Research article

Performance Analysis of 325 kW Solar PV Rooftop System Using PVsyst Program

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Abstract The power demand of electricity growing very fast with high concern of climate change and environmental constrains. According to the Thailand Power Development Plan 2015 (PDP 2015) starting from 2015 to 2036, the national target of 30% of renewable energy to total energy consumption by 2036 is to be achieved. Solar photovoltaic (PV) is an important option makes the PDP 2015 meets the target. This paper aims to present the performance analysis of the solar PV rooftop system installed at Sakon Nakhon Rajabhat University. The system consisted of 1,016 polycrystalline silicon PV modules coupled to 13 units of 25 kW grid tied inverter. This system will be installed at the rooftop of the three buildings namely, the Central Building (CB), the Engineering Technology Building (ETB) and the Multipurpose Building (MB). The PV rooftop system is designed using PVsyst program. The PV modules faced tilts and azimuths with 5°/31°, 10°/31° and 5°/16°, respectively. The simulation results indicated that solar PV rooftop system can produce 452.92 MWh/year. The solar PV rooftop system could produce electricity generating from 06.00 - 18.00. The performance ratio of the system is 0.74. The Central Building has maximum power electricity generating as 44.44%. The Engineering Technology Building has high performance ratio because of its tilts and azimuths of solar panels that affect the irradiation. The solar PV rooftop can reduce the peak demand in time 06.00-18.00 of 13.24% and the reduction of greenhouse gas emissions is 263.65 tco2/year.

Keywords climate change, photovoltaic, PVsyst (PV system design program), renewable energy, solar PV rooftop system, sustainable development

INTRODUCTION

Solar photovoltaic (PV) is now widely used for power generation worldwide. According to the Alternative Energy Development Plan (AEDP 2015-2036), the renewable energy is targeted for 30% of total energy consumption in Thailand. Due to its cost competitive and high potential of solar energy in the country, solar power has been promoted and scheduled to be installed at 6,000 MW by 2036 (Tanatvanit, 2003 and Chimres, 2016). Sakon Nakhon Rajabhat University (SNRU) is an academic institute in Sakonnakhon province which located in the northeastern part of Thailand. Sakon Nakhon Rajabhat University has an area of 1.02 km² and there are 50 buildings. This institute has high energy consumption. The electricity cost per year is 20 million baht. The energy block grant project subsidized from the Ministry of Energy is launched in 2018 for the 325 kW solar PV rooftop to promote the use of renewable energy in the institute.

OBJECTIVE

This work was aimed to present the performance analysis of the 325 kW solar PV rooftop. The PVsyst program was employed as a tool to investigate the technical performance assessment, project design and its simulation. The three proposed buildings will be launched in 2020. This study would be useful to predict the performance of the system, financial analysis and the user perspective on a solar PV rooftop system. The study clearly illustrates the potential to use the PV rooftop system to supply basic energy services that is desired in academic building settings.

MATERIALS AND METHODS

The installation of solar PV rooftop system at the Central Building (CB), the Engineering Technology Building (ETB) and the Multipurpose Building (MB) is shown in Fig. 1.

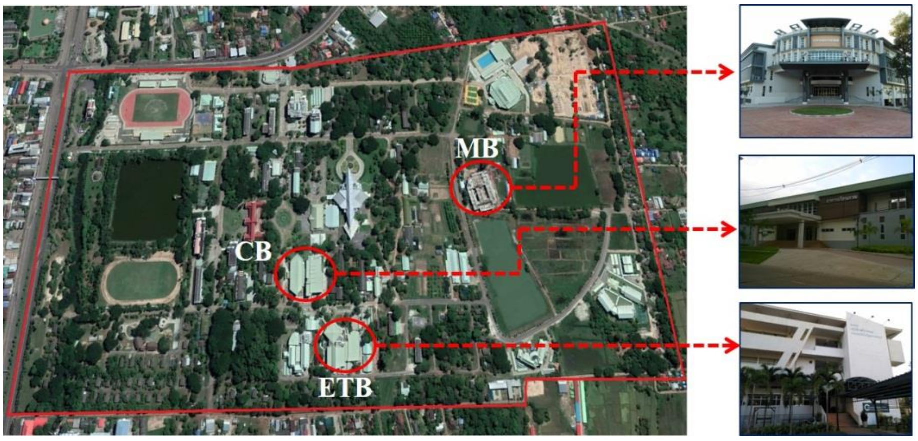

Fig. 1 Research site

Figure 2 shows layout of the solar PV rooftop system. The solar PV rooftop system consists of the following components:

- Polycrystalline silicon PV 320 W_p (1,016 modules)
- Grid tied inverter 25 kW_{ac} (13 units)
- Monitoring system
- Cable wiring

Fig. 2 Layout of solar PV rooftop system

PVsyst Program

The PVsyst program is one of the energy modeling tools. It can show the useful results of solar PV system including the produced power and the occurred losses in the system (Mermoud, 2014 and Boughamrane, 2016). The location site, setting tilt and azimuth, PV module and inverter specifications are the required information for the program as shown in Fig. 3.

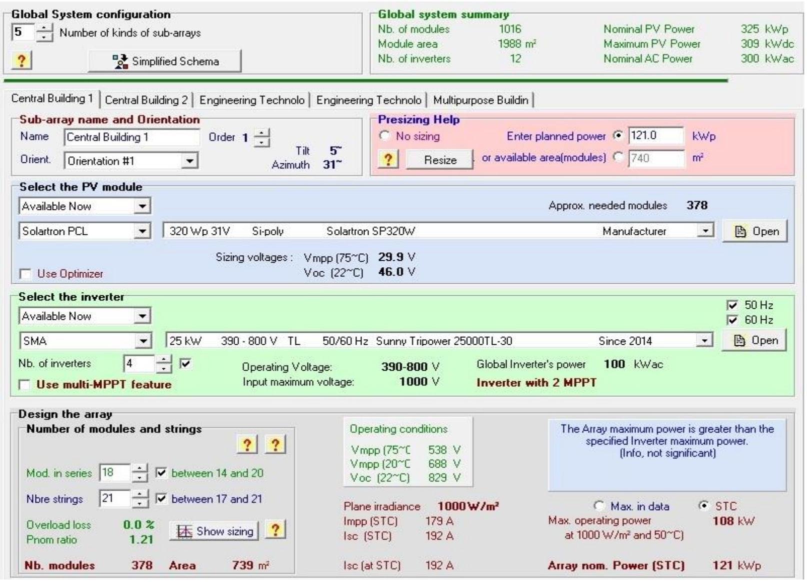

Fig. 3 PVsyst program

Technical Performance Assessment

The parameters for performance analysis of solar PV rooftop system followed by IEC 61724 are shown in Table 1 (Kumar, 2017 and Gurupira, 2017). The following nine parameters are used to analyze the performance of the system: the reference yield (Y_r), the array yield (Y_a), the final yield (Y_f), the array capture losses (L_C), the system losses (L_S), the performance ratio (PR), the array efficiency (η_a), the system efficiency (η_{sys}) and the capacity utilization factor (CUF) (Kumar, 2017 and Yadav, 2018).

Table 1 Equation for technical performance assessment

Parameter	Equation	Unit
Y_r	H_t/G_o	kWh/kWp/day
Y_a	E_{DC}/P_o	$kWh/kW_p/day$
Y_f	E_{AC}/P_o	$kWh/kW_p/day$
L_C	$Y_r - Y_a$	$kWh/kW_p/day$
L_S	$Y_a - Y_f$	$kWh/kW_p/day$
PR	Y_f/ Y_r	-
η_a	$E_{DC}/(A_a \cdot H_t) \times 100$	%
η_{sys}	$E_{AC}/(A_a \cdot H_t) \times 100$	%
CUF	$E_{AC}/(P_o \cdot 24 \cdot 365) \times 100$	%

H_t = Total irradiance at the standard test condition ($kWh/m^2/day$)
G_o = Global irradiance at the standard test condition ($kWh/m^2/day$)
E_{DC} = DC energy of the PV system (kWh)
E_{AC} = AC energy of the PV system (kWh)
P_o = Nominal power of the PV array at the standard test condition (kW_p)
A_a = Array area (m^2)

Project Design and Simulation

Table 2 shows the description of PV system installation in three buildings: CB, ETB and MB. The Central Building has the maximum roof areas for PV installation, followed by the Multipurpose Building and the Engineering Technology Building.

Table 2 Description of PV rooftop system

Description	CB	ETB	MB
Location	17.18° N, 104.08° E	17.18° N, 104.08° E	17.18° N, 104.08° E
Structure building	Metal sheet	Metal sheet	Metal sheet
Roof area	1,643.35 m^2	924.42 m^2	1,323.60 m^2
Tilt/Azimuth	5°/31°	10°/31°	5°/16°
PV modules (320W_p)	454 modules	220 modules	342 modules
PV modules area	888 m^2	430 m^2	669 m^2
No. of PV modules (set 1)	series=18modules parallel=21 strings	series =18 modules parallel=8 strings	series =18 modules parallel=19 strings
No. of PV modules (set 2)	series =19 modules parallel=4 strings	series =19 modules parallel=4 strings	
Grid-tied inverter (25 kW)	6 unit	3 unit	4 unit
Total PV power	145.28 kW_p	70.40 kW_p	109.44 kW_p

RESULTS AND DISCUSSION

Table 3 depicts the monthly average energy injected into grid, global incident, greenhouse gas emissions and performance ratio. Among three buildings, the Engineering Technology Building has slightly high performance ratio than other buildings as 0.743 because of its tilts and azimuths of solar panels that affect the irradiation.

Table 3 Monthly average energy inject to grid

Month	CB				ETB				MB			
	E-grid (MWh)	Global (kWh/m^2)	CO_2 (tco_2)	PR	E-grid (MWh)	Global (kWh/m^2)	CO_2 (tco_2)	PR	E-grid (MWh)	Global (kWh/m^2)	CO_2 (tco_2)	PR
Jan	17.94	163.5	10.44	0.755	9.114	171.3	5.31	0.756	13.62	164.7	7.93	0.756
Feb	16.00	147.0	9.31	0.749	7.992	151.4	4.65	0.750	12.10	147.6	7.04	0.749
Mar	18.22	170.1	10.61	0.737	8.967	172.6	5.22	0.738	13.75	170.3	8.00	0.737
Apr	17.79	167.3	10.36	0.732	8.591	166.6	5.00	0.732	13.42	167.5	7.81	0.732
May	17.72	166.9	10.31	0.731	8.435	163.9	4.91	0.731	13.35	166.9	7.77	0.731
Jun	16.82	156.5	9.79	0.740	7.996	153.4	4.65	0.740	12.65	156.3	7.36	0.740
Jul	16.26	151.8	9.46	0.737	7.745	149.1	4.51	0.738	12.25	151.7	7.13	0.738
Aug	15.43	143.5	8.98	0.740	7.413	142.1	4.32	0.741	11.63	143.6	6.77	0.740
Sep	14.30	132.8	8.32	0.741	6.968	133.4	4.06	0.742	10.80	133.1	6.29	0.742
Oct	17.04	158.4	9.92	0.740	8.440	161.8	4.91	0.741	12.88	158.9	7.50	0.741
Nov	16.35	150.4	9.52	0.748	8.263	156.7	4.81	0.749	12.38	151.1	7.21	0.748
Dec	17.44	159.1	10.15	0.754	8.926	167.8	5.20	0.756	13.24	160.3	7.71	0.755
Year	**201.30**	**1867.4**	**117.18**	**0.742**	**98.848**	**1890.2**	**57.54**	**0.743**	**152.07**	**1872.0**	**88.52**	**0.742**

Table 4 shows the results of overall system, it depicts monthly average energy injected into grid, global incident, greenhouse gas emissions, performance ratio, energy saving analysis and economics. The solar PV rooftop can reduce power consumption by 452.92 MWh/year.

Figure 4 shows the normalized PV production, i.e. the collection losses (L_C) is 1.23 kWh/kW_p/day, the system losses (L_S) is 0.09 kWh/kW_p/day and the produced useful energy (Y_f) is 3.82 kWh/kW_p/day. Figure 5 presents the performance ratio of the overall system for each month. The highest performance ratio is 0.76 in January and December. The lowest performance ratio is 0.73 in May. The performance ratio is slightly different in each month with the average performance ratio of the system is 0.74.

Table 4 Results analysis of the 325 kW solar PV rooftop system

Month	Solar PV rooftop 325 kW				Energy demand		Energy conservation		Economic (Bath)
	E-grid (MWh)	Global (kWh/m^2)	CO_2 (tco_2)	PR	06.00 – 18.00 (MWh)	24 hr (MWh)	Save 06.00 – 18.00 (%)	Save 24 hr (%)	
Jan	40.73	165.6	23.71	0.75	241.07	437.08	16.90	9.32	178,804.70
Feb	36.15	148.1	21.04	0.75	210.79	329.45	17.15	10.97	158,698.50
Mar	41.00	170.7	23.87	0.74	323.89	463.39	12.66	8.85	179,990.00
Apr	39.87	167.2	23.21	0.73	295.75	427.83	13.48	9.32	175,029.30
May	39.56	166.2	23.03	0.73	289.59	418.68	13.66	9.45	173,668.40
Jun	37.52	155.8	21.84	0.74	274.01	397.10	13.69	9.45	164,712.80
Jul	36.31	151.2	21.14	0.74	326.00	459.04	11.14	7.91	159,400.90
Aug	34.53	143.2	20.10	0.74	361.17	475.79	9.56	7.26	151,586.70
Sep	32.12	133.0	18.70	0.74	379.70	540.59	8.46	5.94	141,006.80
Oct	38.42	159.3	22.36	0.74	308.30	451.72	12.46	8.51	168,663.80
Nov	37.05	152.0	21.57	0.75	229.92	352.73	16.11	10.50	162,649.50
Dec	39.67	161.4	23.09	0.75	180.25	298.53	22.01	13.29	174,151.30
Year	452.92	1873.9	263.65	0.74	3,420.44	5,051.92	13.24	8.96	1,988,362.70

**** Emission factor = 0.58, Average electricity cost of SNRU = 4.39 Bath/kWh*

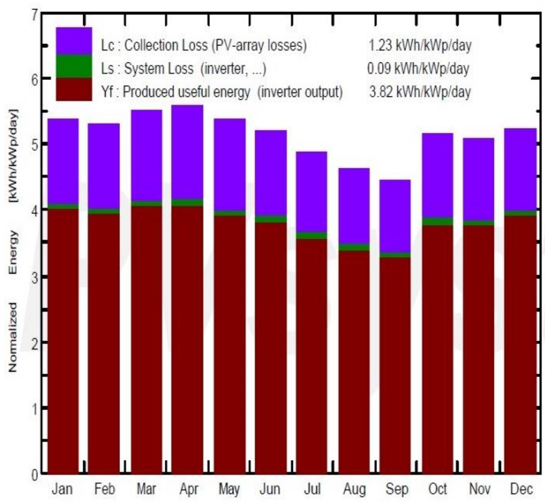

Fig. 4 Normalized PV production

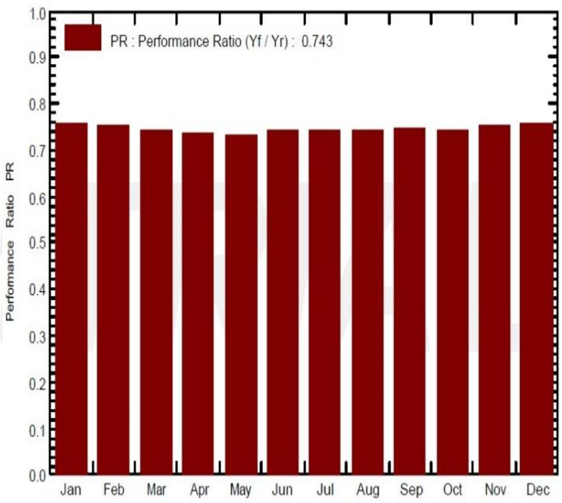

Fig. 5 Performance ratio

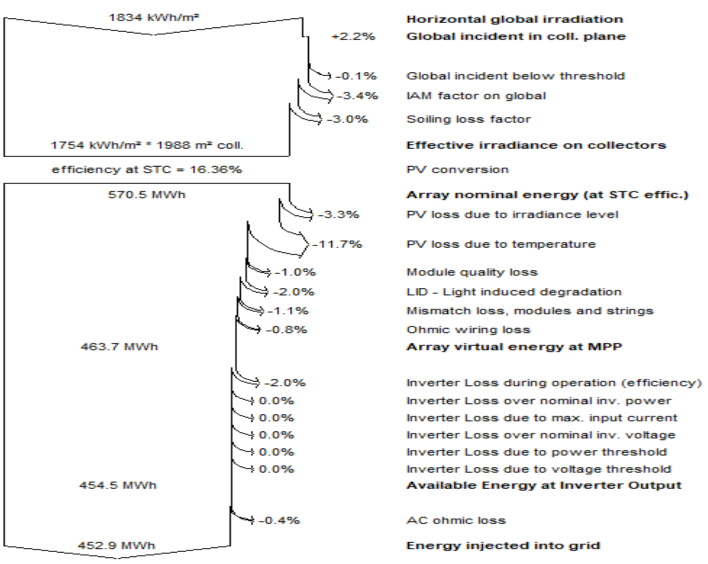

Fig. 6 Loss diagram

Figure 6 presents the loss diagram of the system. The array nominal energy at standard test condition (STC) is 570.5 MWh, the array virtual energy at maximum power point (MPP) is 463.7 MWh. The available energy at the inverter output after the inverter loss was extracted would be the energy injected into the grid is 452.9 MWh. The produced electricity from the solar rooftop system decreases during May to September due to the rainy season in Thailand.

CONCLUSION

The solar PV rooftop system is designed using PVsyst program as a tool. The system is planned to be installed on the roofs of three buildings: the Central Building, the Engineering Technology Building and the Multipurpose Building at the academic institute which located in the northeastern part of Thailand. The Central Building can generated maximum power electricity of 201.30 MWh/year or 44.44% of the total system. The electricity produced during the sun rises (06.00-18.00). The solar PV rooftop system can reduce the peak demand of electricity as 452.92 MWh/year or 13.24%/year during daytime (06.00-18.00). The generated electricity from solar PV energy can reduce the use of electricity by 8.96%/year. The system can save electricity cost throughout the year as 1.98 million baht/year and the reduction of greenhouse gas emissions is equaled to 263.65 t_{CO2}/year.

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