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Feasibility Study of Photovoltaic - Diesel Hybrid Power System as Renewable Energy Source

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Abstract: This paper presents a feasibility study of the opportunity to utilize the hybrid power system in Karimun Jawa island, Indonesia. This small island is located at 5° 49′ 9.01″ S, 110° 27′ 32.4″ E with land area about 71.2km². The research was conducted to optimize and support the stand-alone diesel power plant of diesel power Legon Bajak with hybrid solar PV to reduce fuel cost and CO_2 emission. The systems are switching each other at least 12 hours a day where the solar PV is generated in daytime and diesel engine generator at night time. From the calculation, it is found that generators increase to 5,400 kW with solar PV-diesel hybrid power systems. By implemented the system, the fuel cost is reduced until 50% from the daily fuel cost around 50 million rupiahs to 25 million rupiahs in a day. By the calculation of the Net Present Value (NPV) and especially the Internal Rate of Return (IRR), this project can be held because the IRR (20.9%) is greater than the discount rate (4.25%) in 3 years.

Keywords: Feasibility Study, Diesel Generator, Hybrid Power System, Karimun Jawa, Small Island Electrification

I. INTRODUCTION

In an isolated small island, grids diesel generators have two functions: providing electric energy as well as grid stabilization. With the technical improvement and reduction in cost of renewable energy generators an increasing number of these systems are used in isolated grids to supplement diesel-generated electricity. When implemented well, utilization of renewable energy leads to reduced costs for the energy supply as well as reduced CO_2 emissions [1]. Renewable energy process can be categorized as green ICT (Information and Communication Technology). While ICT can be also considered as a tool to address environmental problems, and as a part of the green Internet of Things (G-IoT) for energy harvesting devices and communications in their role to find an important way in creating green and sustainable place for living [2].

Karimun Jawa island is one of the exotic islands in Indonesia with the total area of 71.2 km² where located in Java Sea, exactly in the northern part of Semarang city. This island has 2 stand-alone diesel power plants with a total power of 4.4 Mega-Watt (MW) which is located at Legon Bajak (northern part of the island). However, this current system, has a high cost of diesel fuel due to the shipping cost from Grati, Pasuruan, East Java. Then with the weather and tidal-wave factors where if the weather deteriorates like rain and tidal waves, the diesel carrier does not dare to send fuel for diesel and makes there is no fuel supply to power the generator. Next, in this island, though it has two diesel generators but used one generator by alternating every 3-4 days and switching with transition turnover one generator with other generator that causing tripping or short circuit which could disrupt the activity of the local citizens. Those are some drawbacks happened currently in that area. Therefore, we conducted a feasibility study as a preliminary research regarding solar Photo Voltaic (PV)-diesel hybrid system to support the existing diesel power system in order to increase the output power capacity. The key motivation of this study is to reduce the cost and CO_2 emission, and also to improve the system performance. This research also supports the Regulation of the Minister of Energy and Mineral Resources of the Republic of Indonesia Number 12 Year 2017 (Peraturan Menteri ESDM Republik Indonesia Nomor 12 Tahun 2017) on the Use of the Renewable Energy Resources for Providing Electricity and also President Joko Widodo's target about the 35000 MW electricity for Indonesia [3].

Furthermore, in this feasibility study, we suggested a better solution by providing optimized analysis results for PV-diesel hybrid power system which is mainly a combination between photovoltaic with diesel generator in Karimun Jawa island, Indonesia. The aim is to avoid power blackout by adding more power in order to support the stand-alone diesel generator and reducing fuel costs by using this alternative renewable energy source technology.

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II. STATE OF THE ART: HYBRID POWER SYSTEM

The most common type of hybrid power system contains a gas or diesel power engine generator. Another approach is a photovoltaic (PV) and wind turbine system because a wind turbine can provide complementary power generation [4, 5]. Generally, hybrid systems consisted of the following elements [6-8]:

- Solar panels mounted on the roof or in open spaces. Photovoltaic modules produce direct current (DC) electrical power.
- Batteries to store DC energy generated by the solar panels.
- Charge controller to prevent overcharging the battery.
- Specially designed inverter to transform the PV generated DC electricity to the grid electricity (which is of Alternating Current/AC) at the grid voltage.

Figure 1 shows the solar-diesel hybrid system. The diesel generator is used to constantly fill in the gap between the present load and the actual generated power by the PV system. In areas where the grid is unstable, it is advisable to have a diesel generator that makes network functions to provide sufficient energy demanded by consumers with the addition of batteries that provide the kit for energy independence, either from the mains or diesel generator, depending on the battery capacity, in addition to improving the quality of the grid electric supply.

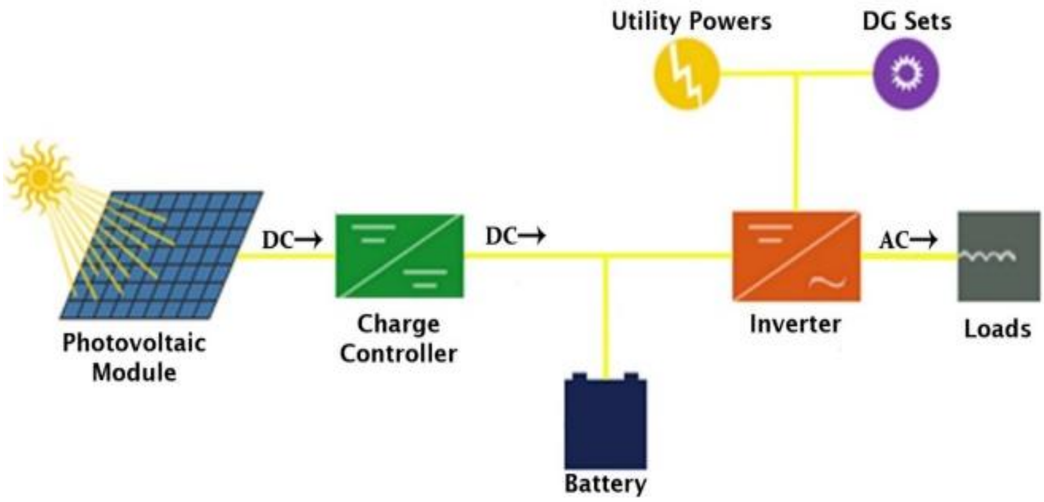

Fig. 1 Schematic diagram of solar PV-diesel hybrid system.

To justify a HPS (Hybrid Power System) design, besides the technical aspects, the economic assessment addresses the economic performance of the system over their life time. Hunter and Elliot [6] suggested three techniques that were commonly used for such assessment including System's Payback Period (SPR), Life-Cycle Engineering (LCE), and Internal Rate of Return (IRR). Payback period is the simplest economic assessment while LCE and IRR are based on the Life-Cycle Cost (LCC) analysis. This section below will briefly explain about those economic assessments.

In the beginning of the economic assessment, there is Biaya Pokok Produksi (BPP) or the Main Cost of Production that has at least 4 component costs that are Component A, B, C, and D. Component A is a fixed cost, which is a cost that must be issued regardless of whether the power plant is operated or not. This component generally consists of the cost of construction of a power plant such as civil works, the cost of purchasing turbines, generators, and others. Components B and D, both of these components are known as variable cost and are usually have a small value. In addition, they are also often referred to as Operation Maintenance (OM) Cost which means the costs incurred for the operation and maintenance of the plant. Component B is a fixed OM Cost, such as salaries of employees, management fees, and others. Component D is an OM Cost variable, such as the cost for the lubricant. The more often and the heavy the work of the generator, the more lubricants are needed. Thus, the cost of this D component will increase according to the demands. And so is the opposite. Component C is a fuel cost. Some factors that affect the price of this component such as the amount of fuel consumption required, the type of fuel, the duration of power generation, and several other things. Therefore, the authors will only take the component A and component C because the component B and component D is not changing much.

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III. METHODOLOGY AND IMPLEMENTATION

We have taken the data from local site of an electricity company especially from Legon Bajak power plant. The important data we have is the daily load of Legon Bajak power plant, single line diagram of Legon Bajak power plant until the 20 Kilo-Volt (KV) line, and BPP or the cost of production that one of the document will know the fuel cost. The electricity company requested to have the rated power of PV array is 1,000 Kilo-Watt peak (KWp) or 1 Mega-Watt peak (MWp) and the battery as the storage capacity is 500 KWp. For the daily load of Legon Bajak power plant, we have taken the load data in 31st December 2017 with a 870 KW peak load in that day and the total daily energy demand is 16,395 Kilo-Watt hour per day (KWh/day). Legon Bajak power plant have 2 Wärtsilä 26 Diesel Generator (DG) that could produce 2.2 MWp for each generator.

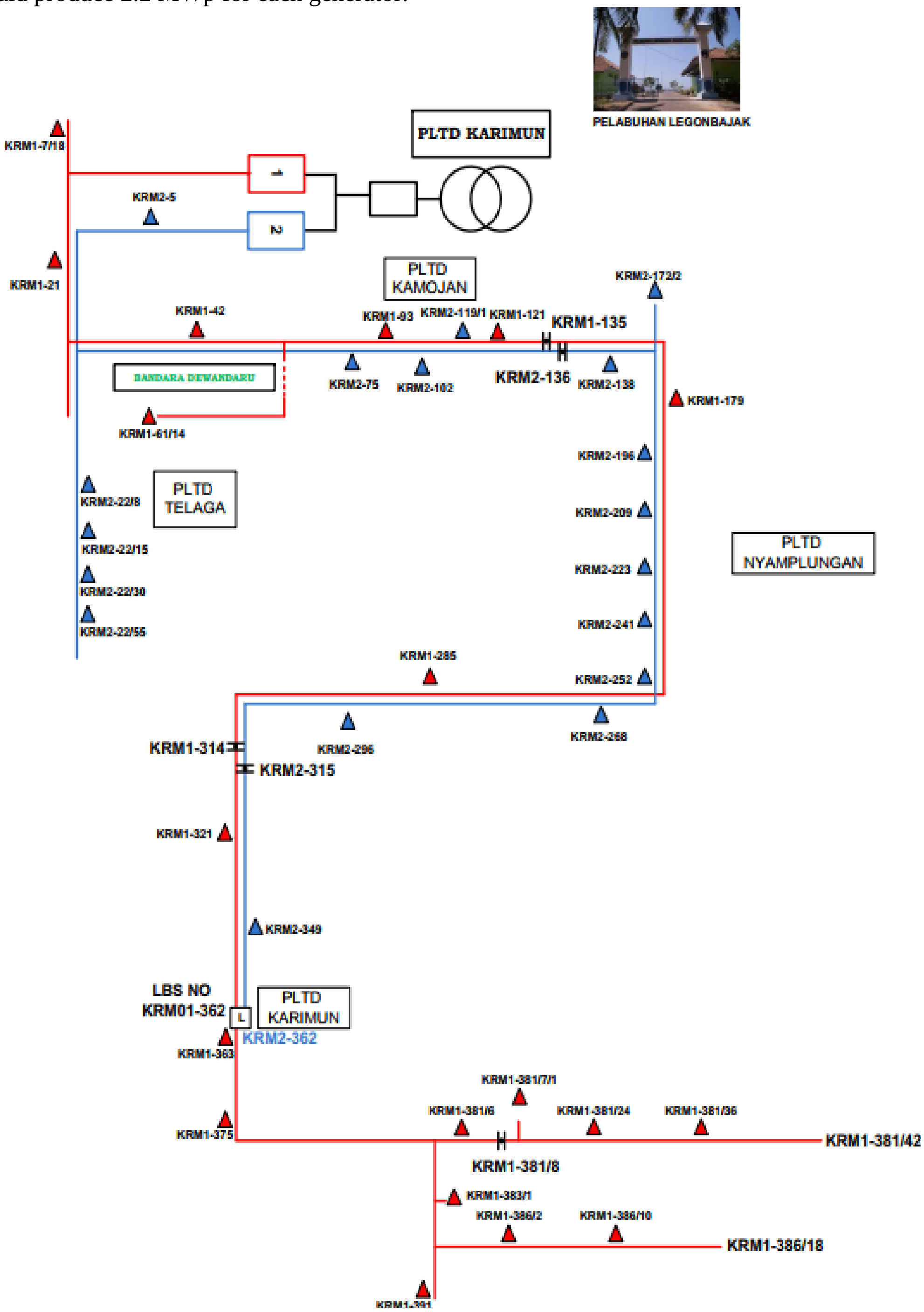

Fig. 2 Single Line Diagram of 20 kV in Karimun Jawa Island. Insert figure (right above): Pelabuhan Legon Bajak.

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Then the ‘Data Jumlah Pelanggan’ or the Customer Data that could use for predict in future how many the customers and the power will be increase to know that if the solar-diesel PV hybrid systems could generate all the customers in Karimun Jawa. The land price around the PLTD Legon Bajak is around Rp. 250,000.00/m². Then the total area in Karimun Jawa is 71.2 km², so the PLTD Legon Bajak could generate the area around more than 70 km² and this is the challenge for the solar-diesel PV hybrid systems that have to generate that area. Figure 2 shows the single line diagram of Legon Bajak power plant until the 20 KV line as the single line diagram in a small Karimun Jawa island.

Another parameters are the average daily irradiance (I_{SOLAR}) at PLTD Legon Bajak and the peak sun hours. Based on IRENA, the average daily irradiance is around 5 kWh/m²/day (PSH = 5 hours/day), but is not really accurate because it is not based on the coordinate of the place or area especially in Legon Bajak. Therefore, we used the HOMER (Hybrid Optimization Model for Electric Renewable) Pro Software Simulation with coordinate point of 5º47.3’S, 110º28.5’E with 5.23 kWh/m²/day and the peak sun hours is 5.23 hours/day. HOMER Pro is a simulation model which is originally developed by National Renewable Energy Laboratory (NREL), but enhanced and distributed by HOMER Energy.

Figure 3 shows the map of electrification in Karimun Jawa island. Yellow line means the 20 kV line (main diesel power plant) starts from Legon Bajak (from northern part of the island) until Karimun Jawa town (in the southern of the island) and lining through some of the diesel plants for example the Nyamplungan Diesel Generator. This one is an old small generator since before there is no big power plant existing yet at Legon Bajak power plant.

Fig. 3 Map of electrification in Karimun Jawa Island.

A. Hybrid Power System (HPS)

There are six elements for the hybrid power systems:

- The Fraction of Electricity Produced by PV System
- The Total Amount of Battery Storage
- The Total Amount of Inverter
- The Area of Solar PV Plant
- HPS Configuration and Site Location
- Load Factory
- The Optimisation of HPS Operation

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B. Techno-Economic Assessment

Four elements for techno-economic assessment are:

- Cash Flow (CF)
- Capital Cost of Solar PV System (C_{SOLAR})
- Net Present Value (NPV)
- Internal Rate of Return (IRR)

IV. RESULTS AND DISCUSSION

We verified the system elements first, then simultaneously presented the results for each of them, started from the HPS and after that the techno-economic assessment.

A. Hybrid Power System (HPS)

The Fraction of Electricity Produced by PV System: The Multicrystalline Solar Panel (Munchen Solar 250W MSP250AS-30) was used for the solar panel with the maximum output power of 250 Watt, the total string is 8, and the total panel is 4,000 units, so the fraction of the solar energy is 32%.

The Total Amount of Battery Storage: The VRLA Battery ULTRACELL 12 V 250 Ah UCG250-12 with the nominal capacity 250 Ampere-Hour (AH) and the nominal voltage 12 Volt was used. Therefore, it is calculated that the amount of transient is 65,000 Watt, the depth of discharge (DOD) is 30.78%, the current of the storage is 295.45 Ampere, the required battery bank capacity is 1,361.58 AH, the ampere-hour storage is 2,272.73 AH, and the total amount of battery storage is 31 units.

The Total Amount of Inverter: The authors use three phase bidirectional dual mode hybrid inverter for mini-grid system that the product is Leonics Apollo MTP-413F with the power ($\boldsymbol{P_{INV}}$) of the inverter 25 KW and the total amount of inverter is 40 units.

The Area of Solar PV Plant: The total area or the field for the solar PV power plant is 6,500 m².

HPS Configuration and Site Location: Considering the existing electricity system in Karimun Jawa island as well as the most feasible site for the installation of PV array, the HPS configuration or we could say the single line diagram (SLD) of HPS is designed to connect the existing Diesel Generators and the PV system through 20kV line as shown in Figs. 4 and 5. The main reason for choosing the site location of the installed PV system is due to the nearest distance with the existing diesel power system. So it makes the easy and low-cost installation.

Fig. 4 The site location of PV system.

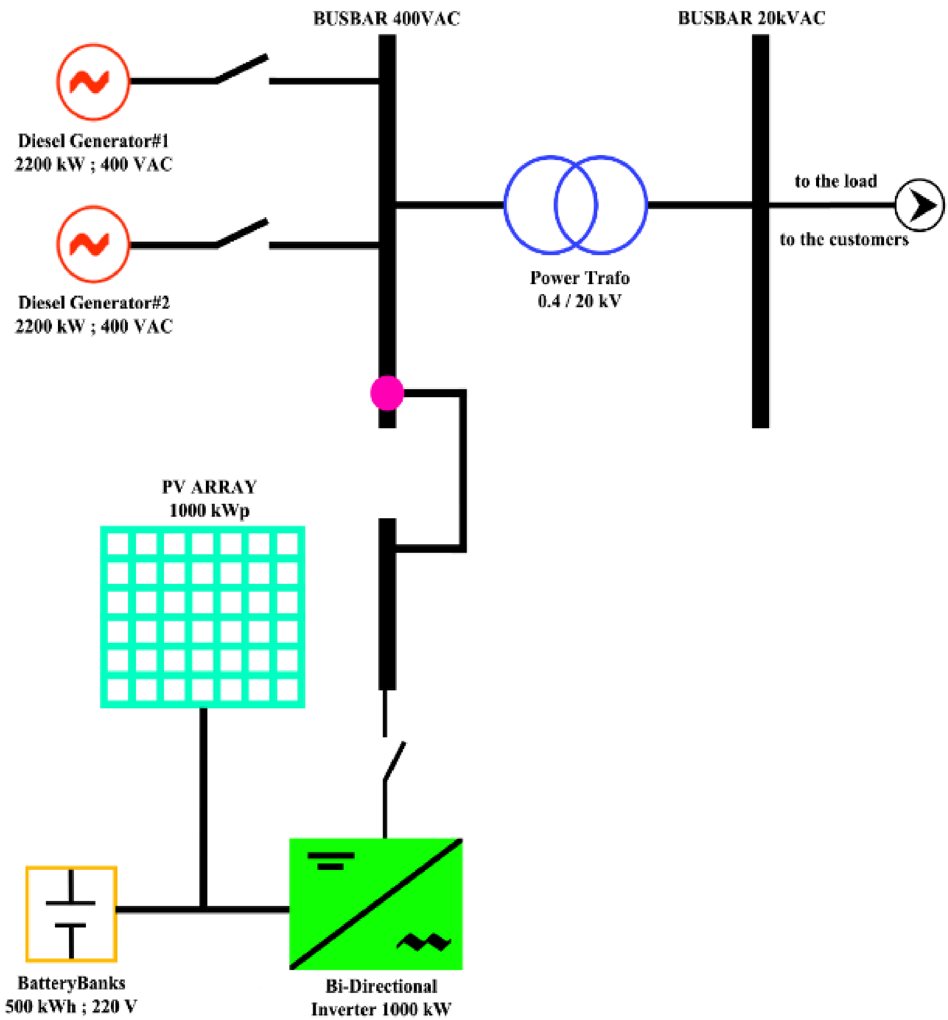

Fig. 5 Single line diagram of the Hybrid Power System (HPS).

Load Factory

To proof the solar PV that could generate all the customers in the island at least 90% so the author will use the 1300 Volt-Ampere (VA) customers because the total of its is 90.12% that know the 1300 VA customers have 1,960 customers and the total customers are 2,175 in February 2018 and the author predict until February 2020. So, the author finds the power factor is 53.66%, the capacity factor is 22.5%, the total power for the 1300 VA customers in February 2018 is 2,548 KVA, the prediction of total 1300 VA customers in February 2020 is 3,714 with the total power is 4,828.2 KVA, and the load factor is 58.3%.

The Optimisation of HPS Operation

One of the important aims of this HPS is to provide 24-hour service of electricity in Karimun Jawa Island with utilising a renewable energy base generation as shown in Figure 6. The penetration of renewable energy in the system is mostly expected to reduce the diesel fuel consumption and subsequently the generation system would be more sustainable by reducing fuel dependency. Therefore, the operation of system ultimately maximises the energy production from PV system in the daytime. In normal conditions, the operation of HPS can be classified as two modes: night time and daytime. In addition, the battery banks are designed to support the operating generators when transient loads occurred such as large sudden load from consumer or the variation of generator power. HPS operation will be explained in the flowchart of Fig. 6: it is started from t_0 where the sun rise is at 6 am and this is where the solar radiation come. Next from the solar radiation, we could know the amount power is consumed by solar PV, then if the amount power of solar PV is bigger than the amount power of the customer or the load so the solar PV is the generator of that time and it happen when daylight. If the load is bigger than the power of solar PV so it will changed to used the battery and then the DG will started or turn-on and the DG will generate for the load. The DG will works at night time started from 6 pm.

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B. Techno-Economic Assessment

Cash Flow

To find the cash flow for the NPV, the authors find that the average daily power is 401.68 KW/h, the load diesel generator (DG) that generated in 24 hours is 9,640.32 KWh, the load DG that generate in 12 hours in HPS from 6 am to 6 pm is 4,820.16 KWh, the specific fuel consumption (SFC) average is 0.449, the component C in 24 hours is Rp. 49,812,506.92, the component C in 12 hours (HPS mode) is Rp. 24,906,253.46, and the cash flow is Rp. 8,966,251,246.

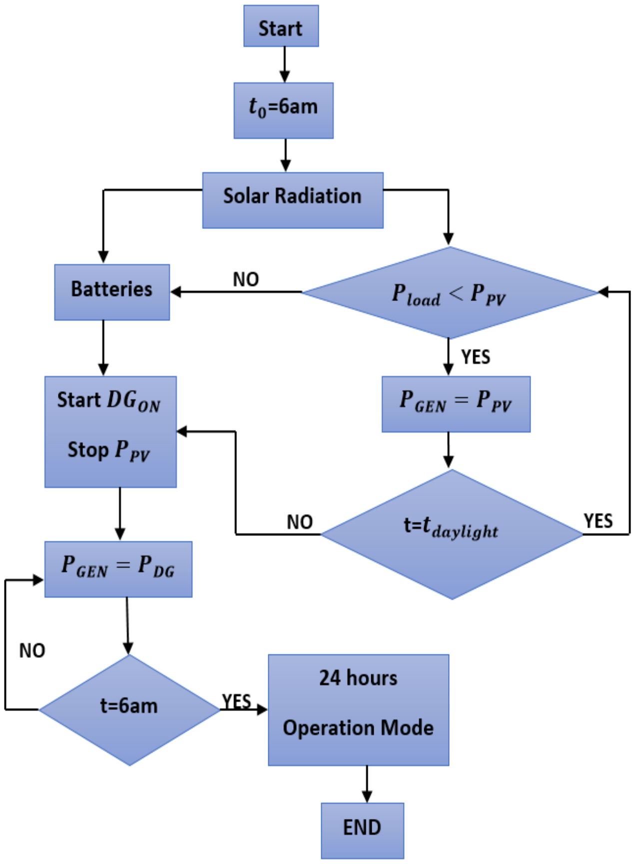

Fig. 6 Flowchart of HPS operation in 24 hours.

Capital Cost of Solar PV System

The total capital cost of solar PV system would be the sum of the capital cost of solar PV (C_{PV}) that is Rp. 13,416,756,214.00, the capital cost of inverter (C_{INV}) that is Rp. 3,327,840,000.00, the capital cost of battery storage (C_{BAT}) that is Rp. 252,058,944.80, and the capital cost of the land area of solar PV site (C_{AREA}) is Rp. 1,625,000,000.00. So, the total capital cost (C_{SOLAR}) is Rp. 18,621,655,160.80.

Net Present Value (NPV): NPV used 5 years' period and the discount rate (d) is 4.25%. Results of NPV is shown in Table I.

Table I NPV Results for Five Years

Year	Cash Flow	Present Value
0	-Rp. 18.621.655.160,80	-Rp. 18.621.655.160,80
1	Rp. 8.966.251.246.000	Rp. 8.600.720.619,66
2	Rp. 8.966.251.246.000	Rp. 8.250.091.721,50
3	Rp. 8.966.251.246.000	Rp. 7.913.757.047,00
4	Rp. 8.966.251.246.000	Rp. 7.591.133.858,04
5	Rp. 8.966.251.246.000	Rp. 7.281.663.173,18

*The Net Present Value (NPV) is Rp. 21.015.711.258,58 and *d = 4.25%.*

Internal Rate of Return (IRR)

IRR used 3 years' period because the payback will be done on the third year. Results for 8 years is shown in Table II.

Table II IRR Results for Eight Years

Year	Cash Flow	Present Value
0	-Rp. 18.621.655.160,80	-Rp. 18.621.655.160,80
1	Rp. 8.966.251.246.000	Rp. 8.600.720.619,66
2	Rp. 8.966.251.246.000	Rp. 8.250.091.721,50
3	Rp. 8.966.251.246.000	Rp. 7.913.757.047,00
4	Rp. 8.966.251.246.000	Rp. 7.591.133.858,04
5	Rp. 8.966.251.246.000	Rp. 7.281.663.173,18
6	Rp. 8.966.251.246.000	Rp. 6.984.808.799,21
7	Rp. 8.966.251.246.000	Rp. 6.700.056.402,12
8	Rp. 8.966.251.246.000	Rp. 6.426.912.615,94

*Net Present Value (NPV) is Rp. 6.142.914.227,37, while Internal Rate of Return (IRR) is 20,90% and the $d = 4.25\%$.

V. CONCLUSION AND FUTURE RESEARCH

Feasibility study to utilize the hybrid PV-diesel power system in Karimun Jawa island Indonesia has been presented. From the results and discussion analysis, we conclude that solar PV power plant should be placed near the diesel power plant, where the two modes: daytime (Solar PV) and night time (Diesel Gen) can be executed. The HPS especially for the Solar PV proof that could at least 90% of the total customers (1300 VA) until February 2020. Also, the most important thing is that the fuel consumption can be reduced up to 50%, where the IRR in 3 years is about 20.90%. For future research, we consider three things: (1) studying the other methods such as wind [9] or geothermal [10] for comparison. Second, grid-tied inverter injects harmonics to the system and the impact of such harmonics and how to dampen them using active/passive/hybrid filters [11-12]. Third, is to find specific formula/criteria to optimize the economic assessment.

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