

# INTENSIVE INTRODUCTION OF RESIDENTIAL PV SYSTEMS AND THEIR MONITORING BY CITIZEN-ORIENTED EFFORTS IN JAPAN

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## ABSTRACT

The authors have made sure that the adequacies of the evaluation of PV systems, with developed sophisticated verification (SV) method. The method provided analytical performance factors such as performance ratio, power conditioner efficiency, temperature factor, shading factor, incidence-angle-dependence factor, load matching factor and other array parameter still undefined factor. Using this method, the authors evaluated residential PV systems. However in their systems measuring point is only system-output without a part of sites, therefore we must substitute not measured data for the estimated data from AMeDAS. In this case, we suggest this estimated method and report the result that was evaluated for using that data. As a result, SV method is applied to this data taken at 39 systems for 5 months in Japanese REPP project. The mean system performance ratio K was identified 69.5% for 39 systems in FY 1999. Furthermore in the 29 systems that the estimated data was used system performance ratio identified 70.4%.

## 1. Introduction

Since April 1997, a Japanese NGO, REPP (Renewable Energy Promoting People's Forum) has aimed to improve social conscious of ordinary people for better environmental method of generation power, introducing PV systems into residences. On the other side, since there is no measuring instrument, it is difficult to evaluate residential PV systems without a part of systems. In this paper, the authors suggest the method of estimating irradiance data and temperature of PV module and clarifying operating characteristic of PV system. Therefore performance analysis of residential system was clarified by system performance ratio and system losses.

## 2. Measuring Point and items

There are 2 types of Simple type and Precise type in residential PV systems of REPP project. Each measuring items are shown in Table 2-1, and the distribution of their PV systems are shown in Fig. 2-1. Though Precise type have measured 4 points, Simple type have do only 1 point which is PV system output. Therefore last 3 items must be estimated from the AMeDAS data to use SV method, because it has been measured at 800 points.

Table 2-1 Measuring items of each type

	Precise type	Simple type
Measuring items	-In-plane irradiance -Temperature of PV module -Array output -PV system output	PV system Output
Number of site	10	85
Sampling time	10 minutes	30 minutes

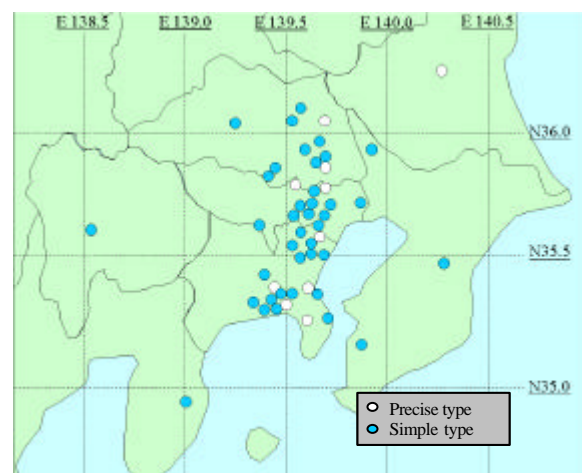


Fig: 2-1 distribution of PV systems in Kanto area, Japan

### 3. Evaluate method of residential PV systems

#### 3.1 SV method

The SV (sophisticated verification) method has been developed by the authors [1][2]. The actual operational PV systems data divided into the loss factors by SV method: performance ratio  $K$ , power conditioner efficiency  $K_C$ , temperature factor  $K_{PT}$ , shading factor  $K_{HS}$ , load matching factor  $K_{PM}$ , incident angle dependence factor  $K_{PI}$  and other array parameter  $K_{PO}$ . SV method can evaluate from only 4 measuring point (irradiance, array output, system output and temperature) with externally available information.

Each loss factor is estimated as follows:

Temperature factor is able to estimate the formula (3-1).

$$K_{PT} = 1 + a_{p_{max}} (T_{CR} - 25) \quad (3-1)$$

The relation among incidence angle dependence factor  $K_{PI}$ , other array parameter  $K_{PO}$  and load mismatching factor  $K_{PM}$  are shown in Fig.3-1 and Fig.3-2. A scattered graph as shown in Fig.3-1 is the relation between array output and in-plane irradiance. An upper straight line corresponds to ideal energy production by array with its capacity  $P_{AS}$  under irradiance  $H_A$ . Scattered dots are all the hourly data divided by temperature correction factor  $K_{PT}$ . A lower straight line is drawn as the upper envelope of scattered points and no mismatch line is assumed along this line ( $K_{PM} = 1$ ).

The difference between upper line and no mismatch line is the incident angle dependent and other array losses and it means  $K_O$ . The difference between scattered dots and no mismatch line is shading and load mismatch losses.

$$K_O = \frac{E_{NM}}{E_S} \quad (3-2)$$

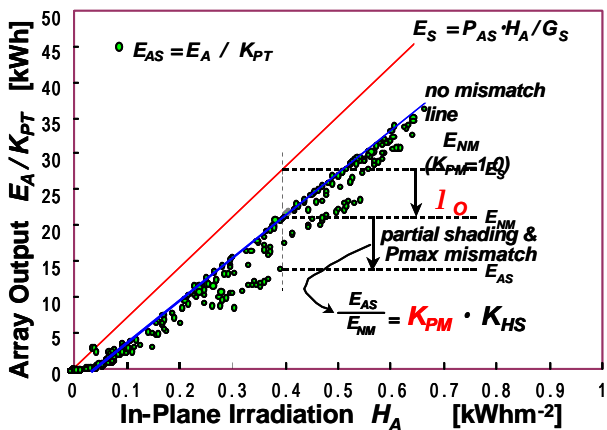


Fig.3-1 Identification of other array factor  $K_{PO}$  and load mismatching factor  $K_{PM}$

The relation incident angle dependence and  $K_O$  is shown in Fig.3-2. In this figure method estimated incident angle dependence loss factor is shown. The line along maximum points of  $K_O$  is incident angle dependence line and the difference between scattered dots  $K_O$  is other array losses  $K_{PO}$ .

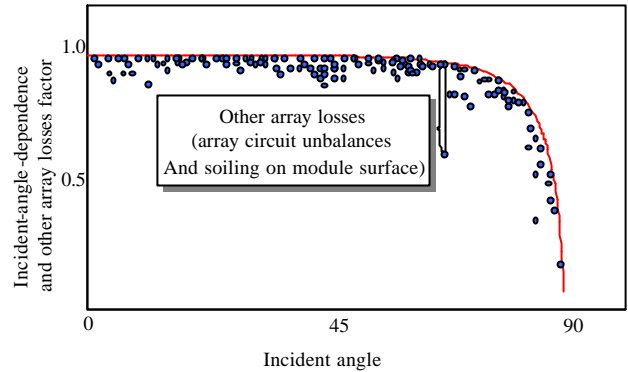


Fig.3-2 Identification of incident angle dependence factor  $K_{PI}$

Therefore the influence of shadow can be estimated from Fig.3-3.

The processes identify the principle of shading effect detection as follow:

At first, irradiance pattern on a specific solar day representing a given month is calculated for each hour by a theoretical model considering array orientation and inclination angle, hourly monitored data for a certain site are plotted keeping hourly relation. Looking at a maximum value for each hour as a fine-day pattern for the month, the scale of given theoretical day pattern is adjusted to fit them as an envelope.

Second, supposing that the influence of a shadow doesn't change during the same month, it observed on the extracted maximum values can be as dip compared with the fit fine-day curve.

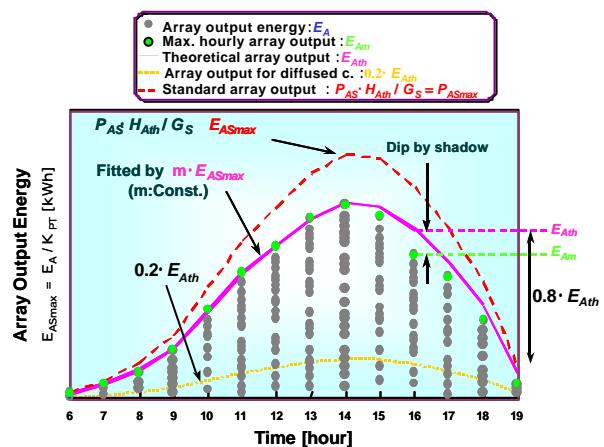


Fig.3-3 Fitting of clear-day power pattern and separation of shading

### 3.2 Method of estimate for insufficient data

The method of evaluation is different between Precise type and Simple type PV systems because the latter has not enough the measuring point for using SV method. Therefore in evaluation of Simple type the insufficiency data must be estimated from adopting AMeDAS data. Each PV system type's flowchart is shown in Fig.3-4 and Fig.3-5.

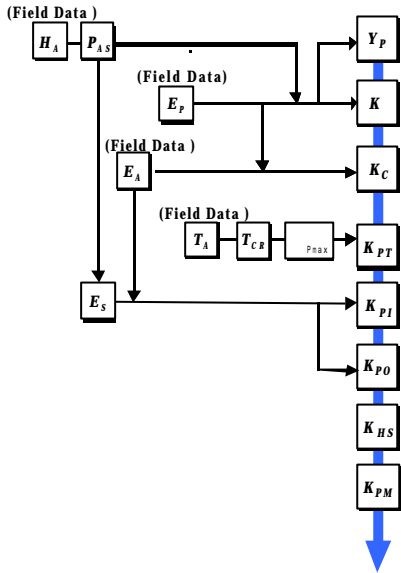


Fig.3-4 Flowchart of Precise type PV system

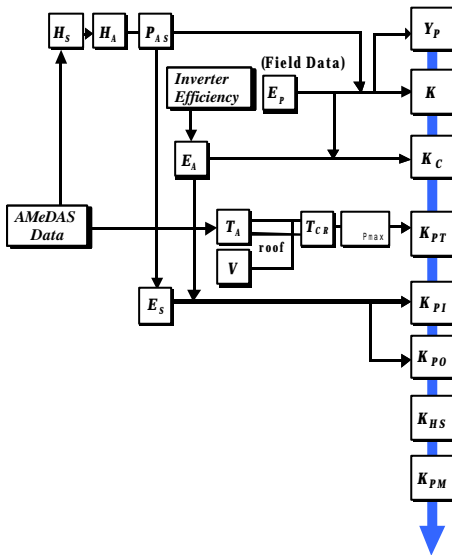


Fig.3-5 Flowchart of Simple type PV system

Irradiance data is estimated from the daylight hour of AMeDAS data.

$$H_s = CFh\{H_{S(n=0)} \cdot (1-n) + H_{S(n=1)} \cdot n\} \quad (3-4)$$

$$H_{S(n=0)} = a \cdot H_o + b \quad (a,b:\text{constant}) \quad (3-5)$$

$$H_{S(n=1)} = c \cdot H_o + d \quad (c,d:\text{constant}) \quad (3-6)$$

The temperature of PV module is also estimated from wind velocity of AMeDAS data. This method is estimated as follow:

$$T_{CR} = T_A + \Delta T \quad (3-7)$$

$$\Delta T = (-6.036 + 0.274 \cdot V + 0.071 \cdot V^2) + H_A \cdot (45.63 - 5.91 \cdot V + 0.333 \cdot V^2) \quad (3-8)$$

Besides array output can be estimated with inverter efficiency of each its type.

$$E_A = E_P / K_C \quad (3-9)$$

Their method of estimation can be evaluated Simple type's PV system.

### 4. Evaluation result of PV system of REPP project in Japan

Under the introduction of PV system in supporting Tokyo Electric Power Company, REPP has installed 95 PV systems in Japan since 1997. To demonstrate the applicability of SV method to actually monitored data, 10 systems of Precise type and 39 systems of Simple type are chosen as a part of the REPP Project in FY 1999. And the method of evaluate for applying to Simple type's PV systems was also applied in evaluate of Precise type's. This result was shown in Fig3-6. The appropriate method of the estimation for irradiance could be proved from this result. In System performance ratio and in-plane irradiance, estimate data is bigger than on-site data because there is possibility that pyranometer was soiled and it could not measured accurately. The result of evaluate their PV systems was shown in Fig.3-7. The average of system performance ratio  $K$  was 69.5%. The average of inverter losses  $C$  was 5.5%, load mismatch  $PM$  was 8.3%, efficiency decrease by temperature  $PT$  was 3.8%, shading losses  $HS$  was 7.5%, incident angle dependence  $PI$  was 2.8% and other losses  $PO$  was 2.6%. The losses related with inverter ( $C + PM$ ) occupied half the whole of PV system losses. Therefore the main parameters are demonstrated in Fig.3-8, Fig.3-9 and Fig.3-10.

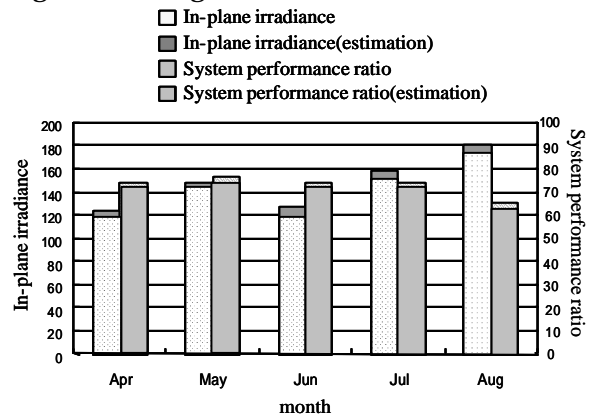


Fig.3-6 Appropriate method of estimate irradiance

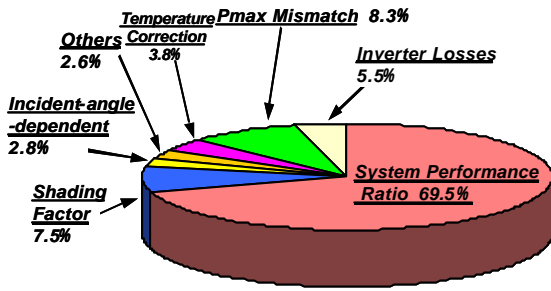


Fig.3-7 Average loss parameters in REPP Project FY1999 Data

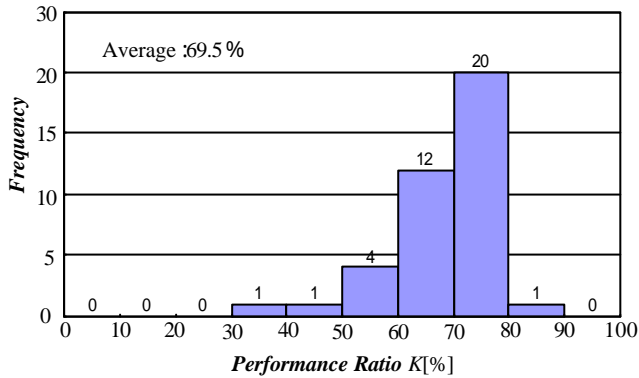


Fig.3-8 performance ratio of PV systems in REPP Project

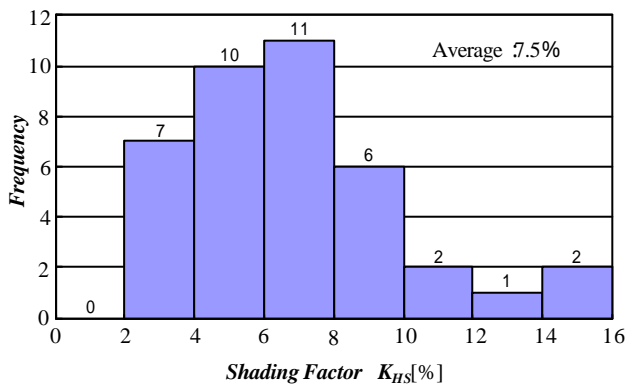


Fig.3-9 Shading factor of PV systems in REPP Project

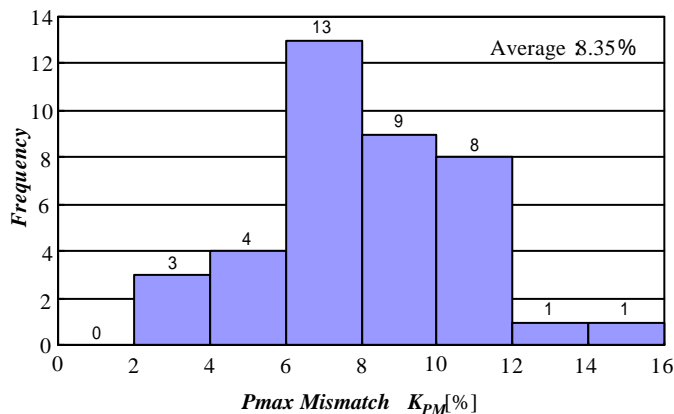


Fig.3-10 Pmax mismatch factor of PV systems in REPP Project

## 5. Conclusion

The author developed SV (Sophisticated Verification) method and evaluated actual operating PV systems data in the REPP Project by SV method. In this study, the algorithm of estimating the method of the residential PV systems and of the PV system that monitoring data is insufficient was improved and certified. As a result, in-plane irradiance  $H_A$  estimated is bigger about 4 ~ 8[kWh/month] than on-site one. However, system performance ratio estimated is smaller about 2 ~ 4[%] than on-site one. Therefore the method suggested in this paper available.

### Nomenclature

$H_s$	: global irradiance
$H_o$	: extraterrestrial irradiance
$n$	: daylight hour
$CF_h$	: standardization factor
$V$	: wind velocity
$T_A$	: temperature
$T_{CR}$	: temperature of PV module
$E_A$	: array output
$E_P$	: PV system output
$K_C$	: inverter efficiency

### ACKNOWLEDGMENT

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