

# Comparison of Voltage Stability Index Before and After Wind Turbine Penetrated to Sulsebar Interconnection Power System Using Modal Analysis Method

*by Agus Siswanto*

---

**Submission date:** 24-Sep-2020 03:58PM (UTC+0200)

**Submission ID:** 1395771154

**File name:** Gunadin\_2020\_IOP\_Conf.\_Ser.\_Mater.\_Sci.\_Eng.\_875\_012043.pdf (1.04M)

**Word count:** 4260

**Character count:** 19821

**PAPER · OPEN ACCESS**

## Comparison of Voltage Stability Index Before and After Wind Turbine Penetrated to Sulsebar Interconnection Power System Using Modal Analysis Method

To cite this article: I C Gunadin *et al* 2020 *IOP Conf. Ser.: Mater. Sci. Eng.* **875** 012043

View the [article online](#) for updates and enhancements.

## Comparison of Voltage Stability Index Before and After Wind Turbine Penetrated to Sulsestrabar Interconnection Power System Using Modal Analysis Method

I C Gunadin<sup>1\*</sup>, Z Muslimin<sup>1</sup>, A M Ilyas<sup>1,2</sup>, and A Siswanto<sup>1,3</sup>

<sup>1</sup>Electrical Department of Hasanuddin University, Indonesia

<sup>2</sup>Khairun University, Indonesia

<sup>3</sup>University of 17 Agustus 1945 Cirebon, Indonesia

\*Email: indarcg@mail.com

**Abstract.** Voltage stability problems and renewable energy penetration in power systems are the main issues in the electric power system at this time. This paper aims to examine the condition of voltage stability at the time before and after the entry of wind power plants in the sulsestrabar interconnection system. There are two wind power-generating units that will be studied, namely the PLTB Sidrap with a capacity of 75 MW and the PLTB Jenepono with a capacity of 72 MW. The simulation using Matlab program. From the simulation results, it can be seen that Sulsestrabar's voltage stability interconnection system at the time of the entry of PLTB Sidrap and PLTB Jenepono, has improved stability, this can be seen from the eigenvalue and bus participation factor values. From the minimum eigenvalues it can be seen that the penetration of PLTB Jenepono is slightly better than PLTB Sidrap in improving voltage stability. The condition that has the greatest influence on improving stability is when the two wind power plant enter to the Sulsestrabar interconnection power system.

### 1. Introduction

The problem of voltage stability becomes a major problem in the electric power system. As the load continues to increase, the problem of voltage stability will also increase [1]. There are many cases of blackouts in the electric power system caused by voltage stability problems [2]. For the case of a total blackout on September 30, 2007, at 09.14.24, the system load was 270 MW off with the total electrical energy not distributed at 860.42 MWh with the extinction time ranging from 4 to 7 hours. If the assumed price of electricity at that time was Rp 580 / kWh, the total loss of PT.PLN at the time of the total blackout was Rp 499,043,600.-. On the consumer side, industries in the South Sulawesi region also suffered losses with hampered their production process. Then the fundamental question arises, whether the total blackout phenomenon due to voltage instability problems can be detected early and how to anticipate so that black-out can be prevented. This study seeks to provide an initial indication (stability index) of system operating conditions, stability limits and scenarios to improve system conditions.

The construction of the Bayu Power Plant (PLTB) in Jenepono Regency with a capacity of 160 MW and in Sidrap amounting to 75 MW, is certain to begin immediately, after the South Sulawesi Provincial Government signed an MoU with PT Indo Wind Power Holdings, a subsidiary of Asia Grand Capital. The inclusion of the PLTB plant will increase the availability of electricity supply in the South Sulawesi interconnection system and is expected to be able to drive industrial growth and



Content from this work may be used under the terms of the [Creative Commons Attribution 3.0 licence](https://creativecommons.org/licenses/by/3.0/). Any further distribution of this work must maintain attribution to the author(s) and the title of the work, journal citation and DOI.

Published under licence by IOP Publishing Ltd

spur rapid economic growth in the South Sulawesi, West Sulawesi and Southeast Sulawesi regions. However, the installation of wind turbine will also cause other negative impacts including ecological impacts, noise impacts, impacts from the electricity side and others, it should also be considered before PLTB penetration [3].

This study aims to analyze the impact of the entry of PLTB on the Sulsestrabar interconnection system which is more focused on the study of the impact of the voltage stability of the electric power system. Does the PLTB penetration cause a significant effect on the Sulsestrabar electricity system and how to minimize the negative effects caused.

To monitor the stability of the system, there are several methods that are often used, including; PV and QV curves, Continuation Power Flow, L-Index. This research uses the Capital Analysis method by observing the eigen value and bus participation factor (BPF). Each bus will be sorted according to the value of its participation in unstable conditions [4].

## 2. Voltage Stability

In electric power systems which are operated in stress conditions, voltage stability becomes very important. In the planning and operation of power systems, stress stability analysis focuses on two aspects including:

1. Prediction, how close are the unstable voltage condition systems?
2. The mechanism, when voltage instability occurs, what is a factor?

Predictions provide a measure of voltage safety, while the mechanism will provide important information that is useful in the operation strategy in preventing voltage instability. The problem of voltage drop is a serious problem in the electrical system in many countries and this occurs in the system of interconnecting electricity [5].

There are several factors that can cause voltage drops including :

- Lack of reactive resources
- Heavy loading of active power
- Protection relay does not work well

Marison and Kundur have succeeded in finding a method to predict the occurrence of a voltage drop in an electric power system, this method is known as Modal Analysis. This method is based on the mechanism of calculating the smallest eigenvalue and eigenvector of the Jacobian matrix system. Eigen value has a correlation with changes in voltage values and changes in reactive power [6].

The stability of the Electric Power System can be evaluated by checking the state of the existing eigenvalue. If all eigenvalues are positive then the system is said to be stable, while the system is said to be unstable if the eigenvalue is negative. Eigenvalue of the Jacobian matrix which is zero indicates that the system is within the limits of instability [7].

The potential for voltage drop can be predicted through an evaluation of the minimum eigenvalue. The magnitude of the minimum eigenvalues indicates how close the system has fallen. By using the participation factor, the weakest bus or node can be determined.

The Q-V curve is the most commonly used method for describing voltage stability. This curve shows the sensitivity and changes in bus voltage to changes in reactive power injection and the stability limit or distance from each bus to a voltage drop condition.

The system has a stable voltage under operating conditions if on every bus in the system the magnitude of the bus voltage increases with increasing reactive power injection on the same bus. The system has an unstable voltage if at least one bus from the system has a reduced voltage magnitude when increasing reactive power injection on the same bus. In other words, the system is stable if the sensitivity of the Q-V curve is positive for each bus and unstable if the Q-V curve has a negative sensitivity on one of the buses [8].

From the results of previous research which is a collaboration of the Department of Electrical Engineering with PT. PLN Unit AP2B South Sulawesi Region, the results show that the transient stability conditions in the South Sulawesi system are very weak. The value of Critical Clearing Time

(CCT) on some buses indicating the value is below the value of 120 ms which is the standard time limit from relay work to open the Circuit Breaker (CB) [9].

From the interference data, it can be concluded that the disturbance trend in the sulseltrabar system has increased from year to year, this indicates that there is a stability problem in the interconnection system in South Sulawesi. The disturbance statistics can be seen in Figure 1.

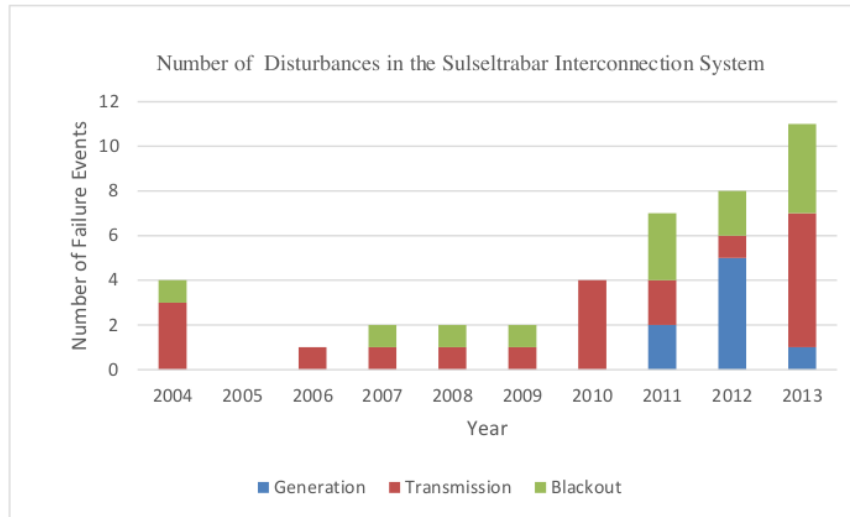


Figure 1. Statistics of the Southern Sulawesi electricity disruption

### 3. Determining the Value of Eigen Value

From Newton Raphson's Power Flow Equation obtained :

$$\begin{bmatrix} \Delta P \\ \Delta Q \end{bmatrix} = \begin{bmatrix} J_{P\theta} & J_{PV} \\ J_{Q\theta} & J_{QV} \end{bmatrix} \begin{bmatrix} \Delta\theta \\ \Delta V \end{bmatrix} \tag{1}$$

where :

- $\Delta P$  = Changes in real power on the bus
- $\Delta Q$  = Changes in reactive power on the bus
- $\Delta\theta$  = Changes in the voltage angle of the bus
- $\Delta V$  = Changes in voltage magnitude on the bus

Conventional power flow models are used to analyze system voltage stability. Voltage stability is affected by changes in active power ( $P$ ) and changes in reactive power ( $Q$ ) even though at the operating point  $P$  is kept constant, so that voltage stability only considers the relationship between increasing the value of  $Q$  and decreasing the value of voltage  $V$  [10].

It is assumed that  $\Delta P = 0$  is obtained:

$$\Delta P = 0 = J_{P\theta} \Delta\theta + J_{PV} \Delta V$$

$$\Delta \theta = -J_{P\theta}^{-1} J_{PV} \Delta V$$

$$\Delta Q = J_{Q\theta} \Delta\theta + J_{QV} \Delta V$$

Substituting Equations (2) and (3) obtains the following equation.

$$\Delta Q = J_R \Delta V \quad (2)$$

where :

$$J_R = J_{QV} - J_{Q\theta} J_{P\theta}^{-1} J_{PV}$$

$J_R$  is the Jacobian reduction matrix obtained from the system of equations (2). Then the following can be written:

$$\Delta V = J_R^{-1} \Delta Q \quad (3)$$

From equation 3 it is found that the  $J_R$  matrix represents a linear relationship between the change in voltage and the change in reactive power injection on a bus. The eigenvalues and eigenvectors of the  $J_R$  matrix are used to analyze the system's voltage stability. The voltage instability can be identified from the form of the  $J_R$  eigen value matrix [11].

Analysis of the results of  $J_R$  eigenvalues is as follows:

$$J_R = \Phi A \Gamma \quad (4)$$

where :

- $\Phi$  = right eigenvector of the  $J_R$  matrix
- $\Gamma$  = left eigenvector of the  $J_R$  matrix
- $A$  = diagonal eigenvalues of the  $J_R$  matrix

by changing  $J_R$  to  $J_R^{-1}$  we get:

$$J_R^{-1} = \Phi A^{-1} \Gamma \quad (5)$$

with :  $\Phi \Gamma = 1$

Equations (3) and (5) are substituted to obtain:

$$\Delta V = \Phi A^{-1} \Gamma \Delta Q \quad (6)$$

$$\Delta V = \sum \frac{\Phi \Gamma}{\lambda} \Delta Q \quad (7)$$

where :

$\lambda$  is eigen value, provided that:

1. If  $\lambda = 0$ , the voltage will fall because the change in reactive power will cause the voltage change to be infinite
2. If  $\lambda > 0$ , the system voltage is stable
3. If  $\lambda < 0$ , the system voltage is unstable

The minimum value of an Eigen value is a value indicating closeness to the instability condition.

#### 4. Methodology of Research

The South Sulawesi interconnection system was used as the case tested in this study. The following is shown in figure 2 single line diagram of the southern Sulawesi electricity interconnection system.

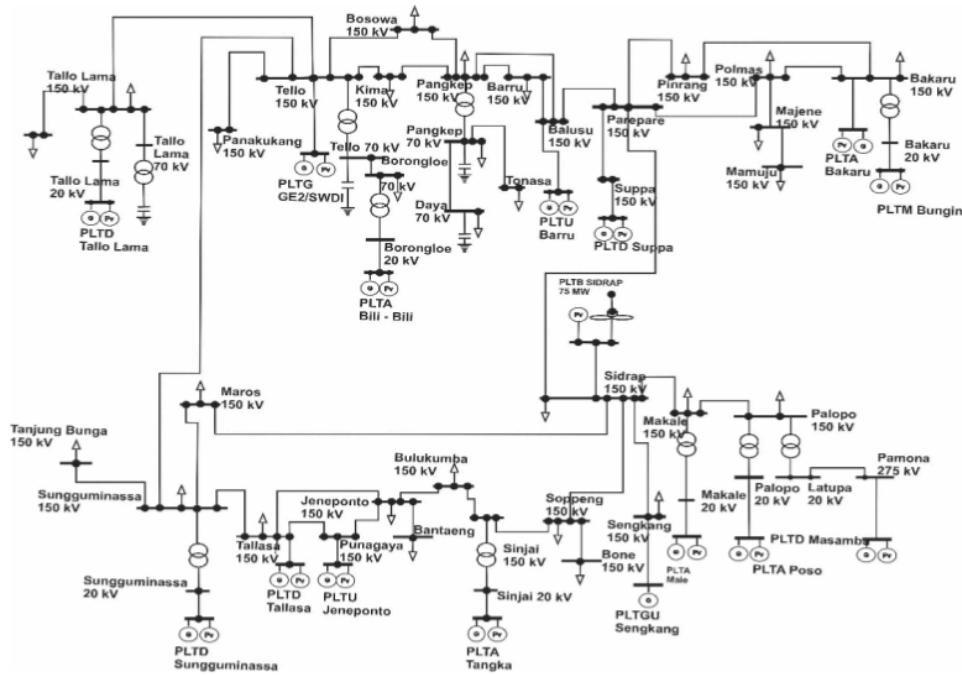


Figure 2. Single Line Diagram of Southern Sulawesi Electricity Interconnection System

In this study, the peak load data on the South Sulawesi interconnection system is 964 MW. The South Sulawesi interconnection system consists of 44 buses with a nominal voltage of 150 kV. Table 1 shows the loading and generation in the southern Sulawesi electricity system.

In this research several case studies will be conducted. There are 4 cases that will be tested in this study:

1. Case-1 : Without Wind Turbine Penetration
2. Case-2 : PLTB-Sidrap 75 MW Penetrated to System
3. Case-3 : PLTB-Jenepono 72 MW Penetrated to System
4. Case-4 : PLTB Sidrap & Jenepono 147 MW Penetrated to System

Furthermore, each case will see the minimum eigenvalue of  $J_R$ . The voltage stability level of the 4 cases can be compared by looking at the eigenvalue. The weakest bus can also be determined by looking at the value of the bus participation factor.

Table 1. Generating data and load data on the South Sulawesi interconnection system

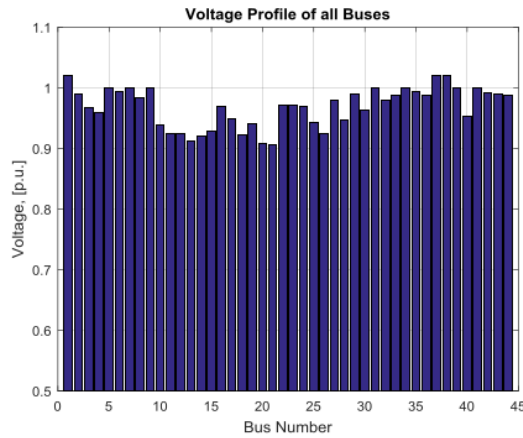
No Bus	Bus Name	Voltage (pu)	Angle Degree	Load		Generator	
				MW	Mvar	MW	Mvar
1	Bakaru	1.030	0.000	3.50	0.20	47.225	79.568
2	Polmas	0.997	-1.366	17.10	4.10	0.000	0.000
3	Majene	0.988	-2.718	23.30	3.70	0.000	0.000
4	Mamuju	0.981	-3.274	9.60	4.80	0.000	0.000
5	Pinrang	1.000	-0.132	24.40	6.20	14.300	-49.721
6	Parepare	0.996	-0.870	18.70	4.70	0.000	0.000

7	Suppa	1.000	0.443	0.00	0.00	31.100	-2.244
8	Sidrap	0.974	4.734	26.50	10.30	0.000	0.000
9	PLTU Barru	1.000	-3.614	0.00	0.00	60.400	63.501
10	Barru	0.953	-12.058	10.10	2.40	0.000	0.000
11	Pangkep150	0.944	-14.570	22.10	8.00	0.000	0.000
12	Pangkep70	0.947	-15.928	0.00	0.00	0.000	0.000
13	Tonasa	0.918	-17.736	18.90	10.60	0.000	0.000
14	Bosowa	0.941	-15.264	33.10	15.40	0.000	0.000
15	Kima	0.953	-17.866	18.00	5.80	0.000	0.000
16	Tello150	1.000	-16.016	63.30	18.30	21.000	90.758
17	Panakukang	0.980	-18.572	68.30	17.70	0.000	0.000
18	Tello70	0.981	-20.521	0.00	-20.00	0.000	0.000
19	Borongloe	1.000	-21.317	11.40	0.00	5.200	13.564
20	Mandai	0.951	-19.782	24.30	2.60	0.000	0.000
21	Daya	0.957	-22.003	45.50	2.80	0.000	0.000
22	Tello30	1.000	-16.025	0.00	0.00	0.000	0.000
23	Barawaja	1.001	-16.034	0.00	0.00	0.000	0.000
24	Tellolama150	1.000	-16.880	19.70	4.70	12.600	18.115
25	Tellolama70	0.975	-19.285	0.00	0.00	0.000	0.000
26	Bontoala	0.958	-19.480	26.50	7.70	0.000	0.000
27	Sunguminasa	1.000	-9.356	15.70	3.60	20.000	129.111
28	Tanjung Bunga	0.968	-12.192	55.20	16.70	0.000	0.000
29	Tallasa	1.000	20.743	20.60	4.70	79.000	28.459
30	Maros	0.959	0.729	18.60	5.50	0.000	0.000
31	Punagaya	1.000	30.519	0.00	0.00	196.100	-0.573
32	Jenepono	0.983	19.439	17.40	3.40	0.000	0.000
33	Bulukumba	0.989	12.671	27.10	6.50	0.000	0.000
34	Sinjai	1.000	11.106	21.90	4.60	4.000	69.558
35	Bone	0.990	10.533	32.10	8.20	0.000	0.000
36	Soppeng	0.975	10.142	14.10	3.40	0.000	0.000
37	Sengkang	1.000	14.142	28.40	11.50	265.200	-34.481
38	Makale	1.000	6.236	11.90	1.50	8.200	69.807
39	Palopo	1.000	39.200	49.20	0.00	4.000	128.970
40	Latuppa	0.972	62.540	0.00	0.00	0.000	0.000
41	PLTA poso	1.000	106.778	0.00	0.00	195.000	55.638
42	Pamona 275	0.993	105.315	0.00	0.00	0.000	0.000
43	Pamona150	0.989	104.738	4.90	0.50	0.000	0.000
44	Poso	0.986	103.885	11.00	1.80	0.000	0.000

## 5. Result and Discussion

### 5.1. Case-1

The first step, carried out a study load flow. For the case, it is found that the voltage value is within the allowable limit, which is between 0.9 p.u to 1.05 p.u. The voltage on bus 21 has the lowest value of 0.906 p.u and the Bakaru bus has the highest voltage of 1.03 p.u. Figure 3 shows the stress profiles on all buses in the South Sulawesi interconnection system.



**Figure 3.** Voltage Profile of All Bus in in the South Sulawesi Interconnection System

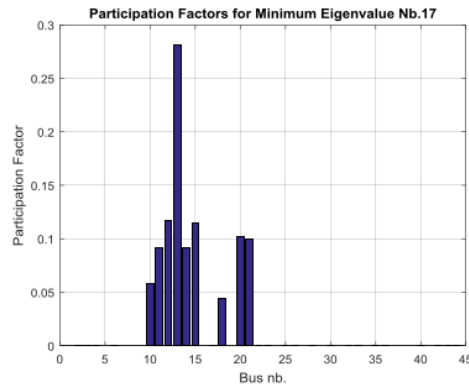
After the load flow study, the eigen value is derived from the Jacobian Reduction matrix. For case-1, the 4 lowest eigenvalues are obtained:

Minimum Eigenvalue is  $\lambda_{(17)} = 1.847$

Minimum Eigenvalue is  $\lambda_{(26)} = 2.673$

Minimum Eigenvalue is  $\lambda_{(20)} = 3.229$

Minimum Eigenvalue is  $\lambda_{(24)} = 3.877$



**Figure 4.** Bus Participation Factor for Case-1

With the lowest eigenvalue ( $\lambda_{.17}$ ), the value of bus participation is obtained. The weakest bus is bus 13 (Tonasa Bus) as shown in Figure 4.

5.2 Case-2

Penetration of the Sidrap PLTB of 75 MW affects the stability of the system voltage. This can be observed from changes in eigenvalues. The 4 lowest eigenvalues at the time the PLTB Sidrap enters the system are:

Minimum Eigenvalue is  $\lambda_{(18)} = 1.856$

Minimum Eigenvalue is  $\lambda_{(26)} = 2.673$

Minimum Eigenvalue is  $\lambda_{(20)} = 3.221$

Minimum Eigenvalue is  $\lambda_{(24)} = 3.884$

The weakest bus is bus 13 (Tonasa Bus) as shown in Figure 5.

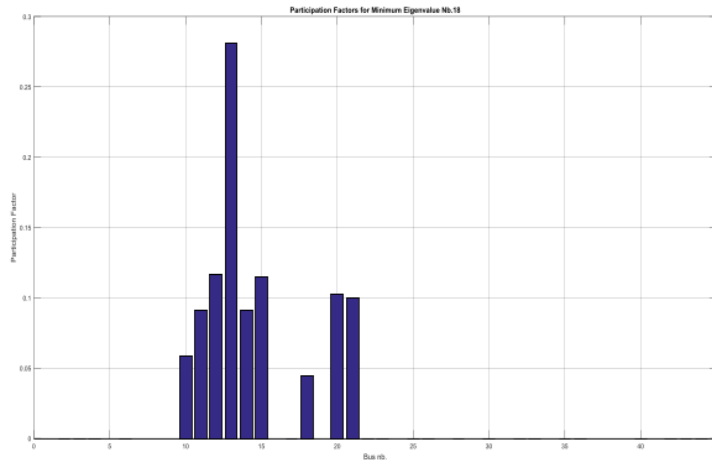


Figure 5. Bus participation factor for Case-2

5.3 Case-3

Penetration of the 72 MW PLTB Jeneponto also affects the stability of the system voltage. The effect of Jeneponto PLTB is better than Sidrap PLTB. This can be observed from changes in eigenvalues. The lowest eigenvalue when PLTB Jeneponto enters the system is higher than when the Sidrap PLTB enters the system

The 4 lowest eigenvalues when PLTB Jeneponto enters the system are:

Minimum Eigenvalue is  $\lambda_{(19)} = 1.860$

Minimum Eigenvalue is  $\lambda_{(26)} = 2.673$

Minimum Eigenvalue is  $\lambda_{(20)} = 3.222$

Minimum Eigenvalue is  $\lambda_{(24)} = 3.888$

5.4 Case-4

Penetration of PLTB Jeneponto and PLTB Sidrap of 147 MW greatly affects the stability of the system voltage. This can be observed from changes in eigenvalues. The lowest eigenvalue when the Jeneponto PLTB and PLTB Sidrap enter the system is higher compared to when one of the Wind Turbine enters the system.

The 4 lowest eigenvalues when Jeneponto PLTB and Sidrap PLTB enter the system are:

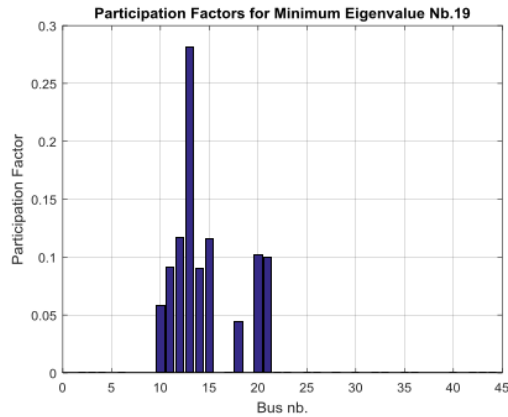
Minimum Eigenvalue is  $\lambda_{(19)} = 1.868$

Minimum Eigenvalue is  $\lambda_{(26)} = 2.673$

Minimum Eigenvalue is  $\lambda_{(20)} = 3.207$

Minimum Eigenvalue is  $\lambda_{(24)} = 3.894$

With the lowest eigenvalue ( $\lambda_{(19)}$ ), the value of bus participation is obtained. The weakest bus is bus 13 (Tonasa Bus) as shown in Figure 6.



**Figure 6.** Bus Participation Factor for Case-4

From the simulation results for all cases the comparison of eigen value values for all cases can be seen in the table 2.

**Table 2.** Comparison of eigenvalues for all cases

No.	Case-1	Case-2	Case-3	Case-4
1	139.7688	140.1985	140.3649	140.7502
2	118.0498	115.4475	117.7507	115.0995
3	80.4251	95.9785	79.9885	95.9785
4	95.9785	58.6243	95.9785	58.5212
5	57.1805	53.8286	57.0366	54.032
6	53.6695	70.3481	53.8896	70.3481
7	70.3481	42.3584	70.3481	42.173
8	41.8707	40.68	41.7274	39.2901
9	40.6068	39.116	39.1684	36.4224
10	38.9803	31.118	36.3293	31.2149
11	31.042	30.6867	31.1473	30.3857
12	30.2834	28.5001	29.9962	28.5816
13	24.8471	19.7055	20.0097	19.6262
14	20.0664	27.9791	24.9226	27.9791
15	16.671	24.9015	16.6089	24.9712
16	17.9308	17.9389	27.9791	14.0541
17	14.0541	8.7551	8.768	8.7982
18	8.7213	14.0541	1.8598	1.8683
19	1.8463	1.8561	14.0541	3.2074
20	3.2019	3.2202	3.1921	9.8038
21	5.4029	9.8038	5.4227	5.4355
22	27.9791	5.4172	9.8038	23.0073
23	9.8038	23.0073	23.0073	3.8941

24	23.0073	3.8844	3.8874	4.9826
25	3.8765	4.9826	4.9826	2.6726
26	4.9826	2.6726	2.6726	4.1785
27	2.6726	4.1785	4.1785	3.9273
28	4.1785	3.9273	3.9273	
29	3.9273			

Table 3 shows the minimum values of eigenvalues for all cases. It can be seen that the lowest minimum eigenvalues occur in case-1 while the highest minimum eigenvalues occur in case-4. When the wind turbine has not entered the system, the minimum eigenvalue is 1.847, while when the Sidrap PLTB enters the eigenvalue system it becomes 1.856. The inclusion of Tolo PLTB makes the stability of the system better with an indication of the eigen value of 1.860.

These results indicate that when Wind Power enters the sulseltrabar electrical system, the steady state stability of the system gets better.

**Table 3.** Comparison of the lowest eigenvalues for all cases

Case	Minimum Eigen Value
1	Minimum Eigenvalue is $\lambda_{(17)} = 1.847$
2	Minimum Eigenvalue is $\lambda_{(18)} = 1.856$
3	Minimum Eigenvalue is $\lambda_{(19)} = 1.860$
4	Minimum Eigenvalue is $\lambda_{(19)} = 1.868$

## 6. Conclusion

From the simulation results it can be seen that the inclusion of wind turbine in the Sulseltrabar electrical system has the effect of improving the stability of the steady state system, this can be seen from the minimum eigenvalues. At the time before penetration of the wind turbine eigenvalues of 1.847. After the penetration of the wind turbine the eigenvalue increased to 1.868. An improvement in steady state stability in the Sulseltrabar system has taken place.

## References

- [1] Savu C.Savulescu. Real-Time Stability Assessment in Modern Power System Control Center. *IEEE Press. Wiley.* 2009
- [2] I. C. Gunadin, A. Soeprijanto, and O. Penangsang, "Steady state stability assessment using extreme learning machine based on modal analysis," *Int. Review of Electrical Engineering*, vol. 7, no. 3, pp. 4532-4537, June 2012.
- [3] Indar Chaerah Gunadin, Eka Sanjaya Putra Az, Yusri Syam Akil, and Steven Humena, "The Impact of the Injection of Wind Power Plant on the Steady State Condition and the Dynamics of Sulselbar Power System", *International Journal of Electrical and Electronic Engineering & Telecommunications* Vol. 8, No. 6, November 2019
- [4] Ching-Yin Lee, ShaoHong Tsai, Yuan-Kang Wu. A New Approach to The Assessment os Steady-State Voltage Stability Margin Using P-Q-V Curve, *Electrical Power and Energy System.* 2010
- [5] Gao, B., Kundur, P., Morisson, G.K, "Voltage Stability Evaluation Using Modal Analysis", *IEEE Transactions on Power Systems*, vol. 7, no. 4, pp. 1423-1543, (November 1992).
- [6] Kundur,P., "Power System Stability and Control", Mc-Graw Hill, New-York, 1994, pp 960-971.
- [7] I. C. Gunadin, A. Soeprijanto, and O. Penangsang, "Real power generation scheduling to improve steady state stability limit in the Java-Bali 500 kV interconnection power

system,"World Academy of Science, Engineering and Technology, vol. 4, no. 12, pp. 1771-1775, December 2010.

- [8] M.Moghavveni, M.O. Faruque, Power System Security and Voltage Collapse: A Line Outage Based Indicator for Prediction, *Electrical Power and Energy System*, 1999; 21; pp 455-461
- [9] I. C. Gunadin, S. M. Said, and M. Irsan, "Determination of stability index of electrical power system using Rei-Dimo methods", *Journal of Theoretical and Applied Information Technology*, vol. 90, no. 1, pp. 161-167, August 2016.
- [10] M.H. Haque. A Fast Method for Determining The Voltage Stability Limit of a Power System. *Electrical Power and Energy System*, 1995; 32; pp.35-43
- [11] Dr. EnemuohF. O., Dr. Onuegbu J. C. and Dr.AnaziaE. A., *Modal Based Analysis and Evaluation of Voltage Stability of Bulk Power System*, International Journal of Engineering Research and Development, Volume6, Issue 12(May2013), pp. 71-79

# Comparison of Voltage Stability Index Before and After Wind Turbine Penetrated to Sulsestrabar Interconnection Power System Using Modal Analysis Method

---

## ORIGINALITY REPORT

---

6%

SIMILARITY INDEX

8%

INTERNET SOURCES

10%

PUBLICATIONS

8%

STUDENT PAPERS

---

## PRIMARY SOURCES

---

1

Submitted to Universitas Samudra

Student Paper

6%

---

Exclude quotes On

Exclude matches < 3%

Exclude bibliography On