INSTITUTO SUPERIOR TÉCNICO
Universidade Técnica de Lisboa

Title of Thesis: Integration in Buildings of Photovoltaic Systems in Domestic Application with 3.68 kW_p of Generated Power

Keywords: Photovoltaic (PV), Energy, Renewable, Sun, Micro electric generation

Author: Samuel Menitra Sousa Gomes

Affiliation: Industrial and Engineering Management

October 2009

Index

List of Acronyms

PV – Photovoltaic

W_p – Quantifies the power of an equipment in watts per peak

BIPV – Building Integrated Photovoltaics

PVGIS – PV Geographical Information System

1. Introduction

The purpose of this work is to study the feasibility of a grid connected photovoltaic (PV) system of microgeneration in the light of current legislation to Portugal, as well as showing the potential of such renewable energy. Photovoltaic electricity generation has many specific advantages, including: the contribution of PV energy to the reduction of Portugal's energy dependence; environmental purposes – using a renewable resource that does not contribute to the depletion of fossil resources and the reduction of Carbon emissions; good incorporation of PV systems in buildings, avoiding having to build specific spaces for the purpose; protection against external actions (wind, rain or snow) of BIPV or the shading of the interior of the building, as well as the aesthetic potential. Other inspiring advantages are: the sun is the most reliable source of energy in the world; photovoltaic modules have a lifetime of about 30 years, which is high; these systems can help reduce the heat load of buildings for ventilation or convection and, finally, the fact that decentralized PV systems for microgeneration make it possible to avoid power losses associated with centralized power generation.

Driven by the many advantages of PV, this dissertation is concerned with the economic feasibility of a photovoltaic (PV) grid-connection in the view of existing legislation to Portugal. The economic study is made from two photovoltaic systems of technological basis: one consisting of crystalline silicon cells and the other of cells in thin film. In addition to these two choices, a tracking equipment for adaptation to higher solar radiation (sun tracking system) will be matched to each of the two devices, so that our economic feasibility study will be divided into four variants.

The final results from the economic feasibility study for the four types of PV systems attributed the most attractive value to the technology in Thin Film combined with Two Axis Solar Tracking system. Using an optimistic legal scenario and a discount rate of 7%, we find that by using Thin Film it is possible to obtain values of payback in less than 5 years (value that coincides with the period of time of maximum subsidized rate in the optimistic scenario). The time of return of this investment option, associated with the cheapest solar tracking system admitted in the study, with a discount rate of 7%, is 4 years and 4 months. Without considering the discount rate, the payback is 3 years and 7 months.

By the other side, the solution of simple crystalline silicon combined with Two Tracking Solar sun has a payback time of 6 years and 3 months, regardless of discount rate. With the applied rate of 7%, has duration of 8 years and 7 months.

As said earlier, as well as looking at the economic feasibility of a photovoltaic microgeneration system, this work also aims to provide a general overview of the photovoltaic industry and its market. Thus, in this paper, I begin by enunciating the photovoltaic process, and then present various materials and technologies for use in the manufacture of photovoltaic cells in the system, especially the technologies in more advanced states of maturation in the sector. Next i will turn to the presentation of some common heuristics related to the electrical generation data that characterize PV. I will also address three paradigms of photovoltaic systems which are favourable to sustainability. This paper dedicates a section to the explanation of the legal framework of photovoltaic microgeneration system in Portugal. It describes the technological solutions under study and the methodology used for calculations of the payback. In the conclusion we make observations about the results and put forward a political strategy to stimulate the Portuguese PV market.

2. The Photovoltaic Process

The photovoltaic (PV) process takes place when photovoltaic's systems are exposed to sunlight, resulting in the production of electricity. The sun's rays are composed of particles of energy called photons which serve as the ignition process of generating electricity. Thus when the sun's radiation affects an area of the PV material, photons will cross the surface and may either be reflected or absorbed. If a photon is absorbed, its corresponding energy will be transferred onto an electron in an atom located in the PV material. After receiving this energy, the electron is able to leave its usual position in the orbit of its host atom. Thus increases the current of an electrical circuit, in what is called the "Photovoltaic" effect.

3. Evolution of Photovoltaic's Cells

The evolution of technology which assists the PV cells can be divided into three generations.

The first generation of crystalline silicon cells still dominates the market, with about 90% of PV production systems in the world made from crystalline silicon (mainly monocrystalline silicon cells and cells in polycrystalline/multicrystalline silicon). The second generation is on the thin film cells and arises from the need to reduce consumption of silicon, a material whose production is very costly. The cells of this generation are also innovative because they have a great capacity for integration into building facades.

In the third generation, there is a mix of technologies, mostly in study phase. It's important to say that some technologies are in permanent improvement but have already been proved to be cost efficient. This is the case for the Photoelectrochemistry and nanocrystalline hybrid technologies. In the latter case, we have the example of the technology in Gallium Arsenic (GaAs), only possible if it is combined with hubs or used in satellites.

4. Heuristics in the PV art

The electricity generation of a photovoltaic system is approximately 1400 kWh per kW_p (study conditions in Portugal).

Heuristically, the value of daily use of solar energy is about 14 hours a day, and for the case of Portugal is estimated at an annual value of 2200 to 3000 hours of sunshine[1]. The last value applies to the South of the country.

The overall efficiency of a global PV system round interval 12%-16%.

---

[1] Source: "*Guia da Energia Solar. Concurso do Padre Himalaya"*, Sociedade Portuguesa de Energia Solar, Edition 2004

Referring on the size of photovoltaic panels, a system of 1 kW_p of power with a common technology in Silicon Crystal represents 8 to 10 m^2 area of cells (variable depending on whether there are associated technologies to increase the performance of the cells).

In terms of the specifications of some solutions for the PV conversion cells, we have the following typical values:

Table 1. Specifications of different FV technologies

Photovoltaic Technology		Photovoltaic Efficiency,%		
		Maximum Cell Value in lab	Maximum Module value in lab	Industrial Module
First generation (Crystalline silicon)	Monocrystalline	24,7%	22,7%	12 to 16%
	Polycrystalline	20,3%	15,3%	11 to 14%
Second generation (Thin Films)	Amorphous Silicon in stable state[2]	13%	10,5%	7,5%
	Multi-junction Amorphous Silicon	12,4%	10,4%	6 to 8%
	Cadmium Telluride (CdTe)	16,5%	10,7%	7 to 8%
	Di-selenide Copper Indium Gallium (CIGS)	19,2%	13,4%	9 to 11%
Third generation	Hybrid Cells HCI	20,1%	17,3%	15,2%
	III-V semiconductor	37,6%	28%	27%
	Cell with Synthetic Dye	12,0%	7%	5%

Source: Green M.A. (2004)

Current production of energy per square meter related to second and third generation (techniques in constant development, organic cells, and others) have much lower costs than those of the first generation, but it must be noted that in these technologies the energy generation decreases considerably.

[2] No crystalline Structure

5. Demystification of some ideas commonly associated with Photovoltaic's Systems

Some common misconceptions of photovoltaic systems have been harmful to the reputation of these products and must be exposed as wrong.

- To the question that refers to the existence of Silicon supply in sufficient quantities at present, the answer is that there is sufficient supply. Pure silicon is abundant in the earth's crust, since 23% of the materials in the stratum of the earth consist of silicon. The production of pure silicon used in crystalline cells is complex in nature, so that the period between the planning stage of a plant of Silicon and output the finished product is approximately two years. The dynamism that assists the PV market by the continuous increase of PV plant capacity will lead to a shortage of silicon medium term, by when it is expected to be substituted by other materials. The availability of silicon will tend to increase as well as maximizing operating efficiencies due to methods of recycling silicon, among others.

- On the question of whether it is possible to recycle photovoltaic modules, the answer is also affirmative. All components of a PV module can be recycled. In terms of economic value, the PV cell is the most valuable component of the system and can be recycled into new wafers, which are the basis for new cells. Other components of the PV system as the support structure in Aluminum, glass or electrical contacts are also recyclable.

- To the question whether the energy used in the production of PV systems is higher than the energy that they generate during their life cycle, the answer is negative. Assuming that the lifetime of a PV system standard in crystalline Silicon standard round a range of 10 to 30 years, the value of surplus power is considerably higher than that used in the production system. By some simple calculations in this we have also been able to show that the energy payback is of about two years and one month in crystalline Silicon cells. In the case of a system based on thin-film technology, the energy balance is even more favourable.

6. Political-Legal Framework of Photovoltaic Energy in Portugal

The legal framework that assists the microgeneration of electricity in Portugal at present is based primarily on three schemes: LD 225/2007, Independent Producer Scheme, LD 68/2002, Producer-Consumer Scheme and LD 80 / 2006, "Renewables in Time" Scheme. This study will focus on these three schemes, with particular emphasis on Scheme "Renewables in Time", which is the most recent and also the one that most increases the FV.

In light of this framework, we will choose the value of 3.68 kW_p to power of PV equipment, for it represents the maximum power limit that is covered by the tariff of € 0.65 per kWh on the first 5 years. This value is nevertheless subject to the progressive reduction in the following years, as well as to the limitation of the total power of installed PV systems in the country. These two scenarios result in an economic feasibility study that ranges from the optimistic and pessimistic view.

Tax concessions in Portugal in Renewable Energy Sources of microgeneration

- VAT 12% on the purchase of equipment for renewable energy;

- Tax deduction of income tax of 30% of the equipment up to a limit of € 777;
- Exclusion from IRS taxation of income of microgeneration below 5000 € per year (paragraph 6 of Article 12 of Decree-Law No. 363/2007 of 2 November, added by the Law of the State Budget of 2008);
- Exemption from Customs Duties

(SPES, 2009)

7. Technological solutions adopted to the economic viability study

The PV module, being the component base of the electricity system generation, is also the most expensive. Of the various technologies that assist the production of photovoltaic cells, the economic viability section of this study considers two types of modules: crystalline Silicon and on Thin Film. These two manufacturing technologies are the most common and also the ones for which consolidated data is available.

In addition to these two choices, a mobile equipment for adaptation to higher solar radiation (sun tracking system) will be matched to each of the two original pieces of equipment, creating the conditions for an economic feasibility study divided into four conditions of technological basis.

8. Methodology for the calculations of economic pay-back

Steps followed

Step 1 - The study will be based on two FV technologies: Crystalline Silicon and Thin Film. The simulator PVGIS (Súri et al, 2007)[3] allows for the measurement of data on geographical areas, for these two types of photovoltaic cells. It also allows for the simultaneous measurement of solar tracking systems on two axes (vertical and horizontal) for each type of PV cell.

Step 2 - For each system described in the previous paragraph two options are selected, one that allows for an increase of efficiency and another which does not. I will be using a variant of modules combined with extra equipment consisting in a solar tracking system of Two Axis to capture more energy and the other with a system made up solely of the solar modules

Brief notes:

Note 1. In the case of the two individual alternatives incorporating two tracking solar systems, they are the result of interbreeding between two data sources, the PVGIS simulator and the economic solutions for businesses (as our reference products, we used a solar tracking system made by WS-Energia[4], and another one from Deger[5]. The latter presented similar values to the former, giving consistency to the data).

[3] Source: http://re.jrc.ec.europa.eu/pvgis/
[4] Source: Site http://www.ws-energia.com/eng/residential/heliots.html, April 2008
[5] Source: Site http://www.energyenv.co.uk/DegerTrackers.asp. September 2008

Note 2. In order to calculate the cost of investment an equipment of 4 kW_p of power, and not of 3.68 kW_p, will be considered. This happens because, in reality, there is a standard around integer values for the electronic power of equipments marketed by companies in the area.

Step 3 - In the study of the PVGIS simulator, the value of the 3.68 kW_p of installed power for the PV equipment will be discriminated as the base value of electricity generation. Regarding the quantification of the generation of electricity, efficiency values provided by the PVGIS simulator will be used, with a maximum amount of 67% taken as reference, a conventional value of efficiency adopted for photovoltaics, from a method used by the California Energy Commission (CEC)[6] in 1999.

For the four solutions studied, values of losses generated by the software are between 25% and 26% of losses, values less than 33%, the value corresponding to the study of CEC. These are associated with declining efficiency of the equipment in your lifetime, such as shadows, angles of incidence, the area chosen for positioning against the sun, topography, latitude, physical deterioration of equipment, between others.

Step 4 - Values of Energy Insolation are collected from four locations within the country (Leiria, Portalegre, Lagos, Covilhã) so as to measure the oscillations in energetic values across the country. For the four technological solutions, the economic viability studies will be done based on the data for Leiria, because it is a localization with medium results compared to the national perspective.

Step 5 - Calculation of the payback period of investment in the installation of the FV electrical power generator, the market prices for the main location selected in step 4. The final results are expressed on four levels: the first free of annual discount rate and the others with a rate equal to 5%, 7% and 9%. 7% is used as the current rate for investment, being in line with the index of consumer prices. The remaining fees of 5% and 9%, are used to consider possible intermediate scenarios, more and less favourable to the development of PV industry, respectively, possible of occur in time.

9. Discussion of results

9.1. Feasibility Considerations

Since this study about economic viability looks at an emerging PV market, which is capable of progressive improvement in time and which goes towards reducing the cost of the technology employed, this economic study must distinguish an investment made today, from an investment for the next year, with a 5% decrease in costs.

[6] See Chapter References

It is important to point out that PV systems with tracking systems or solar concentrators combined have higher initial costs than the simpler systems studied, without Two Axis Solar Tracking System or hub included. The first kind, more complex and therefore more costly, are those with faster gains in the recovery of the initial investment, in time.

9.2. Results

In this economic viability study for the four types of PV's systems, examining the favourable option in practiced tariff terms, it is clear that the technology with the most attractive paybacks is related with Thin Film modules combined with Two Axis Solar Tracking System. The time of return of this investment option on the solution associated with lower costs of the Tracking System used in the study, regardless of the discount rate, is three years and seven months. With a discount rate of 7%, we have an interesting value of four years and four months.

Referring to a second case associated with a slightly higher cost of equipment of solar tracking, the system that uses Thin Film modules with equipment of Two Axis Solar Tracking System, regardless of discount rate, results in three years and eleven months and with a discount rate value equal to 7%, has a value of four years and eight months.

The solution of simple crystalline Silicon combined with Two Axis Solar Tracking System (in the hypothesis with the lower cost of solar tracking equipment) has a payback of approximately six years without taking into account the discount rate. With the applied rate of 7%, this increases to eight years.

The economic viability of less interest among the tested solutions is also the lest technologically complex and most common in domestic photovoltaics applications that exist in Portugal. In this category belong systems in single crystal silicon, without tracking solar system, hubs, and other type. The initial investment is paid in six years and eight months without discount annual rate. With a discount rate at 7%, this value rises to nine years and three months. The unfavorable option in terms of the approach to the legal system in Portugal tells us the following:

Under the Scheme "Renewables in Time", if the FV licenses are greater than 10 MW in 2008 (the year of 2008 has ensured the rate "green" of € 0.65, even though the maximum permit applications of microsystems FV exceeded the limit of total installed capacity of 10MW in November 2008) or/and to step up 20% of that value after the first five following years, we verify the decline in green tariff by 5% per annual limit exceeded. This reduction in the rate indicates that if the equipment costs do not follow this decline of annual revenue, the results of this feasibility study are significantly less relevant.

Thus, in the worst case scenario, without considering discount rate and analysing the hypothesis with the lower cost of solar tracking system, we have the following economic paybacks:

- Crystalline Silicon: Eight years.
- Thin film: Four and a half years.
- Crystalline Silicon combined with Two Axis Solar Tracking System: Seven years

- Thin film combined with Two Axis Solar Tracking System: Three years and eleven months.

10. Conclusion

This work's central aim was to put to test the economic performance of current applications of FV microgeneration from the point of view of a domestic investor, as well as to analyze the specific nature of the sector of photovoltaic electricity. With the progress of work and after collecting information, I decided to study the payback of a simple system in crystalline Silicon and other Thin Film, and of two others in turn combining the initial systems with solar tracking systems of Two Axis (horizontal and vertical). This inclusion of solar tracking systems came about because such mechanisms already have a defined commercial domain and benefits for economic viability of the equipment. The results achieved coincide with some results that were estimated *a priori* from the study. So we have:

- In the optimistic scenario, using a discount rate of 7%, we obtain values of payback of less than 5 years (the period coinciding with the period of time that applies to subsidized rates in the optimistic scenario) in the case of solutions in thin film. Thus a solution of Thin Film with Two Axis Solar Tracking System and 7% rate has a value of pay-back four years and four months and without Two Axis Solar Tracking System, the result is five years.

- The solutions with the use of solar tracking system of two axes are the most attractive comparing with simple ones (without this system), as well as solutions in thin film are more attractive than crystalline Silicon solutions.

It would be interesting, in the near future, to economically evaluate a wide range of manufacturing technologies of cells combined with increased energy devices which are in commercial lines, worldwide.

This study was also important to find and outline political strategies for the PV market, to enable it to grow in a sustainable way. This strategic plan should focus on lower levels of the chain of FV microgeneration of electricity, acting in research and development of technology and production processes of equipment. Thus, rather than a strategy based only on the final cycle of photovoltaic generation, using attractive feed-in tariffs as a criterion, it is the technology factor of FV systems and specific logistics of the process that should be prioritized. In this way, there will be an improvement in the price of electricity due to the implementation of strategies throughout the process and not just at the end.

11. References

- Green M. A., Emery K, Ling DL, Igari S, and Warta W. Solar Cell Efficiency Tables (Version 24). Progress in Photovoltaics: Research and Applications; Code 12; 365-372; 2004

- Šúri M., Huld T.A., Dunlop E.D. Ossenbrink H.A., 2007. Potential of solar electricity generation in the European Union member states and candidate countries. Solar Energy, 81, 1295–1305

- Sociedade Portuguesa de Energia Solar (SPES), Internet site: http://www.spes.pt, 2009

- California Energy Comission (COC), A Guide to Photvoltaic (PV) System Design and Installation, Publication #500-01-020, Versão 1, 14th June 2001;

Internet site: www.abcsolar.com; http://www.abcsolar.com/pdf/2001-09-04_500-01-020.pdf