Design of Microhydro Power Plants Based on Load Flow and Short Circuit Study Using ETAP: A Case Study in East Java, Indonesia

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***Abstract*— This study was conducted to determine the feasibility level of the microhydro power plant development plan in Ngentep Village for the Off Grid On Grid system system and Sarangan Lake, Magetan Regency, East Java. The methodology used includes field survey activities, hydrological analysis, power and energy calculations, mechanical and electrical equipment planning, and technical analysis. In this system there are 4 study cases, including the Off Grid system in Ngntep, the Off Grid system with Hybrid in Ngentep, the On Grid system in Sarangan Lake and the on grid system with hybrid in Sarangan Lake. The results showed that the water discharge was able to generate minimal power in Sarangan Lake and Ngentep, 1.59kW and 1.18kW respectively. Power value for the On Grid system with a value of 1,598 kW. While the power value for Off Grid is 0.072 kW. And has a power factor of up to 99.7% but this is very helpful for the community, especially those in remote rural areas and suppliers in tourist areas. As for the current value in the On Grid system is 2.126 kA and for the Off Grid system it is 1.0209 kA.**

Keywords*— *Microhydro, ETAP, Load Flow, Short Circuit

I. Introduction

Currently, there are around 12,625 villages in Indonesia that do not have access to electricity. Therefore, one of the renewable energies that can be realized in remote villages is micro hydro power plants. For the utilization of water energy by integrating the MHP development program by maximizing the potential of irrigation channels for MHP which are more effective in rural areas [1]. For the use of motion energy in rural areas, one of them needs to be developed from the river in Ngentep Village, Magetan. Within the scope of micro-hydro applications in Indonesia, especially in the Magetan area which has abundant natural water sources, being one of the solutions for rural electricity which is generally difficult to reach by PLN electricity lines will be an advantage for the surrounding community. One of sulution to meet this target is to build power plants using renewable energy, starting from hydro energy, solar energy biofuel energy, biomass energy, geothermal energy, wind energy, and ocean wave energy [2-6]

In addition to rural areas, tourist attractions have potential water sources, one example is Sarangan Lake. Sarangan Lake is known as a tourist spot with the most monthly visitors in Magetan Regency. Until it reaches 2000 visitors every weekend. There is a limit to the use of electricity from PLN, for that it is necessary to provide electrical energy by utilizing water sources in the area

With the Minister of Energy and Mineral Resources No. 04 of 2012, PT. PLN (PERSERO) or State Electricity Company has an obligation to purchase electricity sourced from small and medium scale renewable energy or excess electricity [1]. The Magetan area has excess potential, one of which is a river that can be used for micro-hydro power plants. The existence of various potentials that we have, we should be able to use them to solve existing problems so that the design and techno-economic analysis of the On Grid and Off Grid system micro-hydro power plants in Magetan Regency is designed. Most of the energy produced by the power plant will be distributed to 100 houses and PJUs around the generator site in Ngentep Village and 100 hotels and PJUs around Sarangan Lake. In relation to PLN, PLTMH must meet technical and economic requirements so that it can support the economic development of the community around the power plant [7-8].

II. MAIN POWER EQUIPMENT SIMULATION

A. ETAP Software

Software is used to design electrical systems in an industry or region. ETAP is also to carry out various analyzes that are very helpful in the design of electric power systems. In the design and analysis of an electric power system, to represent real conditions before a system is realized. ETAP itself stands for (Electric Transient and Analysis Program) which is able to work offline for electrical power simulations and online for data processing according to the system design made. There are several features that exist in ETAP, including[9-10]:

- Power flow analysis
- Arc Flash Analysis
- Short circuit analysis
- Starting motor
- Coordination of proxies
- Transient stability analysis

B. Single Line Diagram

The single line diagram is a simplified notation for a three-phase electric power system. Instead of representing a separate three-phase line, a conductor is used. This makes it easier to read diagrams and circuit analysis. Electrical elements such as circuit breakers, transformers, capacitors, bus bars, and other conductors can be represented using symbols that have been standardized for single line diagrams. Elements on a diagram do not represent the physical size or location of electrical equipment, but it is a common convention to arrange diagrams in the same left-to-right, top-to-bottom, switch, or other order represented. Some of the elements used in a single line diagram are Generators, Transformers, Circuit Breakers, etc.

TABLE I. PREVIOUS RESEARCH

Energy System	Grid Connection	Metode	Perfomance measures
PV plants [11]	On Grid & Off Grid	ETAP	Load flow, short circuit analysis
Diesel Power Plant [12]	Off Grid	ETAP	Loadflow, short circuit, motor starting, cable ampacity, relay coordination, transient stability studies
Wind Power Plants [13]	Off Grid	ETAP	short circuit analysis
Ring Main distribution system [14]	Off grid	ETAP	Load flow
System design [15]	Off Grid	ETAP	short circuit calculation
Distribution feeder system [16]	Off grid	ETAP	Distribution losses, load flow analysis

C. Power Grid

In this power grid, it is a voltage source that is able to supply power with a fixed voltage even though the power absorbed is very large. The power grid itself, in the case study, is like an unlimited source of PLN. In the case study, this system using a power grid with nominal voltage is 20 kV, as in the image below :

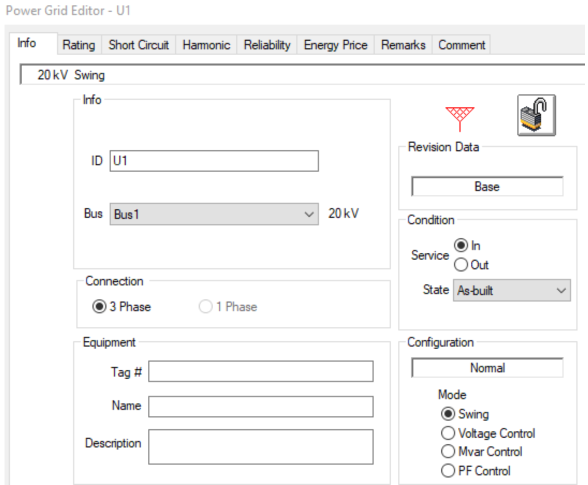


Figure 1. Power Grid Parameter

Usually the grid equivalent is treated as a point in the grid power, and the voltage and frequency are essentially constant so the grid equivalent should have a constant internal potential.

D. Generator Design

In designing this generator to withstand the fault current that is donated to the generator only. But the terminal box on which the generator depends to withstand fault currents as well as switchgear [16]. In this system, generators are used for on grid and off grid systems and both have the same capacity of 100 kW. As in the image below:

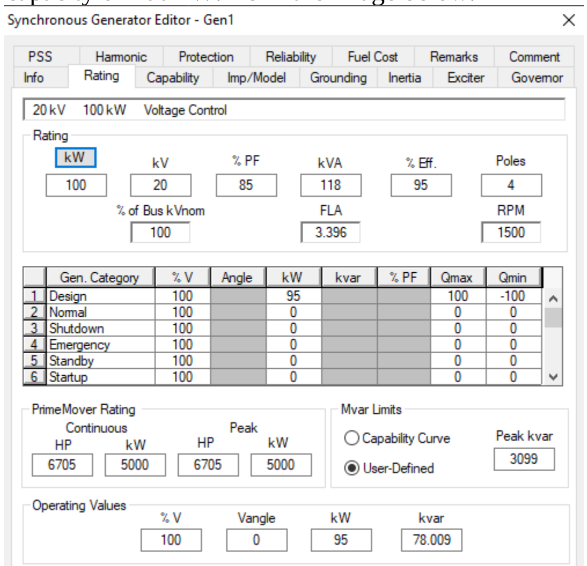


Figure 2. Generator Parameter

E. PV Model

PV is an alternative or backup source for hybrid systems. which can be used if the main source is not sufficient to supply the current load. So that PV is very easy to use and many people have used this generator, because of its good output but in its design it is very practical and efficient. In this system, the PV capacity used is 11 kW, as shown below:

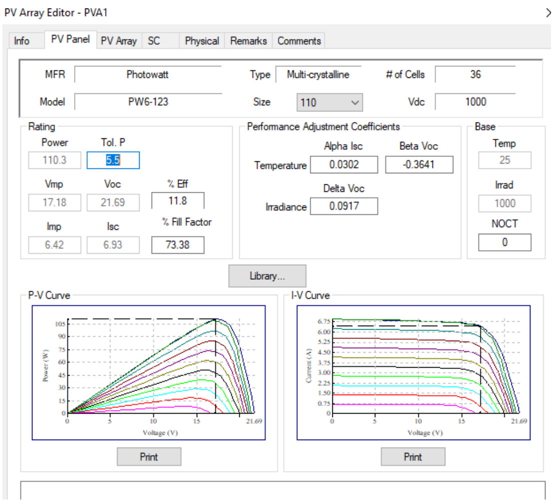


Figure 3. PV Parameter

F. Load Input

The load itself consists of 2, namely for off-grid loads and on-grid loads. The load for off-grid is the burden of residents' houses and street lighting with a large load of 763.5 kWh for houses and 15.6 kWh for street lighting. As for the on-grid load, there is a hotel load and street lighting around the tourist attractions, with a large on-grid load of 11,635 kWh for hotels and 39 kWh for street lighting.

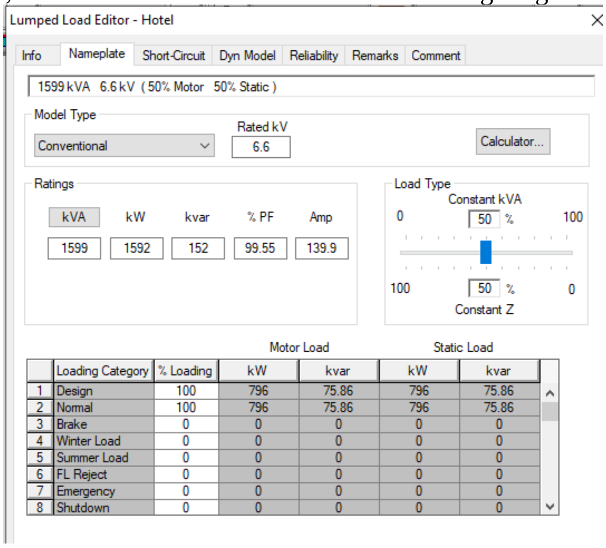


Figure 4. Load Parameter

III. CASE STUDIES

In this case study, it is divided into 4 scenarios or case studies including [15]:

A. Off Grid in Ngentep Village, Magetan

In the first case study for an off grid system in the Ngentep Village area, Magetan Regency. In this system the main source will be supplied only by the generator and turbine. Then there is the burden of residents' houses and street lighting. In off-grid systems, it is usually suitable to be carried out in remote areas. Ngentep village itself has the potential for micro hydro power plants which can be used as a supplier of electricity.

B. Off Grid with Hybrid in Ngentep Village, Magetan

Same as the first study case off the grid but combined with a hybrid system. Where the hybrid is here with the addition of PV as a backup supply if at any time the generator is not enough to meet the load, it will be backed up by this hybrid system. Not only is there an addition to PV but also uses a battery as an energy store, then an inverter as a converter of dc electricity from Pv into ac electricity to load the residents' homes.

C. On Grid in Sarangan Lake, Magetan

For this system, it is an on grid system in the area of one of the tourist attractions in the Magetan area, namely Sarangan Lake. In the on-grid system, this means that apart from using a generator, it also uses a Grid or it can be said that the PLN source is unlimited. In the real case, there are indeed more than 100 hotels in Sarangan and need energy or sources that can supply continuously. But the advantage here is that there is not too much use of PLN energy so that electricity payments are decreasing.

D. On Grid With Hybrid in Sarangan Lake, Magetan

The system is the same as the previous system which is assisted by the Grid or PLN system. But the difference here is the addition of PV as a backup supply as well. For the Hybrid itself he has a very good output and is very consistent continuously. In addition to having a good output.

IV. SIMULATION RESULT

A. Loadflow Result

1) Ngentep Village for Off Grid System

In the report, it can be concluded that there is a power factor in the PLN supply of 99.98% lagging (the presence of an inductive load), then the total demand is 99.98% and lagging. The total motor load is 97.98% lagging power and the total static load is 99.98% lagging (inductive load).

TABLE II. LOADFLOW DATA OFF GRID SYSTEM OF NGENTEP VILLAGE

	MW	MVar	MVA	Pf %
Total Motor load	0.03	0.001	0.03	99.98 lagging
Total Static Load	0.03	0.001	0.03	99.98 lagging

TABLE III. LOADFLOW BUS DATA OFF GRID SYSTEM OF NGENTEP VILLAGE

ID Bus	kV	MW	MVar	% Pf	Amp
Bus 1	12.6	0.072	0.002	100	3.3
Bus 2	6.6	0.072	0.002	100	6.3
Bus 4	6.6	0.072	0.002	100	6.3
Bus 6	6.6	0.001	0.001	88.5	0.1

The picture below is a single line diagram, which shows what components we will simulate for the Off Grid system.

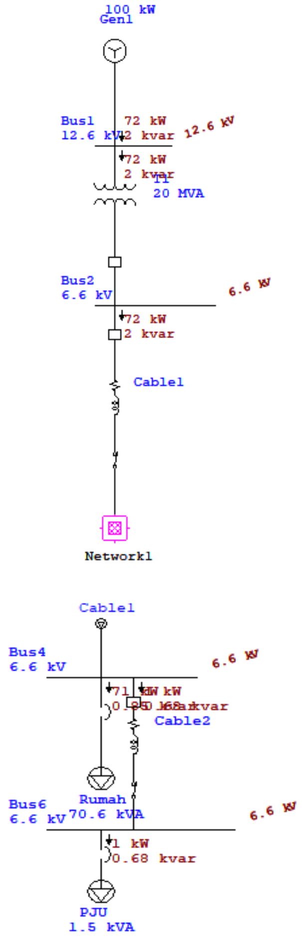


Figure 6. Load Flow Off Grid System Ngentep

2) *Ngentep Village for Hybrid System*

In the report, it can be concluded that there is a power factor in the PLN supply of 86.74% lagging (the presence of an inductive load), then the total demand is 86.74% and lagging. The total motor load is 85.82% lagging power and the total static load is 86.74% lagging (inductive load).

TABLE IV. LOADFLOW DATA OFF GRID WITH HYBRID SYSTEM OF NGENTEP VILLAGE

	MW	MVar	MVA	Pf %
Source with swing	0.001	0.001	0.001	86.74 lagging
Source without swing	0.0	0.123	0.0	
Total Static Load	0.001	0.001	0.001	86.74 lagging
Total Demand	0.001	0.001	0.001	86.74 lagging
Total Motor load	0.018	0.011	0.021	85.82 lagging

TABLE V. LOADFLOW BUS DATA OFF GRID WITH HYBRID SYSTEM OF NGENTEP VILLAGE

ID Bus	kV	MW	MVar	% Pf	Amp
Bus 1	12.6	0.001	0.001	86.7	0.1
Bus 2	6.6	0.001	0.001	86.7	0.1
Bus 4	6.6	-0.001	-0.001	86.7	0.1
Bus 6	6.6	-0.001	-0.001	86.7	0.1

The picture below is a single line diagram, which shows what components we will simulate for the Off Grid system with Hybrid.

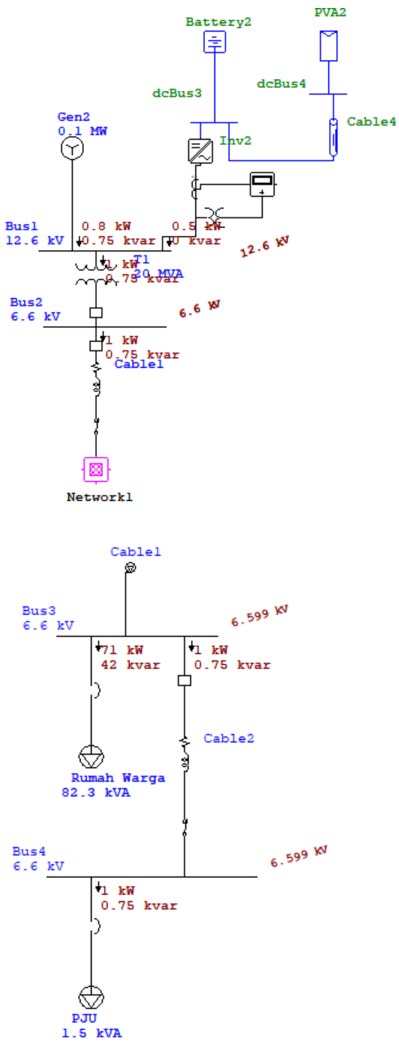


Figure 7. Load Flow Off Grid with Hybrid System Ngentep Village

3) *Sarangan Lake for On Grid System*

In the report, it can be concluded that there is a power factor in the PLN supply of 99.62% lagging (there is an inductive load), then the total demand is 99.62% and lagging. The total motor load is 97.35% lagging power and the total static load is 99.78% lagging (inductive load).

Table 6. Loadflow Data On Grid System Of Sarangan Lake

	MW	MVar	MVA	Pf %
Source with swing	1.598	0.140	1.604	99.62 lagging
Source without swing	0.0	0.123	0.0	100 lagging
Total Static Load	0.798	0.053	0.800	99.78.0 lagging
Total Demand	1.598	0.140	1.604	99.62 lagging
Total Motor load	0.800	0.188	0.821	97.35 lagging

TABLE VI. LOADFLOW BUS DATA ON GRID SYSTEM OF SARANGAN LAKE

ID Bus	kV	V	MW	% Pf	Amp
Bus 1	20	100	1.598	99.7	47.4
Bus 2	6.6	99.919	1.598	97.4	143.7
Bus 4	6.6	99.917	0.007	62.5	1.0
Bus 6	6.6	99.917	1.598	62.5	1.0

The picture below is a single line from the On Grid system

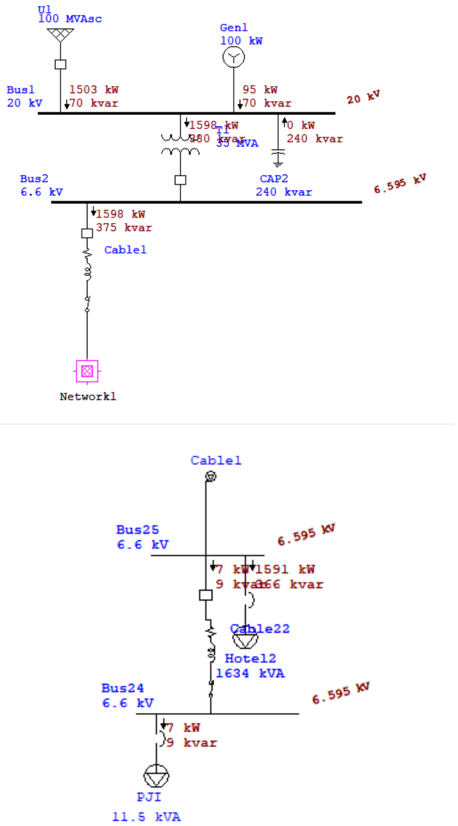


Figure 8. Load Flow On Grid System Sarangan Lake

4) Sarangan Lake for Hybrid System

In the report, it can be concluded that there is a power factor in the PLN supply of 88.47% lagging (the presence of an inductive load), then the total demand is 88.47% and lagging. The total motor load is 88.47% lagging power and the total static load is 88.47% lagging (the presence of an inductive load).

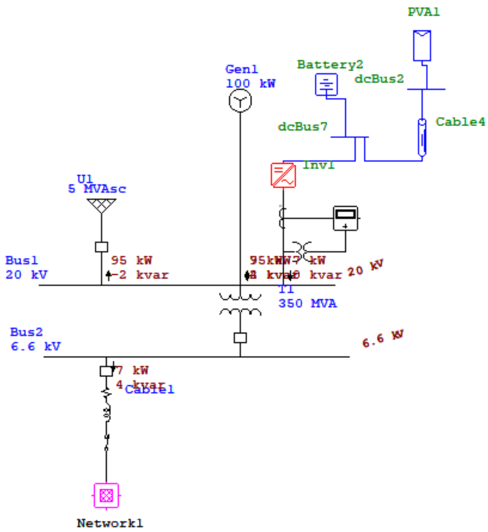
TABLE VII. LOADFLOW DATA ON GRID WITH HYBRID SYSTEM OF SARANGAN LAKE

	MW	MVar	MVA	Pf %
Source with swing	0.007	0.004	0.008	88.47 lagging
Source without swing	0.0	0.123	0.0	
Total Static Load	0.001	0.001	0.002	88.47 lagging
Total Demand	0.007	0.004	0.008	88.47 lagging
Total Motor load	0.006	0.003	0.007	88.47 lagging

TABLE VIII. LOADFLOW BUS DATA ON GRID WITH HYBRID SYSTEM OF SARANGAN LAKE

ID Bus	kV	MW	MVar	% Pf	Amp
Bus 1	20	0.007	0.004	88.5	0.2
Bus 2	6.6	0.007	0.004	88.5	0.7
Bus 4	6.6	-0.007	-0.004	88.5	0.7
Bus 6	6.6	-0.007	-0.004	88.5	0.7

The picture below is a single line diagram, which shows what components we will simulate for the On Grid system with hybrid.



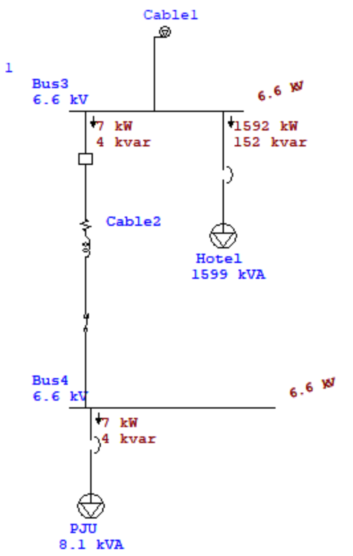


Figure 9. Load Flow to On Grid with Hybrid System Sarangan Lake

B. *Short Circuit Result*

1) *Ngentep Village For Off Grid System*

This short circuit simulation is carried out on 2 different buses, namely: Bus 4 and Bus 6. In this section, short circuits for 2 operating loads and 1 operating load. So that the value of the short-circuit fault current is obtained as shown in the table below.

TABLE IX. SHORT CIRCUIT OFF GRID SYSTEM

ID Bus	kV	Type SC	Ia	Ib	Ic
Bus 24	6.6	3 Phase	0.11		
		L-G	0.11	0.0	0.0
		L-L	0.0	0.06	0.06
		L-L-G	0.0	0.12	0.12
Bus 25	6.6	3 Phase	0.11		
		L-G	0.11	0.0	0.0
		L-L	0.0	0.06	0.06
		L-L-G	0.0	0.12	0.12

Table 9 is the value of the short-circuit fault current from the simulation results of ETAP 12.6. when all loads are operating. The type of 3 phase fault is a disturbance that gives a large current. For Bus 3 and Bus 4 the result is 0.111 kA.

2) *Ngentep Village For Hybrid System*

This short circuit simulation is carried out on 2 different buses, namely: Bus 4 and Bus 3. In this section, short circuits for 2 operating loads and 1 operating load. So that the value of the short-circuit fault current is obtained as shown in the table below.

TABLE X. SHORT CIRCUIT OFF GRID WITH HYBRID SYSTEM

ID Bus	kV	Type SC	Ia	Ib	Ic
Bus 3	6.6	3 Phase	0.065		
		L-G	0.099	0.0	0.00
		L-L	0.00	0.057	0.057
		L-L-G	0.0	0.112	0.112
Bus 4	6.6	3 Phase	0.065		
		L-G	0.099	0.0	0.00
		L-L	0.00	0.057	0.057
		L-L-G	0.0	0.112	0.112

Table 10 is the value of the short-circuit fault current from the simulation result of ETAP 12.6. When all loads are operating. The type of Line to Line to Ground phase fault is a disturbance that gives a large current. For Bus 3 and Bus 4 the result is 0.112 kA

3) *Sarangan Lake For On Grid System*

The short circuit simulation in the On Grid system is carried out on 2 different buses, namely: Bus 24 and Bus 25. The purpose of this short circuit simulation is to see the largest fault current in the network system itself. So that the value of the short-circuit fault current is obtained as shown in the table below.

TABLE XI. SHORT CIRCUIT ON GRID SYSTEM

ID Bus	kV	Type SC	Ia	Ib	Ic
Bus 24	6.6	3 Phase	10.909		
		L-G	10.909	0.0	0.0
		L-L	0.0	6.842	6.842
		L-L-G	0.0	10.749	11.517
Bus 25	6.6	3 Phase	10.916		
		L-G	10.916	0.0	0.0
		L-L	0.0	6.844	6.844
		L-L-G	0.0	10.758	11.543

Table 11 is the value of the short-circuit fault current from the simulation results of ETAP 12.6. when all loads are operating. The type of 3 phase fault is a disturbance that gives a large current. For Bus 24 and Bus 25, the results are 10,909 kA and 10,916 kA respectively.

4) *Sarangan Lake For Hybrid System*

The short circuit simulation in the On Grid system is carried out on 2 different buses, namely: Bus 24 and Bus 25. The purpose of this short circuit simulation is to see the largest fault current in the network system itself. So that the value of the short-circuit fault current is obtained as shown in the table below.

TABLE XII. SHORT CIRCUIT ON GRID WITH HYBRID SYSTEM

ID Bus	kV	Type SC	Ia	Ib	Ic
Bus 24	6.6	3 Phase	0.887		
		L-G	1.329	0.0	0.0
		L-L	0.0	0.770	0.770
		L-L-G	0.0	1.526	1.522
Bus 25	6.6	3 Phase	0.887		
		L-G	1.326	0.0	0.0
		L-L	0.0	0.767	0.767
		L-L-G	0.0	1.522	1.520

Table 12. is the value of the short-circuit fault current from the simulation results of ETAP 12.6. when all loads are operating. The type of line to line to ground fault is a disturbance that gives a large current. For Bus 3 and Bus 4 the results are 1,526 kA and 1,522 kA respectively.

V. CONCLUSION

The power value displayed on each transmission line depends on the type of load used. For On Grid and Off Grid systems only consisting of resistive and inductive loads, there will be active power and reactive power flowing.

From the above comparison, there is the highest power value produced by the On Grid system using a Hybrid of 1,598 MW. Thekon for the highest reactive power also from the On Grid system using Hybrid. The power factor and real power have a directly proportional relationship. Where the greater the power factor, the greater the power obtained.

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