Solar Rooftop PV Power Generation for a Commercial Building in Thailand

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Abstract. Solar energy is significant potential for power and heat production. The Alternative Energy Development Plan 2018–2037 (AEDP2018) developing by Thailand's Ministry of Energy demonstrates that solar energy is a key role in renewable energy utilization, especially for power generation. In general, solar photovoltaic (PV) technology is the most common type of solar power generation technology. This paper presented a potential of using grid-connected solar PV power generation system for the rooftop of a commercial building. The design and simulation of the solar rooftop PV power generation system and the economic analysis were accomplished. The installation of 1.85 MWp grid-connected solar PV power generation system on the rooftop area required 3,440 pieces of 540 Wp solar panels. By using PVsyst version 7.2, the solar panel configuration was connected in 20 pieces/string in series and 172 strings in parallel, with 80 kWac string inverters of 18 units. The simulated results of produced energy, specific production, and performance ratio were 2,678 MWh/year, 1,442 kWh/kWp/year, and 80% respectively. As a result, the energy cost saving was 269,317 USD with payback period (PB), net present value (NPV), and internal rate of return (IRR) of 6.37 years, 1,062,430 USD, and 15%, respectively. In conclusion, the installation of 1.85 MWp solar rooftop PV power generation system is technically feasible for the investment.

Keywords: Solar rooftop · PVsyst · Commercial building

1 Introduction

Renewable energy from solar energy, wind energy, biomass, municipal solid wastes (MSW) and others has been considered to substituting fossil fuels for decades. The Ministry of Energy of Thailand, thereby, notifies the Alternative Energy Development Plan 2018–2037 (AEDP2018) to promote the utilization of various renewable energy [1]. Solar energy is the most abundant and plays an important role in accomplishing the AEDP's plan. The target of solar photovoltaic (PV) power plant and rooftop power system is 12,139 MWp, a double capacity of the AEDP2015. It is remarkably that the

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PV floating system started in the AEDP2018 to achieve its target of 2,725 MWp. On the other hand, the target of solar heat consumption is downward to 100 ktoe. Based on the solar energy status, as shown in Table 1, from Thailand Alternative Energy Situation 2020 Report [2], the central part of Thailand has the highest amount of on-grid installed capacity and heat consumption. Figure 1 illustrates the distribution of solar PV power plant and rooftop power system in 2020.

Table 1. Solar energy status in Thailand in 2020 [2].

Region	On-grid installed capacity (MW)	Heat consumption (ktoe)
Northern	654.10	2.98
North-eastern	439.93	1.12
Central	1,802.03	5.91
Southern	53.05	0.56
Total capacity	2,949.11	10.57

Solar PV technology is a proven technology worldwide for power generation [3, 4]. It is a competitive technology for power generation after a decade due to dramatic cost declines. The total installation costs of solar PV declined about 74% from 2010 to 2018, because of lower cost of solar PV modules and a balance-of-system in the solar PV power generation market [5]. Several review and research articles as well as the case studies regarding solar rooftop PV power systems in Thailand are widely reported in terms of technical performances, economic feasibility, and environmental impacts [6–14]. It is notably observed that the installation of solar PV power system on the rooftop of commercial and residential buildings has continuously increased in terms of the energy efficiency improvement and building space utilization in electricity generation. It is, therefore, this paper studied on technical and economic feasibility of grid-connected solar PV power generation system installed on the rooftop of a commercial building in Thailand.

2 Methodology

A commercial building in this study is located at Prachuap Khiri Khan province which is in the central part of Thailand. The feasibility study steps are described as follows:

2.1 Collect the Relevant Data and Electricity Consumption of the Commercial Building

The location and geographic coordinate system of the commercial building, the amount of solar irradiation, the rooftop structure and area, and the annual electricity consumption were collected on-site at the commercial building, from the available records, and by interviewing the building owners and solar PV system experts.

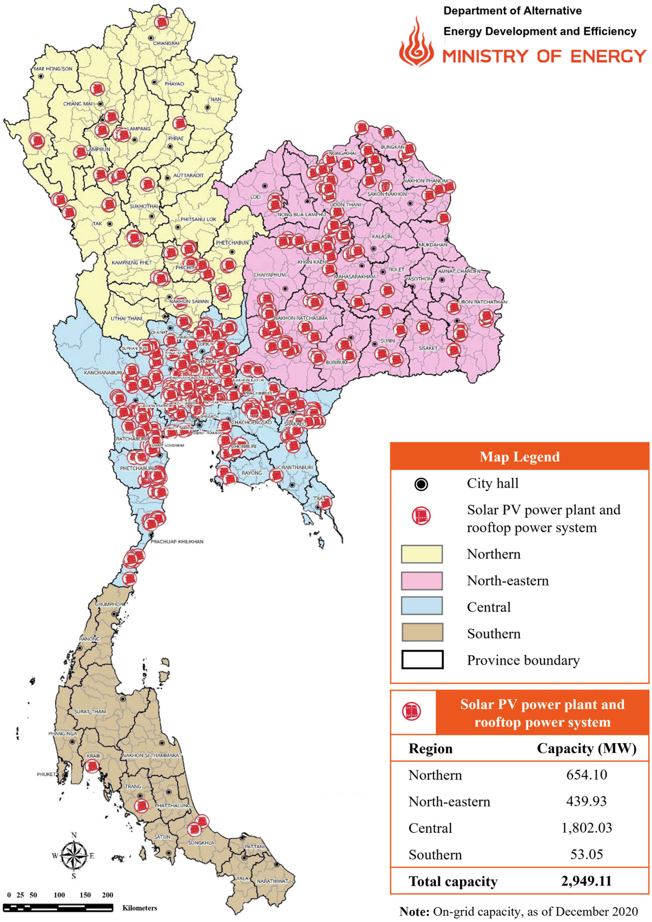


Fig. 1. Thailand solar PV power plant and rooftop power system in 2020 [2].

2.2 Design and Simulate the Solar Rooftop PV Power Generation System by PVsyst Version 7.2

PVsyst is a PC software for studying, sizing, and data analysis of complete PV systems [15]. The PVsyst can be applied to grid-connected, stand-alone, pumping, and DC-grid (public transportation) PV systems. It combines extensive meteo and databases of PV system components, including general solar energy tools. In this study, PVsyst version 7.2 was used to design and simulate the grid-connected solar rooftop PV power generation system of the commercial building.

2.3 Evaluate the Economic Feasibility of the Solar Rooftop PV Power Generation System

Key indicators which are commonly used for the economic feasibility of the solar rooftop PV power generation system includes the payback period (PB), the net present value (NPV), and the internal rate of return (IRR) [4].

- PB is the time required to recover the initial investment cost, thus, it equals initial investment cost divided by net annual cash flow of the project.
- NPV is the difference between the present value of cash inflows and cash outflows over a project period, defined by Eq. (1).

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{ES_t}{(1+i)^t} \quad (1)$$

where I_0 is the total initial investment cost; ES_t is the energy cost saving; i is the discount rate which is determined at 7% according to the effective interest rate [16]; and n is the project period which is considered at 25 years for the solar PV project.

- IRR is the discount rate that makes the NPV of all cash flows zero in the discount cash flow analysis, defined by Eq. (2).

$$NPV = 0 = -I_0 + \sum_{t=1}^{n} \frac{ES_t}{(1+IRR)^t} \quad (2)$$

3 Results and Discussion

3.1 Rooftop Area of the Commercial Building and the Electricity Consumption

The case study commercial building is located at the latitude of 12°34′7″N and longitude of 99°57′28″E. According to the data on solar irradiation, the total solar irradiation in 2020 was at 1,731.5 kWh/m^2 [17]. It was found that the existing roof structure of the building can withstand the additional weight of solar core system components, including PV modules, their accompanying mounting structure, and inverters. The rooftop area of 21,500 m^2 is sufficient to install solar PV power generation system together with enough space for maintenance and inspection activities. The data on electricity consumption of the commercial building was obtained from the electricity bills in 2020, showing the maximum electricity consumption of 4.9 MWp in March.

3.2 Grid-Connected Solar Rooftop PV Power Generation System

Specifications of PV modules and inverters are shown in Table 2. The installation of 1.85 MWp grid-connected solar PV power generation system on the rooftop area required 3,440 pieces of 540 Wp solar panels. The design layout of PV module installation on the rooftop is presented in Fig. 2.

Table 2. Technical specifications of PV modules and inverters.

Component	Type	Capacity	Quantity	Total capacity
PV modules	Monocrystalline half cell	540 Wp	3,440 pieces	1,858 kWp
Inverters	String	80 kWac	18 units	1,440 kWac

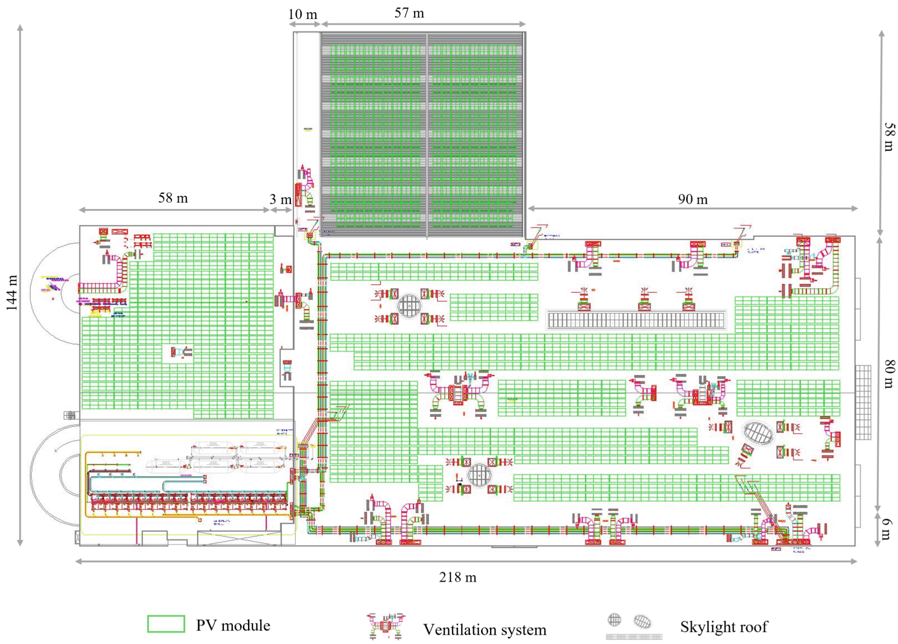


Fig. 2. Layout of PV module installation on the rooftop by AutoCAD.

By using PVsyst version 7.2, the solar panel configuration was connected in 20 pieces/string in series and 172 strings in parallel, with 80 kWac string inverters of 18 units. Figure 3 demonstrates the simulation results of produced energy, specific production, and performance ratio of 2,678 MWh/year, 1,442 kWh/kWp/year, and 80%, respectively. As shown, the installed capacity of the grid-connected solar rooftop PV power generation system is 1.85 MWp; however, the maximum power consumption required for the commercial building in 2020 is 4.9 MWp. To gain sufficient power, therefore, the installation of additional solar PV power generation system will be done.

The flow of solar energy and losses from the global horizontal irradiation to the energy produced to the grid by the 1.85 MWp grid-connected solar rooftop PV power generation system is shown in Fig. 4.

Main results

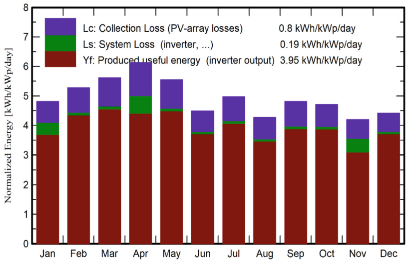
System Production

Produced Energy 2678 MWh/year

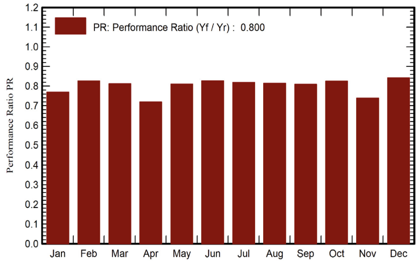
Specific production 1442 kWh/kWp/year

Performance Ratio PR 80.01 %

Normalized productions (per installed kWp)



Performance Ratio PR



Balances and main results

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR ratio
January	138.7	67.37	25.42	149.1	143.3	236.6	213.1	0.769
February	140.9	74.05	27.09	147.9	142.2	231.7	226.9	0.826
March	170.2	84.08	29.16	174.1	167.5	268.3	262.8	0.813
April	184.9	79.97	30.41	184.0	177.2	279.7	246.0	0.720
May	177.1	84.15	30.83	172.1	165.4	264.4	259.0	0.810
June	139.6	85.03	30.11	134.8	129.2	211.5	207.2	0.828
July	159.1	84.88	29.84	154.3	148.2	239.7	234.7	0.819
August	134.0	75.66	29.43	132.2	127.0	204.3	200.0	0.814
September	143.1	72.60	28.12	144.3	138.7	221.7	217.1	0.810
October	141.2	79.03	27.76	146.1	140.4	228.7	223.9	0.825
November	119.0	65.41	27.01	125.9	121.0	198.9	172.9	0.739
December	127.9	72.36	26.02	137.0	131.6	218.8	214.5	0.842
Year	1775.7	924.58	28.44	1801.9	1731.6	2804.2	2678.0	0.800

Legends

GlobHor Global horizontal irradiation
DiffHor Horizontal diffuse irradiation
T_Amb Ambient Temperature
GlobInc Global incident in coll. plane
GlobEff Effective Global, corr. for IAM and shadings
EArray Effective energy at the output of the array
E_Grid Energy injected into grid
PR Performance Ratio

Fig. 3. Simulation results of 1.85 MWp grid-connected solar rooftop PV power generation by PVsyst version 7.2.

3.3 Economic Feasibility

Table 3 shows the details of electricity generation for 25-year operation of solar rooftop PV power generation system. The produced energy was used to estimate the 25-year electricity generation by considering the degradation rate of the PV modules from the specification sheet, which were 2% in the first-year operation and 0.55% for 2-to 25-year operation.

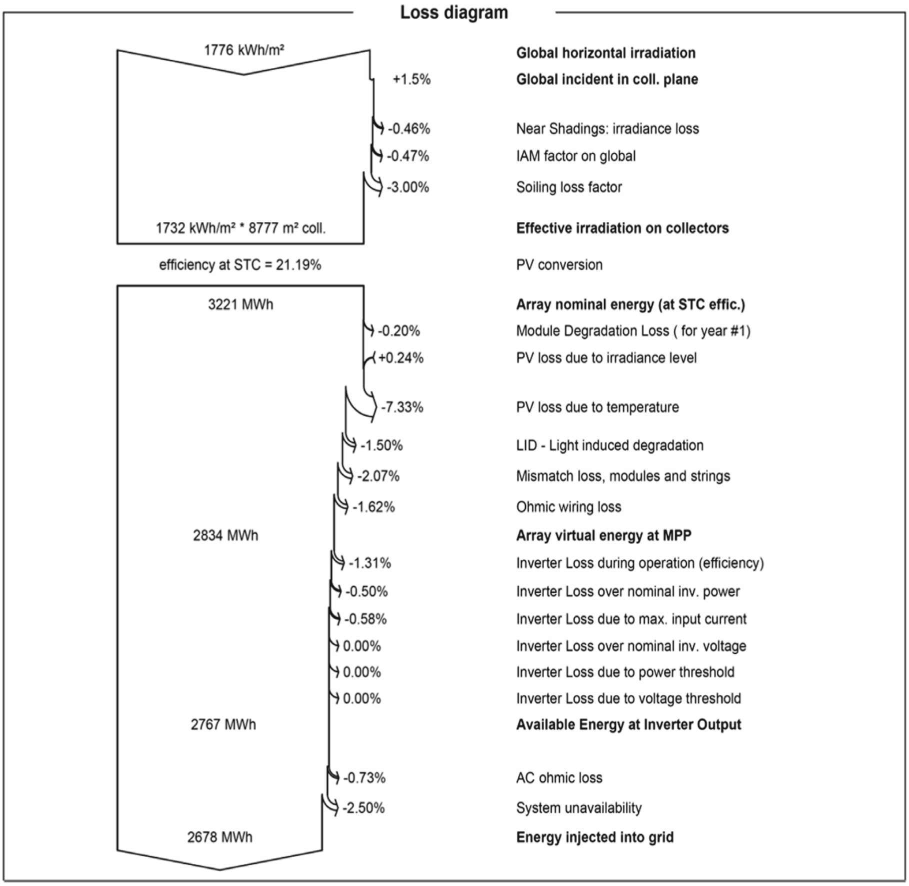


Fig. 4. Loss diagram of 1.85 MWp grid-connected solar rooftop PV power generation by PVsyst version 7.2.

The estimated total initial investment cost was about 1,452,158 USD, mainly for the equipment and the installation cost of the solar rooftop PV power generation system. The energy cost saving in Table 3 was obtained from the calculation of annual electricity generation with the peak and off-peak energy charges. The electricity tariff, which is determined by the Provincial Electricity Authority (PEA), refers to the time of use rate (TOU) in medium general service at the voltage level of 69 kV and over [18]. In the first year, the produced energy of 2,678,659 kWh resulted in energy cost saving of 269,317 USD. Total expenses from year 1 to year 25 accounted for operating and maintenance costs, insurance, utilities, depreciation cost, interests, etc. The economic analysis showed that the PB, NPV, and IRR were 6.37 years, 1,062,430 USD, and 15%, respectively.

Table 3. Economic analysis for 25-year operation of solar rooftop PV power generation system.

Year	Produced energy (kWh)	Energy cost saving (USD)	Total expense (USD)	Net cash flow (USD)	Balance (USD)
0	0	0	0	−1,452,158	−1,452,158
1	2,678,659	269,317	34,089	235,228	−1,216,929
2	2,610,353	265,074	34,231	230,843	−986,087
3	2,595,621	266,214	35,451	230,762	−755,324
4	2,580,888	267,350	36,671	230,678	−524,646
5	2,566,156	268,482	37,891	230,590	−294,056
6	2,551,423	269,610	54,481	215,129	−78,927
7	2,536,690	270,734	55,701	215,033	136,106
8	2,521,958	271,853	56,921	214,932	351,038
9	2,507,225	272,967	58,140	214,827	565,865
10	2,492,492	274,077	59,360	214,717	780,582
11	2,477,760	275,182	61,348	213,834	994,416
12	2,463,027	276,281	61,551	214,730	1,209,146
13	2,448,295	277,374	61,753	215,621	1,424,767
14	2,433,562	278,462	61,956	216,507	1,641,274
15	2,418,829	279,544	62,158	217,386	1,858,660
16	2,404,097	280,620	63,167	217,453	2,076,113
17	2,389,364	281,689	63,369	218,320	2,294,433
18	2,374,631	282,752	63,571	219,181	2,513,615
19	2,359,899	283,808	63,772	220,036	2,733,650
20	2,345,166	284,856	63,973	220,883	2,954,533
21	2,330,434	285,898	65,021	220,876	3,175,410
22	2,315,701	286,931	65,222	221,709	3,397,119
23	2,300,968	287,957	65,422	222,534	3,619,653
24	2,286,236	288,974	65,622	223,352	3,843,005
25	2,271,503	289,983	65,822	224,161	4,067,166

Note: As of 2021, 1 USD = 31.98 THB

4 Conclusions

The installation of 1.85 MWp solar rooftop PV power generation system at the commercial building in this study is technical and economic approved. Using solar energy is sustained for energy efficiency. In the first year, the project achieved energy production of 2,678 MWh resulting in energy cost saving of 269,317 USD. The PB, NPV, and IRR were 6.37 years, 1,062,430 USD, and 15%, respectively. To obtain the electricity sufficiently to the maximum electricity of 4.9 MWp required in 2020, the installation of additional solar PV power generation system will be done. However, the wastes from end-of-life solar panels should be concerned in terms of the recovery of valuable materials and economic analysis.

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