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A novel optimization sizing model for hybrid solar-wind power generation system

Hongxing Yang *, Lin Lu, Wei Zhou

Renewable Energy Research Group (RERG), Department of Building Services Engineering, The Hong Kong Polytechnic University, Hung Hom, Kowloon, Hong Kong

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Abstract

This paper develops the Hybrid Solar-Wind System Optimization Sizing (HSWSO) model, to optimize the capacity sizes of different components of hybrid solar-wind power generation systems employing a battery bank. The HSWSO model consists of three parts: the model of the hybrid system, the model of Loss of Power Supply Probability (LPSP) and the model of the Levelised Cost of Energy (LCE). The flow chart of the HSWSO model is also illustrated. With the incorporated HSWSO model, the sizing optimization of hybrid solar-wind power generation systems can be achieved technically and economically according to the system reliability requirements. A case study is reported to show the importance of the HSWSO model for sizing the capacities of wind turbines, PV panel and battery banks of a hybrid solar-wind renewable energy system.

Keywords: Hybrid solar-wind system; Loss of Power Supply Probability (LPSP); Levelised Cost of Energy (LCE)

1. Introduction

For different regions and locations, climatic conditions, including solar irradiance, wind speed, temperature, and so forth, are always changing. Thus, there exist instability shortcomings for electric power production from photovoltaic (PV) modules and wind turbines. In order to efficiently and economically utilize renewable energy resources of wind and solar energy applications, the optimum match design sizing is very important for solar-wind power generation systems with battery banks. The sizing optimization method can help to guarantee the lowest investment with a reasonable and full use of the PV system, wind system and battery bank, so that the system can work at the optimum conditions with optimal configurations in terms of investment and reliability requirement of the demand load.

There are a number of studies about the optimization and sizing of hybrid PV-wind system since the popular utilization of photovoltaic modules and wind turbines in the 1980s. Generally, there are three main approaches to achieve the optimal configurations of hybrid systems in terms of technical analysis and economical analysis, i.e. the least square method (Castle, 1981; Borowy and Salameh, 1994; Gomaa et al., 1995), the loss of power supply probability (LPSP) method (Abouzahr and Ramakumar, 1990, 1991; Beyer and Langer, 1996; Yang et al., 2003) and the trade-off method (Burke, 1988; Gavanidou and Bakirtzis, 1992; Yang and Burnett, 1999; Chedid et al., 1998; Elhadidy and Shaahid, 1999).

In this paper, the hybrid solar-wind system optimization sizing (HSWSO) model, a novel optimum sizing tool for hybrid solar-wind systems employing a battery bank, is developed based on the loss of power supply probability

* Corresponding author. Tel.: +852 2766 5863; fax: +852 2774 6146.
E-mail address: behxyang@polyu.edu.hk (H. Yang).

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Nomenclature

C	battery capacity, A h
CO	capital and maintenance cost, $
DOD	depth of discharge
E	energy supply, kW h
F	factor
G	solar radiation, W/m^2
I	current, A
LCE	levelised cost of energy, $/kW h
LPSP	loss of power supply probability
N	number
P	power, W
R	resistance, Ω
$r_1 \ldots r_4$	empirical constants
SOC	battery state of charge
T	temperature, K
V	voltage, V
VF	full charge rest voltage, V
v	velocity, m/s
Y	lifetime year
Z	height, m

Greeks

α	power law exponent
β	slope angle of the plane, radians
γ	azimuth angle of the plane, radians
ε	sky clearness
η	charge efficiency factor
θ	angle of incidence, radians
δ	hourly self-discharge rate

Subscripts

a	ambient air
an	annually
bat	battery
bh	beam radiation on horizontal surface
C	cut-in
con	connection losses
dh	diffuse radiation on horizontal surface
dt	diffuse radiation on tilt surface
F	cut-off
in	inverter
O	extraterrestrial
oth	other losses
PV	PV module
PVA	PV array
PVP	parallel connection of the PV module
PVS	serial connection of the PV module
R	rated
r	reference
re	rectifier
tt	total radiation on tilt surface
W	wind turbine
Z	zenith angle of the sun

(LPSP) concept and the levelised cost of energy (LCE) concept. The LPSP technique, which is considered to be the criteria for sizing, is the probability that an insufficient power supply results when the hybrid system is unable to satisfy the load demand. Using the LPSP objective function, the configurations of a hybrid system which can meet the system reliability requirements can be obtained. There are three sizing parameters in the simulation, i.e. the capacity of PV system, the rated power of wind system, and the capacity of the battery bank. Additionally, the orientations of PV modules and the tower heights of wind turbines are also considered. The optimum configuration can be identified from the set of the above obtained configurations by achieving the lowest levelised cost of energy.

2. Model of hybrid solar-wind system

A hybrid solar-wind power generation system consists of a PV system, a wind power system, a battery bank, rectifiers, an inverter, and a controller, other accessory equipment and cables. Sometimes the system loads also include one dump load for safety protection. The power supply from the PV modules and the wind turbine to the demand side, the battery bank and the dump load obey the following priority: first the demand side; second the battery bank; last the dump load.

2.1. Mathematical model for PV system

The power generation simulation model for a PV system is composed of three parts: PV modules, PV array, and the solar radiation on any tilted PV panels for any orientations. The model of PV arrays can be used to represent the model of the PV system.

2.1.1. PV modules

The performance of crystalline silicon PV modules is a function of the physical variables of the PV cell material, the temperature of solar cells and the solar irradiance exposed on the solar cells. In this paper, one simplified applicable model for the maximum power output of PV modules is used. The regressed parameters and the model are described as follows:

$$P_{\mathrm{m}} = -(aG_{\mathrm{tt}} + b) \cdot (T_{\mathrm{a}} + 0.03375G_{\mathrm{tt}}) + cG_{\mathrm{tt}} + d, \tag{1}$$

where G_{tt} is the total solar radiation absorbed by the PV modules, W/m^2; T_{a} is the ambient temperature around PV modules, K; and a, b, c and d are constants from regression results for PV modules.