Real-time voltage stability monitoring model of wind power plant penetration in electrical power system networks

A M Ilyas1*, 2, A Suyuti1, I C Gunadin1, and S M Said1

1Electrical Department, Engineering Faculty, University of Hasanuddin, Jl. Perintis Kemerdekaan Km. 10 Makassar, 90245, Indonesia.
2Electrical Engineering Study Program, Engineering Faculty, Khairun University, Kelurahan Gambesi, 97719, Ternate, North Maluku, Indonesia.

*E-mail: aamilyas@gmail.com

Abstract. The intermittent output power of wind power plants can affect the stability of the power grid, so a real-time monitoring model is needed. This study uses data from the southern Sulawesi network which is interconnected with wind power plants in real-time, and the IEEE 30 bus data is used as method validation. The method used is the New Voltage Stability Index (NVSI) based on Matlab. The results of the stability index on the IEEE 30 bus data are < 1 or are at the standard of stable criteria, namely 0.95 p.u. The result of the stability index of the South Sulawesi network is line number 49 from Latuppa to Poso has the highest value of 0.0473, the second is line number 18 from Bosowa to Tello is 0.0390, and the third is line number 24 from Tello 30kV to Barawaja is 0.0221, the other bus voltages have lower values. So it can be concluded that the network of South Sulawesi is stable, and intermittent wind power has no effect on voltage stability.

1. Introduction
Voltage instability can cause voltage drops or blackouts so that power flow is not optimal. The non-optimal power flow results in high system operating costs [1, 2, 3, 4, 5, 6]. The optimal power flow is an economic dispatch calculation to calculate the cost of generation and power loss on the network [7, 8, 9]. Previous stability index research used various types of methods including L (L-index), Lmn (Line Stability Index), FVSI (Fast Voltage Stability Index), LQP (Line Stability Factor), Control Design of Automatic Voltage Regulator to Improve the Voltage Stability [10], and the Capital Analysis Method [11].

While the calculation of power flow used methods such as Lambda Iteration [12], Genetic Algorithm [13], Particle Swarm Optimization [14], Artificial Bee Colony algorithm ABC [15], Novel Bat Algorithm (NBA) [16]. This study uses the NVSI method which combines the Lmn and FVSI [17, 18, 19]. Meanwhile, the optimal power flow is calculated using the Novel Bat Algorithm [20], which is compared with the Improved Particle Swarm Optimization IPSO method [21, 22, 23]. The novelty of this research is the calculation of the stability index on the power flow system of the Sulselbar network which is connected to a real-time wind power plant energy.

The basic equation for solving the stability index (Kessel and Glavitsch) [24], the indicator L for the voltage stability in the network index value between 0 (zero loads) and 1 (voltage drop), with the following formula.
1.1 L-Index

\[ L = \max_{j \in \alpha_L} \left\{ \left| 1 - \frac{\sum_{i \in \alpha_r} F_{ji} V_i}{V_j} \right| \right\} \]

(1)

\[ F_{ji} = |F_{ji}| < \theta_{ji} \]

1.2 LVSI Method

LVSI is a voltage stability index that discusses the relationship between real power and bus voltage \([25]\) with the following formula

\[ LVSI = \frac{4Bp_r}{V_s \cos \theta - \delta} \leq 1 \]

(2)

Where \( \theta = \tan^{-1} \frac{X}{R} \) is the angle of the transmission network, and \( R \) is the resistance of the network.

1.3 NVSI Method

NVSI is a combination of the Lmn method and the FVSI method which aims to increase the accuracy and speed of computation. The line diagram of a two-bus system power model whose parameters and variables are in units as follows (Figure 1).

\[ NVSI = \frac{4Q_r}{|V|^2} \left[ (\frac{|Z|}{X})^2 \sigma - \frac{X}{\sin^2(\theta - \delta)} (\sigma - 1) \right] \leq 1 \]

\[ \sigma = \begin{cases} 1 & \delta < \delta_c \\ 0 & \delta \geq \delta_c \end{cases} \]

(3)

Where \( \delta \) is used as the modifying variable, \( \sigma \) is the switching function, the value of which depends on the difference in angle, \( \delta \) is very small or not.

2. Methods

Table 1 shows the power output of wind power plant 02 march 2020. Table 2 shows Bus data of Sulselbar network.

| Table 1. The power output of wind power plant 02 march 2020 |
|------------------------------------------------------------|
| Sidrap Wind Power Generator                  | Jeneponto Wind Power Generator |
| a.m. WM | p.m. WM | a.m. WM | p.m. WM |
|--------|--------|--------|--------|
| 1      | 1.67   | 1      | 12.35  |
| 2      | 1.04   | 2      | 17.85  |
| 3      | 8.26   | 3      | 40.12  |
| 4      | 9.66   | 4      | 60.27  |
| 5      | 1.98   | 5      | 64.91  |
| 6      | 14.33  | 6      | 50.72  |
| 7      | 1.86   | 7      | 48.42  |
| 8      | 0.00   | 8      | 49.26  |
| 9      | 2.45   | 9      | 45.82  |
Table 1. (continued)

| No | Bus Code | Voltage Mag. | Load MW | Load Mvar | Generator MW | Generator Mvar |
|----|----------|--------------|--------|----------|-------------|---------------|
| 10 | 0.50     | 10           | 52.17  | 10       | 0           | 10            | 49.2          |
| 11 | 3.60     | 11           | 47.59  | 11       | 0           | 11            | 41.7          |
| 12 | 3.54     | 12           | 45.80  | 12       | 0           | 12            | 34.7          |

Table 2. Bus data of Sulselbar network

| No | Bus Code | Voltage Mag. | Load MW | Load Mvar | Generator MW | Generator Mvar |
|----|----------|--------------|--------|----------|-------------|---------------|
| 1  | 1        | 1.03         | 4.30   | 0.20     | 126.00      | 0.40          |
| 2  | 0        | 1.00         | 14.90  | 3.80     | 0.00        | 0.00          |
| 3  | 0        | 1.00         | 11.10  | 2.20     | 0.00        | 0.00          |
| 4  | 0        | 1.03         | 16.70  | 3.00     | 0.00        | 0.00          |
| 5  | 2        | 1.00         | 23.50  | 7.00     | 0.43        | 0.00          |
| 6  | 0        | 1.00         | 17.20  | 4.60     | 0.00        | 0.00          |
| 7  | 2        | 1.00         | 23.50  | 7.00     | 0.43        | 0.00          |
| 8  | 0        | 1.00         | 25.50  | 9.00     | 0.00        | 0.00          |
| 9  | 2        | 1.00         | 22.93  | 9.41     | 0.00        | 0.00          |
| 10 | 0        | 1.00         | 9.40   | 2.40     | 0.00        | 0.00          |
| 11 | 0        | 0.97         | 22.10  | 8.00     | 0.00        | 0.00          |
| 12 | 0        | 1.01         | 14.90  | 3.80     | 0.00        | 0.00          |
| 13 | 0        | 1.00         | 31.10  | 8.50     | 0.00        | 0.00          |
| 14 | 0        | 1.00         | 40.78  | 13.35    | 0.00        | 0.00          |
| 15 | 0        | 1.00         | 14.10  | 4.50     | 0.00        | 0.00          |
| 16 | 2        | 0.97         | 48.50  | 15.50    | 8.00        | 5.00          |
| 17 | 0        | 1.00         | 69.20  | 18.40    | 0.00        | 0.00          |
| 18 | 0        | 0.96         | 0.00   | -20.00   | 0.00        | 0.00          |
| 19 | 2        | 1.00         | 0.70   | 0.00     | 19.30       | -0.10         |
| 20 | 0        | 1.00         | 17.00  | 2.10     | 0.00        | 0.00          |
| 21 | 0        | 1.00         | 25.50  | 3.90     | 0.00        | 0.00          |
| 22 | 0        | 1.00         | 0.00   | 0.00     | 0.00        | 0.00          |

Figure 2. Flowchart of research
3. Results and Discussion

3.1 Stability Index of IEEE 30 bus data

New Voltage Stability Index analysis performed on IEEE 30 bus data can be seen in Figure below.

![Graph of NVSI Index on IEEE 30 bus data](image)

The test results of the NVSI method used on the IEEE 30 bus data show that the stability index is less than one or below the voltage limit criteria standard of 0.95 p.u, so that it can be used in existing real systems.

### 3.2 Stability Index of Real-Time Wind Power Plant Injection to Sulselbar Network

The wind power plant does not affect the voltage drop in the power flow of the Sulselbar Network. The graph of the stability index of the South Sulawesi network which is injected with the real power of the wind power plant can be seen as follows.

![Graph of NVSI at Sulselbar Network of Real-Time wind power plant injection](image)

The results of the New Voltage Stability Index (NVSI) on the Sulselbar network that are injected with wind power in real-time do not affect system stability.

4. Conclusion

The results of the analysis on the South Sulawesi network which is interconnected with the wind power plant in real time are summarized as follows. The results of the stability index on the IEEE 30 bus data are < 1 or are at the standard of stable criteria, namely 0.95 p.u. The result of the stability index of the South Sulawesi network is line number 49 from Latuppa to Poso has the highest value of 0.0473, the second is line number 18 from Bosowa to Tello is 0.0390, and the third is line number 24 from Tello.
30kV to Barawaja is 0.0221, the other bus voltages have lower values. So it can be concluded that the network of South Sulawesi is stable, and intermittent wind power has no effect on voltage stability.

References
[1] Saadat H 1999 *Power system analysis* (McGraw-hill)
[2] Kundur P 2007 *Power system stability and control* 46 7
[3] Chen J, Milano F and O’Donnell T 2019 *IEEE Transactions on Power Systems* 34 3980
[4] Chen Y, Mazhari S M, Chung C Y, Faried S O and Pal BC 2020 *IEEE Transactions on Power Systems* 35 4632
[5] Gunadin I C, Suyuti A, Ilyas A M and Siswanto A 2020 *IOP Conference Series: Materials Science and Engineering* 875 012045
[6] Samuel I A, Katende J, Daramola S A, and Awelewa AA 2014 *International Journal of Engineering Science Invention* 3 55
[7] Ilyas A M and Rahman M N 2012 *Telkomnika* 10 459
[8] Farh H M, Al-Shaalan A M, Eltamaly A M and Al-Shamma’a A A A 2020 *IEEE Access* 8 27807
[9] Rojanaworahiran K and Chayakulkheeree K 2019 *International Conference on Power, Energy and Innovations (ICPEI)* 2019 78
[10] Gunadin I C, Muslimin Z, Ilyas A M and Siswanto A 2020 *IOP Conference Series: Materials Science and Engineering* 875 012044
[11] Gunadin I C, Muslimin Z, Ilyas A M and Siswanto A 2020 *IOP Conference Series: Materials Science and Engineering* 875 012043
[12] Kristianto D and Suyono H 2014 *Jurnal Mahasiswa TEUB* 2 1
[13] Hanna B, and El-Shahat A 2017 *IEEE Global Humanitarian Technology Conference (GHTC)* 2017 1
[14] Ilyas A, Ontoseno P and Adi S 2010 *Jurnal Telkomnika* 10 459
[15] Pratama DA 2016 *Economic and Emission Dispatch pada Sistem Transmisi Jawa Bali 500KV Berdasarkan Ruptil 2015-2024 Menggunakan Modified Artificial Bee Colony Algorithm* (Doctoral dissertation, Institut Teknologi Sepuluh Nopember)
[16] Fitr S N, Akil Y S and Gunadin I C 2018 *2nd East Indonesia Conference on Computer and Information Technology (EICONIT)* 2018 163
[17] Samuel I A 2017 *A New Voltage Stability Index for Predicting Voltage Collapse In Electrical Power System Networks* (Doctoral dissertation, Covenant University)
[18] Nguyen H D, Dvijotham K, Yu S and Turitsyn K 2018 *IEEE Transactions on Smart Grid*, 10 482
[19] Pratikto H, Hadi S P, and Putranto LM 2014 *Jurnal Penelitian Teknik Elektro dan Teknologi Informasi* 1 17
[20] Chen G, Qian J, Zhang Z and Sun Z 2019 *IEEE Access* 7 52060
[21] Ilyas A M, Suyuti A, Gunadin I C and Siswanto A 2020 *IOP Conference Series: Materials Science and Engineering* 850
[22] Khan N H, Wang Y, Tian D, Raja M A Z, Jamal R and Muhammad Y 2020 *IEEE Access* 8 146785
[23] Alkebsi K and Du W 2020 *IEEE Access* 8 124734
[24] Kessel P and Glavitsch H 1986 *IEEE Transactions on power delivery* 1 346
[25] Samuel I A, Katende J, Awosope C O and Awelewa A A 2017 *International Journal of Applied Engineering Research* 12 190