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Feasibility Study of Hybrid PV-Generator Set Power Plant at Palm Oil Mill

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Abstract **– Kuko Palm Oil Mill is one of the palm oil mills that has not been interconnected with PLN electricity and the need for electrical energy is supplied by generators with a capacity of 1100 kVA and 650 kVA fueled by diesel. Utilization of the potential of renewable energy sources is carried out to reduce the use of diesel fuel with a Hybrid Power Plant (PLTH) system consisting of generators, batteries and Photovoltaic (PV) and conduct optimization studies for feasibility studies in technical and economic aspects using HOMER software. The optimal PLTH results in technical aspects are 8,727 kW PV, 500 kW generator, 1,000 kW generator, 25,708 battery units, and 1,481 kW converter. Electricity production from PLTH is 14,389,116 kWh/year and is able to meet the electricity needs of PKS. The resulting economic aspects are PLTH, namely NPC of Rp356,000,000,000, initial capital or initial investment in PLTH of Rp77,400,000,000, operation and maintenance costs of Rp21,600,000,000, LCOE of Rp3,147/kWh. The IRR value is 22%, the NPV is positive at R.124,000,000,000 and the investment will return capital within 3.5 years. Based on these results, PLTH can be said to be feasible from the technical and economic aspects.**

Keywords: Feasibility, Hybrid Power Plant, Optimisation, PV, Generator Set

I. INTRODUCTION

Along with the massive development of technology and the rapid development of the times, it has an impact on the greater need for energy. PLN data states that in the past 6 years, electricity sales by PLN nationally have increased every year by 3.5% with a significant increase in the number of customers of 3.7 million customers. In 2020, PLN was recorded selling electricity to customers in various sectors with a total of 241,140 GWh [1]. One of the largest PLN customer sectors enjoying electricity is the industrial sector. The industrial sector has the second largest energy demand after the household sector. Since 2011-2019, the industrial sector has consistently used electrical energy with an annual increase of 4-6% for annual national electricity consumption. Even in 2020, the industrial sector used 30% of the total electricity sold by PLN [1].

The industrial sector that is among the largest electricity customers and uses a large amount of electricity is the palm oil industry. This is because Indonesia is the largest producer and country with the largest palm oil industry in the world, which has a total land area of 14.3 million ha of palm oil land. The region with the largest palm oil industry in Indonesia is Riau Province. Riau has 2.7 million ha of oil palm land or equivalent to 19% of the total oil palm land area in Indonesia. One of the palm oil companies that has a large land area and the largest production in Riau is PT Duta Palma Nusantara PKS Kuko. PKS Kuko Palm Oil Mill has a total land area of 14,257 ha of land with a total of 168,980 oil palm trees and a total electricity demand of 1,800,597 kWh / year to serve the electricity needs of offices, production and mess staff employees. Electricity needs for offices and mess staff employees are supplied by generators with a capacity of 1100 kVA, while electricity needs for production that operates from 06.00 - 18.00 WIB are supplied by generators with a capacity of 650 kVA. In addition to the high price of diesel fuel, PKS also has standards for the use of fossil fuels on their impact on the environment. Therefore, PKS is also trying to reduce the use of diesel fuel. The Genset Power Plant at Kuko PKS using diesel fuel has a high price problem, in 2021 IDR 10,726/liter [2] and increased to IDR 16,000/liter in 2023 [3].

The problem of diesel-fueled generator power plants in Kuko PKS has been studied by research [2]. Research [2] which conducted a study on the potential of bioethanol by utilizing oil palm sap waste from the results of oil palm replanting as a generator fuel at Kuko PKS into electrical energy. The results of the research study [2] found that the potential for electrical energy from the utilization of palm oil sap waste obtained from E0 compared to E10 and E100 is with the potential of E10 of 34,166,278.6 kWh while for E100 of 22,628,077.7 kWh. The results of the research study [2] E10 has greater potential with a content of

10% ethanol and 90% diesel. These results show that the percentage of diesel fuel use is still quite large, therefore the use of diesel fuel is replaced by utilizing renewable potential sources at Kuko PKS. Kuko PKS has renewable energy potential including biomass and solar energy. The potential of solar energy in Kuko PKS is 4.8 kWh/m2 or equivalent to 112,000 GWp [4]. PKS has the potential in the form of solar energy which can be a Solar Power Plant (PLTS) as a source of electricity at PKS.

Several studies have examined the feasibility between PLTD with generators, offgrid PLTS and PLTH from PLTS and PLTD. Research [5] has examined the performance of the PLTD generator against load changes, the results obtained by increasing the load affect the capacity of the generator and the use of fuel is increasing up to 1140 liters per 24 hours according to the generator's working time and periodic maintenance is required every 250 hours. Research [6] has examined the economics of designing off-grid solar power plants at a workshop with several scenarios. The result of research [6] is the lowest NPV value of - Rp252,285,665 which means the investment does not return capital. Solar Power Plants (PLTS) can be hybridized with various other power plants. Several studies have conducted studies on this hybrid power plant. Research [7] conducted the feasibility of a hybrid power generation system (PLTH) between PLTD and PLTS using the HOMER simulation method to get the optimal scenario of the plant. This research produced the best scheme with electricity generated by PLTS as much as 1,374,514 kWh / year and PLTD 879,024 kWh / year where PLTS contributed 61% and PLTD 39% to meet the load.

Seeing the large use of diesel as a generator fuel [5], and the loss if only using off-grid PLTS as a stand alone [6], the authors propose a solution based on research [7] to hybridize between PLTD and add a new type of generator by utilizing the renewable energy potential of solar energy for offgrid Solar Power Plants (PLTS). PLTS in this study is designed a hybrid system with generators because there is still no electricity supply from the PLN network which results in the availability of electricity at the PKS only being supplied from two diesel-fueled generators with a capacity of 1100 kVA and 650 kVA so that other available energy sources are needed to reduce the use of diesel fuel.

This research will examine the most optimal Hybrid Power Plant (PLTH) system between PLTD, namely 1100 kVA, 650 kVA generators and off-grid PLTS using HOMER Pro software. HOMER Pro serves to simulate the hybrid power generation system to find out the most optimal system [8] [9]. In addition, in this study, HOMER Pro software is used to analyze the economic aspects of hybrid power plants which include the price of electricity from generating sources (LCOE), analysis of the payback period, and the cash flow rate of the investment built (NPC) [10] [11]. This research will examine optimization for the feasibility of hybrid power generation (PLTH) between PV and generator set in technical and economic aspects in palm oil mills.

II. METHOD

At PT Duta Palma Nusantara PKS Kuko has not been interconnected with the PLN electricity network, therefore the electricity supply is supplied by two generators with a capacity of 1100 kVA and 650 kVA fueled by diesel. The high price of diesel fuel makes PKS want to reduce the operation of generators to minimize the use of diesel fuel. In this study, to reduce the use of diesel fuel, a solution is proposed, namely replacing the 650 kVA generator with a solar power plant so that it becomes a hybrid power plant and electricity is supplied by these two plants. Before implementing a hybrid between the two plants, it is necessary to carry out optimization to see the best scenario of PLTH and feasibility tests, namely from the technical and economic aspects of PLTH.

This research is a simulation by utilizing HOMER (Hybrid Optimization Model for Electric Renewable) Pro [12] software by designing a hybrid power plant (PLTH) between off-grid solar power plants and diesel power plants with generators. HOMER Pro will optimize the generation system and economic analysis of the Hybrid Power Plant (PLTH) system. This research is quantitative research and uses secondary data from research [2] in the form of load or energy consumption, resource assessment and specifications of generators and data from simulation software.

A. Research Flowchart

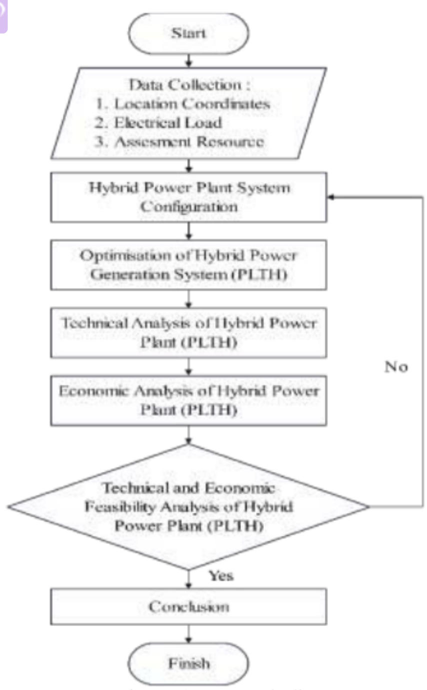


Figure 1. Research diagram

B. Data Collection

1. Site Selection of PT Duta Palma Nusantara PKS Kuko

The location used in the study was taken from research [2] which is located at PT Duta Palma Nusantara PKS Kuko, Kuantan Singingi Regency, Riau Province. This PT is located with coordinates 101° 32"30'- 101° 43"00' East and 0° 30"30'- 0° 42"40'. With latitude and longitude - 0.5798798426457958,101.58075293891874. This data is taken using the coordinate points on Google Maps. Later the latitude and longitude coordinate points will be inputted into the HOMER Pro simulation software.

2. Electricity Demand Load Data for Production PT Duta Palma Nusantara PKS Kuko

Load or energy consumption data at PT Duta Palma PKS Kuko is secondary data taken from research [2].

Table 1. Electricity Demand Data of PT Duta Palma Nusantara PKS Kuko

Years	Electricity Demand Per Year (kWh)	Average Electricity Demand Per Month (kWh)
2021	1.771.160	198.680
2020	1.800.597	208.480
2019	2.531.656	201.812
2018	2.178.964	214.676

Load demand data is the average monthly data for each year. The data will then be input to the simulation software and assumed to be the same every hour of the day.

3. Specification of PT Duta Palma Nusantara PKS Kuko Genset [2]

Table 2. 1100 kVA generator set specifications

Specification	Description
Manufacturer	Cummins
Model	QST 30 G4
Engine Power Output at rated rpm	970kWm 1300 HP
Total Displacement	30.480 L
Fuel Consumption at full load	202 L/h
Dimensions (LxWxH)	4400 x 1776 x 2341 mm

Table 3. 650 kVA generator set specifications

Specification	Description
Manufacturer	Catterpillar
Model	C18DEAP
Cooling System	Engine Coolant Capacity 20,8L
Combustion Air Inlet Flow Rate	35.8 m³/min
Fuel Consumption at full load	133 L/h
Heat Rejection to Exhaust (Total)	27 kW

The generator specification data is needed for input to the HOMER Pro simulation software which will then be hybridised with solar power plants.

4. Assesment Resource

Site assessment data in the form of resource assessment is data provided by the HOMER Pro software, this data is obtained after inputting the location through coordinate points that have been obtained from research.

Table 4. Global Horizontal Solar Irradiation

Month	Clearnes Index	Daily Radiation (kWh/m²/day)
January	0.401	4.051
February	0.439	4.574
March	0.409	4.296
April	0.427	4.345
May	0.433	4.161
June	0.455	4.220
July	0.432	4.072
August	0.431	4.275
September	0.396	4.089
October	0.394	4.082
November	0.395	4.994
December	0.388	3.857

Global Horizontal Irradiation (GHI) data is data in 2023 which is useful for knowing the potential of solar energy at the location so that it is possible to know whether solar power plants are feasible to build at the location. The average solar radiation at the location is 4.17 kWh/m²/day.

5. Equipment Cost

Table 5. Hybrid Generation System Cost

Tools and Materials	Harga
Diesel fuel	Rp16.000,00 / Litre
570wp PV	Rp2.058.409,69
1 kW converter	Rp4963.000,00
1 unit battery	Rp1.500.000,00

Table 5 is the cost of the hybrid generation system, for maintenance costs is 10% of the price of equipment for PV, Converter and Battery.

C. Configuration of Hybrid Power Plant (PLTH) System

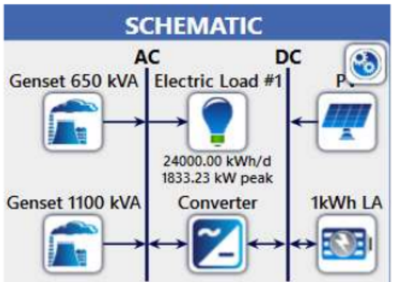


Figure 2. PLTH configuration in HOMER Pro

The configuration of the generating system is a hybrid between a diesel power plant with a generator and an off-grid solar power plant. The components that are input to the HOMER Pro software are

1. 650 kVA generator set
2. 1100 kVA generator set
3. PV Module
4. Converter
5. Battery

The capacity of the PV, converter and battery will be generated after optimisation in the simulation software to find the best results.

D. Optimisation of Hybrid Power Generation System with HOMER Pro

Optimisation is carried out using HOMER Pro software which is useful for simulation, optimisation and sensitivity analysis [13]. The software will perform calculations to find the best system scenario of a hybrid power plant (PLTH) based on technical and economic aspects [10]. The best results obtained after optimisation will show the performance of the PLTH between PV-generator set that works to meet the load at the PKS.

E. Technical Calculation of Hybrid Power Plant (PLTH)

Technical calculations are carried out in the HOMER Pro software, the software will calculate based on the best optimisation results so that it will display the division of labour of each plant to generate electricity. The results obtained from optimisation in the form of :

1. Power plant electricity production
2. Capacity of PV
3. Battery capacity
4. Converter capacity
5. Total fuel consumption of generator set

F. Economic Calculation of Hybrid Power Plant (PLTH)

The output of the simulation using HOMER Pro software is an economic analysis in the form of NPC, LCOE, payback period, investment costs and operating costs. From these output parameters, it can be seen whether the proposed system is feasible or not.

1. Net Present Cost (NPC)

Net Present Cost or NPC can be defined as the total cost of all costs incurred for investment in the length of use, including initial investment funds, tool replacement costs, operation and maintenance, fuel costs, and other costs that may arise during the project. The equation used by HOMER Pro in calculating NPC is as follows [14].

$$C_{NPC} = \frac{Cann,tot}{CRF(i,Rproj)} \quad (1)$$

Description :

Cann, tot	=	Total Cost/year (IDR/Year)
CRF	=	Capital Recovery Factor
I	=	Interest Rate (in per cent %)
R project	:	Lifecycle Project (25-30 years)

2. Life Cycle Cost of Energy (LCOE)

LCOE or Life Cost of Energy is the ratio between the total annual cost of the system and the energy produced in the same time period. If observed further, the cost of PLTS is influenced by several factors including the initial investment cost which is quite expensive but there is no need for fuel expenditure, followed by low operational and maintenance costs and knowable energy costs, thus affecting the difference between the cost of PLTS plants compared to other conventional plants [15]. The LCOE value can be calculated with the equation :

$$COE = \frac{total\ annualized\ cost}{consumption\ energy\ (\frac{kWh}{year})} \quad (2)$$

Description :

COE	=	Cost of Energy (Rp)
Total Annualized Cost	=	Total annual cost (Rp)
Consumption Energy	=	Energy used (kWh/year)

3. Initial Capital

Initial capital is the initial investment cost for the construction of a power plant [16] In this hybrid design research, a PLTS system with a generator is designed, therefore important components in this hybrid design include solar modules, inverters and generators as generating components. Initial cost can be calculated with the equation :

$$Initial\ capital\ cost = cost\ (PV\ modules + Inverters + Battery + genset\ fuel) \quad (3)$$

4. O&M (Operation and Maintenance) Cost

O&M costs are annual costs that must be incurred for complete plant operations with maintenance to prevent or repair damage [16]. Annual operation and maintenance costs can be calculated by summing up all variables including maintenance costs and replacement of tools or components, more details of O&M costs can be calculated by the equation:

$$O\&M\ Cost\ per\ Year = O\&M\ Plant + Replacement \quad (4)$$

Description :

O&M Plant	=	Plant Operation and Maintenance Cost (Rp/Year)
Replacement	=	Component Replacement Costs (Rp/Year)

G. Feasibility Standard for Hybrid Power Plant (PLTH)

1. Technical Feasibility

PLTH is said to be technically feasible if it is able to meet the load requirements at the PKS. If the results of the simulation produce electricity in excess of the PKS electricity needs in accordance with table 1, then PLTH can be said to be feasible.

2. Economic Feasibility

a. IRR (Internal Rate of Return)

One of the feasibility parameters of a project is the capex value, which is the value of expenditure for purchases and maintenance during the project. This capex value is interconnected with the IRR value, the greater the IRR value, the smaller the capex II value and as long as the IRR value is positive, the project can be said to be feasible when it exceeds the bank interest rate of 5.75% [17]. The IRR value can be calculated using the following equation [18].

$$IRR = i_t + \frac{NPV_1}{NPV_1 - NPV_2}(i_2 - i_1) \quad (5)$$

Description

i_1	=	1st interest rate
i_2	=	2nd interest rate
NPV_1	=	NPV at interest rate i_1
NPV_2	=	NPV at interest rate i_2

b. Payback Period

Payback period can be defined as the length of the payback period in a certain time. The value of the payback period or return of capital must be smaller than the life of the project so that the project can be said to be feasible when the capital returns before the end of the project period. The payback period value affects the investment value, when the investment value is large but the project income is small, the project is said to be unfeasible [19]. The payback period can be calculated using the equation [20] :

$$Payback\ period = \frac{System\ installation\ capital}{Annual\ savings} \quad (6)$$

Description :

Payback period	=	Payback period (Years)
Installation Capital	=	Total Initial Investment Cost (Rp)
Annulai savings	=	Annual Savings

c. Net Present Value (NPV)

Net Present Value (NPV) is a method in engineering economics to calculate the difference between the value of the investment made and the cash value in the future. If the future net cash value is positive or > 0, it means that the project is profitable and feasible. Conversely, if the NPV value <0 then the project is losing money. NPV can be calculated with the following equation [21].

$$NPV = \sum_{t=1}^{n} \frac{NCF_t}{(1-i)^t} - II \quad (7)$$

Description :

NCF_t	=	Net Cash Flow for the year period
II	=	Initial investment
i	=	Discount
t	=	Length of investment

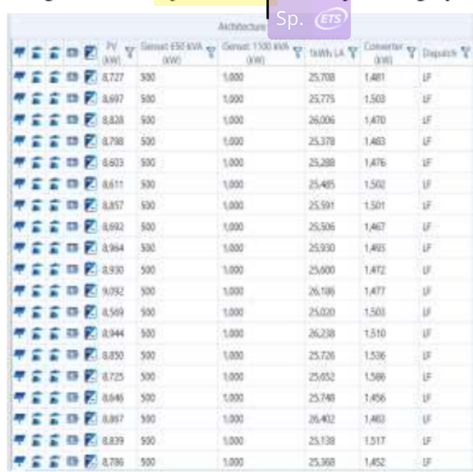
III. Results and Discussion

A. Hybrid Power Plant System Optimisation

The optimisation results will rank the best scenarios of the hybrid power plant system according to the technical aspects and performance of each component.

Architecture					
PV (kW)	Genset 650 kVA (kW)	Genset 1100 kVA (kW)	1kWh LA	Converter (kW)	Dispatch
8,727	500	1,000	25,708	1,481	LF
7,162		1,000	5,116	1,459	CC
	500	1,000	687	172	CC
31,256	500		36,436	1,386	LF
30,502			42,702	2,023	CC

Figure 3. PLT Optimisation Results per Category



Architecture					
PV (kW)	Genset 650 kVA (kW)	Genset 1100 kVA (kW)	1kWh LA	Converter (kW)	Dispatch
8,727	500	1,000	25,708	1,481	LF
8,697	500	1,000	25,775	1,503	LF
8,828	500	1,000	26,006	1,470	LF
8,798	500	1,000	25,378	1,463	LF
8,603	500	1,000	25,288	1,476	LF
8,611	500	1,000	25,485	1,502	LF
8,857	500	1,000	25,591	1,501	LF
8,692	500	1,000	25,506	1,467	LF
8,964	500	1,000	25,930	1,495	LF
8,930	500	1,000	25,600	1,472	LF
9,092	500	1,000	26,106	1,477	LF
8,569	500	1,000	25,020	1,503	LF
8,944	500	1,000	26,238	1,510	LF
8,850	500	1,000	25,726	1,536	LF
8,725	500	1,000	25,652	1,588	LF
8,646	500	1,000	25,748	1,456	LF
8,867	500	1,000	26,402	1,463	LF
8,839	500	1,000	25,138	1,517	LF
8,786	500	1,000	25,368	1,452	LF

Figure 4. Overall Optimisation Results

From the results obtained in Figure 3 and Figure 4, the best scenario is a combination of PV with a capacity of 8,727 kW, 500 kW generator set, 1,000 kW generator set, 25,708 battery units, and 1,481 kW converter. This scenario is better than using only two generators in the current condition. This is influenced by several factors, namely the use of PLTS as renewable energy is more optimal when compared to using diesel-fuelled generators within 25 years.

B. Technical Analysis of Hybrid Power Generation System (PLTH)

1. Electricity Production of Hybrid Power Plant (PLTH)

The electricity production generated from the best scenario between the solar power plant and two generators is as follows.

Table 6. Electricity Production Results of PLTH

Generating components	Electricity production (kWh/year)	Percentage (%)
PV	12.592.701	87,8
650 kVA generator set	672.041	4,69
1100 kVA generator set	1.074.374	7,49
Total	14.339.116	100

From Table 6, it can be seen that the electricity production generated in one year is 14,339,116 kWh with each component, namely PV generating electrical energy of 12592,701 kWh / year, 650 kVA generator generating 672,041 kWh / year and 1100 kVA generator generating 1,074,374 kWh / year. PV contributes 87.8%, 650 kVA generator 4.69% and 1100 kVA generator 7.49% of the total 100% energy in one year. This means that the electricity generated by PLTH is sufficient for the electricity needs of the mill.

2. Comparison of Solar Fuel Usage of PLTH and PLTD

Table 7. Comparison of Solar Fuel Consumption

Plant type	Solar Fuel Consumption Per Year (Litres)	Average daily diesel fuel consumption (litres)
PLTH	467.047	1.280
PLTD	2.287.976	6.268

Table 7 is the result of the comparison of diesel fuel consumption between PLTH and PLTD. PLTH uses diesel fuel in one year around 467,047 litres, while if only using PLTD the amount of diesel fuel consumption is 2,287,967 litres. This means that if you use PLTH, PKS is able to save 1,820,929 litres of diesel in one year. If calculated with the price of industrial diesel in 2023, which is Rp16,000, PKS can save costs of Rp29,134,864,000.

C. Economic Analysis of Hybrid Power Plant (PLTH)

HOMER Pro software presents a comparison of the results between PLTH and only using PLTD.

Table 8. Summary of Power Plant and Solar PV Costs

Category	PLTD	PLTH
NPC	Rp480B	Rp356B
Initial Capital	Rp1,88	Rp77,4B
O&M	Rp37,0B/yr	Rp21,8B/yr
LCOE	Rp4,239/kWh	Rp3,147/kWh

Table 8 is the result of the comparison between PLTD and PLTH from the economic aspect. The factor that most influences the optimisation results from the economic aspect is the NPC (Net Present Cost) value. The best scenario results from the smallest NPC value. PLTH produces an NPC value of Rp356,000,000,000 smaller than using only PLTD, which is Rp480,000,000,000. The NPC value of PLTH is able to save Rp124,000,000,000. The initial capital or initial investment value of PLTH is Rp77,400,000,000,000. The cost of operation and maintenance of PLTH, which is Rp21,600,000,000, is more efficient at Rp15,400,000,000 than using PLTD at a cost of Rp37,000,000,000. The price of electricity generated or LCOE from PLTH is IDR 3,147/kWh while for PLTD is IDR 4,239/kWh. From the economic aspect, the use of PLTH is more profitable if it is implemented than only using PLTD.

D. Feasibility Analysis of Hybrid Power Plant (PLTH)

1. Technical Feasibility

Table 9. Comparison of MCC Electricity Demand and PLTH Electricity Production

Electricity Demand Per Year (kWh)	Power Plant Electricity Production Per Year (kWh)
2.531.656	14.339.116

Based on table 9, the electricity production generated by PLTH is 14,339,116 kWh in one year can meet the electricity needs of the PKS. From these results, it can be said that PLTH is feasible from a technical aspect.

2. Economic Feasibility

Economic metrics are parameters that can analyse the profitability of a project. There are three parameters of metric economics, namely Internal Rate of Return (IRR), Net Present Value (NPV) and Payback Period.

Table 10. Economic feasibility of solar power plant

Internal Rate Of Return (IRR)	Net Present Value (NPV)	Payback Period
22%	+Rp124B	3,5 Tahun

Table 10 is the metric economic results of the hybrid power plant (PLTH) which obtained an IRR value of 22% and NPV of +Rp124,000,000,000. With a payback period of 3.5 years. From the calculations carried out, it can be analysed that if NPV > 0 and IRR are positive, the investment will get a return (profit), otherwise if it is negative, it can be concluded that the investment made will lose profit (loss). With the results obtained, IRR, NPV and payback period are positive, so PLTH can be said to be feasible from an economic aspect [17] [19].

IV. CONCLUSION

Hybrid power plant (PLTH) at PT Duta Palma Nusantara PKS Kuko with PV-genset configuration based on HOMER Pro simulation getting the most optimal results with PV components 8,727 kW, 500 kW generator, 1000 kW generator, 25,708 battery units and 1,481 kW converter is the most optimal result. Using PLTH is able to reduce the use of diesel fuel by 1,820,929 litres of diesel in one year from previously using PLTD with diesel fuel consumption of 2,287,976 litres a year to 467,047 litres with PLTH for one year. PLTH can produce electricity in one year of 14,339,116 kWh in one year which has met the electricity needs of PKS by 2,531,656 kWh one year. While for the economic side, the NPC value of PLTH is Rp356,000,000,000, initial capital is Rp77,400,000,000, operation and maintenance costs are Rp21,600,000,000, and LCOE is Rp3,147/kWh. PLTH is more profitable in a project time of 25 years with an IRR value obtained of 22%, a positive NPV value of Rp124,000,000,000 and investment will be recouped within 3.5 years. Based on the results obtained through the HOMER Pro simulation, PLTH can be said to be feasible from the technical and economic aspects.

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