19th EUVPSEC, Paris, France
7-11 June, 2004
6DV.2.112

IDENTIFING OPERATION STATUSES OF GRID CONNECTED PV SYSTEMS WITH BATTERIES UNDER LIMITED DATA ITEMS
- APPLYING THE SV METHOD TO EVALUATE GRID CONNECTED PV SYSTEMS WITH BATTERIES -

Takashi OOZEKI*, Hirotaka KOIZUMI*, Kenji OTANI**, and Kosuke KUROKAWA*
* Kosuke KUROKAWA Lab., Tokyo University of Agriculture and Technology,
2-24-16 Naka-cho, Koganei, Tokyo, 184-8588 Japan Phone: +81-42-388-7445, Fax: +81-42-388-7445 oozeki@cc.tuat.ac.jp
** National institute of Advanced Industrial Science and Technology
AIST Tsukuba Central 2, 1-1-1 Umezono, Tsukuba, Ibaraki 305-8568 Japan

As well as grid-connected photovoltaic (PV) systems have expanded rapidly, the power system in a district where PV systems are clustered tends to induce over-voltage in the distribution lines in the power network which depresses the output of the PV systems. Grid connected PV system with the battery is expected to be one of technologies to resolve these kinds of problems. Moreover, we have developed the Sophisticated Verification (SV) method which is one of the evaluation methods for PV system. To apply the SV method to grid connected PV with battery system, the method to identify operation statuses was developed by using monitoring items which are needed by the SV method. It is essence of the method that the efficiency curve can be estimated with two steps, which are set the temporally threshold and then identify the operation statuses by using variable threshold value. As a result, chosen the relevant threshold value can be modulated the number of difference less than 10 times in 2,000 data sampling.
Keywords: Evaluation, Experimental Methods, Battery Storage and Control, Monitoring, Performance, System

1 BACKGRAOUNDS AND OBJECTIVE

The rapid growth and expansion of grid-connected photovoltaic (PV) systems utilization is significantly beneficial to the mitigation of environmental issues. However, the power system in a district where PV systems are clustered tends to induce over-voltage in the distribution lines in the power network which depresses the output of the PV systems. Grid connected PV system with the battery (GPVBS) is expected to be one of technologies to resolve these kinds of problems [1]. The evaluation method of the PVBS, however, is not enough to develop due to fact that few GPVBS are installed in the field, Japan. Meanwhile, a sophisticated verification (SV) method [2][3], which is an evaluation method for PV systems, has been developed in our laboratory. The method can identify losses by a few monitoring data items. Therefore, the objective is to apply the SV method to grid connected GPVBS. At the first step, this paper aims to identify operation statuses by using monitoring items which are needed to evaluate in the SV method.

2 THE SV METHOD

The authors have been developing the SV method as an evaluation method, which is using monitored data. During converting input energy into output energy, the PV system has numerous kinds of losses, which seem not to be measured. The SV method, however, can estimate system losses from irradiation energy (optical energy) to system electricity output power (AC power). Evaluating needs typical four monitored data such as in-plane irradiation data: H_{Ag}, cell junction temperature: T_C- which can be estimable from ambient temperature, array output power: E_A, and system output power: E_P, so that the system losses are allocated the part of the total system loss. For the latest version of the SV method, classifiable characteristics of PV systems are eight factors: shading losses, optical losses, losses by load mismatching, temperature effect on module efficiency, power conditioner standby losses, power conditioner efficiency, DC circuit losses, and the other losses which reduce the fundamental system performance, for

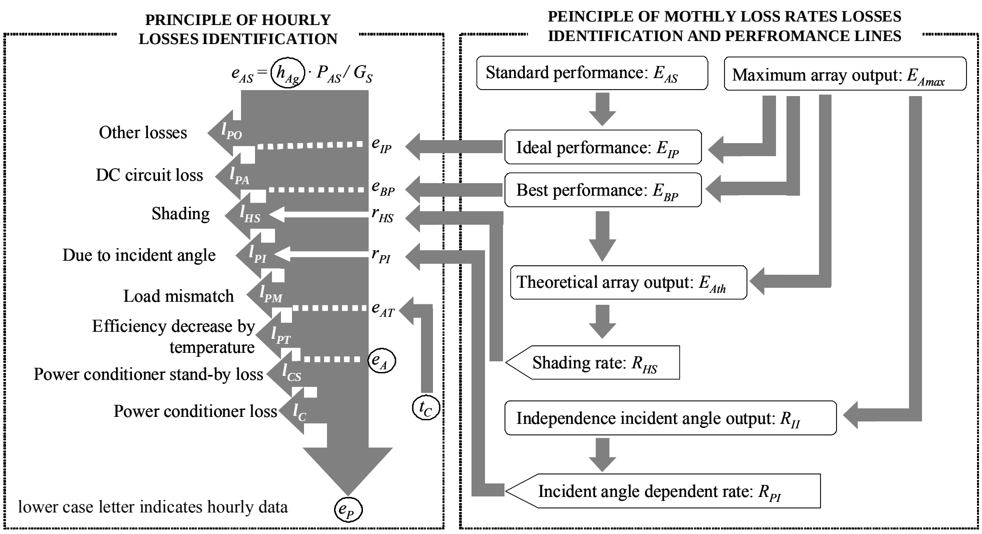
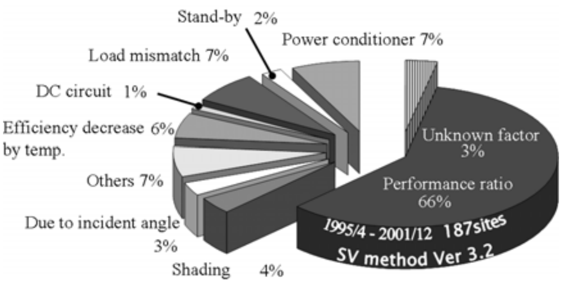


Figure 1: The flow chart of the SV method

instance; soil on modules, depleted modules, and the erroneous system rate. **Figure 1** gives the principle of the SV method. This method adopts ordinary formulas in order to classify those characteristics, performance ratio, power conditioner efficiency, and temperature effect on efficiency. The essence of the method, in addition, is to draw the performance lines which are based on certain assumptions from experience according to real monitored data in the principle of monthly. To develop an individual evaluation model of losses for a specific month and a specific site indicates to identify losses which are difficult to measure on site; i.e., shading effect, load mismatch, incident-angle optical losses, and DC circuit losses.

Figure 2 reveals the percentage of losses and shows an example of the evaluation result for FT of public - the total of 187 systems form 1995/2 to 2001/12 - facilities by using the SV method.



* Unknown factor: According to error data during easuring and outlying data

Figure 2:The evaluation result for PV Field Test Program for public facilities' systems by using the SV method (1995/4-2001/12).

3 THE PV SYSTEM WITH THE BATTERY

GPVBS has a lot of the system operation statuses as shown **Figure 3** and **Table 1**. Identifying those operation statuses is important due to evaluate the system performance. As usual, four monitoring data are available in the SV method as describe before ; therefore, it is focused that the operation status of PVBS is identified from four monitoring data, especially PV array output (E_A) and system output (E_P).

Considered the system is that the PV array and the battery are linked DC energy by connected DC/DC converter. The battery can becharged from both of energy PV array and utility.

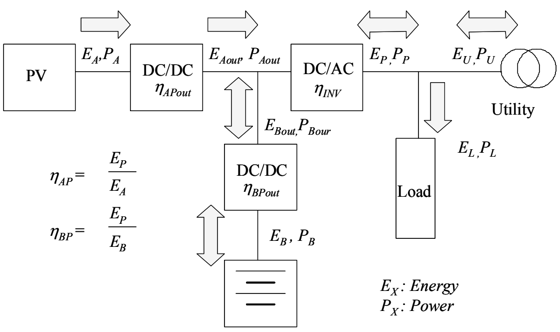


Figure 3:Schematic diagram of the system and energy flow.

Table 1: Operation statuses of the grid connected PV with Battery system.

operation status		Irradiation	Array output	system output	Ratio between array output and system output
item	operation status	H_{Ag}	E_A	E_P	η_{AP}
A	Supplied by PV	+	+	+	same as normal value
B	Charged by PV	+	+	0	$E_P = 0$
C	Supplied and chaged by PV	+	+	+	Low value
D	Supplied by PV and battery	+	+	+	high value
E	Supplied by battery	0	0	+	$E_A = 0$
F	Charged by utility	0	0	-	$E_A = 0$
G	Charged by PV and utility	+	+	-	E_P is minus

4 METHODOLOGY OF ESTIMATION

The relation between E_A and E E_P is depended on the system operation status. As shown in **Table 1**, focusing polarity of E_A and E_P can identify those statuses except the operation of parallel running. For example, both of E_A and E_P are positive polarity in such a way that the PV outputs without the battery. In case of that the PV and the utility charge the battery at the same moment, E_A is positive, and E_P is negative value. Using relationship, the number of the system operation status and energy flow is identified.

Moreover, the ratio (η_{AP}) between E_A and E_P, which can include the battery output (E_B) through the DC/DC converter, is indicated to be efficiency of power conditioners, DC/DC converter and DC/AC inverter. In naturally, it is drawn a curve line and values from 0 to 1.0. However, in the operation of parallel running case, η_{AP} is higher or lower than normal η_{AP} because E_P includes E_B output through the DC/DC converter, and E_B is assumed not monitored. The parallel operation status is identified by informed η_{AP} which is set at certain threshold, shown in **Figure 4**. Under the threshold value is constant, operation statuses cannot be identified because the efficiency curve is depend on the load factor, and the value is necessary to be variable. As shown **Figure 4**, there are dead zone to identify operation statuses. Therefore, it is necessary to estimate efficiency curve and figure out if the operation status is the surround the curve or not. And also the threshold has the margin band: β. This argument leads to the way and expression to be identified operation statuses:

Step 1: Identify the operation of PV array output without the battery by setting the temporally threshold which is the constant value α.

Step 2: Estimate the efficiency (η_{APest}) by using data of PV array output which are obtained step 1.

Step 3: Identify the operation statuses by using the threshold value which is variable with estimated the efficiency curve and margin band: β.

Figure 5 shows the flow chart of estimated operation statuses with estimation the efficiency curve of power conditioner, and the equations are as flowing:

A. PV outputs without battery output

$E_A > 0,\ E_P > 0,\ \eta_{APest} - \beta < \eta_{AP} < \eta_{Apest} + \beta$ equation 1

B. PV charges battery

$E_A > 0,\ E_P = 0$ equation 2

C. PV charges battery and outputs

$E_A > 0,\ E_P > 0,\ \eta_{APest} - \beta \geq \eta_{AP}$ equation 3

D. PV with battery output

$E_A > 0,\ E_P > 0,\ \eta_{AP} \geq \eta_{Apest} + \beta$ equation 4

E. Battery output without PV array output

$E_A = 0,\ E_P > 0$ equation 5

F. Utility charges battery

$E_A = 0,\ E_P < 0$ equation 6

G. PV with utility charges battery

$E_A > 0,\ E_P < 0$ equation 7

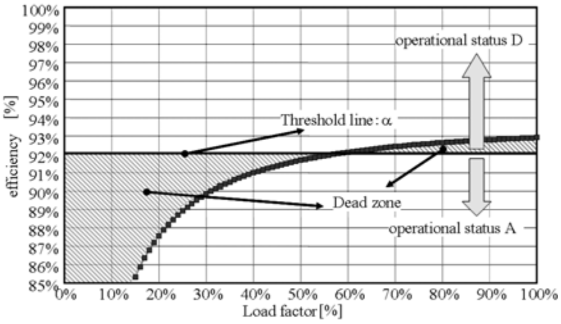


Figure 4: Schematic diagram of the relation between operation status and threshold value and efficiency curve. In natural, efficiency curve, E_P/E_A, is from 0 to 100%. Therefore, the threshold value is decided from 90% to 100%. The optimal threshold value is most important to identify the operation status.

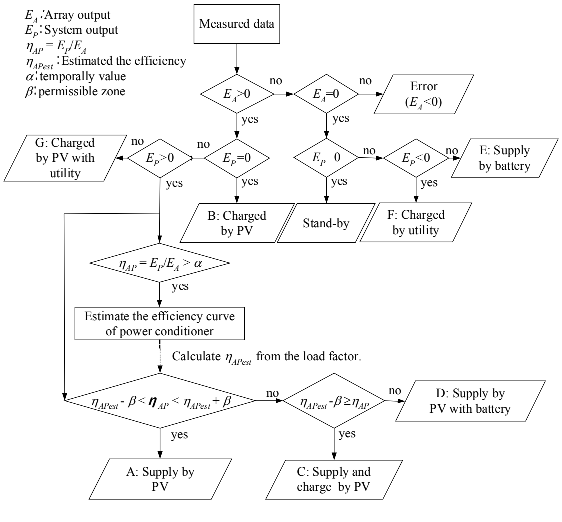


Figure 5: Flow chart of estimated operation statuses with estimation the efficiency curve of power conditioner.

5 EXPERIMENT OF ETIMAION AND DATA SET

The measuring data of GPVBS are obtained by using PV array simulator. **Figure 3** is shown schematic diagram of the system, and specification of system simulator is shown in **Table 2**. **Figure 6** is illustrated an example of experience result. PV array output is simulated by I-V curve simulator, 3.7kWp, and load is programmable by using resistance load. Note that this system has only four operation statuses, A, D, E, and F in the **Table 2** [4].

In this paper, focused operation status is PV array output without the battery (Operation status A) and PV array output with the battery output (Operation status D) because It is most importat to identify the operation status under the parallel operation condition. Considered data are under the condition of clear day and simulated the general residential load papern in Japan. Irradiation data is obtain from field test data of which sampling time is one minutes. A number of data sampling are 2,000, and monitored data items are PV array output , system output, battery output, utility power, and load consumption energy, and irradiation which is input to I-V curve simulator.

Table 2 Specification of system simulation

Facility	Rating	Remark
PV rate	3.7 kW	I-V curve simulator
Power coinditioner rate	4.5 kW	-
Battery capacity	8.96kWh	2kW max output

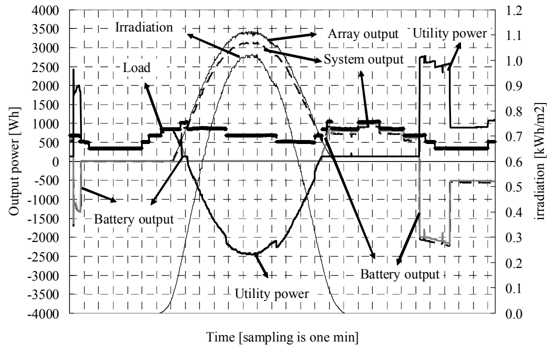


Figure 6: An example of experience result

6 RESULTS

Figure 7 is shown the difference of output power between theoretical data and estimated data every the threshold values of α. More increase the positive error of status D, more increase the negative error of status A. In this case, α is optimized 0.94, of which are used constant threshold values. However, it is not critical different from 0.94 to 1.0 of the temporally threshold value.

Moreover, the result of estimated efficiency curve by using identified PV array output data on Step 1, shown in **Figure 8**. Theoretical efficiency curve is in simulator's value. X-axis is threshold α is selected in order to classify array output data. Resultant efficiency curve is estimated by using array output data which was classified every threshold data. As a result, accuracy of esitimated of efficiency curve are almost same value by selecting over 0.94 of the temporally threshold value except 0.1 of load factor. As consider that load factor is rarely 0.1 in operation and low level power, the temporally threshold value can be set from 0.94 to 1.00 flexibility.

In addition, the margin of threshold from efficiency curve is effected accuracy to be estimated the operation status. In **Figure 9**, the number of difference times between theoretical data and estimated data in such way the margin band: β was changed. Chosen the relevant threshold value can be modulated the number of difference less than 10 times in 2,000 data sampling. As a result, focusing the relation E_A and E_P can classify the operation status of GPVBS with estimation of efficiency curve.

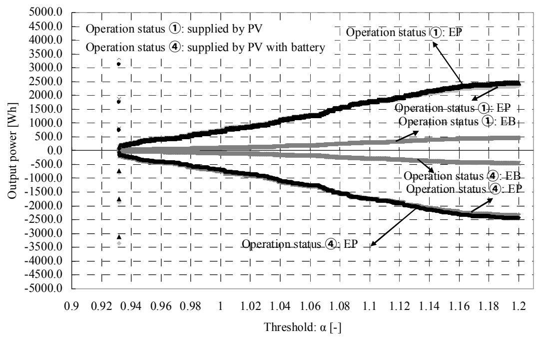


Figure 7: Difference of output power between theoretical data and estimated data.

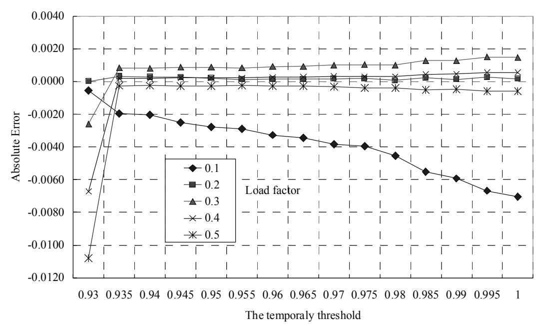


Figure 8: Absolute error for efficiency power conditioner every load factors.

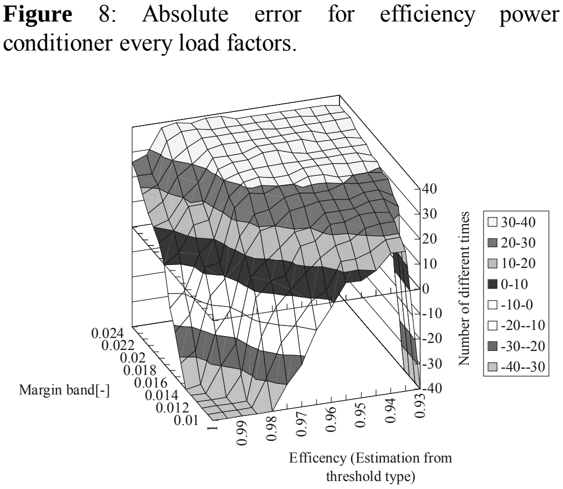


Figure 9: Number of difference times between theoretical data and estimated data by using efficiency curve.

7 CONCLUSIONS

To apply the Sophisticated Verification (SV) method to grid connected PV with battery system (GPVBS), the method to identify operation statuses was developed by using monitoring items which are needed to evaluate in the SV method as first step. It is essence of the method that the efficiency curve can be estimated with two steps, which are set the temporally threshold and then identify the operation statuses by using variable threshold value and margin band. As a result, chosen the relevant threshold value can be modulated the number of difference less than 10 times in 2,000 data sampling.

In this case, the estimation result is evidenced to identify the operation status base on instantaneous value. In the future, the method should be developed base on hourly average value with added monitoring data item, the energy of charge or discharge to the battery, because the SV method is available under the hourly data. Moreover, we will evaluate hundreds of real GPVBS in the field using the SV method and data obtained under the project "Demonstrative Research on Clustered PV systems"

ACKNOWLEDGES

This work was supported by NEDO as part of the "Demonstrative Research on Clustered PV systems" under METI.

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