PAPER • OPEN ACCESS

Analysis of AC and DC Lighting Systems with 150-Watt Peak Solar Panel in Denpasar Based on NASA Data

To cite this article: A A N M Narottama *et al* 2018 *J. Phys.: Conf. Ser.* **953** 012100

IOP Conf. Series: Journal of Physics: Conf. Series **953** (2018) 012100 doi:10.1088/1742-6596/953/1/012100

Analysis of AC and DC Lighting Systems with 150-Watt Peak Solar Panel in Denpasar Based on NASA Data

A A N M Narottama[1], K Amerta Yasa[1], I W Suwardana[1], A A N G Sapteka[1] and P S Priambodo[2]

[1]Electrical Engineering, Politeknik Negeri Bali, Jimbaran, Bali, 80361, Indonesia
[2]Electrical Engineering, Universitas Indonesia, Depok, Jawa Barat, 16424, Indonesia

E-mail: narottama@pnb.ac.id

Abstract. Solar energy on the Earth's surface has different magnitudes on every longitude and latitude. National Aeronautics and Space Administration (NASA) provides surface meteorology and solar energy database which can be accessed openly online. This database delivers information about Monthly Averaged Insolation Incident On A Horizontal Surface, Monthly Averaged Insolation Incident On A Horizontal Surface At Indicated GMT Times and also data about Equivalent Number Of No-Sun Or Black Days for any latitude and longitude. Therefore, we investigate the lighting systems with 150-Watt peak solar panel in Denpasar City, the capital province of Bali. Based on NASA data, we analyse the received wattage by a unit of 150-Watt peak solar panel in Denpasar City and the sustainability of 150-Watt peak solar panel to supply energy for 432-Watt hour/day AC and 360-Watt hour/day DC lighting systems using 1.2 kWh battery. The result shows that the maximum received wattage by a unit of 150-Watt peak solar panel is 0.76 kW/day in October. We concluded that the 1.2 kWh installed battery has higher capacity than the battery capacity needed in March, the month with highest no-sun days, for both AC and DC lighting systems. We calculate that the installed battery can be used to store the sustainable energy from sun needed by AC and DC lighting system for about 2.78 days and 3.51 days, consecutively.

1. Introduction

Solar panel is an interesting instrument of renewable energy source to study. Research in various locations in Indonesia regarding solar panel has been done by several researchers. Hiendro *et al.* investigated the techno-economic analysis of solar panel / wind hybrid system at Temajuk, a small village in West Kalimantan [1]. Giriantari *et al.* examined the economic cost of photovoltaic for hotels in Nusa Lembongan [2]. Tarigan *et al.* studied solar panel power generation for households in Surabaya [3]. Manik *et al.* studied the diesel-wind-diesel hybrid system in Nusa Penida [4]. Putra *et al.* examined the hybrid solar panel-generator in Aceh Singkil, Alor and Raja Ampat [5]. Pramana *et al.* studied PV performance in Ciparay, West Java [6]. Sihotang *et al.* examined the potential of solar panel in Makassar [7]. Pangaribuan *et al.* investigated the photovoltaic panel in Medan [8]. Musaruddin *et al.* reported the application of solar energy at Halu Oleo University in Kendari [9]. Tanoto *et al.* investigated the feasibility study of off-grid renewable energy in Mamasa, West Sulawesi [10]. Research at these different locations are based on the uniqueness of solar energy and meteorological conditions at each location. In this study we conduct an analysis of 432-Watt hour/day AC and 360-Watt hour/day DC lighting systems with two units of 150-Watt peak solar panel in Denpasar, Bali based on surface meteorology and solar energy data of Monthly Averaged Insolation Incident On A Horizontal Surface

IOP Conf. Series: Journal of Physics: Conf. Series **953** (2018) 012100 doi:10.1088/1742-6596/953/1/012100

(kWh/m^2/day), Monthly Averaged Insolation Incident On A Horizontal Surface At Indicated GMT Times (kW/m^2) and Equivalent Number Of No-Sun Or Black Days (days) from NASA.

2. Methodology

Using NASA surface meteorology and solar energy data [11], we conduct an analysis of AC and DC lighting systems with 150-Watt peak solar panels. Data from NASA includes the Monthly Averaged Insolation Incident On A Horizontal Surface (kWh/m^2/day), the Monthly Averaged Insolation Incident On A Horizontal Surface At Indicated GMT Times (kW/m^2) and the Equivalent Number Of No-Sun Or Black Days (days) data for Denpasar, Bali according to Table 1, Table 2 and Table 3.

Table 1. Monthly averaged insolation incident on a horizontal surface (kWh/m^2/day)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
22-year average	4.93	5.04	5.43	5.39	5.19	4.84	4.79	5.33	5.95	6.19	5.67	5.28

Table 2. Monthly averaged insolation incident on a horizontal surface at indicated GMT times (kW/m^2)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Average@00	0.22	0.19	0.22	0.24	0.23	0.2	0.17	0.21	0.27	0.33	0.33	0.28
Average@03	0.63	0.65	0.71	0.71	0.68	0.63	0.61	0.67	0.76	0.79	0.74	0.68
Average@06	0.56	0.61	0.63	0.62	0.61	0.59	0.6	0.66	0.7	0.7	0.6	0.59
Average@09	0.17	0.18	0.19	0.16	0.15	0.15	0.16	0.18	0.19	0.17	0.15	0.16
Average@12	0	0	0	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	0
Average@15	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Average@18	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Average@21	0	0	0	0	0	0	n/a	0	0	0	0	0

Table 3. Equivalent number of no-sun or black days (days)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1 day	0.95	0.96	0.96	0.94	0.78	0.61	0.60	0.86	0.85	0.74	0.79	0.95

The data is then used to analyse the electrical energy generated by 150-Watt peak solar panel for lighting system that consists of three units 10W 220V AC LED and four units of 9W 12 V DC LED.

3. Result and Discussion

3.1. Research Location and Focus

The study is conducted in Denpasar City, Bali on 150 Watt-peak solar panel lighting system. The city of Denpasar is located at 8.67 south latitude and 115.21 eastern longitude. The research is focused on AC and DC lighting systems with energy source from two units of 150-Watt peak solar panel with specification as shown in Table 4.

The solar cell system under study consists of two units of 150-Watt peak solar panels, four units of 9W 12V DC LED (432Wh / day) and three units of 10W 220V AC LED (360Wh / day) and two units of 1.2 kWh sealed lead-acid battery. The scheme of these lighting systems is shown in Figure 1. Both systems are turned on for 12 hours per day at night.

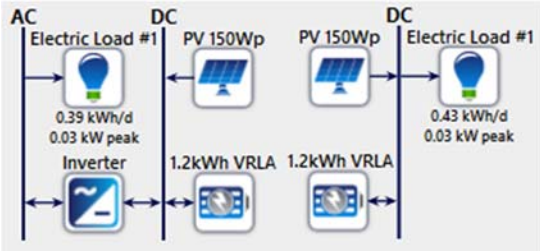

Figure 1. AC and DC Lighting systems using 150-Watt peak solar panels

Table 4. Specification of 150-Watt peak Solar Panel

Item	Value
Rated Maximum Power	150 W
Open Circuit Voltage (Voc)	21.6 V
Short Circuit Current (Isc)	9.70 A
Voltage at Maximum Power (Vmp)	17.2 V
Current at Maximum Power (Imp)	8.72 A
Output Tolerance	0~5%
Length	122 cm
Width	72 cm
Area	0.88 m^2
Nominal Operating Temperature	-40~85^{o}C

3.2. *Data Analysis*
Based on the data in Table 1, we calculate the value of insolation incident on a horizontal surface per day of 0.88m^2 area. The insolation value in kWh per day in Denpasar City is shown in Table 5.

Table 5. Insolation value per day for 0.88m^2 area in Denpasar City

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Insolation (kWh/day)	4.34	4.44	4.78	4.74	4.57	4.26	4.22	4.69	5.24	5.45	4.99	4.65

Table 5 shows that the largest insolation energy is generated in October (5.45 kWh / day), meanwhile the smallest one is produced in July (4.22 kWh / day).

According to Table 3, the solar panel will receive its peak energy from 03.00 GMT (11.00 local time) to 06.00 GMT (14.00 local time). As stated by Priambodo *et al*., energy-conversion efficiency of solar panel typically lies between 12% to 14% [12]. Therefore, we calculate the received wattage by a unit of 150-Watt peak solar panel as shown in Table 6 using efficiency of 14%. The maximum received wattage of 0.76 kW/day will happen in October. By taking the data in January at Table 6, the 150-Watt peak solar panel will received the energy in about 4 hours effectively in Denpasar city.

Table 6. Received wattage by a unit of 150-Watt peak solar panel in Denpasar City

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wattage (kW/day)	0.61	0.62	0.67	0.66	0.64	0.60	0.59	0.66	0.73	0.76	0.70	0.65

Furthermore, we analyse the battery capacity, which is needed to store the electrical energy generated by solar panels [13]. The battery capacity value is determined by Eq. (1) for DC lighting system and Eq. (2) for AC lighting system.

$$C_{batt} = \frac{E_{PV} \times \beta_a}{\rho_{wire} \times \rho_{ctrl} \times \rho_{batt} \times DOD} \quad (1)$$

$$C_{batt} = \frac{E_{PV} \times \beta_a}{\rho_{wire} \times \rho_{ctrl} \times \rho_{batt} \times \rho_{inv} \times DOD} \quad (2)$$

where
C_{batt} is battery capacity (kWh)
E_{PV} is electric power generated by solar panels (kWh/day)
β_a is number of autonomous days (Table 6)
ρ_{wire} , ρ_{ctrl}, ρ_{batt}, ρ_{inv} are consecutively the efficiency of cable, controller, battery and inverter
DOD is battery's depth of discharge

Equations (1) and (2) include parameters of efficiency of cable, charge controller, battery and inverter. These parameters are necessary to obtain the actual battery capacity value. Therefore, it requires several assumptions based on study from previous research for some following parameters [13]. Except for Depth of Discharge (DOD), we assume its value of 80% due to uses of sealed lead-acid battery. The assumption is shown in Table 7.

Table 7. Assumption of lighting system parameters

Parameter	Symbol	Value	Unit
Wire efficiency	ρ_{wire}	97	%
Battery discharge efficiency	ρ_{batt}	85	%
Charge controller efficiency	ρ_{ctrl}	98	%
Inverter efficiency	ρ_{inv}	95	%
Depth of discharge	DOD	80	%

While the determination of the number of autonomous days parameter (β_a) is taken base on data from NASA in Table 3. The value of β_a is used to solve the Eq. (1-2) and it is determined monthly according to Table 8.

Table 8. Number of autonomous days

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
No-sun days β_a	0.95	0.96	0.96	0.94	0.78	0.61	0.60	0.86	0.85	0.74	0.79	0.95

The calculation of battery capacity, C_{batt} (kWh), according to NASA data for AC and DC lighting systems for 150-Watt peak solar panel are shown monthly in Table 9 and Table 10. The value of this parameter is obtained from Eq. (1) and Equation (2). It is seen that for AC lighting system requires larger battery capacity compared to DC lighting system. It is caused by the installation of inverter circuit in the AC lighting system [13].

Table 9. Battery Capacity For AC Lighting System

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C_{batt} (kWh)	0.94	0.97	1.05	1.02	0.81	0.59	0.58	0.92	1.01	0.92	0.90	1.01

Table 10. Battery Capacity For DC Lighting System

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C_{batt} (kWh)	0.89	0.92	0.99	0.97	0.77	0.56	0.55	0.87	0.96	0.87	0.85	0.96

Based on Table 9 and Table 10, it is seen that the highest battery capacity needed is 1.05 kWh in March for AC lighting system and 0.99 kWh in March for DC lighting system. However, the value of the battery capacity needed in these months is still lower than the installed battery capacity of 100Ah 12V or 1.2 kWh. Under fully charged condition, the 1.2 kWh installed battery will be able to supply the AC lighting system that consist of three units of 10W 220V AC LED (360Wh / day) for about

$$days\ of\ autonomous = \frac{1.2\ kWh}{0.360kWh/\ days} \approx 3.51\ days \tag{3}$$

Meanwhile the other 1.2 kWh installed battery will be able to supply the DC lighting system that consist of four units of 9W 12V DC LED (432Wh / day) for about

$$days\ of\ autonomous = \frac{1.2\ kWh}{0.432\ kWh/\ days} \approx 2.78\ days \tag{4}$$

4. Conclusion

We have been investigate the lighting systems with 150-Watt peak solar panel in Denpasar, the capital province of Bali, based on Monthly Averaged Insolation Incident On A Horizontal Surface, Monthly Averaged Insolation Incident On A Horizontal Surface At Indicated GMT Times (kW/m^2) and Equivalent Number Of No-Sun Or Black Days data from NASA. By taking assumption on some parameters, it can be concluded that the 150-Watt peak solar panel in Denpasar City, Bali has maximum received wattage of 0.76 kW/day in October. By taking the data in January at Table 6, the 150-Watt peak solar panel will received the energy in about 4 hours effectively. The highest battery capacity needed is 1.05 kWh in March for AC lighting system and 0.99 kWh in March for DC lighting system. The installed battery capacity is 1.2 kWh, which is larger than battery capacity needed in peak month. We calculate that the installed battery can be used to store the sustainable energy from sun needed by AC and DC lighting system for about 2.78 days and 3.51 day consecutively.

5. Acknowledgment

This research was funded by DIPA of Politeknik Negeri Bali (PNB) No. SP.DIPA-041.01.2.2401006 /2017. We thank the Centre for Research and Community Service (P3M PNB) for providing the kind support.

6. References

[1] Hiendro A, Kurnianto R, Rajagukguk M, Simanjuntak Y M and Junaidi 2013 *Energy* **59** 652-657

[2] Giriantari I A D, Kumara I N S and Santiari D A 2014 *Inter. Conf. on Smart-Green Technology in Electrical and Information System* pp 13-16
[3] Tarigan E, Djuwari and Purba L 2014 *Energy Procedia* **47** 85-93
[4] Manik C T, Wijaya F D and Juliandhy T 2014 *Inter. J. of Scientific and Engineering Research* **5** 40-45
[5] Putra A W, Kamandika E, Rosyadi S, Purwadi A and Haroen Y 2016 *The 13th IEEE Conf. on Power Engineering and Renewable Energy*
[6] Pramana R I, Santoso A, Darussalam R and Rajani A 2016 *Inter. Conf. on Sustainable Energy Engineering and Application* pp 50-54
[7] Sihotang M A and Okajima K 2017 *J. of Power and Energy Engineering* **5** 15-29
[8] Pangaribuan A B, Rahmat R F, Lidya M S and Zalesak M 2017 *IOP Conf. Series: J. of Physics* **801** 1-8
[9] Musaruddin M, Rianse U and Rachman A 2015 *Inter. J. of Smart Grid and Clean Energy* **4** 151-158
[10] Tanoto Y, Santoso M and Massay C 2013 *IEEE 7th Inter. Power Eng. and Optimization Conf.* pp 464-468
[11] NASA. Atmospheric Science Data Centre [Online]. Available: https://eosweb.larc.nasa.gov/cgi-bin/sse/grid.cgi
[12] Priambodo P S, Sukoco D, Purnomo W, Sudibyo H and Hartanto D 2013 *Electric Energy Engineering and Management in Solar Cell System* Intech pp 327-351
[13] Veldhuis A J and Reinders A H M E 2015 *Renewable and Sustainable Energy Rev.* **52** 757-769