Syntax Literate: Jurnal Ilmiah Indonesia p–ISSN: 2541-0849 e-ISSN: 2548-1398
Vol. 8, No. 12, Desember 2023

TECNO-ECONOMIC ANALYSIS OF NEW WIND POWER PLANT DEVELOPMENT IN SOUTHERN SULAWESI ELECTRICAL POWER SYSTEM

Santosh, Budi Sudiarto, I Made Ardita
Faculty of Engineering, Universitas Indonesia, Indonesia
Email: santosh@ui.ac.id, budi.sudiarto@ui.ac.id, i.made61@ui.ac.id

Abstract

Global warming due to carbon emissions has resulted in climate change, which negatively impacts the lives of living things. On the other hand, electricity demand is increasing every year due to the increasing human population, economic growth, and equipment electrification. At the moment, most of the electricity generation in Indonesia uses fossil energy power plants which produce carbon emissions. PT. PLN (Persero) is a State-Owned Enterprise tasked with managing the electricity system in Indonesia. PT. PLN (Persero) through the General Plan for Electricity Supply (RUPTL) for 2021-2030 is targeting the construction of New and Renewable Energy Power Plants. One of possible plan is the Wind Power Plant (WPP) construction in the Southern Sulawesi electrical power system. The use of WPP is expected to reduce carbon emissions. However, the integration of WPP causes other problems in the existing system such as dropped voltage, increased equipment loading, increased short circuit current, and decreased stability. So, it is necessary to conduct a study on the effects of integrating WPP into the existing system. Using DIgSILENT Power Factory software, Load Flow, Short Circuit, and Transient Stability simulations were carried out. Then an economic analysis was carried out including calculating net present value (NPV), internal rate of return (IRR), profitability index (PI), payback period (PBP), and levelized cost of energy (LCOE. The use of WPP at a certain capacity will not disrupt the stability of the system's power because it is still supported by the fast response generators in the system during variable WPP output. Also voltage drop, equipment loading, and short circuit current will not exceed the design value of the system. From a financial aspect, with certain assumptions, WPP development can be proven to be economically feasible.

Keywords: Carbon emissions; RUPTL; Southern Sulawesi; WPP, integration effects; LCOE.

How to cite:	Santosh, Sudiarto, B., & Ardita, I. M. (2023). Tecno-Economic Analysis of New Wind Power Plant Development in Southern Sulawesi Electrical Power System, *Syntax Literate (8) 12,* http://dx.doi.org/10.36418/syntax-literate.v8i12
E-ISSN:	2548-1398
Published by:	Ridwan Institute

Introduction

Global warming is an increase in the earth's average temperature that occurs globally which results from carbon emissions. Global warming has resulted in climate change in the world which has an impact on the lives of living things slowly. Some examples of impacts include extreme climate or weather, large floods due to extreme rainfall, storms, heat waves, damage to ecosystems, extinction of several types of animals and plants, the emergence of new diseases (by viruses and bacteria), rising sea levels due to melting polar ice, loss of water sources and the emergence of new deserts and so on. One of the main causes of carbon emissions is the massive use of fossil energy in the electrical energy generation sector. A total of 196 countries, including Indonesia, have ratified the Paris Agreement to reduce global warming and build resilience to climate change due to global warming.

Against the backdrop of rapid cost reduction of wind generation and minimizing of carbon emissions, the last decade bears witness to the accelerated global deployment of wind power with the total installed capacity increasing from 81 GW in 2010 to 622 GW in 2019 (Wu, Zhang, & Sterling, 2022).

Indonesia is one of the countries that has the largest renewable energy potential in the world, including solar, wind, water, sea, bioenergy (biomass, biogas, biofuel), and geothermal energy (Dalimi, 2021). Among all that has been mentioned, wind energy has quite a large potential in parts of Indonesia, especially Sumatra, Java, Southern Sulawesi, Nusa Tenggara, and Maluku. Southern Sulawesi is chosen as the location for the study because it has a fairly high average wind speed of 6 m/s and a maximum of 9 m/s in certain months at an altitude of 150m based on data from the Global Wind Atlas.

The three main factors of power quality are voltage, frequency, and waveform, if one of them does not meet the requirements it will affect safety and electric power production (Liu & Zhang, 2018). Electric power in an electrical system must be capable of serving loads continuously with quality good service such as voltage and frequency constant and quickly stable when experiencing changes (Noviantara, Suweden, & Mataram, 2018).

The integration of Wind Power Plants (WPP) into the existing electricity system often causes problems. The addition of new power generation including WPP tends to change the magnitude and direction of power flow so a load flow study is required. Excessive penetration of WPP plants leads to a noticeable increase in maximum short circuit current in the network. Simply, as the wind power increases, a higher short-circuit current will be injected into the system (Papathanassiou et al., 2014). Then short circuit study is required.

The effects of different types of wind turbines on the power grids greatly vary from one type to another (Zobaa, Ahmed, & Abdel Aleem, 2019). The WPP is one of renewable energy generation that is highly dependent on wind conditions. This is what causes the power to be unstable and affects system stability (Riasa, Hartati, Manuaba, & Santiari, 2020). WPP power output can increase (ramp up) and decrease (ramp down) quickly and can also leave the system (trip). The control strategies of most wind power plants isolate the mechanical system from the electrical system in case of any disturbance that reduces the wind power plants' contribution to the network inertia (Ekanayake & Jenkins, 2004).

The introduction of wind-generated power to the electrical grid contributes to the reduction of the overall system inertia (Sang et al., 2019). WPP also can cause voltage instability. Voltage instability occurs in the form of a progressive fall or rise of voltages at some buses. A possible cause of voltage instability is loss of loads in an area, or tripping of transmission lines and other elements by their protective systems leading to cascading outages (Feilat, Azzam, & Al-Salaymeh, 2018). WPP themselves may be used to provide reactive power support to maintain voltage but may be limited (Opila, Zeynu, & Hiskens, 2010). Then transient stability study is needed.

To resolve the challenges mentioned in association with the integration of wind energy into the grid, accurate modeling, simulation, and evaluation techniques are needed to investigate electrical power systems and develop adaptation strategies (Ahmed, Al-Ismail, Shafiullah, Al-Sulaiman, & El-Amin, 2020). This technical analysis will be carried out through simulations with power system analysis software for Southern Sulawesi electrical power systems in the year 2025 with several WPP capacities.

From the technical analysis mentioned before, it is then determined which WPP capacity is most likely to be integrated without affecting the system badly. Then an economic analysis will be carried out including calculating net present value (NPV), internal rate of return (IRR), profitability index (PI), payback period (PBP), and levelized cost of energy (LCOE) to determine the economic feasibility of investment.

Research Methodology

A. Method and Data Type

This research is quantitative research using experimental methods, namely methods used to study the differences and effects that arise if the value of a parameter or quantity is changed. The research was carried out by simulation using DIgSILENT Power Factory software version 15.1 for technical analysis and manual calculation for economic analysis. The data used in this research is quantitative.

B. Time and Place

This research was carried out at PT. Synkrona Engineering Nusantara, Jakarta, Indonesia for three months.

C. Data Collection

Conducting literature studies and collecting data on the existing electrical power system of Southern Sulawesi (Sulbagsel) at PT. Synkrona Engineering Nusantara is a renewable energy consultant in Indonesia. Existing electrical data includes single line diagrams, load data, and technical specifications for Southern Sulawesi electrical system equipment. The data was also used on plans for developing the electricity system for

Southern Sulawesi in 2025 from PT.PLN's General Plan for Electricity Supply (RUPTL).

The existing electricity system that will be studied is the electricity system of Southern Sulawesi (Sulbagsel) which covers four provinces, namely West Sulawesi, South Sulawesi, Central Sulawesi, and Southeast Sulawesi. Apart from technical data, economic data was also collected through literature studies for inflation rate, discount rate, capacity factor, operation and maintenance (O&M) costs, and initial investment costs. Also, a literature study was carried out to collect other economic data such as the selling price of existing WPP and the basic costs of providing local generation. Technical data used are as follows.

Table 1 Wind Turbine Data

No.	Description	Remark
1	Type	Type 4 (Full-Scale Converter)
2	Nominal Power	4,7 MVA (4,2 MW PF 0.9)
3	Nominal Voltage	0,69/33 kV
4	R to X" Ratio	0,1

Note: Wind Turbine Generator (WTG) Type 4's short circuit current contribution is a maximum of 110% of the WTG nominal current (Muljadi, Gevorgian, Samaan, Li, & Pasupulati, 2010). This value is used as DIgSILENT PowerFactory sub transient short circuit current input. The value is in RMS (root main square).

Table 2 Power Transformer 33/150kV 250MVA Data

No.	Description	Remark
1	Type	Two winding step-up transformer
2	Nominal Power	250 MVA
3	Nominal Voltage	33/150 kV
4	Frequency	50 Hz
5	Positive Sequence Impedance	14 %
6	Zero Sequence Impedance	14%
7	Load Losses	400 kW
8	No Load Losses	70 kW
9	No Load Current	0,2 %
10	Short Circuit Withstand Current	40 kA
11	Vector Group	Ynd5
12	No Load Tap Changer	±10% (step 1,25%)

Table 3 ACSR Hawk Conductor Data

No.	Description	Remark
1	Type	ACSR Hawk
2	Aluminum Cross Section	240 mm2
3	DC Resistance pada 20^{O}C	0,1154 Ohm/km
4	Positive & Negative Sequence AC Resistance at 20^{O}C	0,2 Ohm/km
5	Zero Sequence AC Resistance	0,3 Ohm/km
6	Positive & Negative Sequence AC Reactance at 20^{O}C	0,4063 Ohm/km
7	Zero Sequence AC Reactance	1 Ohm/km
8	Nominal Current	535 A
9	Short Circuit Withstand Current	40 kA
10	Frequency	50 Hz

Note: The 150kV line from New WPP to GI Sidrap uses 2xHawk conductors

Table 4 Large Power Plants in the Southern Sulawesi System in 2025 Based on RUPTL 2021-2030

No	Power Plant	Capacity (MW)
1	PLTU Sulbagsel 2023/2024	420
2	PLTU Punagaya	200
3	PLTU Jeneponto	450
4	PLTU Sulsel Barru 2-2020	100
5	PLTA Malea 2x45 MW	90
6	PLTU Kendari 3	100
7	PLTU BARRU unit 1 & 2	90
8	PLTA Bakaru 1 2x63 MW	126
9	PLTA Bakaru 2 2x70 MW	140
10	PLTGU Sulbagsel	450
11	PLTGU Sengkang	290
12	MPP (PLTG) Sulselbar	120
13	MPP (PLTG) Kendari	50
14	PLTU Palu 3	100
15	PLTA Poso I	120
16	PLTA Poso II	195
17	PLTA Poso II Ext (Poso Peaker)	200
18	PLTU Mamuju	50
19	PLTD Tello GE 1 & 2	55
20	PLTB Sidrap 1	75
21	PLTB Sidrap 2	75
22	PLTB Jeneponto	72

Table 5 Peak Load of the South Sulawesi System Based on RUPTL 2021-2030

Year	Peak Load (MW)				
	South Sulawesi	Southeast Sulawesi	West Sulawesi	Central Sulawesi	Total
2020	1127	231	71	245	1674
2021	1293	251	84	269	1897
2022	1382	347	90	285	2104
2023	1443	403	97	309	2252
2024	1505	429	103	326	2363
2025	1573	444	109	345	2471
2026	1642	457	116	367	2582
2027	1708	471	122	387	2688
2028	1777	486	129	409	2801
2029	1848	501	135	433	2917
2030	1932	516	143	458	3049

Economic data used as follows

1. Based on Indonesian Minister of Energy and Mineral Resources Decree

No.169.K.HK.02.MEM.M.2021, the Basic Cost of Providing (BPP) Generation in the Southern Sulawesi electricity system is 10,013 USD/kWh.
2. Based on an estimation from the Indonesian Ministry of Energy and Mineral Resources, the initial investment costs are 1.650.000 USD/MW and the operation and maintenance cost is 35 USD/kW/year.
3. WPP capacity factor is assumed as much as 30%. The capacity factor is a part of the average power output by a generating system to the peak power or rated power of the generator (Gharibeh, Khiavi, Farrokhifar, Alahyari, & Pozo, 2019). Generally, the WPP capacity factor is around 25-35%. It depends on many factors.
4. Based on references from The European Wind Energy Association (EWEA), the annual operation and maintenance costs are 3% of the initial investment costs.
5. Inflation values can refer to data released by Bank Indonesia i.e. around 5% on average. Annual inflation value for calculating the increase in operation and maintenance (O&M) costs per year.
6. The discount rate value can refer to data released by Bank Indonesia, namely the BI Rate or BI 7-Day (Reverse) Repo i.e. around 10% on average.
7. Corporate Income Tax (CIT) is a tax imposed on the income of a company. In Indonesia, the Ministry of Finance sets it at 22% (PPh 22).
8. Debt to Equity Ratio and Repayment Period are assumed 50% and 10 years respectively. Interest Rate is assumed as much as 6%.

D. Electrical System Modelling

System modeling uses DIgSILENT PowerFactory software version 15.1. Modeling was carried out for the existing electrical system of Southern Sulawesi and the new WPP using WTG Type 4. This new WPP is connected to Sidrap 150kV Substation with some distance long. Data for the existing electrical system of Southern Sulawesi was obtained from PT. PLN, this data is then processed to adjust the plan for developing the Southern Sulawesi electricity system in 2025 based on PT. PLN's General Plan for Electricity Supply (RUPTL) 2021-2030.

An imbalance between the mechanical power generated by generators and the electrical loads leads to a change in the grid frequency. When the frequency deviation exceeds a certain limit, controllers (governors) are activated to change the power output set point to the prime movers. This is called the primary frequency control and is divided into the phases of inertial response and governor response (IEEE Power & Energy Society & Institute of Electrical and Electronics Engineers, 2014). When the voltage deviation exceeds a certain limit, Automatic Voltage Regulators (AVR) are activated to change the voltage output of generators by changing the excitation current. The types of Governor and AVR used for various power plants in this modeling are

Table 6 Governor and AVR Type for Various Power Plants

Power Plant	AVR	Governor
Steam Power Plant (PLTU)	IEEET1	TGOV1
Geothermal Power Plant (PLTP)	REXSYS	IEEEG1
Hydro Power Plant (PLTA)	SCRX	HYGOV2
Diesel Power Plant (PLTD)	SEXS	DEGOV
Gas Power Plant (PLTG)	ESST1A	GAST
Combine Cycle Power Plant (PLTGU)	IEEET1	GAST

For PLTM (Minihydro Power Plants) and PLTMG (Gas Engine Power Plants), it is assumed that they do not use AVRs and adjustable governors (free governors). Apart from that, there are several Steam Power Plants (PLTU) in the Southern Sulawesi system whose Governor cannot be regulated, such as PLTU Tawaeli, PLTU Mamuju, PLTU Bau-Bau, PLTU Kendari 3 and PLTU Nii Tanasa.

E. Electrical System Simulation

System simulation using DIgSILENT PowerFactory software version 15.1. The simulations carried out include Load Flow, Short Circuit, and Transient Stability study. Several simulations will be carried out for several scenarios with various new WPP capacities (cases) i.e 70MW (Case 1), 90MW (Case 2), 110MW (Case 3), 130MW (Case 4), 150MW (Case 5), 170MW (Case 7) and 190MW (Case 8). Base case or Case 0 is a case when there is no new WPP integrated into the system. Then for each scenario, the WPP capacity will be analyzed. For the Transient Stability study, only case 1 until 7 was simulated. In the initial condition (precondition) of the simulation, the new WPP transformer is positioned in the middle tap or neutral. PLTGU Sulbagsel is set as a swing generator.

For the Load Flow study, the voltage and loading that occur will be checked, where the voltage value must remain within the limits required in the Indonesian Minister of Energy and Mineral Resources (ESDM) Regulation No. 20 of 2020 concerning Electrical Power System Network Regulations (Grid Code). The required voltage variation limits are +5%, -10% of the nominal voltage (150kV), and the frequency variation limits are ±0.2 Hz from the nominal frequency (50Hz) and the loading value is not allowed to exceed the equipment's capabilities.

For the Short Circuit study, short circuit currents will be checked that occur where the value is not allowed to exceed the equipment's capabilities. Simulation performed for 3 phase and 1 phase to ground faults. In the simulation, fault impedance is ignored.

For the Transient Stability study, voltage and frequency will be checked, the values of which must remain within the limits required in the Indonesian Minister of Energy and Mineral Resources (ESDM) Regulation No. 20 of 2020 concerning Electrical Power System Network Regulations (Grid Code). The required voltage variation limits are +5%, -10% of the nominal voltage (150kV), and the frequency variation limits are ±0.2 Hz from the nominal frequency (50Hz). For short transient conditions, a frequency deviation of ±0.5Hz is allowed. Two case studies will be examined, namely:

1. The output power of all WPPs in South Sulawesi, namely WPP Sidrap 1 and 2 (150 MW), WPP Jeneponto (72 MW) and new WPP (variable MW) decreased by 10%.
2. The output power of the new WPP fell by 100% (to 0 MW) or the WPP was tripped.

Before carrying out this simulation, first, ensure that the AVR and Governor models for each generator are filled in. The simulation at DIgSILENT PowerFactory was carried out for 100 seconds to see changes in voltage and frequency due to changes in WPP power.

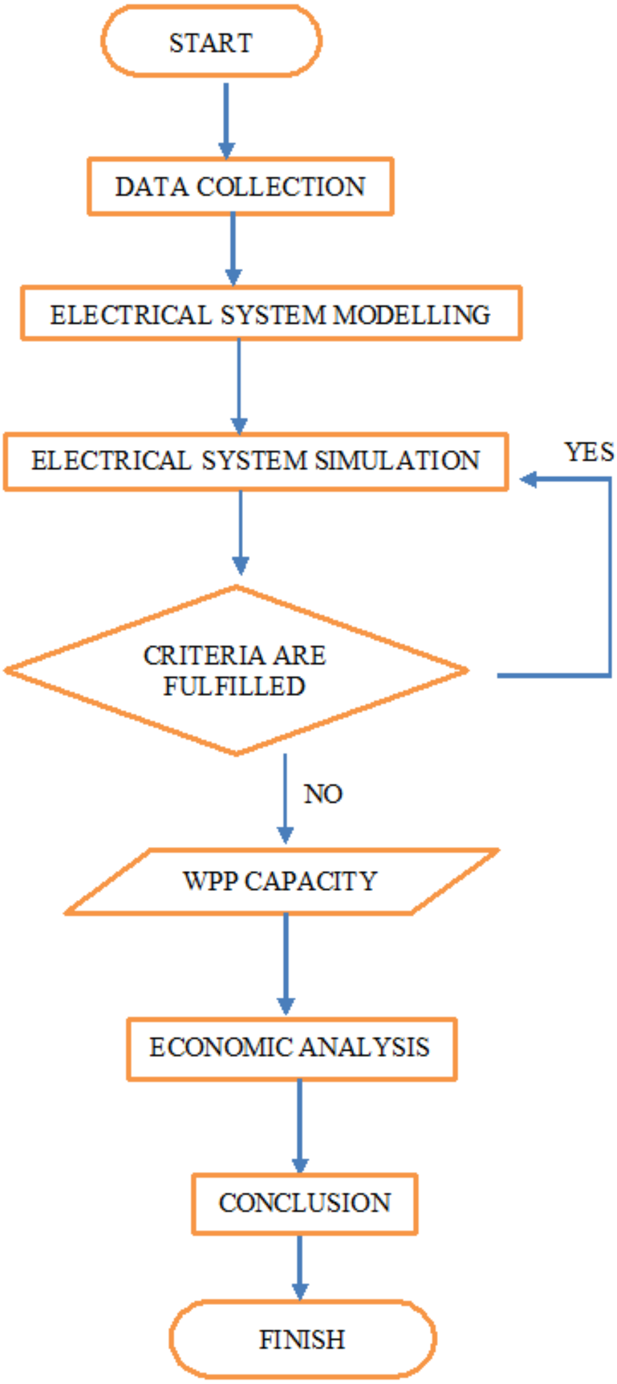
F. Economic Analysis

Economic analysis is carried out to determine the economic feasibility of a project. The analysis carried out includes calculating net present value (NPV), internal rate of return (IRR), profitability index (PI), payback period (PBP), and levelized cost of energy (LCOE) for the selected design and capacity. The parameters and units used are as follows: 1) Initial Investment Cost per MW (USD/MW). 2) Initial Investment Cost (USD). 3) Operations and Maintenance (O&M) Costs per year (USD/kW/year). 4) Annual Operations and Maintenance (O&M) Costs (USD). 5) Inflation/O&M Growth Rate (%). 6) Annual Fuel Costs (USD). 7) Annual Electricity Output (kWh). 8) Project Construction Time (years). 9) Project Lifespan/Contract Term (years).

10) Discount Rate (%). 11) Interest Rate (%). 12) Repayment Periode (years). 13) Debt to Equity Ratio/DER (%). 14) Corporate Tax (%). 15) Plant Installed Capacity (MW). 16) Plant Capacity Factor (%). 17) Electricity Tariff (USD/kWh). 18) Tariff Escalation (%)

The method used in calculating LCOE or energy cost is the Life Cycle Cost (LCC) method, which is a method that calculates the overall cost of a system starting from planning, development, operations and maintenance, equipment replacement, and salvage value during the lifetime of the system (Sugirianta, Giriantari, & Kumara, 2016). In this analysis, salvage value is not considered.

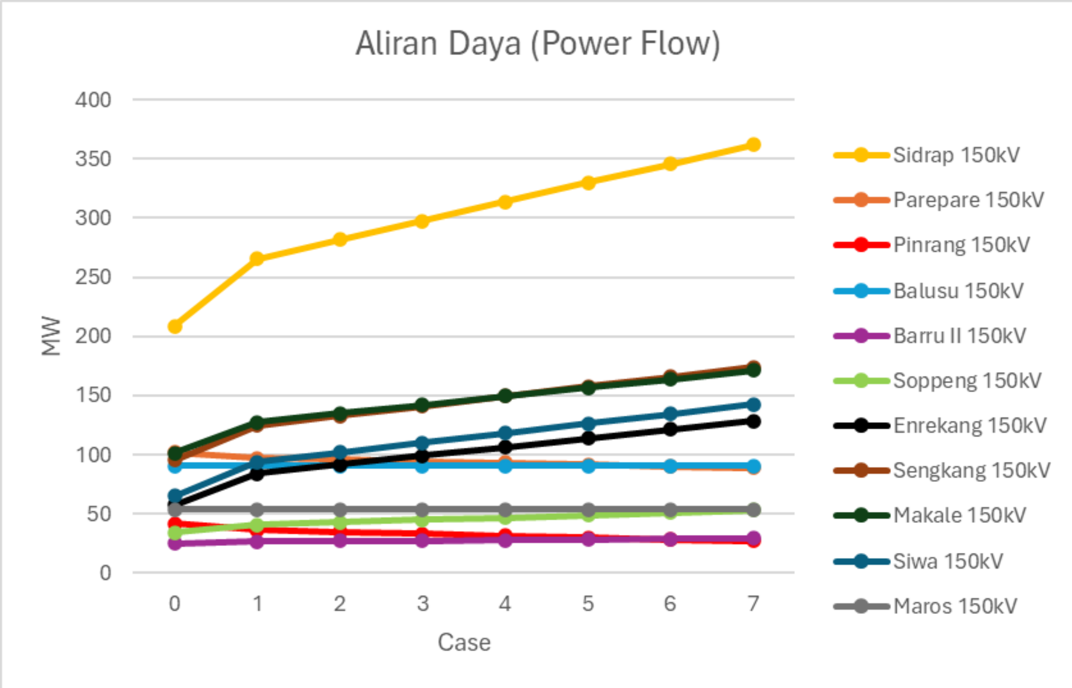
G. Flowchart



Picture 1 Research Flowchart

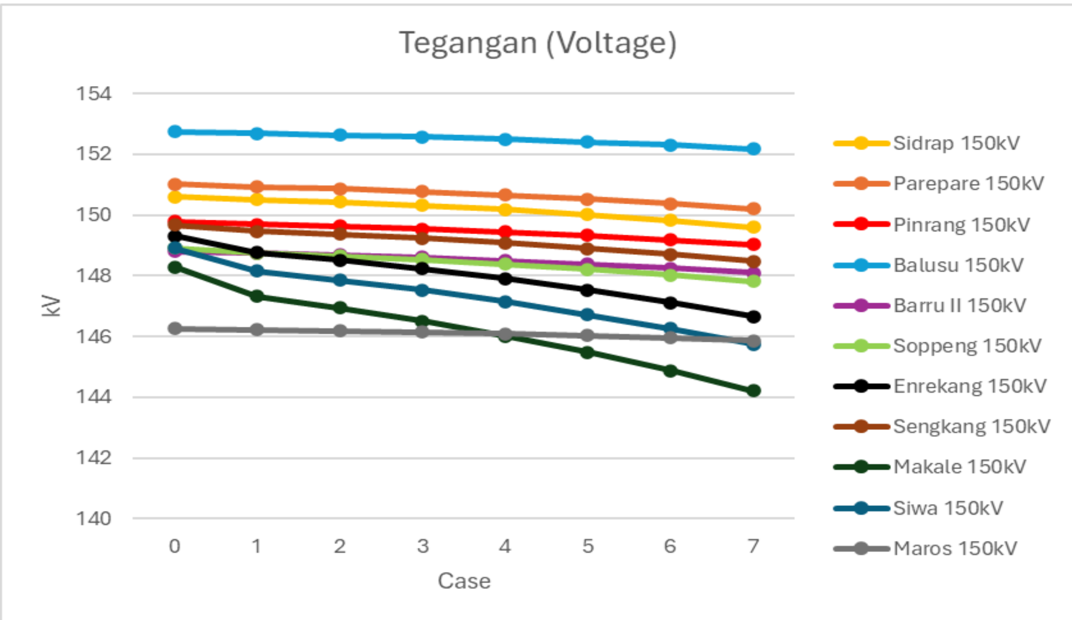
Result and Analysis

From the electrical system simulation, several trend curves can be created and analyzed as described below



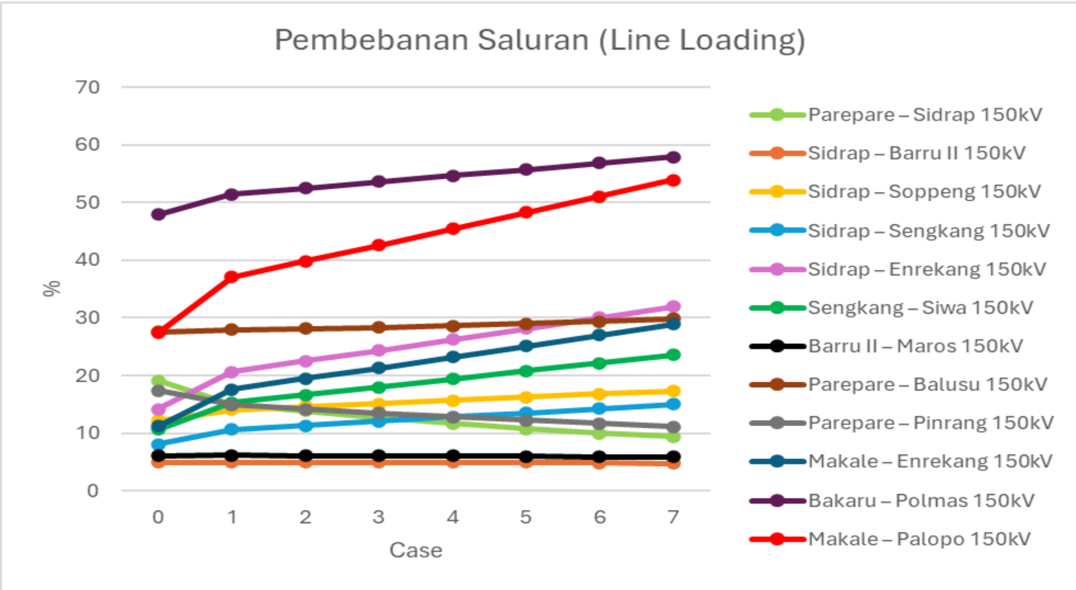
Picture 2 Power Flow Trend Curve

Power flow tends to increase except for the Pinrang and Parepare 150kV substations (GI), this is due to a decrease in power transfer from the Pinrang to the Parepare 150kV Substation and then to the Sidrap 150kV substation due to the power that should be supplied from those substations being replaced by power from the new WPP to the Sidrap 150kV substation. For substations that are far from the new WPP, such as Maros and Balusu 150kV substation, power flow tends not to change much (the influence of WPP integration is small).



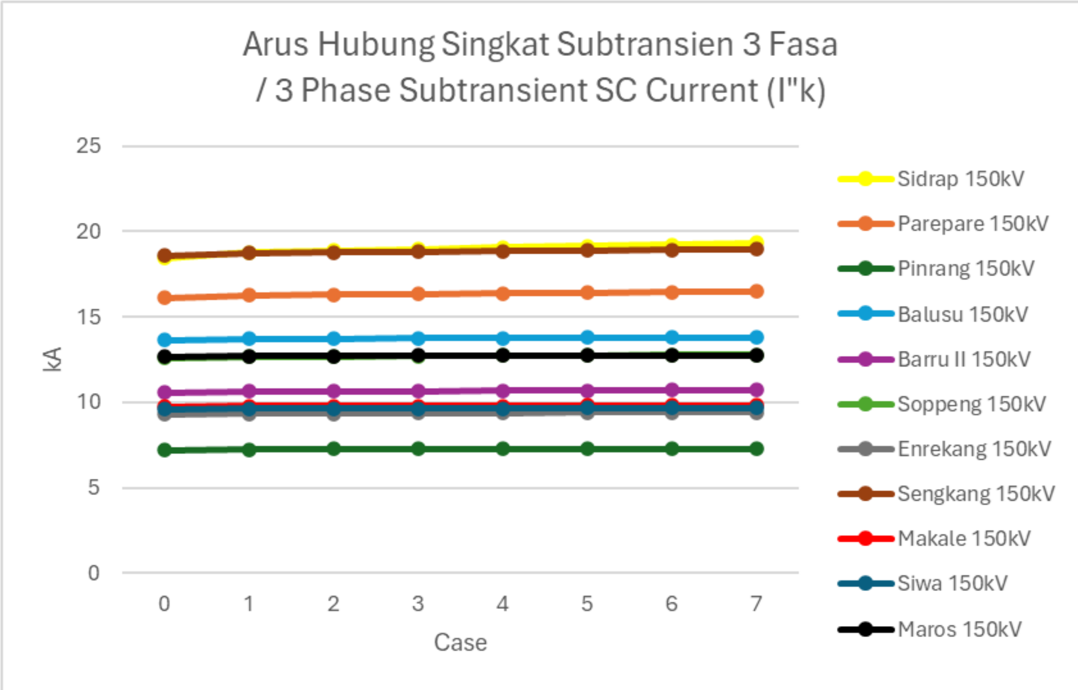
Picture 3 Voltage Trend Curve

The voltage tends to decrease due to losses on lines as a result of the increase in power distribution. However, the voltage is still within the permitted operating limits, i.e.135kV.

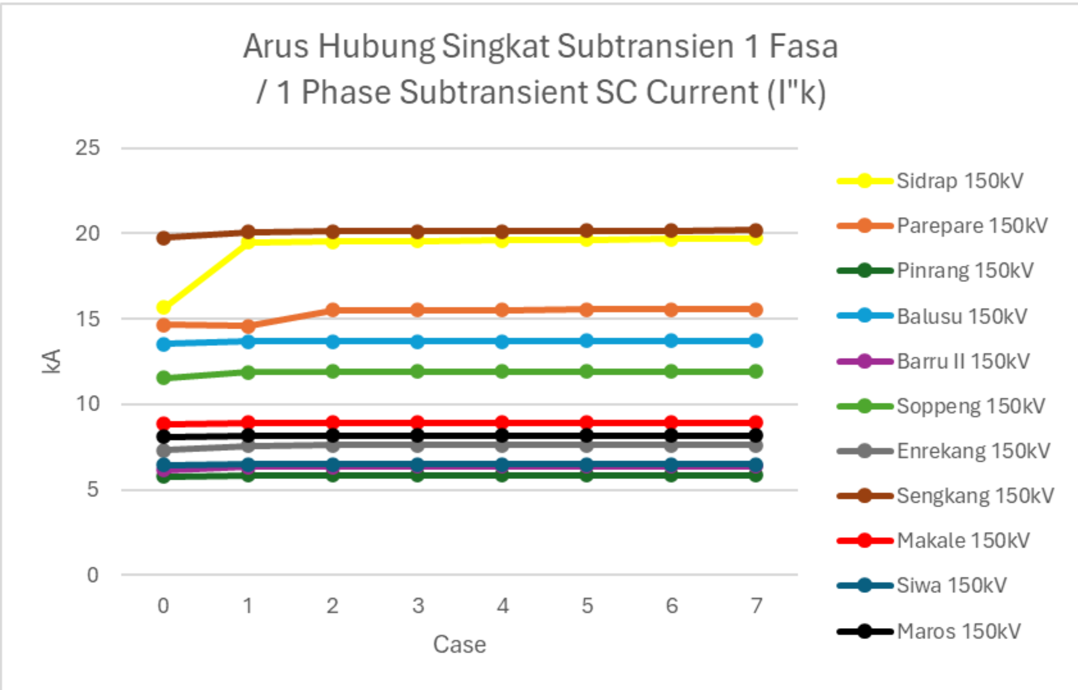


Picture 4 Line Loading Trend Curve

Line loading tends to increase except for a few lines. However, the loading is still below 60% of the capacity of each line. It is necessary to pay attention to the reliability of the Bakaru – Polmas and Makale – Palopo 150kV lines because the line loading in some cases exceeds 50%. There is also reduced line loading such as Parepare - Pinrang and Parepare – Sidrap 150kV, this is due to a decrease in power transfer from the Pinrang to the Parepare 150kV substation then to the Sidrap 150kV substation due to the power that should be supplied through the line being replaced by power from the new WPP to the Sidrap 150kV substation.

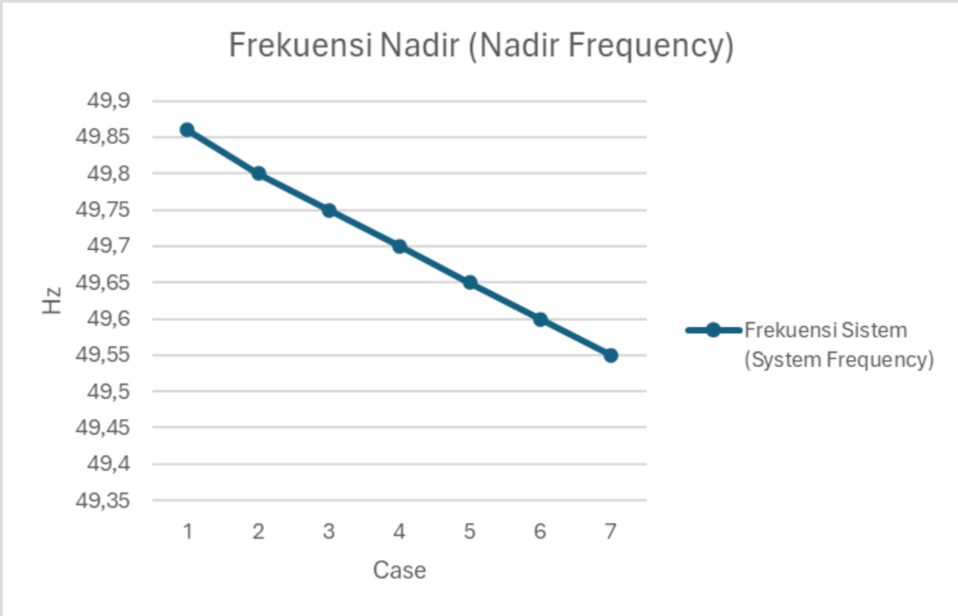


Picture 5 Three Phase Subtransient Short Circuit Current Trend Curve

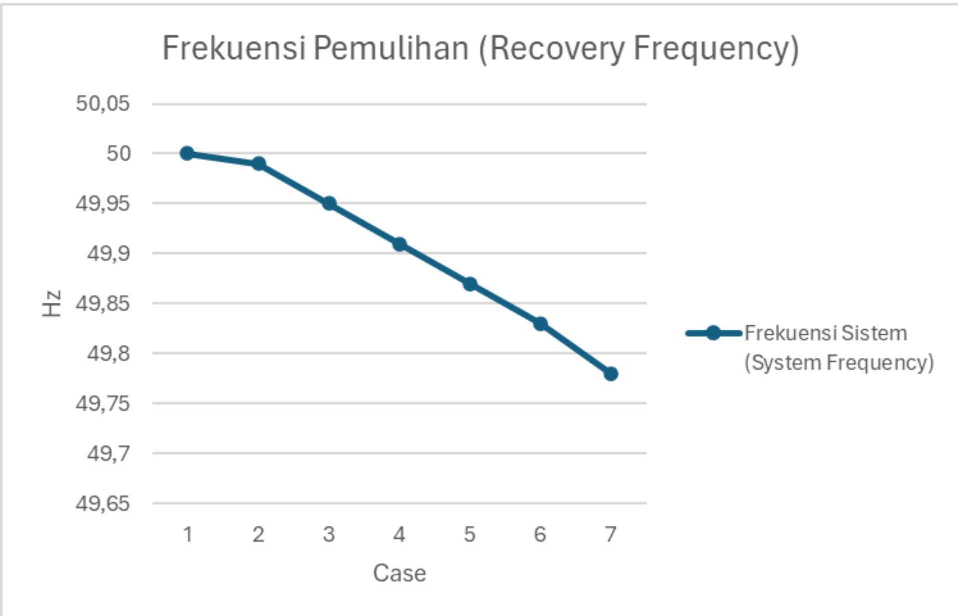


Picture 6 Single Phase Subtransient Short Circuit Current Trend Curve

The short circuit current for both 3 phases and 1 phase does not increase significantly due to the integration of WPP into the system, even for large capacities. This is because the short circuit current produced by the new WPP, which uses WTG Type 4, is small because it is limited by the power electronic components. The short circuit current value that occurs at each substation is still smaller than the minimum value of short circuit capacity for substations, namely 31.5 kA.



Picture 7 Nadir Frequency Trend Curve (New WPP Trip Scenario)



Picture 8 Recovery Frequency Trend Curve (New WPP Trip Scenario)

In all cases, the nadir frequency is still above the required limit during transient conditions, namely 49.5 Hz. Nadir frequency is the minimum frequency that occurs during transient conditions. This is because the total inertia of the system is still large enough to withstand a decrease in frequency even though the WPPs in the system have no inertia. So the main focus of the analysis is the frequency of recovery.

For case 6 the system recovery frequency is just above the permitted operating frequency limit, namely 49.8 Hz. For case 7 the system recovery frequency is below the permitted operating frequency limit. So it is necessary to consider using a connected WPP capacity that is smaller than 170MW, namely cases 1 (70 MW) to 5 (150 MW). If WPP more than 150MW wants to be integrated, then fast response spinning reserve generators or batteries need to be provided. At certain WPP capacities, the system recovery frequency does not deviate much because it is still supported by the presence of Hydro, Diesel, Gas, and Combine Cycle Power Plant in the system where these generators will respond to power deficit by increasing the power of each of these generators.

There are no significant changes in voltage due to changes in WPP power for various capacities (cases). So the trend curve does not need to be created. The biggest voltage change occurred when the new WPP tripped in case 7, the initial voltage of 149.61kV dropped to 149.15kV during recovery. This is because the reactive power supplied by other generators in the system is still sufficient to maintain voltage.

For economic analysis, data input as below is used. The simulated WPP capacity is 150 MW because it is technically more feasible as explained in the previous:

Table 7 Economic Data Input

Data Input	**Value**
Initial Investment Cost (USD/MW)	1.650.000
Initial Investment Cost (USD)	247.500.000
Operations and Maintenance Costs (USD/kW/year)	35
Annual Operations and Maintenance (O&M) Costs (USD)	5.250.000
Inflation/O&M Growth Rate (%)	5,0%
Annual Fuel Costs (USD)	-
Annual Electricity Output (kWh)	394.200.000
Project Construction Time (years)	1
Project Lifespan/Contract Term (years)	25
Discount Rate (%)	10,0%
Interest Rate (%)	6,0%
Repayment Periode (years)	10
Debt to Equity Ratio/DER (%)	50,0%
Corporate Tax (%)	22,0%
Plant Installed Capacity (MW)	150
Plant Capacity Factor (%)	30,0%
Electricity Tariff (USD/kWh)	9
Tariff Escalation (%)	3,0%

From the simulation, the following economic indicators results are obtained:

Table 8 Economic Indicator Result

Indicator	Value
IRR (%)	11,94
PBP (year)	9,81
PI	1,49
NPV (USD)	60.146.654
NPV Cost (USD)	319.682.564
NPV Energy (kWh)	3.578.169.175,19
LCOE [cUSD/kWh]	8,93

From the data input and the assumptions used, it can be seen that
1. The PI value is greater than 1 and the NPV is positive, meaning the project is financially profitable.
2. The payback period is still less than 10 years, less than the loan term and the IRR is bigger than 10%, bigger than the BI Rate.
3. The LCOE value obtained (8,93 cUSD/kWh) is still smaller than the average Basic Cost of Providing (BPP) Generation in the Southern Sulawesi electrical system (10,013 cUSD/kWh).

This means the project is still economically feasible.

Conclusion

From the research conducted, several conclusions can be drawn as follows: 1) The power flow experiences changes (increases or decreases) due to the integration of the WPP into the existing system. 2) The voltage tends to decrease due to line losses due to the increase in power distribution, but the voltage is still within the permitted operating limits, namely 135kV. 3) The line loading changes (increases or decreases) depending on changes in power flow that occur. 4) Short circuit current for both 3 phases and 1 phase does not increase significantly due to the integration of WPP into the system, even for large capacities. This is because the short circuit current produced by the WPP which uses WTG Type 4 is small. After all, it is limited by the power electronic components in the wind turbine power converter to a value around the nominal current of the wind turbine.

5) The capacity limit for connected WPP must be smaller than 170MW, in this case, cases 1 (70 MW) to 5 (150 MW). If the capacity of the connected WPP is more than that, then when the WPP trips, the system frequency will not recover above the operating limit required in the network regulations, namely 49.8 Hz. This is because the Hydro, Gas, Combine Cycle, and Diesel which are fast response generators in the system are unable to compensate for the frequency decrease that occurs.

6) There are no significant changes in voltage due to changes in WPP power for various capacities (cases). 7) The LCOE value obtained (8,93 cUSD/kWh) is still smaller than the average Basic Cost of Providing (BPP) Generation in the Southern Sulawesi electrical system (10,013 cUSD/kWh). 8) From the simulation carried out, the use of WPP with a capacity of 150 MW is technically and economically feasible.

BIBLIOGRAPHY

Ahmed, S. D., Al-Ismail, F. S. M., Shafiullah, M., Al-Sulaiman, F. A., & El-Amin, I. M. (2020). Grid Integration Challenges of Wind Energy: A Review. *IEEE Access*, *8*, 10857–10878. https://doi.org/10.1109/ACCESS.2020.2964896

Dalimi, R. (2021). *Menuju Era Energi Terbarukan*. Depok: Universitas Indonesia.

Ekanayake, J., & Jenkins, N. (2004). Comparison of the Response of Doubly Fed and Fixed-Speed Induction Generator Wind Turbines to Changes in Network Frequency. *IEEE Transactions on Energy Conversion*, *19*(4), 800–802. https://doi.org/10.1109/TEC.2004.827712

Feilat, E. A., Azzam, S., & Al-Salaymeh, A. (2018). Impact of Large PV and Wind Power Plants on Voltage and Frequency Stability of Jordan's National Grid. *Sustainable Cities and Society*, *36*, 257–271. https://doi.org/10.1016/j.scs.2017.10.035

Gharibeh, H. F., Khiavi, L. M., Farrokhifar, M., Alahyari, A., & Pozo, D. (2019). Capacity Value of Variable-Speed Wind Turbines. *2019 IEEE Milan PowerTech*, 1–5. IEEE. https://doi.org/10.1109/PTC.2019.8810839

IEEE Power & Energy Society, & Institute of Electrical and Electronics Engineers. (2014). Determination of Acceptable Inertia Limit for Ensuring Adequacy under High Levels of Wind Integration. *11th International Conference on the European Energy Market : Energy for Future : Krakow, Poland*.

Liu, Y., & Zhang, J. (2018). *Research on The Effects of Wind Power Grid on The Distribution Network of Henan Province*. 030005. https://doi.org/10.1063/1.5033604

Muljadi, E., Gevorgian, V., Samaan, N., Li, J., & Pasupulati, S. (2010). *Short Circuit Current Contribution for Different Wind Turbine Generator Types*. Retrieved from http://www.osti.gov/bridgeonlineordering:http://www.ntis.gov/ordering.htm

Noviantara, M. D., Suweden, I. N., & Mataram, I. M. (2018). Analisis Stabilitas Sistem Tenaga Listrik Dengan Automatic Generation Control (AGC) Dua Area Menggunakan Fuzzy Logic Controller. *Majalah Ilmiah Teknologi Elektro*, *17*(2), 263. https://doi.org/10.24843/MITE.2018.v17i02.P15

Opila, D. F., Zeynu, A. M., & Hiskens, I. A. (2010). Wind Farm Reactive Support and Voltage Control. *2010 IREP Symposium Bulk Power System Dynamics and Control - VIII (IREP)*, 1–10. IEEE. https://doi.org/10.1109/IREP.2010.5563248

Papathanassiou, S., Hatziargyriou, N., Anagnostopoulos, P., Aleixo, L., Buchholz, B., & Carter-Brown, C. (2014). *Capacity of Distribution Feeders for Hosting DER*. CIGRÉ.

Riasa, I. P., Hartati, R. S., Manuaba, I. B. G., & Santiari, D. A. S. (2020). Pengaruh PLTB Sidrap Terhadap Sistem Kelistrikan Sulawesi Selatan. *Majalah Ilmiah Teknologi Elektro*, *19*(1), 27. https://doi.org/10.24843/MITE.2020.v19i01.P04

Sang, S., Zhang, C., Cai, X., Molinas, M., Zhang, J., & Rao, F. (2019). Control of a Type-IV Wind Turbine With the Capability of Robust Grid-Synchronization and Inertial Response for Weak Grid Stable Operation. *IEEE Access*, *7*, 58553–58569. https://doi.org/10.1109/ACCESS.2019.2914334

Sugirianta, I. B. K., Giriantari, I. A. D., & Kumara, I. N. S. (2016). Analisa Keekonomian Tarif Listrik Pembangkit Listrik Tenaga Surya 1 MWp Bangli dengan Metode Life Cycle Cost. *Teknologi Elektro*, *15*(2).

Wu, C., Zhang, X. P., & Sterling, M. (2022). Wind Power Generation Variations and Aggregations. *CSEE Journal of Power and Energy Systems*, *8*(1), 17–38. https://doi.org/10.17775/CSEEJPES.2021.03070

Zobaa, A. F., Ahmed, I., & Abdel Aleem, S. H. E. (2019). A Comprehensive Review of Power Quality Issues and Measurement for Grid-integrated Wind Turbines. *Recent Advances in Electrical & Electronic Engineering (Formerly Recent Patents on Electrical & Electronic Engineering)*, *12*(3), 210–222. https://doi.org/10.2174/2352096511666180608115140