PERFORMANCE ANALYSIS OF STAND ALONE PV SYSTEMS FROM A RATIONAL USE OF ENERGY POINT OF VIEW

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ABSTRACT

The performance analysis of stand alone PV systems (SAS) is not as straight forward as it is for grid connected systems. A poor performance does not mean that the system encounters technical problems but can also be the consequence of a bad matching between the production and the load. Some coefficients have already been introduced within IEA PVPS Task 2 ([1], [2]) to consider poor sizing and technical problems by complementing the performance ratio .
This paper presents, through examples, different cases where the commonly used factors show their limits and highlight how some new coefficients, can better inform on the operational performance of stand alone systems.

1. EXISTING QUANTITIES FOR SYSTEM PERFORMANCE ASSESSMENT AND THEIR LIMITATION

The quantities usually used to assess the performance of SAS are the following :

$Y_A=E_A/P_o$ (kWh/kWp.d) : array yield (1)

$Y_R = H_i/G_{STC}$ (kWh/kWp.d) : reference yield (2)

$Y_f=E_{PV}/P_o$ (kWh/kWp.d) : final yield (3)

$E_{PV}=E_L/(1+E_{BU}/E_A)$ (kWh): PV energy consummed (4)

$L_C= Y_R-Y_A$ (kWh/kWp.d) : capture losses (5)

$L_S=Y_A-Y_f$ (kWh/kWp.d) : system losses (6)

$PR=Y_f/Y_R$ Performance ratio (7)

With :
P_o : Peak Power (W_p)
Hi : Mean daily irradiation in array plane ($kWh/m^2.d$)
G_{STC}: Reference irradiation at STC (1 kW/m^2)
E_A : Array output energy (kWh/d)
E_L : Energy to loads (kWh/d)
E_{BU} : Energy from back-up system (kWh/d)

The performance ratio (PR) was introduced to characterize the system operation whatever the application considered. PR shows how the potential energy of a PV systems is used. This potential energy is defined under Standard Tests Conditions (STC).

The higher PR is, the better the system uses its potential. A low PR value means production losses due to technical or design problems.

Within the frame of the International Energy Agency Photovoltaic Power Systems (IEA PVPS) Programme a data base has been built up by Task 2 experts in order to gather operational data and assess the performance of PV systems. More than 30 SAS (Stand Alone Systems) installed worldwide for domestic applications are registered in the data base with peak powers varying from 450 Wp to 5 000 Wp. From these systems about 43 annual data sets have been used to deliver useful information on their performance and more generally on SAS performance.

The analysis of the systems performance (see Fig. 1) shows that SAS present a wide range of PR, which does not reflect the proper operation of a system from the technical point of view (such as component degradation or low components efficiency) as it is the case for grid-connected systems. An oversized system faces frequent partial or complete array disconnections to protect the batteries against overcharge, which reduces the PR value.

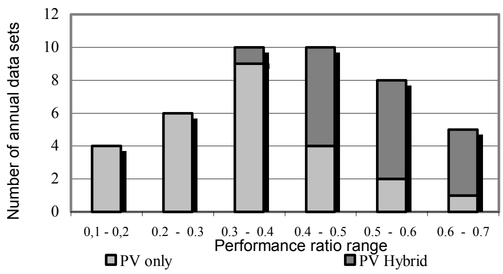

Fig. 1 : Range of yearly PR for typical domestic SAS

The value of the PR is user consumption dependent. If the consumption level is not correlated to the potential energy of the PV generator, the PR will reach values which can be less than 20 % on a monthly basis (see Fig. 2). Such low values are caused by high capture losses.

Hybrid systems with back up generators may show a better performance than PV only systems in most cases. The consumption level matches more efficiently the potential energy of the PV generator (see Fig. 3). Those hybrid systems which have low performance (see Fig.1) are designed in a way, that the back-up generator is only active during unfavourable time periods with low irradiations.

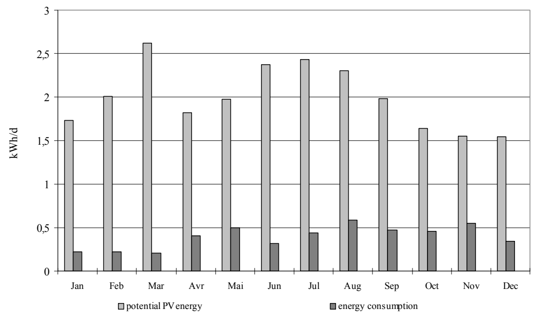

Fig 2: Consumption level : PV only system (PR=0.20)

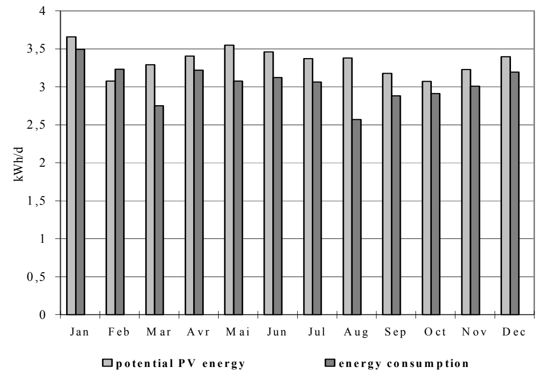

Fig 3: Consumption level : hybrid system (PR=0.65)

Oversized systems lead to low PR values as most of the incident solar energy is not used. So, in this case, the only observation of PR cannot give a relevant picture of the system operation. There is a need for new "quantities" to be introduced to fill this gap.

2. INTRODUCTION OF NEW COEFFICIENTS

2.1 The usage Factor (UF)

A SAS which is not operating properly will show a low PR. But as it has been demonstrated this is not reciprocal. In order to have an idea on how the system is using the potential solar energy, a new factor has been introduced, defined as follows :

$$UF = E_A / E_{POT} \qquad (8)$$

In Stand Alone Systems E_{POT} is determined by measuring the PV array current even during disconnections.
In a grid connected system E_{POT} is equal to E_{II}, the energy at the inverter input.

Fig. 4 shows the correlation of PR and UF for 37 annual data sets of the SAS within the IEA PVPS T2 data base. UF is more or less a linear function of the PR. The better the system uses its solar potential, the higher is PR. However, there are three systems which deviate from this linear trend. When analysing their operational characteristics it can be seen from Fig. 6 that the systems losses are abnormally high in comparison with a system having the same PR (see Fig. 5)

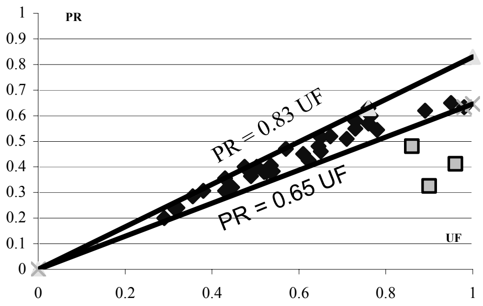

Fig. 4: PR as a function of UF

Introducing :

$$\eta_{SYS} = Y_A/Y_f \quad : \text{system efficiency} \qquad (9)$$

$$\eta_{PROD} = E_{POT}/ P_o.Y_R \quad : \text{production efficiency} \qquad (10)$$

$$PR/UF = \eta_{SYS} . \eta_{PROD} \qquad (11)$$

This ratio represents the global system efficiency (by reference to the peak power) including all the possible losses (temperature effects, incomplete use of solar energy, components efficiency, malfunctions,…).

The best conditions of operation are obtained when the system uses all the potential available (UF=1), which means that, taking into account the SAS available in the Data Base, the maximum value of PR lies between 65% and 83%. Such values can be compared to the one obtained in grid connected systems.

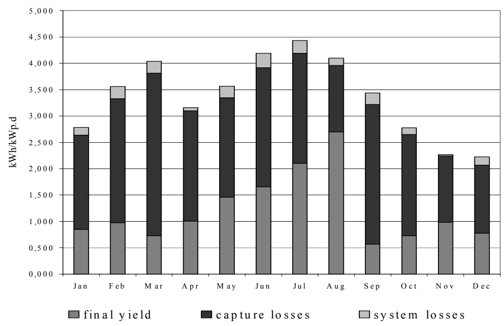

Fig. 5 : System performance with PR=0.3 – UF=0.45

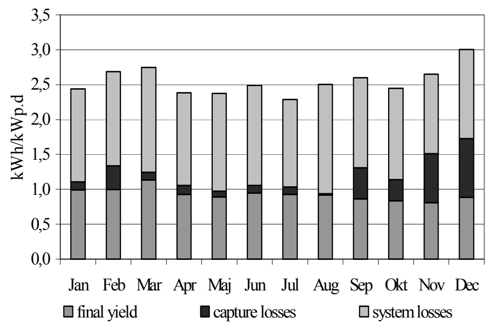

Fig. 6 : System performance with PR=0.3 – UF=0.90

Both systems in Figure 5 and 6 are characterised by the same PR value (PR=0.3) but very different UF (UF=0.45 and UF=0.9). The system with the low UF is one of the 3 systems indicated with a grey square in fig. 1 deviating from the linear function of PR. This system is characterised by extreme system losses due to technical malfunctions. Provided that E_{POT} is able to be measured, then UF to be calculated, the combination of PR and UF as a representation of the system performance allows to detect systems with technical problems.

2.2 Production factor

Unfortunately, for most of the installed systems E_{POT} is not monitored, therefore UF can't be determined. Hence a new coefficient is introduced in the following by calculating the array production to the one specified at STC by the manufacturer of the systems :

$$PF = E_A / (P_o \cdot H_i/G_{STC}) = Y_A/Y_R \qquad (12)$$

$$PR/PF = \eta_{SYS} = Y_f/Y_A \qquad (13)$$

PF is calculated from the data implemented in the IEA PVPS data base and is presented in Fig.7. The system efficiency, the relationship between PR and PF, is more or less a linear function like UF.

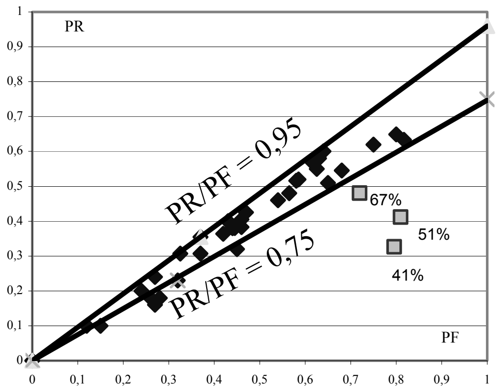

Fig. 7 : PR versus PF for domestic SAS

Analysing the system efficiency in Fig. 7 leads to the following results:

- The system efficiency of most SAS is in the range from 75% to 95%.
- PF lower than 30% means in most cases that the array production is limited due to a low consumption level. Then, the system losses can reach some few 10% of the array production without facing any technical problems. In such a situation the system efficiency can be in the range 60 to 65%.
- The systems identified with grey squares have high PF values and efficiencies lower than 75% which is caused by technical problems..

2.3 Conclusions regarding the two introduced coefficients UF and PF

The Ispra Guidelines have only been elaborated to measure the systems performance and not to distinguish between bad results due to a poor sizing or to a technical problem. It is difficult or even impossible to find out the technical reasons of e.g. a disappointing performance of a PV-system. The two introduced coefficients UF and PF allow to overcome this fact and give indications on the system operation with monitoring data typically gathered at a monthly or even yearly basis within the IEA PVPS T2 data base. First calculations and system analysis show that strong deviations of the expected combined PR&UF or PR&PF curves may indicate malfunctions of the systems.

3. CASE STUDIES

The following chosen case studies may underline the advantages of the introduced coefficients. Two systems installed in Indonesia are identical regarding the size and the architecture. The two hybrid systems have the following components:

- a 23.52 kWp PV array operating at 240 V
- a 334 kWh battery (1140 Ah/240 V)
- a 40 kVA three phases diesel genset
- a 20 kW battery charger (240 V/100 A)
- a 30 kW inverter (240 V=/400 V~)

The performance of these two systems is shown in Table I.

Table I : Energy balances of the two systems during the period March – June 2000

	Muara Ancalong	Kalumpang
EA (kWh/d)	79.0	48.3
EL (kWh/d)	73.1	27.5
EBU (kWh/d)	14.1	6.5
PR	0.56	0.22

The mean irradiation of both sites is the same for the chosen time period. PF and the system efficiency are calculated for both systems in Table II.

Table II : PF and η_{SYS} value for the two systems during the period March – June 2000

	Muara Ancalong	Kalumpang
PF	0.715	0.44
PR/PF	0.78	0.50

Taking into account the conclusion of the second chapter the Muara Ancalong system is operating in good conditions as its efficiency is higher than 75% with a PF value higher than 0.3. In opposition to this result the Kalumpang system shows a system efficiency of about 50% (with PF higher than 0.3). Looking into other calculated parameters of this system shows that the storage efficiency is rather low. This low efficiency is an additional indication of a malfunction in the system operation.

4. CONCLUSION

The work performed on the data collected and gathered in the IEA PVPS Task 2 data base shows that more information is needed than only the Performance Ratio to assess the operation of Stand Alone Systems. Two new correlated coefficients ,are introduced to complete the set of information needed to have access to the system performance. The conclusions presented in chapter 2.3 rely on selected data of about 30 domestic PV systems installed in Austria, France Metropole and oversea islands. The calculation of two case studies in chapter 3 underline the advantage of the new coefficients and points out some possible malfunctions which cannot be easily highlighted as the consumption level is rather low and consequently easily supplied by the PV system, even in a not proper way.

Moreover, such factors, in the same way than the PR for grid connected systems can be used to compare the operational performance of SAS among themselves

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