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Assessment of photovoltaic distributed generation – Issues of grid connected systems through the consumer side applied to a case study of Brazil

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ABSTRACT

The growing application of renewable energy with accessible price and technology, together with Distributed Generation techniques came to bring a paradigm shift in the existing relations of distribution network in the past years. This work assesses the application of Distributed Generation by the consumer as a microgenerator – a “pro-sumer” - by usage of Photovoltaic generation. The presented methodology considers the financial and technical effects in the relations between the utility and the prosumer. The results shows that, even with the residential consumer providing the project and the installation of the PV generation, it is in the distribution framework that this relation is technical and commercially affected, as both the utility and residential microgenerators face the infeasibility of the project. The methodology is validated by an application showing that further regulating and market efforts are required in order to effectively disseminate cogeneration for residential consumers and explore their solar potential.

1. Introduction

Electrical energy supply, since the industrial revolution, is one of the most present topics on the agenda of governments, quality of life analysis, infrastructure, economical indexes and discussions about the environment. In general, over a big part of this time period, electrical energy supply to consumers was always studied and treated in conventional manner, i.e. power plants connected to transmission systems responsible by the transport of high powers over large distances to the places near by the load centers and, finally, the distribution system, which attends the demand of consumers in medium and/or low voltage. It is inside this context, that a few decades earlier, Europe and the US added a new element on the conception of power supply: the Distributed Generation (DG). DG came up thanks to technological breakthrough, pushed by the need of serving the growing electrical energy demands. Also associated with this need is the population and government concern with the environment, especially by searching natural resources available to all. Among these resources, there is the sun light and one of the most widespread techniques: the application of Photovoltaic (PV) generation. This concept has significantly altered not just the “natural” power flow in the electrical networks but also the technical and commercial relations between the utility and the residential consumer.

Also, considering the economical growth and the continuous investments in infrastructure by various nations, it is natural that power demand should walk along with this process [1]. However, over the past years society is becoming more conscious about the need to reach a sustainable development, noticing the importance in avoiding greater impacts on the environment, like the emissions of greenhouse gases. According to [2], “The unrestrained emission of greenhouse gases is a consequence of the economical model, which encourages unsustainable use of energy and natural resources. It's necessary for us to rethink the development model, the cause of the problem.”

In this train of thought, the efforts for this scenario is noticed in countries worldwide, looking for alternatives to attend their electrical energy demand, but avoiding to cause greater impacts on the environment. Germany, for example, is gradually diminishing the use of nuclear power plants, the UK made heavy investments on off-shore wind farms, in the USA there was a great increase on solar generation, and in Brazil, the Hydropower plants adopted the ‘run-of-the-river’

Abbreviations: PV, Photovoltaic; DG, Distributed Generation; PRODIS, Procedimento de Distribuição; ANEEL, Agência Nacional de Energia Elétrica; CCEE, Câmara Comercializadora de Energia Elétrica; ONS, Operador Nacional do Sistema

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concept (where no water storage is provided), avoiding water reservoirs and therefore the need for large flooded territory [3–5].

Now, looking backwards on the evolution and transformation on how power system interacts with industry and population, it is undeniable the dependency of electrical supply on the improvement of quality of life and economic development [6]. In developing countries, power system planning and expansion forces down great challenges for regulators, researchers and all stakeholders involved in this matter, in order to provide good quality, reliable, sustainable and accessible power to their population [7]. First, the concept of DG gained strength along the past years joining forces with technological breakthroughs – such as rooftop PV – granting, then, the possibility of the consumer become also a producer – thus "pro-sumer" – which leads to an important element to base the present paper: the solar potential of residential consumers worldwide [8–10,17,20]. Fig. 1 represents a simplified concept of a photovoltaic system, basically divided in two major parts: 1) **Photovoltaic Panel**: composed of photovoltaic cells that for commercial maters can be found in three different types: i) monocrystalline silicon; ii) policrystalline silicon; iii) thin film; 2) **Frequency Converter**: responsible for the conversion of direct current (DC) into alternate current (AC).

Distribution service is the closure of the power production cycle, and at this moment the utilities are responsible to set technical and commercial relationships with residential consumers. In this scenario two main actors are highlighted and will be analyzed: the utility and the prosumer. This paper presents a methodology to analyze this impact as well a scenario in Brazil. The result discussion section also includes the implemented solutions from developed countries and how they addressed some of the issues here presented.

2. Methodology

Although DG is a reality in many countries world-wide, in order to avoid integration issues, its implementation imposes: i) on regulators, the need to rework their regulation; ii) grid operator's demands; iii) financial aspects that are of utmost importance to carry out such projects. This tripod is the foundation for the methodology here presented as a step by step analysis.

2.1. Regulation analysis

Before going through the calculations, the first and perhaps most significant topic is a clear and correct understanding of DG as per the regulation of the country/region in which the analysis takes place. Is the market regulated or deregulated, is it already legal to connect oneself at the distribution grid as mini/microgenerator, is there any compensation for such matter, are there any benefits for the prosumer and/or for the utility? These are short examples of issues to be worked around, unless the microgenerator is working on an isolated grid, which is not to be discussed in this paper.

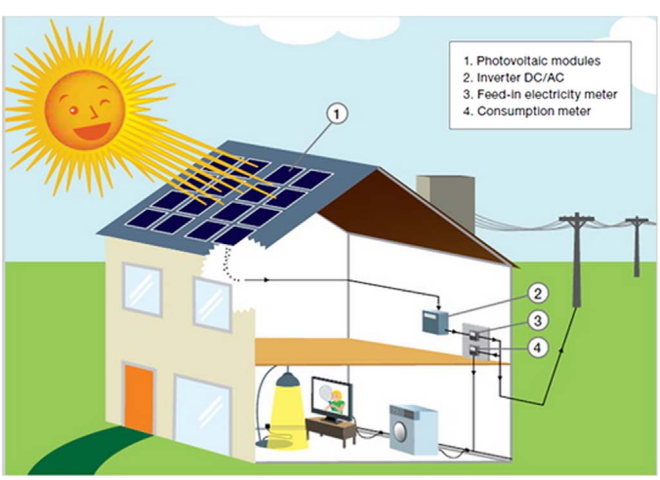

Fig. 1. Representation of a Rooftop PV system. (Ref: www.eupvplatform.org).

Therefore, it is absolutely necessary to raise the regulation possibilities and limits, the particularities of the local regulation, so that one can go further with the analysis.

2.2. Grid operator demands

After the first step as per Section 2.1, it is also necessary to understand the grid operator demands regarding protection, control and energy quality. Therefore, to point out who is responsible for the grid and all the technical and/or commercial issues it may have to deal with.

2.3. Financial aspects

Finally, the financial analysis is necessary to decide whether the application is feasible or not. Inside this topic, the local market prices for both the energy bill and the PV generation are important for the decision making.

The acquisition of electrical energy is known both on regulated or deregulated market. A typical generation curve for a rooftop PV system is shown in Fig. 2:

For the PV generation cost, we first need to calculate the annual generation capacity of the plant. Eq. (1) gives us the amount of energy generated:

$$E = A \times r \times H \times PR \quad (1)$$

where,

E=Energy (kWh)
A=Total solar panel Area (m^2)
r=solar panel yield (%)
H=Annual average solar radiation on tilted panels (kWh/m^2) (shadings not included)
PR=Performance ratio (%)

For the financial analysis, a simple monthly Net Present Value (NPV) or similar method can be applied. In this paper, a table comparing some scenarios of the investment is presented in Section 3.3. In order to simplify the monthly basis for the calculation of power generation, let us assume from Fig. 2 that E[kWh] is directly proportional to the time of the day and the radiation at this very moment. As per Fig. 2, Eq. (1) can be rewritten as function of time and radiation, thus:

$$E(t, h) = \iint (A \times PR \times r)\, dt\, dh \quad (2)$$

Considering,
Limits of solar radiation (h).
Amount of hours within a month (t).

In possession of the amount of energy produced in a monthly basis, the next step is simply compare how profitable (or not) this cogenera-

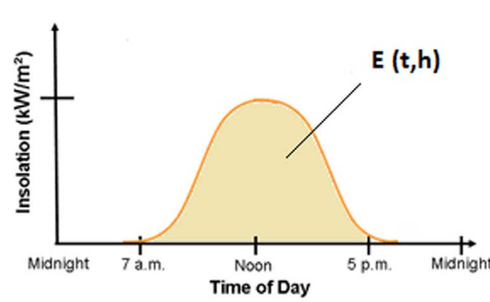

Fig. 2. Typical PV daily generation curve.