Solar power plant utilization on mass rapid transit based public transportation company

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Abstract. Nowadays, the growth of population and business activities in a city is creating a new problem, which is the movement of the people itself. Mass Rapid Transit (MRT), which included in public transportation with a dedicated lane continues to prove that this kind of public transportation is effective and efficient to solve that problem by reducing congestion and creating a greener environment. However, MRT requires electrical power in a relatively big number. To meet this requirement and support a greener environment, a study is conducted. The method of this study is to simulate on how much potentially a solar power plant can be built on Jakarta MRT facility and conduct an analysis on engineering, economic, regulation, and strategic of the Company itself. The result is a 451.2 kWp Solar Power Plant could be built on the Workshop Building on Jakarta MRT, has NPV of US$ 44,706.70, and payback period in 12.82 years if the implementation in year 2022. The Cost of Capacity Charge could be avoided by giving the Power Utility Company of Indonesia a Business to Business (B2B) scheme.

1. Introduction  
The growth of population and business activities are causing congestion in the city. Jakarta, Indonesia is included in a city who has big growth of population and leads to causing congestion in the city. One active solution to solve the congestion problem is to make a public transportation with a dedicated lane. Numerous studies have shown that the using of public transportation is reducing congestion in the road. Mass Rapid Transit, which included in public transportation with a dedicated lane continues to prove that this kind of public transportation is effective and efficient in so many ways. However, mass rapid transit requires electrical power in a relatively big number. To meet this requirement and support a greener environment, the research of solar power plant utilization on mass rapid transit-based public transportation is needed. PV solar power is a safe, reliable, without noise and pollution, less constrained, and convenient maintenance choices [1]. Also, the Green House Gases (GHG) as a result of the dependency on fossil fuel for generating electricity continue to increase [2],[3],[4].  

The main object of this study is to discuss the utilization of solar power plants that are seen in many aspects. Those aspects are engineering, economic or financial views, political and regulation, and also planning and strategic of The Company itself. Accordingly, Railway Company has a lot of potential for implementation of photovoltaic power generation around railway premises [5],[6],[7]. Also, a railway transportation is considered to be eco-friendly transportation systems among others [8],[9],[10].  

Currently, Jakarta MRT has 1 Depot Area in Lebak Bulus, 7 elevated stations, and 6 underground stations from Lebak Bulus to Bundaran HI (Hotel Indonesia). Jakarta MRT has a very high power cost
proportionally to its operating cost. The Jakarta MRT already begin it conserving energy strategy by adjusting headway and using regenerative braking. The percentage of energy saving is increases with operative coasting and shorter headway [11]. Also, by enabling reuse of the regenerative energy, the energy saving can be achieved by adjusting the headway to ensure the better use of regenerative braking energy, otherwise it would be lost through heat dissipation [12].

2. Methodology

This study used a software to predict and simulate on how much solar power plant can generate power on installed place. In Lebak Bulus Depot area of Jakarta MRT, the Depot has a Workshop Building who has over 10.032 m². The flow diagram of this study could be seen down below.

![Methodology flow diagram](image1.png)

Figure 1. Methodology flow diagram.

![Workshop Building of Jakarta MRT, Lebak Bulus](image2.png)

Figure 2. Workshop Building of Jakarta MRT, Lebak Bulus.

This study used Workshop Building of Jakarta MRT at Lebak Bulus, Jakarta, Indonesia as the main object to simulate the installation of solar power plant. The top view of this building could be shown on the above photograph. The roof has the live load of 0.5 kN/m², which means that this roof can take approximately 51.02 kg/m²[13]. Beside this building, Jakarta MRT has 7 elevated stations across his north-south line. But, the roof could not take much load as the design of the roof is not for any additional load on that roof.

The simulation use PV*SOL Premium 7.5 Software. PV*SOL premium is a software for dynamic simulation program with 3D visualization and detailed shading analysis of photovoltaic systems. This software support 3D design visualization of object building and shading on those object, rotate area within the objects, animated sun-path, and detailed analysis of shading area even for each module individually. The user of the software can also select number of used areas, PV-Module, inverters, PV Generator Output, Orientation, Azimuth, Inclination, and Installation type.
The specification of the photovoltaics (PV) module and the inverter used in this study could be seen on the table below.

**Table 1. The Specification of PV Module.**

| Company      | SunPower |
|--------------|----------|
| Type         | SRP-E20-320 |
| Power Rating | 320 W    |
| Max. Power Voltage (Vmp) | 54.7 V |
| Max. Power Current (Imp) | 5.86 A |
| Efficiency   | 19.6 %   |
| Cell type    | Si Monocrystalline |
| Max. System Voltage | 1,000 V |
| Dimension    | (1,599x1,046x46) mm |
| Weight       | 18 kg    |
| Output Coefficient | -0.38%/°C |

**Table 2. The Specification of Inverter.**

| Company        | Helios Systems |
|----------------|----------------|
| Model          | HS200          |
| Max. DC Power  | 230 kW         |
| Max. AC Power  | 220 kW         |
| AC Power Rating | 200 kW        |
| Max. Input Current | 500 A    |
| Max. Input Voltage | 900 V  |

For determining the economic value, this study uses Present Worth (PW) method by calculating the expenditure and income. The expenditure would be Investment cost and annual O&M (Operation and Maintenance) Cost. The income would be electricity produced by installed PV annually minus Cost of Capacity Charge due to a regulation by Ministry of Energy and Mineral Resources (ESDM) Indonesia number 16 year 2019.

\[
\text{Present Worth (PW)} = -\text{Investment} - \text{O&M Cost} \left(\frac{P/A}{i\%,n}\right) + \text{Income} \left(\frac{P/A}{i\%,n}\right) \\
\text{Annual O&M Cost} = \text{PV Power (kW)} \times \text{O&M Cost} \\
\text{Cost of Capacity Charge} = \text{PV Power (kW)} \times 5 \text{ hours} \times \text{Energy Price ($/kWh)} \\
\text{Income/Year} = \left(\frac{\text{Daily Energy Used (kWh)}}{365 \text{ days}}\right) \times \text{Energy Price ($/kWh)} - \text{Cost of Capacity Charge}
\]

3. **Result and Discussion**

3.1. **Simulation Result**

*Figure 3. 451.2 kWp of Solar Power Plant Simulation Result.*
The simulation shown that 451.2 kWp of Solar Power Plant could be installed in Workshop roof area on Jakarta MRT. The arrangement of PV Module could be seen in Figure 3. The total of 1,410 PV modules is used with an arrangement of 713 PV Modules on North Side and 697 PV Modules on South Side. For the north side, the arrangement is 8 array with 5 modules in serial and 19 modules in parallel and 1 array with 3 modules in serial and 16 modules in parallel. For the south side, the arrangement is 8 array with 5 modules in serial and 19 modules in parallel and 1 array with 2 modules in serial and 16 modules in parallel. This differences on north side and south side arrangement is needed because of ease of maintenance (cleaning and other activities) and distribute the load within the roof.

| Subject                      | Result                              |
|------------------------------|-------------------------------------|
| Inclination                  | 7°                                  |
| PV Generator Surface         | 2,299.3 m²                          |
| Type of System               | On Grid with Power Utility Company of Indonesia |
| PV Generator Output          | 592,055 kWh/year                    |
| Global Irradiance            | 1,657.6 kWh/m²                      |
| Performance Ratio            | 79.9 %                              |
| Cable Loss                   | 3.00 %                              |
| CO₂ Emissions Avoided        | 355,139 kg/year                     |

### 3.2. Regulation Analysis

As regulation by Ministry of Energy and Mineral Resources (ESDM) Indonesia number 16 year 2019, any solar power plant installed by any consumer of Power Utility Company of Indonesia that include in Industry type of consumer, Consumer has to pay cost of capacity charge [14]. The energy price for Jakarta MRT is Rp 1,051.74/kWh or equal to US$ 0.07. For this study, we use US Dollar to Indonesian Rupiah currency of US$ 1 equal to Rp 14,500.00. The cost of capacity charge of the simulation result is:

\[
\text{Cost of Capacity Charge} = 451.2 \text{ kW} \times 5 \text{ h} \times \text{US$ 0.07} = \text{US$ 163.64/month or equal to US$ 1,963.64/year}
\]

### 3.3. Financial Analysis

| No  | Component   | Capacity Parameter | Total (US$) |
|-----|-------------|--------------------|-------------|
| 1   | PV Module   | US$ 0.46/wp        | 207,920     |
| 2   | Inverter    | US$ 0.08/wp        | 36,160      |
| 3   | Cabling     | US$ 0.03/wp        | 13,560      |
| 4   | Installation| US$ 0.30/wp        | 135,600     |
| 5   | Contingency | 5% of 1-4          | 19,662      |
| 6   | Tax         | 10% of 1-4         | 39,324      |
|     | Total       |                    | 452,226     |

For operational and maintenance cost, based on a study conducted by Andy Walker from National Renewable Energy Laboratory (NREL) [15], the annualized unit O&M costs will be US$ 12.65/kW/year. Therefore, for this project, the O&M cost would be:

\[
\text{O&M Cost} = 451.2 \text{ kWp} \times \text{US$ 12.65/kW/year} = \text{US$ 5,707.68/year}
\]
Currently the loading of Workshop building is around 160 kW or from 9 AM to 3 PM equal to 1,130 kWh [13]. Therefore, income in 2021 would be:
Income in 2021  = (1,130 kWh x 365 days x US$ 0.07) – (US$ 1,963.64) = US$ 26,907.86

In 2022, The Maintenance team of Jakarta MRT will begin to starts overhaul activity of the rolling stock, therefore the load will increase significantly. According to the design of the workshop itself [13], the base load of Workshop building is 1,330 kVA with pF of 0.95, thus the continuous load is 1.263.5 kW. As a result of that, the installed solar power plant will generate it peak loading with 451.2 kWp or 440 kW AC power. Based on the result of the simulation, total production of the solar power plant is 592,055 kWh/year. Therefore, income/year starts from 2022 would be:
Income/year starts from 2022 = (592,055 kWh x US$ 0.07) – (US$ 1,963.64) = US$ 39,480.21

Another assumption that used on this study are interest rate is 5% per year and lifetime of The project is 25 years.

**Implementation in 2021**

With the lifetime of the project is 25 years, the income of the first year is US$ 26,907.86 and the next 24 years would be US$ 39,480.21. The calculation of Present Worth (PW) would be:
PW = -US$ 452,226 – US$ 5,707.68(P/A,25,5%) + US$ 26,907.86 + US$ 39,480.21(P/F.1.5%)(P/A,24,5%)
PW = US$ 33,653.62

**Implementation in 2022**
PW = -US$ 452,226 – US$ 5,707.68(P/A,25,5%) + US$ 39,480.21(P/A,25,5%)
PW = US$ 44,706.70

Based on those 2 calculation, the biggest Present Worth (PW) or Net Present Value (NPV) of the project is implementation in 2022. This is due to the fact that until the end of 2021, the workshop building has no additional loading because of the major overhaul activity will begin in early 2022. The payback period of this project is shown below.

\[
\text{Payback period} = \frac{\text{US$ 452,226}}{\text{US$ 39,480.21} - \text{US$ 5,707.68}} = 12.82 \text{ years}
\]

### 3.4. Strategic Planning

**Implementation Planning**

The most profitable choice is to implement this study in 2022. The project has the biggest NPV and acceptable payback period of 12.82 years. Jakarta MRT has to wait for most activity in Workshop area will begin in early 2022, so that this project will give most benefit to the company itself.

**Political Negotiations**

The cost of capacity charge could be avoided by giving The Power Utility Company of Indonesia a Business to Business (B2B) scheme. The B2B scheme can be by a form of some agreement between Jakarta MRT and Power Utility Company of Indonesia where Jakarta MRT has to share the information of new line and new Transport Oriented Development (TOD) area. This is a precious information for Power Utility Company of Indonesia, as Power Utility Company of Indonesia could invest more on TOD area. Another alternative scheme is Jakarta MRT gives Power Utility Company of Indonesia some space on the station in new line, so that Power Utility Company of Indonesia could build medium scale of substations for the need of TOD area across the Jakarta MRT line.

### 4. Conclusions

Based on the result of this study, the 451.2 kWp Solar Power Plant could be installed in Workshop Building in Depot Area of Jakarta MRT in Lebak Bulus, Jakarta, Indonesia. Due to a regulation by Ministry of Energy and Mineral Resources (ESDM) Indonesia number 16 year 2019, Jakarta MRT has to pay the Cost of Capacity Charge of US$ 1,963.64 / year annually. Yet, the most profitable choice
for Jakarta MRT is to implement this study in 2022 with The NPV of the project is US$ 44,706.70 and has payback period of 12.82 years. The Cost of Capacity Charge could be avoided by giving a B2B scheme between Jakarta MRT and Power Utility Company of Indonesia.

References
[1] Liu J, Wang J, Tan Z, Meng Y and Xu X 2011 The analysis and application of solar energy PV power International Conference on Advanced Power System Automation and Protection Beijing pp 1696-1700 doi: 10.1109/APAP.2011.6180758
[2] Alam S S, Omar N A, Suhaim M, Siddiquei and Nor S M 2013 Renewable Energy in Malaysia: Strategies and Development Environment Management and Sustainable Development 2 51
[3] Ishii Y et al. 2019 A Study of Introduction of the Photovoltaic Generation System to Conventional Railway 8th International Conference on Renewable Energy Research and Applications (ICRERA) Brasov Romania pp 1003-1007 doi: 10.1109/ICRERA47325.2019.8996789.
[4] Cheng Q 2018 Energy Management System of a Smart Railway Station Considering Stochastic Behaviour of ESS and PV Generation International Symposium on Computer, Consumer and Industrial System (ISIC) Taichung, Taiwan pp 457-460 doi: 10.1109/IS3C.2018.00121
[5] Hayashiya H et al. 2012 Potentials, peculiarities and prospects of solar power generation on the railway premises International Conference on Renewable Energy Research and Applications (ICRERA) Nagasaki pp 1-6 doi: 10.1109/ICRERA.2012.6477458
[6] Hayashiya H, Furukawa T, Yoshizumi H, Kondo T, Kitano M, Aoki T, and Suzuki T 2011 Necessity and Possibility of smart grid technology application on railway power supply system 14th European Conference on Power Electronics and Applications (EPE2011) No.0353
[7] Hayashiya H, Watanabe Y, Fukasawa Y, Miyagawa T, Egami A, Iwagami T, Kikuchi S, Yoshizumi H 2012 Cost impacts of high efficiency power supply technologies in railway power supply -traction and station 15th International Power Electronics and Motion Control Conference (EPE-PEMC2012) No.251
[8] Hayashiya H et al. 2013 Possibility of energy saving by introducing energy conversion and energy storage technologies in traction power supply system 15th European Conference on Power Electronics and Applications (EPE) Lille pp 1-8 doi: 10.1109/EPE.2013.6631780
[9] Jan C, Stijn V, Thomas VM 2011 An all-in-one power electronic solution for introduction of PV and storage for smart grids 14th European Conference on Power Electronics and Applications (EPE2011) No.0601
[10] Suzuki T, Hayashiya H, Yamanoi T and Kawahara K 2014 Application examples of energy saving measures in Japanese DC feeding system International Power Electronics Conference (IPEC-Hiroshima 2014 - ECCE ASIA) Hiroshima pp 1062-1067 doi: 10.1109/IPEC.2014.6869718
[11] Thong M, Ho M, and Siow PS 2005 Energy Conservation Measures for Rapid Transit Systems in Singapore IPEC International Power Engineering Conference pp 1-581 Singapore
[12] Mellitt B, Mouneimne ZS, and Goodman CJ 1984 Simulation Study of DC Transit Systems with Inverting Substations IEE Proceedings B, Electric Power Applications pp 38-50
[13] Jakarta MRT Project Documents
[14] Regulation of Ministry of Energy and Mineral Resources (ESDM) Indonesia number 16 year 2019.
[15] Walker A 2017 PV O&M Cost Model and Cost Reduction. Lakewood, California https://www.nrel.gov/docs/fy17osti/68023.pdf

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