Simplified methods for calculating the performance of solar power plants

1 Principle of methods

In the study of solar thermal conversion, we are led to focus on phenomena of threshold (start, transition between operating modes etc.) and nonlinearity of efficiency as a function of radiation. The solar resource is therefore characterized by the cumulative frequency curve.

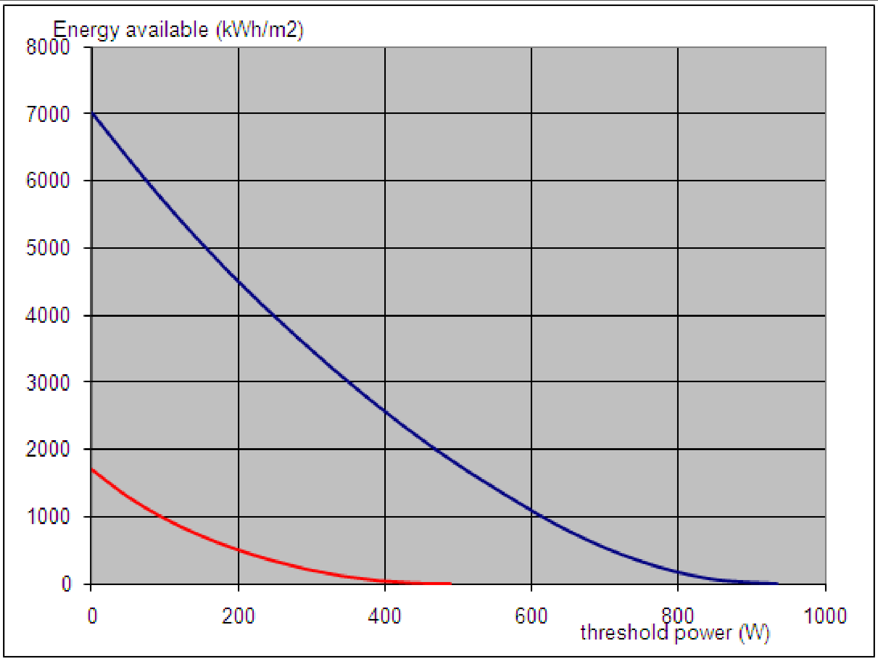

Figure 1: Energy available in Ajaccio, on a horizontal plane in January and July

For collectors of a given type characterized by their optical factor τ and thermal conductance U (see Section 8.2.2), control being set (values of the differential, mass flow), the amount of heat that we can recover, at best, only depends on the fluid inlet temperature (T_i) in collectors. We call it "Energy available at temperature T_i " and we denote it $Q(T_i)$.

The easiest way to calculate it is to admit that during each hour, the steady state corresponding to the average hourly radiation and the outdoor temperature is established: stop, steady pulse or steady operation without pump stop. It is a linear function of the surface of the CFC below the threshold.

We call usable energy the area between the curve itself and the operating threshold. It can also be determined analytically based on CFC formulations, to provide usability curves presented below.

2 Usability curves

If the reduced threshold value of a solar system is y_S, solar energy available is given by:

$$g(y_S) = \int_{y_S}^{1} f(t)\, dt \qquad (11.10)$$

It is thus possible to express g as:

$g(y) = g_0(y)+A_1g_1(y)+A_2g_2(y)+A_3g_3(y)+A_4g_4(y)+A_5g_5(y)+A_6g_6(y)+A_7g_7(y)+A_8g_8(y)$

with

$g_0 = 0.5\ (1-y)^2\ (1-y)$

$g_1 =(2\ y + 1)\ (1-y)^2\ (5/6)^{0.5}$

$g_2 = y^2\ (1-y)^2\ (105/2)^{0.5}$

$g_3 =(1-y)^2\ (1 + 2\ y - 42\ y^2 + 84\ y^3)\ (1/10)^{0.5}$

$g_4 = y^2\ (1-y)^2\ (1 - 4\ y + 4\ y^2)\ (1155/2)^{0.5}$

$g_5 = (1-y)^2\ (1 + 2\ y - 207\ y^2 + 1404\ y^3 - 2970\ y^4 + 1980\ y^5)\ (13/420)^{0.5}$

$g_6 = y^2\ (1-y)^2\ (18 - 176\ y + 605\ y^2 - 858\ y^3 + 429\ y^4)\ (35/4)^{0.5}$

$g_7 = (1-y)^2 (1+2 y -627 y^2 +8404 y^3 -41470 y^4 +94380 y^5 -100100 y^6 +40040 y^7) /210 (595)^{0.5}$
$g_8 = y^2(1-y)^2(30-520 y +3445 y^2 -11154 y^3 +18837 y^4 -15912 y^5 +5304 y^6) (10.45)^{0.5}$

This curve, known as usability (Figure 1), reads very easily: the daily energy available H on a horizontal plane in Ajaccio above threshold 200 W/m^2, is equal to 4,500 Wh/m^2 in July and 600 Wh/m^2 in January. These values fall to 1,010 Wh/m^2 for threshold 500 W/m^2 in July and 0 in January.

It is thus possible for different thresholds, to determine energy available during the year (Figure 2).

The calculation of the collector output is done by multiplying this energy by optical factor τ, and subtracting heat losses, equal to the product of the difference (T_i - T_{out}) by U and the number of hours of operation. The threshold varying according to T_{out}, we must first determine the threshold value for each month, taking as value of the average outdoor temperature T_{out} the daytime one, as solar collectors do not operate at night.

Knowing usability curves, it is possible to determine the energy available at the desired temperature T_i. This energy is indeed equal to the sum of several terms:

- usable energy as given by curves of Figure 1, multiplied by the optical factor τ of solar collectors;
- energy threshold, multiplied by the number of hours above the threshold and τ;
- heat losses, counted negatively, multiplied by the number of hours above the threshold.

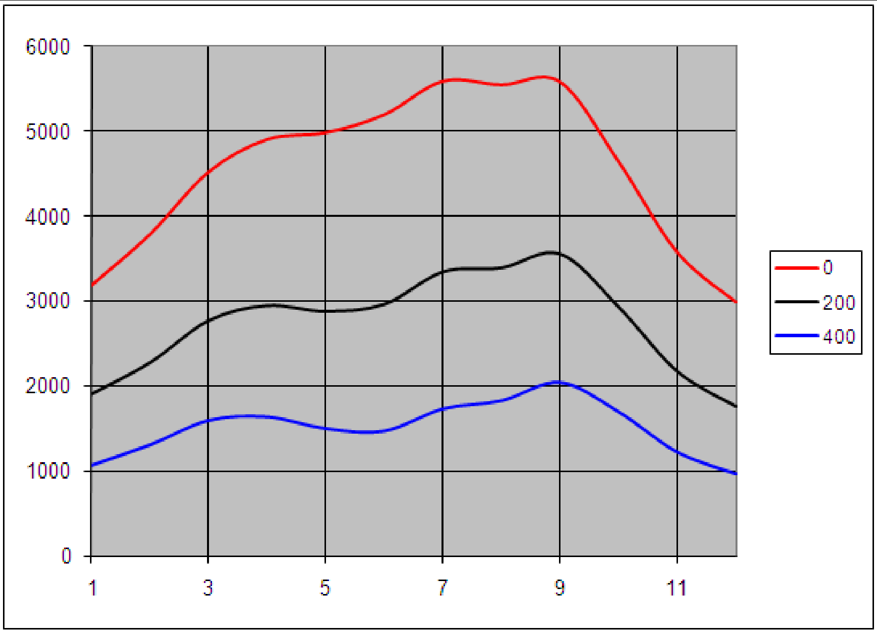

Figure 2: Monthly energy use in Ajaccio, 60 °, depending on the threshold

The first two terms correspond to the whole irradiation received by the collectors, reduced by the optical factor, and the third to heat loss. It turns out that the sum of the two latter is nil, so that only the first has to be taken into account.

In a solar power plant, all the power produced by thermal collectors is not converted into electricity, because of:

- the need to store that energy when it is available, until the stored heat is sufficient so that the power plant operates stabilized, which implies some storage losses;
- storage capacity, which is necessarily limited, so that at certain periods in summer, solar heat can be a surplus, which induces additional specific losses during this period.

We can consider a storage effectiveness constant for the first of these terms, and depending on the radiation received and the storage volume for the second. Simplified methods being unable to calculate the influence of these losses, they often include correction terms based on hourly simulation software which allow them to be estimated with reasonable accuracy.

References

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