obtained:

$$\eta \, \Delta V = \Delta^{-1} \, \eta \, \Delta Q \quad (11)$$

$$V = \Delta^{-1} \, Q \quad (12)$$

where:

$V = \eta \, \Delta V$ is a modal voltage vector *analysis*

$Q = \eta \, \Delta Q$ is a modal analysis reactive power vector

So that it obtains:

$$\Delta V_{mi} = \frac{1}{\lambda_i} \Delta Q_{mi} \quad (13)$$

So that:

- If λi > 0, the voltage is stable
- If λi = 0, voltage *collapse*
- If λi < 0, the voltage is unstable.

3. Results and Analysis

3.1 Java-Bali Electricity Data 500 kV

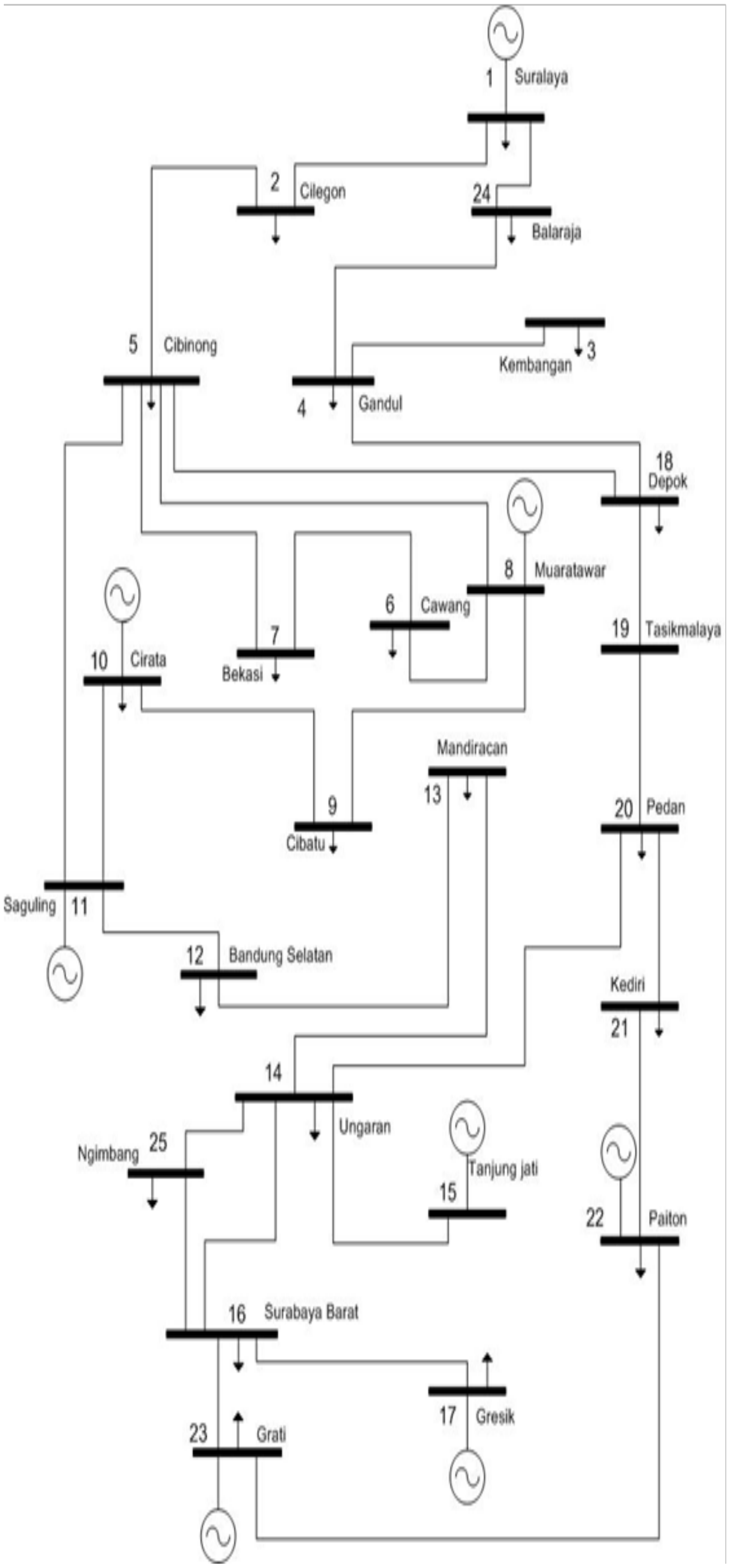

Fig. 2. One-line diagram of Java-Bali 500 kV electrical system

Load and plant data on the Java-Bali 500 kV system, as shown in Table 1.

Table 1
Load And Plant Data

Bus Number	Name of Bus	Code For Bus	Generator		Load	
			MW	MVAR	MW	MVAR
1	Suralaya	Swing	3211.6	1074.1	219	67
2	Cilegon	load	0	0	333	179
3	Kembangan	load	0	0	202	39
4	Gandul	load	0	0	814	171
5	Cibinong	load	0	0	638	336
6	Cawang	load	0	0	720	217
7	Bekasi	load	0	0	1126	331
8	Muaratawar	Generator	1760	645	0	0
9	Cibatu	load	0	0	1152	345
10	Cirata	Generator	948	200	597	201
11	Saguling	Generator	698.4	150	0	0
12	Bandung Selatan	load	0	0	477	254
13	Mandiracan	load	0	0	293	65
14	Ungaran	load	0	0	193	118
15	Tanjung Jati	Generator	1321.6	90	0	0
16	Surabaya Barat	load	0	0	508	265
17	Gresik	Generator	900	366.3	127	92
18	Depok	load	0	0	342	95
19	Tasikmalaya	load	0	0	133	33
20	Pedan	load	0	0	365	101
21	Kediri	load	0	0	498	124
22	Paiton	Generator	3180	917.3	448	55
23	Grati	Generator	398.6	100	180	132
24	Balaraja	load	0	0	732	287
25	Ngimbang	load	0	0	264	58

While the data of Java-Bali 500 kV line system as shown in Table 2.

Table 2
Line Data

No	From Bus	To Bus	R pu	X pu	½ B pu
1	1	2	0.000626	0.007009	0
2	1	24	0.003678	0.035333	0
3	2	5	0.013133	0.146926	0.003531
4	3	4	0.001513	0.016928	0
5	4	18	0.000694	0.006669	0
6	5	7	0.004442	0.042675	0
7	5	8	0.006212	0.059678	0
8	5	11	0.004111	0.045995	0.004421
9	6	7	0.001974	0.018962	0
10	6	8	0.005626	0.054048	0
11	8	9	0.002822	0.027113	0
12	9	10	0.00274	0.026324	0
13	10	11	0.001475	0.014168	0
14	11	12	0.001958	0.021902	0
15	12	13	0.006991	0.067166	0.006429

16	13	14	0.013478	0.12949	0.012395
17	14	15	0.013534	0.151407	0.003638
18	14	16	0.015799	0.151785	0.003632
19	14	20	0.009036	0.086815	0
20	16	17	0.001395	0.013399	0
21	16	23	0.003986	0.044597	0
22	18	5	0.000819	0.007868	0
23	18	19	0.014056	0.157248	0.015114
24	19	20	0.015311	0.171288	0.016464
25	20	21	0.010291	0.115128	0.011066
26	21	22	0.010291	0.115128	0.011066
27	22	23	0.004436	0.049625	0.00477
28	24	4	0.002979	0.028623	0
29	25	14	0.02348	0.225581	0.010097
30	25	16	0.005967	0.057324	0

3.2 Results of Power Flow and Loss Simulation on Line

To obtain simulation results of the power flow and losses on this transmission line using the Newton-Raphson method, as obtained in Table 3 and Table 4.

Table 3
Newton-Raphson Method Power Flow Simulation Results

Bus	Voltage	Adjective	Load		Power Plant		Injected
No	**Bus**		**MW**	**MVAR**	**MW**	**MVAR**	**MVAR**
1	1.02	0	219	67	1452.007	1614.532	0
2	1.016	-0.153	333	179	0	0	0
3	0.961	-1.567	202	39	0	0	0
4	0.962	-1.358	814	171	0	0	0
5	0.964	-0.809	638	336	0	0	0
6	0.964	-2.539	720	217	0	0	0
7	0.958	-2.897	1126	331	0	0	0
8	1	0.679	0	0	1760	1737.158	0
9	0.983	0.428	1152	345	0	0	0
10	0.98	1.926	597	201	948	746.738	0
11	0.97	2.493	0	0	698.4	400.799	0
12	0.948	4.077	477	254	0	0	0
13	0.911	11.35	293	65	0	0	0
14	0.907	28.816	193	118	0	0	-93.6
15	1	41.008	0	0	1321.6	626.718	0
16	0.963	37.84	508	265	0	0	0
17	0.97	38.44	127	92	900	507.87	0
18	0.96	-0.941	342	95	0	0	-89.96
19	0.875	10.441	133	33	0	0	-188.56
20	0.874	25.628	365	101	0	0	-185.22
21	0.902	34.017	498	124	0	0	-189.13
22	1	44.837	448	55	3180	1124.494	-100.63
23	0.99	41.465	180	132	398.6	580.617	0

24	0.982	-1.386	732	287	0	0	0
25	0.946	35.347	264	58	0	0	0
	Total		**10361**	**3565**	**10658.61**	**7338.924**	**-847.1**

Table 4
Results of simulated losses on system channels Jawa-Bali 500 kv

From Bus	To Be Bus	Power Flow			Channel Loss	
		MW	MVAR	MVA	MW	MVAR
1		1233.007	1547.532	1978.677		
	2	441.100	530.243	689.730	0.286	3.205
	24	791.907	1017.289	1289.183	5.875	56.443
2		-333.000	-179.000	378.061		
	1	-440.814	-527.038	687.085	0.286	3.205
	5	107.814	348.038	364.355	1.721	12.330
3		-202.000	-39.000	205.730		
	4	-202.000	-39.000	205.730	0.069	0.775
4		-814.000	-171.000	831.767		
	3	202.069	39.775	205.947	0.069	0.775
	18	-963.449	449.512	1063.153	0.847	8.139
	24	-52.621	-660.287	662.380	1.411	13.559
5		-638.000	-336.000	721.069		
	2	-106.093	-335.708	352.073	1.721	12.330
	7	795.703	75.232	799.252	3.054	29.341
	8	-474.315	-528.172	709.887	3.369	32.369
	11	-1169.818	6.488	1169.836	6.056	59.484
	18	316.523	446.160	547.034	0.264	2.534
6		-720.000	-217.000	751.990		
	7	333.765	289.088	441.555	0.414	3.979
	8	-1053.765	-506.088	1168.994	8.274	79.496
7		-1126.000	-331.000	1173.643		
	5	-792.649	-45.891	793.976	3.054	29.341
	6	-333.351	-285.109	438.646	0.414	3.979
8		1760.000	1737.158	2472.917		
	5	477.684	560.540	736.470	3.369	32.369
	6	1062.039	585.584	1212.780	8.274	79.496
	9	220.276	591.034	630.748	1.123	10.787
9		-1152.000	-345.000	1202.551		
	8	-219.153	-580.247	620.254	1.123	10.787
	10	-932.847	235.247	962.052	2.622	25.196
10		351.000	545.738	648.869		
	9	935.469	-210.052	958.762	2.622	25.196
	11	-584.469	755.789	955.417	1.402	13.467
11		698.400	400.799	805.234		
	5	1175.875	52.996	1177.068	6.056	59.484
	10	585.871	-742.323	945.668	1.402	13.467
	12	-1063.345	1090.125	1522.851	4.825	53.984
12		-477.000	-254.000	540.412		
	11	1068.171	-1036.141	1488.146	4.825	53.984
	13	-1545.171	782.141	1731.848	23.407	213.775
13		-293.000	-65.000	300.123		
	12	1568.578	-568.36	1668.376	23.407	213.775
	14	-1861.578	503.366	1928.432	60.593	561.663
14		-193.000	-211.600	286.398		
	13	1922.171	58.29	1923.054	60.593	561.663
	15	-1292.584	-308.736	1328.943	29.016	317.981
	16	-920.409	-171.003	936.160	16.806	155.109

	20	539.609	304.678	619.683	4.217	40.513
	25	-441.787	-94.836	451.851	5.783	38.208
15		1321.600	626.718	1462.669		
	14	1321.600	626.718	1462.669	29.016	317.981
16		-508.000	-265.000	572.965		
	14	937.215	326.111	992.331	16.806	155.109
	17	-771.858	-404.897	871.612	1.142	10.972
	23	-1388.545	-412.012	1448.382	9.014	100.841
	25	715.187	225.798	749.985	3.617	34.755
17		773.000	415.870	877.768		
	16	773.000	415.870	877.768	1.142	10.972
18		-342.000	-184.960	388.811		
	4	964.296	-441.373	1060.508	0.847	8.139
	5	-316.260	-443.626	544.816	0.264	2.534
	19	-990.036	700.038	1212.529	22.724	228.725
19		-133.000	-221.560	258.414		
	18	1012.760	-471.314	1117.059	22.724	228.725
	20	-1145.760	249.754	1172.665	27.645	284.101
20		-365.000	-286.220	463.839		
	14	-535.392	-264.165	597.016	4.217	40.513
	19	1173.405	34.347	1173.908	27.645	284.101
	21	-1003.013	-56.402	1004.598	13.586	134.539
21		-498.000	-313.130	588.264		
	20	1016.599	190.941	1034.375	13.586	134.539
	22	-1514.599	-504.071	1596.276	32.136	339.446
22		2732.000	968.864	2898.710		
	21	1546.735	843.517	1761.791	32.136	339.446
	23	1185.265	125.347	1191.875	6.307	61.111
23		218.600	448.617	499.042		
	16	1397.559	512.853	1488.687	9.014	100.841
	22	-1178.959	-64.236	1180.707	6.307	61.111
24		-732.000	-287.000	786.253		
	1	-786.032	-960.846	1241.399	5.875	56.443
	4	54.032	673.846	676.008	1.411	13.559
25		-264.000	-58.000	270.296		
	14	447.570	133.043	466.925	5.783	38.208
	16	-711.570	-191.043	736.769	3.617	34.755
Total power losses					**297.607**	**2926.825**

3.3 Bus Voltage Profile Simulation Results

The simulation results of the bus voltage profile on the Java-Bali 500 kV system are shown in Figure 3.

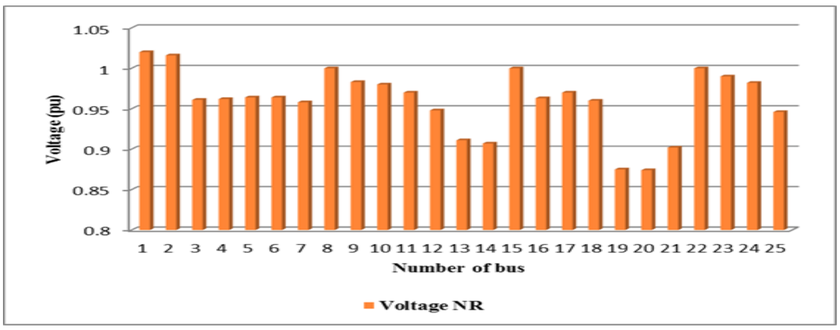

Fig.3. Voltage profile

The simulation results of Figure 3 represent the initial simulation of power flow analysis using the Newton-Raphson method. At the beginning of this simulation, there were 8 problematic buses, namely bus 12 = 0.948 pu, bus 13 = 0.911 pu, bus 14 = 0.907 pu, bus 19 = 0.875 pu, bus 20 = 0.874 pu, bus 21 = 0.902 pu, bus 24 = 0.982 pu and bus 25 = 0.946 pu.

3.4 Eigenvalue Value Simulation Results

The simulation results of Eigenvalue values for the following simulations are obtained in Table 5.

Table 5
Eigenvalue value simulation results

Bus No	Bus Name	Eigenvalue
2	Cilegon	434.65
3	Kembangan	221.11
4	Gandul	150.43
5	Cibinong	120.19
6	Cawang	118.32
7	Bekasi	77.55
9	Cibatu	72.48
12	Bandung Selatan	61.31
13	Mandiracan	59.85
14	Ungaran	41.32
16	Surabaya Barat	5.11
18	Depok	24.09
19	Tasikmalaya	20.84
20	Pedan	9.66
21	Kediri	16.87
24	Balaraja	12.87
25	Ngimbang	13.79

Based on Table 5, the eigenvalue (λ) from the entire load bus has a positive eigenvalue or (λ>0), which means that all load buses have a stable system voltage. The highest eigenvalue (λ) occurred at load two buses (Cilegon) with 434.65, while the lowest eigenvalue (λ) happened at load 16 bus (West Surabaya) with 5.11.

3.5 Bus Participation Factor Simulation Results

To assess the stability of the bus voltage in the Java-Bali 500 kV electrical system, the Bus Participation Factor is used, which is determined from the highest mode value indicating the weakest mode value.

Table 6
Bus Participation Factor Value Simulation Results

Bus No	Bus Name	Participation Factor Value
2	Cilegon	0.00001
3	Kembangan	0.02189
4	Gandul	0.01734
5	Cibinong	0.00989
6	Cawang	0.00448
7	Bekasi	0.00637

9	Cibatu	0.00002
12	Bandung Selatan	0.00144
13	Mandiracan	0.02181
14	Ungaran	0.05830
16	Surabaya Barat	0.00087
18	Depok	0.01738
19	Tasikmalaya	0.41333
20	Pedan	0.25740
21	Kediri	0.14989
24	Balaraja	0.00774
25	Ngimbang	0.01186

Table 6 and Figure 4 indicate that the load bus with the biggest participation value is load bus 19 (Tasikmalaya) with 0.41333, while the smallest factor participation value is load bus 2 (Cilegon) with 0.000001. Therefore, load bus 19 (Tasikmalaya) has a higher chance of becoming unstable and experiencing a voltage drop in this scenario.

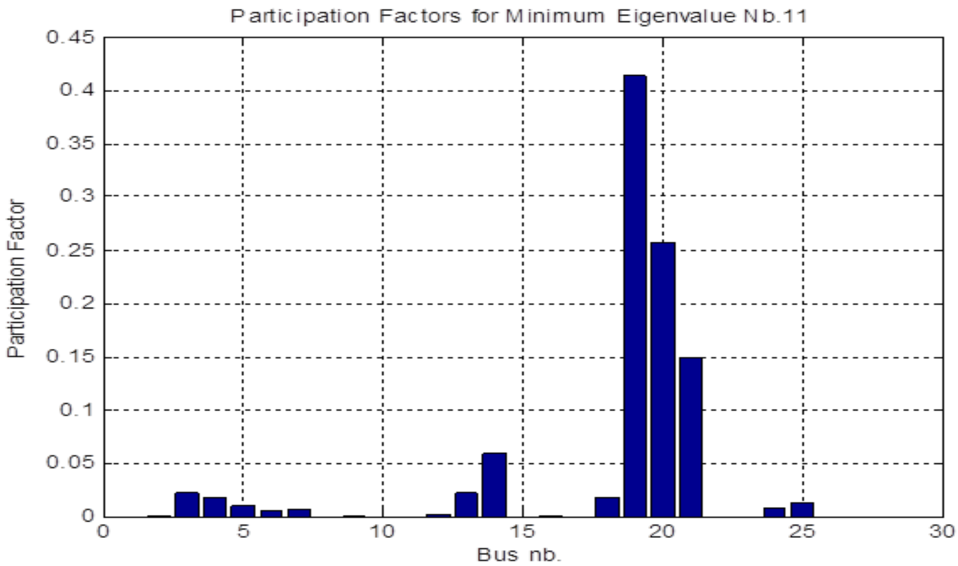

Fig.4. of load bus participation factors against system mode instability

4. Discussion

The increasing issue of voltage collapse has become a concern, both by PLN as the electricity provider and the society as consumers or users of electrical power who directly experience the impact. Numerous public complaints question the voltage collapse that occurs beyond the allowable tolerance limit of ± 10%. Technically it will disrupt the performance of consumer electrical equipment such as various types of lighting, heating devices, and electric motors. In some cases, it will even lead to direct damage to these devices.

This issue is extremely important in the operation and planning of electric power systems. An electric power system will be considered stable when all the variables, including bus voltage and system frequency, are also stable.

Voltage stability is highly dependent on the system's ability to maintain stable voltage conditions on all buses, both during normal operation conditions and after a fault.

In this study, researchers will take the location of the Java-Bali Interconnection System operating in 150 kV voltage levels to analyze the voltage stability. The Modal Analysis method is expected to provide a clear picture of voltage stability in the Java Bali 150 kV interconnection system.

The stability analysis is needed in future planning when the 150 kV Java Bali interconnection system is adding a new load. The Modal analysis method can determine the stability of the system.

5. Conclusion

Based on the initial power flow results using the Newton-Raphson method and the Bus Participation Factor values obtained from the Capital Analysis method, it is concluded that the voltage value in the Java-Bali 500 kV electrical system ranges from 0.874 pu to 1.020 pu. The Newton-Raphson power flow simulation shows that 8 buses have voltages outside the range of 0.95 ± 1.05 pu. Additionally, the eigenvalue analysis in the Java-Bali electricity system 500 kV for the entire load buses results in positive eigenvalue values.

Acknowledgment

The researcher would like to thank the Distribution System laboratory and DIPA Research Faculty of Engineering Universitas Tanjungpura for providing facilities and financial assistance during this research period.

References

[1] Isaiah Adebayo and Yanxia Sun. “New Performance Indices for Voltage Stability Analysis in a Power System.” Energies, no.10 (12) (2007): 2042; https://doi.org/10.3390/en10122042

[2] Abbas F.G. Mohmmedali, Messaoud Hamouda, and Ghaitaoui Touhami. “Impact Analysis of Distributed Solar Photovoltaic Power Generation System Integration on Power Grid Voltage Stability Using Static Techniques.” International Journal of Emerging Trends in Engineering Research Available. Volume 11. no.1 (January 2023): https://doi.org/10.30534/ijeter/2023/041112023

[3] Xinyu Liang, Hua Chai, and Jayashri Ravishankar. “Analytical Methods of Voltage Stability in Renewable Dominated Power Systems: A Review.” Electricity, no. 3(1) (2022): 75-107; https://doi.org/10.3390/electricity3010006

[4] Jian Zhang, Ruicong Ma, and Changgang Li. “Quantitative assessment of static voltage stability for power system with high-penetration wind power based on energy function.” Energy Reports. No. 12 (2024): Pp. 699–707. https://doi.org/10.1016/j.egyr.2024.06.069

[5] Xuan Zhang, Hao Yang, Dongbo Guo. “Steady-state voltage stability assessment of new energy power systems with multi-quadrant power modes.” Energy Reports. Volume 9 (December 2023): Pages 3851-3860. https://doi.org/10.1016/j.egyr.2023.02.093

[6] D. Gomila, B. A. Carreras, and O. Gomis-Bellmunt. “Analysis of the blackout risk reduction when segmenting large power systems using lines with controllable power flow.” International Journal of Electrical Power & Energy Systems. Volume 148, (June 2023): 108947. https://doi.org/10.1016/j.ijepes.2023.108947

[7] Yuan-Kang Wu, Shih Ming Chang, and Yi-Liang Hu. “Literature Review of Power System Blackouts.” Energy Procedia. Volume 141, (December 2017): Pages 428-431. https://doi.org/10.1016/j.egypro.2017.11.055

[8] Peter Stenzel, Timo Kannengießer, and Detlef Stolten. “Emergency power supply from photovoltaic battery systems in private households in case of a blackout – A scenario analysis.” Energy Procedia. Volume 155 (November 2018): Pages 165-178, https://doi.org/10.1016/j.egypro.2018.11.058

[9] Saurabh Ratra, Rajive Tiwari, K. R. Niazi. “Voltage stability assessment in power systems using line voltage stability index.” Computers & Electrical Engineering. Volume 70 (August 2018): Pages 199-211. https://doi.org/10.1016/j.compeleceng.2017.12.046

[10] Salah Mokred, Yifei Wang, Tiancong Chen. “Modern voltage stability index for prediction of voltage collapse and estimation of maximum load-ability for weak buses and critical lines identification. “ International Journal of Electrical Power & Energy Systems. Volume 145 (February 2023): 108596. https://doi.org/10.1016/j.ijepes.2022.108596

[11] M. Ginarsa, A. Soeprijanto, M.H. Purnomo. "Controlling chaos and voltage collapse using an ANFIS-based composite controller-static var compensator in power systems." International Journal of Electrical Power & Energy Systems. Volume 46. (March 2013): Pages 79-88. https://doi.org/10.1016/j.ijepes.2012.10.005

[12] Majid Moazzami, Mohammad Javad Morshed, Afef Fekih. "A new optimal unified power flow controller placement and load shedding coordination approach using the Hybrid Imperialist Competitive Algorithm-Pattern Search method for voltage collapse prevention in power system. " International Journal of Electrical Power & Energy Systems. (July 2016): https://doi.org/10.1016/j.ijepes.2016.01.022

[13] Hooman Nasrazadani, Alireza Sedighi, Hossein Seifi. "Enhancing long-term voltage stability of a power system integrated with large-scale photovoltaic plants using a battery energy storage control scheme." International Journal of Electrical Power & Energy Systems. Volume 131, (October 2021): 107059. https://doi.org/10.1016/j.ijepes.2021.107059

[14] Rahmat-Allah Moradi, Roohalamin Zeinali Davarani. "Introducing a new index to investigate voltage stability of power systems under actual operating conditions." International Journal of Electrical Power & Energy Systems. Volume 136 (March 2022): 107637. https://doi.org/10.1016/j.ijepes.2021.107637

[15] Gao, B., Morrison, G., and Kundur, P. "Voltage Stability Evaluation Using Modal Analysis." IEEE Transactions Power Systems. no. 3. 8 (Aug. 1993): 1159-1171. https://doi.org/10.1109/59.260881

[16] Adnan Saif Al Mamari, Siti Fauziah Toha, Salmiah Ahmad, Ali Salim Al Mamari. "A modal analysis based on reactive power compensation on 6-bus Oman electrical grid." International Journal of Power Electronics and Drive Systems (IJPEDS) Vol. 12, No. 2 (Jun 2021): pp. 757~764 ISSN: 2088-8694, http://doi.org/10.11591/ijpeds.v12.i2.pp757-764

[17] Aneke, E. N., B. E. Ibekwe, J. C. Iyidobi, and E. N. C. Okafor. "Voltage Stability Evaluation in the Nigeria 44 Bus Grid Network Using Modal Analysis". Journal of Engineering Research and Reports 20. No.11 (2021): 80-89. https://doi.org/10.9734/jerr/2021/v20i1117411

[18] Stanislav N. Vassilyev, Igor B. Yadykin, Natalya G. Kiryanova. "Participation factors and sub-Gramians in the selective modal analysis of electric power systems." IFAC-PapersOnLineJuly 2017. Volume 50, Issue 1 (July 2017): Pages 14806-14811. https://doi.org/10.1016/j.ifacol.2017.08.2560

[19] Vinod Pottakulath, Elizabeth P. Cheriyan, R. Sreerama Kumar. "Determination of reduced order model for torsional interaction investigations using selective modal analysis – Part II: Application to practical power systems. " International Journal of Electrical Power & Energy Systems. Volume 44, Issue 1 (January 2013): Pages 454-460. https://doi.org/10.1016/j.ijepes.2012.07.060

[20] F. X. Wu, H. Wu, D. Q. Gan. "Validation of power system non-linear modal analysis methods." Electric Power Systems Research. Volume 77, Issue 10 (August 2007): Pages 1418-1424. https://doi.org/10.1016/j.epsr.2006.10.016

[21] M. H. Ibrahim, S. P. Ang, M. A. Salam. "Voltage stability assessment for solar photovoltaic penetration using Reactive Power–Voltage and Active Power–voltage modal analysis." Energy Reports. Volume 9, Supplement 10 (October 2023): Pages 486-493. https://doi.org/10.1016/j.egyr.2023.05.124

[22] Ahmad Fateh Mohamad Nor, Marizan Sulaiman, Aida Fazliana Abdul Kadir, Rosli Oma. "Voltage Instability Analysis for Electrical Power System Using Voltage Stability Margin and Modal Analysis." Indonesian Journal of Electrical Engineering and Computer Science Vol. 3, No. 3 (September 2016): pp. 655 ~ 662 https://doi.org/10.11591/ijeecs.v3.i2.pp655-662

[23] Adnan Saif Al Mamari, Siti Fauziah Toha, Salmiah Ahmad, Ali Salim Al Mamari. "A modal analysis based on reactive power compensation on 6-bus Oman electrical grid. "International Journal of Power Electronics and Drive Systems (IJPEDS). Vol. 12 No. 2 (Jun 2021): pp. 757~764 ISSN: 2088-8694. https://doi.org/10.11591/ijpeds.v12.i2.pp757-764

[24] Xinyu Liang, Hua Chai, Jayashri Ravishankar. "Analytical Methods of Voltage Stability in Renewable Dominated Power Systems: A Review. " Electricity, (3) (2022): 75–107. https://doi.org/10.3390/electricity3010006

[25] Isaiah Adebayo and Yanxia Sun. "New Performance Indices for Voltage Stability Analysis in a Power System. " Energies, 10 (2017): 2042 https://doi.org/10.3390/en10122042