Towards a New Model of Evaluation of Transformation Losses in Solar Orchards

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Abstract. In this article is analyzed the economic yield that would turn out from replacing the conventional transformers currently used on solar orchards by others of higher performance. In this way, the losses would be reduced increasing at the same time the injected energy to the network. Moreover, it would have a beneficial effect in the efficiency of the global installation including the connection to the distribution network.

Key words

Solar orchard, High efficiency transformers, Net present value (NPV), Pay-back.

1. Introduction

At the moment, in Spain it is a common practice that the low-voltage grid-connected photovoltaic facilities gather into the so called 'solar orchards', so that, on the one hand, common costs are saved and the administrative transaction is facilitated, and on the other hand, the special tariff for generators of less than 100 kW [1] can still be used.

The lay-out of the installation is as follows (Fig. 1): each photovoltaic generator consists on a photovoltaic field connected to an inverter, an energy meter to know the individual production and a breaker to isolate each generator from the whole installation. The inverter is used to modify the electricity characteristics to allow the connection with the middle voltage network (cc to ac). All the generators are connected to the low tension bar of the transformers. These convert the electricity from low tension to middle tension, being the energy finally ready to the connection to the distribution network. The total energy produced is injected to the medium voltage (MV) network by means of the 'extension' installation (Fig. 1).

As it can be seen, there is a unique connection point for the whole installation. The distribution company, which is the responsible of the energy retribution to the owners of the solar orchard, is not obligated to use a meter in the middle voltage part or the installation, and will usually consider the losses in the extension installation as a fixed percentage of the installed power of transformation (between 2 and 3%). This means a reduction in the retribution to the owners, which are pay for less energy than what they actually produce due to the extension installation losses. This reduction affects in an equitably way all the generators.

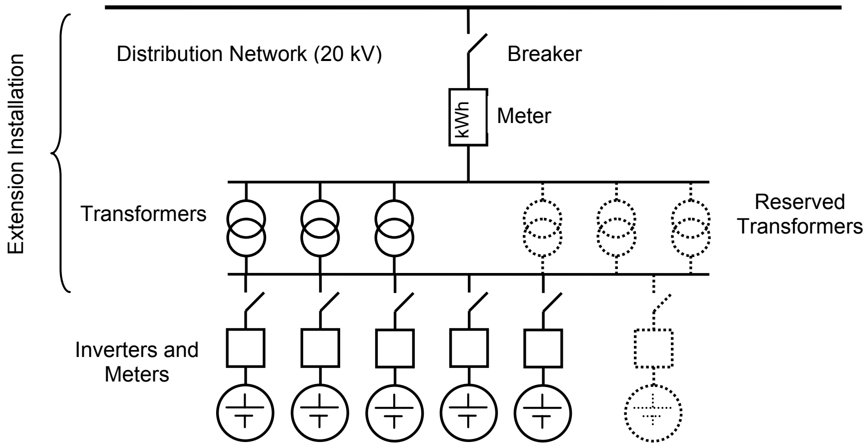

Fig. 1. Solar orchard diagram.

Most of the losses produced in the extension installation are transformer losses, so it is logical to think that an improvement in transformer efficiency will also lead to an improvement in the power efficiency of the whole installation.

The impact of the transformer efficiency in distribution networks has been exhaustively studied before [2],[3], but not many times in small facilities like solar orchards, as is the aim of this paper.

To achieve a correct evaluation of the effect of the substitution of the transformers, the present model of evaluation of losses, based on a fixed percentage of the installed power of transformation, should be changed into another based on the real measurement of the losses, or at least, into another based on a more accurate evaluation of them.

In this paper the economic advantages of the use of higher efficiency transformers is analyzed. In all the studied cases a payback of less than 4 years is obtained, leading to the conclusion that a greater accuracy in the evaluation of losses is advantageous from both an economic and a technical (increase of efficiency) point of view.

2. Estimation of Energy Losses

It will be assumed that all the producers are simultaneously generating the same power. The produced energy of a photovoltaic generator depends on several factors, being the most important ones the radiation from the sun and the temperature. For the sake of simplicity, two typical days where considered, one for the period of spring-summer and the other for autumn-winter, obtaining two curves of generation per hour in each period. These, although approximate, allow the extraction of useful results that eventually can be refined on a case by case analysis (Fig. 2, Fig. 3). In order to consider the dimmed days, 170 days of sun in spring-summer and 130 in autumn-winter will be assumed.

It will be also assumed that all the transformers, including those of reserve (in equal number than the ones on duty, according to [4]), are identical. Open-circuit and short-circuit losses of each kind of transformer will be taken from [5], whose values are also recognized by the distributing companies.

TABLE I. – Short-circuit and open-circuit losses of each kind of transformer.

	Type A		Type B		Type C	
Sn KVA	Pcc (W)	Po (W)	Pcc (W)	Po (W)	Pcc (W)	Po (W)
50	1100	190	1350	145	875	125
100	1750	320	2150	260	1475	210
160	2350	460	3100	375	2000	300
250	3250	650	4200	530	2750	425
400	4600	930	6000	750	3850	610
630	6500	1300	8400	1030	5400	860
1000	10500	1700	13000	1400	9500	1100

Global losses are given by:

$$P_p \cong P_0 + C^2 P_{cc} \quad (1)$$

being P_0 the losses in the iron, P_{cc} the losses in copper, and C the load index. Because C is variable throughout the day, this will be divided into periods of 30 minutes, obtaining a value of C for period j by means of the expression:

$$C_j = \frac{I_{2,j}}{I_{2n}} = \frac{\sqrt{3} U_{2,j} I_{2,j} \cos\varphi}{\sqrt{3} U_{2,j} I_{2n} \cos\varphi} \approx \frac{P_{2,j}}{S_n \cos\varphi} \approx \frac{\frac{n_g}{n_t} P_{g,j}}{S_n \cos\varphi} \quad (2)$$

where

U_{2j}: voltage in MV bus (considered equal to the nominal voltage)
$I_{2,j}$: average current yielded by the secondary for period j
I_{2n}: nominal secondary current of the transformer
S_n: transformer nominal power
$P_{g,j}$: average generated power of each generator for period j
$\cos\varphi$: power factor of the output power
n_g: number of photovoltaic generators
n_t: number of transformers that are on duty

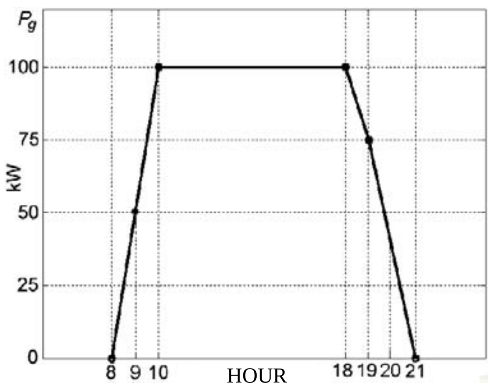

Fig. 2. Generation in a sunny day of one generator in spring-summer.

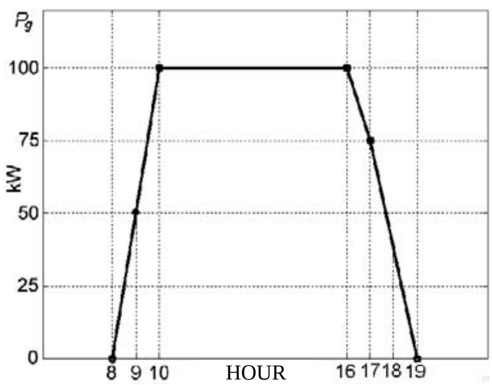

Fig. 3. Generation in a sunny day of one generator in autumn-winter.

Using (1) and (2) the mean losses of each period can be evaluated multiplying the mean loss of each transformer on each period by the number of transformers (n_t) and the duration of the period (j-i).

$$W_{i-j} = n_t P_{p,i-j}(j-i) \quad (3)$$

Different values of W will be obtained when considering transformers type A, B, or C.

3. Economic Feasibility

For the feasibility study it will be used two current indexes, the Net Present Value (NPV) and the Pay-back period, which represents the time elapsed to the total investment recovery.

The investment amount (ΔI) corresponds to the difference in price between transformers type C and A. The savings of year *k* are obtained multiplying the losses reduction ΔL (kWh) by the price of the photovoltaic energy (*pe*) [1].

$$A_k = \Delta L \cdot pe \cdot (1+i)^{k-1} \quad (4)$$

where *i* represents the annual inflation of the energy price. The NPV is computed using (5).

$$NPV = \sum_{k=1}^{n} \frac{A_k}{(1+t)^k} - \Delta I \quad (5)$$

If the NPV is 0 or negative means that the investment is not profitable.

Another index used to assess investments is the pay-back, this is the time n_e which complies (6).

$$\Delta I - \sum_{k=1}^{n_e} \frac{A_k}{(1+t)^k} \leq 0 \quad (6)$$

If the pay-back period index is small means that the investment is very profitable.

4. Results

To obtain the results of this paper it has been supposed that the useful life of the installation is 25 years, the discount rate is 10% and the annual interest rate is 3%. The analysis has been applied to 25 different cases, varying the installed power of the orchard and the transformers nominal power. Two different types of transformers have been considered based on the losses of each type: A (conventional) and C (high efficiency).

The price (*pe*) used was obtained from [1] and is 0,44 €/kWh.

The price of the different types of transformers can be seen in Table II.

The NPV and the pay-back were computed for 25 different cases, changing the power of the installation and the nominal power of the transformers. The results obtained with this data and for the most usual solar orchard configurations are shown in Table III.

TABLE II. – Cost of different types of transformers.

Sn (kVA)	Cost (€)	
	Type A	Type C
50	750	975
100	1150	1495
160	1900	2470
400	4600	5980
630	6900	8970
800	8700	11310
1000	10650	13845

As it can be seen in table III, there are several factors that seem to affect the NPV. For example, it can be noticed that the greater the power of the installation the greater the NPV. Also, it has to be considered if the transformers are used at their full capacity or not, since some configurations allow a better use of the transformation capacity than others.

TABLE III. – Results for the most typical configurations.

Sn (kVA)	n_t	n_g	NPV (€)	Pay-back (years)
1000	3	30	44659	3y. 0m.
1000	2	20	29773	3y. 3m.
1000	1	10	14886	2y. 11m.
630	3	19	44480	1y. 6m.
630	2	15	34514	1y. 7m.
630	2	12	28265	2y. 1m.
630	1	6	14132	2y. 1m.
400	4	16	39170	1y 2m.
400	2	8	19585	1y. 10m.
400	1	4	9792	1y. 10m.
250	3	7	18937	1y. 7m.
250	2	5	13420	1y. 9m.
160	3	5	17106	1y. 10m.
160	2	3	10534	1y. 10m.
100	3	3	12913	1y. 3m.
100	2	2	8608	1y. 3m.
50	4	2	12987	1y. 2m.
50	2	1	6494	1y. 2m.

5. Conclusions

From the results obtained, it can be concluded that in all 25 cases the payback is smaller than 4 years when conventional transformers (type A) are replaced by high efficiency ones (type C). The cases with better results are obtained with medium-size transformers (400 or 600 kVA) that reach a load index of 1 in the period of higher production.

A good example is the solar orchard formed by n_g = 19 generators, and n_t = 3 transformers of 630 kVA, indeed the configuration more used in the facilities that at the moment are in authorization and commission process in Spain.

References

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