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# Techno-Economic Analysis of Tracker Based Rooftop PV System Installation Under Tropical Climate

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**ABSTRACT**
This paper presents a techno-economic analysis of the tracker-based PV system that is connected to the grid on building rooftop. The Engineering Faculty electrical system is used as a case study of the feasibility analysis of the PV system installation. The simulation and analysis is conducted using Homer Pro software under tropical climate solar resource data. The electricity tariff was used IDR 1114.47 per kWh; discount rate assumed 8%, average inflation rate 2.9 %, and solar panel life expectancy 25 years. The technical results found that the tracker-based PV can increase electrical energy production from solar sources, as well as increasing the fraction of renewable energy and reducing $CO_2$ emissions compared to flat PV. The results of the cash flow rate for both PV system indicate that a positive NPV can be achieved, and the payback time is less than the expectations of the solar panel's lifespan. However, by using a tracker-based PV system, the investment cost will be increased for the panel structure and tracker controller, the payback period being longer and higher NPC. Therefore, technically using a solar tracker is better, economically, the fixed installation more profitable.

**Key words:** Techno-economic analysis, Tracker-based PV system, and Tropical climate.

## 1. INTRODUCTION

Sunlight is a source of energy which have very beneficial for life. Sunlight energy at this time has been used as an alternative energy source to produce renewable electricity with minimal pollution, so it does not harm the environment. Geographically, Indonesia is in a tropical climate, which means that geographically, Indonesia's territory lies in the equator from 6° North Latitude to 11° South Latitude and from 95° to 141° East Longitude. Indonesia has abundant renewable energy sources in the form of sunlight. The territory of Indonesia receives thermal radiation up to 4.8 $kWh/m^2$ day [1], but 96% of energy use comes from non-renewable energy sources [2].
The utilization of this energy source is obtained by using a type of photovoltaic power generation. Electrical power injection from photovoltaics into the distribution network can reduce the daily load where the previous power supply depends on the grid [3]. However, the performance of solar panels is dependent on the location area which they installed [4]. Generally, solar panels in tropical areas are installed with fixed mounting structures. This structure will cause the performance of solar panels to be decreased because the amount of electrical power conversion produced is affected by the sunlight it receives [5]. To improve the solar energy conversion, a solar position tracker mechanism and solar panel controller to operate at the MPP point are needed [6][7]. The MPP point is the operating point where it produces maximum power according to the intensity of solar radiation. The most commonly used tracking method is an active tracker (electrical) because it is easy to set the drive like using a DC motor [8]. The previous studies in the development of solar tracker both one axis and two axes require a large power supply for the movers [9]. This structure makes tracking techniques such as impractical and reduces efficiency when used. However, the mechanical construction with appropriate damping springs is needed to reduce the load and oscillation of solar panels. The combination with passive tracker has increased the efficiency of solar panel output power, reduced oscillation, and mechanical resistance, however, the economic feasibility needs to be further analyzed.
A large amount of electricity used has an impact on the electricity bills to be paid by Andalas University each month [10]. The high monthly electricity usage has burdened the campus management. Therefore efficiency efforts and saving electricity usage are needed, and related parties must think of solutions to cut the monthly budget for electricity in the long term. One solution is a renewable energy-based power generation system integration. However, with the price of solar modules that are still very expensive, people assume that it requires significant initial investment capital to build a rooftop solar power system [11]. Therefore, the Andalas University electrical power system is used for a techno-economic feasibility case study.

## 2. TRACKER BASED PV SYSTEM IN TROPICAL CLIMATE

### 2.1 Sun Radiation and Temperature

The sun radiation at the Engineering Faculty of Andalas University obtained from Homer Pro after input location coordinate is as shown in Figure 1. The data was downloaded on July 19, 2020, from NASA's surface meteorology and solar energy database. From the graphic images, it can be seen that solar radiation at case study locations has values above 4 kWh/m²/d, with a brightness level of around 3 kWh/m²/d. The annual average radiation is 4.91 kWh/m2/day.

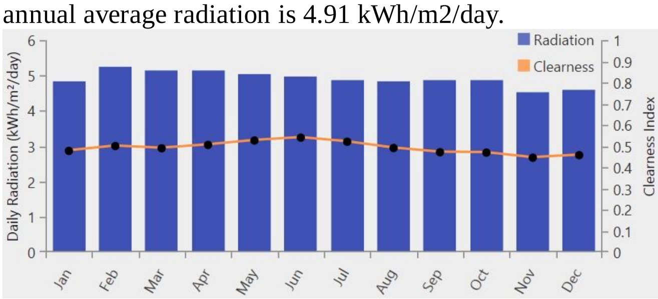


**Figure 1**: Solar radiation at Universitas Andalas

The ambient Temperature at Universitas Andalas is shown in Figure 2:


**Figure 2**: Ambient temperature at Universitas Andalas

The solar radiation data and environmental temperature can represent weather condition data in tropical climates, so it is expected that the results of the feasibility analysis can represent the installation of PV systems for other tropical areas.

### 2.2 Solar Tracker

Solar panels are usually installed in a fixed orientation. However, they can be made to track the sun to maximize the incident of solar radiation. PV tracking systems are classified based on the number of axes of rotation and frequency of adjustment. HOMER can consider the following tracking systems:

1. Fixed Tracking: The panel is mounted on a fixed tilt and azimuth. This structure is the simplest and most common case.
2. Single-axis, with adjustment for rotation, is around the horizontal east-west axis. The slope can be adjusted on the first day of every month, weekly or daily, so that the sun's rays are perpendicular to the surface during the day.
3. Two Axes: Panels are rotated around horizontal and vertical axes so that sunlight is always perpendicular to the surface. This type of tracking system maximizes PV panel power production, but this is the most expensive.

The semi-active tracker based developed in ref [7] can use a single-axis Homer PV tracking model with an extra charge for damping spring. The semi-active single-axis considered in this study is, as shown in Figure 3. For every unit, tracker consists of 16 solar panels, two DC actuators and eight pairs of suspension, one Arduino based controller, and a 100Ah Battery for tracker power supply. The semi-active solar panel frame structure is shown in Figure 4, located on the central axis of the solar panel.

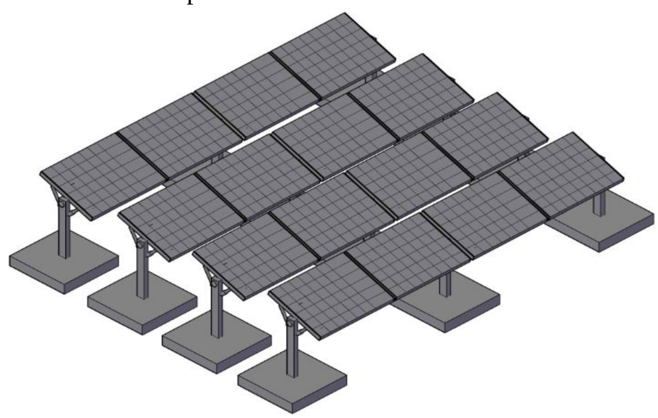

**Figure 3**: Semi-Active Tracker design for 16 panels/units Tracker

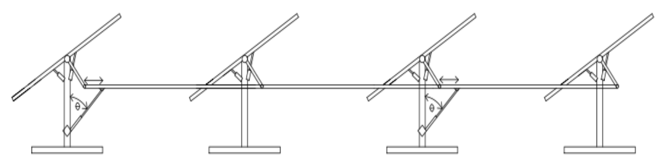

**Figure 4**: Semi-Active solar panel frame structure

## 3. HOMER PRO TECHO-ECONOMIC ANALYSIS

The techno-economic analysis to achieve optimal system design is necessary. The technical and economic studies of the tracker-based PV systems installation are located in the building of Engineering Faculty, Universitas Andalas. The buildings are consisting of the Dean Building and All Department Buildings (Mechanical Engineering, Electrical Engineering, Civil Engineering, Industrial Engineering, and Environmental Engineering), where the solar module will be placed on the roof position Building. This system is known as the rooftop PV system, which is more optimal in capturing solar radiation [12], and the loss due to the shading effect (shadow effect) from other buildings is minimized.

The characteristics of the daily peak load of each building in the Faculty of Engineering were used in as system load profile. The initial investment cost needed (total investment), cost of energy (CoE), net present value (NPV), the payback period will be analyzed for economic parameters to determine whether the application of PV rooftop is feasible or not. Thus, the academic community can see the value of benefits in implementing the system and becomes consideration whether this research is viable to be developed or not.

Homer Pro defines that cost of energy (COE) as the average cost per kWh of electrical energy produced by the system study. To calculate the COE, Homer divides the total annualized cost minus the cost of serving the thermal load by the whole electric load served. The annual cost of a component is that which, if occurring equally in each year during the periode of the project, would provide the same net present cost as the sequence of actual cash flows associated with that component. Homer computes annual costs by first calculating net present costs, then multiplying by the capital recovery factor.

The electricity tariffs charged to consumers have been regulated by the Ministry of Energy and Mineral Resources. The determination of electricity tariffs varies for each tariff group. According to Minister of Energy and Mineral Resources Regulation No. 31 of 2014 and No. 9, In 2015, there were 12 classes whose electricity tariffs were adjusted accordingly. The tariff adjustment, which is usually announced once every three months, is now announced every month. This rate adjustment was made after going through a study based on the US dollar exchange rate against the rupiah, the price of crude oil or Indonesian Crude Price (ICP), and inflation. The official 2020 electricity tariff from the Ministry of Energy and Mineral Resources for the P2/TR is IDR 1114.47/kWh [13].


**Figure 5**: Inflation rate [14]

Based on the regulation of the Minister of Energy and Mineral Resources No. 49 of 2018 concerning the use of solar rooftop power generation systems by consumers of nasional grid will be purchased the excess PV power. The majority of electricity produced by PV rooftop is used alone, for excess power can be exported to nasional electricity company (Perusahaan Listrik Negara - PLN) at a purchase price multiplied by a multiplier of 65%. Therefore, a system grid that sells back price is used 65% of IDR 1114.47/kWh is equal to IDR 742.58/kWh. The inflation rate values are considered with the latest inflation release value, as shown in Figure 5, on average 1.98%, this value is under the Central Bank target set 2-4% [14].

The price per 1 kWp of solar panels is now on a downward trend, so IDR 10 million per 1 kWp was chosen in this study. For a PV system with semi-active Tracker Figure 3, per 4 kWp requires 2 DC actuator units, one Arduino controller unit, and eight suspension units. Additional charge per 4 kWp of solar panel requires an additional fee of IDR 4800000 or IDR 1200000 per 1 kWp of solar panel capacity.

## 4. RESULT AND DISCUSSION

The schematic diagram of a PV system integrated with the PLN grid in the Homer Pro V3.13 application to serve the load demand 1657.35 kWh/day is shown in Figure 6.

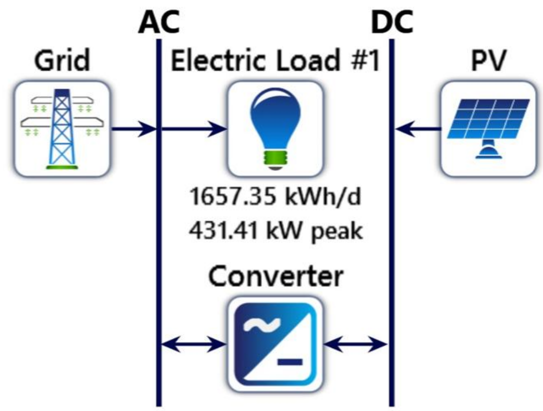


**Figure 6**: Schematic diagram of the system

Homer's simulation results show that the most optimal configuration will be the main choice, because the optimal results will be able to serve household scale electricity demand continuously. HOMER will display results based on the lowest NPC value to the highest NPC value. The simulations designed to use in this study consist of two categories, namely the PV system which is fixed and the solar system that moves in the direction of the sun or PV tracker system. The following is a summary of the simulation results from the first category without a tracker system. Electrical energy purchased from PLN and produced by PV panels per month can be seen in Table 1. The amount of energy produced by PV systems will reduce the amount of energy consumed from the PLN grid as a cost savings.

**Table 1:** Test results for current and voltage readings

| Month | Energy Purchased (kWh) | Energy Sold (kWh) | Net Energy Purchased (kWh) |
|---|---|---|---|
| January | 40,450 | 4,317 | 36,133 |
| February | 34,212 | 3,645 | 30,567 |
| March | 45,075 | 2,592 | 42,484 |
| April | 39,574 | 3,534 | 36,040 |
| May | 39,419 | 3,664 | 35,755 |
| June | 41,608 | 3,112 | 38,495 |
| July | 38,804 | 3,458 | 35,346 |
| August | 44,139 | 3,318 | 40,821 |
| September | 40,845 | 2,913 | 37,932 |
| October | 38,865 | 3,303 | 35,562 |
| November | 39,422 | 3,174 | 36,248 |
| December | 42,689 | 3,007 | 39,683 |
| Annual | 485,102 | 40,036 | 445,066 |

The excess electricity production occurs when the total solar PV production exceeds the amount of consumption. The excess power will be sold back to the network at a rate of 65% of the PLN rate, however, because in the system designed the PV capacity is much smaller than the power consumption, so there is no excess electrical power sold back to the network as shown in Figure 7.

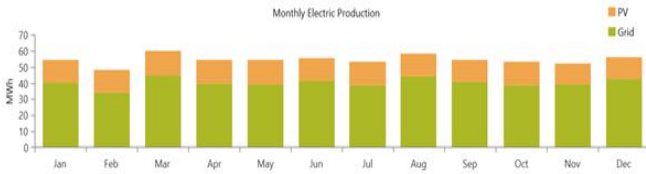


**Figure 7**: PV electricity production and grid supply

The comparison with tracker-based PV systems that for electrical summary results show in Table 2. From Table 2 found that the use of a semi-active tracker can increase the electrical energy production of the PV system from 168,280 kWh/yr to 176,147 kWh/yr. These results will be reduced energy purchased from the PLN grid by 7,867 kWh/yr. The composition of renewable energy plant usage increased to 25.9%.

**Table 2:** Electrical summary results

| Electrical design | Flat PV | Tracker PV |
|---|---|---|
| Load Consumption | 604,933 kWh/yr | 604,933 kWh/yr |
| Energy Production | 168,280 kWh/yr | 176,147 kWh/yr |
| Grid Purchases | 485,102 kWh/yr | 480,147 kWh/yr |
| Renewable fraction | 24.8 % | 25.9 % |
| Investment | IDR 1,175M | IDR 1,316M |

Economically the solar power plant installation is profitable and feasible because the COE value is smaller than the electricity tariff, the NPC is positive, and the payback period is shorter than the project observation period, as shown in Table 3. However, the addition of a solar tracker will increase investment costs for solar panel structure and controller. Based on Table 2 indicates that there is a need extra fee around IDR 141,000,000 for procuring a tracker system.

**Table 3:** Economic summary results

| Parameters | Flat PV | Tracker PV |
|---|---|---|
| NPC | IDR 9,284,704,000 | IDR 9,318,388,000 |
| COE | IDR 1,016.93 | IDR 1,016.15 |
| Operation cost | IDR 528,732,900 | IDR 521,151,800 |
| RoI | 4.1 % | 3.9 % |
| IRR | 6.4 % | 6.1 % |
| Payback | 11.07 yr | 11.41 yr |
| Disc payback | 21.18 yr | 21.91 yr |

From the environmental side, using a tracker-based PV gives better results, where there is a decrease in emission for the three environmental parameters, i.e., $CO_2$, $SO_2$, and $NO_x$, as shown in Table 4.

**Table 4:** Emission comparison of the system

| Environment Param | Flat PV | Tracker PV | Different |
|---|---|---|---|
| Carbon dioxide (kg/yr) | 306,585 | 303,453 | 3,132 |
| Sulfur dioxide (kg/yr) | 1,329 | 1,316 | 0,013 |
| Nitrogen oxides (kg/yr) | 650,000 | 643,000 | 7,000 |

Therefore, the use of a passive-active tracker can increase the electrical energy production of solar sources as well as increasing the fraction of renewable energy so that it is feasible to apply and reduce emissions. But economically, it is not practical when compared to a fixed installation system because it will increase the investment cost for the panel structure and tracker controller. This is indicated by the increasing payback period of the project.

## 5. CONCLUSION

Techno-Economic Analysis of Tracker-Based Rooftop PV System using Homer Pro Software has been presented in this paper. According to the simulation results, it is found that the use of an active tracker can increase the production of electrical energy from solar sources, thereby increasing the fraction of renewable energy and reducing $CO_2$ emissions. But economically it becomes impractical because it will increase the investment cost for the panel structure and tracker controller. This can be seen from the payback period being 11.41 years longer and higher NPC.

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