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Sustainable feasibility of solar photovoltaic powered street lighting systems

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ABSTRACT

In the last few years, due to soaring fuel prices and gas emissions, renewable energy technologies have been suggested as the power source for infrastructures. The interest in solar photovoltaic (PV) assisted street lighting systems stems from the fact that they are sustainable and environmentally friendly compared to conventional energy powered systems. The present paper investigates and compares the economic feasibility of two types of systems: islanded and grid-connected system, for the street lighting systems in Hunan Province, China. Based on two options of solar panel materials, a simulation model of the system is developed for economic, technical and environmental feasibility. The comprehensively sustainability feasibility of these systems is conducted taking into account the cost, energy generation, CO_2 emissions and renewable fraction. Radar plot is employed to integrate all the sustainability indicators into a general indicator, which presents system's sustainability as a real number in the interval [0, 2]. Results show that for street lighting systems of all the cities, single crystal panel has a larger number of annual electricity generation, less emissions and higher environmental performance, but is more expansive than polycrystalline. It is also found that when the feed-in tariff higher than 1.27 CNY/kW h, the cost of energy (COE) of the solar powered lighting systems is less than a pure grid powered system. This will incite the use of solar PV in infrastructures. Through comparing the scores of sustainability, it is found that the Loudi system has the highest feasibility while the Yongzhou system has the lowest in the province.

1. Introduction

Street lighting systems consume 43.9 billion kW h electricity every year. Solar photovoltaic (PV) technology is claimed as a solution for this part of electrical load because of its environmental advantages (e.g., cleaner, less emissions, and no fossil fuel). However, solar PV powered street lighting system has also two important shortcomings: (1) the devices have a relatively higher price than grid electricity from traditional electricity generation; (2) a bigger size of energy storage component is needed, because of the time difference between the energy resource peak and electricity consumption peak. As a result, the comprehensive sustainability assessment is a big issue in the feasibility study of solar based street lighting systems.

The feasibility study of street lighting system based on energy saving analysis and economic feasibility have been highlighted in a number of research projects [1–4]. Overall, these studies are all able to confirm that under their local solar irradiation, the energy consumption of street lighting system is significantly reduced by integrated solar energy devices, but the extent would vary from region to region. It seems that few of these literatures quantified the relationship between energy saving behaviors and local climate conditions.

While most of the current studies about system design and optimization concentrate on the technical feasibility for either grid-connected or stand alone street lights [5–13], there appear to be few studies comprehensively considering environmental sustainability. In spite of some previous studies about the feasibility of the application of solar energy generation [14–18] just focusing on some one aspect of sustainability, it is difficult to find literature about comprehensively sustainable feasibility study of solar street lighting systems. This could seriously hinder the feasibility study, design and evaluation strategy for the utilization of solar energy in street lighting system.

This paper studies the sustainable feasibility of street lighting systems in Hunan Province, China. Through building computer simulations based on the local solar irradiation data, three types of performance indicator (technical, economic and environmental indicators) of the systems during their whole life time are quantified for all the fourteen cities in Hunan.[1] Through comparing two different materials (monocrystalline silicon and polycrystalline silicon)

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[1] Hunan Province has fourteen cities: Changde, Changsha, Chenzhou, Hengyang, Huaihua, Loudi, Shaoyang, Xiangtan, Xiangxi, Yiyang, Yongzhou, Yueyang, Zhangjiajie and Zhuzhou.

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Nomenclature

C	costs ($)
E	electricity (kW h)
EF	emissions factor $\left(\frac{kg}{kW\,h}\right)$
Em	emissions (kg)
f	derating factor (–)
I	solar irradiation $\left(\frac{kW}{m^2}\right)$
N	number (–)
P	power generation (kW)
Q	electricity throughput (kW h)
t	life time (h)
T	electricity tariff $\left(\frac{}{kW\,h}\right)$
Y	rated capacity (kW)
η	efficiency (–)

Subscripts

ann, tot	total annualized
bat	battery
float	float time of battery
G	global solar irradiation
grid, sales	the total grid sales
prim	primary load served
pur	electricity purchased from the grid
PV	photovoltaic
rep	replacement
S	standard conditions
sb	electricity sale back to the grid
thrpt	throughput

based PV panel, the annual energy generation, cost of energy, carbon dioxide emission mitigation, and renewable fraction of the systems are studies. A sensitivity analysis investigates the relationship between the cost of energy and the feed-in tariff. In addition, an integrated indicator is used to study the comprehensively sustainable feasibility of the systems. These results provide transport department and electrical sector with information as to the extent of energy saving, costs and emission reduction which can be achieved by installing a PV based street lighting systems. It is believed that the results from this research will form a basis for the formulation of government incentive policies. For power companies and electrical grid, these results can be used as a reference to make the best marketing strategies when the purchasing tariffs and feed-in tariff of electricity are being formulated.

2. Research methodology

The reported research was undertaken using computer-based renewable energy simulation tool, with collected weather data and economic data as inputs. The model of a grid-connected and islanded PV street lighting system is introduced in this section, as well as the system optimization objective and the simulation software. The performance characteristics of monocrystalline silicon and polycrystalline silicon, the related weather data of the fourteen cities of Hunan, the local prices of devices, electricity tariffs, and feed-in tariffs are introduced as well. In addition, the approach of radar plot is also employed to comprehensively assess the sustainable feasibility of the systems.

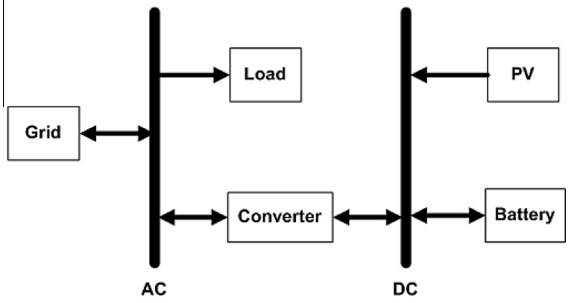
2.1. System configuration and component simulation

The sample solar PV based street lighting system, as shown in Fig. 1(a), is classified into two types. One is grid-connected system, and the other one is islanded system. The grid-connected street lighting system (Fig. 1(b)) has a DC (Direct Current) PV panel as the energy generator, a DC battery as electricity storage system, as well as inverter converting electricity between DC and AC (Alternating Current). The configuration of the islanded system is simpler than the grid-connected one, as shown in Fig. 1(c), which has only PV panel and storage devices. It has only a PV panel and a battery, and the size of battery is expected to be larger.

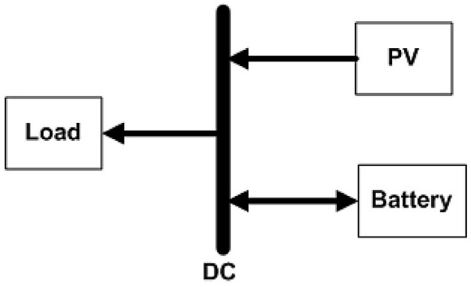
2.1.1. Components modelling

In general, two PV panels (2×80 W) are included in a solar based street light. The PV panels receive solar irradiation and convert it into DC (Direct Current) electricity. The electricity

(a) Picture of street lights



(b) Configuration of grid-connected street lights



(c) Configuration of islanded street lights

Fig. 1. The solar powered street lighting system configurations.