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Cost–benefit analysis of a photovoltaic power plant

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ABSTRACT

This work evaluates the energy generated by photovoltaic generators with different mounting angles to the horizontal plane, and the optimum angle is estimated. Other aspects considered are the costs and legal framework associated with installing a photovoltaic power plant in Santa Fe, Argentina. After having done a cost–benefit analysis under different scenarios, results showing the feasibility of building a photovoltaic power plant were obtained. However, the assessment of costs shows that the rates set by Act 26190 need to be modified in order to increase its feasibility in the location studied.

1. Introduction

The generation of renewable energies has grown steadily in the last two decades, mainly caused by the concern about the climate change and the high oil prices. Laws on renewable energies and incentives also supported this growth. For these reasons, the solar photovoltaic market has grown strongly during the last years and, particularly, systems connected to the conventional electrical grid [1].

In order to install a photovoltaic power plant, it is necessary to take some measurements to estimate the resource. Afterwards, the characteristics and productivity of photovoltaic generators must be considered. Besides the array of modules, it is necessary to take into account that the conversion chain of a power plant has a series of phases that affect the system's global performance [23] and, therefore, the alternating current energy that is generated. If the measured values of the resource and the estimate of the power plant generation are used jointly with the costs involved, the context and current legislation, it is possible to do an at least preliminary cost–benefit analysis. Since the cost structure and regulations aimed at encouraging the development of electricity generation from renewable energy —Act 26190 in Argentina [4]— vary from country to country, it is necessary to study the dimensions specific to the possible place of installation. In the case of Argentina, papers analyzing these aspects are very scarce. This work evaluates the feasibility of installing a photovoltaic power plant in the city of Santa Fe, Argentina. For this purpose, field measurements of climate variables and electricity generation are used, and cost conditions (to the year 2011) and current legislation are considered.

This article presents a preliminary analysis of costs. In the following section, an evaluation of the photovoltaic power plant generation with real data is carried out. Afterwards, the feasibility of the power plant under different scenarios is

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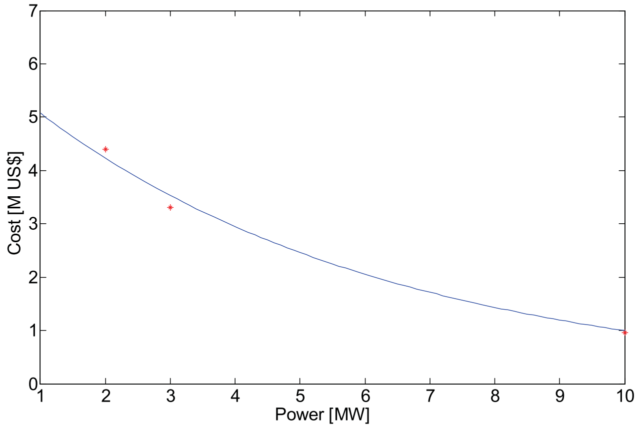

Fig. 1 – Total costs of power plants in South America. Points indicate the data and the continuous line is adjustment to them.

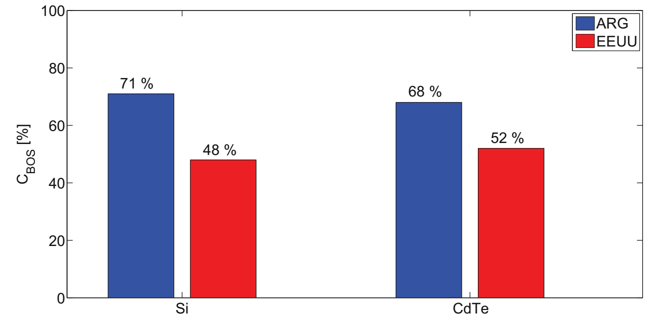

Fig. 2 – Costs of photovoltaic modules made with different materials.

discussed, and lastly, the conclusions drawn from the work are presented.

2. Preliminary cost analysis

This section attempts to evaluate the generation of electric power based on the solar resource and weather conditions, but considering costs and service life. It is possible to state that the global cost of a photovoltaic power plant is composed of two big groups: the one corresponding to photovoltaic modules and the one related to the Balance of System (BOS). The BOS includes hardware and non-hardware costs. Hardware costs comprise the inverter, wires, junction boxes, structures, etc. The other type of cost involved is related to planning and building the plant. The foregoing statements make possible to propose

$$C_T = C_M + C_{BOS} \quad (1)$$

where C_T is the total cost of the plant, C_M is the cost associated to the photovoltaic modules, and C_{BOS} is the cost derived from considering the BOS. The total cost is the result of a function that depends on the power of the plant. Since the C_{BOS} depends on the place where the power plant will be installed, this work will use the total cost of recently bid plants in Argentina and Peru [5] as reference values. Fig. 1 shows that in Argentina a photovoltaic power plant with an installed capacity of 1 MW costs 5 MUS$.

Bearing in mind that the cost of the modules is continuously decreasing, today we can consider approximately 1.45 US$/W for silicon (Si) modules and 0.75 US$/W for cadmium telluride (CdTe)[1] ones [6] as representative values. From the costs of the power plants and modules it is possible to estimate how the use of different technologies affects the BOS for a power plant in Argentina (Fig. 2). Using Si modules the C_{BOS} represents 71% of the total, while in the case of CdTe modules it is 68%. These results differ greatly from the situation in, for example, the United States (USA), where the BOS absorbs 48% of the total cost for Si modules and 52% for CdTe modules [7]. The difference lies in transportation costs, export-import duties, and intermediation of modules that would be part of the BOS plus the components specific to the balance of system that vary from country to country. Therefore, if the aim is to reduce total costs in Argentina, it is very important to optimize the power plant design, even more that in the USA, because of the strong contribution of the BOS in the total costs. In the case of installations with CdTe modules, it is clear that the BOS is more important in the total cost than when Si modules are used. The difference in the cost of the modules made with these materials holds true for both countries.

3. Evaluation of the generation

This section addresses the dependence of the annual generated energy on the module installation angle. Also, the optimum angle is estimated considering real weather conditions. For this evaluation, a photovoltaic power plant in the city of Santa Fe, Argentina, is taken as the case study. The optimum angle for installing fixed modules was defined as the angle that allows maximizing the annual accumulated energy.

A second-order equation that allows adjusting the experimental data and getting the optimum angle was obtained. These results are shown in Fig. 3, where the energy generated

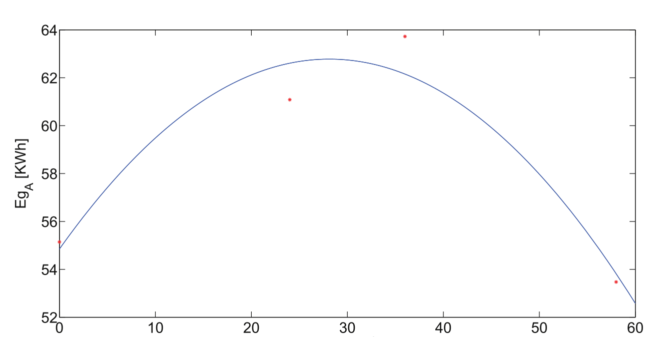

Fig. 3 – Annual energy generated by photovoltaic modules when the mounting angle is changed.

[1] They refer to the Free On Board (FOB) value. The FOB value is the market value of goods exports at a country's customs, including all transportation costs, export duties, and the cost involved in placing the goods in the means of transport used, unless the latter is paid by the carrier.

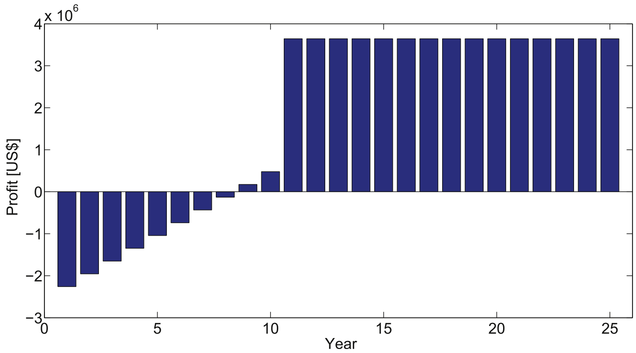

Fig. 4 – Scenario A: with 1700 W/m^2 and current rate of 0.21 US$/Wh (0.9 $/Wh).

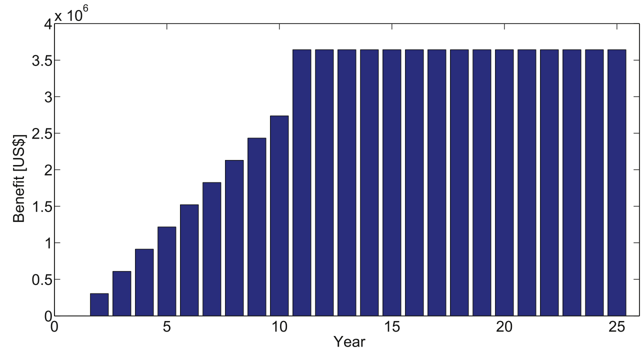

Fig. 6 – Scenario C: with 1700 W/m^2 and critical rate of 0.35 US$/Wh.

by the modules in one year is charted in the ordinate axis and their tilt angle value is charted in the abscissa axis.

For comparative purposes, incident energy values reported by the National Aeronautics and Space Administration (NASA) [8] were used. The NASA allows choosing a geographic site and for that site it is possible to obtain, among others, data of the incident solar radiation —both direct and diffuse— for different angles, as well as the angle that maximizes the incident energy. Values in the website are presented as monthly and annual averages, and are based on satellite observations made in the last 22 years.

An optimum angle of 28.12° was obtained, while the NASA obtains an optimum angle of 29°. This shows that in spite of having used not only totally different methods but data obtained in different periods, the results found are very consistent. In addition, in both cases the annual optimum angle is lower than the latitude of the site, unlike the one usually used in our country that is calculated adding 11° to the latitude.

4. Feasibility of a power plant

This section does a preliminary evaluation of a photovoltaic power plant considering the weather conditions, costs and service life. The case study is a plant located in the city of Santa Fe.

Act 26190 from the national promotion regime for the use of renewable energy sources for the production of electric power establishes a compensation of 0.9 $/kWh. For the city of Santa Fe, the generation of photovoltaic modules is around 1600 kWh/kWp per year for the optimum angle. The case study will be an array of 10 MWp photovoltaic modules considering that the loss of the system's conversion chain is approximately 10%. Besides, the use of a credit to invest in the project will be considered. Specifically, the Banco de Inversión y Comercio Exterior (BICE) grants credits for this kind of installations and, taking as an example the cases reported up to now, we can assume that they are to be paid in 10 years with a 10% annual interest rate. In addition, this evaluation considers the power plant costs 30 MUS$, and an annual generation of 1700 kWh/kWp.

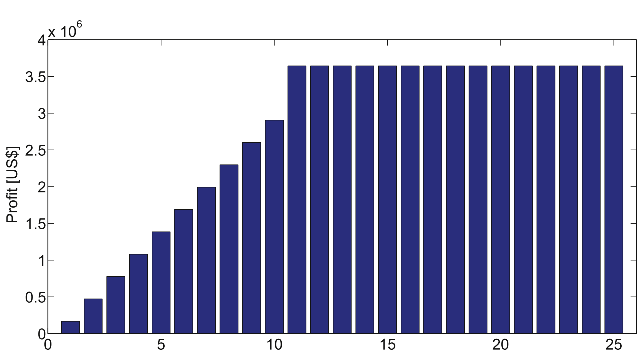

Fig. 5 – Scenario B: with 1700 W/m^2 and European rate of 0.36 US$/Wh (0.25 €/Wh).

Figs. 4–6 show the evolution in time of what this work considers profits (disregarding the fixed costs during the project), taking the years of service life of this type of installation (between 25 and 30 years) as the end of the temporary scale. Analyzing the expected generation with the rate set by the current Act, it is possible to observe that profits would be obtained after approximately 8 years (Fig. 4). On the other hand, if an incentive rate as the European one is taken under the same conditions, the project becomes very attractive even during the first years (Fig. 5). This rate is slightly higher than the critical rate, which is around 0.35 US$/Wh. Regarding these latter incentive rates, it should be noted that although in Europe the incentive is higher, the profitability of power plants located there is lower that in Argentina because the available solar resource levels are lower.

Based on these results, implementing this type of power plants in the province of Santa Fe is considered feasible since it is possible to pay the credit within the time considered with a margin. However, it is advisable to include some fixed costs and minor expenditures in future studies in order to determine more precisely what the appropriate rate would be.

5. Conclusions

The solar resource in Santa Fe is good compared to places such as Europe where, except from Spain, the values obtained are not higher than 1400 Kwh per year per installed Kwp, and more than 10 GW per year are being installed in that continent. The solar resource in the Argentine Andean foothills —from San Juan to Jujuy— presents significantly higher values.

Secondly, in view of the prices of modules nowadays, it is possible to observe that with the current incentives or with the real costs of the Kwh provided by Argentine distribution companies, photovoltaic power plants are competitive and profitable. For the case study of a 1 MWp power plant, it is estimated that profits will be obtained after approximately 8 years, the installations' service life ranging from 25 to 30 years. However, it is advisable to modify the current rates established by Act 26190 in order to increase the feasibility.

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