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Energy efficiency evaluation of building integrated photovoltaic systems with different power configurations

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ABSTRACT

The photovoltaic (PV) modules used in the building integrated photovoltaic (BIPV) system generally are installed in different orientations and angles. The performance of them is easily to be affected by partial shadows and mismatch of their electrical parameters. Some high performance power configurations have been proposed to solve these problems. This paper presents an energy efficiency analysis method to evaluate the energy efficiencies of BIPV systems with different power configurations. The principles and performance of seven types of power configurations for BIPV systems are discussed. The energy efficiency analysis model of each BIPV power configuration is built, and the simulation results of each configuration under different partial shade and electrical parameter mismatch conditions are presented to quantitatively evaluate their energy efficiencies. The evaluation results show that the AC module and photovoltaic DC building module is the optimal configuration since they have better anti-shading and anti-mismatch performances than the other power configurations.

1. Introduction

Public awareness of the world energy crisis and building energy saving issue has encouraged many countries around the world to promote building integrated photovoltaic (BIPV) applications. BIPV systems use the no-cost and renewable solar energy to generate electricity pollution-free and can be seamlessly integrated with buildings to reduce installation costs and shorten energy payback time.

The operating circumstance of BIPV systems is different to those of the ground photovoltaic (PV) power plants and roof PV systems. In ground mounted PV power plants, the PV modules generally operate under identical irradiance conditions. However, the PV modules used in BIPV systems are generally installed in different orientations and angles. They are easily to be partially shaded by the neighboring buildings, trees and passing clouds. Therefore, their energy efficiency might decrease under difference irradiance and temperature conditions.

Building integrated systems have certain requirements that are difficult for centralized systems, which are usually used in ground PV power plants and roof PV systems, to satisfy [1]. Some improved power configurations are proposed, such as the string/multi-string system [2], string system based on bypass DC module [3], string system based on generation control circuit (GCC) [4,5], cascaded system [3,6,7], AC module based system [8,9], and photovoltaic DC building module (PV-DCBM) based system [10,11]. Each power configuration is able to improve the energy efficiency of BIPV systems under partially shaded condition. Several widely used power configurations are introduced and some qualitative characteristic analyses are performed in literatures [1,3]. The impact of partial shadowing on the array performance is evaluated based on the

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Nomenclature

η	energy efficiency of a BIPV system
P_{MO}	practical output power of all the PV modules in a BIPV system (W)
P_{BOS_loss}	total loss of BOS (W)
n	number of PV modules
P_{M_k}	maximum available power of the kth PV module (W)
V_j	output voltage of the jth PV module (V)
V_{MPP_j}	MPP voltage of the jth PV module (V)
V_{Str}	total output voltage of a PV module string (V)
I	output current of a PV module (A)
I_{ph}	photocurrent (A)
I_{D1}	current through the diode D_1 (A)
I_{D2}	current through the diode D_2 (A)
I_v	avalanche breakdown current (A)
I_{sh}	current through R_{sh} (A)
V_D	voltage across the diode D_1 (V)
R_{sh}	shunt resistance (Ω)
V	output voltage of a PV module (V)
m	number of PV cells in a PV module
R_s	series resistance (Ω)
I_{ph0}	photocurrent at the standard test condition (A)
I_{rr}	irradiance (kW/m^2)
S_t	shadow's transmittance of per PV module
I_{s1}	reverse saturation current of D_1 (A)
I_{s2}	reverse saturation current of D_2 (A)
A_1	quality factor of D_1
A_2	quality factor of D_2
q	magnitude of the electron charge (1.602×10^{-19} C)
k	Boltzmann constant (1.38×10^{-23} J/K)
T	absolute temperature of PV cell (K)
V_{br}	avalanche breakdown voltage (V)
α	constant value
nn	constant value

monitoring result from a 5 kWp photovoltaic system, which consists of three independent subsystems (a central inverter, a string inverter, and a number of AC modules) in [12]. Literature [13] evaluates the impact of tilt angles and orientations on the annual performance of PV modules (mono-crystalline silicon type) based on a single diode model of PV modules. A statistical analysis method was proposed in [14] to evaluate the output performance of the photovoltaic modules. A fast algorithm suitable for modeling the behavior of a photovoltaic field operating in both uniform and mismatched conditions is proposed to evaluate the long-term energetic performances of photovoltaic fields in [15]. However, quantitative evaluations on the energy efficiency of various power configurations are limited.

There are two main objectives of this paper. The first objective is to present a method to analyze the energy efficiency of existing power configurations. The second objective is to use evaluation models to quantitatively compare the energy efficiency of various power configurations under different partial shade and electrical parameter mismatch conditions. Finally some simulation results and conclusions are presented to guide future BIPV system' design.

2. Energy efficiency analysis method

2.1. Energy efficiency definition of BIPV systems

A BIPV system consists of PV modules, balance of system (BOS) and the electrical grid. The BOS includes power converters, power transfer cables, power distribution device, monitoring system, structures for mounting the PV modules, etc. Under the certain environment conditions (such as illumination, shade conditions and temperature), the energy efficiency η of a BIPV system can be defined as:

$$\eta = \frac{P_{MO} - P_{BOS\_loss}}{\sum_{k=1}^{n} P_{M\_k}} \times 100\% \tag{1}$$