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Light-receiving characteristics of a distributed solar module with a plant shoot configuration

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ABSTRACT

The object of this study is to develop a solar power generation system with high energy density. In order to improve the energy density of a solar power generation system, compaction of the system (improvement of light-receiving density) and a directive fall (dependency on the solar position is excluded) are required. So, in this study, because the issues described above are resolved, a solar cell module is divided and distributed. In this paper, the relation between the shoot shape of a "dogwood tree," "ginkgo tree," "*Dendropanax trifidus*," and "*Acer palmatum* var. *matsumurae*" and the light-receiving amount is clarified by numerical analysis, and the optimal solution of each shoot shape and result of the light-receiving density were obtained. Furthermore, the characteristics of variables, such as leaf size, installation location, length of the branch of a leaf, and light-receiving amount of each shoot, were examined. As a result, in the distribution of the solar cell module with the shoot shape of each plant except dogwood, the light-receiving density showed clear improvement compared with the distribution of a square module. Compared with a square leaf, the maximum differences of each light-receiving density of *D. trifidus*, ginkgo, and *A. palmatum* var. *matsumurae* were 2.0 times, 7.4 times, and 6.4 times in January, respectively. On the other hand, they were 1.9 times, 8.7 times, and 7.3 times in July.

1. Introduction

In order to increase the energy density of a solar power generation system, it is necessary to accomplish weak directivity and space saving. Regarding compaction of a solar power generation system, the approach to improve the generation efficiency by material development is important. Moreover, if a system (directive small system) independent of the degree of incident angle of the insolation to a solar cell module can be developed, high generation efficiency can be obtained at all insolation times. Until now, there has been the development of a spherical silicon solar cell, a double-sided light-receiving solar cell, etc., as a method of reducing the directivity of a solar cell module [1–3]. On the other hand, in this study, the issue described above is improved by referring to plant light-receiving characteristics.

Almost all plants depend on carbohydrates obtained by photosynthesis for energy. Therefore, it is thought that the shape of a plant shoot (formed from one stem, leaves, and branches of a leaf) with competitors has evolved into a round shape so that greater insolation may be obtained. Although a solar location changes over time, it is expected that the plant shoot shape is optimized for the maximum photosynthetic rate. Accordingly, the plant shoot shape is designed so that insolation may be received efficiently in a narrow installation space. However, the shape of the plant shoot may be designed under the multiple objective problem including factors other than the maximum light-receiving amount, such as reproduction.

In this study, the possibility of a solar power generation system with installation space saving and weak directivity is investigated by considering the distribution of a solar cell module that simulates the shape of a plant shoot (DSMS: distribution system of a solar module with the form of a plant shoot). We have been developing a light-receiving analysis algorithm of a plant shoot (LAPS) [4]. Furthermore, the relation of the shoot shape of dogwood and the light-receiving amount of insolation was investigated using LAPS [5]. LAPS is an analysis method using the Monte Carlo method and a genetic algorithm (GA), while the relation between the shape of a plant shoot and the photosynthetic rate is investigated. In the Monte Carlo method, insolation is simulated with many light quanta and it determines the absorption, transmission, and reflection on the leaf with light quantum probability. A genetic algorithm is used to search for the shape of the plant shoot that maximizes the light received.

The shoot of a dogwood leaf analyzed by the last report is a paripinnately compound leaf with an ellipsoidal shape. The dogwood plant has a paripinnately compound leaf with ellipsoidal

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Nomenclature

$E_{w,k}$	Number of light quanta that reach surface element k in leaf w
e	Level surface global solar radiation
J_e	Number of leaf surface elements
J_l	Number of leaves
$\overrightarrow{N}$	Normal line vector of the leaf model
N_a	Total number of light quanta emitted in a day
nq	Number of light quanta to emit
P	Point on coordinates
P_e	Coordinates of the radiation position on the virtual radiation surface
P_r	Corner point of the central line in the leaf model (Fig. 4)
P_s	Apex coordinates of a surface element of a leaf
P_t, P_u	Coordinates of the light quantum achieved on a leaf
P_v	Apex coordinates of a virtual radiation surface
$\dot{q}_d$	Coordinates of a light quantum that reaches directly from the virtual radiation surface
$\dot{q}'_h$	Coordinates of the light quantum that reaches after transmitting other leaves
$R_{g,st}$	Rate emitted to st among N_a
r	Length
r_{et}	Length between $P_{e,q}$ and $P_{t,m}$ (Fig. 8)
r_{lt}	Length showing the apex of the leaf model (Fig. 4)
$\overrightarrow{V_e}$	Normal line vector of P_e

Roman characters

α	Absorptivity
β	Angle of rotation (degree)
ϵ	Content of photosynthesis enzyme
φ	Angle of elevation (degree)
γ	Reflectivity
$\eta_{t,x,m}$	Angle of the central line on the leaf, and apex x of element m (Fig. 9(a)) (degree)
θ	Angle of direction (degree)
τ	Transmissivity

Subscript

a, b	Light quantum number that reaches the leaf directly from the virtual radiation surface
g	Representative day
i, j	Number of the leaf model
k, m, n	Surface element number of the leaf
q	Simulated light quantum number
st	Sampling time
t, u, w	Number of the leaf model

shoots arranged in pairs on opposite sides of a central stem. On the other hand, coptophyllus designs (ginkgo tree, etc.), which have divided leaves, can avoid insolation being covered due to leaf overlap and may have high space efficiency. Here, the coptophyllus means a division leaf. So, in this paper, the light-receiving amount and space efficiency of insolation are investigated for certain coptophyllus shoot shapes. In the analysis of this paper, the location of the radiation virtual plane that simulates the sun is changed for every sampling time to mimic the sun. Moreover, the magnitude of the light-receiving amount in a day defines the fitness value of the chromosome model in GA. Therefore, the optimal solution obtained by GA is the shape of a plant shoot that can receive maximum insolation on a representative day. From these results, the distribution method of a solar cell module with a plant shoot shape is proposed.

2. Development of DSMS (distribution system of a solar module with the form of a plant shoot)

2.1. Aim of development

Fig. 1(a) shows an example of installation of the solar power generation system that has spread most in Japan. In urban areas in Japan, there are many examples of installation of flat plate-shaped solar cell modules on the roofs of houses. Generally, this system is fixed to the roof. A large setting surface is required for obtaining

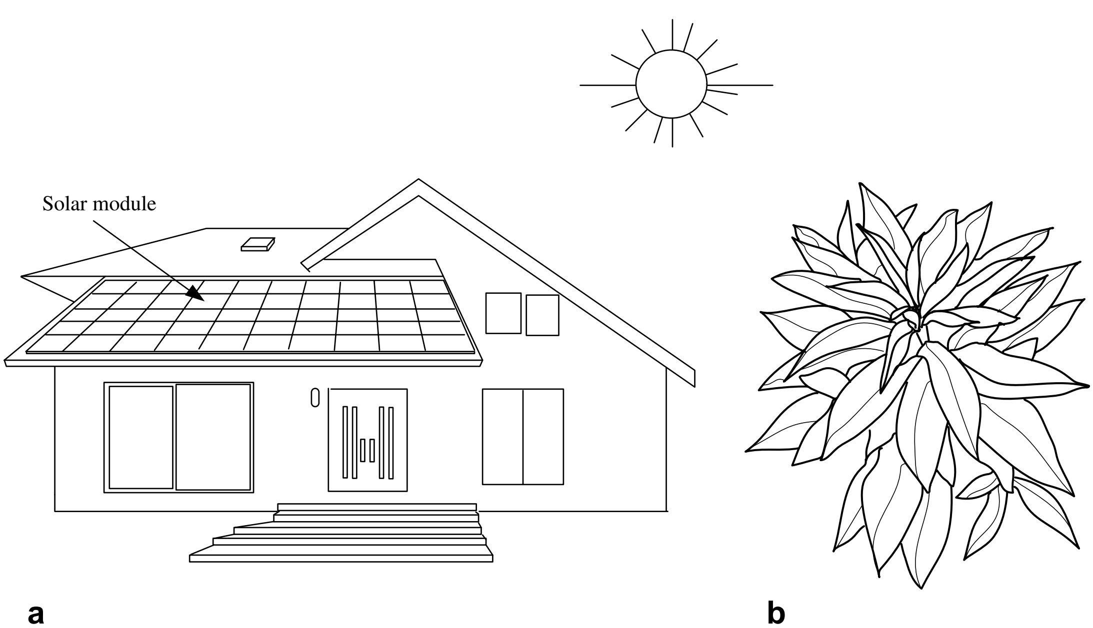

Fig. 1. Surface of light received. (a) Conventional system. (b) Plant system.