Analysis of Stand-Alone Solar Photovoltaic System for Engine Assembly Line at Manufacturing Factory in Indonesia

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Abstract—**Industrial sector is the third biggest energy consumption comes after household and transportation energy in Indonesia. To reduce the energy consumption of industry and also impact to reduce the manufacturing cost of the industry, solar photovoltaic on the rooftop of the factory can be an alternative solution to supply energy at engine assembly line, one section of production at the factory. This paper studies about the impact of utilization stand-alone photovoltaic at rooftop of factory building in Jakarta technically. The analysis is using spreadsheet program to compare between stand-alone photovoltaic with battery, stand-alone photovoltaic with diesel generator that operate only when there is no sunshine, and stand-alone photovoltaic with diesel generator that always operating. Simulation demonstrates with estimated available area 7.000 m ^{2} to install photovoltaic array. Result of this research is the stand-alone photovoltaic scenario with battery fulfilled all the demand load by 947,17 kWp installed photovoltaic capacity. The scenarios with diesel generator reduced the photovoltaic generation contribution by 49,25% for 676,69 kWp installed photovoltaic capacity, and diesel generation operating tandem with 297,92 kWp installed photovoltaic capacity that contribute to 33,09% for fulfillment energy demand. The reduced capacity of photovoltaic that installed, the less contribution generation by renewable energy, and the less area that needed to be utilized for photovoltaic system.**

Index Terms—**energy, renewable energy, solar energy, manufacturing industry, solar photovoltaic**

I. Introduction

Indonesia's industrial section is keep growing in line with the government intend to speed up infrastructure. Specially at Java island, where the most economical activities of Indonesia is located. However to ensure the nation's energy security and to keep the growth of

Indonesia's economic, fossil energy is no longer capable to withstand the future demand. The best solution for this problem is to use renewable energy as source of energy including at industrial customers. One of the most developed renewable energy world wide is solar energy from the shine of the sun.

Industrial section as 24 % [1] contributor of the total Indonesia's energy demand can be a huge potential to reduce the fossil energy consumption and also reduction to carbon emission as the affect of converting fossil energy to PV generation.

Indonesia has the potential of solar energy 4,8 kWh/m ^{2} day. If the total potential in Indonesia is fully utilized, there is a potential of 94 Twh/year energy that can be generated by total installed 80 GW solar photovoltaic (PV) system, with an efficiency 15% [2]. However this potential is still undeveloped. To develop PV generation in Indonesia some strategies that has been studied such as [3]:

1. Appropriate and have a clear objective subsidies from government.
2. Encourage development manufacturing of PV.
3. Make clear and absolute regulation for solar PV.
4. Increase private participation (industrial or business consumer) to use PV to fulfill energy demand.
5. Intensify research and development by experts to develop PV technologies.
6. Invite the household customers to utilize PV as power source with proper feed in tariff.

Solar energy that reach the earth's surface can be converted into energy by two ways, which are as a solar thermal and PV. Solar thermal converting heat from the solar to heat up water or air to generate electricity by steam-turbin driven electrical generators. PV system converting solar light to Direct Current (DC) using photovoltaic effect [4].

Due to its nature, the intermittency of PV system, it needs the energy storages to handle the fluctuation energy output at PV. In the future, PV module price will be reduced, so with more cheaper PV module, the PV system will be preferred in the future than the fossil fueled power plant.

One dominant obstacle of PV system is for a big scale PV system, very wide area is needed to harvest more energy [5]. Another issue is distribution losses of electricity. It is better for PV system to be located as near as possible to the load to increase power quality at the feeder and also another electric components [6]. The solution for both issues is by installing the PV modules as the main component to harvest the solar energy on the roof of the building [7]. This rooftop concept is already developed worldwide currently. Also by this concept, we also eliminate the investment land component cost for

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calculating generation cost. The investment land in Indonesia, specially Java island is the biggest investment, and usually this component makes the PV generation didn't accepted economically if using soil land to place the PV system.

II. Stand-Alone PV System

PV can be installed by connected to the grid or off the grid (stand-alone PV). Stand-alone PV can't supply the load by only depending on the PV. Stand-alone PV needs another electric component to ensure the load constantly fulfilled, even the energy that generated from PV system is intermittent based on the weather. Typical stand-alone PV consists of [8]:

1. Photovoltaic cells: Converting sunlight into DC electric energy.
2. Inverter: Converting DC electric to AC electric energy from PV or battery to the loads.
3. Battery: store excess energy from PV to supply system when there is no sunlight
4. Charge controller: control the battery voltage to prevent from under or overcharged condition.

The stand-alone PV with battery is supplying energy directly to the loads when the sun shines. If there is excess energy, it is stored in battery [9]. The excess energy that stored in battery will be used in the night time when there is no sunlight or if the demand energy is higher than energy supplied by PV arrays. (Fig. 1)

Figure 1. Image of PV arrays installed at roof of factory.

Figure 2. Geographical location of sunter 1 plant.

To analyze the stand-alone PV system, first assess the solar resource. The research is done at Toyota Motor Manufacturing Indonesia, one of the manufacturing factory named Sunter plant (6.2 ° S longitudes and 106.9 ° E latitude), located in Sunter, Jakarta Utara, Indonesia (as seen in Fig. 2) [10].

A. *Energy Demand Modeling*

Not all the loads that installed in the factory will be supplied by PV system, due to the manufacturing tools are dominantly high load electric equipment (motors, heater, etc). This research is focus only at assembly engine line loads which are listed as below:

TABLE I. Engine Assembly Equipment and Daily Appliance Loads

EQUIPMENT NAME	Rated Load KVA	Demand Capacity KW	Duration Hour	Energy kWh
LEAK TEST M/C	24	5,76	20	115,2
PRODUCTION INSTRUCTION SYSTEM & ID DATA WRITER	3	0,72	20	14,4
WASHING & DRYING M/C	6	1,44	20	28,8
FIPG APPLY M/C	50	12	20	240
ASSEMBLY AND CHECK M/C	11	2,64	20	52,8
TIGHTNING M/C	76	18,24	20	364,8
CONVEYOR	44	10,56	20	211,2
PARTS INDICATION & PRODUCTION INSTRUCTION SYSTEM	6	1,44	20	28,8
LABEL PRINT, CALCUALTION & ID DATA M/C	4	0,96	20	19,2
STAMP AND LABEL PRINT M/C	45	10,8	20	216
PRESS M/C	25	6	20	120
FUEL AND WATER SUPPLY EXHAUST (2 M/C)	80	19,2	20	384
LLC SUPPLY M/C	3	0,72	20	14,4
TEST BENCH (5 M/C)	85	20,4	20	408
MONITORING UNIT AND LIGHTING	35	8,4	23,3	195,72

B. *Research Methodology*

In order to simulate the supply of assembly line loads by PV system stand-alone, based on the energy demand modeling, the load curve can be calculated. This load curve must be fulfilled, with additional 20% safety factor to ensure at all time the load is fulfilled.

After the load curve is calculated, then the hourly data irradiance in the research area is gathered from Photovoltaic Geographical Interaction System (PVGIS) from Euro Commission. Based on hourly graph of irradiance, the energy that generated from PV system is calculated. The energy that generated will be calculated based on space available at research area. The space that available on the factory rooftop is calculated 10.000 m^2. Based on this data, the actual area that can be utilized for estimated maximum 70%. The area that used for PV system calculated for the amount of PV stand-alone rooftop installed capacity.

There are 3 scenarios that will be analyzed, which are stand-alone PV with battery, stand-alone PV with diesel generator that operate only when there is no PV, and stand-alone PV with diesel generator that always operating.

C. PV System Sizing Calculation

The load that need to be supplied varied with the utilization of the equipment in assembly line. The true power (*P*) is calculated based on demand factor (*DF*) that represent the utilization of a machine or equipment compare to its maximum installed capacity. The true power is calculated with following equation:

$$P = S * CF * PF \quad (1)$$

where P is the apparent power (maximum rating of the equipment load) and PF is the power factor

The maximum value of demand is 286.3 kW, and happened when all the machines, equipment, and lights are utilized. The load curve is shown in Fig. 3 below.

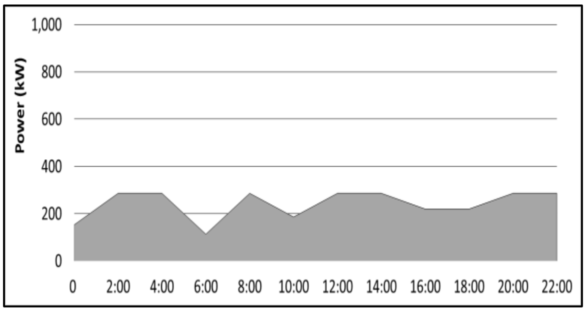

Figure 3. Hourly load curve assembly line.

The total energy calculated based on equation below:

$$E_{Tot} = E_{load\ 1} + E_{load\ 2} + .. + E_{load\ n} \quad (2)$$

where E_{Tot} is the total energy,$E_{load\ 1}$ is the number of the load that installed at the assembly line engine electrical power system. The total energy demand is 2,413.32 kWh total daily for total machine and lighting for engine production 2 shifts operation.

Based on this demand energy that needed to fulfilled, the PV system is calculated based on load curve and also the available space that can be used to install the PV system. The maximum installed PV system that can be installed based on the available area is calculated based on following equation:

$$P_{inst} = PV_{size} * A \quad (3)$$

where P_{Inst} is the total installed PV capacity, PV_{size} is the peak power for a size area of PV array, the PV module that chosen is JinkoSolar JKM330P-72, and A is available area to install the PV array. To calculate the battery size that used for the system with battery, using equation:

$$Batt_{size(AC)} = \frac{E_{Tot}}{V_{AC}} \quad (4)$$

where $Batt_{size(AC)}$ is the battery size for AC system, V_{AC} is the AC voltage.

To convert to the DC electric system using equation:

$$Batt_{size(DC)} = Batt_{size(AC)} * convertion\ factor * \eta \quad (5)$$

where $Batt_{size(DC)}$ is the battery size for DC system, and η is the efficiency of the inverter (normally 10% to 15%).

For the diesel generator installed, is determined based on the peak power that needed to fulfilled by the generator. The generator that used is the diesel generator, using the conventional fuel as the source of the energy.

III. Result and Discussion

PV that installed on the rooftop is an effective solution to reduce the usage of conventional energy and to reduce the cost of PV installation. Based on the simulation and calculation, the scenario PV with battery will supplied all the load by generation from PV. Battery will be charging while there is excess energy that generated by PV, and will be discharged when there is no sun light.

Scenario 1, PV system with battery utilize the maximum total area that available to install the PV array at the rooftop of the factory, total 7.000 m ^{2} with the total installed capacity 884,2 kWp. (Fig. 4)

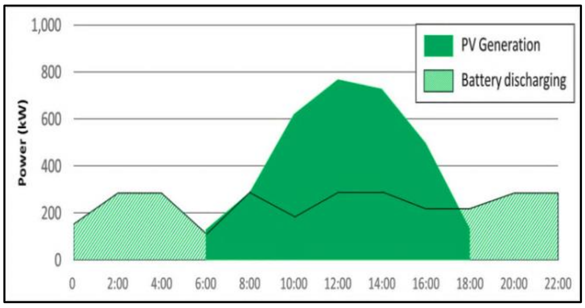

Figure 4. Scenario 1 load curve fulfillment result.

To fulfill all the load the battery that installed is calculated based on the energy that needed to be charged to battery, the battery size is 4 batteries 12 V 10 Ah, arranged in series arrangement, calculated using equation (4) and (5).

Scenario 2, while there is no battery to save energy that exceed from PV generation, diesel generator will fulfilled the energy demand when there is no sunlight. The PV that installed is 631,6 kWp for total 5.000 m ^{2} area that utilized for PV system. (Fig. 5)

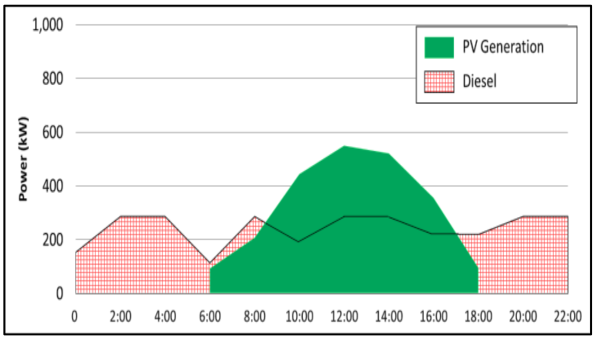

Figure 5. Scenario 2 load curve fulfillment result.

The diesel generator capacity is calculated based on the peak demand, that happened at night. To ensure the diesel generator fulfill when there is no sunlight, the capacity is 350 kW. When the PV fulfilled the demand, the diesel generator is turned off.

Scenario 3, there is a difference operation with scenario 2, while the diesel generator always operating to tandem with PV when there is sunlight. The PV that installed is very low compare to the 2 other scenarios, that utilized 2.200 m ²area for total installed PV capacity 278,1 kWp. The diesel generator capacity is same as scenario 2, because considered based on the same peak power of the demand. (Fig. 6)

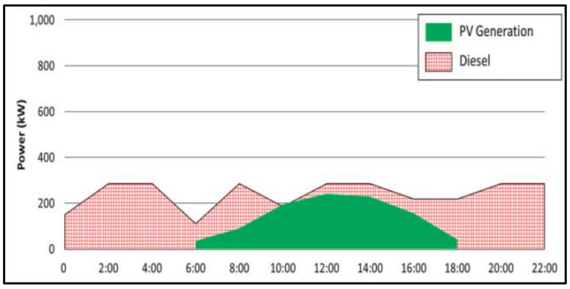

Figure 6. Scenario 3 load curve fulfillment result.

The result and the differences is summarized in Table II below.

TABLE II. RESULT AND DISCUSSION

	Scenario 1	Scenario 2	Scenario 3
PV Size	947,17 kWp	676,69 kWp	297,92 kWp
Area utilized for PV	7,000 m²	5,000 m²	2,200 m²
Percentage of contribution	52,28 %	49,25 %	33,09 %
Battery Size	48 V 40 Ah	0	0
Percentage of contribution	45,72 %	0 %	0 %
Diesel Generator	0	350 kW	350 kW
Percentage of contribution	0 %	50,75 %	66,91 %

For scenario 1, the total load demand is supplied by PV generation, with exceed energy is utilized when there is no sunlight with battery as energy saving equimpment, but this scenario need wide area to be utilized to install PV system. At scenario 2, the contribution of PV is reduced by 49,25%, with the installed PV also reduced, but the remaining load demand is covered by diesel generator.

For scenario 3, the diesel generator contribution become dominant, only 33,09% of the demand load is supplied by PV generation, but the installed capacity of PV also reduced compare to scenario 2.

IV. CONCLUSIONS

In this study, the 3 scenarios are reviewed based on simulation and calculation. The engine assembly load that supplied by PV stand-alone to increase the renewable energy implementation at industrial section.

With 3 scenarios that simulated, the result is scenario 1, the load is fulilled with PV that supported by battery as energy saving equipment. Scenario 2 and scenario 3 are backed up with diesel generator. The PV contribution for these scenarios are less than 50%, but the PV capacity installed is reduced 71% for scenario 2, and 31% for scenario than scenario 1.

This research shows that the assembly line loads at one factory at Jakarta can be fulfilled by PV system with additional equipment (battery or diesel generator) to backup supply energy to the loads. This research can be also impact to reduce the pollution impact from fossil fueled power plant.

This research further can be developed by increasing the accuracy of the data by measuring the irradiation of the sun, and the load energy demand. Also economic assessment can be determined if this research is acceptable economically.

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