Design and Simulation of On-Grid Solar Power Plant for the Power Needs of PPI Madiun Crossing Gate

Asep Dwi Pandurisnawan[1*], Natriya Faisal Rachman[2], Santi Tri Wijaya[3], Sunardi Sunardi[4]

[1,2,3,4]Railway Electrical Technology Study Program,
Indonesian Railway Polytechnic, Madiun, Indonesia
asepdwi@gmail.com

Abstract. At PPI Madiun, the power supply system to operate the level crossing doorstop is currently still dependent on electricity from PLN. However, to reduce dependence on electrical energy from PLN as recommended by the Minister of Energy and Mineral Resources (ESDM) and the Director of PPI Madiun, the abundant potential of renewable energy in Indonesia can be utilized. The potential for sunlight in Madiun reaches 5,446 kWh/m2/day. Therefore, it is proposed to use an On-Grid solar power plant (PLTS) with a certain configuration connected in series. The system uses a 5.5 kWh Inverter to convert DC electricity into AC. LEONI 4mm (100m) and AWG (50m) type cables connect the components. A 230 Vac ATS with 2 sources manages the power supply, and a converter is required to convert AC loads to DC (230 Vac capacity to 24 Vdc). The solar panel installation area is 15.6 m². Simulation results with Homer Pro show the On-Grid Solar PV design is capable of generating 4,778 kWh/year, exceeding the daily requirement of 4,776 kWh for doorstop operation. The total cost for the implementation of On-Grid Solar Power at level crossing PPI Madiun is Rp.103,808,213. With the adoption of this system, PPI Madiun can reduce dependence on PLN and switch to renewable energy that is more environmentally friendly.

Keywords: Level Crossing, On-Grid Solar Power, Design Configuration, Homer Pro.

1 Introduction

At PPI Madiun, the level crossing gates still use electricity from PLN with daily needs of 1,600,000 VA. However, to operate the doorstop, it only requires 4,776 Watts or 4,776 kWh per day. Director of PPI Madiun and Minister of Energy and Mineral Resources [11] advocates saving electricity by putting a warning on every socket and light switch. The solution for PPI Madiun is to utilize the abundant potential of renewable energy in Indonesia.

PLTS is a power generation system that uses solar energy as the main source. On-Grid Solar Power Plant benefits include daily electricity utilization and selling excess energy to PLN. The system also provides stability and reliability of electricity supply, especially when the weather is bad or energy demand exceeds the production of solar panels. The implementation of On-Grid Solar Power Plant at PPI Madiun will help reduce dependence on PLN and improve energy efficiency. The potential for sunlight that reaches 5446 kWh/m2/day in Madiun is a great opportunity to provide sustainable and environmentally friendly electrical energy.

An application called HOMER to validate the results of the calculation of the planned Solar Power Plant design in accordance with the power requirements for the operation of the level crossing at PPI Madiun.

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2 Literature review

2.1 PPI Madiun Direct Crossing Route

Level crossings are intersections between highways and railway lines, where priority is given to the railway line. Level crossing is used by railways to provide warnings to motorists on the highway to stop and wait for the train to pass [1].

At level crossing Madiun, there are motors (2x75W att), XC lights (2x31W att), arm lights (2x10W att), top lights (1x10W att), and sirens (1x30W att) which use 24Vdc voltage. The lighting in the level crossing building (2x12 Watt) uses a voltage of 220-240Vac.

2.2 Solar energy

Solar energy is a renewable energy source that comes from the sun's rays and heat. Even though solar heat cannot be directly used as a source of electrical energy, it needs to be converted first into electrical energy and stored in a battery. After that, the electrical energy can be used as a conventional energy source [2] . The PV power forecast model uses weather forecasts from public websites, weather variables are uniform, but solar radiation is different between Nganjuk and Madiun [7].

2.3 Solar Power Plant

PLTS is renewable energy that is abundant and renewable throughout the world, using sunlight to produce heat, light and electricity. This technology is considered environmentally friendly and is the choice of many groups. [3] On-Grid Solar Power is a system connected to a commercial network. Solar panels convert sunlight into electrical energy for daily needs. Excess energy can be returned to the commercial grid or used when demand exceeds solar panel production.

2.4 Battery

The battery functions as a storage place for electrical energy originating from solar modules and wind turbines, to be used for daily needs [4]. The DoD 80% requirement is implemented to maintain battery life, where only 80% of the energy is used and the remaining 20% remains as reserves.

2.5 Inverters

An inverter is a device used to convert direct current (DC) into alternating current (AC) according to the needs of the electrical load used. An inverter functions as the opposite of a converter or adapter which basically changes AC current to DC [4].

The inverter connection concept is a form of inverter circuit in a On-Grid Solar Power system for generating electrical power by solar panels, and the connection between the inverter and the load or network. In general, there are two classes of inverters, namely, central inverters or what are called central inverters and string inverters.

2.6 Homer Pro

HOMER is simulation software that optimizes power generation systems, both independent and connected to the electricity grid [5][8].

3 Research Methodology

3.1 Research Method

This research uses Excel 2019 to process level crossing Madiun energy load data and obtain daily totals, daily peaks and hourly loads. Based on the AS/NZS 4509.2:2010 [6] standard, the On-Grid Solar Power configuration and main component specifications will be determined based on energy potential and load requirements. The On-Grid Solar Power system will be designed with this information and simulated using HOMER with energy potential data, electrical load and main component information.

3.2 Method of collecting data

On-Grid Solar Power design at level crossing PPI Madiun involves several stages with data processing using Microsoft Excel 2019 used to determine the next steps for making On-Grid Solar Power :

Table 1. Total daily load of Level Crossing at PPI Madiun

No	Tool	Total Power
1	DC motors	1,500 Watts
2	CFL Lamps (Lighting)	336 Watts
3	XC/Andreas Cross (Level Crossing) lights	840 Watts
4	Top Lights	200 Watts
5	Arm Light (Level Crossing)	400 Watts
6	Level Crossing of siren	600 Watts
7	Electrical Terminals (Others)	900 Watts
	Total	4,446 Watts

The maximum capacity of On-Grid Solar Power Rooftops is 100% of PLN Consumer power [11].

4 Results And Discussion

4.1 *On-Grid* PLTS components at PPI Madiun

In designing the On-Grid Solar Power system at PPI Madiun, calculations were carried out to find out how much was needed. The requirements needed are to calculate the number of PVs and the number of inverters adjusted to the capacity of the solar cells. This research uses the Australian/New Zealand standard AS/NZS 4509.2:2010 regarding Stand Alone Power Systems [6].

4.1.1 Solar Panel Requirements

1) Selection of solar modules

The solar panels used in this study were manufactured by Canadian Solar Inc [9].

Table 2. Solar panel specifications

Type	Detail
Manufacturer	Canadian Soalaar Inc
Brand and Model	MaxPower CS6U-340
Nominal Max. Power (Pmax)	340 W
Opt. Operating Voltage (Vmp)	37.9 V
Opt. Operating Current (Imp)	8.97 A
Open Circuit Voltage (Voc)	46.2 V
Short Circuit Current (Isc)	9.48 A

2) Oversupply coefficient (f_0)
Oversupply coefficient value (f_0) is chosen as 2 for PV Array systems with batteries for maximum energy efficiency.
3) Irradiation on tilted plane (H_{tilt})
Solar panels with a tilt angle of 20° at PPI Madiun can capture 5,446 kWh/m2/day of radiation from the Solargis website .
4) Design load Ah
The nominal DC system voltage is determined based on the inverter voltage (80-550 Vdc).

$$Design\ Load\ A\ h = \frac{\text{Etot}}{\text{Vdc}} = \frac{4.776}{96} = 49{,}75 \text{ Ah}$$

5) Required Array Output

$$RAO\ Ah = \frac{\text{Design load Ah}}{\eta\text{bat}} = \frac{49{,}75}{80\%} = 62{,}18 \text{ Ah}$$

6) Daily Charger Output per module

$$\text{DCO} = (1\text{-}5\%) \times IT.V \times fdin \times Htilt$$
$$\text{DCO} = (1\text{-}5\%) \times 7{,}76 \times 96\% \times 5{,}446$$
$$= (95\%) \text{ x } 40{,}57 = 38{,}54 \text{ Ah}$$

7) Number of Parallel String Required

$$NoPSR = \frac{\text{Required Array output} \times \text{f0}}{\text{Daily charge output per modul}} = \frac{62{,}18 \times 2}{38{,}54} = 3{,}22 \sim 4 \text{ pcs}$$

8) Number of Seriees Module per Sring

$$Ns = \frac{\text{Vdc}}{\text{Voc}} = \frac{96}{46{,}2} = 2{,}07 \sim 2 \text{ pcs}$$

9) Total Number of Module in Array

$$N = Np \times Ns = 4 \text{ x } 2 = 8 \text{ pcs}$$

10) Capacity of Each PV Array

$$PpvArray = J\text{ml} \times Daya\ modul = 8 \text{ x } 340 = 2{,}720 \text{ Wp}$$

The planned solar panel PV Array power capacity is 2,720 kWp.

4.1.2 Battery Requirements

1) Design load (Ah)

$$Design\ Load\ A\ h = \frac{\text{Etot}}{\text{Vdc}} = \frac{4.776}{96} = 49.75\ \text{Ah}$$

2) Autonomy day targets (T_{aut})
Standard AS/NZS 4509.2:2010 [6] recommends an autonomy time of 2-3 days for automatic power generation systems, this research uses 2 days.

3) Maximum Depth of Discharge (DoD_{max})
This research uses a battery charge limit (DoD) of 80% to extend battery life and avoid overloading.

4) Battery discharge rate capacity (C_x)
AS/NZS 4509.2:2010 [6] suggests $C_{x\ battery\ capacity}$ based on maximum load and duration. A discharge rate of 20 hours was chosen because the peak load is large.

5) Temperature correction factor
Based on AS/NZS 4509.2:2010 [6] the temperature correction factor for batteries with a 20 hour discharge (C20) is 98%.

6) Required battery capacity

$$Ah = \frac{Design\ Load\ x\ T_{out}}{DoD\ x\ fakto\ koreksi\ temperatur} = \frac{49{,}75\ x\ 2}{80\%\ x\ 98\%} = \frac{99{,}5}{0{,}784} = 126.91\ \text{Ah}$$

7) Battery selection
On-Grid Solar Power system , the Solana SOL12-150 battery was chosen because the specifications suit the application needs [12].

Table 3. Battery specifications

Type	Information
Nominal Voltage	12 V
Nominal Capacity	150 Ah
Life Design	10 years
Terminal	M6
DoD	80%
Max Charge Current	33.4 A
Max Discharge Current	335 A
Operating Temperature	-20-60 ^{0}C

8) Number of batteries connected in series

$$\text{Series} = \frac{V_{dc}\ (\text{Inverter})}{V_{dc}\ (\text{Baterai})} = \frac{92\ \text{V}}{12\ \text{V}} = 7.6 \sim 8 \text{ pcs}$$

9) Number of batteries connected in parallel

$$\text{parallel} = \frac{\text{kapasitas Baterai diperlukan}}{\text{Kapasitas pada } c_x} = \frac{126{,}91}{200} = 0.63 \sim 1 \text{ pc}$$

10) Total number of batteries

Total = series x parallel = 8 x 1 = 8 pcs

The total batteries in the system are 8, the result of combining series and parallel.

4.1.3 Inverter Requirements

At this stage, researchers will use an oversupply coefficient (f_0) of 1.1 to determine the inverter capacity like at table 4.

Inverter Capacity = PLTS Capacity x F_o = 4,776 x 1.1 = 5,253.6 wH

Based on theoretical calculations, a minimum inverter of 5,253 kW is used, Growatt MIN 5000TL-X with Shine WiFi MIC 5KW [11].

Table 4. Inverter specifications

	MODEL	
	RATED POWER	
PV INPUT (DC)	Maximum recommended DC power (W)	5750
	Nominal DC operating voltage (V)	360
	Maximum DC voltage (V)	550
	Strat voltage (V)	100
	MPPT voltage range (V)	80-550
	Maximum input current (A)	11 / 11
	No of MPP tracker	2
	Strings per MPP tracker	1
GRID OUTPUT (AC)	Nominal AC output power (W)	5000
	Maximum AC output power (VA)	5000
	range (V)	180-280
	AC grid frequency (Hz);	50/60

4.1.4 Cable Requirements

The cable functions to carry electricity from the solar panels to the inverter and battery and from the inverter to the load. In the design, 100 meters of DC cable and 50 meters of AC cable are used, including cable reserves [11].

4.2 *On-Grid* PLTS Design at PPI Madiun

4.2.1 Load Technical Specifications

Technical specifications for AC and DC loads are needed to plan a PLTS system at table 5 and table 6.

Table 5. AC load specification

TECHNICAL SPECIFICATIONS air conditioning				
Tool	Amount	Voltage (V)	Current (I)	Watts (W)/item
CFL Lamps (Lighting)	1	220-240 V	0.12 A	12 W
Electrical Terminals (Others)	2	220-240 V	0.204 A	45 W
Total		220-240 V	0.324 A	57 W

Table 6. DC load specification

TECHNICAL SPECIFICATIONS D.C				
Tool	Amount	Voltage (V)	Current (I)	Watts (W)/item
DC motors	2	24 V	4.5 A	75 W
XC/Andreas Cross (LEVEL CROSSING) lights	4	24 V	0.875 A	21 W
Top Lights	2	24 V	0.42 A	10 W
Arm Light (LEVEL CROSSING)	4	24 V	0.42 A	10 W
LEVEL CROSSING siren	2	24 V	1.25 A	30 W
Total		24 V	7.565 A	146 W

On-Grid Solar Power of Roof Area

On-Grid Solar Power at PPI Madiun will be placed in the Power House near the LEVEL CROSSING building or to the east of the Nurul Ilmi Mosque. The roof area for solar panels is 20 m x 26.5 m.

Roof area = pxl = 20 x 26.5 = 530 m^2

The solar panels used are 1,954 m long and 1 m wide, with a total of 8 panel modules.

Solar panel roof area = pxlx qty = 1.954 x 1 x 8 = 15.6 m^2

The roof area of the Power House is sufficient (530 m^2) for solar panels.

4.2.3 SLD Design in On-Grid Solar Power

Research combining renewable energy and backup batteries in On-Grid Solar Power systems. The goal is uninterrupted electricity, allocation to PLN when there is a surplus, and reducing energy dependence from PLN. The image above is a single line diagram design for the On-Grid Solar Power at level crossing PPI Madiun. Consists of 8 solar modules connected in parallel and series, and connected to an On-Grid Inverter. Hybrid system with backup sources from PLN and Generator to ensure loads operate without interruption. Electrical energy from On-Grid Solar Power is channeled to the Inverter, converted into AC current, and distributed to loads. Loads with DC current get energy from an external converter.

Table 7. AC load specification

Description	Factory Specifications	Installation Specifications	Amount
Solar Panels	37.9 V-46.2 V, 8.97-9.48 A	4 Parallel, 2 Series 96 V, 10 A	8
Battery	12 V, 150 Ah	8 Series 96 V, 150 Ah	6
Inverters	80-550 V, 11 A	96 V, 11 Ah	1
Cable	2x4mm, 100 meters	2x4mm, 100 meters	100
MCB Ac	20 Amperes	20 Amperes	4
MCB DC	15 Amperes	15 Amperes	3
ATS	230 Vac, 125 A	231 Vac, 125 A	1
Converter	230 Vac, 24 Vdc, 20 A	231 Vac, 24 Vdc, 20 A	1
Ground	6mm	6mm	5

4.2.4 Laying design for *On-Grid PLTS*

The On-Grid Solar Power design at the PPI Madiun Power House uses a Helioscope.

Figure 3. Helioscope design

The picture above shows the design for installing 8 solar panels on the roof of the PPI Madiun Power House, installed 4 parallel and 2 in series, tilt 20^{0}, Azimuth 15^{0}. For larger power needs, 117 solar modules were installed on a roof area of 530 m2 , producing 69,206 kWh/year or 189.60 kWh/day. With the same panel module components and 2 SMA Sunny Tri power 24000 TL inverters with a total capacity of 24 kWh. The design in question is to use the maximum roof area of the Power House. Figure 3 shows the PLTS design if the roof area is used optimally.

4.3 Homer Pro On-Grid Solar Power Design Simulation

Simulation stages using HOMER for electrical energy results from On-Grid Solar Power designs:

1) Enter the coordinates of the research location.
2) Input solar energy potential data.
3) Input research location load data.
4) Solar panel data input.
5) Inverter data input.
6) Battery data input.
7) Generator and PLN data input.

Figure 4 shows the design results in the Homer software.

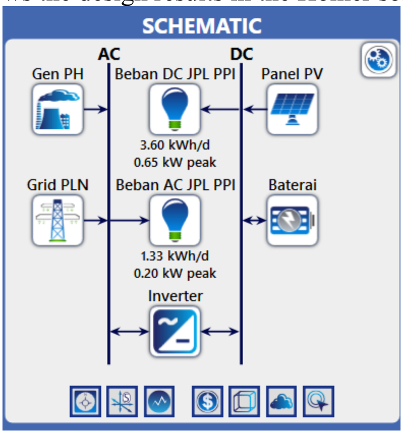

Figure 4. Designs in Homer

4.3.1 Total Production Produced

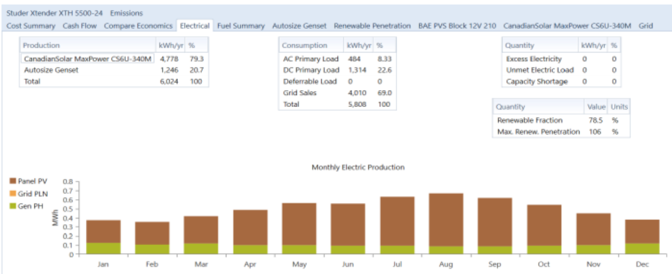

Figure 5. Total electrical energy production

Figure 5 shows that solar panel energy production is 4,778 kWh/year, AC power consumption is 484 kWh/year, and DC is 1,314 kWh/year. The potential for solar irradiation is good for PLTS.

4.3.2 Validation of Electrical Energy Production

Validation of the daily output results of On-Grid Solar Power is needed to ensure that the technical calculations are correct and able to meet the electrical energy needs of 4,776 kWh/day.

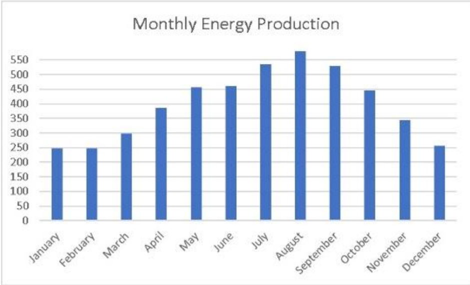

Figure 7. Energy production based on simulation

On-Grid Solar Power as an alternative power supply based on average data from the 11 year solar cycle. Highest production in August (578.84 kWh), daily average 18.67 kWh. Lowest production in February (246.16 kWh), daily average 8.79 kWh. Production results are compared with the power load requirements of level crossing PPI Madiun every month.

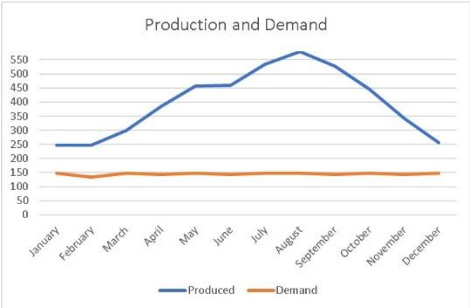

Figure 8. Simulation production and needs of level crossing PPI Madiun

On-Grid Solar Power simulation production in Homer are able to meet the total load for a month (148,056 kWh). The total accumulated production reaches 4,778 kWh/year, so the On-Grid Solar Power design is technically feasible and the remaining power can be allocated to PLN.

4.4 On-Grid Solar Power Cost Budget Draft

The estimated budget for building On-Grid Solar Power at level crossing PPI Madiun uses the Feasibility Estimate or Appraisal Estimate. Initial stage but can be used as a comparison with other cost plans. After calculating the component requirements, the Cost Budget Draft calculation is carried out based on the price from the manufacturer of each component.

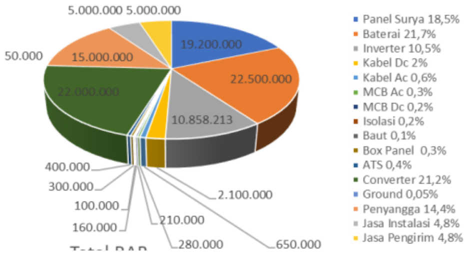

Figure 9. Draft Cost Budget for *On-Grid PLTS*

Figure 9 shows the Cost Budget Draft for the construction of On-Grid Solar Power at level crossing PPI Madiun. The highest cost is for battery components, Rp. 22,500,000 (21.7% of the total Cost Budget Draft Rp. 103,808,213). Does not include licensing fees to PLN.

5 CONCLUSION

The conclusions that can be obtained from the results of this research are:

1. On-Grid Solar Power research at level crossing PPI Madiun requires components: 8 solar panels installed 4 in parallel, 2 in series; 8 batteries in series; 1 inverter 5.5 kWh; 100m LEONI 4mm cable; 50m AWG cable; 1 ATS 230 Vac with 2 sources; AC to DC converter 230 Vac to 24 Vdc; panel installation area 15.6 m². On-Grid Solar Power produces 4,778 kWh of electrical energy per year according to the required load
2. On-Grid Solar Power design simulation using Homer Pro shows the success of the design. The calculation validation results show that the On-Grid Solar Power system is able to meet load requirements for one day without a shortage of electrical energy, even producing excess energy of 4,776 kWh. The planned budget for implementation is IDR 103,808,213 to meet the total electrical energy needs at level crossing PPI Madiun. This design is proven to be feasible and efficient in utilizing solar power as a sustainable and environmentally friendly source of electrical energy.

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