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Energy Procedia 103 (2016) 183 – 188

Energy Procedia

Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid, 19-21 April 2016, Maldives

Long term performance analysis of a 19.8kWp standalone photovoltaic system in a remote island

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Abstract

This study investigates the long term operation performance of a 19.8kWp standalone photovoltaic (PV) system on a remote island of Hong Kong. After several months of testing and commissioning, the environmental and operating data of the system from August 2010 to July 2012 were collected. The evaluation results show that the PV plant worked very effectively during the reporting period. This study suggests that the residents should be trained for better utilization of the energy from the PV array and battery bank based on weather condition and battery bank status. The result also indicates the limitation of this standalone PV system, suggesting that it would be better to develop or integrate it into a microgrid system if possible.

Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid.

Keywords: Performance evaluation; stand-alone photovoltaic system; remote islands; normalized performance parameters

1. Introduction

Out of 7 billion people globally, 1.2 billion people in developing countries live in dark homes, without access to utility electricity, instead rely on inefficient and often dangerous alternatives such as diesel generator, kerosene lamps, candles, flashlights and batteries [1]. In this context, during the last two decades, some interesting studies have been published concerning the utilization of standalone photovoltaic (PV) system to supply power for isolated consumers, such as in Mediterranean area, Middle

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Peer-review under responsibility of the scientific committee of the Applied Energy Symposium and Forum, REM2016: Renewable Energy Integration with Mini/Microgrid.
doi:10.1016/j.egypro.2016.11.270

East, Africa, India, and Western China [2]. However, the long term sustainability of off-grid PV systems, as explained by many case studies, possesses significant challenges. Therefore, there is a need to understand and evaluate the operation performance of a standalone PV system, which can assist the users to fully utilize the PV system and to periodically ensure that the equipment response meets design expectations.

This study is a follow-up of our previous study [3-5], in which only one-year operation data is evaluated. In the present study, the onsite data from August 2010 to July 2012 is analyzed, including the environmental data and subsystem operation data, to investigate the long term operation performance of the solar PV system.

2. Background of the studied PV system

Town Island (22°36′N and 114°40′E), the island involved in this study, is located in the southeastern part of the Sai Kung District of Hong Kong. The island is as much as 22km off the coast of Hong Kong. A non-profit-making organization, Operation Dawn, has run the Drug Addiction Treatment & Rehabilitation Centre on this island since 1976. At present, the island has around 60 recovering drug users and employees on the island. Operation Dawn is contemplating extending accommodation provision to include about 100 residents. In 2009, a local utility company CLP Power Hong Kong Limited planned to use the available renewable energy resources (RE) for power supply. In Stage 1 of this project, a stand-alone 19.8kWp PV system was installed on the island in 2010. This is the first standalone commercial-scale RE system in Hong Kong. This system was used mainly to test PV system's feasibility, understand its operating characteristics, and prepare for the system implementation in next stage.

The schematic diagram of the PV plant is illustrated in Fig. 1.

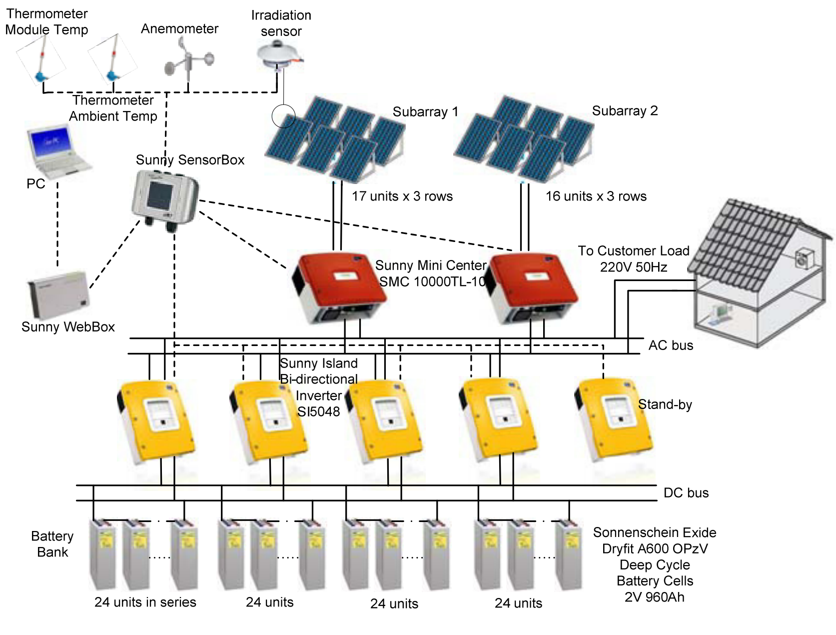

Fig. 1 Schematic diagram of the PV plant

The system employs two different types of inverters: two PV inverters (also known as grid-tied inverters) and five bi-directional inverters (one for standby). The two Sunny Mini Center (SMC) PV inverters directly transform the PV output DC to supply AC to the load while surplus energy is used to charge the battery bank via the Sunny Island (SI). The SI inverter can also provide AC output using the energy stored in the battery bank when there is high demand or when solar energy is not available. The battery tank is composed of 96 deep cycle cells (960Ah, 2V). 24 cells are connected in series to provide a 48V nominal storage voltage. The PV system consists of subarrays with 99 solar panels from Suntech with each panel of 200Wp.

3. Evaluation method

There are three main generally recognized evaluation methods [6]: 1) international standard IEC 61724 [7], which provides photovoltaic system performance monitoring guidelines for measurements data exchange and monitoring parameters, frequency of measurements and duration of monitoring; 2) Ispra Guidelines [8] that follow an analytical monitoring method; and 3) the normalized parameters that are developed by International Energy Agency (IEA). This study is a follow-up of our previous study, therefore the same evaluation methodology is employed based on the guideline of IEC 61724.

4. Evaluation results and analysis

4.1 Module temperature and ambient temperature

Fig. 2 shows the hourly mean temperatures of ambient air and PV module in June 2011. The ambient air temperature varied from 25 °C to 35°C, while the PV module temperature fluctuated greatly from 30 °C to 60°C. The peak difference between ambient and PV module can reach to 30 °C. High PV temperature will have negative impact of PV power generation at the rate of 0.47% per °C.

4.1 PV array performance analysis

The relationship between instantaneous PV array efficiency and module temperature power is presented in Fig. 3, demonstrating that the high temperature has negative impact on its power generation. When the PV module temperature changes from 30°C to 55 °C, the PV module efficiency reduced from 12.5% to 11.5%. This figure also indicates that the slope of the fitting trendline is -0.348, which is exactly equal to the temperature coefficient of power output provided by the manufacturer (-0.47%/°C/13.6%).

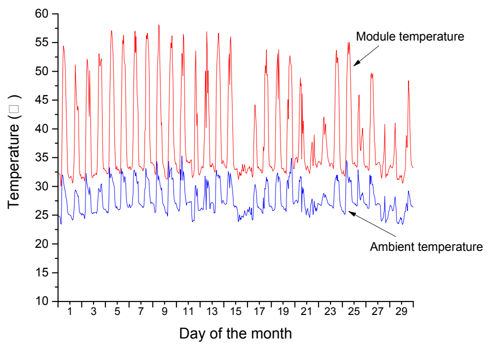

Fig. 2 Hourly average ambient temperature and PV module temperature in June 2011

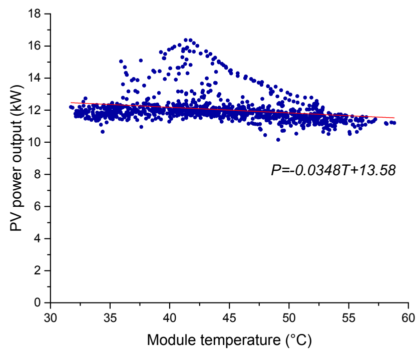

Fig. 3 PV array efficiency versus module temperature (from 1st to 10th May 2011)

The daily electricity generated by the two PV subarrays in December 2011, as an example, is given in Fig. 4 to compare their operating performance. It can be seen that the daily energy production of the subarray 1, with three parallel stings of 16 modules connected in series, is lower than that of subarray 2 with a similar configuration of 17×3. The total energy production in this month is 979kWh from the subarray 1 and 1,082kWh from the subarray 2. The production ratio between them is 0.90, slightly lower than the capacity ratio of 0.94 (=16/17), demonstrating that the subarray 2 performs a little better than the subarray 1.

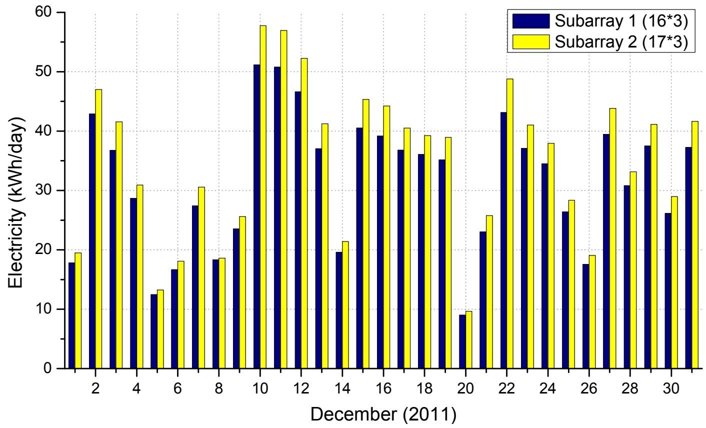

Fig. 4 Electricity production comparisons between the two PV subarrays in December 2011

4.2 Battery bank performance

The hourly averages of the batter bank SOC over the reporting period is depicted in Fig. 5, demonstrating that the daily lowest and highest SOC value occurred at about 7:00am (60.6%) and 5:00pm (88%), respectively. At 7:00am, solar radiation is increasing and the battery bank is being recharged, and thus a significant increase in SOC can be observed. The SOC growing rate is great at the beginning before the peak solar radiation at about 1:00pm, and afterwards the growth of SOC continues but the rate is less. This growing trend ends at about 5:00pm when load consumption is balanced with energy supply. During this period, the solar radiation experiences an increase, a peak value and a decrease. Thereafter, the SOC declines continuously until 7:00am next morning. It should be noted that this difference between the maximum and minimum SOC values could be reduced if a hybrid solar and wind system can be used with their good complementary characteristics [9]. This aspect will be further studied during Stage 2 involving an optimal hybrid solar and wind system design.

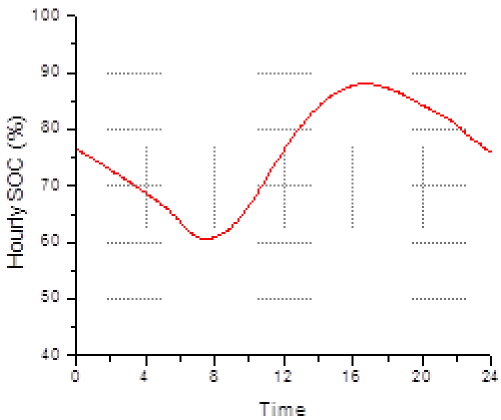

Fig. 5 Battery bank SOC's hourly variation during two years (time interval: 5 minutes)

4.3 Normalized performance parameters

Fig. 6 presents the monthly average normalized parameters results during two years including final yield, array capture losses, and system losses. The monthly final yield ranged between 0.84h/d and 4.24 h/d, with high values in summer and low values in winter. The daily array capture losses varied from between 0.35 h/d to 0.89 h/d, and the system losses was in the range of 0.34 h/d to 2.72 h/d. Based on Fig. 6, the annual average monthly array yields were 3.20h/d, 3.08h/d, 2.88h/d in 2010, 2011 and 2012, respectively, and the final yields were 2.49 h/d, 2.49 h/d and 2.33 h/d, respectively. The results reveal that the anticipated output of PV array was 4.08 kWh/kWp/day, which is equivalent to 3.05 hours per day at its nominal/rated power (19.8kWp), among which 2.45 hours was ultimately used to meet the load demand. Compared to other PV systems installed globally, the annual final yield of the studied system is higher than the systems in European countries (1.8 h/d in the Netherlands, 1.8 h/d in Germany and 2.0 h/d in Italy), while lower than those in some Asia countries (2.7 h/d in Japan and 3.0 h/d in h d−1) [10].

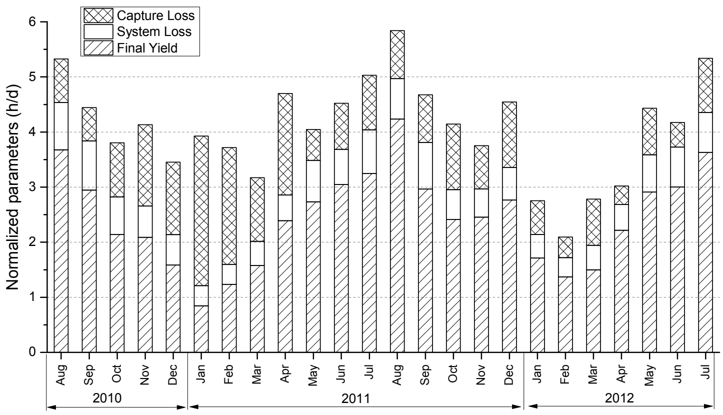

Fig. 6 Monthly average normalized parameters during two years

5. Conclusions

Based on the two-year data analysis, it can be observed that the 19.8kWp standalone PV system worked very effectively during the reporting period. The PV system worked very well with AC power generation efficiency of 10%. The results reveal that the reference yield, array yield and final yield are 4.08, 3.05, and 2.45 kWh/kWp/day, respectively. The mismatching between electricity production and load consumption not only results from the energy losses in the balance of the system (BOS) including SMC inverters, SI inverters, battery bank, and conduction losses in distribution cables, but also depends on the energy utilization pattern of the local residents on the island. The result is an also indication of the limitation of this standalone PV system, suggesting that it would be better to develop or integrate it into a microgrid system if possible and a better utilization pattern of the power should be introduced so that a high energy utilization plan should be promoted to local residents.

Acknowledgements

The authors would appreciate the financial supports provided by Research Institute for Sustainable Urban Development (RISUD) (Grant No.: K-ZJK1/1-ZVED) of The Hong Kong Polytechnic University, and the National Natural Science Foundation of China (NSFC) through the Grant 51506183. CLP Power Hong Kong Limited has provided great supports and help for data collection from the system.

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