Solar Energy Microgeneration in Serrana Meso-Region: Project of a Grid-Connected Photovoltaic Power System in Lages/SC

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Abstract

Currently, renewable energies and their methods of use are being increasingly discussed due to the energy crisis in some regions and the environmental problems caused by pollution from other forms of electricity generation. One of the alternatives for electricity is solar energy, however, it is known that the cost for the construction of a photovoltaic plant in Brazil is still has a high and not feasible for some regions. Therefore, this work aims to make a study of the use of solar energy in the form of a Grid-Connected Photovoltaic Power System in the Serrana Meso-Region. For the development of this study will be conducted a study of the operation, factors that influence this type of electricity generation and its costs in the city of Lages/SC, this way evaluating its viability.

Keywords: Solar energy; Grid-Connected PV Power System; Serrana Meso-region; Viability.

1. Introduction

Two major concerns today are the environmental impacts caused by the forms of energy generation and the current cost of the same, for that the study of solar energy as one of the solutions to such problems must be analyzed in different regions.

Currently, the cost for the construction of a photovoltaic plant in Brazil is still considered high, in some regions the investment is still worthwhile as in the Northeast region that has an average daily incidence of 4.5 to 6 kWh, but in other locations alternatives become more viable, such as distributed generation that is becoming more common although the cost is still not considered accessible to all.

In the mountain mesoregion, despite the milder climate, it has sufficient potential for the generation of electric energy from the sun, and this is already being disseminated every year as we can see in the data of the consumer units with distributed generation of the distributor "CELESC DISTRIBUÇÃO S.A." where each year more residences acquire this type of generation. Cities like Curitibanos, Campos Novos, Lages and São Joaquim already have residences that generate their own energy through solar panels (ANEEL, 2017).

One of the most important forms of generation is the Grid-Connected Photovoltaic Power System. The objective of this research is to study the operation of solar energy in particular the Networked Photovoltaic Systems and to analyze if it would be feasible the implantation of the same in the Serrana Mesoregion; more specifically analyze a project in the city of Lages/SC.

As for the methodological form, the research is classified as an exploratory case study based on bibliographical research. Government sites such as ANEEL (Agencia Nacional de Energia Elétrica), MME (Ministério de Minas e Energia), CELESC (Centrais Elétricas de Santa Catarina) and CRESESB (Centro de Referencia para Energia Solar e Eólica Sergio Brito) were used for data on electricity. In addition to these, the Engineering Manual for Photovoltaic Systems also served as the basis for the research (Pinho & Galdino, 2014).

2. Photovoltaic Solar Energy

According to CRESESB (2016) Solar Photovoltaic Energy is the energy obtained through the direct conversion of light into electricity (Photovoltaic Effect). The photovoltaic effect, reported by Edmond Becquerel in 1839, is the appearance of a potential difference at the ends of a semiconductor material structure, produced by the absorption of light. The photovoltaic cell is the fundamental unit of the conversion process.

According to Chapin, Fuller and Pearson (1954) Becquerel's scientific discovery only began to be commercially used after the development of the silicon photovoltaic cell in 1954, in Bell Laboratories by Calvin Fuller, Daryl Chapin and Gerald Pearson. The photovoltaic cell developed at that time had a conversion efficiency of approximately 6%. Currently, the average efficiency of the cells is 16%, and in some United States Renewable Energies laboratories have proposed a new solar cell structure that, according to its first tests, reaches an efficiency of over 40% (Vallêra & Brito, 2006).

One of the advantages of using solar energy according to Shayani, Oliveira and Camargo (2006) is that solar energy does not need to be extracted, refined or transported to the generation site, avoiding the costs of high voltage transmission. In addition, it uses solar cells close to the load, responsible for the generation of energy and an inverter to transform the voltage and frequency to the nominal values of the devices, making the process simpler, without emission of pollutants or noises and with minimum need of maintenance.

Solar energy takes advantage of the incidence of sunlight particles (photons) emitted on a photovoltaic plate and turns it into electrical energy, this photovoltaic plate is made of semiconductor materials, generally used two different types of silicon (one positively charged and another negatively) (Pinho & Galdino, 2014). In order to create a negative charge, silicon is combined with boron, and to create a positive charge, silicon is combined with phosphorus, so more electrons are created in positively charged silicon (p-type layer) and less electrons in negatively charged silicon (n-type layer).

Positively charged silicon is enveloped by negatively charged silicon in a sandwich-like structure, allowing the silicon cell to react with the sun producing electrical energy. From the moment the photons strike the plates, they cause some of the electrons that surround the atoms to come off, these free electrons will migrate, through the electric current, to the part of the silicon cell that is in the absence of electrons, during the day all electrons will flow in one direction constantly, leaving atoms and filling gaps in different atoms. This flow of electrons creates an electric current, or what we casually call Photovoltaic Solar Energy (Pinho & Galdino, 2014).

The cost of this form of energy is still considered high, but it is declining each year and compared with the value that decreases from one year to the next, it is still less than the savings that a system will generate in a year. In addition to other benefits that the implementation will bring over the years making the investment very promising (Agostinho et al., 2017; Barp et al., 2016; Pacheco Costa et al., 2017).

To further facilitate its dissemination many programs and actions geared towards renewable energy in Brazil are in force and others being created (Righez et al. 2016).

In view of the above, this research is necessary for a more in-depth study of solar energy in the on-grid in the Serrana region, having as main objective the sizing of this system in the city of Lages for its economic and energetic analysis

2.1 Micro and Mini Photovoltaic Generation

Microgeneration and minigeration mainly using renewable sources become attractive in several aspects and are being disseminated every year. According to ANEEL (2015, p.1) each corresponds to an installed power.

I - Distributed microgeneration: an electric power generating plant, with an installed power of 75 kW or less and using qualified cogeneration, according to ANEEL regulations, or renewable sources of electric energy, connected in the distribution network through facilities of consumer units.

II - Distributed minigeration: power generating plant with an installed power above 75 kW and less than or equal to 3 MW for water sources or less than or equal to 5 MW for qualified cogeneration, according to ANEEL regulations, or for other renewable sources of electricity, connected to the distribution network through consumer units (ANEEL, 2015, p. 1).

In photovoltaic microgeneration the solar panel is usually installed on the roof (it can also be in facades or even in the ground in the form of ground plants) and generates continuous current when sunlight radiates on it, that current then passes through an inverter that turns this direct current into alternating and the same frequency of the electrical network (60Hz), is usually connected to the light board. From that moment the energy consumed by the residence, from the lighting and appliances to the energy used in the panel, if the residence needs to consume more than what was generated, the distributor provides and case about energy the consumer can "sell it"for the distributor as an energy credit (valid for 60 months), where the network will act as a" battery", allowing that credit to be used, for example, on rainy days when the consumer generates less energy than is consuming, according to Normative Resolution nº 687/2015 and Normative Resolution nº 482/2012, this system is called Grid-Connected Photovoltaic Power System.

Networked Photovoltaic Systems do not require the use of accumulators (batteries), because the energy they produce can be directly consumed by the load, or injected directly into the conventional grid, to be consumed by the consumer units connected to the distribution system. According to CRESESB (2016) it is also possible to install an isolated system (off-grid), but the cost increases due to the need of accumulators (batteries), to store energy to be used at night and on rainy or cloudy days.

So, because of the cheaper cost and the ease the systems connected to the network are becoming more common than the insulated ones. A Grid-Connected Photovoltaic System usually consists of the following components, as shown in Figure 1.

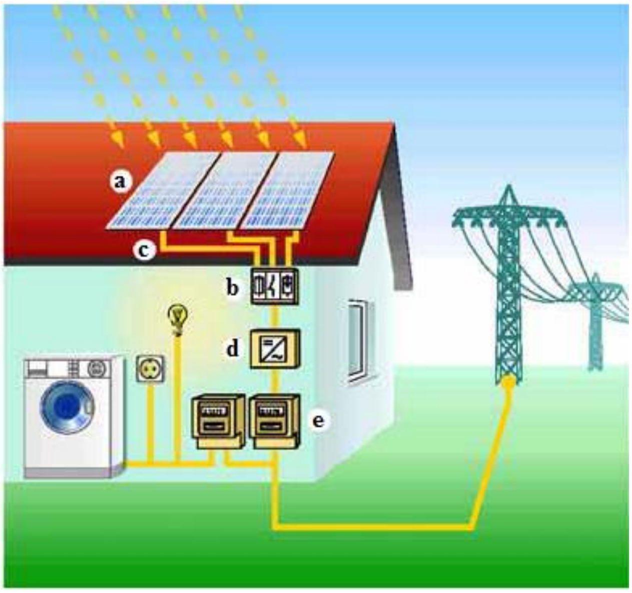

Figure 1. Main structure of a photovoltaic system connected to the grid (ALTENER, 2004, p. 26)

The Figure 1 is composed by: a) Photovoltaic panel; b) Junction box equipped with protection devices (String Box); c) DC - AC cables; d) Inverter (CC-CA) and e) Measuring device (Bidirectional meter)Each of the components shown in the previous illustration (Figure 1) will be described below.

2.1.1 Photovoltaic Panel

It is composed of several solar cells that are responsible for the operation of a photovoltaic system, because it is in them that the photovoltaic effect occurs, through which the solar radiation is converted directly into electric energy. In this process, semiconductor materials such as crystalline silicon are used which are predominant in the market due to their high efficiency (approximately 11 to 16%). Crystalline silicon is the most traditional of photovoltaic technologies and the one with the largest scale of commercial production (86%) of world production, Brazil being one of the largest producers of metallurgical grade silicon. The silicon used in solar cells is the 6M (99.999999%) purity.

According to Pinho and Galdino (2014) the module is generally identified by its peak electrical power (Wp), where its definition is made in standard test conditions (STC), considering irradiance of 1000 W/m² under a standard spectral distribution for AM 1.5 and cell temperature of 25 °C.

According to Torres (2012, p. 80) "Photovoltaic modules can be connected in series, parallel or serial-parallel combinations in order to obtain the desired current and voltage values."

The boundaries for association of panels commonly used in Grid-Connected Photovoltaic Power System are:

- Serial panels: Inverter input voltage, usually in the 500 VDC range.
- Panels in parallel: inverter current, about 20 A.

The combination of the panels must be made to ensure that they do not exceed the indicated parameters of the inverter, to guarantee a better efficiency of the system. Resulting in a mixed association with panels in series and parallel.

2.1.2 Junction Boxes

Also called String Boxes, they are used to accommodate all DC connections from the Photovoltaic Panel, through the protection devices, such as Switching Keys, Fuses, Circuit Breakers and Surge Protection (DPSs), producing an output (DC) - already properly protected - that connects to the DC input of the Power Inverter. Often the Power Inverter (CA) output returns to the same String Box, and through Circuit Breakers (AC) and DPSs, they go to the local power distribution circuits (Garcia et al., 2016).

2.1.3 CC-CA Cables

For the electrical installation of a photovoltaic system, it is recommended to use cables that meet the requirements for such an application. Photovoltaic cables must provide secure and durable connections through MC-4 and MC-3 connectors between solar panels and the inverter that turns solar energy into electrical energy. They must guarantee optimum fire protection for installation on roofs through their double insulation that confers resistance against the sun, wind and rain, as well as great resistance to heat and temperature variations (Energia Solar, 2017).

Complementing with ALTENER (2004) photovoltaic roof tile manufacturers have measured temperatures up to 70 ºC on the roof, which is why "solar cables" are used in outdoor applications, the main characteristics of these cables are resistance to ultraviolet and weather, being suitable for a wide range of temperatures (between -55 °C and 125 °C).

2.1.4 Inverter (DC-AC)

The solar panels generate electricity in direct current DC and the public power grid is in AC alternating current, for that reason, it is necessary to use an inverter to transform the DC to AC with the characteristics of frequency and waveform necessary for the interconnection to the network.

For the specification of an inverter the maximum operating voltage of the photovoltaic array (Vmpp) must be compatible with the nominal input voltage (DC) of the inverter. In addition, the maximum open circuit voltage of the photovoltaic arrangement (VOC) must be within the maximum voltage limit that the inverter can tolerate (Ruther, 2004).

2.1.5 Bidirectional Meter

A bidirectional meter is required which is an equipment that counts the amount of energy sent (credit in kW/h) and consumed by the electricity grid. However, according to the Technical Note n. 0129/2012-SRD, ANEEL (2012) the necessary measurement for the implementation of the Energy Compensation System can be realized by the use of two simple one-way meters: one for measuring the active energy and to measure the amount of electricity consumed.

Who makes the exchange is the distributor itself. In this way it is easy for the distributor and the customer to have control over the credits and debits of energy, the consumer pays only for the cost difference between the conventional clock and the new installed clock, usually something between R$ 100 and R$ 200.

An interesting fact is that according to the MME (2014), INMETRO published in decree nº 004 that defines the "Conformity Assessment Requirements for Photovoltaic Energy Systems and Equipment", applicable for modules, load controllers, inverters and stationary batteries of low intensity of discharge where it was established that from July 2012 the systems and equipment for photovoltaic energy should be commercialized, in the national market, only in accordance with the requirements hereby approved.

It should be remembered that for the connection of the system a project must be done by the responsible engineer or electro technician (depending on the power of the system and the concessionaire responsible for the connection) that will issue an ART (Technical Responsibility Note) to CREA, where a project, descriptive memorial and a set of documents will be delivered to the distributor for evaluation and approval. The engineer should be aware of all the standards for the execution of the project, such as NBR 16274, which talks about Grid-Connected Photovoltaic Systems, where there are minimum requirements for documentation, commissioning, inspection and performance evaluation tests (Associação Brasileira de Normas Técnicas, 2014).

Other factors directly influence the efficiency of the plant's energy conversion and will be addressed during the work.

2.2 Grid-Connected Photovoltaic Power System in Serrana Meso-Region

The Serrana meso-region is one of the six meso-regions of the Brazilian state of Santa Catarina. It is formed by the union of thirty municipalities grouped in two microregions: The microregion of Campos de Lages composed by: Anita Garibaldi, Bocaina do Sul, Bom Jardim da Serra, Bom Retiro, Campo Belo do Sul, Capão Alto, Celso Ramos, Cerro Negro, Correia Pinto, Lages, Otacilio Costa, Panel, Palmeira, Rio Rufino, São Joaquim, São José do Cerrito, Urubici and Urupema; and the micro-region of Curitibanos composed by: Abdon Batista, Brunópolis, Campos Novos, Curitibanos, Frei Rogério, Monte Carlo, Ponte Alta, Ponte Alta do Norte, Santa Cecilia, São Cristóvão do Sul, Vargem and Zortéa (Cidade Brasil, 2017).

Within these thirty municipalities, four of them stand out because they already use the microgeneration of solar energy in the Grid-Connected Photovoltaic Power System: São Joaquim e Lages, belonging to the microregion of Lages and Curitibanos and Campos Novos belonging to the micro-region of Curitibanos.

In São Joaquim the residence has 8 modules with 2 kWp, 13.04m2 of arrangement and 1 inverter with 2.5 kWp, totaling 2 kW of installed power. The date of connection with the concessionaire was on 05/13/2016 (Cassel, 2016).

In Campos Novos, at FUNOESC- Fund.Universidade do Oeste de Santa Catarina, 3 kWp were installed, the date of connection with the concessionaire was on 02/16/2017 and in a residence 3 kWp were installed with the date of connection on 17/01/2017 (ANEEL, 2017).

In Curitibanos a residence has 3 kWp installed with connection to the concessionaire on the date 08/30/2016 (ANEEL, 2017).

Also in Curitibanos was installed on the 12th floor of a residential building 18 modules of 255 Wp of the brand Yingli resulting in an installation with 4.59 kWp total, 29.16m2 of arrangement, with metal structure in aluminum profile K2 and a PHB-SS inverter -4600, totaling 4.60 kWp installed. It produces a monthly average of 550 kWh of electricity for its owner since June 2015. It is called the Louisseville I Solar Power Plant (Cassel, 2016).

In Lages there is a residence with 1.3 kWp installed with date of connection with the concessionaire on 07/04/2017 (ANEEL, 2017). The system has 5 modules of 260 Wp each and a 1.5 kWp inverter. The system generates 100% of the demand for the residence and has a simple payback[1] estimated from 5 to 6 years. It cost about R$ 7,500.00, because the electrical design and installation of the system were carried out by the owner himself and a friend. They claim that even with the average generated so far, being in a period of low incidence, the investment would be paid in less than 6 years and then very worthwhile[2].

In the entire state of Santa Catarina, 410 requests for access to photovoltaic microgeneration systems were carried out. Of these, 288 are already in operation, with a total installed capacity of 1,674 kW (Cassel, 2016).

3. Methodology

A case study was conducted in the city of Lages/SC based on bibliographical sources and data collected in the region for the construction of a Grid-Connected Photovoltaic Power System project for a local residence. The design of a photovoltaic system involves the orientation of the modules, aesthetics, availability of area, availability of the solar resource, demand to be met and several other factors.

Firstly, for the sizing of the photovoltaic system the most practical way is by means of an analysis of the

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[1] Payback in Portuguese means "return" is a technique widely used in companies to analyze the term of return on investment in a project. We can complete that the Payback is the time of return of the initial investment until the moment in which the accumulated gain equals the value of this investment. Usually this period is measured in months or years. (Alves, 2014).

[2] In an interview with Guilherme Schwendler, owner of the system in Lages, on 05/15/2017 around 20:00 at UNIPLAC located in Lages/SC.

consumption profile of the unit, then starting by averaging the monthly consumption of the consumer unit. According to CELESC (2016), the billable minimum values, applicable to the billing of consumer units of Group "B", according to the limits established by type of connection are:

- Single-phase: value in currency equivalent to 30 kW/h;
- Biphasic: value in currency equivalent to 50 kW/h;
- Three-phase: value in currency equivalent to 100 kW/h.

The minimum values are applied whenever the measured or estimated (average) consumption is lower than those mentioned above (CELESC, 2017). They are charged due to transmission and distribution of energy from the concessionaire.

Then, after calculating the monthly average, you must discount the minimum billable amount according to the type of connection. For example, the monthly average of a consumer unit in Group B is 500 kW/h and the type of connection of the same is biphasic, in which case one should discount the 500 kW/h minimum value of 50 kW/h which will always be charged, regardless of whether you are using it or not.

To define the number of panels, it´s necessary to know the amount of daily energy that the system must generate to meet demand. For this calculation it is necessary to know the monthly average solar irradiation of the place (for the photovoltaic system the irradiation is the horizontal plane and then according to the angle that the modules will be corrected with correction factors), that can be obtained through various means. The Solar Potential program (SunData) is available on the CRESESB website for free and is designed to calculate the average monthly solar irradiance at any point in the national territory and is an attempt by CRESESB to provide a tool to support the project of photovoltaic systems (CRESESB, 2016). The software RADIASOL2 also is available on the website, in this the calculation of the intensity of solar radiation on inclined surfaces is a laborious procedure due to the large number of arithmetic operations involved (UFRGS, 2017).

The minimum angle used for the panels is 10° to prevent dust accumulation on the panel and facilitate natural cleaning through the rain. Many installers prefer to use the latitude angle only for efficiency, for example, in the city of Lages/SC the latitude is 27.8 degrees, so the panels should be on this same slope or as close as possible to this value, but if it is not possible, it should be used correction factors according to the angle.

The temperature that the system will operate must also be analyzed, because the heat disrupts the photovoltaic plates, where the higher temperature takes to a lower yield, because when the temperature goes up, the current gives a slight increase and the voltage drops a lot, causing power losses. The manufacturers quantify this effect through a parameter known as Coefficient of Power, which indicates the percentage of energy is lost for each °C added the panel temperature. This is due to the fact that the cell voltage decreases significantly with the increasing of the temperature, while the current undergoes a very small, almost insignificant elevation. To define the number of panels required, it is necessary to consider the average daily consumption and the solar irradiation. For the definition of average daily consumption, the average value of monthly consumption should be used and divided by the number of days of the month (defined as the average value of 30 days).

$$\text{Consumo Médio diário} = \frac{\text{Consumo Médio Mensal}}{\text{Número de dias}} \tag{1}$$

The required plate power can be found according to the equation below:

$$\text{Potência de Placas Necessária} = \frac{\text{Consumo Médio Diário}}{\text{Irradiação solar Média}} \tag{2}$$

Considering heating losses and other factors makes an efficiency factor to better tune the system. Simply divide the Required Plate Power by this factor. For example, for an efficiency of 70% of the system, the factor will be 0.7.

$$\text{Potência Corrigida} = \frac{\text{Potência de Placas Necessária}}{\text{Fator de eficiência}} \tag{3}$$

For this number of modules it is necessary:

$$\text{Quantidade de Módulos} = \frac{\text{Potência Total Necessária}}{\text{Potência do Módulo Individual}} \tag{4}$$

For the definition of the inverter which is one of the most important components of a solar photovoltaic system, it is important to analyze the maximum power that can be generated by the system and find an inverter that has a near power, generally choose one with a little more power, to not overload the inverter, in addition to its voltage characteristics with the photovoltaic adjustment as already mentioned above.

It is recommended that the installation of the photovoltaic panels be turned to the North, as the sun rises in the East, rises to the North and sets in the West, so the loss is diminished. However, if the roof does not allow the North-facing installation, the directional losses for roofs with Northeast or Northwest face vary between 3% and 8% and for a roof with East or West face the loss can vary between 12% and 20%.

The c-Si (Crystalline Silicon) modules contain serially associated photovoltaic cells. When one or more of these cells receives less solar radiation than the others of the same association, its current will limit the current of the whole series. This shadowing directly affects the available energy in the place, as much shading by trees, building, by dirt as dust, leaves, etc. Then for this reason we use blocking diodes in the junction box (usually 2 diodes in parallel per String (in the positive phase) as a way of protecting the panels from the reverse current that is caused by the voltage difference of the branches due to these unwanted situations. According to Hecktheuer and Krenzinger (2017) the branch that presents a lower tension is subject to act as load for the other branches. In this way, part or all of the current generated by the branches that present greater voltage will flow through the branch of less tension, causing a warming in this last branch and loss of power of the system, then these diodes are connected in series in each of the branches for to avoid the appearance of reverse chains.

Fuses are also used for protection, which according to Cabral (2001) are devices used to protect circuits against not normal currents, such as short circuit and overload. The three types of fuses most common are Cartridge, NH and Diazed, where the cartridges are the most used in the protection of residential circuits, using solar energy. Usually two fuses are used per String (one in the positive phase and the other in the negative phase). They are actually needed when the installation is with 3 strings or more for reverse current protection. For the end of calculations the most important analyses is the payback or the time to return the investment presented in (5).

$$\text{Payback simples} = \frac{\text{Investimento Inicial}}{\text{Ganho no período}} \qquad (5)$$

4. Results and Discussion

Through the collected data it was possible to do the sizing and choose the necessary equipment. In the present article, will be used 100% of the necessary energy of the residence, it should be remembered that we could scale to generate the amount of energy that we would consider convenient, making the project cheaper and sometimes more viable.

4.1 Average Monthly Consumption

Initially one should obtain the monthly average of consumption through the last 12 energy bills according to Table 1.

Table 1. Monthly consumption data in kW/h for a period of 12 months and the monthly average.

Month	**Energy Consumption (kW/h)**
January/2016	450
February/2016	462
March/2016	468
April/2016	468
May/2016	470
June/2016	482
July/2016	480
August/2016	479
September/2015	480
October/2015	474
November/2015	460
December/2015	452
Monthly Average	468,75

Due to the type of connection in the residence selected for the study to be single-phase, it is necessary to discount 30 kW/h of the monthly average consumption, thus totaling: 468.75 kW/h - 30 kW/h = 438.75 kW/h, to 439 kW/h to make easier calculation.

To define the amount of panels required, it is necessary to consider the average daily consumption through equation 1 above. This gives the average daily consumption, which in the case was 14633.33W/h. Therefore, it will be used an average daily consumption of 14633.00 W/h to simplify the calculations.

For the calculation of the power of the necessary plates we must have the average solar irradiation in the place. With the use of the RADIASOL2 program, we selected the city (Lages/SC) and set the slope and Azimuth or Azimuthal Deviation to 0° according to Annex B (UFRGS, 2017). Then it can be observed in Figure 2 the average irradiance in kWh/m². The graph with the solar irradiance in the inclined plane at 0° according to the data obtained that corresponds to the horizontal plane.

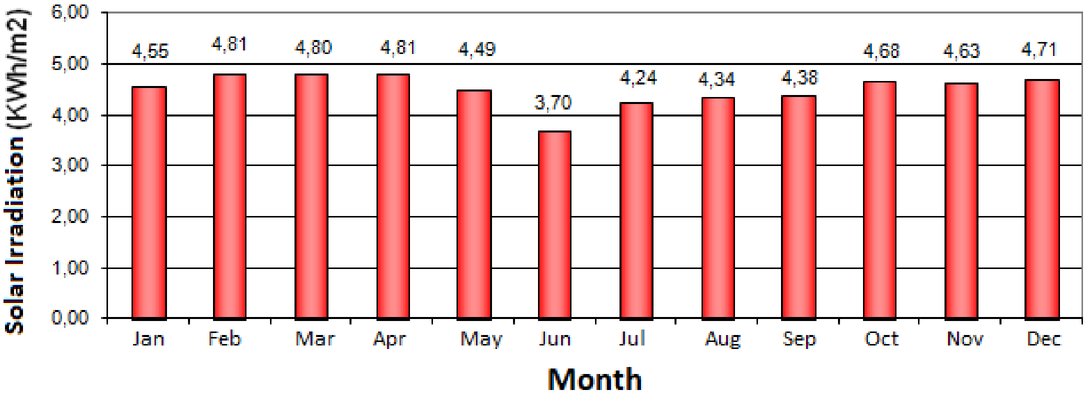

Figure 2. Solar irradiance in the inclined plane at 0 ° (horizontal plane).

In the residence that are dimensioning the system, the angle of the roof is 15º, for this reason should be used the correction factors according to Figure 3.

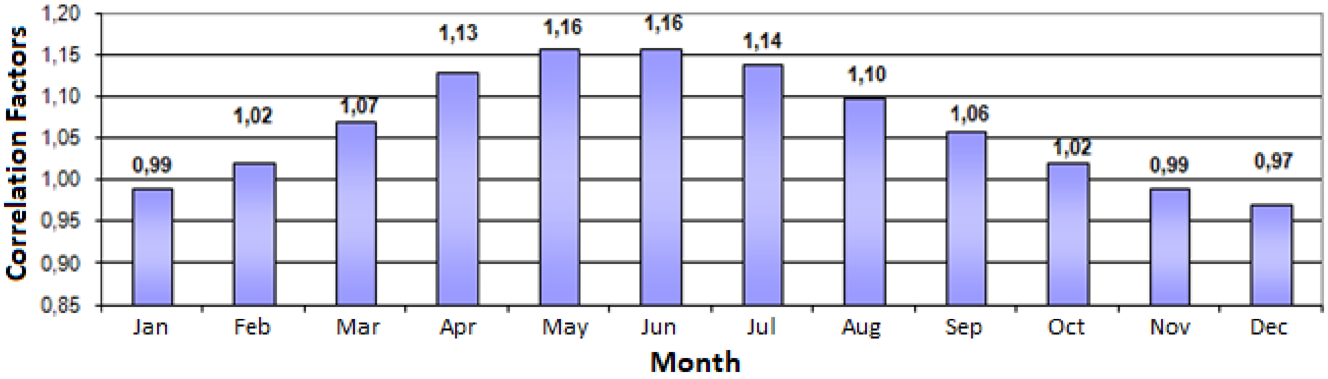

Figure 3. Correction factors for 15º slope of the modules (Kasburg, 2016).

Thus, with the use of slope correction factors, a new corrected irradiation graph is presented in Figure 4.

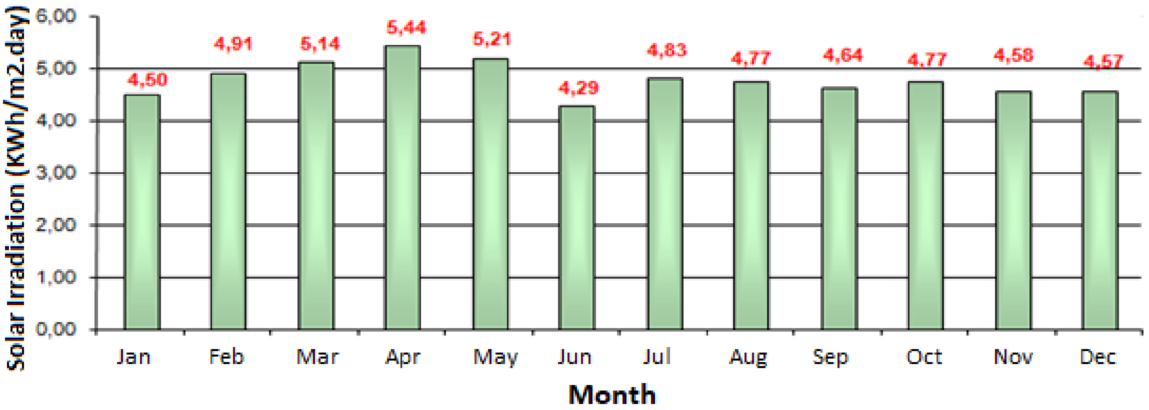

Figure 4. New Solar Irradiation in the inclined plane corrected through correction factors with a 15º.

It´s considered an average solar irradiance of 4.8 kWh/m². With this data from the calculation of the required plate power through equation 2, the it´s found the value of 3048.54Wp. As mentioned earlier to consider the system losses caused by heating among other factors, so it will be considered an efficiency of 80% of the system. For the calculation of the new power already corrected by equation 3, the value of 3810,67Wp is obtained.

Now with the necessary total power already calculated it could be chosen the modules that together should generate the demanded power. In this work, the chosen module was the Jinko 265Wp Photovoltaic Module JKM275M, (DATASHEET JKM275M-60, 2017).

For the calculation that will define the number of modules required is used (4). Substituting the data into the equation, the value is equivalent to 14.37. For better efficiency it is considered 16 modules required.

The inverter chosen in this work was the On-Grid 4600W Solar Inverter, which is the 1st Solar Inverter connected to the Brazilian grid to be certified by INMETRO concession 000150/2015 with appropriate operating characteristics for the Brazilian grid.

For the dimensioning of the inverter it is necessary to analyze the maximum power that can be generated by the system (3810,54W), generally we choose one with a little more power to not generate overload in the inverter. In addition, the voltage and current characteristics must be observed so that the panels are joined in a way that respects these characteristics.

The module's second datasheet current is 8.5A each module and the short-circuit current is 9V each module. The voltage of each module according to the datasheet is 29.6V and its open circuit voltage is 36V. The maximum current of the inverter according to the datasheet thereof is 20A and its maximum voltage lost at the input is 580VDC.

The association of the modules must be made to ensure that they do not exceed the indicated parameters of the inverter, to guarantee a better efficiency of the system. Then, 2 strings will be used in parallel with 8 modules in series each. Where the 8 connected modules added their voltages (29.6 V) resulting in 236.8V and connected in parallel with the other 8 modules in series also with their added voltages, will generate in the input of the inverter only 236.8V, because in parallel the tension holds. Since the current, the modules are in series, the current is unchanged (not added or divided) totaling 8.5A in each string, and the input of the inverter as the strings are in parallel their currents will add up resulting a current 17A at the input of the inverter. The open circuit voltage will be at 288 V and the short-circuit current at 18A.

In addition, two fuses in each String (one in the positive phase and one in the negative phase) will be used, totaling 4 fuses of 15A (standard value for Strings) and two blocking diodes in parallel for the positive phase of each Strings (4 blocking diodes). The water of the roof oriented to the North, which will serve as accommodation for the modules has a total area of 47.73m².

According to the dimensions of the modules (1,638m x 0,982m), the occupied area of water for the accommodation of the 16 modules will be 25.74m². For the measurement, it is necessary a bidirectional meter which is an equipment that counts the amount of energy sent (credit in kW / h) and consumed of the electric network.

4.2 Economic Viability

For the analysis of the feasibility of installation it is necessary a cost survey. In contact with the company Sol Central Energias Alternativas, an Electrical and Computer Engineering Services company oriented to the stimulating market of Solar Energy and other alternative sources of clean energies, located in Curitibanos/SC belonging to the Mountain Region, the company offers complete kits according to the system's necessary power (Kasburg, 2017).

According to Kasburg (2017) according to the information provided and sizing calculations made, a system of 4,240Wp was proposed with 16 photovoltaic modules and 1 single-phase inverter composed of the following equipments:

a) 16 Jinko 265 Wp Photovoltaic Modules (JKM275M) each (Total 4,240 Wp);
b) 1 Single-phase PHB 4600-SS Interactive Inverter of 4.600W;
c) 1 DC + AC Junction Box and Protection Devices;
d) Metal support structure for 16 modules:
    i. 8 Anodized aluminum profiles for 4.2m photovoltaic modules;
    ii. 28 Grounding clips;
    iii. Grounding jumpers;
    iv. 16 Cable Ties;
    v. 4 Grounding clips;
    vi. 4 Splices for aluminum profile;
    vii. 24 Hook steel kit #;
    viii. 8 End clip kit 40mm;
    ix. 28 Inter clip kit 40mm;
e) Connectors and Terminals;
f) Electrical Wiring AC + DC (3x40m).

The total price of the system, including the electrical design, equipment, installation and homologation with CELESC, will be R$ 21,650.00, and the equipment kit alone will cost R$ 17,650.00, the electric project and ratification will cost R$ 1,500.00, and installation plus R$ 2,500.00 (except eventual expenses of adaptation in the standard of entry of the residence).

All material and workmanship are included, as specified below:

- Elaboration of electrical diagrams and project specifications;
- Installation of the panels on the roof of the residence;
- Cable routing;
- Installation of protection systems;
- Connection of the protection system and inverters;
- Approval of the project from the local energy concessionaire (CELESC).

They are not covered in the proposal:

- Costs with civil works and adequacy of the current installation (it will not necessary);
- Cost of the meter of the local power company (around R$ 200,00);
- Expenses with the installation of adequate grounding system (it will not necessary);
- Expenses with connection to the network of the concessionaire (it will not necessary);
- Materials for the installation, such as ducts and switchboards (it will not necessary).

Thus, a total value of R$ 21,650.00 + R$ 200,00 (Bidirectional Meter) = R$ 21,850.00.

The feasibility of the project, according to the comparison Consumption vs. Generation (kW/h), and consequently Original Invoice x New Reduced Invoice (R $). We will consider a reduced invoice of R $ 34.90 (30 kW/h fixed + rates) that can vary. Thus, we will obtain the approximate annual savings that we will use to payback the investment, according to Tables 2 and 3.

Table 2. Estimates of consumption and new invoice reduced until June.

	Jan	Feb	Mar	Apr	May	Jun
Historical Consumption Estimate (kWh):	462	468	468	470	482	480
Generation (kWh):	464	456	529	541	536	427
Balance for the following month:	2	0	61	132	186	133
Net Energy Billable:	30	30	30	30	30	30
Original invoice (R$)	296,32	300,12	300,12	301,39	308,99	307,72
New Reduced Invoice	34,90	34,90	34,90	34,90	34,90	34,90
Monthly Savings (R$)	261,00	265,00	265,00	266,00	274,00	273,00

Table 3. Estimates of consumption monthly savings from July to December and original invoice, reduced and annual savings.

	Jul	Aug	Sep	Oct	Nov	Dec	Averages	Annual totals
Historical Consumption Estimate (kWh):	479	480	474	460	452	450	468,75	
Generation (kWh):	497	491	462	491	456	470	485,14	
Balance for the following month:	152	163	151	182	187	207	130	
Net Energy Billable:	30	30	30	30	30	30	30	
Original invoice R$)	307,09	307,72	303,92	295,05	289,99	288,72	300,59	**3.607,14**

New Reduced Invoice (R$)	34,90	34,90	34,90	34,90	34,90	34,90	34,90	**418,75**
Monthly Savings (R$)	272	273	269	260	255	254	265,70	**3.188,39**

Through the presented data we can verify the generation estimate in kWh / month according to Figure 5.

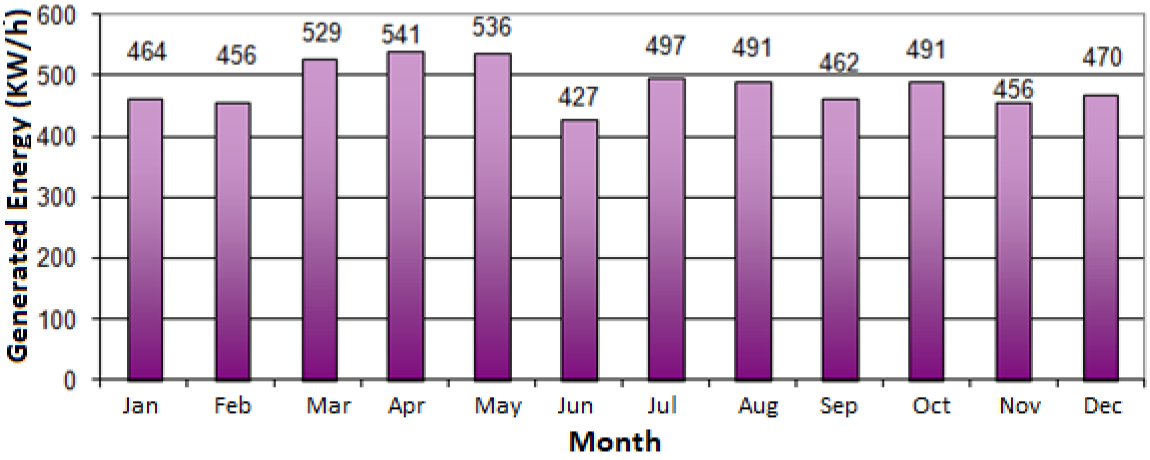

Figure 5. Estimation of generation (kWh/month), how much the system can generate per month.

And then it can be seen the comparison of generation and consumption in each month according to Figure 6.

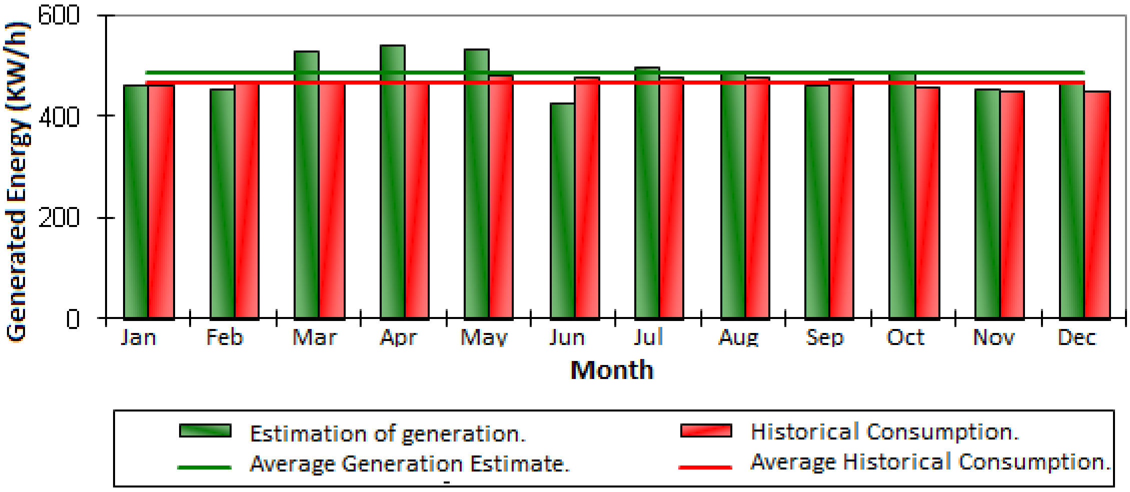

Figure 6. Comparison of generation and consumption estimation (kWh/month). How much the system can generate per month compared to historical consumption

As observed the annual savings amount will be around R$ 3,188.39 so it's possible to calculate the simple payback through equation 5, obtaining the value of 6.85 years. This shows that the payback will return close to 7 years (6 years, 10 months and 6 days), however it should be taken into account that the annual savings amount will not always be the same, in many years it will probably be higher, because in this study the inflation was not not take account, and also tariff increases and even the yellow and red flags (1), for this reason the system may have a fast payback.

5. Conclusion

Although Brazil is a tropical country, in some regions the implementation of solar power plants is not feasible, and it is necessary to use other ways to take advantage of the solar potential. In the Serrana Meso-region, the irradiation is smaller, thus making the region more suitable for use in buildings and residences and not in solar power plants.

The constant preoccupation with the environment and the economy that solar energy can generate led to the dissemination of the use of solar energy in several regions, mainly on-grid. These systems have the advantage of not wasting energy, since the unused energy is injected directly into the grid, providing energy credits valid for 60 months to be used on rainy or cloudy days after the creation of Normative Resolution No. 482/2012, and it also provides several benefits to the electrical system, such as the advance of investments for expansion in distribution and transmission because of the distributed systems, low environmental impacts, improvement of the network voltage level during the heavy load period and diversification of the energy matrix.

In Serrana Meso-region, four municipalities that already use the micro-generation of solar energy on-grid: São Joaquim e Lages, belonging to the micro region of Lages and Curitibanos and Campos Novos, belonging to the micro-region of Curitibanos. In an interview with the owner of the system in Lages / SC, they inform that the system can generate about 1.5 kWp per day, because the system cost about R$ 7,500.00 and with the average generated so far, even in a period of low incidence the investment would be paid in less than 8 years.

In the case studied - a networked photovoltaic system in the city of Lages/SC belonging to the Serrana meso-region, with an average consumption of 468,75 kW/h per month - according to the system design, it would generate 3.18 kWp per day and would leave around R$ 21,850.00 with a payback of approximately 7 years, without taking into account the increase in inflation and increase in tariffs that will probably happen, making the payback become much smaller. In addition to valuing the property, the environmental and energy issues, maintenance is still minimal (only close to the 12th year and it is necessary to maintain the inverter or until the exchange of the same) and the useful life of the system is about 30 years.

Comparing the two cases in Lages/SC, in relation to the value of the investments, the larger the system, the lower the cost per Watt installed, improving the time of return, because the studied system that will generate more than twice the power that the system has already existing, has almost the same payback, this still taking into account that the existing system came with a price much more in account because the design and installation will be done on their own, otherwise the value would rise and payback as well. It should be remembered that another option to be evaluated is the installation of the system to supply only a percentage of the electric energy demanded and not 100% as shown, so the cost would become smaller and would already have advantages in the energy bill and in energy terms and environmental issues.

The Brazilian government should grant tax incentives to promote the development of the photovoltaic industry in the country, for the manufacture of inverters, modules and other electrical components, thus, besides providing jobs would be motivating new research in the area, reducing costs making the investment still more feasible and attractive and also create or support more projects such as the Photovoltaic Bonus Project that is part of the CELESC Energy Efficiency Program, which is being operated by ENGIE Photovoltaic Power Generation, which its objective is to encourage the solar generation of solar energy with 60% bonus on the acquisition of a photovoltaic system of 2.6 kWp and five LED lamps (CELESC, 2017).

It is concluded that although it is still a very high investment, grid-connected photovoltaic systems are a recommended way to use solar energy in the plateau region, because of its local characteristics and its other advantages that have already been mentioned in this work.

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