Analysis of Transmission Line Stability

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Analysis of Transmission Line Stability for Sulselbar Interconnection System with the Penetration of Renewable Energy to Prevent Voltage Collapse

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Abstract. There are three main requirements to meet the criteria both in the electric power system, namely reliability, quality, and stability. Stability is the ability of the system to return to work normally after experiencing interference. System stability analysis is a guide for operators to detect or prevent voltage drops and power outages. This research discusses the stability of the 150 KV electrical system in South Sulawesi before and after interconnection with the Sidrap and Jeneponto Wind Power Plant. The method used is the Line Stability Index (Lmn Index) to view the voltage profile. Index Lmn coding is run and simulated using Matlab. Validation is done by IEEE 14 bus simulation data, and comparing the results of the analysis before and after penetration with PLTB. The study was conducted on the Sulselbar 150 KV system before penetration with PLTB, namely 44 buses, 14 generators, and 52 lines / networks. The highest Lmn index result is the network from bus 38 to bus 39 that is equal to 0.0292. Second is bus 15 to bus 16 which is 0.0291, and third is bus 40 to 42 that is 0.0273. After penetration with PLTB Sidrap and Jeneponto, the number of generators will be 16 generators. The highest Lmn index results are from bus 38 to 39 that is 0.0292, then bus 15 to bus 16 that is 0.0290 ranks second, and bus 40 to 42 equals 0.0272 or keeps the third order. After the sidrap load bus is converted to a bus generator, the Lmn index before in reactive power supplied to the load by a generator is a certain thing, this condition must be maintained so that the plant continues to work in stable conditions.
Keywords : Transmission Line, Stability, Renewable Energy, Voltage Collapse, Wind Power

1. Introduction

Voltage stability analysis illustrates the ability of the system to maintain its voltage value under normal conditions or after a disturbance has occurred. System instability caused by interruptions, load increases, and changes in system configuration can also affect the voltage stability of the electric power system. Voltage instability occurs when the voltage value on the receiver / consumer side will drop from its normal limit, in that case it can cause a condition called voltage collapse. Voltage will drop at the lowest point, so it can cause a blackout of the system.

Calculation of voltage stability is required when planning or operating an electric power system. If there is an unintentional change in system configuration such as contingency, it is very likely that the system's voltage stability will not be the same as normal conditions. An example is the loss of a channel or generator can result in a decrease in the ability of voltage stability in a system.

There are several methods for analyzing voltage stability, including the P-V curve, discussing the relationship between power and voltage, and the Fast Voltage Stability Index (FVSI). In this study using the Line Stability Index (Lmn Index) to determine the stability index of the 150 KV transmission system in Sulselbar.

2. Literature

Voltage stability analysis can be interpreted as the ability of the power system to maintain the value of the system voltage, under normal conditions and in a state of interference [1] [2]. There are two types of voltage stability based on the simulation time, namely, static voltage stability, and dynamic voltage stability. Dynamic analysis is used to study transient stability by paying attention to load dynamics, and generators. And statilc analysis uses algebraic equations which are computationally easier than dynamic analysis. Static analysis is more ideal for the study of voltage stability limits in cases before contingency, and after a system contingency. Static voltage stability analysis is based on curve calculations, or on the singular Jacobian matrix on power flow [3].

2.1. Power System Stability

The stability of a power system is a complex dynamic system and consists of linear, nonlinear subsystems that are constantly experiencing internal, and external interference. Power system stability can be defined as the ability of the power system to remain in equilibrium conditions under normal operating conditions and to regain equilibrium conditions that can be received after a disturbance [4].

2.1.1. Rotor Angle Stability

The stability of the rotor angle of a power system is the ability of interconnected synchronous machines of the power system network to stay in line with each other ie in synchronous conditions [4]. Analysis of the stability of the rotor angle involves the study of electro-mechanical oscillations. A fundamental factor of rotor angle stability is the way in which the synchronous engine power output varies with the rotor oscillation. This can be either steady state stability or transient stability.

2.1.2. Frequency Stability

Frequency stability analysis refers to the ability of the power system to maintain a stable frequency after system interference. This results in a significant imbalance between generation and load. This depends on the network's ability to maintain or restore the balance between the system generator, and the load, with accidental minimum load losses. In general, the problem of frequency stability is related to insufficient equipment response, or inadequate generator reserves [4]. Frequency stability can be short-term (ranging from a fraction of a second) or a long-term phenomenon.

2.1.3 Voltage Stability

Voltage stability is related to the ability of the power system to maintain an acceptable voltage level in all buses in the system under normal operating conditions, and after a breakdown [4]. This involves all voltage levels on each bus under different load conditions to determine the stability limits, and margins. Based on the size of the disturbance, voltage stability can be classified into the following two subcategories:

a. Large fault voltage stability refers to the ability of the system to maintain a constant voltage after a large fault such as a system error, loss of generation, or circuit contingency.
b. Small fault voltage stability refers to the ability of the system to maintain a fixed voltage when experiencing a small disturbance such as a gradual change in the system load.

2.2. L-Index (L)

L-index based on power flow solutions was developed by Kassel [5]. This L-Index measures the voltage instability and is suitable for a constant type of power load. The values range from 0 to 1. The L-index formulation is as follows.

$$L = \max_{j \in \alpha L}\{Lj\} = \max_{j \in \alpha L}\left\{\left|1 - \frac{\sum_{i \in \alpha G} F_{ji} * V_i}{V_j}\right|\right\} \quad 1$$

$$F_{ji} = |F_{ji}| \angle \theta_{ji}$$

where L is the load / consumer area, and G is the generator / generator area, Lj is the local indicator that determines the busbar from which the collapse might originate [5]. [F] is calculated using the formula [F] = $[F_{LL}]^{-1}[Y_{LG}]$, where $[Y_{LL}]$ and $[Y_{LG}]$ computed using a matrix Y-bus. Voltage V_i and V_j is voltage at the I bus, and j [6].

2.2 Line Stability Index (Lmn-Index)

The stability index (Lmn) is derived based on the concept of power transmission lines in one network. Moghavvemi and Omar [7] lowered the network stability index to evaluate the stability between two buses in an interconnected system as shown in the following figure.

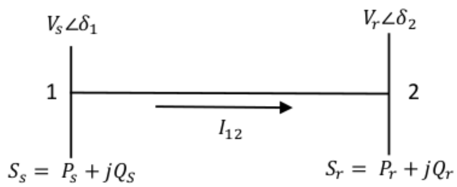


Figure 1: Tipical One-Line Diagram of Transmission Line

Where, Vs, Ps, and Qs are the sending / generating voltage, real power and reactive power, respectively. Vr, Pr and Qr are the receiver / load tip voltage, real power, and reactive power, respectively. δ1 is the phase voltage of the generator, and δ2 is the phase angle of the load at the load, I12 is the line current and θ is the angle of the transmission line.

Power flow through the transmission line using the representation of the pie model (π) for a two-bus system uses a quadratic equation of voltage set greater than or equal to 0 (zero). If the value is less than 0, then the root will be imaginary indicating that there is instability in the system. The formula for the Lmn index is as follows.

$$Lmn = \frac{4\,X\,Q_r}{|V_s|^2\,sin^2\,(\theta - \delta)} \leq 1 \qquad 2$$

The lmn-index is also directly related to reactive power, and not directly related to active power through the voltage phase angle δ. Networks in the system are said to be close to instability when the Lmn-index is close to one (1). On the other hand, if the Lmn-index value is less than 1, the system is said to be stable [7].

3. Materials and Methods

3.1 Sistem Sulselbar System

The Electricity System in South Sulawesi Barat consists of 44 buses and 14 conventional generator buses and 2 new renewable energy buses, namely PLTB located in Sidrap and Jeneponto Regencies. The bus generators in question are: Bakaru as slack buses and bus generators namely Pinrang, Suppa, Sidrap (PLTB), Barru, Tello, Borongloe, Tellolama, Sungguminasa, Tallasa, Punagaya, Sinjai, Sengkang, Makale, Palopo, Poso, the rest as much as 28 a bus is a load bus [8]. The results of the analysis of the transmission stability of the 150 KV system were compared before and after penetration with PLTB.

The transmission stability analysis method used is the Lmn Index. The generator data, and the single line system of South Sulawesi can be seen in Table 1 and Figure 2 below.

Tabel 1. Data Sistem 44 bus 15 dan 16 Generator Sulselbar

No	Bus Code	Voltage Mag.	Angle Degree	Load		Generator			Injected	
				MW	Mvar	MW	Mvar	Qmin	Qmax	Mvar
1	1	1.0300	0.0000	3.5000	0.2000	63.0000	3.1000	0.0000	0.0000	0.0000
2	0	0.9984	0.0000	17.1000	4.1000	0.0000	0.0000	0.0000	0.0000	0.0000
3	0	0.9900	0.0000	23.3000	3.7000	0.0000	0.0000	0.0000	0.0000	0.0000
4	0	0.9827	0.0000	9.6000	4.8000	0.0000	0.0000	0.0000	0.0000	0.0000
5	2	1.0000	0.0000	24.4000	6.2000	14.3000	0.8000	0.0000	0.0000	0.0000
6	0	0.9977	0.0000	18.7000	4.7000	0.0000	0.0000	0.0000	0.0000	0.0000
7	2	1.0000	0.0000	0.0000	0.0000	31.1000	8.2000	0.0000	0.0000	0.0000
8	2	0.9847	0.0000	26.5000	10.3000	75.000	0.0000	0.0000	0.0000	0.0000
9	2	1.0000	0.0000	0.0000	0.0000	60.4000	4.8000	0.0000	0.0000	0.0000
10	0	0.9387	0.0000	10.1000	2.4000	0.0000	0.0000	0.0000	0.0000	0.0000
11	0	0.9255	0.0000	22.1000	8.0000	0.0000	0.0000	0.0000	0.0000	0.0000
12	0	0.9253	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
13	0	0.8954	0.0000	18.9000	10.6000	0.0000	0.0000	0.0000	0.0000	0.0000
14	0	0.9208	0.0000	33.1000	15.4000	0.0000	0.0000	0.0000	0.0000	0.0000
15	0	0.9286	0.0000	18.0000	5.8000	0.0000	0.0000	0.0000	0.0000	0.0000
16	2	0.9700	0.0000	63.3000	18.3000	21.0000	7.9000	0.0000	0.0000	0.0000
17	0	0.9497	0.0000	68.3000	17.7000	0.0000	0.0000	0.0000	0.0000	0.0000
18	0	0.9400	0.0000	0.0000	-20.0000	0.0000	0.0000	0.0000	0.0000	0.0000
19	2	0.9400	0.0000	11.4000	0.0000	5.2000	0.2000	0.0000	0.0000	0.0000
20	0	0.9189	0.0000	24.3000	2.6000	0.0000	0.0000	0.0000	0.0000	0.0000

21	0	0.9205	0.0000	45.5000	2.8000	0.0000	0.0000	0.0000	0.0000	0.0000
22	0	0.9704	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
23	0	0.9710	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
24	2	0.9700	0.0000	19.7000	4.7000	12.6000	0.0000	0.0000	0.0000	0.0000
25	0	0.9443	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
26	0	0.9260	0.0000	26.5000	7.7000	0.0000	0.0000	0.0000	0.0000	0.0000
27	2	0.9800	0.0000	15.7000	3.6000	20.0000	5.9000	0.0000	0.0000	0.0000
28	0	0.9474	0.0000	55.2000	16.7000	0.0000	0.0000	0.0000	0.0000	0.0000
29	2	0.9900	0.0000	20.6000	4.7000	79.0000	39.1000	0.0000	0.0000	0.0000
30	0	0.9632	0.0000	18.6000	5.5000	0.0000	0.0000	0.0000	0.0000	0.0000
31	2	1.0000	0.0000	0.0000	0.0000	196.1000	38.6000	0.0000	0.0000	0.0000
32	2	0.9786	0.0000	70.0000	12.5000	72.0000	0.0000	0.0000	0.0000	0.0000
33	0	0.9881	0.0000	27.1000	6.5000	0.0000	0.0000	0.0000	0.0000	0.0000
34	2	1.0000	0.0000	21.9000	4.6000	4.0000	0.5000	0.0000	0.0000	0.0000
35	0	0.9937	0.0000	32.1000	8.2000	0.0000	0.0000	0.0000	0.0000	0.0000
36	0	0.9869	0.0000	14.1000	3.4000	0.0000	0.0000	0.0000	0.0000	0.0000
37	2	1.0200	0.0000	28.4000	11.5000	265.2000	7.9000	0.0000	0.0000	0.0000
38	2	1.0200	0.0000	11.9000	1.5000	8.2000	2.1000	0.0000	0.0000	0.0000
39	2	1.0000	0.0000	49.2000	0.0000	4.0000	2.0000	0.0000	0.0000	0.0000
40	0	0.9528	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
41	2	1.0000	0.0000	0.0000	0.0000	195.0000	27.2000	0.0000	0.0000	0.0000
42	0	0.9913	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
43	0	0.9897	0.0000	4.9000	0.5000	0.0000	0.0000	0.0000	0.0000	0.0000
44	0	0.9881	0.0000	11.0000	1.8000	0.0000	0.0000	0.0000	0.0000	0.0000

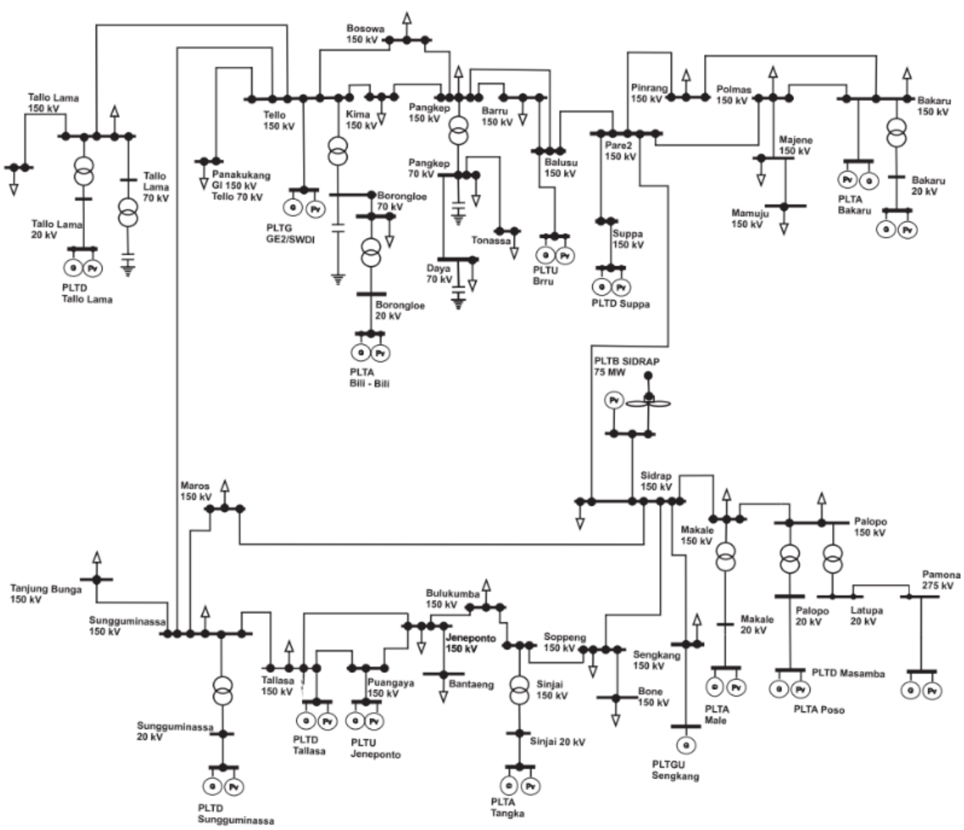
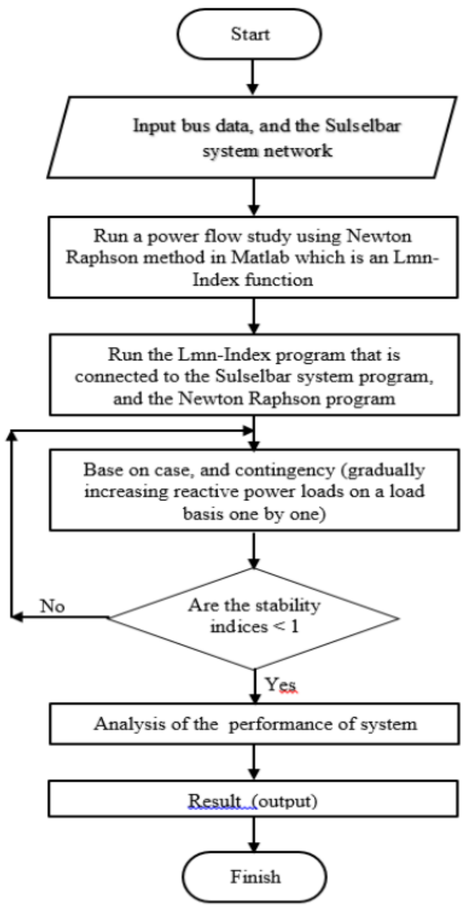


Figure 2. Single Line System 150 KV Sulselbar

For more details about the steps of the research carried out, it can be seen in the following research flwochar.



Figre 2. Flowchar of Research

3 Results and Discussion

3.1 Result Analysis

The results obtained from the South Sulawesi 150 KV transmission system Lmn-Index method were analyzed and compared before and after penetration with the Sidrap and Jeneponto Wind Power Plant (PLTB). Table 2 shows the network stability index and Figure 3 shows a graph of the Lmn-index system of 150 KV, 44 buses, 14 generators, 15 generators, and 16 generators.

Table 2. Result of Analysis of Transmission System 150 KV Selselbar

Line No.	From Bus	To Bus	Lmn_Indeks			
			Sulselbar	Sulselbar+Sidrap	Sulselbar+Jeneponto	Sulsebar+Sid+JP
1	1	2	0.00561	0.00558	0.00558	0.00555
2	2	3	0.00339	0.00338	0.00340	0.00338
3	3	4	0.00552	0.00550	0.00553	0.00550
4	1	5	0.00229	0.00229	0.00229	0.00228
5	2	6	0.00138	0.00137	0.00138	0.00137
6	5	6	0.00647	0.00642	0.00643	0.00637
7	6	7	0.00349	0.00346	0.00349	0.00347
8	6	8	0.00362	0.00360	0.00362	0.00360
9	6	9	0.00203	0.00201	0.00203	0.00201
10	9	10	0.00470	0.00469	0.00469	0.00467
11	10	11	0.00148	0.00148	0.00148	0.00147
12	11	12	0.00143	0.00143	0.00143	0.00143
13	12	13	0.00993	0.00991	0.00991	0.00988
14	12	20	0.00590	0.00588	0.00588	0.00585
15	11	14	0.00174	0.00173	0.00173	0.00173
16	11	15	0.02208	0.02202	0.02202	0.02195
17	15	16	0.02912	0.02909	0.02909	0.02905
18	14	16	0.02223	0.02218	0.02217	0.02211
19	16	24	0.00212	0.00212	0.00212	0.00212
20	16	17	0.00332	0.00332	0.00332	0.00332
21	16	18	0.01885	0.01889	0.01889	0.01894
22	16	22	0.00254	0.00254	0.00254	0.00254
23	16	27	0.00320	0.00320	0.00320	0.00320
24	22	23	0.00906	0.00906	0.00906	0.00906
25	18	19	0.00752	0.00751	0.00751	0.00750
26	18	20	0.00615	0.00615	0.00615	0.00614
27	20	21	0.00664	0.00663	0.00663	0.00661
28	18	21	0.00757	0.00757	0.00757	0.00756
29	24	25	0.00871	0.00871	0.00871	0.00871
30	25	26	0.00739	0.00739	0.00739	0.00739
31	27	28	0.00495	0.00495	0.00495	0.00495
32	27	29	0.02046	0.02043	0.02091	0.02092
33	27	30	0.00670	0.00671	0.00671	0.00671
34	29	31	0.00820	0.00820	0.00820	0.00820
35	29	32	0.00688	0.00688	0.00689	0.00689
36	31	32	0.01075	0.01075	0.01077	0.01077
37	32	33	0.00612	0.00612	0.00589	0.00589
38	33	34	0.00199	0.00199	0.00198	0.00198
39	34	35	0.00149	0.00149	0.00149	0.00149
40	33	35	0.01836	0.01836	0.01819	0.01819
41	35	36	0.00448	0.00448	0.00453	0.00453
42	8	36	0.00397	0.00385	0.00397	0.00384
43	36	37	0.00340	0.00337	0.00342	0.00338
44	8	37	0.00564	0.00548	0.00563	0.00544
45	8	38	0.00372	0.00358	0.00373	0.00358
46	8	30	0.00289	0.00280	0.00289	0.00279
47	38	39	0.02920	0.02920	0.02920	0.02920
48	39	40	0.00827	0.00827	0.00827	0.00827
49	40	42	0.02727	0.02727	0.02727	0.02727
50	41	42	0.00059	0.00059	0.00059	0.00059
51	42	43	0.00320	0.00320	0.00320	0.00320
52	43	44	0.00630	0.00630	0.00630	0.00630

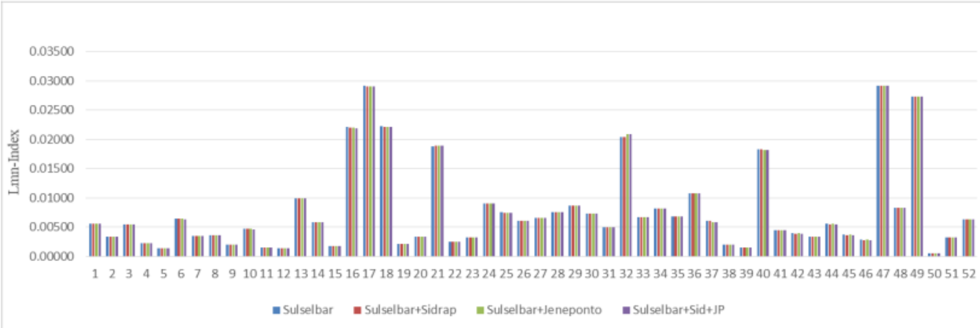


Figure 3. Grafik Lmn-Index of Transmission System 150 KV Sulselbar

Table 2, and Figure 3 show that Sulselbar's 150 KV transmission system is stable because there is no stability index for each network close to one (1). All networks, 52 of which are in the stability index range of less than one. Before penetration with PLTB, the highest Lmn index was network from bus 38 to bus 39, which was 0.0292. Second is bus 15 to bus 16 which is 0.0291, and third is bus 40 to 42 that is 0.0273. After penetration with PLTB Sidrap and Jeneponto, the number of generators will be 16 generators. The highest Lmn index results are from buses 38 to 39 namely 0.0292, then bus 15 to bus 16 ie 0.0290 are ranked second, and buses 40 to 42 are equal to 0.0272 or third. This condition needs to be known by the operator so that the stability of the system can be maintained.

4.Conclusions

In the research that has been done it can be concluded that:

1. Based on the results of the analysis using the Lmn-index, the Sulselbar 150 KV transmission system is stable.
2. The results of the Lmn index analysis can be used as one of the variables to identify system stability.

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