# Paper_35_PI_INSuamir_2022

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# Potential of a Grid-Tied PV System: A Field Study in Hot and Sunny Climate Region

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## 1 Introduction

Along with policies in most countries in the world including Indonesia, to encourage the use of renewable energy, various modifications of solar power technology were applied to buildings with building integrated photovoltaic system [1, 2]. Such system can integrate energy source from renewable energy with energy from the national electricity grid. Braun and Ruther [3] have also reported their research on applying building integrated photovoltaic system for commercial buildings. Their research is very beneficial, especially in the hot climate regions.

Photovoltaic (PV) systems are prospective for rural area with low electrification. The applications of PV systems are economically more attractive due to their price tends to decline. The systems can have a substantial impact on countryside development with various applications such as for lighting and for PV home system. The PV systems were also widely applicable for productive events with power range from 130 to 250 $W_p$ (watt-peak) [4].

This paper presents a field study of a lab-scale PV system installed at educational building located in Bali Island Indonesia. The investigation was based on Bali Island weather conditions which has intensive value of solar irradiation ranging from 4.6 to 7.2 kWh $m^{-2}$. The region had high potential solar energy sources [5, 6]. The utilization of solar energy of the country was only 2.78 MW (0.03% of the total energy use and about 0.41% of the total renewable energy utilization) [7]. The share of solar PV energy source in Indonesia and also in Bali Island was nonetheless insignificant. Therefore, this paper that presents the advantages of PV systems in terms of energy efficiency and reduction of environmental impacts due to replacement of the use of fossil fuel-sourced electricity can contribute to the commitment of energy policy makers in improving the application of solar energy source in the country.

## 2 Materials and Methods

### 2.1 Description of the Grid-tied PV System

The grid-tied PV system is located at Politeknik Negeri Bali south region of the Bali Island. The schematic of the PV system is presented in Fig. 1. The PV system includes: power

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generation, power distribution, integration to the grid and a protection system. The power generation system comprises an array of 10 solar PV panels of 310 Wp each, and a grid inverter of 5 kW. The PV panels used are monocrystalline which has higher efficiency compared with the polycrystalline type. The power distribution and grid integration system is completed with some breakers and analog energy meter to record renewable energy production and also one digital power meter for monitoring energy exported to the grid. PV system also incorporates a protection system to prevent damages from both direct and indirect lightning. The protection system consists of DC and AC Surge Protective Devices (SPDs).

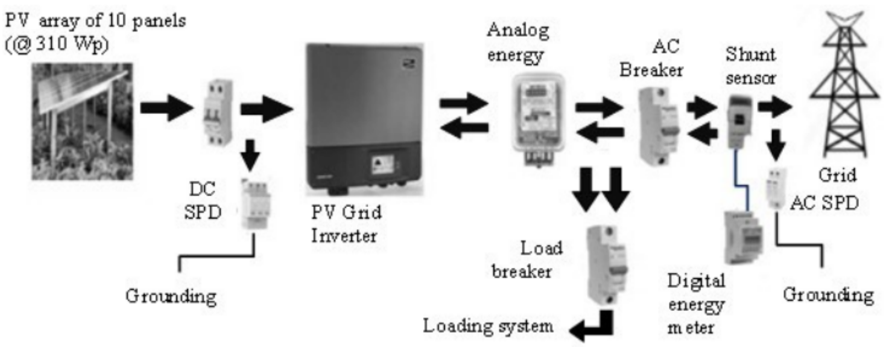


**Fig. 1** Schematic of the PV system and its integration to the grid

The PV system employs a fixed array type installation with tilt angle of 17° and azimuth direction facing north. The tilt angle applied is in the range of optimum tilt angle based on Bali solar radiation conditions. The optimum tilt angle in the region was reported ranging from 10° up to 18° with azimuth direction facing north [8]. This is also in agreement with the PV system array installed in East, Central and West Java regions. The regions are located in the west direction of Bali Island. The optimum tilt angle of PV array for azimuth direction facing north of those three regions are respectively from 0º to 40º, from 1º to 34º at optimum 18º and 10º [9].

The PV panel has a maximum power of 310 Wp at maximum voltage and current of 33 V and 9.4 A respectively. Each PV panel contains 60 PV cells. The PV cell type is monocrystalline silicon of size 0.150 m x 0.150 m each; thus PV cell area of each panel becomes 1.35 $m^2$. Based on the standard test conditions (irradiance 1000 W $m^{-2}$ at 25 °C), the PV system is specified for a maximum efficiency of 22.96%.

### 2.2 Data Gathering Method

The PV system incorporates an Internet of Things-based (IoT) monitoring system which are embedded with sensors, software, and other technologies for connecting and exchanging data with other devices and systems over the internet. A comprehensive data (hourly, daily, monthly and yearly) related to system performance can be accessed through the internet. Recorded data in 2020 were used for the analysis.

Some data were also recorded on site which included solar radiation, energy generated and exported to the grid. Solar irradiance was measured by using a Lutron solar power meter SPM-1116SD of 10 W m$^{-2}$ accuracy. For irradiance lower and higher than 1000 W m$^{-2}$ the resolutions can reach 0.1 W m$^{-2}$ and 1 W m$^{-2}$ respectively. The energy meters used have measurement accuracy in the range of ±1%. Recorded data from the measurement system were processed using spreadsheet software. Performance parameters of the PV system were identified and calculated. The parameters included energy generated by the solar PV system, electricity intensity and solar PV cell efficiency. The environmental impact reduction due to replacement of fossil fuel-based electricity was also established.

### 2.3 Energy Performance Analysis

The energy performance parameters considered in this paper involve renewable energy generation, capacity factor and efficiencies. Capacity factor (*CF*) is the ratio of AC energy ($E_{AC}$ in kWh) produced to the installed capacity ($P_{max}$ in kW) during analysis period in (h). The *CF* in (%) can be calculated from Eq. (1) [10].

$$CF\ (\%) = \frac{E_{AC} \text{ in Analysis Period } (kWh)}{P_{max}\ (kW)\ x\ Analysis\ Period\ (h)}\ x\ 100 \tag{1}$$

Efficiencies of the PV system comprises efficiency of the PV cells, efficiency of the inverter, and overall efficiency. Efficiency of the PV cells ($\eta_{PV}$) in (%) can be calculated from Eq. (2).

$$\eta_{PV}(\%) = \frac{P_{DC}}{GHI}\ x\ 100 \tag{2}$$

where: $P_{DC}$ is DC electrical power intensity of the PV cell (kW m$^{-2}$); GHI is global horizontal irradiance (kW m$^{-2}$) measured at the same period as reported in [11,12].

The efficiency of grid-inverter ($\eta_{Inv}$) in (%) can be calculated from Eq. (3).

$$\eta_{Inv}(\%) = \frac{P_{AC}}{P_{DC}}\ x\ 100 \tag{3}$$

where: $P_{AC}$ is AC electrical power intensity (kW m$^{-2}$). The overall PV system efficiency ($\eta_{Sys}$) can be determined from Eq. (4).

$$\eta_{Sys}(\%) = \frac{P_{AC}}{GHI}\ x\ 100 \tag{4}$$

Data of site solar irradiation applied for energy efficiency calculations refer to irradiance data of the region as reported in [11,13].

### 2.4 Environmental Analysis

Reduction of the environmental impact through replacement of the fossil fuel-based electricity sources was estimated according to BS EN 378-1 Standard [14]. While the greenhouse gases (GHG) emissions factor for electricity production in Indonesia used emissions factor of 0.84 $tCO_{2e}$ MWh$^{-1}$ as reported in [15].

## 3 Results and Discussion

### 3.1 Renewable Energy Generation

Results of the renewable energy generation and capacity factor of the PV system are presented: (i) in Fig. 2 for one-year period; (ii) in Fig. 3 for daily generation in August (the highest generation month). From Fig. 2, it can be seen monthly electrical energy generation of the PV system for one year in 2020. The figure also shows one-year variation of the PV system capacity factor. Monthly electrical energy generation varies from 300 kWh to 499 kWh with average of 412 kWh. Annual energy generation of the PV system can reach 4.95 MWh. Utilization potential of the PV system stated as capacity factor can reach annual average value of 38.7%. The maximum monthly utilization potential with capacity factor value of 46.1% occurs in August, while the minimum value 26.1% happens in December.

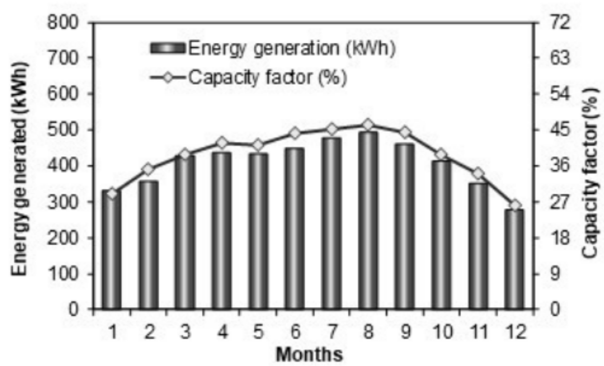


**Fig. 2** Monthly solar energy generation and capacity factor for the investigated year

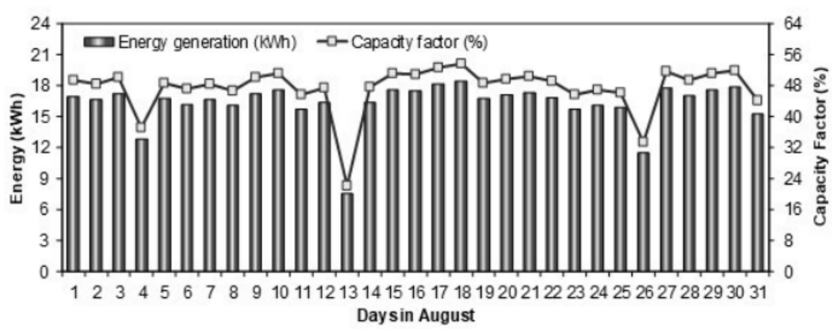


**Fig. 3** Daily solar energy generation and capacity factor in August (month with the highest energy generation)

The utilization potential of the PV system where the electrical energy generation and capacity factor are above the annual average is found to occur from March to October.

This shows eight months of the year the PV system can show good energy performance and utilization potential. For the remaining four months, the potential utilization is relatively decreased due to rainy weather conditions.

More thorough investigation can identify energy production and potential utilization of the PV system in the months with the highest energy generation in a year as shown in Fig. 3. The maximum daily energy generation and PV system utilization of the highest potential month August (Fig. 3) are respectively 18.5 kWh and 53.7%. While the lowest potential month occurs in December with maximum daily energy as high as 11.8 kWh with a capacity factor of 34.3%. The average daily energy generation in August is 16.6 kWh and December 9.0 kWh with a difference of around 45.8%.

### 3.2 Power Generation and Energy Efficiency Analysis

Figure 4 shows variation of the AC and DC power generation together with electrical energy generation during production period of the selected day in August (the highest production month). Time of production is 11 hours starting from 6.40 to 17.40. The average instant AC and DC power generations during production period are 1662 W and 1858 W, respectively, while the maximum AC and DC power generations, which occur at around 12 o'clock, can reach, respectively as high as 2552 W and 2811 W. AC and DC cumulative energy generation of the PV system in the selected highest day can correspondingly reach 18.5 kWh and 20.8 kWh. While the AC electrical power generation during the lowest production day in December occurs in about 10 hours starting from 6.30 in the morning to 4.30 in the afternoon. It is one hour shorter than the time of production in August. Average instant power generation during production period is 274 W and maximum power is 741 W. While cumulative AC electrical energy generation in the selected lowest day of production is only 2.82 kWh.

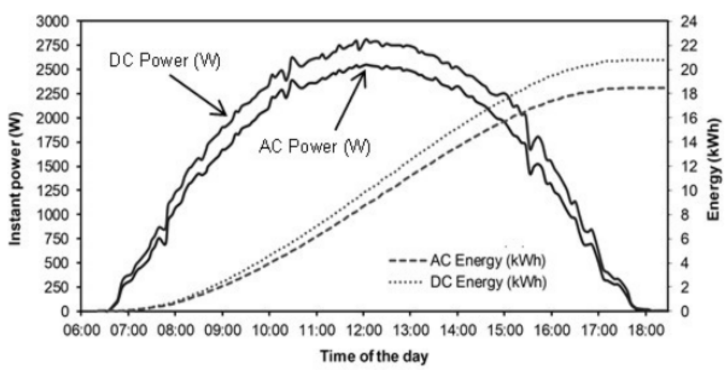


**Fig. 4** AC and DC electrical power as well as energy generation during the highest production day in August.

Figure 4 also clearly shows that the AC power or AC energy generation is lower than the DC power or DC energy generated from the PV system. This happens due to losses in the grid-inverter which also means the AC power or AC energy generation is directly influenced by the efficiency of the PV grid inverter.

Variation of the PV system efficiencies can be seen in Fig. 5. The efficiencies comprise PV cell efficiency and grid-inverter efficiency. In general, the efficiencies tend to increase from the start of the production time at 6.40 until 8.30, afterward relatively flatten up to 15.00 and then decrease until the end of the production time. The PV cell efficiency can reach maximum value of 21.8% and of about 18.6% in average. The installed PV cells can perform with cell efficiency that is very closed to the specified maximum efficiency of 22.96%. Whereas the grid-inverter efficiency of the PV system is 89.4% in average with maximum value is as high as 93.4%. Overall efficiency of the PV system spans from 11.2% to 19.7% with average value of 16.7%.

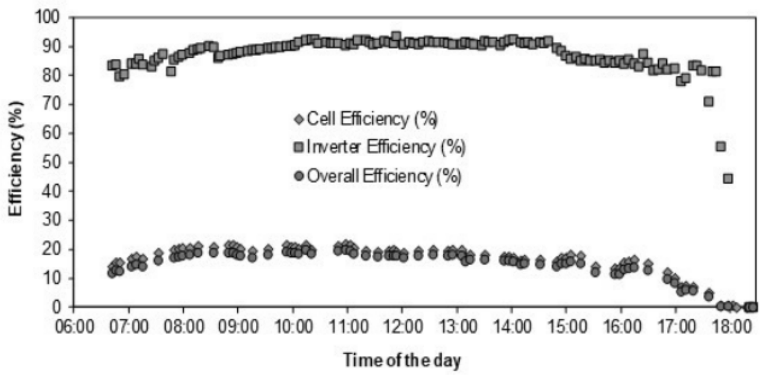


**Fig. 5** Energy efficiencies of solar PV system investigated at a clear and sunny day in August

### 3.3 Environmental Impact Reduction

Figure 6 illustrates the variation of environmental impact reduction (emissions reduction) of the investigated PV system. Emissions reduction due to the replacement of fossil fuel-based electrical energy varies following the quantity of solar PV energy generation. The maximum impact reduction occurs in August and the minimum one in December. The PV system is found to have a potential annual contribution on environmental impact reduction with equivalent to $CO_2$ emissions reduction of 4.12 tons.

As previously discussed, the utilization potential of the investigated PV system of a maximum 46.1% is significantly higher than overland and floating PV systems that have been reported in [10]. Such systems have maximum utilization potential of 17.6% and 20.8% respectively. This means that the utilization potential of the investigated PV system (46.1%) is higher of about 162% than the overland PV system and 122% higher than the floating PV system. The exceptional utilization potential together with the potential reduction in annual environmental impact make the grid-tied PV system as an incredibly prospective alternative for implementing renewable energy sources to power commercial buildings in Indonesia, especially in Bali Island.

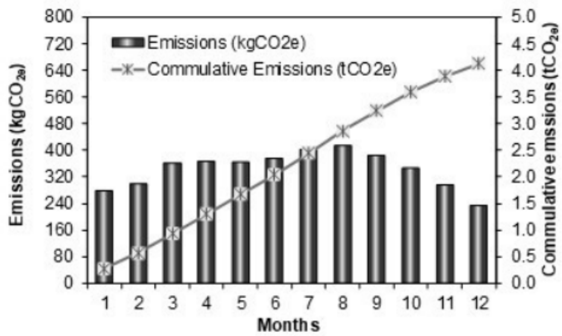


**Fig. 6** Reduction of $CO_2$ emissions due to the use of renewable energy from the PV system

## 4 Conclusions

A grid-tied PV system has been developed and investigated for renewable energy generation potential in southern region of Bali Island, Indonesia. The investigation results have shown that monthly solar electrical energy generation can reach 499 kWh and about 4.95 MWh annually. The PV system also has average utilization potential of 38.7%. Efficiencies of the PV system were found to vary from 11.2% to 19.7%. It has also been proven that the PV system has a potential contribution on environmental impact reduction of about 4.12 $tCO_2e$ per year due to replacement of fossil-fuel-based electrical energy. Substantial reduction on the environmental impact and excellent utilization potentials can make the grid-tied PV system as a prospective alternative of renewable energy source for commercial buildings in Indonesia.

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