Performance Evaluation of 3.5 kWp Rooftop Solar PV Plant in Thailand

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Abstract—**This article presents an evaluation of the performance of the 3.5kWp rooftop solar PV plant (latitude 17.07°N and longitude 99.05°E) in Thailand's solar rooftop program. Performance parameters, including final yield (Y_F) and performance ratio (PR) are evaluated via Sunny Portal application. The Y_F of this PV Plant was monitored between December 2014 to November 2015 but the PR and physical parameters, solar radiation, module and ambient temperatures and wind speed, have been measured in December 10th – 23rd, 2015 due to additional sensor box has just been installed. Among those recorded data, the annual final yield was 3.81 kWh/kWp/day with the annual total energy generated was 4,869 kWh and its maximum monthly generated energy, 505 kWh on May. The average daily PR was between 59% to 76.4%. The maximum hourly average solar radiation, ambient temperature, module temperature and wind speed recorded were 1,149.1 W/m^2, 37.79 °C, 60.9 °C and 1.48 m/s, respectively. In additionally, economic analysis for this project was elaborated by net present value, the result showed that the investment will be returned in the 9th year later.**

***Index Terms*—solar PV rooftop, final yield, performance ratio**

I. Introduction

LUANCHED in 2013, the first round of the PV rooftop in Thailand [1] with feed in tariff 6.96 THB (Thai Baht) per unit (kWh) for 25 years contract. All power generation from solar PV rooftop system is supplied to network of two distribution utilities; Metropolitan Electricity Authority (MEA) and Provincial Electricity Authority (PEA). The commercial operating date (COD) is also defined within the end of December 2014. Accurate and consistent evaluations of photovoltaic (PV) system performance are critical for the continuing development of the PV industry. This study is aim to evaluate performance of the PV small site (3.5 kWp) both technical and economic base. The study solar PV rooftop system is under PEA responsibility and its COD was on November 7th 2014.

This paper consists of seven parts, introduction, PV plant description, performance parameters, data acquisition system, monitoring results, economical analysis and conclusion.

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II. PV Plant Description

The 3.5 kWp grid-connected solar power plant is in Thailand's solar rooftop program [1]. It consists of 14 modules, each module rated at 250 Wp (Solar World AG) [2]. All modules were divided into two strings and connected them in series for each string. Two strings have been wired to an inverter rated 3.6 kWp (SMA Solar Technology) [3]. The PV plant is located in Bantak district, Tak province, Thailand with latitude 17.07°N and longitude 99.05°E. All modules were tilted equal to their site's latitude (17°) toward the equator, as shown in Fig. 1. More specifications of the PV module and the inverter are illustrated in Table I and Table II, respectively.

III. Performance Parameters

A. Final Yield (Y_F)

Final Yield is defined as the ratio of the annual, monthly, or daily net AC output energy of the plant to the rated dc power of the installed PV plant [6], as in

$$Y_F = \frac{AC\ output\ energy}{Rated\ \ PV\ Plant\ \ Power} \tag{1}$$

The rated PV plant power of this study is 3.5 kWp calculated from 14 PV modules (250Wp per module). The Y_F is widely used to compare the energy produced from PV plants differing size.

B. Reference Yield (Y_R)

Reference Yield [4] is the ratio of total in-plane solar insulation to the PV's reference irradiance (1000W/m^2 at standard test condition, STC), as in

$$Y_R = \frac{Total\ In-Plane\ \ Solar\ Insolation}{reference\ \ Irradiance} \tag{2}$$

C. Performance Ratio (PR)

Performance Ratio [4] is the ratio of Final Yield to the Reference Yield, as in

$$PR = \frac{Final\ \ Yield\ \ (Y_F)}{reference\ \ Yield\ (Y_R)} \tag{3}$$

PR is one of the most important measures for evaluating of a PV plant and also be used to compare PV plants supplying the grid at different locations all over the world.

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Fig. 1. View of the 3.5kWp rooftop PV plant.

TABLE I
PV MODULES AND ARRAY SPECIFICATIONS

Characteristics	Value
Module type	Poly-crystalline Si
Manufacturer	Solar World AG
Module model	Sun module plus sw 250 poly
Module max. power	250 W (STC)
Open circuit voltage	37.6 V
Short circuit current	8.81 A
Max. system voltage	1000 V
Max. reverse current	16 A
NOTC	46 ^{o}C
No. of modules	14
Module area	1.67 m^2
Weight	21.2 kg

TABLE II
INVERTER SPECIFICATIONS

Characteristics	Value
Manufacturer	SMA Solar Technology AG
Model	Sunny Boy 3600TL-21
Input	
Max. dc power	3880 W
Max. dc voltage	550 V
No. of input port	2 (A and B)
Max. input current	15 A per string
PV- voltage range at MPPT	175 - 440 V
Output	
Max. ac power	3680 W
Rated frequency and voltage	50 Hz and 230 V
Max. output current	16 A
Efficiency	
Max.efficiency	97%
European efficiency	96.3%
Operating temperature range	-25 ^{o}C to +60 ^{o}C
Weight	25 kg

IV. DATA ACQUISITION SYSTEM

The data acquisition system for the 3.5 kWp PV plant consists of a Sunny Boy 3600TL-21 inverter, a Sunny SensorBox, and a Sunny WebBox. To operate the SensorBox, an ambient and an module temperature sensors are required. Wind sensor is optional part but this study has included it. RS485 protocol is used to communicate among, the Sunny Boy inverter, SensorBox, and WebBox. Measured data has been recorded and uploaded via Sunny WebBox though public internet network to SunnyPortal server. Sunny Portal analyzes the recorded data and also generate an important parameter, PR.

V. MONITORING RESULTS

A. Measured Y_F

The measured Final Yield's data were recorded and averaged monthly for one year from December 2014 to November 2015 as shown in Fig. 2. Maximum Y_F occurred on May 2015 with 4.65 kWh/kWp/day. The minimum and the averaged Final Yields are 3.34 and 3.81 kWh/kWp/day, respectively. To learn what happen in the peak month, Fig. 3 is illustrated energy produced in daily. Total monthly production is 505 units (kWh) or about 3,515 THB in cash.

In addition, a day in May 2015 is also be the day, which the highest daily yield is recorded at 18.947 unit, if we calculate the daily Final Yield, it is 5.41 kWh/kWp/day. There are seven days, which the PV plant can produce energy to grid more than 18 units.

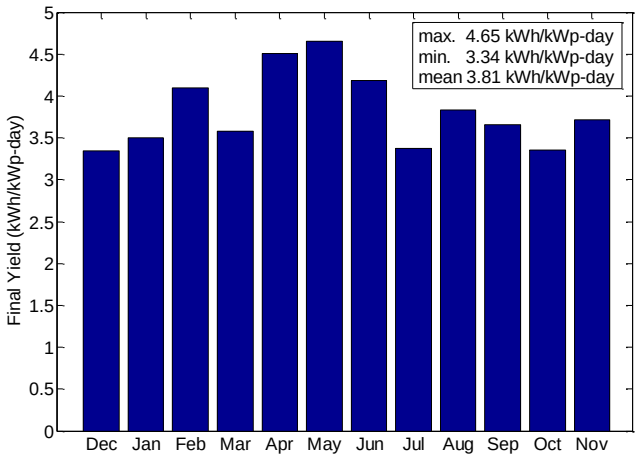

Fig. 2. Monthly average daily PV plant's final yield from December 2014 to November 2015.

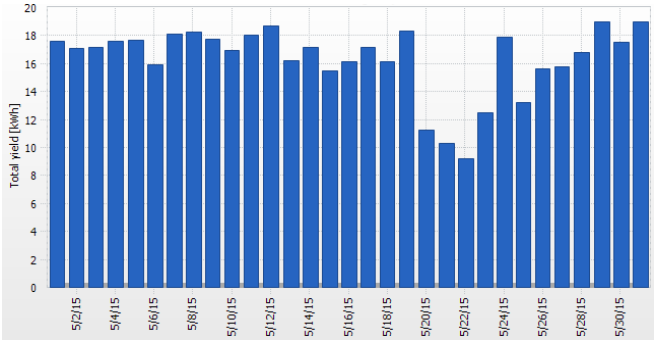

Fig. 3. The 3.5kWp PV plant's daily yields in May 2015(peak of the year).

B. Measured Radiation, Temperatures. and Wind speeds

Example measured solar radiation in hourly average of December 23rd,2015 are depicted in Fig.4. The maximum solar radiation of the day is 1,035 W/m^2 between 12am to1 pm while average power fed to grid is2.301 kW or 2.301 kWh energy produced this period and all day energy production is 14.687 units.

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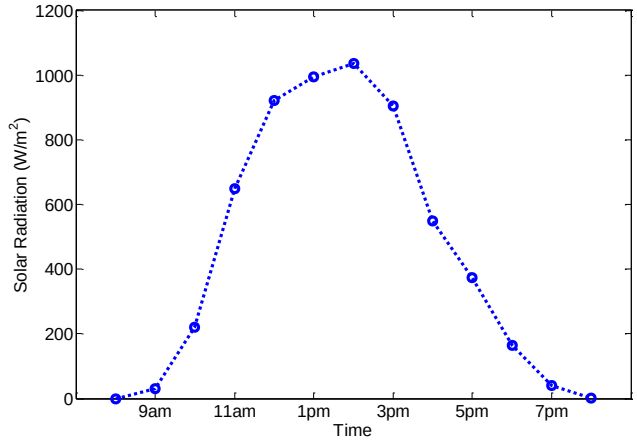

Fig. 4. Hourly average measured radiation on December 23rd, 2015

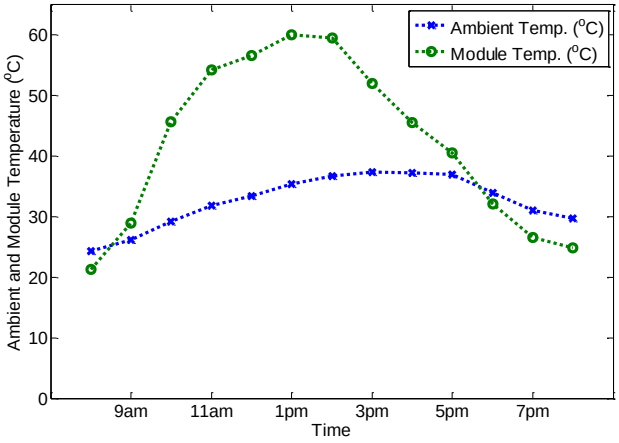

Fig. 5. Ambient and module temperatures on December 23rd 2015.

Example measured ambient and module temperatures (selected December 23rd 2015) are shown in Fig.5. In the clear sky day, peak module temperature can reach 60°C differed from ambient temperature nearly 25 °C at 1pm. Average wind speed of the day is 0.3 but of 1 pm is 0.5 m/s.

C. Performance Ratio

The example measured PRs on December 10th to 23rd, 2015 are investigated. Those PRs are shown in Fig.6 with maximum value at 76.4% on December 17th and the lowest PR at 59.7% on December 22nd.

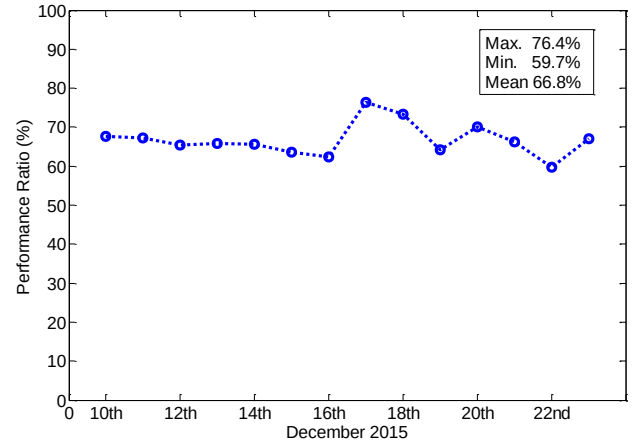

Fig. 6. Performance ratio of the PV plant between 10th to 23rd Dec.2015

TABLE III
PERFORMANCE PARAMETERS OF DIFFERENT ROOFTOP PV PLANTS

Location	PV type	Y_F (kWh/kWp)	PR (%)	Reference
Crete, Greece	Poly-	2.0-5.1	67.4	[5]
Germany		1.9	66.5	[6]
France		3.1	75.8	[7]
Malaga, Spain		3.7	64.5	[8]
Calabria, Italy	Poly-	3.4	-	[9]
Ireland	Mono-	2.4	81.5	[10]
Poland	Amor.	2.3	60-80	[11]
USA		2.5-5.0	65-80	[12]
Pha Bong,Thailand		2.9-4.0	70-90	[13]
Tak, Thailand	Poly-	3.8	59.7-76.4	Present Study

Table III are summarized some important parameters, PV type, Y_F and PR, different rooftop PV plants around the world for comparison approach. Of the study plant with 3.5kWp can obtain higher Final Yield, 3.8 kWh/kWp/day, than of many countrys in Euro zone but it PR is fair.

VI. ECONOMICAL ANALYSIS

The 3.5kWp residential rooftop PV plant had been built and set up completely by a specialized company. The investment total cost included 7% tax is 307,090 THB (Thai Baht), including 14 PV modules, 3.6 kW inverter, accessories and labor cost to build the plant. Table IV collects important data to calculate the net present value (NPV) of the PV project.

TABLE IV
ECONOMIC DATA OF THE 3.5KWP PV ROOFTOP PLANT

Value	Amount
Plant total cost	307,090 THB
Feed in tariff rate	6.96 THB
Initial annual yield	4,788 unit (kWh)
Yield reduction rate	0.05% per year
Project period	25 years

To generate NPV curve by

$$NPV = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i} \qquad (4)$$

Where C_0 is plant total cost (investment), C_i are incoming cashflow, r is discount rate, i is time step (year) and T is time period (25 years for this project).

C_i can be generated by

$$C_i = C_{i-1} \times (1 - yield\ \ reduction\ \ rate) \qquad (5)$$

For example, C_1 is 33,324 THB from 4,788 multiplying by 6.96. Another one,C_2 is 33,157 from C_1 multiplying by 0.995. Complete generated NPV curve is shown in Fig. 7. From the NPV curve, the cash flow of this 3.5 kWp rooftop PV plant project will positive at 9th year with 6,991 THB until 25th year with 497,990 THB. It is a reliable investment.

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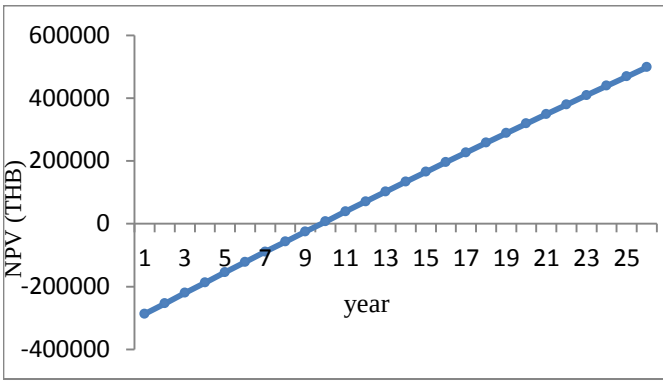

Fig. 7. The 3.5kWp rooftop PV plant NPV calculation.

VII. Conclusion

Performace evaluation of the 3.5kWp rooftop in Thailand is done in the first year. The annual Final Yield is average 3.8 kWh/kWp/day. The Performance Ratio in December 2015 is between 59% to 76.4%. The economic analysis confirm that this project is reliable investment. Further work is planned to record more data for improving the performance of the 3.5 kWp PV Plant.

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