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Long term performance analysis of a standalone photovoltaic system under real conditions

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HIGHLIGHTS

- Two-year environmental and operating data of a standalone PV system was collected to analyze its long term performance.
- The PV array operated well with AC power generation efficiency of 10% and overall system efficiency is 7.7%.
- Results suggest that it would be better to develop or integrate the PV system into a microgrid.

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ABSTRACT

Renewable energy based power generation system holds the most promising solution for remote area power supply. In this study, the long term operation performance of a 19.8 kWp standalone solar photovoltaic (SAPV) system in a remote island is investigated. The methodology for evaluating system performance is introduced, and then the detailed assessment results are presented, accompanying with analysis and discussion. Results show that the photovoltaic (PV) array operated well with AC power generation efficiency of about 10% and overall system efficiency is about 7.7%. The reference yield, array yield and final yield are 4.08, 3.05, and 2.45 kW h/kWp/day, respectively, therefore the resultant performance ratio is 60%, demonstrating that the performance of SAPV plant is satisfactory during the reporting period. However, after long term performance monitoring and analysis, the limitation of SAPV system begins to arise due to lack of grid management and compensations from other energy sources, suggesting that it would be better to develop or integrate it into a microgrid system with hybrid sources if possible.

1. Introduction

At present there are still about 1.2 billion people still living in dark homes, without access to utility electricity [1], instead rely on inefficient and often dangerous alternatives such as diesel generator, kerosene lamps, candles, flashlights and batteries, or even on power supply. As illustrated in Fig. 1, about of 95% live in sub-Saharan Africa and South and East Asia, including 5 million people in China [2]. Currently it is a big challenge for most of the developing countries to provide electricity through national grid. Solar photovoltaic (PV) system, as one of most important part of renewable energy, provides a viable option for rural electrification and in some areas it has been proved as a cost-effective means of rural electrification in developing countries. In this context, during the last two decades, there has been a constant increase of the investment in the research of PV conversion of solar radiation to produce high quality, yet cheap solar cells and other components of the PV systems [3], and some interesting studies have been published concerning the utilization of PV system to supply power for isolated consumers, such as in Mediterranean area, Middle East, Africa, India, and Western China [4–7].

It is widely acknowledged that the efficiency and power output of PV system under natural conditions is lower than the rated values under standard test conduction (STC), because the real operating performance is substantially affected by local environmental conditions such as ambient temperature, relative humidity, dust storms and suspension in air, global solar radiation intensity, spectrum distribution, degradation and maintenance [8–10]. In this context, it is important to monitor and evaluate PV system's operation performance under highly uncertain weather conditions, because it not only provides a platform to understand its energy production, loss mechanisms, reliability and causes of system failures, but also assists the users to fully utilize the electricity

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Nomenclature

Abbreviations

AC	alternating current
DC	direct current
PF	production factor
PR	performance ratio
PV	photovoltaic
SAPV	standalone photovoltaic
SI	Sunny Island
SMC	Sunny Mini Center
SOC	state of charge
STC	standard test condition
UF	usage factor

Symbols

η_{PV}	solar energy conservation efficiency of PV array
η_{SMC}	efficiency of the Sunny Mini Centre inverter
η_B	roundtrip energy efficiency of the battery bank
η_{sys}	overall conversion efficiency of the PV plant
P_i	instantaneous DC output power of the PV subarray 1 and 2 (W)
P_{SMC}	output power of SMC inverter (W)
P_{SI}	input or output power of SI inverter (W)
E_{PV}	electricity production of PV array/plant (kW h)
E_{PV}	electricity production of PV subarray 1 and 2 (kW h)
$E_{B_{in}}$	energy input into the battery bank (kW h)
$E_{B_{out}}$	energy output from the battery bank (kW h)
U_{PVi}	voltage of PV subarray 1 and 2 (V)
I_{PVi}	current of PV subarray 1 and 2 (A)
G_t	incident solar radiation on unit area of tilted PV panel (W/m^2)
A	total solar cell area (m^2)
t	time period during which solar radiation exists (h)
E_{actual}	actual reading of PV plant output (kW h)
$E_{nominal}$	calculated nominal PV plant output (kW h)
Y_F	final yield (kW h/kWp/day)
Y_A	array yield (kW h/kWp/day)
Y_R	reference yield (kW h/kWp/day)
L_S	system loss (kW h/kWp/day)
L_C	capture loss (kW h/kWp/day)

output and to periodically ensure that the equipment response meets design expectations [11]. From a design perspective, the real-time long term monitoring can also highlight potential deficiencies of the power supply design, thus allowing the adoption of adequate countermeasures [12,13].

In recent years, substantial research has been conducted to evaluate operation performance of grid-connected PV systems around the world in terms of system performance, energy yield and economic effectiveness [3,11,14–18]. However, little has been done in the field of standalone photovoltaic (SAPV) systems for remote area power supply. For example, International Standard IEC 61724 [19] recommended procedures for the analysis of monitored data to assess the overall performance of PV systems and help to identify any malfunction at an early stage, but it did not provide a well-adapted method for the analysis of SAPV [13]. In the literature, a life cycle assessment of a 4.2 kWp SAPV system was performed in south-east of Spain [20], while the focus of this study is energy payback time and CO_2 emission reduction. A standalone lighting system powered by PV in Malaysia was assessed in [21], which employs the simulation tool PVSYST software for predicting energy output, instead of evaluating real-time operating data. The performance of an SAPV system in Saudi Arabia was analyzed in [8], whereas only two-month data was used and the emphasis is the effect of high temperature on PV power generation. The study [22] suggests that remote monitoring can strongly increase the PV system performance, in particular for those SAPV systems installed in remote locations. However, available studies provide scarce information on long term monitoring and evaluation of SAPV system operation under real outdoor conditions, especially in the sub-tropical weather like Hong Kong.

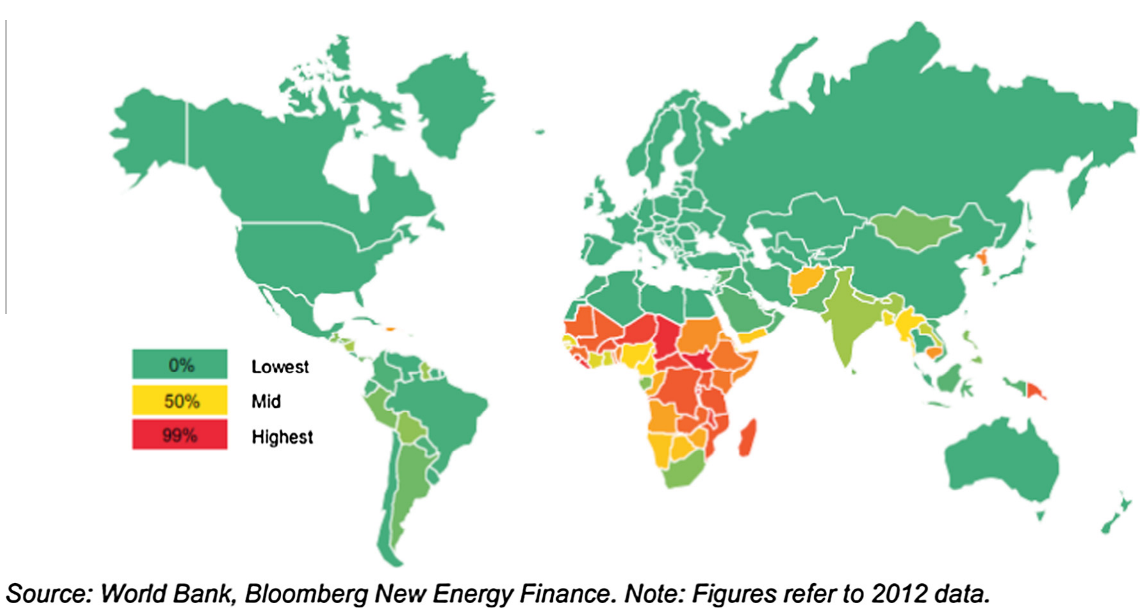

Fig. 1. Share of population without grid access (percent of total) [2].