SEMAU SOLAR HYBRID INTERACTIVE MICROGRID

Halomoan Parningotan T.S
PT. PLN (Persero) - Indonesia
halomoan.parningotan@pln.co.id

Daniel K F Tampubolon
PT PLN (Persero) - Indonesia
daniel.tampubolon@pln.co.id

Albertus Koko Hendriyanto
PT. PLN (Persero) - Indonesia
albertus.hendriyanto@pln.co.id

ABSTRACT

The first Hybrid Solar (PV) Power Plant in NTT, was operational in August 2019 on Semau Island, Kupang Regency, NTT. The Semau Hybrid system supplied from Solar Power Plant Semau and Diesel Generator Semau is used to illuminate 3,719 customers with a capacity of 450 kilo watt peak (kWp) equipped with an inverter with a capacity of 250 kW, a battery capacity of 2.8 MWh and a generator with a capacity of 1170 kW. Customers on Semau Island was fully supplied using Solar Power Plant starting from 10:00 WITA to 14:00 WITA and when the sun's rays decrease, the supply automatically switches to using diesel generator without any flickering at the customer's house.

A microgrid is defined as a collection of power generation sources and loads that operate when connected to the utility grid, but can also continue to operate when disconnected from the utility grid. In this system, there is a Solar Power Plant system and a diesel generator as a source of electrical energy, an energy storage system in the form of batteries, and local loads. The Solar Power Plant system in the Interactive Microgrid topology can operate in on-grid mode (using the utility network as a frequency and voltage reference) or islanded (without being connected to the utility network). In islanded mode, the energy storage system component or diesel generator acts as a grid-former so that the Interactive Microgrid system continues to operate and is able to supply the load in the microgrid. Another advantage of the Interactive Microgrid System is that it is capable of blackstarting to support the system during the transition from on-grid mode to unstable islanded mode so that all generator units must be turned off first.

Since the operation of the PLTS Hybrid, there has been a significant decrease in fuel consumption, from the previous 2,022 liters per day to 1.861 liters per day, or there is a savings of 161 liters per day or the equivalent of IDR 1,547 million per day. With this technology, there is an efficiency of IDR 0,565 billion per year which has a positive impact on the efficiency of the cost of supply (BPP) of the Celagen electricity system, which was previously IDR 5,882 per kWh to IDR 4,814 per kWh, or decreased by IDR 1,068 per kWh. The operation of the first PLTS Hybrid in NTT, namely Semau, is a strategic step in the success of the program to achieve new and renewable energy (EBT) in the energy mix of 23 percent by 2025.

INTRODUCTION

Global warming issue is one of the biggest challenges faced worldwide. The high utilization of fossil fuels in all sectors is the main reason for this problem. Climatic conditions are affected by the release of greenhouse gases such as carbon dioxide (CO2) and nitrogen dioxide (NO2) from the burning of fossil fuels. Reducing the use of fossil fuels by employing renewable energy sources (RESs) is an effective solution to overcome the global warming in the future [1].

NTT is the future of Indonesia and even the world for solar electric energy because according to research by experts, the best intensity of sunlight in Indonesia is on the islands of Sumba and Timor. This can also be seen from The maps and data for Indonesia have been released in parallel with Global Solar Atlas, which is published by the World Bank Group, funded by ESMAP, and prepared by Solargis.

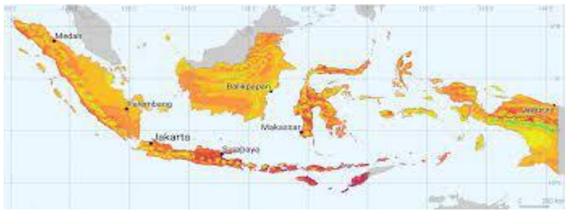


Figure 1 Map of solar energy potential in Indonesia

Seeing the huge potential of solar energy, PLN and the government developed PLTS on Semau Island to provide a source of electricity. This is also in line with Indonesia's energy policy which prioritizes clean energy in accordance with Law no. 16 year 2016.

Solar power generation technology is one of the renewable power generation technologies that has significant developments. This development makes a lot of variations in PV panels, PV inverters, batteries, battery inverters which give rise to many development options for hybrid systems. Each of these hybrid system options will provide different LCOE values. Most of the current battery inverters can only supply to the local grid without paralleling the grid. For this reason, in the manufacture of hybrid microgrids in Semau, a good calculation and control system is needed.

Semau Island is one of the islands in the province of East Nusa Tenggara. This island is about 1-2 km from the city of Kupang, the provincial capital so it has its own electricity system that makes it operate isolated. There are two types of power plants on the island of Semau, namely the Diesel semau power plant and the PLTS Semau. As one of the areas developed to become a tourist area, the island is encouraged to increase its clean energy sources. For this reason, in 2020 the Semau Island Hybrid Micro Grid began to be developed

MATERIAL AND METHODS

A. Data Collection

Data collection for this study was obtained from several sources including:

1. Central Bureau of Statistics (BPS) = Customer data
2. Solargis = Sunlight potential data
3. PLN (National Electricity Company) = Location data, capacity

B. Data Analysis

1. Define (future) Demand & Supply
2. Define Goal & Possibility : 1
   - Eliminating Diesel?
   - Reducing Fuel Consumption?
   - Renewable Energy Penetration?
3. Define the Control Concept
   - Always On Grid?
   - Always Off Grid?
   - On – Off Grid without seamless transition?
   - On – Off Grid with seamless transition?
   - 12 hour PV operation? 24 hour PV operation?
4. Define possible PCS / Inverters
5. Ensure you have enough experts in your team :
   - Power System & Protection
   - Genset
   - Control & Communication Systems
   - Power Electronics
6. Do Detailed Site Survey, not just the PV but also the Gensets and Communication Line
7. Flowchart depicting the On-Grid operation mode on an interactive Microgrid topology.

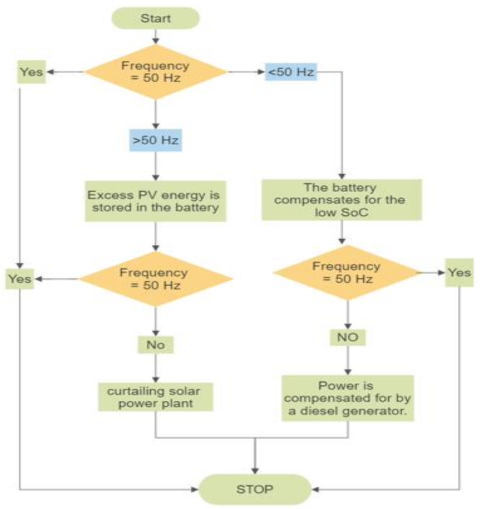


Figure 2 Flowchart Operation mode

ANALYSIS AND DISCUSSION

The first analysis is the collection of data from various sources to determine the hybrid system in Semau Island.

A. Data Collection

- Electricity Customer Data

Accurate forecasting of the load plays an essential role in the management of the HESs. High accuracy of load prediction is of great significance for safe, economic, stable and reliable operation of the power system [2].

Desa	Listrik PLN	Listrik Non PLN	Non Listrik *)
(1)	(2)	(3)	(4)
01. Bokonusan	312	-	-
02. Otan	246	-	-
03. Uitao	245	-	-
04. Huilelot	225	-	-
05. Uiasa	276	-	-
06. Hansisi	412	-	-
07. Batuinan	103	-	-
08. Letbaun	119	9	-
Jumlah	1 938	9	

Table 1 Number of households by main power source by village in sub-district at will

From BPS data [3] it can be seen that on Semau Island there are 1,938 PLN electricity customers and 9 non PLN customers. The largest number of customers are in Hansisi Village around the Semau Island port and the least are in Batuinan Village.

The daily operating pattern can be seen from the data below. It can be seen that the peak load of the island's electricity occurs at night with a value of +/- 383 kWh and the peak load during the day is in the range of 245 kWh. For daily consumption from Semau Island is 5,415 kWh.

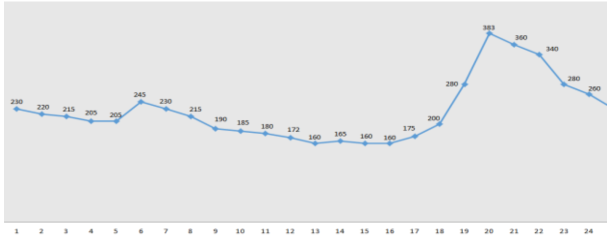


Figure 3 Daily electrical load graph

- Solar Irradiation Data on Semau Island

To find out the potential value of irradition on Semau Island, it was taken from the Global Solar Atlas website with a DNi value of 1980 kWh/m2 in 1 year. The monthly DNI value varies depending on the weather where it looks like the picture below that the highest DNI value is in August-October with a DNI value above 200 kWh/m2.

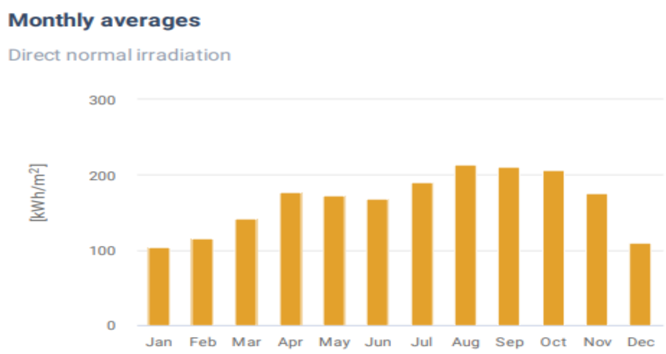


Figure 4 Direct Normal Irradiance on Semau Island

For the radiation value based on hours, it can be seen that the average value of DNi is at its peak in August at 11-12 noon with a value of 783 Wh/m2.

- Existing Electrical system Data

Semau Island has 2 power generation sources located in two separate locations. The first power plant is PLTD in Uiasa Village and then there is PLTS Semau which is in Huielot Village. The distance between these two plants is about 6.4 km with the customer connected to the 20kV network. For the location of the PLTD and a map of the electricity network on Semau Island, see the image below

Figure 5 Location of diesel (PLTD) and solar power plants (PLTS) on Semau Island

The installed capacity of the PLTS Semau is 450 kWp with a PV inverter of 200 kW. As for the PLTD Semau, there are 5 Diesel Engines with 4 different brands and capacities as shown in the picture below

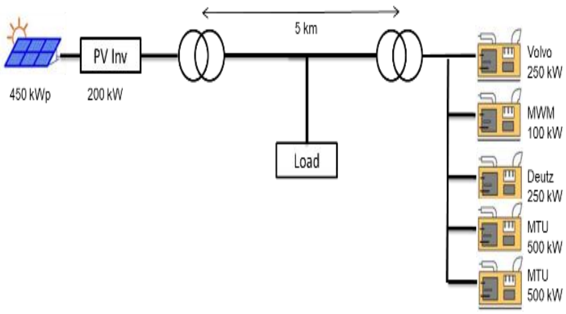


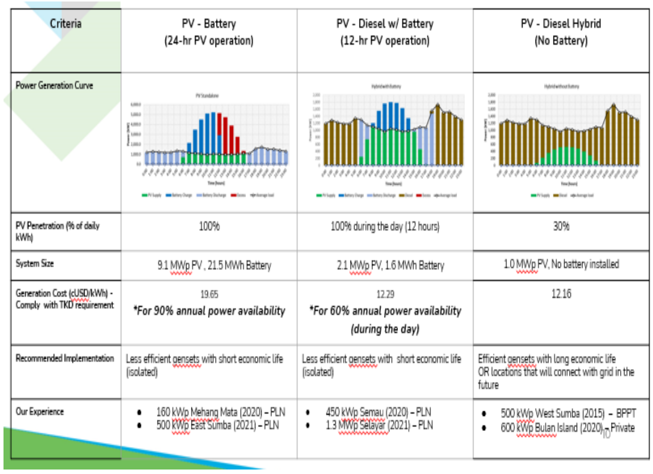
Figure 6 Diesel and solar power generation scheme

Figure 7 Semau Solar Power Plant and diesel power plant interior

- Hybrid PV types

There are three hybrid PV schemes that can be used in PLTD Semau, with details:

1. PV-Battery 24 hours full operation
2. PV-Battery 24 hours partial operation with backup from PLTD
3. PV-Diesel operation without using battery



Criteria	PV - Battery (24-hr PV operation)	PV - Diesel w/ Battery (12-hr PV operation)	PV - Diesel Hybrid (No Battery)
Power Generation Curve			
PV Penetration (% of daily kWh)	100%	100% during the day (12 hours)	30%
System Size	9.1 MWp PV , 21.5 MWh Battery	2.1 MWp PV, 1.6 MWh Battery	1.0 MWp PV, No battery installed
Generation Cost (cUSD/kWh) - Comply with TKD requirement	19.65 **For 90% annual power availability*	12.29 **For 60% annual power availability (during the day)*	12.16
Recommended Implementation	Less efficient gensets with short economic life (isolated)	Less efficient gensets with short economic life (isolated)	Efficient gensets with long economic life OR locations that will connect with grid in the future
Our Experience	• 160 kWp Mehang Mata (2020) – PLN • 500 kWp East Sumba (2021) – PLN	• 450 kWp Semau (2020) – PLN • 1.3 MWp Selayar (2021) – PLN	• 500 kWp West Sumba (2015) – BPPT • 600 kWp Bulan Island (2020) – Private

Figure 8 Hybrid PV Type

B. *Data Analysis*

- Revitalization Concept

In order to operate reliably, usefully, and optimally, the system must be designed to operate in Hybrid with PLTD. taking into account the PV capacity, the existing battery and the system load as well as the operating pattern are the key initial steps to determine the concept of revitalizing the PLTS Semau. Not only that, changes from time to time related to the increase in customer load and changes in seasons also need to be considered in order to make the system more optimal.

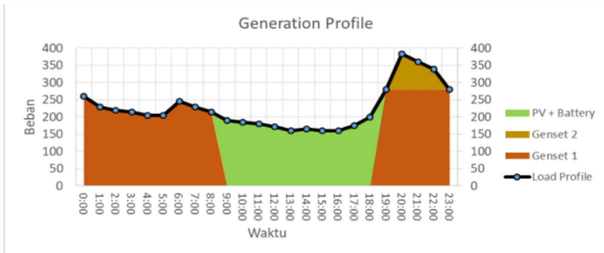


Figure 9 Electricity generation profile

The initial concept of developing this system is referring to the condition of the existing system, from the picture above we can see that in the morning, around 8-9 hours, when the battery has been charged quite a lot, the PV and battery take over the entire load from the generator. When the battery SoC reaches its bottom, the diesel takes over the entire load. In addition to the above, one of the things that must be achieved is when all the transfers and transitions must be carried out automatically and do not cause flickering or other network problems.

- Purpose Development

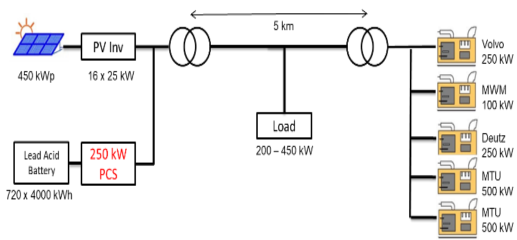


Figure 10 Development plan semau solar hybrid interactive microgrid

450 kWp PV • Operating PV inverter 400 kW • 2.8 MWh battery with 250 kW battery inverter – seamless mode switching • ESS will compensate load step and PV drops, DG will operate as main power generator at night • Automatic operation, monitoring and remote control from PLN office

- Control of Grid-Interactive Microgrids

El-Hefnawi (1998) presented a method to design PV- Diesel systems. The optimisation procedure starts by the definition of a model of the Diesel generator, and then optimising the PV and battery sizes, determining the minimum number of storage days and the minimum PV array area [3].

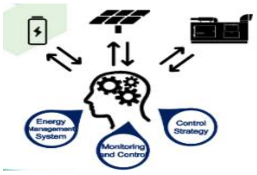


Figure 11 Design control semau solar hybrid interactive microgrid

Interactive Microgrid Integration comes with component of the 'brain' that ensures the system operate according to design. It is actualized by the Microgrid Controller which functions to process system data and then give operation orders to every component in the Interactive Microgrid. The Microgrid Controllers can be ready-to-use Controllers, or Custom Controllers using PLC / DCS

Hybrid control system using PLC is needed to realize the system. The control system designed must be able to operate easily and reliably. This system is designed as simple as possible so that operators can understand and operate easily.

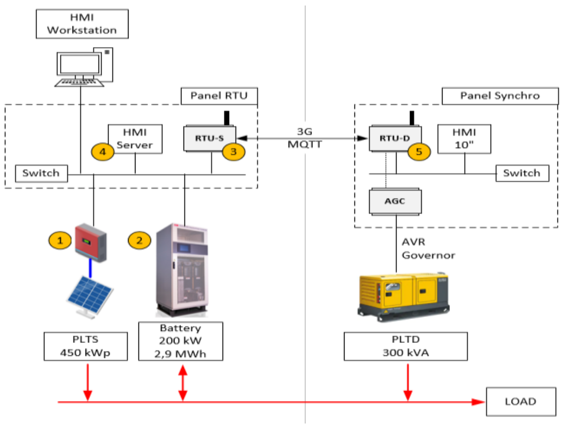


Figure 12 Design control semau solar hybrid interactive microgrid scheme

In the control system diagram above, it can be seen where in principle, the PLC system in PLTS (RTU-E) is the brain of the operation of the system. The PLC system will instruct the genset (RTU-G) to ON and OFF via the communication system according to the battery condition, and also set the P and Q setpoints.

- Virtual Generator

Virtual Generator mode is a unique operating mode for a power electronic converter whereby the converter mimics the behavior of a rotary generator and thus interacts with the power system in the same way as a traditional synchronous machine. This behavior is achieved purely through power electronic control and there are no large spinning masses.

The monitoring and indication of a grid failure can be done externally or by internal supervision based on frequency and voltage monitoring. Thus, when set to Virtual Generator mode, it can be operated in two control modes :

- PQ power flow control, where the converter operates with set-points for active and reactive power
- Vf control, where the converter operates with fixed voltage and frequency set-points enabling islanding

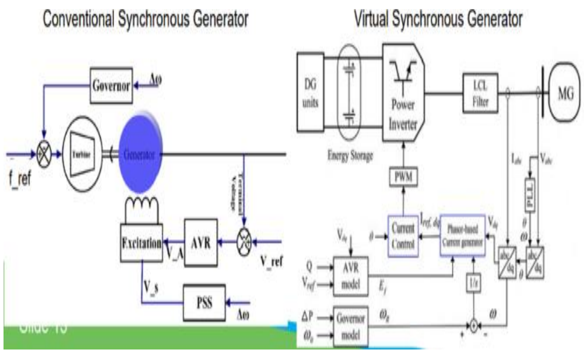


Figure 13 Difference conventonal synchronous vs virtual synchronous generator

- Control Concept

The concept of control is how to optimize existing assets, for example :

- How much load system is there?
- What is the average daytime load so that PV and battery can take over the system?
- And when the system will be taken over again by the diesel engine.

This must be thoroughly matured and also prepared for a step when there is a change maybe increase load, or from a climate perspective, when the rainy season will occur so that the sun's radiation will decrease, thus this system will be more flexible in the sense that PV can be baseload or as follower to the system.

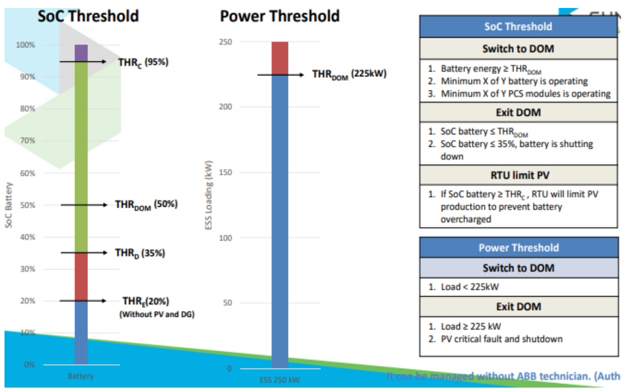


Figure 14 Storage VS ESS System

From the table below, it can be seen that there are several events that must be considered in the operation of the hybrid system. Starting from the conditions at night, transitions in the morning, daytime conditions, transitions in the afternoon, conditions when there is no battery and conditions when PV and DG are not detected

Event	State			Control Concept
	PV	ESS	DG	
Night			ON	• DG operation need to be confirmed to PLN (minimum DG loading and underload condition)
Morning transition	OFF to ON	OFF to ON	ON to OFF	• DG supply the load • PV charge the battery • If PV excesses, DG is ramping down to minimum loading • If DG is operating at minimum loading and ESS maximum charge capacity reached, RTU will limit PV to prevent DG underload and LV bus overcurrent. • Able switch to DOM, if ▪ Battery SoC ≥ THR_{DOM} ▪ Load < 225kW ▪ Minimum 1 out of 2 battery is operating ▪ Minimum 3 out of 3 PCS modules is operating
Day	ON	ON		• ESS will compensate PV drop and load steps. • If SoC battery reach THR_C, RTU will limit PV to prevent battery overcharged
Afternoon transition	ON to OFF	ON to OFF	OFF to ON	• Battery discharged until reach THR_{DOM} • Exit DOM if : ▪ Battery SoC ≤ THR_{DOM} ▪ Load ≥ 225kW ▪ PV critical fault and shutdown • ESS is turned off when SoC ≤ THR_0
Battery is unavailable	ON		ON	• RTU will limit PV production • Prevent DG underload. • DG load step ≤ 20% operating rating • PV ≤ 20% load
PV and DG are unavailable		ON		• Dispatched until SoC THR_E at maximum 250kW, if PV and DG still unavailable system is shutting down

Table 2 Control Concept Design

CONCLUSION

One of the advantages of the hybrid interactive microgrid system is that it can absorb electrical energy from the sun. In addition, the diesel engine can be used as a baseload power plant, while for PV panels and batteries it can be used as a follower generator. In addition, when the battery system has sufficient energy, the diesel generator can be completely turned off.

Parameter	Before	After
System	Pure On Grid	Hybrid On - Off Grid
Absorption	only 25% because the system is not smart enough for automatic load sharing settings with the generator	100% absorbed
Synergize with Diesel Engine	- minimum '- Diesel Engine disturbed due to intermittent PV	- Diesel Engine can be used as baseload '- PV and Battery can be load follower '- during the day when the battery is sufficiently charged, the solar power plant can take over the system
Operation & Maintenance	Manual, Local Operator	Automatic, Remote Control

Figure 15 Parameter review before and after development

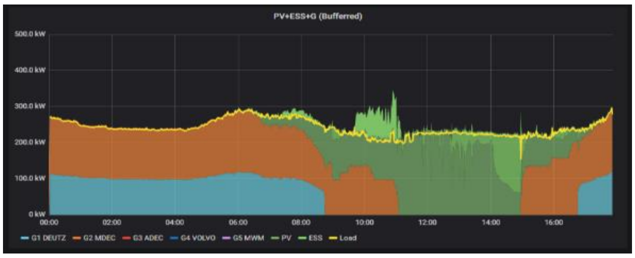


Figure 16. The realization of the Semau system's electrical operation

From the picture above, it can be seen that around 10 am, when the electrical energy from the solar panels is higher than the system load, the excess energy will be channeled into the battery. When it happens intermittently, when the electrical energy from the solar panel drops due to weather conditions, the difference in electrical energy will be filled from the battery (example case in Fig.16 at 14.00)

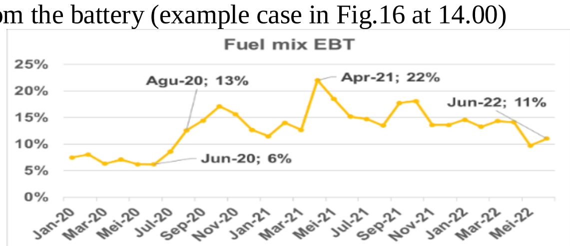


Figure 17 Percentage of use of NRE electricity in the Semau system

The effect of changing the Semau system to a Solar Hybrid Interactive Microgrid can be explained in June 2020 the percentage of NRE was still in the range of 6%. This NRE percentage increased to 13% in August 2020 and reached its maximum value in April 2021 with a value of 22%. The percentage of this energy mix experienced a decrease of up to 11% in June 2022 because battery problems began to appear in PLTS Semau.

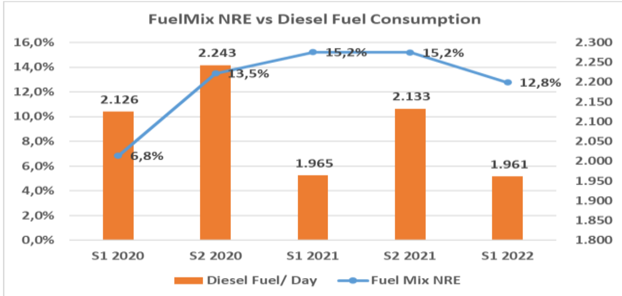


Figure 18 Fuel Mix vs Diesel Fuel Consumption

From the Fig.18 we can see the performance of PLTS in each semester, it can be seen that when the system does not use the interactive microgrid system, the value of PLTS Fuel mix is 6.8% in semester 1 of 2021. This value continues to rise to 12.5% and reaches its peak at 15.2% in 2021. When there is an increase in PLTS Fuel mix, there is a decrease in daily fuel consumption. If the SFC from PLTD is assumed to be 0.32 liters / kwh and the cost of transporting fuel to the location is assumed to be 9616 rupiah, then the savings that occur between S1 in 2021 and S1 in 2020 are around 161 liters / day or the equivalent of 1.547 million / day. The value in S2 2020 increased even though there was an increase in the PLTS fuel mix due to an increase in kWh of electricity production of 177,786 kWh. This increase was compensated by PLTS by 62% or 110,752 kWh and PLTD by 38% or 67,034 kWh.

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