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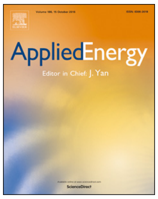

System design and policy suggestion for reducing electricity curtailment in renewable power systems for remote islands

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HIGHLIGHTS

- Remote renewable power system is optimized with limited electricity curtailment.
- Variations of optimal design for decreased electricity curtailment are explained.
- A policy for reducing electricity curtailment in remote islands is suggested.

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ABSTRACT

In renewable power systems for remote islands, a significant amount of electricity is curtailed for power balance. This study examines the effect of reducing electricity curtailment on optimal renewable power system design for remote islands. A Mixed-Integer Linear Programming problem for obtaining the optimal design of remote renewable power systems is formulated with an additional constraint which limits the total electricity curtailment. For a parametric study, the problem is solved with various values of electricity curtailment limit, for four cases; two islands - one with a higher and the other with a lower capacity factor of wind turbines - in South Korea, and two renewable power penetrations - 60% and 90% - in the two islands. Variations in the optimal capacities of photovoltaic panels, wind turbines, and batteries for limited total electricity curtailment are examined for every case. Reasons of the variations are explained by an analysis on the temporal operation profiles of the remote renewable power systems. In addition, the appropriate upper limit of total electricity curtailment considering cost increment, normalized by the total electricity demand, is newly suggested as a function of renewable power penetration to guide policy design.

1. Introduction

There are many remote islands that are not connected to the national power grid, and diesel generators have been commonly used in these islands [1]. Using diesel for power generation has disadvantages such as air pollution, fuel cost, and fuel shipping. Recently, renewable power sources such as photovoltaic (PV) panels and wind turbines have been installed in remote islands for clean, on-site power generation. Thus, in many of the islands, renewable power penetration is expected to reach 50% ~ 100% in the near future [2]. Renewable power systems in the remote islands consist of renewable power generators (a combination of PV panels and wind turbines [3,4]), diesel generators, and components for load balancing (batteries, dump load). Capacities of PV panels, wind turbines, and batteries are determined by optimization for minimum total cost [5,6]. Thus, much research has been done on optimal design of renewable power systems for remote islands [7–16].

When the renewable power generation exceeds the power load, all of the excessive power should be stored in the batteries in the ideal case. However, the optimal battery capacity is not sufficiently high since electricity storage is the most costly option among grid flexibility resources [17] and takes the greater part of total cost in the remote renewable power systems [18]. Therefore, some of the excessive power should be "curtailed" by a large scale dump load [19]; typically three-phase resistors in isolated renewable power systems [20]. The amount of electricity curtailment increases significantly as the renewable power penetration increases [21]. Katsaprakakis et al. [10] studied an island

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Nomenclature

Variables

E_{batt}	energy stored in the batteries [kW]
P_{ch}	charging power [kW]
P_{diesel}	power generated by the diesel generator [kW]
P_{disch}	discharging power [kW]
P_{dump}	power curtailed by the dump load [kW]
S_{batt}	capacity of the batteries [kWh]
S_{PV}	capacity of the photovoltaic panels (1 for 1-kW panel)
S_{WT}	number of the wind turbines
x	binary variable

Constants & coefficients

c_{batt}	annual equivalent cost of the batteries [$/kWh]
c_{diesel}	cost of electricity generated by the diesel generator [$/MWh]
c_{PV}	annual equivalent cost of the photovoltaic panels [$]
c_{WT}	annual equivalent cost of one wind turbine [$]
M	a sufficiently large number
m_l, m_u	lower and upper margin of state-of-charge of the batteries [%]
P_{load}	power load of the island [kW]
P_{PV}	power generated by a 1-kW photovoltaic panel [kW]
P_{WT}	power generated by one wind turbine [kW]
α_{dump}	electricity curtailment over a 1-year period divided by the total power demand over a 1-year period [%]
$\bar{\alpha}_{dump}$	electricity curtailment over a 1-year period divided by total power demand over a 1-year period when there is no limitation of electricity curtailment [%]
α_{RE}	renewable penetration [%]
ε	a sufficiently small number
η_{batt}	charging & discharging efficiency of the batteries [%]
η_{inv}	DC-AC inverter efficiency [%]
γ	c-rate of the batteries

in Greece with a renewable power penetration of 90%, and the total electricity curtailment was 48.2% of the total renewable power generation. Ma et al. [14] studied an island in Hong Kong with a renewable power penetration of almost 100%, and the total electricity curtailment was 48.6% of the total renewable power generation. Yang and Nehorai [15] studied a virtual remote community with a power load similar to a power load profile in the Electricity Reliability Council of Texas (ERCOT) database with a renewable power penetration of about 50%, and power curtailment occurred in nearby 15% of the total hours over a 1-year period. Significant electricity curtailment reduces profit and capacity factor of the renewable power systems [22]. In remote islands, lower capacity factors mean higher capacities of PV panels and wind turbines for a target renewable power penetration, resulting in more use of land, more shipping in construction process, and more maintenance. These problems become more significant if electricity curtailment is exploited for building an oversized renewable power system aimed at a large project.

Recently, several studies on reduction of electricity curtailment in renewable power systems have been reported. Also, some policies have been announced for reducing electricity curtailment in large renewable power systems. In Ireland, the expected electricity curtailment in the future Irish wind power system has been calculated, and system improvements for reducing the electricity curtailment has been suggested [23]. In the United States, curtailment experiences of utilities have been investigated, and strategies to mitigate the electricity curtailment have been discussed [24]. Especially in California, it has been recommended for grid operators to limit the total curtailment of electricity from renewable power sources [25]. In China, comprehensive reviews on electricity curtailment [26] and design and operation strategy for reducing electricity curtailment [27,28] have been carried out. Furthermore, a policy announcement known as “Document 625” has been issued to require the grid companies to purchase electricity from renewable generators at least up to an allocated number of hours [29].

The main focus of the research and the policy announcements mentioned above is large-scale renewable power systems connected to the national power grid. However, research on reducing electricity curtailment in remote renewable power systems has not yet been reported. Furthermore, a detailed policy for reducing electricity curtailment in renewable power systems in remote islands has not been suggested yet. Therefore, this paper (1) examines the impact of reducing electricity curtailment on optimal design of remote renewable power systems; and (2) suggests an appropriate upper limit of electricity curtailment in remote renewable power systems for policymaking. The specific research questions are as follows:

(1) How does the optimal design (capacities of PV panels, number of wind turbines, and capacity of batteries) of remote renewable power systems change as electricity curtailment is decreased? Why does the optimal design change in that way?
(2) How much electricity curtailment in remote renewable power

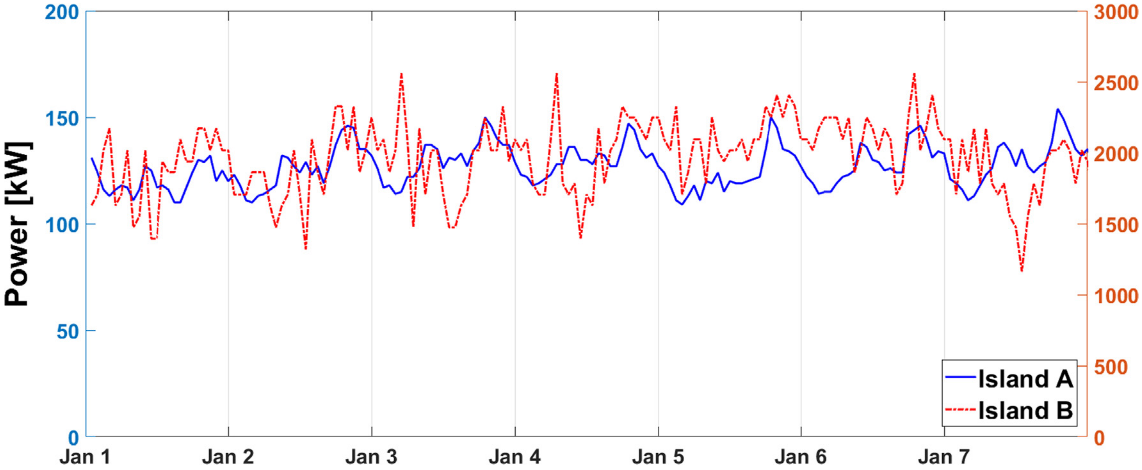

Fig. 1. Power load profiles of Island A (left y axis) and Island B (right y axis).