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Analysis of output power and capacity reduction in electrical storage facilities by peak shift control of PV system with bifacial modules

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HIGHLIGHTS

- Characteristics of a large-scale power plant using bifacial solar cell is described.
- Conversion efficiency of bifacial photovoltaics obtained using 3D-CAD modeling.
- Power supply of bifacial PV can be matched with demand by adjusting the orientation.

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ABSTRACT

Bifacial photovoltaics are widely investigated with the aim of reducing the amount of silicon used and increasing conversion efficiencies. The output power of bifacial photovoltaics depends on the quantity of solar radiation incident on the reverse face. Furthermore, controlling the orientation can distribute the times of peak power output in the morning and afternoon to better match the demand. In this study, the demand patterns of individual houses or the whole Hokkaido region were analyzed assuming the substitution of a conventional large-scale electric power system with one using bifacial photovoltaics. The supply–demand balances and electrical storage capacities were investigated. When comparing a large scale solar power plant (mega-solar power plant) using monofacial photovoltaics or vertical bifacial photovoltaics (in which the orientation could be adjusted), the supply–demand could be better balanced for individual houses in the latter case, thereby allowing the storage capacity to be reduced. A bifacial solar module was modeled by 3D-CAD (three dimensional computer aided design) and thermal fluid analysis. The module temperature distribution of bifacial photovoltaics was calculated with respect to the environmental conditions (wind flow, direct and diffuse solar radiation, etc.) and internal heat generation, as well as the orientation of the solar panels. Furthermore, the output power of bifacial photovoltaics can be easily obtained from the analysis result of modular temperature distribution and the relation between temperature and output power.

1. Introduction

There are examples of study on evaluating the reliability of large-scale photovoltaic (PV) systems and the effect of photovoltaics interconnection on the reliability of local distribution system [1–3]. Furthermore, cost and efficiency of new design photovoltaics are investigated [4,5]. Bifacial photovoltaics are being investigated for the purpose of reducing the quantities of silicon required and increasing the conversion efficiency [6–8]. The amount of silicon can be reduced by reducing the distance that the charge carriers need to travel in a bifacial photovoltaic system. Standard monofacial solar cells have an opaque backing on the reverse face, whereas bifacial photovoltaics have a transparent glass on the back that allows the input of solar radiation—which is the source of electricity generation—from the reverse face also. Moreover, when solar radiation is incident on the reverse face, the dependence of the electric power generation on the orientation and angle of inclination of bifacial photovoltaics is small compared to standard monofacial photovoltaics. The reverse face of a bifacial photovoltaic system can easily capture reflected and diffused solar radiation, and therefore, these systems are thought to be suitable for installation on, for example, the roofs of parking areas, walls of buildings, fences, and rooftop signs [9–11]. The output power of bifacial photovoltaics greatly depends on the amount of incident solar radiation on the reverse face. Moreover, when exposed to high temperature, the conversion

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Nomenclature

A_{pm}	area of a solar module [m^2]
$c_{p,pm}$	specific heat of the solar module [J/(g K)]
$c_{p,\infty}$	specific heat of air [J/(g K)]
F	view factor
G_{pm}	mass of the solar module [kg]
h_{pm}	heat transfer rate on the surface of a solar module [kW/(m^2 h K)]
I_{pm}	current of the solar cell [A]
Q_{ca}	heat of air current [J]
q_{ca}	rate of heat of air current [kW]
q_{dc}	output rate of direct current [kW]
Q_{gh}	heat of the solar module [J]
q_{gh}	generation rate of heat of the solar module [kW]
Q_{ht}	heat by heat transfer [J]
Q_r	reflection energy of solar radiation [J]
q_r	reflection energy rate of solar radiation [kW]
q_{rb}	amount of insolation incident on the modules reverse face [kW]
q_{rN}	net radiation energy [kW]
Q_{rS}	amount of radiation energy exchange by solar radiation [kW/m^2]
q_{rS}	solar radiation [kW/m^2]
Q_{rT}	amount of radiation energy exchange between two surfaces [kW/m^2]
q_{rT}	radiation energy between two surfaces [kW/m^2]
q_{sd}	direct solar radiation [kW/m^2]
q_{sf}	diffuse solar radiation [kW/m^2]
Q_{tr}	heat transfer of radiation [J]
q_{tr}	heat transfer rate of radiation [kW]
R_{Load}	resistance of load [Ω]
R_{ir}	internal resistance [Ω]
T	temperature [°C]
t	sampling time [h]
T_{pm}	surface temperature of solar module [°C]
T_∞	outside air temperature [°C]
u_∞	velocity of air [m/s]

Greek characters

ε	emissivity
γ_r	reflectivity of solar radiation on the surface of the solar module
ρ_S, ρ_T	reflectivity
ρ_∞	density of air [kg/cm^3]
σ	Stefan–Boltzmann constant [J/(s cm^2 K^4)]

efficiency falls, as for the standard solar cells [12]. Therefore, in order to predict the electric power generation of bifacial photovoltaics, thermal fluid analysis can be applied to obtain the temperature distribution in the module as a function of the environmental conditions (outside air temperature, vector of the wind, solar position, direct solar radiation, diffuse solar radiation, radiation reflected from the ground) and geometrical parameters related to the installation (orientation, number of modules, height from the ground, etc.). The output power can be obtained by applying the relation between module temperature and output power to the temperature distribution of the bifacial photovoltaics obtained from thermal fluid analysis. A simple method for obtaining the output power from such analysis is proposed here.

It is necessary to compensate the inconsistent power output of photovoltaics by connecting them with a commercial power system. However, in order to make the power output of photovoltaics increase with an electrical power system, a stable supply from the photovoltaic power plant side is desired [13–16]. Electrical storage equipment is required for stabilizing the supply from a large-scale photovoltaic power plant (mega-solar power station), and although NAS cells (Na–S batteries), pumped hydro power generation, etc. can be considered, they are very expensive. An alternative for controlling the peaks in power-generation output is by changing the orientation of vertical bifacial photovoltaics, as will be presented in this study. When installing bifacial photovoltaics in the east–west directions, peaks occur in the electric power generation in the morning and the afternoon. On the other hand, two load peaks are seen in the general electricity demand in the morning and evening, and hence, if the two output peaks of bifacial photovoltaic generation and the two load peaks of electricity demand can be synchronized, it may be possible to reduce the storage capacity for balancing the supply–demand. This could result in a reduction in the installation cost of electrical storage equipment. In this study, the supply–demand balance and storage capacity facilities of a mega-solar power plant using bifacial photovoltaics is investigated on the basis of the load pattern of individual houses and assuming substitution of a large-scale electric power system.

2. Materials and methods

2.1. Scheme of bifacial photovoltaics

Fig. 1 shows a schematic of a bifacial photovoltaic device in which the active n-type single crystal layer is sandwiched between two amorphous silicon layers (above and below), forming a symmetrical cell. Therefore, electricity is generated when light enters from either the upper or lower face of a bifacial solar cell. However, because the intensity of the incident light is not equal on both sides, the amount of electrical power generation is not simply doubled. Moreover, because the maximum voltage (open circuit voltage) falls when the temperature of a solar cell rises, the output power will drop under high-temperature conditions. Although there are few voltage drops due to the amorphous material under high temperatures compared to the single crystal, the temperature characteristics of bifacial photovoltaics are slightly better than single crystal silicon because of the resistances of other components.

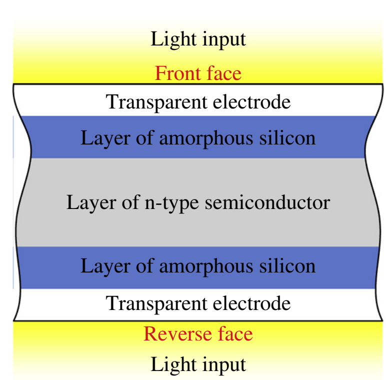

Fig. 1. Schematic showing the basic configuration of a bifacial solar cell.