Evaluation of Effective Shading Factor by Fitting a Clear-Day Pattern Obtained from Hourly Maximum Irradiance Data

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ABSTRACT

The authors have made sure that adequacies of the evaluation of PV systems, with the developed sophisticated verification (SV) method by them, where performance ratio, power conditioner efficiency, temperature factor, shading factor, load matching factor and other array parameter. However, originally proposed method accepts PV installations facing the south only. To improve the accuracy of evaluation, the SV method has been modified, taking account of arbitrary orientation and inclination in this paper. Therefore, it is being intelligible shading effect of each hour. The evaluation of PV systems has been precisely with the result that. The mean shading losses in FY1997 in Japanese 104 systems were estimated 4.7 %. A maximum value of shading losses reached 13.1 %.

Keywords: Photovoltaic (PV); Sophisticated Verification (SV) method; Performance ratio; PV system evaluation; Parameter

1. Introduction

The evaluation of actual operational PV systems seems to be very important in order to attain the diffusion of more reliable the various PV technologies for the future; a design and a location of PV systems, operational character, and so on. In Japanese Field Test (FT) Project, 180 of PV systems have provided basic monitoring data at the end of FY1998. The items of the data were carefully selected enough to evaluate PV system's performance. They are as follows; horizontal global irradiance, in-plane global irradiance, ambient temperature, array output and PV system output etc.. Although in-plane irradiance data are essential to estimate the total input of energy into PV arrays, some of the PV systems have not monitored neither in-plane irradiance nor PV cell temperature because of insufficient funds to install extra instruments in addition to a pyranometer for horizontal global irradiance measurement. The authors have improved the irradiance estimation for SV method, therefore the shading effect was become precisely. The evaluation of shading effect by SV method is simple, this suggestion will be very important for shading effect of PV system.

2. Irradiance estimation and evaluation of shading factor for SV method

2.1 SV method

The authors developed the SV (sophisticated verification) method [1-2]. The actual operational PV systems data are 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} and other array parameter K_{PO}. SV method was improved from OV (Ordinary Verification) [3-4]. SV method can evaluate from only 4 monitored points (irradiance, temperature, array output and system output) with other externally available information. At present, we have gone forward with estimation of PV loss factor of the SV method using PV systems data for years.

2.2 Clear-sky irradiance estimation

Almost PV systems were recorded in-plane global irradiance, but few systems were recorded only horizontal global irradiance. As for the data on horizontal global irradiance, the estimation of in-plane global irradiance corresponding to the inclination and the azimuth of that system becomes necessary. This problem was solved by advanced SV method. Relations between a certain maximum in-plane global irradiance in one month and time are shown in Fig.1. The shading effect can be recognized from 15:00 to 18:00 as shown in the graph. The envelope curve of the hourly biggest global irradiance was quoted as clear-day pattern, and standard array output E_{Ath} was calculated by clear-day pattern irradiance H_{Ath} and array rated output (P_{AS}). The diffusion irradiance can be recognized from 6:00 to 10:00 as shown in the graph.

2.3 Evaluation of shading factor

At first, 2 step processes identify the principle of shading effect detection as follows:

(i) 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 angles, hourly monitored data for a certain site are plotted keeping hourly relation. It makes a kind of scattered plot. Looking at a maximum value for each hour as a fine-day pattern for the month, the scale of the given theoretical day pattern is adjusted to fit them as an envelope.

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

Therefore, aforementioned clear-sky irradiance estimation becomes important.

Supposing that the influence of a shadow doesn't change during the same month so much, it observed on the extracted maximum values can be as a dip compared with the fit fine-day curve. Figure.2 gives a typical example of the shading effect that was observed in July 1997 by Kotohira Water Treatment Plant. This system faces 30° wests from the south. The shading effect is calculated by comparison of aforementioned standard array output E_{Ath} and actual measured array output E_A. As a preparation for calculation of K_{HS}, a top curve E_{ASmax} in Fig.2 is calculated by using a clear-day irradiance H_{Ath} and array rated output P_{AS}. E_{Ath} is estimated by applying direct/diffuse separation [5] to theoretical global, horizontal irradiance. Then, the scale of curve E_{Ath} is adjusted so as to fit the array output maximum values E_{Am} for hourly period. An envelope of E_{Ath} fitting is shown as mE_{ASmax}. As it decided m, E_{Am} must not exceed an estimated curve (mE_{ASmax}) at any points. The shading factor K_{HS} detected in an actual measured array output maximum values E_{Am} for hourly period. If a diffused component of clear-day irradiance is assumed 20 %, the shading factor can be calculated by the following equation.

$$K_{HS} = (E_{Am} - 0.2\ E_{Ath}) / 0.8E_{Ath}$$

When it is no shading, the shading factor is 1.

The vertical axis of Fig.2 corresponds to hourly array output energy at standard cell temperature 25 °C.

The hourly shading factor by Kotohira Water Treatment Plant is shown in Fig.3 (June 30, 1997). Although shading factor was 1 from 6:00 to 11:00, it fitted as time of Fig.1. Efficacy of shading factor in various inclinations and azimuths of each PV system is recognized by Fig.1-2.

3. Pmax Mismatch evaluation by SV method

3.1 Load mismatching factor K_{PM}

A scatter diagram of array output by in-plane irradiance shows in Fig.4. An upper straight line corresponds to theoretical array output E_S by array rated output P_{AS} under in-plane irradiation H_A. Therefore, It is needless to say that aforementioned clear-sky irradiance estimation becomes important. E_S can be shown by the following equation.

$$E_S = P_{AS} \bullet (H_A / G_S)$$

Where:

E_S: theoretical array output (kWh)

P_{AS}: array rated output (kW)

H_A: in-plane irradiation ($kWhm^{-2}$)

G_S: reference irradiance (= 1 kWm^{-2})

Scattered dots of actual operation array output E_{AS} are all the hourly data divided by temperature correction factor K_{PT}. A lower straight line is drawn as the upper envelope of scatted points. This lower straight line E_{NM} means no mismatch (K_{PM} = 1) because the upper envelope of scatted points is the most efficient performance in actual operation. Therefore, it is MPPT (Maximum Power Point Tracking) control line in this case. Practically the lower line can be drawn by the following procedure. With respect to all the hourly data, the first straight line is drawn by the method of least square regression. After that, the data that are located above the first line are utilized for second regression. Second regression is processing for fitting to maximum value of scatted dots. The similar processing is repeated three times to get an envelope line in the Fig.4. It means K_{PM}<1 and/or partial shading when the scattered data are located below this line. Shading effect and Pmax mismatch remain between E_{NM} and E_{AS}. Relation between E_{NM} and E_{AS} is the following.

$$E_{AS} / E_{NM} = K_{PM} \bullet K_{HS}$$

If shading effect was analyzed by aforementioned method on referring to Clause (2.3), load mismatching factor K_{PM} can be calculated easily using the following equation.

$$K_{PM} = E_{AS} / (E_{NM} \bullet K_{HS})$$

3.2 Other array factor K_{PO}

The loss between the upper and lower straight lines in the Fig.4 defined other array losses λ_{PO}. λ_{PO} include soiling on module surface λ_{PS}, incident-angle-dependent optical losses λ_{PI}, array circuit unbalances losses λ_{PE} and so on. λ_{PI} is majority of λ_{PO}. Exact separation of λ_{PI} is developing by improved SV method.

4. Evaluation result of 104 PV systems in Japan

4.1 Shading Losses for 104 PV systems

Figure.5 shows the histogram of shading losses λ_{HS} on PV system in FY1997. The average of shading losses in 104 PV systems was 4.7 % in FY1997. For your Information, the average of λ_{HS} was 4.1 % in FY1996 (71 systems). 19 systems (18.3 %) were indicated the shading losses of 6 to 10 % and 5 systems

(4.8 %) of 10 to 14 % in the Fig.5. Most value of λ_{HS} was less than 6 %. A maximum value of shading losses was estimated 13.1 %. The shading losses λ_{HS} was calculated by "λ_{HS} [%] = (1- K_{HS}) $\times$ 100". The ratio of shading was 16.5 % in the all losses.

4.2 Overall Losses and performance for 104 PV systems in FY1997

Overall results for SV method include aforementioned shading losses. As accuracy of shading factor was well, accuracies of other factor were well. Figures.6 - 8 show the histogram of system performance ratio K, inverter losses λ_C and efficiency decrease by temperature λ_{PT}. These basic parameters were calculated by using defined formula. The average of system performance ratio K was 71.5 % in FY1997 (104 systems). The peak distribution of K is observed in the class 70-80 % in Fig.6. As shown in Fig.7, the inverter losses λ_C of 6.8 % is considered excellent. The inverter efficiency can be calculated definitely by inverter input and output energy values. In the Fig.8, the average of array efficiency decrease losses by temperature λ_{PT} was 2.0 %. If λ_{PT} was negative side, annual average array temperature of its system is smaller than reference temperature (25 °C). Load mismatching losses λ_{PM} and other array losses λ_{PO} are shown in Fig.9 and 10. These parameters (inclusive of shading losses λ_{HS}: cf. Fig.5) were calculated by using SV method. The average of load mismatching losses λ_{PM} was 4.7 % in the Fig.9. 23 % of all systems are showing worse than 6 % and nearly 3 % are worse than 10 %. The average of other array losses λ_{PO} was 10.2 % in the Fig.10. Overall losses result of 104 systems in FY1997 was shown in Fig.11.

5. Conclusions

The authors developed the SV (Sophisticated Verification) method and evaluated actual operating PV systems data in the FT (Field test) Project by SV method. In this study, the algorithm of estimating the shading loss was improved and certified. It was used the time series analysis. To improve the accuracy of evaluation, the SV method has been modified, taking account of arbitrary orientation and inclination. Therefore, it is being intelligible shading effect of each hour. The SV method is very simple and accuracy. The method of aforementioned evaluation will be important about a design and a location of PV systems. The mean shading losses in FY1997 in Japanese 104 systems were estimated 4.7 %. A maximum value of shading losses reached 13.1 %.

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Fig.1 Maximum in-plane global irradiance - Time

Fig.2 Fitting of clear-day power pattern and separation of shading (#A9: Kotohira Water Treatment Plant in July 1997)

Fig.3 Shading factor K_{HS} - Time

Fig.4 Estimation of load mismatching factor K_{PM} and other array factor K_{PO}

Fig.5 Histogram of shading losses in Japan (FY1997)

Fig.6 Performance ratio of various systems

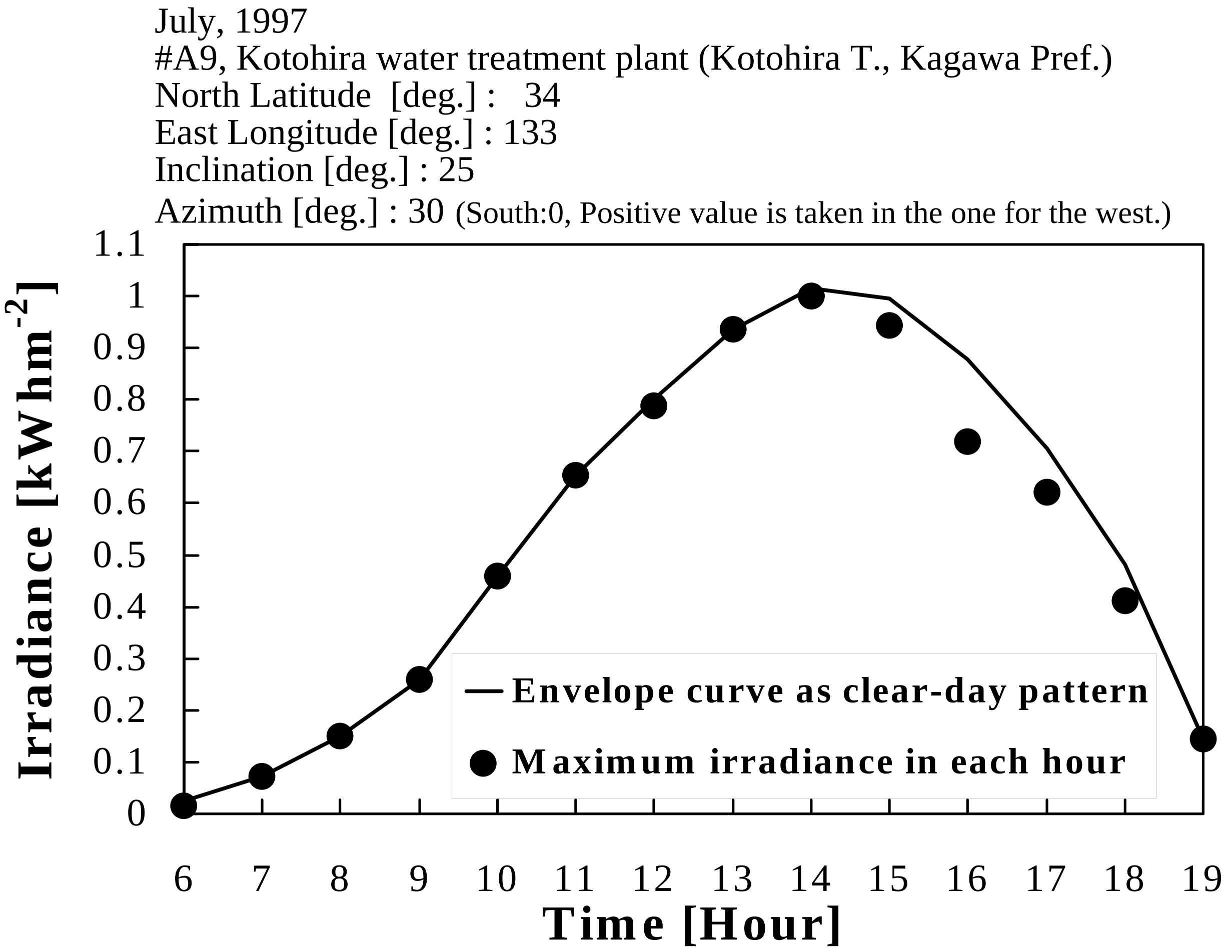
Fig.7 Inverter losses of various systems

Fig.8 Efficiency decrease by temperature of various systems

Fig.9 Load mismatching losses of various systems

Fig.10 Other array losses of various systems

Fig.11 Overall results for 104 PV systems of the Japanese Field Test (FT) Project in FY1997



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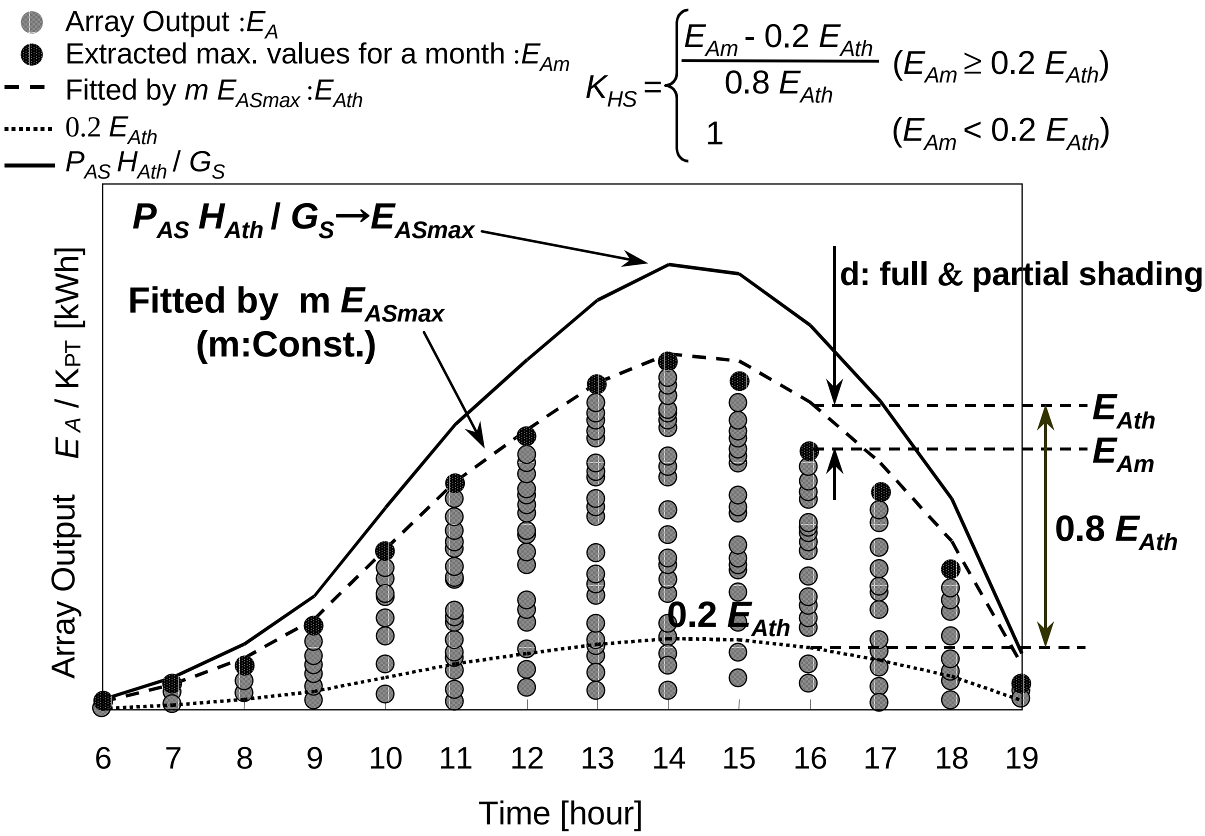

Fig.2 Fitting of clear-day power pattern and separation of shading

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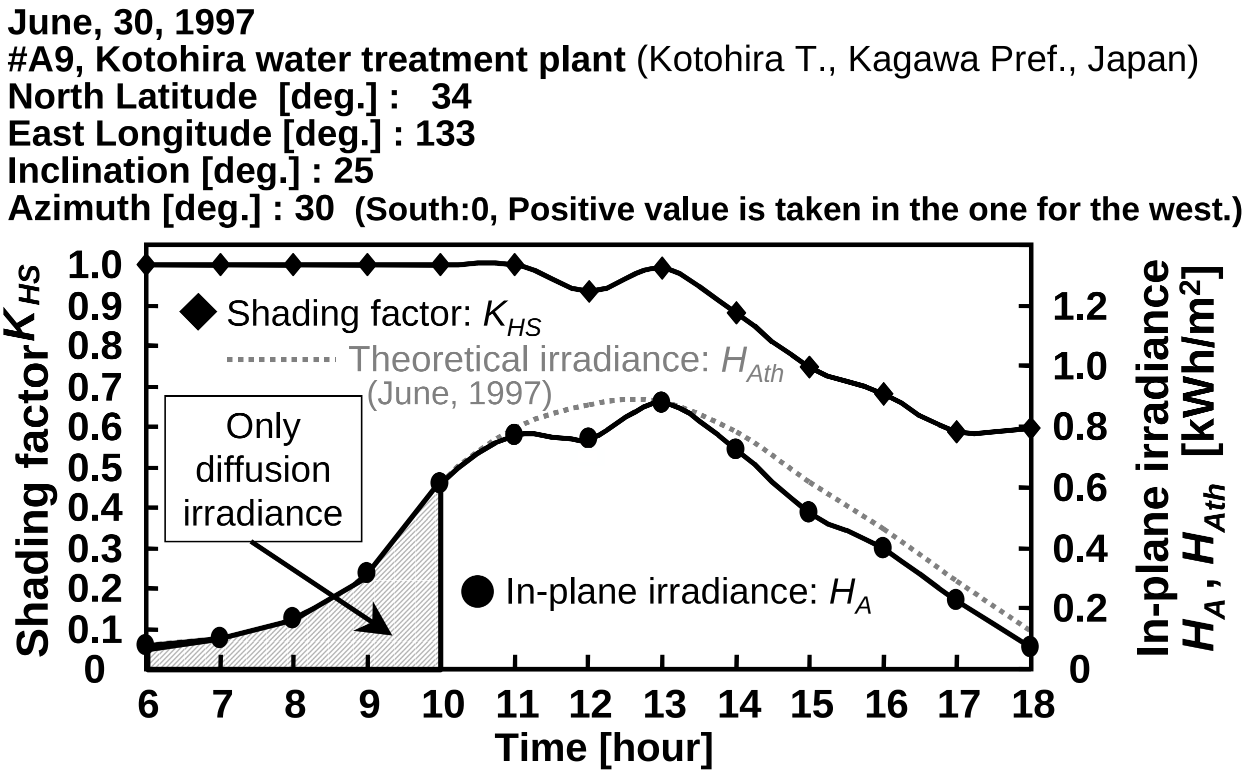


Fig.3 Shading factor K_{HS} – Time

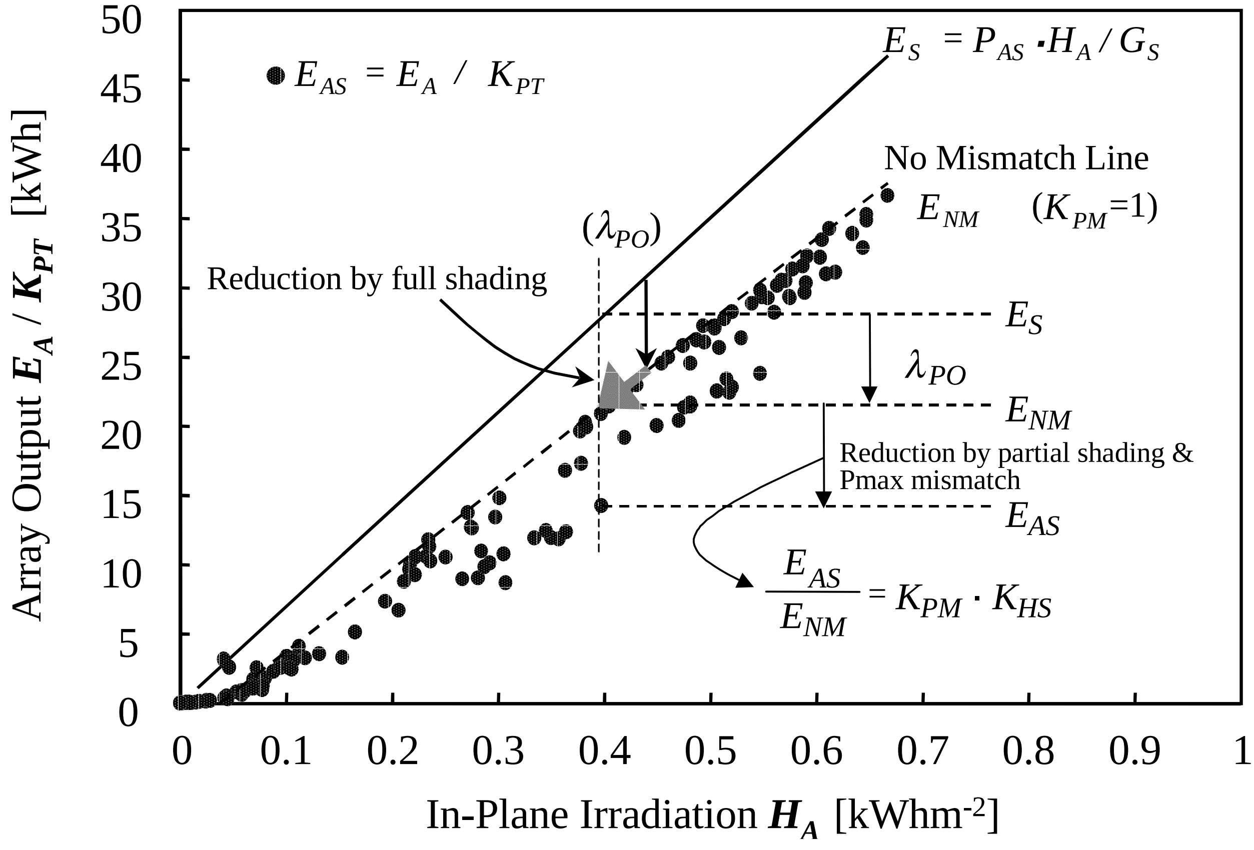


Fig.4 Estimation of load mismatching factor K_{PM} and other array factor K_{PO}

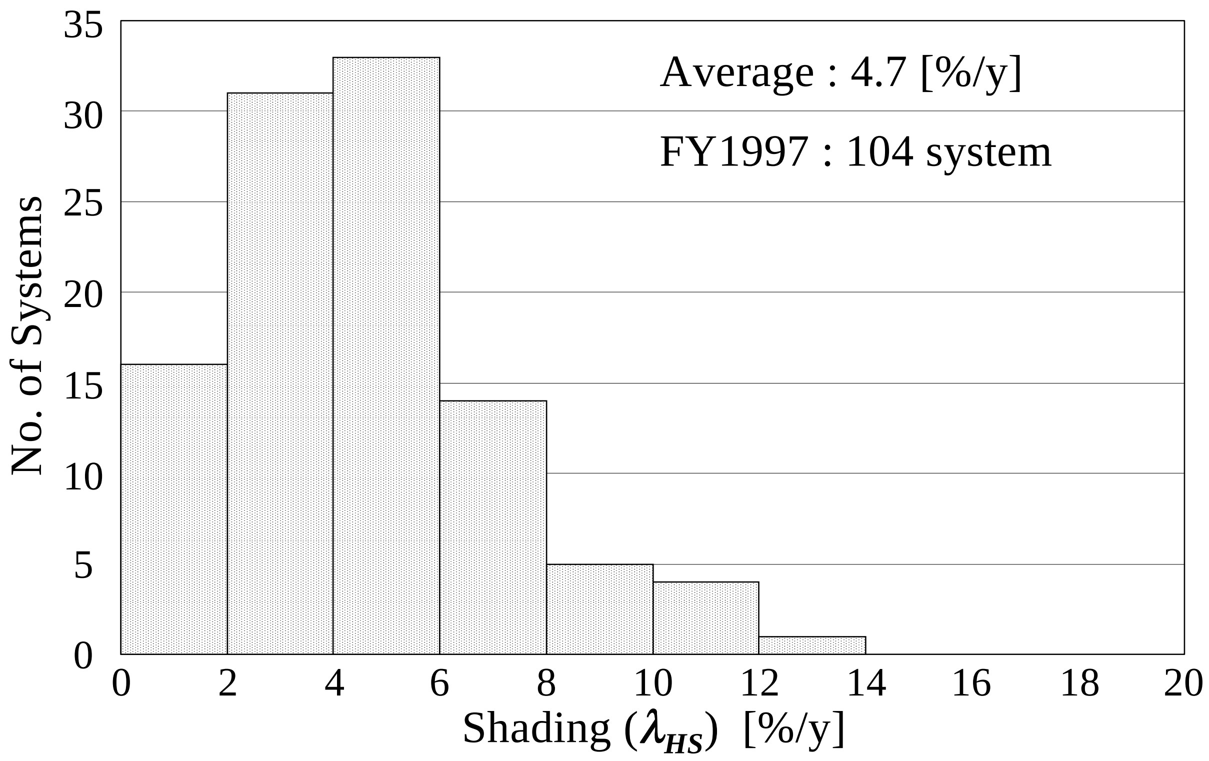


Fig.5 Histogram of shading losses in Japan (FY1997)

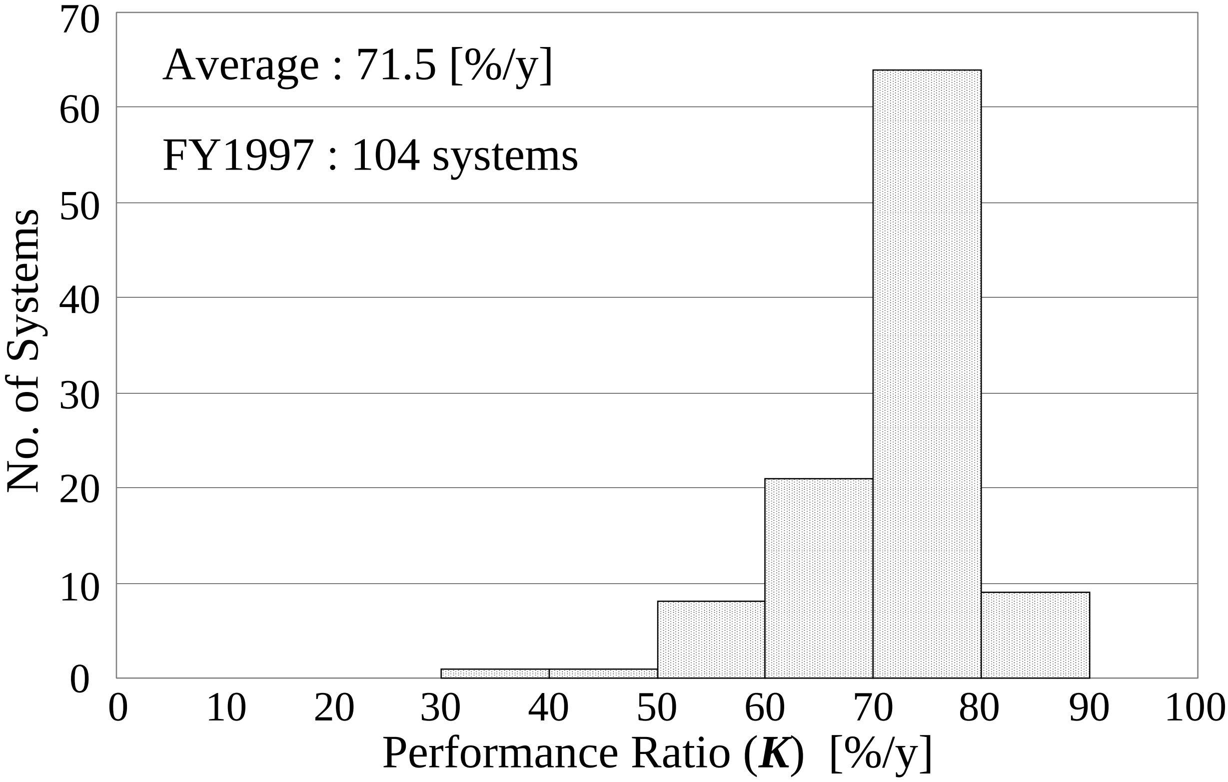


Fig.6 Performance ratio of various systems

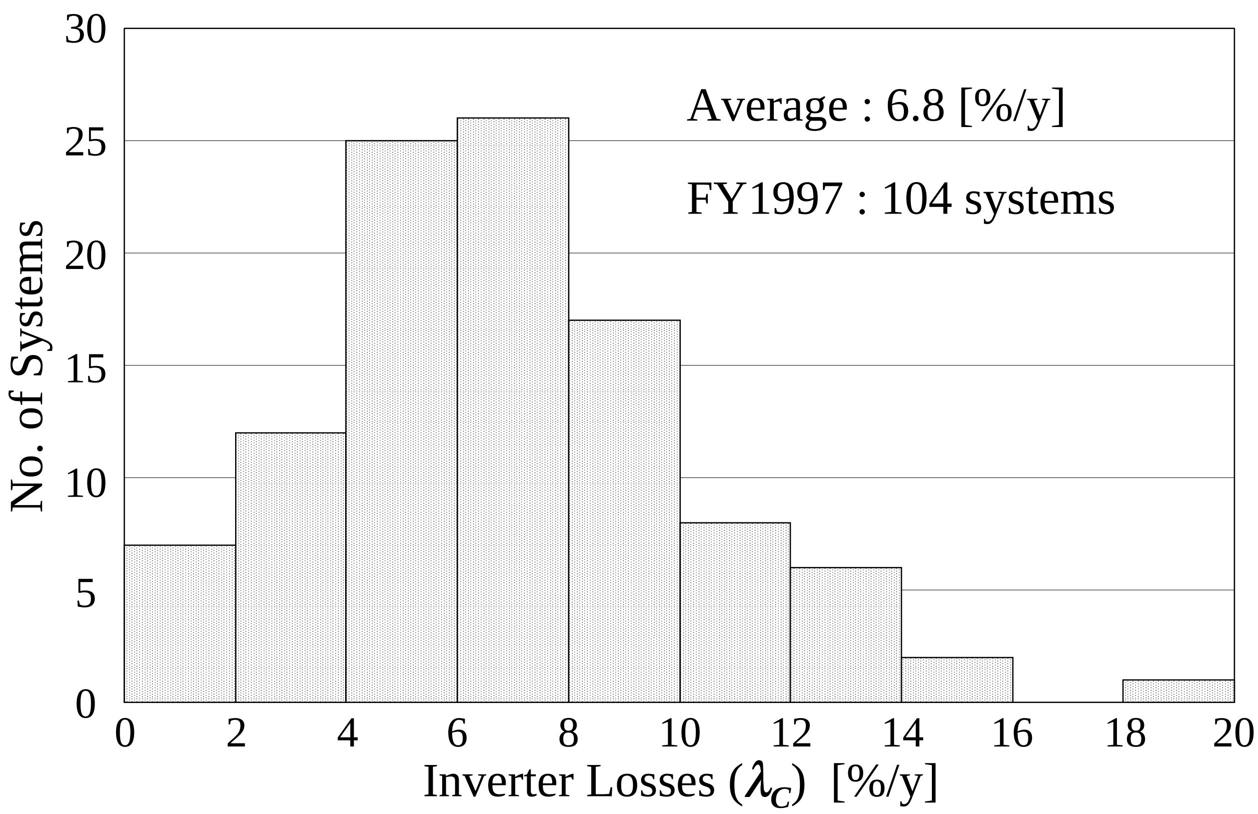


Fig.7 Inverter losses of various systems

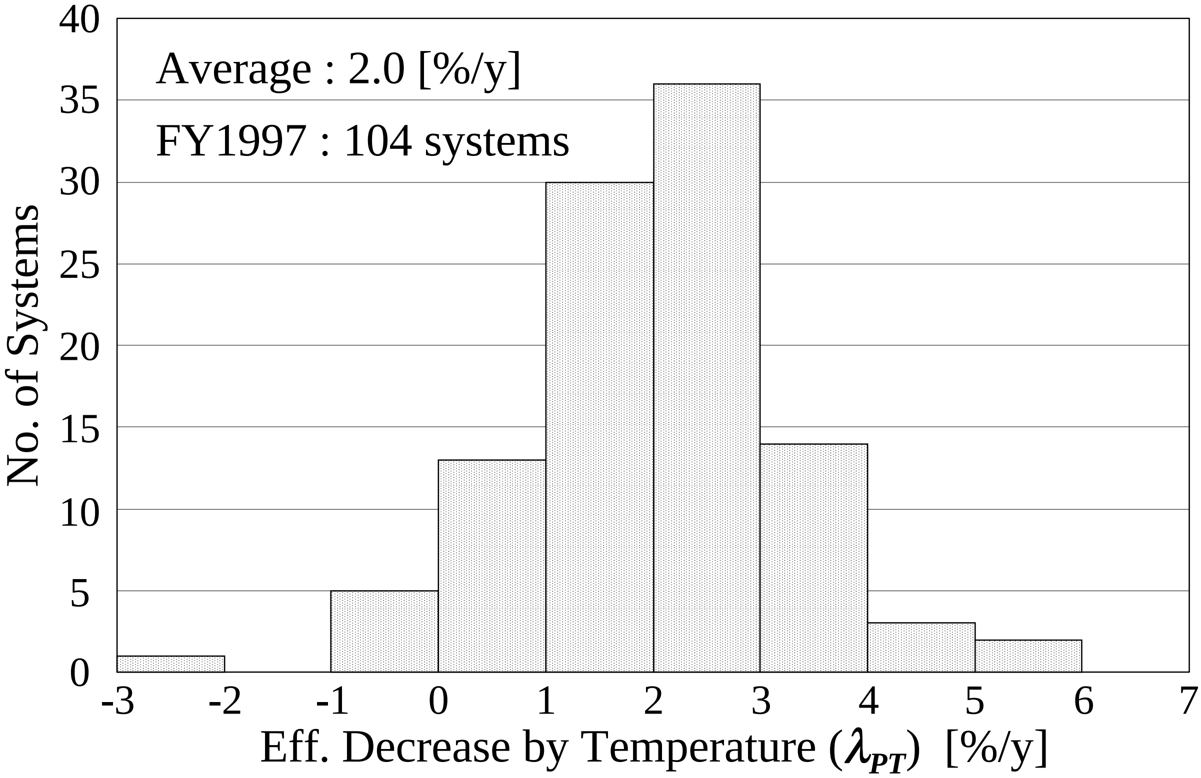


Fig.8 Efficiency decrease by temperature of various systems

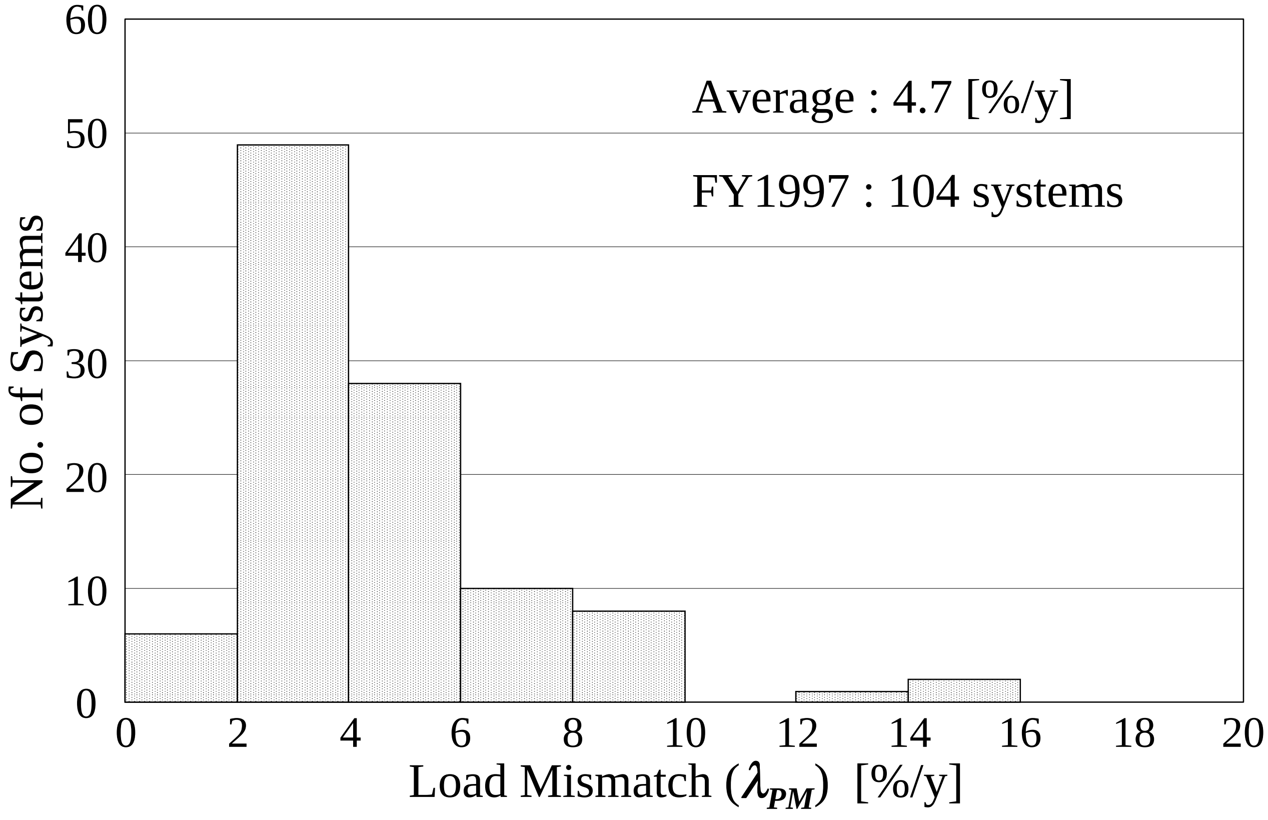


Fig.9 Load mismatching losses of various systems

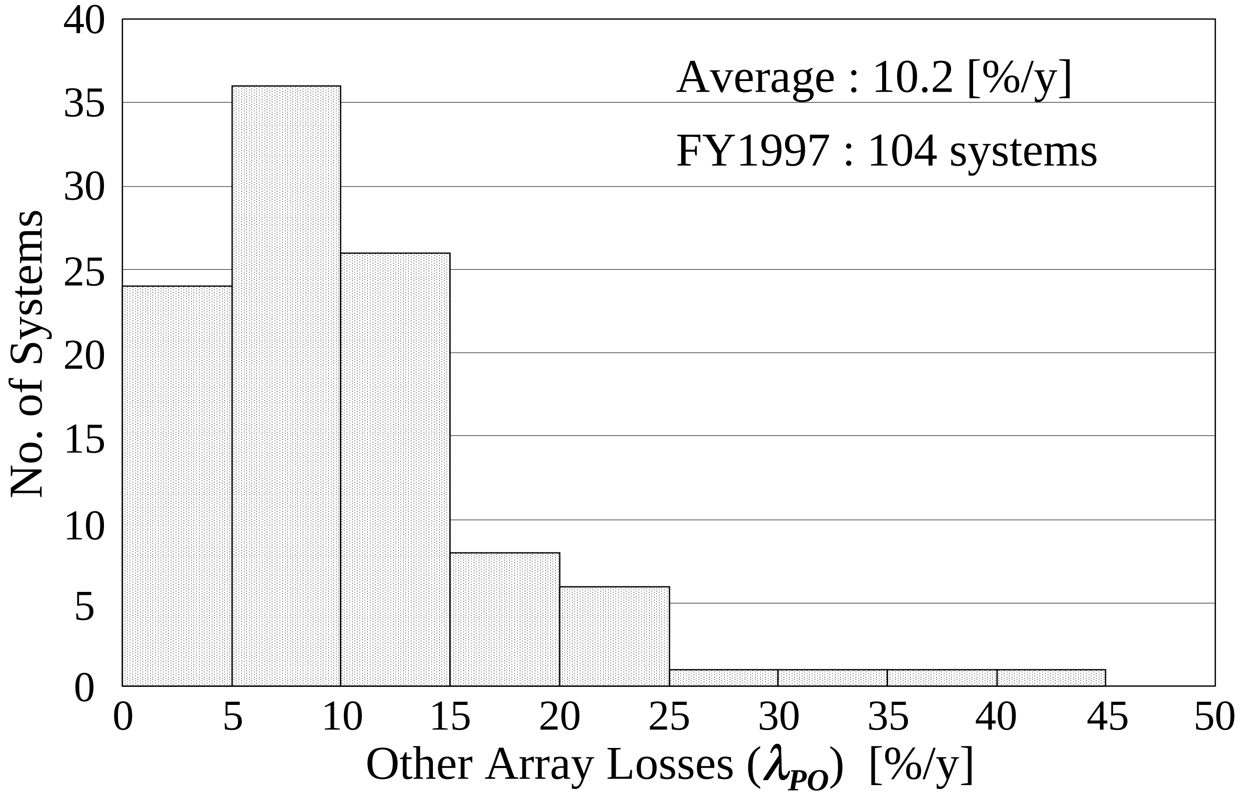
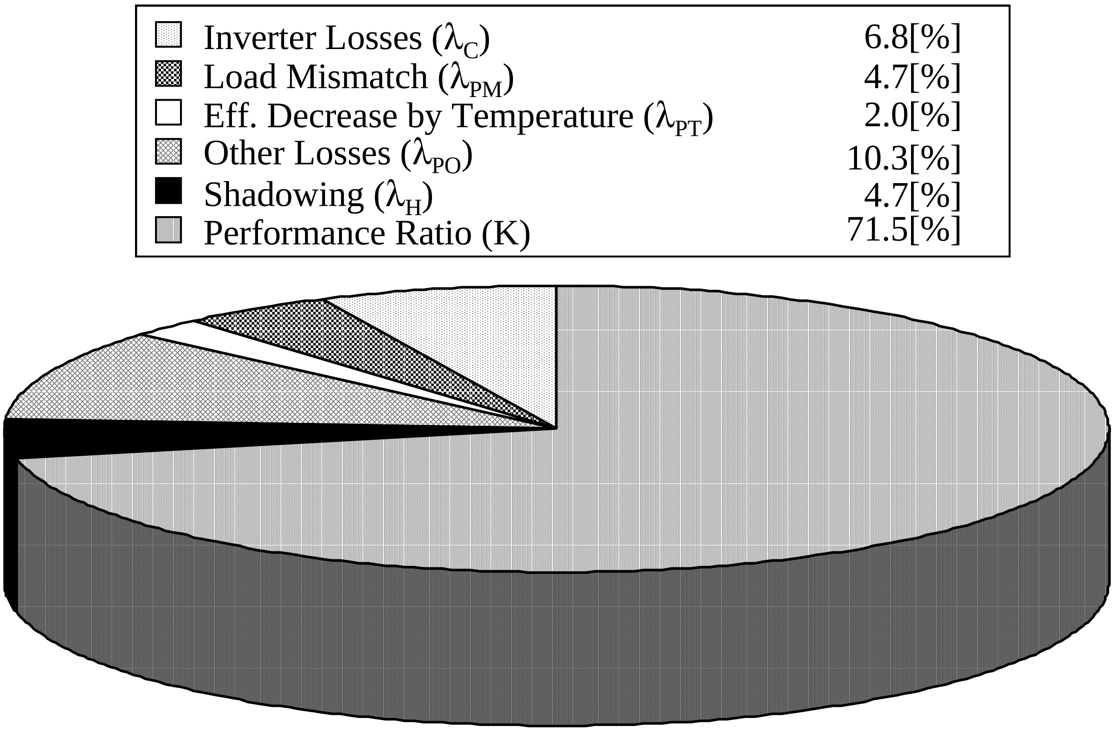


Fig.10 Other array losses of various systems



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