Engineering design development of 52.5 KiloWatt peak solar photovoltaic system for industrial Rooftop building

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Abstract. The purpose of this research is to develop on-grid engineering design of 52.5 KW photovoltaic system on Industrial Rooftop Building. The development of solar photovoltaic system is to satisfy high demand of electrical energy for industry, offices, and public with minimum cost. Taking consideration of green energy, solar energy might be chosen as an alternative to generate electric power by utilization of Rooftop on industrial building. This research was conducted using broad database of meteorological data i.e. global daily horizontal solar irradiance. Additionally, Rooftop photovoltaic development, layout plan, photovoltaic array connection, Single Line Diagram and structure support photovoltaic module were developed using Helioscope and PV Syst software. Based on 6 months’ period simulation, annual energy produced on Rooftop is 1043.88 kWh/kWp, Global Horizontal Irradiance (GHI) 1301.96 kWh/m², actual Global Horizontal Irradiance 5.6%, and performance ratio (PR) 80.30 % and capital Rooftop photovoltaic project forecast. This results can be used for industrial and big office in west Indonesian recommendation to develop solar energy system on Rooftop building

1. Introduction

Electrical power demand is going on increasing day by day especially for industrial industry, offices are greatly increased but the increase in demand for electricity is not accompanied by the additional power supply, it is responsible for industrials to make the power generating with good efficiency, continuity and low cost. Taking One of consideration is using green energy from renewable energy resources as their primary source backup One of the best alternatives is choosing Non-conventional sources is Solar energy. The power from the sun intercepted by the earth is approximately 1.8 x 1011 MW, which is many thousands of times larger than the present consumption rate on the earth of all commercial energy sources [1]. It is estimated that the global capacity for concentrating solar energy production will reach 147 GW in 2020, 337 GW in 2030 and 1089 GW in 2050 [2].

Most of industry area especially at cikarang industrial area, west java Indonesia have potential to generate electrical power plant system by developing photovoltaic power plant at Rooftop building and house. Moreover, solar energy applied in industrial environments is an effective and environmentally friendly technology, since panels and photovoltaic (PV) equipment, as well as thermal solar collectors, can be placed on the roofs of buildings, where they function efficiently, without hindering normal activity and with low maintenance both, to meet the growing demand for energy in cities and, to reduce greenhouse gasses emissions [3]. Research is needed to achieve more efficient, profitable and sustainable of photovoltaic electrical power plant for industrial Rooftop area with regard to use of...
renewable energy in industrial power plant is of utmost interest based on regulation number 49th, 2018 from Indonesia’s ministry of energy and human resource about the uses of Photovoltaic on Rooftop.

Rooftop Photovoltaic generation system has advantages the easier and cheaper to integrate with existing electricity system, Photovoltaic modules or panels are made of semiconductors that allow sunlight to be converted directly into electricity. These modules can provide you with a safe, reliable, minimum cost of maintenance and environmentally photovoltaic source can be cost of electrical generation Because of improved technology and reduction in photovoltaic (PV) cost, solar energy is expected to play a substantial role in the future global energy mix, both in the developed and developing countries [4,5]. Beside utilize existing land for generation by using Rooftop to generate photovoltaic it can be reducing land investment costs, and can also reduce load one existing industrial electrical network system.

The purpose of this research is to develop on-grid engineering design of 52,5 KW photovoltaic system on industrial Rooftop building started with analysed Geographical location of the site, calculation potential generation power by using helioscope and PV Syst, develop photovoltaic material dan component engineering design, photovoltaic performance parameter and capital Rooftop photovoltaic project forecast to satisfy high demand of electrical energy for industry, offices, and public with minimum cost. Electricity generation using photovoltaic (PV) systems is important, reliable and has the potential to play a significant role in CO2 emissions mitigation [6,7]. It is widely accepted that PV will become one of the major future sources of electricity generation considering the potential for cost reduction of PV systems and grid-parity expected in Southern and Northern Europe around 2020 [8]. The growing energy demand in developing nations has triggered the issue of energy security. This has made essential to utilize the untapped potential of renewable resources. Grid connected PV systems have become the best alternatives in renewable energy at large scale. Performance analysis of these grid connected plants could help in designing, operating and maintenance of new grid connected systems [9].

2. Material and methods

2.1. Solar power plant
Photovoltaic modules or panels are made of semiconductors that allow sunlight to be converted directly into electricity. These modules can provide you with a safe, reliable, maintenance-free and environmentally friendly source of power for a very long time. A successful implementation of solar PV system involves knowledge on their operational performance under varying climatic condition [10]. Roof plan can help quantify the roof area available for the PV power plant. The plan should indicate the location (including longitude and latitude), height, and slope of the roof itself, as well as any additional structures present on the roof. Identify any possible conflicts in usage of the roof, such as a helipad or communication antennae, and contact relevant bodies to ascertain if any special permission is required to use and/or alter usage of the roof space [11]. The research object roof top Solar PV station of 52,5KWp on-grid located in one of biggest industry in cikarang industrial park, located at latitude 6.3 ° S and longitude 107.1 ° E, west java Indonesia. Figure.1, represents a roof top Solar PV station of 52,5KWp and design on grid with electrical power from State Electricity Enterprise.

A Rooftop solar PV installation comprises of PV panels assembled in arrays, mounting frames to support the panels and secure them to the roof, wiring, inverters, and other components depending on the type of installation. The roof site must be able to accommodate all of these components, which requires examining the following aspects [11].

2.1.1. Accessibility. The roof must be accessible to carry out installation and maintenance. It must be possible to lift the solar system components onto the roof and for personnel to physically access the site to install and maintain the system.
2.1.2. **Roof configuration.** A roof plan can help quantify the roof area available for the PV power plant. The plan should indicate the location (including longitude and latitude), height, and slope of the roof itself, as well as any additional structures present on the roof.

2.1.3. **Roof materials and structure.** For existing buildings, first find out when the roof would need replacement. If a roof is nearing the end of its life span, it is more cost-effective to install the Rooftop PV system once the new roof is in place. It is also easier to integrate a system into the design of a new roof.

Helioscope software used to design accessibility, arrange solar cell position and determinate numbers of solar cell, design Rooftop photovoltaic generation design with REC Twinpeak 2S 72 Series 350 Wp solar cell module, cable tray model and size position and elevation orientation. Roof configuration solar cell module showed on figure 2.
4° elevation angle on 180° south azimuth orientation. Design specifications of design model development showed on table 1.

| Design Capacity       | 52.5 kWp       |
|-----------------------|----------------|
| Distance between solar cell | 0.4 m     |
| Number Of Modules    | 150 pcs       |
| Modul Layout placement | 4 string on North |
|                       | 4 string on South |
| Photovoltaic Module parameter |             |
| a. Nominal power (P_{MPP}) | 350 Wp    |
| b. Nominal voltage (V_{MPP}) | 38.9 V    |
| c. Nominal current (I_{MPP}) | 9 A      |
| d. Open circuit voltage (V_{OC}) | 46.7 V   |
| e. Short circuit current (I_{SC}) | 9.72 A   |
| f. Photovoltaic module efficiency | 17.4%    |

2.2. Roof material and structure development design method

Main material photovoltaic component and supporting component design for 52 kWp Rooftop Photovoltaic development showed at figure 3.

Photovoltaic module used REC Twinpeak 2S 72 Series 350 Wp, SMA Sunny Tripower 20000TL Inverter, Kipp & Zonnen RTI Rooftop Pyranometer sensor and SMA Cluster Control. 5° splay considered to treatment and photovoltaic reliability monitoring. SMA Sunny Tripower 20000TL-30 Inverter has 98.4% efficiency and 20000 W AC power maximum used to change ac to dc voltage and connected to utility network. This Sunny WebBox inverter connect to RS485 serial to record voltage and AC power every 5 minute and can be monitored by computer system. All materials used in Rooftop PV generation plan represented on figure 4.
Figure 4. Material and equipment.

The rack structure model for PV module supporting placement designed with Structure Analysis Program (SAP) software and showed on figure 5.

![Rack PV module model](image)

Figure 5. Rack PV module model.

Development model considered Dead Load (DL), Live Load (LL) (22.4 kg per pv-module), Wind Load measured from wind velocity is 120 km/h. Supporting rack designed that support structure can be restraining 80 kg/m wind load.

2.3. Performance analysis of the PV system

The performance parameters are developed by International Energy Agency (IEA) for analyzing the performance of solar PV grid interconnected system [9,12]. Many performance parameters are used to define the overall system performance with respect to the energy production, solar resource and overall effect of system losses. The various parameters are the performance ratio, final PV system yield and
reference yield. Evaluation performance analysis parameter in this research are; output energy, energy losses system, PV system evaluation performance ratio and capacity factor [4,13-15]. System Efficiency measured from all solar cell array area [16]. This Performance Parameter is average value of various operation condition [4].

2.3.1. Global Horizontal Irradiance. Global Horizontal Irradiance (GHI) is total sun radiation on horizontal surface and its sum of Direct Normal Irradiance (DNI), Diffuse Horizontal Irradiance, and reflection sun radiation from land [17]. The equation relationship of GHI, DNI, on horizontal surface is:

$$ \text{GHI} = \text{DHI} + \text{DNI} \cdot \cos (\theta_Z) $$  \hspace{1cm} (1)

where:
- **DHI** (Diffuse Horizontal Irradiance) = horizontal radiation that spreads (kWh/m²)
- **DNI** (Direct Normal Irradiance) = normal radiation directly to the surface (kWh/m²)
- \( \cos (\theta_Z) \) = radiation angle to the horizontal surface

2.3.2. Photovoltaic energy production. Total energy is defined as the amount of alternating current power produced by the system over a period of time. The energy yield of a PV array is a meteorological function of the location where it is installed [18]. This is the PV system energy output estimated as [19,20]. Total energy per Hour, daily and monthly was obtained from the equation as follow.

$$ E_{\text{AC,h}} = \sum_{t=1}^{60} E_{\text{AC},t} $$ \hspace{1cm} (2)

$$ E_{\text{AC,d}} = \sum_{h=1}^{24} E_{\text{AC},h} $$ \hspace{1cm} (3)

$$ E_{\text{AC,m}} = \sum_{d=1}^{N} E_{\text{AC},d} $$ \hspace{1cm} (4)

Note
- **E_{AC,t}** = AC Energy Output on t minute
- **E_{AC,h}** = AC Energy Output on t hour
- **E_{AC,d}** = AC Energy Output on daily
- **E_{AC,m}** = AC Energy Output on month
- **N** = days in 1 month

2.3.3. Performance ratio
Performance Ratio (PR) mentioned all effect from normal solar cell array power output losses and PR value that shows how close the ideal performance during operation and compare PV system from PV plan location, slope angle, orientation and nominal power capacity. The performance ratio is defined as the ratio of the final energy output of the PV system, YF (kWh AC/kWp) with reference YR (kWh/kWp) [21]. Performance ratio, RP is defined as the ratio of the final energy yield of the PV system, Yf, to the reference yield, Yr [22].

$$ R_P = \frac{Y_f}{Y_r} $$ \hspace{1cm} (5)

In this equation, Yf is calculated as the ratio of the monthly yield (Wh) of the PV array, Eout, to the installed array’s rated output power (Wp), PSTC provided by the manufacturer. That is, Yf is given as:

$$ Y_f = \frac{E_{out}}{P_{\text{STC}}} $$ \hspace{1cm} (6)
Yr is calculated by dividing the total monthly tilted PV surface irradiation (Wh/m²) Et by the reference irradiance G_{STC} = 1000 W/m². That is:

\[
Y_f = \frac{E_{out}}{P_{STC}}
\]  

(7)

\[
Y_f = \frac{E_t}{G_{STC}}
\]  

(8)

\[
PR = \frac{100 \times Y_f}{Y_R} \%
\]  

(9)

2.3.4. Project cost

a) Levelized cost of energy

Model life cycle cost model for system energy developed by Department of Energy US dan regulated in the National Bureau of Standards, 1980. This model considers total relevant total cost from an energy system begun from cost design, civil building, materials, components and operation cost’s. especially initial investment costs, maintenance cost, the cost of replacing equipment in the future, security, insurance and resale value. Thus, the life cycle costs of the energy system are formulated as follows [23]:

\[
LCC = EC + IC + SV + NFOMC + NRC + RC
\]  

(10)

LCC : current value of life cycle cost  
EC : current value of energy costs  
IC : current value of investment costs  
SV : current value of salvage  
NFOMC : current value of recurring annual non-fuel operations and maintenance costs  
RCC : current value of recurring fees or annual fees

“Levelized Cost of Energy (LCoE)” is electrical energy generated costs from certain energy sources to reach breakeven in certain time period. Usually the time period is determined based on the lifetime of the generating system. LCoE calculation defined with following equation [24]:

\[
LCoE = \frac{\sum_{t=1}^{n} \frac{LCC}{(1+r)^t}}{\sum_{t=1}^{n} \frac{LCC}{(1+r)^t}}
\]  

(11)

Note ;  
It : investment costs for t-year period generator  
LCCt : t-year period generator Life Cycle Cost  
r : applicable interest rates  
Et : t year generation of electrical energy produced (kWh)  
n : age of use of the generator

3. Results and discussion

3.1. PV system design

52.5 kWp Rooftop photovoltaic electric generation has an installation scheme of 2 PV Array with a capacity of 26.25 kWp, 2 Inverters with a capacity of 20 kWp each, 1 Cluster Control, 1 Irradiance sensor and 1 AC Combiner box connected to the Main Distribution Panel (LVMDB) existing. As shown in figure 6.
Rooftop Photovoltaic 52.5 kWp capacity design with 150 pcs PV module and each module designed Distance between modules is 40 centimetres. Photovoltaic module divided into 2 directions, 4 string at south and 4 string at north. Nominal power (P-MPP) of each Photovoltaic is 350 Wp with 38.9 V Nominal voltage (V-MPP), 9 A Nominal current (I-MPP), 46.7 V Open circuit voltage (VOC), 9.72 A Short circuit current (ISC) and 17.4 % PV module efficiency.

PV Array connections for 1 string consist 19 modules. Figure 8. show schematic diagram for PV array connection.
Figure 8. PV Array connection for 19 modules in 1 strings.

Grounding system schematic diagram Design for Rooftop 52.5 kWp is shown in figure 9.

Figure 9. Grounding system for PLTS 52.5 kWp.

Grand design for Rooftop 52.5 kilo Watt peak model is designed electrical transient analysis program (ETAP) with one-line diagram scheme as result and represented on figure 10.

Figure 10. One-line diagram Rooftop PV 52.5 kWp.
3.2. Rooftop PV Performance

2.5 kWp Rooftop photovoltaic performance measured with actual and helioscope simulation of Global Horizontal Irradiance (GHI), energy production and Performance Ratio. GHI of Rooftop PV observed in the April 2018 until December 2018 period. data processed based on Helioscope and PV Syst simulation and compared actual measurement data and showed on figure 11.

![Global Horizontal Irradiance](image-url)

**Figure 11.** Global horizontal irradiance from January to December 2018.

The simulation results and actual annual GHI generated by 52.5 kWp Rooftop PV from April 2018 to December 2018 obtained as follows: Results of annual GHI estimates of is 1.307,2 kWh/m². Helioscope annual GHI result 1.304,7 kWh/m² and actual measurement is 1.301,96 kWh/m².

Energy production on Rooftop PV analysed from period time is 55,390 kWh from PV Syst software, 56,502 kWh from Helioscope and 54,804 kWh from actual measuring PV. The Comparison energy production showed on figure 12.

![Monthly Energy Production](image-url)

**Figure 12.** Monthly PV energy production.

Actual average Energy generated by 52.5 kWp Solar cell is 1.06 - 3.00%, lower than predicted by PV Syst and Helioscope simulations.
3.3. Performance ratio
The simulation results and annual actual Performance Ratio on 52.5 kWp Rooftop PV electrical energy generation from April 2018 to December 2018 are obtained as follows: 80.71% from PV Syst simulation, 82.42% from Helioscope simulation, and 80.30% from actual measurement. Figure 13 represents a comparison of simulation results and actual Performance Ratio (PR).

Comparison of annual Performance Ratio values (April 2018 to December 2018), actual PR is lower than 0.51% of predictions based on PV-Syst simulation is 2.64% lower from Helioscope simulation. From results of comparison between the actual value of PR and simulation, of 52.5 kWp Solar Cell Rooftop system operates well.

3.4. 52.5 kWp Rooftop PV project cost estimation
Capital Expenditure estimated capital costs for the construction of the 52.5 kWp Rooftop PV project depend on Assumption 1 US $ = IDR. 13,550 per December 8, 2017, additional costs for changes to the pyranometer specifications include the addition of an aluminium clamp supporting module. Table 3 described 52.5 kWp Rooftop PV project Cost Estimation.

| No | Item                        | CAPEX Price | Segmentation Price |
|----|------------------------------|-------------|--------------------|
| 1  | PV Modul                     | 20.175 ($)  | 20.175 ($)         |
| 2  | Inverter & Accessories       |             | 10.194 ($)         |
| 3  | Cabling                      |             |                    |
| 4  | Electrical Board & Accessories | Rp.          |                    |
| 5  | Module Support               | 484,000.000 | 25.526 ($)         |
| 6  | Project Management           |             |                    |
| 7  | Transportation               |             |                    |
|    | Total                        | 56,195 ($)  |                    |
|    | CAPEX/Wp ($)                 | 1.07        |                    |
|    | CAPEX/Wp (Rp)                | 14,503,55   |                    |

Calculation "Levelized Cost of Energy (LCOE) for 52.5 kWp Rooftop PV project can be described as follows:
Total lifetime = 25 years (REC Power Output Warranty)

OPEX = 1% CAPEX/Years (assumption)

Annual degradation = -0.7%/year (REC Power Output Warranty)

Energy production in the first year based on PV Syst) = 70320 kWh

Energy production in the first year based on Helioscope) = 71361 kWh

LCoE for 52.5 kWp Rooftop PV is,

\[ \text{a) LCoE PV Syst} = \frac{\text{CAPEX+OPEX for 25 years (US$)}}{\text{Total Energy Production for 25 Years (kWh)}} \]
\[ = \frac{56194.5572+14048.6393 (US$)}{1610282 kWh} \]
\[ = 4.36 \text{ Cent/kWh} \]
\[ = 590.78 \text{ Rp/kWh (assumption 1 US$ = Rp. 13.550)} \]

\[ \text{b) LCoE Helioscope} = \frac{\text{CAPEX+OPEX for 25 Tahun (US$)}}{\text{Total Energy Production for 25 Years (kWh)}} \]
\[ = \frac{56194.5572+14048.6393 (US$)}{1634167 kWh} \]
\[ = 4.30 \text{ Cent/kWh} \]
\[ = 582.65 \text{ Rp/kWh (assumption 1 US$ = Rp. 13.550)} \]

Calculation of the levelized cost of energy generation of electrical energy uses the principle of effectiveness, efficiency and accountability of the overall cost of generating energy from electrical energy produced by photovoltaic the output. The basic cost energy of Rooftop solar electricity generation from 52.5KWP in this study is 4.30 cent dollar / KWH. Compared to electricity generation cost according to the decree of the Minister of Energy and Mineral Resources of the Republic of Indonesia in 2018 stated cost of generation i used as a reference for the purchase price of electricity from generation for the West Java region is 6.81 cent / KWh [25]. So the price of the basic cost of Rooftop solar energy generation compared to other generation is cheaper and the level of pollution, decay and global warming level is lower limiting global warming to a maximum of 2 degrees Celsius until the year 2100 according Paris Agreement

4. Conclusion
Research subjected to develop on-grid engineering design of 52.5 KW photovoltaic system on Industrial Rooftop Building. The development of solar photovoltaic system is to satisfy high demand of electrical energy for industry, offices, and public with minimum cost. Taking consideration of green energy of 2015 United Nations Climate Change Conference, stated that limits global warming to a maximum until the year 2100 is 2 degrees Celsius [26], solar energy might be chosen as an alternative to generate electric power by utilization of Rooftop on industrial building. Design of the 52.5 KWp Rooftop in this study was to create a solar-powered generation system on a roof building to reduce global warming and support the use of conventional plants in meeting the lack of electrical energy supply in an industry in a simple, efficient and profitable way. The cost of PV system depends on the installed capacity. However, because of benefit of system scale-up, the cost of PV per kW decreases as the installed capacity increases. Therefore, cost per kW of installed capacity of a residential PV system is generally higher when compared with the large-scale utility size PV [4] system It is hoped that through the Rooftop design research of the 52.5 KWP PV power generation system, industry players can consider economically, the feasibility of the system and the utilization of the building’s Rooftop in industrial buildings has the potential for the development of solar power plants.
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