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SOLAR PHOTOVOLTAIC ON GRID INSTALLATION: PROJECT, LEGAL ASPECTS, ACTUAL DATA AND ECONOMIC VIABILITY

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Abstract. The present work aims to study the design of a solar photovoltaic installation that has been interconnected to the electricity grid at a residence located in Itajubá, Minas Gerais, by using technologies which are available in the market and following the public policies on its implementation. It is based on a single-family home, thence it is considered an average price of electricity demand from a bill supplied by the local electricity agency. Furthermore, data on sunlight potential in the region has been collected, thus it was designed a project aimed at implementing a photovoltaic system (PV) facility which is able to supply the required local demand. An economic feasibility analysis has also been performed by considering actual data of a PV system installed in this residence, current electricity charges, and investment cost with current data on the Brazilian market so as to calculate some decision-making parameters, such as Internal Rate of Return (IRR), Net Present Value (NPV) and their respective Payback. On the other hand, it was also assessed legal and political issues in order to depict the Brazilian scenario as regards the implementation of new photovoltaic solar projects for homes.

Keywords: Energy, Photovoltaic, Solar, microgeneration, economic viability

1. INTRODUCTION

With the advancement of the Fordist production system, characterized as a mass production and consumption process worldwide, an alarming cause for concern about environmental issues has emerged in recent years. After all, not only industries must have electricity for production, but also consumers need it to use in favor of their well-being. In order to obtain it, it is necessary to generate it, which often occurs by burning fossil fuels or exploiting natural resources, thus causing damage to the environment.

In order to reduce environmental and social impacts caused by traditional energy sources with the purpose of preserving natural resources, it was sought alternatives that resulted in the so-called renewable energy sources. These include: solar, wind, hydropower, biomass, biogas, biofuels and geothermal energy sources, which are becoming increasingly popular and competitive with other existing energy sources.

Solar energy can be used to produce electricity by the photovoltaic effect, which consists in a direct conversion of sunlight into electricity.

Photo is Greek for light and voltaics refers to electricity, thus the term "photovoltaics" refers to directly converting light energy into electricity. Photovoltaic devices are composed of modules which produce direct current voltage. These modules are also known as photovoltaic panels that are assembled in arrays and connected to each other. Electricity is generated by incident sunlight and it is used locally by powering an electric panel.

In addition to exerting substantially smaller impacts, they avoid the emission of tons of carbon dioxide into the atmosphere. The ongoing debate on the impacts generated by fossil fuel dependence contributes decisively to the world's interest in sustainable solutions through energy generation from clean, renewable and environmentally sound sources (BERMAN, 2008).

The world's interest in renewable energies has been arousing in recent years, mainly as regards photovoltaic solar energy. The number of researches and publications in journals and magazines on photovoltaic solar energy generation has grown significantly between 1996 and 2016, i.e. 142 articles were published. The year in which there was the largest number of publications is 2014 with 26 articles. The countries that have published the largest number of articles are the United States, with 26 publications, China (15) and Germany (14). Other countries like Japan, Italy, Spain, Denmark, South Korea, Belgium, Croatia, Lithuania, Scotland, Greece, United Arab Emirates, Singapore, Spain, Australia, Austria, Brazil, India, Poland, Pakistan, Israel, Morocco, Mexico, Malaysia, Chile, Turkey, United Kingdom and Taiwan, Norway gathered 87 published manuscripts (SAMPAIO & GONZÁLEZ, 2017). There are many performance evaluation studies on outdoor PV systems throughout Europe, India and Brazil as reported by (MICHELI et al., 2014; KUMAR et al., 2014; ADARAMOLA & VAGNES, 2015; LIMA et al., 2017), as well as the economic viability of these developments.

As in the most industrialized countries, electricity consumption in Brazil has also been increasing these days. Economic and social development has led to a significant electricity demand, and thus to the need for a high level of security and sustainability in order to avoid adverse environmental impacts. Sustainability is a means to promote economic and social growth by reducing environmental impacts.

Therefore, it is hereby aimed to analyze technical and economic viability of a residential photovoltaic solar installation by designing a system that meets the average demand and considering optimal and affordable solar panels available in the local market. The values obtained by the theoretical model have been compared to actual data collected from the installation in the studied residence itself. It is also aimed to review the laws adopted in this context, i.e. whether they allow independent generation or encourage small and micro generation of electricity. Lastly, it is aimed to contextualize the development of solar panel installation through statistical data and technologies available in Brazil.

2. PHOTOVOLTAIC SYSTEM IN BRAZIL

Traditional energy sources are still used to generate electricity worldwide. However, there has been a strong participation of alternative sources for electricity generation in many countries, including Brazil.

In 2016, 1% of the electricity supplied in the Brazilian electricity grid is produced from solar energy (MME, 2017). According to projections made by the Energy Research Company (EPE), solar energy projects can reach 25GW in installed capacity by 2030. Thus, it is estimated that the participation of solar energy generation in the electricity grid will be over 10% in 2030 (EPE, 2017).

A study carried out by (JANNUZZI & MELO, 2013) has analyzed the policies and potential impacts of grid-connected photovoltaic systems in Brazil until 2030 by considering political processes to promote their development. The study provided Brazil with good opportunities to diversify its electricity grid with potential economic and environmental benefits.

About 5 years ago in Brazil, photovoltaic solar energy was used mainly by small remote systems that were not supplied by the electricity grid because installation of power distribution lines was impracticable. However, the number of photovoltaic systems connected to the grid has increased in recent years and should be even greater in upcoming years due to authorizations by the National Electric Energy Agency (ANEEL) through laws that encourage small and micro generation for low-voltage distribution systems powered by renewable energy sources, such as solar energy. These systems are known as Distributed Generation (DG).

Distributed microgeneration systems are those in which its generator has installed capacity of up to 75kW, and distributed minigeneration systems are those whose power ranges between 75kW and 5MW, except for hydropower generation whose maximum limit is 3MW (ANEEL, 2016).

When installing a photovoltaic system, e.g. in an urban area and connected directly to a low-voltage grid (on-grid connection), it will produce electricity at a very competitive cost, which can then be used to reduce prices of electricity bills for consumers. Similar systems to these become even more advantageous by considering the current electricity inflation, as it occurs in Brazil because they reduce losses and the cost of their possible expansion in the electricity grid. After all, generation occurs next to the consumption unit, consequently, there is also an increase in assurance of supply and, lastly, there are environmental gains, since they are totally sustainable projects.

2.1 Scenario of Small and Micro Generation Systems in Brazil

According to data from ANEEL dated November, 2017, there are 16,664 small and micro generation power plants whose installed capacity is 185,513.25 kW altogether. As sunlight is the most commonly used source by consumers and generators, it corresponds to 99% of all power plants, as it can be seen in Tab. 1 (ANEEL, 2017). The installed capacities of generation units in each Brazilian state are depicted in Tab. 2. It should be emphasized that these values include all types of small and microgeneration units, such as solar, wind, thermoelectric, hydropower, biodigesters, etc. The state of Minas Gerais leads the rankings with 3,736 connections, followed by São Paulo with 3,291 and Rio Grande do Sul in the third place with 1,902 (ANEEL, 2017).

Table 1 – Consumer units (UC) with distributed distribution by type of source

Consumer units (UC) with distributed generation			
Type	Quantity	Quantity of UC that receives the credits	Intalled Power [kW]
Hydropower	20	238	15190.70
Wind	53	96	10285.60
Photovoltaic	16521	18641	136854.69
Thermoelectric	70	196	23182.26
	Total plants: **16664**	**Total UCs receiving credits:** **19171**	**Total Power:** **185513,25 kW**

Table 2 – Consumer units (UC) with distributed generation by state

UF	Quantity	Quantity UCs that receiving credits	Installed Power (kW)
AC	6	6	27.52
AL	69	84	989.15
AM	7	7	54.86
AP	8	8	305.60
BA	369	439	3,697.44
CE	616	706	21,840.32
DF	264	276	2,632.72
ES	567	590	2,022.96
GO	331	384	5,972.11
MA	178	192	2,309.27
MG	3736	4868	42,123.43
MS	318	348	2,641.99
MT	217	230	7,476.68
PA	94	94	449.80
PB	149	214	1,447.01
PE	293	390	4,756.96
PI	23	23	507.8
PR	1274	1276	10,350.99
RJ	1373	1449	13,290.15
RN	272	276	3,693.95
RO	38	56	3,892.47
RS	1902	2169	22,794.17
SC	1102	1303	11,63.67
SE	76	80	642.51
SP	3291	3606	19,336.88
TO	91	97	623.84
Total plants: 16664		**Total UCs that receiving credits: 19171**	**Total Power: 185,513.25 kW**

As more tax encouragement laws assigned to such power generation system installations are created and the price of kWh of electricity increases, many industries will develop interest in photovoltaic systems.

In Figure 1, despite the lack of data on a few states, it can be observed a significant increase in the use of photovoltaic energy by the industrial sector in the states of Rio Grande do Sul and Paraná in 2017. The common feature of this sector is that there is large amount of power generated by a single industry. For instance, in Ceará, 2016, there was a total of 5696.06 kW of installed capacity, from which 2,983.50 kW was produced by a single unit (ANNEL, 2017). This is something that differs from other sectors; e.g. commercial and residential sectors, where it was obtained low values of installed capacity, but occurring more often.

Figure 1 – Values of powers installed in photovoltaic panels in the Brazilian industrial sector

Based on data from 2017, the residential sector is the one with the largest number of small and micro generation PV installation, which represents about 49.97% of the country's total amount, i.e. a slightly higher percentage than the commercial sector with 44.15 %. Figures 2 and 3 represent a comparison of years, from 2015 to 2017, for both previously mentioned sectors.

Figure 2 – Values of powers installed in photovoltaic panels in the Brazilian residential sector
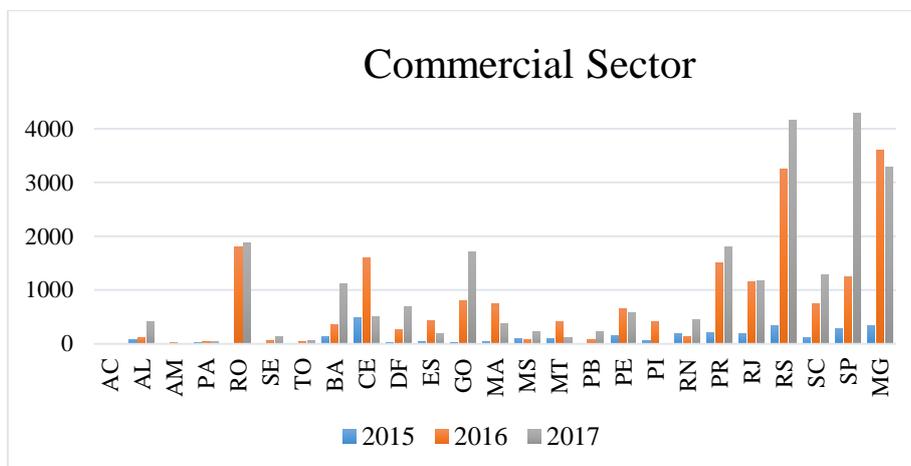

Figure 3 – Values of powers installed in photovoltaic panels in the Brazilian commercial sector

By comparing the percentage values of 2016 and 2017 with installed capacities, a decrease can be observed in the industrial sector: there was a growth of 10.32% from 2015 to 2016, while there was a fall of 11.48% from 2016 to 2017. This can be explained by the current moment of crisis that has devastated the country, thus exerting great influence on the industrial sector, which often opted to cut back on its production and investments, as it would be the case of energy generation through photovoltaic panels.

2.2 Brazilian Legislation

In order to understand the process of encouraging renewable energy generation, it is worth mentioning Alternative Energy Sources Incentive Program in Brazil (PROINFA). Among many programs, laws and facilities created to encourage the use of renewable resources as energy sources, PROINFA stands out.

Alternative sources, such as Small Hydro Power Plant (SHP), wind, biomass and sunlight are now encouraged by four basic mechanisms: market share and discount on charges, renewable energy auctions and PROINFA, which took place in a couple of stages (MAIA, 2009).

A.   PROINFA I

Due to the need for investments in renewable energies, either through small or large generators, PROINFA has been created.

In accordance with Law 10.438 of April 15, 2002, it is a result of efforts devoted towards seeking alternative energy sources in Brazil in the 1990s. This program allowed outsourcing the generation of 3,300 MW involving alternative energy projects, such as biomass, SHP and wind power. Wind power generation has been encouraged by outsourcing the generation of 1422 MW, which is estimated to occur until 2008 [6]. In 2009, 60 SHPs, 50 wind farms and 20 biomass units were in operation, thus totaling 3030 MW, i.e. 92% of the estimate (MAIA, 2009).

B.   PROINFA II

In the second stage of PROINFA, guidelines have been laid down for the participation of such renewable sources, which correspond to about 10% of all electricity demand in the country within 20 years (2022) (DUTRA, 2006).

Other characteristics of this stage of the program are that a nationalization index of 90% of equipment has been adopted. Furthermore, additional credits would be provided through fees to be shared by all consumers. Costs would be split through special financing conditions provided by National Development Bank (BNDES) and there would be a 20-year contract, at competitive electricity price, with Eletrobrás (MAIA, 2009).

When discussing the scenario that can more directly affect Brazilian citizens, it is worth mentioning resolution No. 482/2012 by Brazilian Electricity Regulatory Agency (ANEEL) and its review which resulted in Normative Resolution (REN) No. 687/2015, which establishes the general access conditions of small and micro generation systems to the electricity grid, and it also establishes the compensation system for such energy generation. Once consumers can install small power-generating units and if the amount generated in a given month is greater than that consumed in the period, the consumer will obtain credits through discounts on future invoices, with a maximum period of 60 months for such deduction. Moreover, there is the so-called remote self-consumption in which credits can be claimed by another consuming unit since it has the same account holder and is located in the same service area of the agency in question (ANEEL, 2016).

The federal government and agencies of the energy sector have increasingly sought to stimulate distributed generation, thus they have introduced laws and regulations that are favorable to consumers and generators equally. This is evidenced by an action taken by the Brazilian Council of Tax Policy (CONFAZ), which revoked the collection of ICMS (Value-added tax - VAT) in April, 2015, thus consumers will be exempt from taxation once they supply electricity to the grid. They will only be taxed for surplus consumption, i.e. when they are supplied by the grid because generation is unable to supply their demand (CONFAZ, 2015).

Currently, federated states are responsible for collecting the ICMS tax, or not in the case of exemption, up to present time, i.e. November, 2017. 23 states plus the Federal District are already entitled to the tax exemption law, which are Acre, Amapá, Alagoas, Bahia, Ceará, Goiás, Maranhão, Mato Grosso, Mato Grosso do Sul, Minas Gerais, Pará, Paraíba, Pernambuco, Piauí, Rio Grande do Norte, Rio Grande do Sul, Rondônia, Roraima, São Paulo, Sergipe and Tocantins. In 2015, the Distributed Generation Development Program for Energy (ProGD) (CONFAZ, 2015) was launched. It is expected that, by 2030, 2.7 million consumer units, among which are residences, businesses, industries and those belonging to the agricultural sector, will generate their own electricity, which can result in 23,500 MW of clean and renewable energy generation (MME, 2015).

3. METHODOLOGY: CASE STUDY

A model for designing a photovoltaic system for a single family dwelling to supply the electric energy demand will be carried out. The theoretical model will be compared with actual photovoltaic electricity generation data on the photovoltaic panels that have already been installed in this residence.

It is located in the city of Itajubá, Minas Gerais, Brazil, in which a single-family with four residents live. The analysis presented herein considers that the system will be interconnected to the grid, thus being composed of photovoltaic panels and an inverter. The electricity agency under consideration in this region is Energy Company of Minas Gerais (CEMIG) and has mandatory availability of at least 50kWh by considering a biphasic connection. Once knowing this value and considering, for the sake of calculation, that its average consumption is 315 kWh a month besides data on local irradiance, for example, the on-grid system was then designed.

3.1 Irradiance Data

In Brazil, solar irradiance levels are highly favorable to use a photovoltaic generation system. The lower levels of irradiance in the country are higher than in some countries where technology is already widespread, such as Germany. When sunlight enters the Earth's atmosphere, some of it is absorbed, some is spread and the rest enters without being affected by molecules in the atmosphere. Therefore, it is either absorbed or reflected by objects at ground level. Sunlight

that reaches the earth's surface without dispersion is called direct irradiance and varies greatly throughout the day due to atmospheric conditions, especially in locations with high cloudiness. Spread sunlight is called diffuse irradiance and it is the patch dispersed and attenuated by reflection in atmospheric components such as clouds, dust and water vapor, for example. The patch that is reflected from the ground is called Albedo or Reflective Power, which can be included in diffuse irradiance. When these three components are together, they become the Horizontal Global Irradiance (HGI), which is very important for photovoltaic generation because it quantifies the irradiance emitted on a horizontal flat surface. On-site Irradiance are values of solar irradiance converted from a horizontal plane to a local latitude plane, because panels must be placed at local latitude thus, for sizing purposes, one must use the irradiance values referring to the tilt angle of the local latitude itself.

Figure 6 presents data on global horizontal irradiance and on-site irradiance in the city of Itajubá. The values were obtained by the *Solar and Wind Energy Resource Assessment* (SWERA) – *OpenEI* which shows irradiance in kWh/m².day. Average irradiance throughout the year, whose value is 5.09 kWh/m², will be used for the calculations (SWERA, 2017).

3.2 Design of PV Modules

The starting point for the theoretical design model is to find out the residence demand, which in this case is 315 kWh a month, and subtract the minimum amount that CEMIG requires as availability for a residence containing a biphasic connection, i.e. 50 kWh. Thus, the design should be performed so as to supply at least 265 kWh/month of electricity.

After analyzing the cost of purchasing photovoltaic panels, their installation and availability in the market, a Maximal Power Point Tracking (MPPT) model with maximum rated power of 260 W was chosen. It was opted to use Canadian Solar™ modules due to the fact that it is the same model used in the home installation. Thus, in order to make calculations and future analyzes bearing resemblance to reality, it was used an equipment of the same brand, both with regard to the modules and the Fronius™ inverter. Other brands and models that are also available in Brazil will be presented in the results section.

Table 3 shows the technical specifications of the CS6P 260P panel required for the calculations, which have been obtained from the company's catalog (CANADIAN SOLAR).

Table 3 – Technical specifications CS6P 260P (Canadian Solar)

Brand	Canadian
Model	CS6P
Power	260 Wp
Dimensions	1.638 x 0.982 x 0.04 m
Operating Voltage (Vmp)	30.4 V
Operating Current (Imp)	8.56 A
Open Circuit Current (Voc)	37.5 V
Short Circuit Current (Isc)	9.12
Temperature Coefficient (Voc)	-0.31% / °C

Thus, one can calculate its efficiency from Eq. 1:

$$Efficiency = \frac{P_{nominal}}{1000 \; x \; module \; area} \qquad (1)$$

From the efficiency of each panel, panel area and average on-site irradiance, 5.09 kWh/m²day, one can calculate the energy produced monthly in kWh per panel, according to Eq. 2:

$$Power = Average \; radiation \; X \; Module \; area \; X \; Efficiency \qquad (2)$$

Given that demand is 315 kWh/month and the power produced by each panel is 39.702 kWh/month, it is concluded that the number of panels required would be 7.93. Therefore, 8 panels connected in series are going to be used and the total generated power by them will be 317,616 kWh/month. This value is above consumer demand.

According to data from Table 3, the maximum voltage of each panel (open circuit voltage) is 37.5 V. By considering that the 8 panels are connected in series and assuming a safety factor of 10%, the maximum voltage of the circuit is calculated from Eq. 3.

$$Voltage_{maximum} = Voltage_{panel} \; X \; Number \; of \; modules \; x \; safety \; factor \qquad (3)$$

However, this voltage may vary according to temperature conditions. In accordance with catalog specifications for the chosen panel, this variation would be -0.31%/°C. By assuming that, in the city of Itajubá, the commonly reached temperature is not lower than 0°C and, that 25° is the temperature under Standard Conditions for Temperature (STC), it can be concluded that with maximum voltage variation and by considering temperature variations, it is produced a maximum voltage of 355.57 V.

The calculations of voltage variation by temperature are presented in Equation 4.

$$Voltage_{maximum\ corrected} = \Delta T \ X \ catalog \ variatio \tag{4}$$

Equation 5 shows the calculation to obtain maximum voltage.

$$Voltage_{maximum\ corrected} = (Voltage\ variation)\ X\ Voltage_{maximum} \tag{5}$$

Therefore, a string of 8 modules of 260 W will produce maximum power of 2080 Wp, i.e. 2.08kWp with maximum voltage of 355.57 V.

It should be considered that, for a medium to large-scale facility, there can be electrical losses of 11% due to temperature conditions, 2.27% to the DC-AC conversion, 7% to dirt and shading and 2% to cabling, totaling 22.27% of electrical losses.

Thus, in order to verify the theoretical model effectiveness by considering the 8 modules and aforementioned electric losses, it is obtained Figure 7 which presents a comparison of theoretical values calculated for each month, thence with monthly irradiance and actual values obtained from the monitoring system in the residence that has a photovoltaic installation. In such a case, it has been generating electricity for 10 months, from June 2017 to March 2018. The analysis of Figure 7 shows that the theoretical model is valid in comparison with actual photovoltaic generation by the modules.

The purpose of this specific installation is to provide sufficient power so that the electricity bill paid to the local agency does not exceed the amount generated by the photovoltaic system, given that the system is well-sized and the electricity generated by the modules considering the transmission losses mainly due to cabling, together with that provided by the agency, is 315kWh/month, which is represents the peak demand of the residence.

3.3 Inverter Selection

As it was with the panels, the inverter was selected according to quality, price and availability in Brazil, in addition to respecting the project limitations.

In this case, it was chosen to use a Fronius[TM] inverter, Fronius Galvo model, 2kWp. The reason such a choice is that the string open circuit voltage does not exceed the maximum allowable voltage at the inverter input, i.e. from the calculations presented in the equations 5, it was obtained maximum string voltage of 355.58V, thus the inverter must be able to withstand this voltage and power must be equal to or greater than the maximum power rating of the set of modules.

The chosen model, therefore, is able to withstand power of up to 2kWp, frequency of 60Hz, maximum efficiency of 96% and maximum input voltage of 420V.

The inverter technical information can be observed in Tab. 4.

Table 4 – Inverter data Fronius Galvo 2.0-1

Input Data	
Max. DC power for cos φ=1	2140 W
Max. Input current	17.8 A
Short circuit current	26.8 A
MPP minimum voltage	120 V
Minimum input voltage	140 V
Nominal input voltage	260V
Max. input voltage	420 V
MPP voltage range	120 - 335 V
Number of DC connection	3
Output Data	
Nominal output	2000W
Max. output power	2000 VA
Max. output current	9.7 A
Minimum output voltage	180 V
Max. output voltage	270 V
Frequency	50/60 Hz

The Fronius inverter has a Wireless Local Area Network (WLAN) interface which allows easy monitoring of the system online. This system, very common in the inverters, allows users who have PV panels in their residence to access various items of data, e.g. on energy generation in real time, monthly reports through charts and tables that facilitate understanding, besides values of photovoltaic generation and consumption of electricity by the residence. The interface of both the website and the applications to be installed on a cellphone, for example, facilitates understanding and control by users, thus making it economically feasible to invest in such installation.

Finally, Figure 4 shows the photographs taken from the residence through which the 8 installed PV panels can be observed.

Figure 3 –Installation of the inverter and the installation of the 8 PV

4. ECONOMIC ANALYSIS

4.1 Photovoltaic system investment

For the aforementioned residence, low-voltage and biphasic connection, group B, availability of 50kWh, and electricity tariff of R$ 0.86 per kWh with tax, the total investment cost of the project was R$ 15,930.00 (US$ 5,105.76) (estimated in February, 2017, R$ 3.12 = US$ 1.00). The details of this investment are listed below:

- ✓ 08 Canadian solar panels, module 260 Wp, 60 cell multicrytalline
- ✓ Fronius inverter with 2.5 kWp of rated power
- ✓ Aluminum roofing structures for attachment
- ✓ Remote monitoring system of generation and operation of the photovoltaic system, with data storage and analysis capability, internet connection and remote data visualization
- ✓ Various electrical materials for connection, protection (string box -1 output string) in direct current, protection in alternating current, sectioning, among others for optimal system operation
- ✓ Full electrical design
- ✓ Distribution and protection board
- ✓ Monitoring of local agency
- ✓ Project documentation and registration with the agency
- ✓ ART of the project

4.2 Charging of photovoltaic electricity

In accordance with ANEEL regulations, distributed generation applied to small and microgeneration units, as it is the case of this case of this study; residence with installed photovoltaic modules that generates electricity to be credited in the same place operates as follows: one has the monthly consumption of the residence without operation of the panels, whereas one has the price of electricity produced by the panels, this difference between consumption and what could have been injected into the grid by the photovoltaic system results in credits in kWh, which are charged through the monthly energy bill.

For example, by observing Tab. 5, in February, consumption was 187 kWh, while the panels would theoretically produce about 240 kWh, thus 53 kWh were not used and will become credits that can be used in the future.

The value of 240 kWh for the month of February was obtained as follows: using Eq. (2) in which the mean irradiation was 4.95 kWh/m^2.day, the panel area and efficiency are 1.6085 m^2 and 16.16%, respectively, thereby a value of 1.287 kWh/day is obtained. It would total 38.61 kWh/month and, finally, by taking into account the 8 modules and the aforementioned losses (22.27%), it would total 240.092 kWh/month.

As it is class B, i.e. biphasic connection and low voltage, the minimum availability to be paid to the electricity agency, in the case of CEMIG, is 50 kWh, i.e. even if the consumption were less than 50 kWh, the holder must always pay the minimum amount referring to this minimum energy consumption, i.e. R$ 42.92 when considering an energy charge of R$ 0.86 per kWh.

Table 5 – Balance of consumption and energy injected into the grid

Month	Consumed [kWh]	Injected [kWh]	Difference	Accumulated credit [kWh]	Invoice Without / PV	Invoice with /PV	Economy
Jan/17	272.00	236.21	-35.79	0	R$ 233.46	R$ 42.92	R$ 190.55
Feb/17	187.00	240.09	53.09	53.09	R$ 160.51	R$ 42.92	R$ 117.59
Mar/17	339.00	238.64	-100.36	2.73	R$ 290.97	R$ 42.92	R$ 248.05
Apr/16	278.00	248.82	-29,.18	2.73	R$ 238.61	R$ 42.92	R$ 195.70
May/16	290.00	234.27	-55.73	0	R$ 248.91	R$ 45.49	R$ 203.42
Jun/16	343.00	239.61	-103.39	0	R$ 294.40	R$ 88.74	R$ 205.66
Jul/16	352.00	246.40	-105.60	0	R$ 302.13	R$ 90.64	R$ 211.49
Aug/16	306.00	276.96	-29.04	0	R$ 262.65	R$ 42.92	R$ 219.73
Sep/16	306.00	247.37	-58.63	0	R$ 262.65	R$ 50.32	R$ 212.32
Oct/16	223.00	250.28	27.28	27.28	R$ 191.40	R$ 42.92	R$ 148.49
Nov/16	316.00	250.76	-65.25	12.04	R$ 271.23	R$ 42.92	R$ 228.31
Dec/16	272.00	251.25	-20.75	0	R$ 233.46	R$ 42.92	R$ 190.55
				TOTAL	**R$ 2.990.38**	**R$ 618.52**	**R$ 2,371.85**

Then, there is the month of March, where consumption was the highest, 339 kWh, while the panels would generate only 238.64 kWh, thus about 100.36 kWh would be charged in the energy bill. However, according to Normative Resolution 687, 2015, 50 kWh of availability can be withdrawn from this amount of consumption, through which there would still be 50.36 kWh to be charged from the previous month, i.e. from 53 kWh referring to the month of February and there will still be 2.73 kWh of credit.

It should be noted that for a complete balance of the residence bill, present in Table 7, it was considered values in kWh to be injected from a theoretical calculation of monthly irradiance. In addition, for comparison purpose, the amount of the invoice to be paid was calculated if the installation of the photovoltaic system did not exist, in this case, an annual value of R$ 2,990.38 was obtained and also by considering photovoltaic electricity generation (8 panels), in which the annual value of the electricity bill would then be R$ 618.52.

4.3 Economic viability

By subtracting the difference between the electricity bill invoice without the photovoltaic panels and their use, there would be annual saving of R$ 2,371.85.

As mentioned previously, the investment value of such a venture was R$ 15,930.00 which refer to an actual case by using 100% of own funds (without any bank financing). By considering the value of annual economy that would have used the photovoltaic panels for electricity generation to supply the residence demand, i.e. R$ 2,317.85, and considering annual inflation and minimum acceptable rate of return (MAROR) of 10%, a cash flow of 23% IRR and NPV of R$ 27,194.5 is obtained. It should be noted that less than six years spent on the installation of the entire photovoltaic system would already be paid, and it is worth noting that it was considered that the electricity charge will not tend to increase, despite the fact that this charge has currently been increasing yearly, thus there would be payback in probably less than 5 years.

By considering a hypothetical case of financing, in which 50% of the investment cost would be loaned from BNDS, for example, which has a differentiated line of credit for this type of project, with an interest rate of 1.2% per month with financing of up to 48 months (RENEW ENERGIA, 2017). There would have been an IRR of 25% and NPV of R$ 26,467.2, and also about five and a half years for payment of the total investment cost of the system, thus it is still an economically viable undertaking which can be accomplished even by those who do not have their own funds and, therefore, need loans and commodities from banks.

5. CONCLUSION

The growing need to diversify the Brazilian energy sources is mainly due to the costs associated with common sources that supply the current national electricity demand, besides the environmental concern, but mainly by the impact that the

consumer economy has had. I. e. by linking an increase in energy consumption with the difficulty of common energy sources such as; hydroelectric and thermoelectric power plants, to meet these demands, the cost of kWh charges has increased, which, when passed on to consumers, has had a great impact on their budget, which has led many to start searching for alternatives.

Mini or microgeneration of modern electricity had already been disclosed by the Brazilian Electricity Regulatory Agency (ANEEL) about 5 years ago, however, it can be said that its applicability has been spread when consumers, mainly residential consumers, envisaged a solution to minimize expenses with electricity bills through on of its forms, i.e. by installing photovoltaic panels.

It is now easy to find companies that make budgets and installations of solar panels in homes or other sectors, such as industrial or commercial ones. As well as obtaining quality equipment at an affordable price, without accounting for the ease of control and monitoring of the system, as it is the case of several investors in the market, which offer weekly reports, applications and other interfaces that can be accessed remotely and allow interaction between consumers and their system, especially concerning knowledge popularization.

The residential sector is highlighted in comparison with other sectors, mainly due to encouragement rules and regulations, such as financing credit facilities, such as those provide by BNDES or ICMS (Brazilian Tax) exemption that occurs in some Brazilian states or exempted taxes on the equipment of PV solar installations. All this only tends to aid in the development of the ever-increasing implementation of mini and micro solar generation.

Information provided by ANEEL shows how the power installed in recent years, by sectors and state, has increased, thus it is noteworthy that the state of Minas Gerais, in which the study residence is located, is first in the ranking in states with the highest installed capacity. Therefore, particular emphasis should be given to it as regards micro solar generation.

Once technical and economic viability of solar photovoltaic installations is being questioned by considering many issues, many researches have been developed in order to prove the efficiency of such systems and, with this article, one has to ratify the notorious applicability in a residence since, in addition to theoretical calculations, there is still actual information about the residence in which the photovoltaic system had been installed, moreover, an economic viability study was carried out to prove that, in a few years, the return on investment will occur. A similarity is observed by comparing the theoretical model with actual generation data, thereby, this model could be a standard for future installations.

After all, the installation described herein consisted of a total investment cost of R$ 15,930.00 (US $ 5,105.57), which comprises 8 Canadian photovoltaic panels of 260Wp, a Fronius inverter with a maximum rated power of 2kWp and the entire physical structure required for its installation (cables, metal structures, supports, etc.) and system for measuring electricity generation (bidirectional meter). Starting from the investment using own funds through cash flow, it was obtained 23% IRR, and NPV of R$ 27,194.50. Thus, in about five and a half years, the cost of the installation would have been reimbursed.

There is much yet to be done with regard to propagation of knowledge on the applicability of sunlight as a source of electricity generation, but much has been done mainly by the government and industries, with the aim of, in addition to savings in their energy bills, a change of image, seeking sustainability principles. Furthermore, through research, software development and new technologies to increase panel efficiency, it will be possible to prove sunlight to be one of the sources of the national energy grid.

6. ACKNOWLEDGMENTS

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