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Power Flow Analysis in N-1 Contingency Conditions Due to the Entry of Renewable Power Plants in the Sulselrabar System

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Abstract— **Contingency analysis on a 150 kV network aims to see the network's reliability against interference. Contingency is a scheme for releasing one element of the generating unit or transmission line (N-1), which will affect the performance and reliability of the electric power system. Power flow analysis in an electric power system is an analysis that reveals the performance of an electric power system and the flow for certain conditions when the system is working. The analysis was carried out using the ETAP 16.00 software. The method used was the newton raphson to calculate the load flow in the N-1 contingency condition. From the results of the study, it can be seen that the power flow occurs in each channel of the 150 kV system in the South Sulawesi system. When conducting a contingency analysis of N-1 by removing the load on the middle lane of South Sulawesi, namely Maros and Sidrap, a voltage change occurs, increasing buses experiencing critical and marginal voltage conditions. This happens because of the sudden release of essential loads, so over or under voltage appears on the bus.**

Keywords—**Load Flow, Contingency N-1, Marginal, Critical, Voltage, ETAP.**

I. Introduction

The electric power system is vital in providing and delivering electrical energy to the load reliably and continuously. The need for electrical energy continues to increase in direct proportion to the increase in the transportation sector, industry, and other activities that require electrical energy. To provide reliable service, the electric power system must be able to overcome various kinds of disturbances that may occur [1].

Disruption of the discharge of the generating unit or transmission line in the electric power system is unavoidable, so if the disturbance occurs, it can cause the flow of power to be channeled to experience a significant change. This term is closely related to the ability of a system to serve the load in the event of a disturbance in one of its elements.

Contingency analysis is the study of the safety of the electric power system by analyzing the power flow from the impact of several N-1 contingency cases (release of one generating unit or transmission line). With the contingency analysis of an electric power system, it is possible to calculate the disturbances that occur in the transmission line so that it can predict changes in transmission capacity and the remaining bus voltage, whether it can still be loaded or has experienced an overload condition. So it is essential that the system be planned so that in the event of a contingency condition of one of the transmission lines, it does not result in blackouts in part or all of the system [1].

After the presence of the Wind Power Plant, it can increase the stock of available power capacity in the South, Southeast, and West Sulawesi (Sulseltrabar) regions, thus increasing the number of burdens that must be borne. For this reason, it is necessary to conduct a power flow analysis to determine the overall condition of the electric power system in the current Sulselrabar system. Power flow analysis in an electric power system is an analysis that reveals the performance of an electric power system and power flow (real and reactive) for certain conditions when the system is working [2]. The main result of the power flow is the magnitude and phase angle of the voltage on each line (bus), the real

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power, and the reactive power on each line [3].

In this study, two methods of analysis were carried out: when the system was in average condition and contingency N-1. Under normal conditions, it will be known how much active power and reactive power occur, while in the N-1 contingency, it will be known the changes in dynamic power and reactive power that arises. The Performance Index (IP) was obtained from the calculation. The calculation of the power flow for the electric power system in the Sulselrabar System section after the entry of renewable plants, if done manually, will be very complicated and requires a lot of time, therefore in this study, computer software was used to simplify and speed up the process of calculating the power flow. ETAP (Electrical Transient Analysis Program) Power Station is software that can calculate the flow of power in an electric power system. Using the ETAP Power Station 16.00 software, you can analyze a comprehensive electric power system and many conditions [4].

Previously, some studies discussed average power flow analysis and the N-1 contingency condition. For moderate conditions, as in research [4] which discusses the analysis of power flow in the South Sulawesi system, [5] discusses the analysis of the power flow of the electric power system in the texturizing section at PT Asia Pacific Fibers Tbk Kendal, [6] discusses the voltage analysis of each bus in the Gorontalo electric power system through power flow simulation, [7] discusses the study of power flow in the South Sulawesi electrical system, [8] discusses the contingency analysis of the Riau electric power system using the Newton Raphson power flow method, [9] discusses the load flow analysis on the East Kalimantan interconnection system. As for N-1 contingency conditions, such as [1] discusses contingency analysis in the Central Java system, [10] discusses contingency analysis by calculating two active performance indices (PIP) and reactive power performance index (PIV) for single transmission line blackouts, [11] iscusses the contingency analysis of the power system using voltage and active power performance index, discusses the study when there is a blackout in each component or equipment in the power system, contingency analysis shows an indication about what might be the position of the power system [12] discusses the contingency analysis of the unbalance transmission system.

From these studies, it is necessary to develop a power flow analysis, such as an up-to-date analysis, by testing several case studies. The current Sulselrabar system continues to grow [13], especially after the entry of several renewable plants and in the N-1 contingency condition. The power flow characteristics need to be reviewed to see the system's features. This study proposes a power flow analysis approach to enter renewable power plants in the Sulselrabar system under N-1 contingency conditions.

II. Research Method

The research was conducted by simulating the electric power system of the Sulserabar system of PT. PLN AP2B Sulselrabar Region due to the entry of renewable power plants using the ETAP 16.00 application. The modeling of the system to be carried out adjusts the parameters needed and has been accepted by the researcher when collecting data. The simulated system is designed in such a way as to achieve similarity to the actual 150 kV Sulserabar network system.

The initial step of the research is to determine the parameters or technical data supporting the desired value. This data will be obtained when researchers carry out data collection at PT. PLN AP2B Sulselrabar Region, Makassar.

After the data and method analysis has been carried out, the next step is to design a single-line diagram of the 150 kV Sulselrabar network system on the ETAP 16 application, which helps facilitate the next stage.

Network modeling is the next step by entering data in each installed component with already available data. The modeling stage plays an essential role in this research because the network is made according to the actual conditions of the Sulserabar system.

After the design and modeling are complete, the next step is to run load flow on the ETAP 16 application to ensure the modeling runs well. After successfully simulating, the power flow results are obtained, then identify the parameters of active power and bus voltage

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under normal conditions before the N-1 contingency scheme is carried out.

In the next step, the researchers simulated contingency by removing one channel installed in the selected system and conducting a power flow analysis during contingency. Then analyze the power flow generated during contingency by identifying the parameters needed for calculating the Performance Index. The active power and bus voltage will be recorded during line disconnection.

III.Results and Discussions

The currently active Sulselrabar electricity system consists of 21 generating units, namely 6 PLTA, 8 PLTU, 1 PLTG, 1 PLTGU, 3 PLTMH, and 2 PLTB. It operates at 150 kV. The Sulselrabar Electricity System is dominated by Steam Power Plants (PLTU) such as PLTU Sengkang, PLTU Barru, PLTU Jeneponto, and PLTU Mamuju, each of which has a different generating capacity. The Sulselrabar bus system numbering is shown in table 1.

Table 1. Bus Numbering

ID BUS	kV	ID BUS	kV
BU28_MAROS	150	BUS21_SENGKANG	150
BUS1_BAKARU	150	BUS22_BONE	150
BUS2_POLMAS	150	BUS23_SINJAI	150
BUS3_MAJENE	150	BUS24_BLKMBA	150
BUS4_PINRANG	150	BUS25_JNPNTO	150
BUS5_PARE	150	BUS26_PLTUMmuju	150
BUS6_SUPPA	150	BUS27_PUNAGAYA	150
BUS7_BARRU	150	BUS28_ENRKG	150
BUS8_PNGKEP	150	BUS29_PLTBSidrap	150
BUS9_BOSOWA	150	BUSBNTAENG	150
BUS10_TELLO	150	BusBOLANGI	150
BUS11_TLAMA	150	BUS26_PANGKEP70	70
BUS12_PKANG	150	BUS27_TNASA70	70
BUS13_SGMNS	150	BUS29_MNDAI	70
BUS14_TBNGA	150	BUS30_DAYA	70
BUS15_TLASA	150	Bus31_TELLO70	70
BUS16_SIDRAP	150	BUS32_BRLOE	70
BUS17_MKALE	150	Bus33_TLAMA70	70
BUS18_PALOPO	150	BUS34_BNTLA	70
BUS19_MMUJU	150	Bus35_TELLO30A	30
BUS20_SPPENG	150		

a) N-1 Contingency Power Flow Simulation Results After Wind Turbine Entry

The contingency simulation analysis of the 150 kV Sulselrabar interconnection system after the entry of the Wind Turbine is made to determine the voltage and current conditions when a load is released. This simulation releases the load on the middle lane of the Sulselrabar system, namely Maros and Sidrap. Then the following results are obtained.

b) Active Power and Reactive Power Simulation Results

After disconnecting the load from Maros and Sidrap, the simulation is carried out again as in normal conditions, resulting in data for active and reactive power, which flows in each channel in table 2.

c) Active Power and Reactive Power Interconnection System 150 kV Sulselrabar Contingency N-1

The results of the N-1 contingency power flow simulation analysis can produce the following data conclusions,

- ➢ The total active power in the channel under normal conditions is 1508.10 MW, where the active power is the largest, 171.67 MW from BUS15_TLASA to BUS13_SGMNSA.
- ➢ The most significant reactive power is 30.45 Mvar from BUS_PUNAGAYA to BUS15_TLASA
- ➢ The highest Power Factor efficiency of 100% occurred in two channels, BUS5_PAREPARE to BUS4_PINRANG and BUS21_SENGKANG to BU16_SIDRAP, while the lowest efficiency occurred on the BUS22_BONE to BUS20_SOPPENG channel, which was 29.46%.

The complete power flow results can be seen in table 2 below.

Table 2. Simulation Results of Power Flow of Each Interconnection System Bus 150 Kv Sulselrabar At N-1 . Contingency

Lines		**Load Flow**	
From	**To**	**P (MW)**	**Q (Mvar)**
BU28	BusBOLANGI	12,16	-0,24
	BUS13	7,22	-0,53
BUS1	BUS2	64,10	8,71
BUS2	BUS1	65,20	-5,44
BUS3	BUS2	3,91	2,85
BUS4	BUS1	82,32	-12,42
BUS5	BUS8	8,88	-3,58
	BUS4	107,72	0,08
	BUS2	63,64	-7,48
BUS6	BUS5	19,98	5,86
BUS7	BUS8	28,70	-5,01

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	BUS5	11,75	-0,44
BUS8	BUS9	14,69	25,52
BUS10	BUS9	30,72	-8,69
	BUS8	15,28	18,30
	BUS12	33,66	9,99
	BUS11	44,77	10,14
BUS11	BONTOALA150	37,19	11,53
	Bus33	3,08	0,10
BUS13	BusBOLANGI	4,92	-1,62
	BUS14	25,68	4,56
	BUS10	128,07	11,32
BUS15	BUS13	171,68	24,07
BUS16	BUS5	73,89	-7,48
	ENRKG	9,87	0,32
	BUS17	19,70	4,52
BUS17	BUS18	16,10	5,40
BUS19	BUS3	9,22	3,31
BUS20	BUS16	25,38	4,48
BUS21	BUS16	58,06	-0,06
	BUS20	17,95	-12,98
BUS22	BUS20	4,16	13,49
BUS23	BUS22	7,92	-2,99
BUS24	BUS22	13,52	-1,39
	BUS23	20,71	1,79
BUS25	BUSBNTAENG	15,62	-10,15
	BUS24	24,88	-20,74
BusPLTUMamuju	BUS19	20,31	5,97
BUS_PUNAGAYA	BUS25	26,88	-13,32
	BUS15	133,31	30,46
ENRKG	BUS17	9,84	2,72
PLTBSidrap	BU28	9,69	-1,28
	BUS16	5,78	-9,58

d) Active Power and Reactive Power on Bus Loading

The simulation results using ETAP with the Newton-Raphson method show that the differences in active, reactive, and PF (Power Factor) occurs in each channel. The Loading bus's total active power (P) is 1077.21 MW. The Bus Loading with the most significant active power is found in the Loading BD_10 bus, which is 231.50 MW with a reactive power (Q) of 45 Mvar and a Power Factor of 98.16%, while the complete results can be seen in table 3 below.

Table 3. Simulation Results of Power Flow of Each Bus Loading Interconnection System 150 Kv Sulselrabar At Contingency N-1

No	ID BUS	P (MW)	Q (Mvar)
1	BD1_BNTLA	6,15	0,00
2	BD1_BONE	6,49	-2,04
3	BD1_DAYA	11,98	0,00
4	BD1_MNDAI	8,22	-2,64
5	BD1_PLPO	17,10	-1,31
6	BD1_PNGAYA	0,76	-0,11
7	BD1_PNKNG	17,26	-3,23
8	BD1_PNRNG	24,84	-6,46
9	BD1_TLAMA	12,48	-4,10
10	BD1_TLLASA	16,54	-4,73
11	BD2_BONE	6,49	-2,04
12	BD2_DAYA	12,22	-4,67
13	BD2_MNDAI	11,36	0,00
14	BD2_PLPO	14,96	-6,35
15	BD2_PNKNG	18,35	-4,27
16	BD2_PNRNG	1,00	-0,01
17	BD2_TLAMA	33,50	1,15
18	BD3_PNKNG	31,53	-7,93
19	BD_5	95,00	9,50
20	BD_9	89,80	15,00
21	BD_10	231,50	45,00
22	BD_BARRU	4,66	-1,39
23	BD_BKRU	1,00	0,00
24	BD_BLKMBA	0,48	-1,73
25	BD_BNTAENG	6,40	-1,21
26	BD_BOLANGI	17,02	-3,93
27	BD_BOSOWA	45,04	-9,87
28	BD_BRLOE	6,11	0,85
29	BD_BRWJA	23,36	-0,01
30	BD_JNPNTO	13,19	-3,74
31	BD_MJENE	10,56	-1,43
32	BD_MKLE	2,82	-0,55
33	BD_MMUJU	21,95	-2,86
34	BD_MROS	-	-
35	BD_PARE	18,14	-4,19
36	BD_PLMAS	4,80	-1,54
37	BD_PNGKEP	25,72	-11,31
38	BD_SDRP	-	-
39	BD_SGMNSA	35,35	-1,00
40	BD_SIWA	6,46	-1,46
41	BD_SNGKNG	20,16	-5,55
42	BD_SNJAI	12,66	-4,27
43	BD_SPPENG	6,74	5,34
44	BD_TBNGA	51,20	-1,02
45	BD_TELLO	36,40	-14,56
46	BD_TELLO2	37,06	-8,91
47	BD_TONASA	2,40	-22,50

e) Voltage Simulation Results at Each Bus When Contingency N-1 Sulselrabar System 150 kV

The voltage at each bus is 150 kV in the Sulselrabar system when the Maros and Sidrap load. At the same time, the voltage changes in the sulselrabar system as a whole can be seen in table 4, which can also be seen in Figures 1 and 2 of the respective voltage profiles buses.

Table 4. Voltage of Each Bus in Normal and Contingency Conditions N-1

No	**ID BUS**	**VOLTAGE (kV)**
1	BONTOALA150	150,58
2	BU28_MAROS	152,57
3	BUS1_BAKARU	150,00
4	BUS2_POLMAS	151,53
5	BUS3_MAJENE	152,13

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6	BUS4_PINRANG	151,12
7	BUS5_PARE-PARE	153,10
8	BUS6_SUPPA	153,343
9	BUS7_BARRU	153,521
10	BUS8_PANGKEP	153,119
11	BUS9_BOSOWA	151,404
12	BUS10_TELLO	151,399
13	BUS11_TLAMA	150,966
14	BUS12_PKANG	151,033
15	BUS13_SGMNSA	151,964
16	BUS14_TBNGA	151,684
17	BUS15_TLASA	154,143
18	BUS16_SIDRAP	153,711
19	BUS17_MAKALE	151,215
20	BUS18_PALOPO	150,183
21	BUS19_MAMUJU	152,992
22	BUS20_SOPPENG	155,438
23	BUS21_SENGKANG	154,548
24	BUS22_BONE	157,212
25	BUS23_SINJAI	157,181
26	BUS24_BLKMBA	158,442
27	BUS25_JNPNTO	156,724
28	BUS26_PLTUMamuju	154,618
29	BUS27_PUNAGAYA	156,42
30	BUS28_ENRKG	152,62
31	BUS29_PLTBSidrap	152,604
32	BUSBNTAENG	157,42
33	BusBOLANGI	151,69
34	BUS26_PANGKEP70	71,80
35	BUS27_TNASA70	71,54
36	BUS29_MNDAI	71,75
37	BUS30_DAYA	72,06
38	Bus31_TELLO70	72,24
39	BUS32_BRLOE	72,54
40	Bus33_TLAMA70	70,42
41	BUS34_BNTLA	70,37
42	Bus35_TELLO30A	29,85

Figure 1. Graph of Voltage on the 150 kV Bus System at Maros and Sidrap Load Release

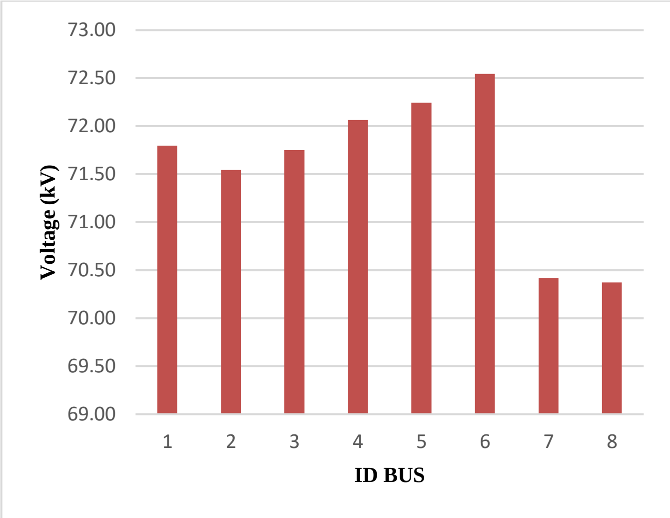

Figure 2. Graph of Voltage on the 70 kV Bus in the Sulselrabar system at the time of releasing Maros and Sidrap loads

f) Analysis of Critical and Marginal Voltage Conditions in N-1 contingency

Critical Voltage Condition is a condition where the voltage on the bus cannot be tolerated because it exceeds the standard PLN limit, while the Marginal Voltage Condition is when the bus is in a state of over-voltage but is still within the allowable limits. It can be seen in the graph that many buses experience over-voltage due to voltage drop due to the loss of large loads on Maros and Sidrap. Buses sharing Marginal Over Voltage can be seen in table 5.

- The 170 kV bus experiencing Critical Voltage Condition is found in BUS24_BLKMBA with a 158.442 kV or 105.6712%.
- For 70 kV Bus, none of them experienced Critical Voltage Conditions.
- As for the Distribution Bus, Buses that experience Critical Voltage Conditions are BD_9, BD_10, BD_BOSOWA, and BD_PANGKEP.

Table 5. Simulation results of the 150kV Sulselrabar interconnection system voltage experiencing Critical Voltage Condition

ID BUS	Voltage (kV)	Condition
BUS24_BLKMBA	158,442	Over Voltage
BD_9	21,092	Under Voltage
BD_10	21,111	Over Voltage
BD_BOSOWA	9,912	Under Voltage
BD_PNGKEP	18,701	Under Voltage
BUS37_BWAJA	28,49	Under Voltage

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- The 150 kV bus experiencing Marginal Voltage Condition is located at BUS5_PARE-PARE, BUS6_SUPPA, BUS7_BARRU, BUS8_PANGKEP, BUS15_TLASA, BUS16_SIDRAP, BUS20_SOPPENG, BUS21_SENGKANG, BUS22_BONE, BUS23_SINJAI, BUS25_JNPNTO, BUSBNTAENG, BusPLTUMamuju, BUS_PUNAGAYA.
- For 70 kV Bus, there are 6 buses that experience Marginal Voltage Condition.
- As for the Distribution Bus, the Bus experiencing the Marginal Voltage Condition consists of 14 buses.
- The number of buses experiencing Marginal Voltage Condition is 34 buses of which 30 have Over Voltage and 4 Under Voltage. The characteristics can be seen in table 6.

Table 6. Simulation results of the 150kV Sulselrabar interconnection system voltage experiencing Marginal Voltage Condition

ID BUS	VOLTAGE kV	CONDITION
BUS5_PARE-PARE	153,104	*Over Voltage*
BUS6_SUPPA	153,343	*Over Voltage*
BUS8_PANGKEP	153,119	*Over Voltage*
BUS15_TLASA	154,143	*Over Voltage*
BUS16_SIDRAP	153,711	*Over Voltage*
BUS20_SOPPENG	155,438	*Over Voltage*
BUS21_SENGKANG	154,548	*Over Voltage*
BUS22_BONE	157,212	*Over Voltage*
BUS23_SINJAI	157,181	*Over Voltage*
BUS25_JNPNTO	156,724	*Over Voltage*
BUS26_PANGKEP70	71,796	*Over Voltage*
BUS27_TNASA70	71,542	*Over Voltage*
BUS29_MNDAI	71,75	*Over Voltage*
BUS30_DAYA	72,064	*Over Voltage*
Bus31_TELLO70	72,244	*Over Voltage*
BUS32_BRLOE	72,543	*Over Voltage*
BD1_BNTLA	20,585	*Over Voltage*
BD1_BONE	20,699	*Over Voltage*
BD1_DAYA	20,497	*Over Voltage*
BD1_PNGAYA	20,842	*Over Voltage*
BD2_BONE	20,701	*Over Voltage*
BD2_MNDAI	20,412	*Over Voltage*
BD_5	20,646	*Over Voltage*
BD2_MNDAI	20,7842	*Over Voltage*
BD_10	20,8039	*Over Voltage*
BD_BLKMBA	20,924	*Over Voltage*
BD_BNTAENG	20,828	*Over Voltage*
BD_BRLOE	20,836	*Over Voltage*
BD_SIWA	20,407	*Over Voltage*
BD_SPPENG	20,801	*Over Voltage*
BD_TBNGA	19,5604	*Under Voltage*
BD_TELLO	19,569	*Under Voltage*
BD_TELLO2	19,3837	*Under Voltage*
BD_TONASA	19,3177	*Under Voltage*

IV. Conclusion

The conclusions obtained from the results of the analysis are that the Newton-Raphson method used for power flow simulation in this study shows efficiency in terms of the speed of the computational process in ETAP 16 Software. There are 2 impacts generated when the Maros and Sidrap loads suddenly release, namely 6 buses experiencing Critical Voltage Condition and 34 buses experiencing Marginal Voltage Condition, which is 34 buses.

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