DESIGN AND SIMULATION OF ON-GRID PV SYSTEM ON A MOSQUE BUILDING USING PVSYST: CASE STUDY OF MASJID TABLIGHIYAH, INDONESIA

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ABSTRACT

Solar energy is a renewable energy source that can be used in the long term as an alternative energy source. Globally, the use of rooftop PV is currently being promoted in both public and private buildings. Mosques are suitable for rooftop PV installations because of the relatively large roof area available. On the other hand, mosques also have unique occupancy schedules and electricity load profiles. However, there has been no research conducted on designing PV utilization for mosque buildings. In this study, we design and simulate the PV performance of a mosque building, with a case study of Masjid Tablighiyah in Indonesia, using PVsyst. We compare 3 scenarios to analyze which placement will give a better performance of PV for an on-grid system: i) the main building's rooftop, ii) the mosque's walkway, and iii) the combination of both places. The simulation results include design details, array losses, near-shading losses, annual generated energy, and losses diagram. Based on the 3 scenarios that have been simulated for rooftop PV installation at the mosque, the most efficient installation is scenario 2, where the PV rooftop is installed on top of the mosque's walkway with a total performance ratio of 80.41% and annual energy generation of 50.63 MWh/year.

Keywords: solar photovoltaics, PVsyst, energy modelling, mosque, design and simulation, on-grid system.

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INTRODUCTION

The need for energy is rising quickly all over the world as a result of diverse activities. On the other hand, fossil fuel resources are depleting rapidly. To meet the increasing energy demand, it is crucial to use alternative energy sources such as solar and wind to generate electricity [1], [2]. Utilizing renewable energy sources like solar, wind, hydro, and biomass is therefore vital because they are easily accessible, non-exhaustible, and pollution-free [3]. Renewable energy sources will also diversify the energy landscape, provide consumers with affordable options, aid in securing dependable long-term power supply, and lessen the world's carbon footprint [4].

To fulfill the growing need for electricity, renewable energy sources, such as PV systems, are frequently used to produce electricity. On-grid, off-grid, and hybrid solar energy systems are the three topologies that are used to further characterize PV systems. Off-grid solar energy systems come with an energy storage system, so they can power a load even if there isn't any sunlight because of this [5], [6]. However, off-grid systems often come with a battery storage system, thus its price would become expensive and also bulky.

On-grid or grid-connected solar PV systems, on the other hand, might provide electricity throughout the day when the sun is shining. Since an on-grid system does not use battery storage, this system is less expensive, less bulky, and less dangerous [7], [8]. The hybrid system may charge the energy storage system using both the grid and solar PV installations. As a result, on-grid solar PV systems are frequently chosen because of their efficiency and simplicity. On-grid solar energy systems are connected to the grid directly. Therefore, this type of PV system only adds electricity to the grid during the day or when there is sunshine.

The usage of solar PV in electrical energy sources is growing as a result of its advantages, which include being environmentally friendly and having low maintenance costs. Due to Indonesia's vast solar potential, photovoltaic energy will, therefore, be more profitable to use in the long term as an alternative energy source than fossil fuels. [9]. However, the intermittent nature of the source, the high installation costs, and the relatively poor energy conversion performance (from 12% to 29% efficiency) are drawbacks of the solar power plant. [10].

On-grid rooftop PV system modelling and sizing calculations must be done correctly because improper sizing increases the system's overall cost. It might be challenging to select the best PV panel and inverter combination that can fulfil essential specifications like the voltage, current, power rating, number of MPPT, etc., even though there are numerous kinds and categories of PV modules and inverters available on the market. Therefore, it is essential to pre-size PV panels and inverters before installation. [11].

In Indonesia, the use of rooftop PV is currently being promoted through various strategies and policy implementations [12], considering its vast potential for solar energy [13]. The Indonesian government is currently pushing the use of rooftop solar systems as an alternative energy source in both public and private buildings [14]. The Institute for Essential Services Reform (IESR) has researched the technical potential of rooftop PV in Indonesia, which includes around 66 million residential buildings. The study concluded that rooftop PV potential in Indonesia has a range of capacity between 194 GW to 655 GW across the nation, assuming an average of 33% acceptable roof space for PV [15].

Among all buildings, mosques are suggested to be suitable structures for rooftop PV installations because of the relatively large roof area available [16]. Mosques are buildings with unique occupancy schedules and special electricity load profiles. Muslims congregate in the mosque for daily prayers five times a day; weekly discourses; periodic celebrations; and other religious and social events [17]. Previous studies have shown that installing on-grid PV at a mosque is technically feasible and financially viable at the same time [16], [18]-[21].

A lot of study suggests using PVsyst software to design a PV system. Among the many PV simulation programs available, PVsyst software offers a speedy simulation procedure. The software is used to study the performance of PV systems under various operating situations [22]. Along with the economic evaluation criteria, it provides extensive meteorological and component data for the preliminary and project design of both off-grid and on-grid PV systems. PVsyst makes it possible to determine the configuration of the system and compute the amount of electricity produced. The results are based on a simulation of PV system sizing, which also relies on the placement of the PV's geographical site. Numerous simulation variables that may be shown as monthly, daily, or hourly values may be included in the results. The system design losses are addressed by the Loss Diagram. [23].

Many researchers have also used PVsyst to analyse the performance of the PV system [24]. Muralidhar and Rajasekar (2021) used PVsyst to determine the feasibility of 3 various PV systems using PVsyst software. Comparing hybrid PV systems with various PV capacities was done in the study to determine the ideal PV capacity for the greatest performance and to shorten the payback period [25]. Another study in India used PVsyst to study and simulate the performance ratio (PR), efficiency, and various losses occurring during the operation of the PV system which was installed at a campus rooftop [26]. PVsyst was also used to evaluate the feasibility of installing a PV system to supply the electric load [27].

Of all the studies that have used PVsyst to simulate and analyse PV systems, however, there is no research has been conducted on designing PV utilization for mosque buildings using PVsyst. Therefore, this paper will design and simulate the PV performance of a mosque building, with a case study in Masjid Tablighiyah located in Bukittinggi, Indonesia, using PVsyst. Several scenarios will be developed further to better understand the energy yield, performance ratio, efficiency, and various losses occurring during the operation of the PV System, especially the near-shadings losses.

METHODOLOGY

Choosing the Project

PVsyst provides 4 types of projects that can be simulated, namely grid-connected, stand-alone, pumping, and DC-Grid. In this study, Masjid Tablighiyah Bukittinggi is selected as the project site where an on-grid rooftop PV system has been planned to be installed. Masjid Tablighiyah is located at latitude 0.296681° S and longitude 100.3898442° E. Figure-1 shows the solar pathways at Masjid Tablighiyah.

Creating Site File

Creating a site file is done by selecting a location and importing meteorological data. There are 2 ways to choose a location on PVsyst: selecting a location directly from the interactive map on PVsyst or entering location coordinates. Based on this location, monthly meteorological data will be imported from Meteonorm, such as solar irradiation, temperature, wind velocity, link turbidity, and humidity. These data will be used for simulation purposes.

Designing PV System

First, it is important to choose the field type and the tilt and azimuth values. The field type is the orientation type of PV installation, either fixed, 1-axis tracking, or 2-axis tracking. Tilt is the angle of inclination of the PV horizontally, while azimuth is the angle facing the PV horizontally. In this study, the rooftop PV design at Masjid Tablighiyah has more than one PV array with different orientations, hence a fixed type is chosen with several orientations. Secondly, it is also important to choose the PV module and inverter and set the sizing to determine the rooftop PV capacity. Finally, PVsyst will calculate the feasibility of sizing based on the specifications of the PV module, inverter specifications, number of modules, number of strings, and working temperature.

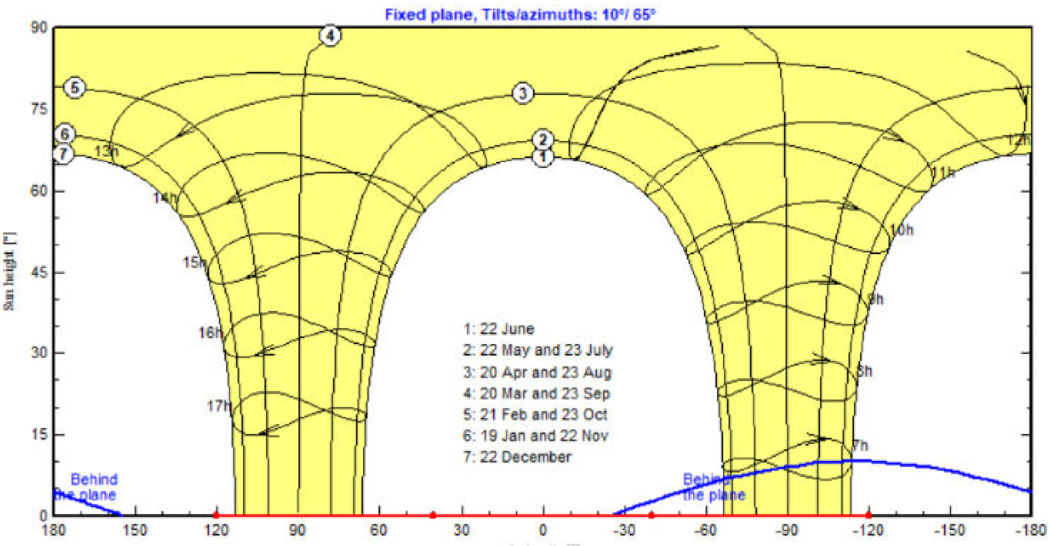

Figure-1. Solar path at Masjid Tablighiyah.

Creating Construction Shading Scene

PVsyst has a tool for near-shading analysis, which helps review the expected solar irradiance of a PV design. In this study, we recreate the Masjid Tablighiyah design on PVsyst to see the effect of solar radiation on the designed PV Rooftop. Figure-2 shows the model of the Masjid Tablighiyah building.

Figure-2. Model of Masjid Tablighiyah building in PVsyst.

Simulation

The simulation is run by taking into account the meteorological data from the selected location, orientation (tilt and azimuth), system (pv module, inverter, number), and 3D Near shading. The simulation results include a project summary, system summary, result in summary, design details, array losses, near shading, generated energy, and losses diagram. The workflow of this study is shown in Figure-3.

The sizing of PV depends basically on the irradiation potential of a specific site and the required energy. Estimated energy demand in a day is given by eq (1):

$$E_{total} = \sum n \times t \tag{1}$$

where: E_{total} is the total energy required for each device daily, n is the number of devices that has been used in a day, and t is the time for each device used in a day.

The connection between the actual energy yield and the expected energy production is known as the performance ratio of a PV system [28]. It is used to calcualte how much of the electricity output could be brought to use. Performance ratio is the factor for measuring the quality of solar PV systems [29]. Performance ratio is given by eq (2):

$$PR = \frac{Y_a}{Y_e} \tag{2}$$

where: PR is the performance ratio of PV systems, Y_a is the actual energy yield, and Y_e is the expected energy yield of the PV system.

The ratio of the actual electricity generated by PV to the nominal DC power could be used to measure the actual energy yield of a PV system. The ratio between in-plane solar irradiance and the irradiance under standard test conditions (STC), which is often assumed to be at 1000 W/m^2 is used to define the expected energy production of a PV system. The expected energy yield normalizes the energy produced by the system size. Y_a and Y_e are further given in eq (3) and (4):

$$Y_a = \frac{\text{Actual energy output in kWh}}{\text{Nominal DC power in kW}} \tag{3}$$

$$Y_e = \frac{\text{in-plane solar irradiance in kW/m}^2}{\text{reference solar irradiance in kW/m}^2 \text{ at STC}} \tag{4}$$

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RESULTS AND DISCUSSIONS

Scenario 1: Area around Mosque's Dome

PVsyst model construction for scenario 1 is shown in Figure-4. In this scenario, there are 2 PV orientations used: i) 10° tilt and 65° azimuth, and ii) 10° tilt and -115° azimuth. PV system in this scenario requires 120 units of CS3L-335P PV modules and 2-unit SMA Sunny Tripower 20000TL-30 inverters, making the total capacity 40 kWp. PV system in this placement consists of two arrays, each consisting of 60 modules and 1 inverter. Array #1 uses 10°/65° tilt/azimuth with a module arrangement of 3 strings x 20 modules (series) connected to a 20 kW inverter. Array #2 uses a tilt/azimuth of 10°/-115° with a module arrangement of 3 strings x 20 modules (series) connected to a 20 kW inverter.

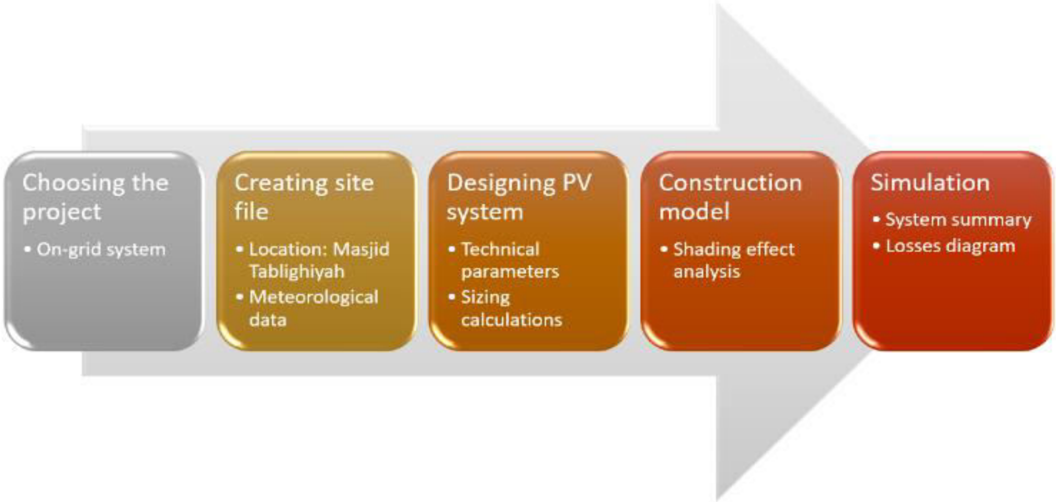

Figure-3. Study workflow.

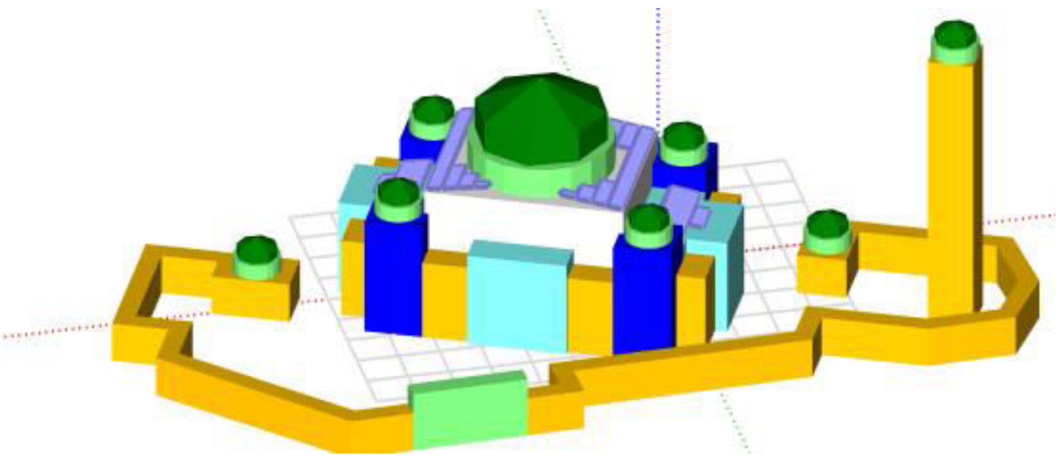

Figure-4. Rooftop PV placement in scenario 1.

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The energy generated from scenario 1 is 45.18 MWh/year or 1,124 kWh/kWp/year, with a performance ratio of 71.87%. The energy produced by this scenario in the monthly average is shown in Figure-5.

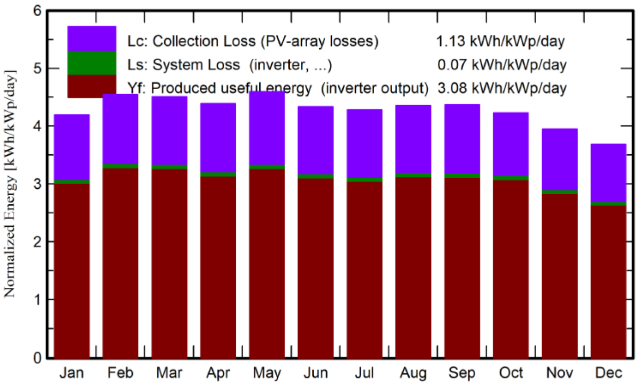

Figure-5. Energy produced in scenario 1.

The loss diagram is shown in Figure-6. It can be seen that the most significant losses are caused by the shading effect of the mosque's large dome in the centre area, which causes losses of 15.51%. Other significant losses were due to the temperature, at 8.13%. The final energy generated from this scenario is 45.18 MWh from the inverter output, which will be injected into the grid annually.

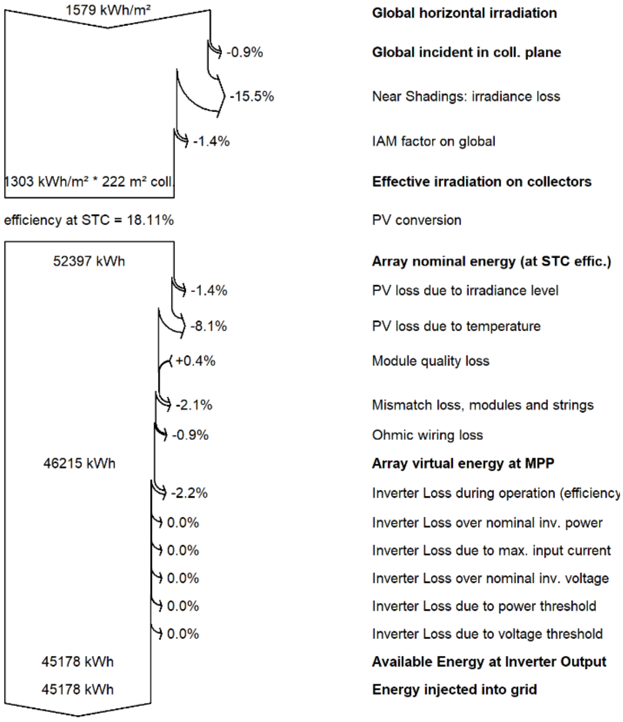

Figure-6. PV Loss diagram in scenario 1.

Scenario 2: Area on Top of Mosque's Walkway

Scenario 2 placement is shown in Figure-7. In this scenario, there are four PV installation orientations used: i) 10° tilt and -115° azimuth, ii) 10° tilt and -46° azimuth, iii) 10° tilt and 2° azimuth, and iv) 10° tilt and -25° azimuth. 120 PV modules used were CS3L-335P model and the inverter used were SMA Sunny Tripower 25000TL-30, SMA Sunny Tripower 10000TL-30, and SMA Sunny Tripower 20000TL-30. The total capacity of the system is 40 kWp.

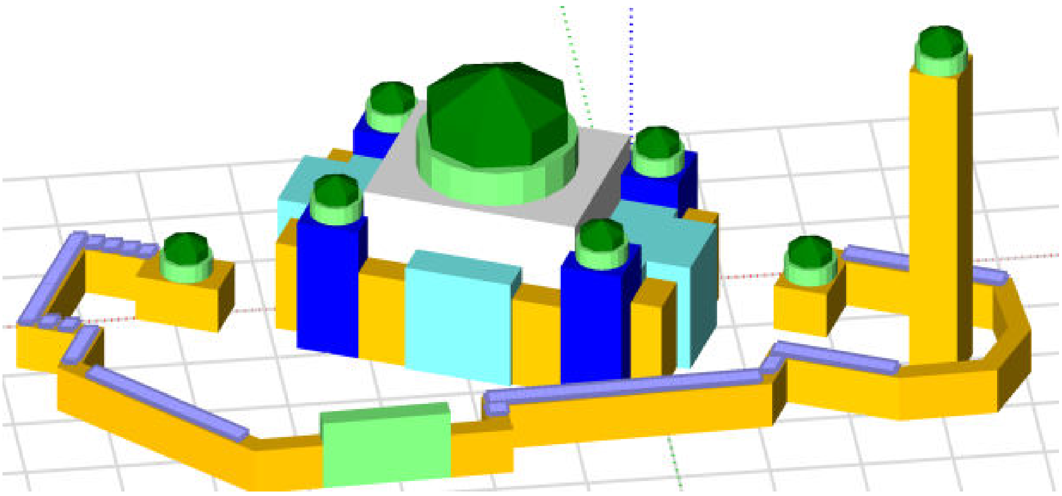

Figure-7. Rooftop PV placement in scenario 2.

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The PV system in this scenario consists of 4 arrays concerning each orientation. Array #1 uses a tilt/azimuth of 10°/-115° with a module arrangement of 2 strings x 20 modules (series) connected to a 25 kW inverter. Array #2 uses a tilt/azimuth of 10°/-46° with a module arrangement of 1 string x 20 modules (series) connected to a 10 kW inverter. Array #3 uses 10°/2° tilt/azimuth with a module arrangement of 2 strings x 15 modules (series) connected to a 20 kW inverter. Array #4 uses a tilt/azimuth of 10°/-25° with a module arrangement of 2 strings x 15 modules (series) connected to a 20 kW inverter.

The summary of energy generated in this scenario is shown in Figure-8. PVsyst simulation results showed that this scenario is expected to produce 50.63 MWh of electricity per year or 1,260 kWh/kWp/year, with a performance ratio of 80.41%.

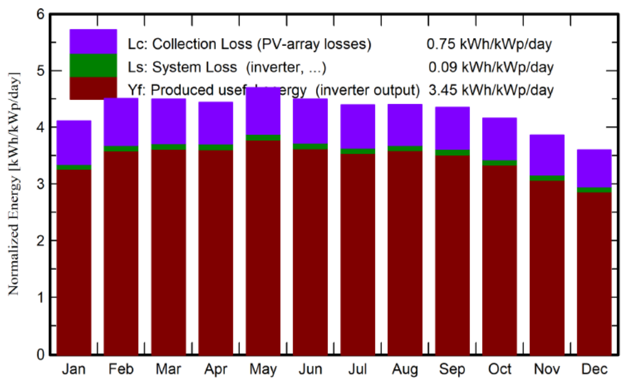

Figure-8. Energy produced in scenario 2.

The loss diagram is shown in Figure-9. It can be seen that a temperature loss of 8.34% causes the most significant loss, unlike scenario 1 where shading loss was the highest. In scenario 2, losses due to the shading effect only contribute to 4.61% of total energy produced. The final energy produced from this scenario is 50.6 MWh from the inverter output, which is much better on annual electricity production than scenario 1 despite having the same installed capacity.

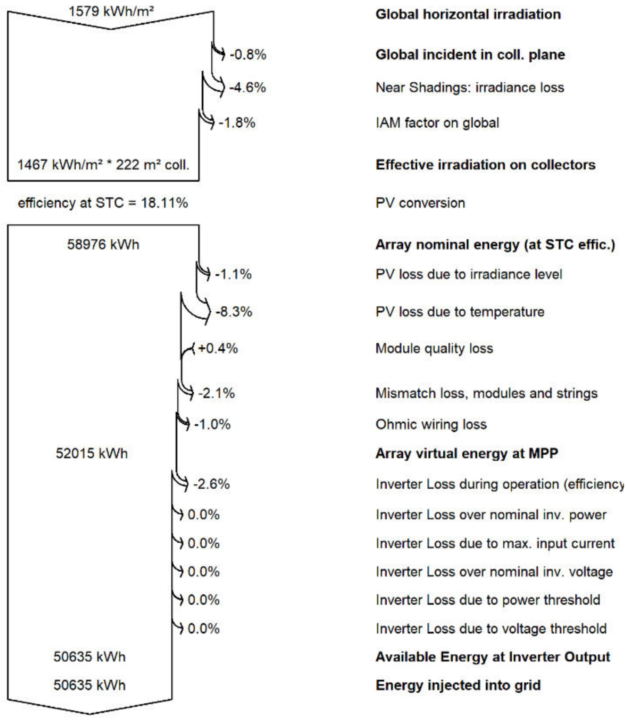

Figure-9. PV loss diagram in scenario 2.

Scenario 3: Combination of Area around the Mosque's Dome and on Top of the Mosque's Walkway

Scenario 3 is shown in Figure-10. In this scenario, 5 PV installation orientations are modelled: i) 10° tilt and 65° azimuth, ii) 10° tilt and -115° azimuth, iii) 10° tilt and -46° azimuth, iv) 10° tilt and 2° azimuth, and v) 10° tilt and -25° azimuth. 240 PV modules are used in this scenario (CS3L-335P) and 3 inverters are used for the system (SMA Sunny Tripower 20000TL-30, SMA Sunny Tripower 25000TL-30, and SMA Sunny Tripower 10000TL-30). The total installed capacity of the system is 80 kWp.

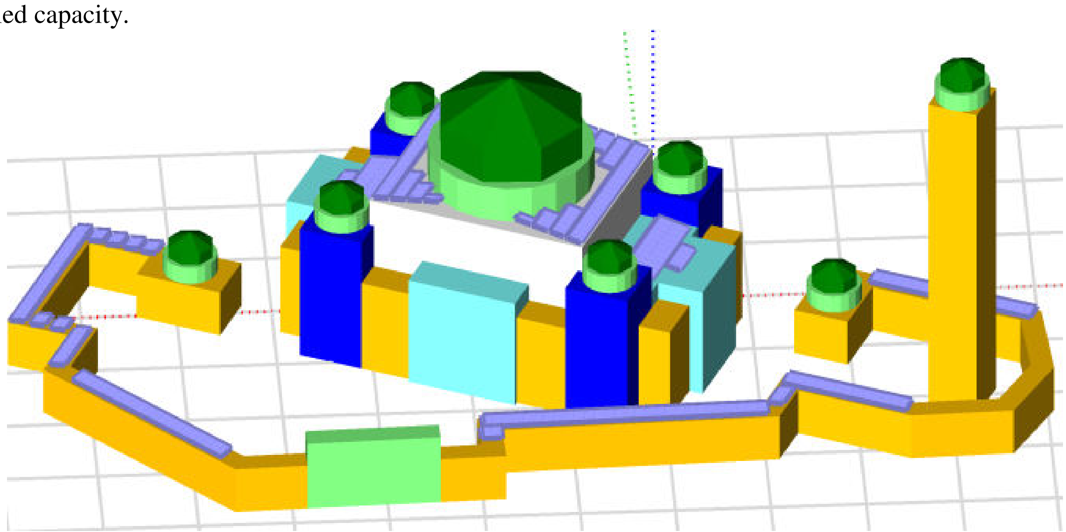

Figure-10. Rooftop PV placement in scenario 3.

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PV system in this scenario consists of 6 arrays, which is a combination of scenario 1 and scenario 2. Array #1 uses tilt/azimuth of 10°/65° with a module arrangement of 3 strings x 20 modules (series) connected to a 20 kW inverter. Array #2 uses a tilt/azimuth of 10°/-115° with a module arrangement of 3 strings x 20 modules (series) connected to a 20 kW inverter. Array #3 uses a tilt/azimuth of 10°/-115° with a module arrangement of 2 strings x 20 modules (series) connected to a 25 kW inverter. Array #4 uses a tilt/azimuth of 10°/-46° with a module arrangement of 1 string x 20 modules (series) connected to a 10 kW inverter. Array #5 uses 10°/2° tilt/azimuth with a module arrangement of 2 strings x 15 modules (series) connected to a 20 kW inverter with 50% input. Array #6 uses a tilt/azimuth of 10°/-25° with a module arrangement of 2 strings x 15 modules (series) connected to a 20 kW inverter. The energy generated from this scenario is 95.84 MWh per year or 1,192 kWh/kWp/year, with a performance ratio of 76.17%. The energy produced in this scenario on a monthly average is shown in Figure-11.

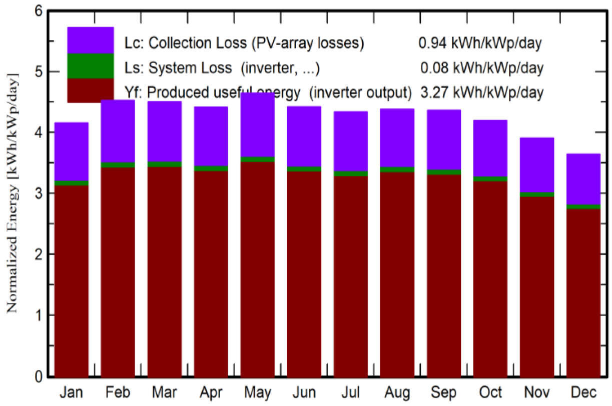

Figure-11. Energy produced in scenario 3.

The loss diagram of scenario 3 is shown in Figure-12. It can be seen that the most significant losses are caused by the shading effect of the mosque building, which resulted in a 10.06% loss. Another significant loss was due to the temperature, at 8.21%. The final energy produced from this scenario is 95.8 MWh of inverter output, which will be injected into the grid throughout the year.

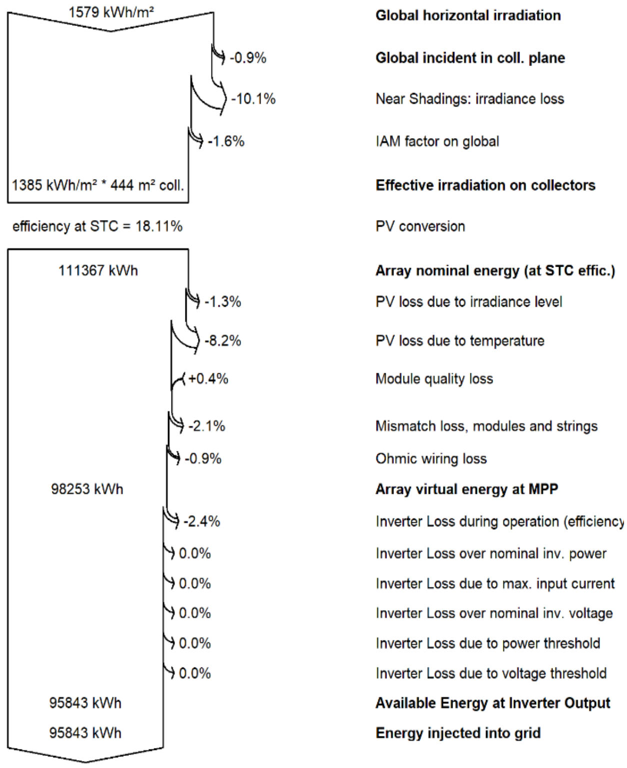

Figure-12. PV loss diagram in scenario 3.

Scenarios Comparison

Table-1 shows the main results of all three scenarios. Scenario 3 has the highest energy output to the grid due to its larger capacity compared to the other two scenarios. Regarding system losses due to near-shading, it is obvious that scenario 1 has the highest impact from the mosque's dome shading while scenario 2 has the lowest loss in percentage. For the overall performance ratio, the PVsyst simulation obtained that scenario 2 gives the best ratio with 80.4%.

Table-1. Scenarios Comparison.

KEY RESULTS	SCENARIO		
	1	**2**	**3**
PV Capacity (kW)	40	40	80
Energy Output from PV Array (MWh)	46.22	52.02	98.25
Energy Injected to Grid (MWh)	45.18	50.64	95.84
Shading Loss (%)	15.5	4.6	10.1
Performance Ratio (%)	71.9	80.4	76.2

CONCLUSIONS

Based on the 3 scenarios that have been simulated for rooftop PV installation at Masjid Tablighiyah, the most efficient installation is scenario 2, where the PV rooftop is installed on top of the mosque's walkway with a total capacity of 40 kWp. Compared to other scenarios, installing PV on top of the walkway causes relatively small losses since it has a minimum shading effect from the mosque's dome. It also has the highest performance ratio compared to other scenarios with 80.41% while other scenarios only have around 71% and 76% performance ratio. The annual energy generated from this scenario is 50.63 MWh or 1, 260 kWh/kWp/year.

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