International Conference on Renewable Energies and Power Quality (ICREPQ'18)
Salamanca (Spain), 21th to 23th March, 2018
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.16 April 2018

Economic Analysis for Brazil Residential Consumers Considering the Time-of-use Tariffs and Demand Side Management of Electricity Using HOMER PRO Energy.

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Abstract.

Between tendencies of contemporary word, it is the growth of need energy supply and the increase environmental concerns. Other advantages of energy use associated with distributed photovoltaic generation are the reduction of greenhouse gases, the reduction of demand for power generation, the reduction or the replacement of investment in generation, transmission and distribution, and the increase the availability of energy supply. If, on the one hand, renewable sources of energy, like solar, wind and biomass, it has lower environmental impact at power generation, the insertion of these sources requires investments, which should be carefully analyzed, aiming to obtain the best cost-benefit of the implanted technology. In addition, it is important to highlight the use of energy use of equipment more efficient, in other words, the possibility of a demand side management like the use of solar heating equipment. In this context, it can think about the importance of simulation technologies, which address not only economic issues, but also environmental and electrical issues. To carry out a technical-economic-environmental analysis, simulations were performed using the computational tool HOMER PRO Energy applied to residential consumers. A comparative study was conducted considering the option of "Time-of-Use Tariffs", the load profile take into account the electric shower and the use of solar heating system and a grid-connected photovoltaic system.

Key words

Solar heating system, economic analysis, photovoltaic system, Time-of-Use Tariffs, demand side management.

1. Introduction

By 2016, solar installed capacity in the world grew by approximately 50%, equivalent to 75 GW, bringing the installed world power to 303 GW, with China accounting for 40% of this.

Countries such as India, the United Arab Emirates, Mexico and Argentina record the lowest value of investment in solar energy since the beginning of technology use, registering around three cents per kWh produced [1]. And such a reduction in the price of investment of photovoltaic systems caused that the production of solar energy jumped from 19 GWh in 1990 to 21,8 TWh in 2016.

The net growth of solar energy in 2016 surpassed the growth of any other source of energy used in the world, and this growth allowed the CO_2 emission rate to remain practically null (0.2%) for the third consecutive year [1].

In Brazil, the estimate is that by 2024 the country will reach 7 GW installed, increasing, in this way, the participation of solar energy in the energy matrix from 0.02% in 2014 to around 4%[3].

This exponential increase is due to numerous factors, among them the fall in prices of the equipment that makes up a photovoltaic system and the incentives given by the government through ordinances regulating the form of compensation of the energy generated by the consumer. This growth has occurred in two directions: photovoltaic systems installed on the roofs of residential consumer units and the investment of large companies in the construction of solar plants.

Regarding residential photovoltaic systems, it is important to emphasize at the project stage that it is essential to carry out an energy diagnosis in order to identify the possibilities of reducing consumption by replacing low-cost electric charges with others that may result in the rational use of energy power.

In this context, it can be observed that among the several residential loads, the electric shower constitutes the most energy-intensive load and is used, as a rule in Brazil, in the peak hours of the national electric system.

In low-income households the electric energy consumed by the electric shower is responsible for 45% of the monthly energy bill, which shows the high potential of using solar heating systems instead of the electric shower.

Another favourable factor for the use of solar heaters is since the Brazilian territory is in the intertropical region that has a high index of solar irradiation. The average annual levels of global irradiation in Brazil are higher than in most European countries ranging from 1,500 kWh / m² to 2,500 kWh / m², and in some regions of the Brazilian territory such irradiation can reach 6,500 kWh / m² [5]. Germany is the European leader in the use of solar heater even with a temperate climate and this leadership has been reached from incentives through public policies. The German solar thermal market benefits not only from rising energy prices, but also from subsidy programs granted by the government [4].

2. Tariffs Analysis

Another strategy that must be analysed, when the dimensioning process of photovoltaic systems consists of the tariff analysis and the possibility of choosing energy billing according to tariffs established by ANEEL (National Electric Energy Agency, in Portuguese).

The fare structure for consumers supplied at a voltage below 2.3 kV is set in Group B [6]. For residential consumers, the conventional tariff is used with only one tariff point as established by subgroup B1. The tariff, in Brazil, is composed of two components: Distribution System Use Rate and Energy Tariff. The first is relative to the monthly billing of users of the distribution system through its use. The second refers to the monthly billing of energy consumption of the consumer unit. At the conventional rate the kWh price does not change during the daytime hours.

With the Brazilian energy crisis and the need for the insertion of thermoelectric plants to supply the country's energy consumption, tariff prices have increased significantly in recent years. To stimulate the efficient use of energy, ANEEL, after numerous public hearings, established a new tariff modality, denominated by White Rate. It is a tariff with three tariff posts: peak, intermediate and off-peak

Peak hours consist of a period of 3 consecutive hours, ie from 6 p.m. to 9 p.m. (outside daylight saving time), except on Saturday, Sunday, and holidays. At peak times the fare value is 1,818 times higher than the rate practiced in the off-peak hours. The intermediate period is established as being one hour earlier and one hour after peak hours, totaling two hours a day, in this period the energy value is 1,145 times higher than that practice in the off-peak hours. In the off-peak period the tariff is 78.7% lower than that practiced by the Conventional Rate.

Figure 1 illustrates the tariffs practiced by the White Tariff for the weekday period. For the period of Saturdays, Sundays and holidays, the value of the White Tariff to be charged is the same for the off-peak hours [7].

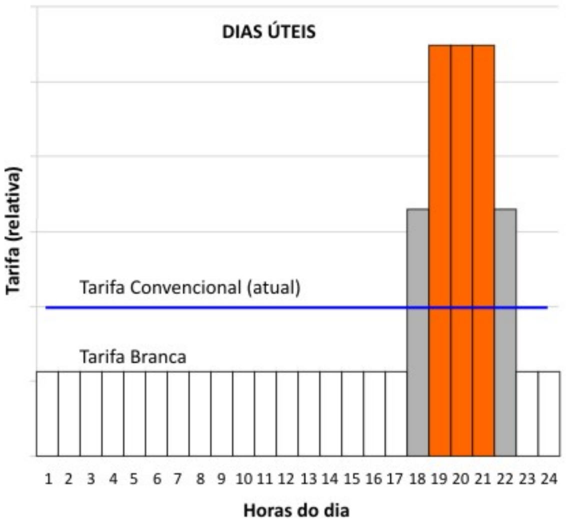

Fig.1. Comparison between conventional tariff and white tariff (Hours of the day per Relative Tariff)

The White Tariff (tariff-of-use tariff) seeks to influence the consumption habits of electric energy for low voltage consumers in Brazil. This tariff modality allows the consumer to pay different values for the energy consumed according to the time and day of the week. In this first moment the consumer can opt for this tariff modality and its effective application depends on the adequacy of the energy concessionaires with the installation of electronic meters of energy.

3. Demand Side Management

It is not enough to just carry out the option for the White Tariff to reduce the monthly electricity bill. The consumer should change their habits by shifting their consumption to times in the off-peak period. Before joining the White Tariff, it is necessary to make a study of the profile of consumption and the difference between the White and Conventional Tariffs. The greater the difference between the White and Conventional Tariffs, and the more the consumer shifts their consumption out of peak hours, the greater their benefits.

It is important to mention that before joining the Tariff White, an energy audit should be carried out to identify the electric charges used in the residential unit and verify the possibility of replacing them with more efficient ones. For consumers who use the electric shower to heat the bath water, the first alternative is the installation of a solar heating system (SHS).

An alternative to not changing the consumption profile and enjoying the benefits of the White Tariff is the use of solar thermal energy, as this would reduce the energy expenditure of the shower. Therefore, electricity concessionaires, especially at peak hours, can make better use of the energy that is no longer consumed thanks to the solar heating system.

In view of this context, this work aims to identify the most economically feasible option for the white tariff option considering several aspects: the implementation of solar heating systems in replacement of the electric shower, the installation of photovoltaic systems for generation of electricity and different tariffs.

4. Materials and methods

To meet the proposed objectives, the computer program HOMER Pro Energy was used to evaluate the technical and economic performance of electrical installations with distributed generation systems connected to the grid, considering the different tariff types, different types of generation, as well as the curve load of the consumer unit.

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Once inserted the data for installation under study, the program determines the best option from a technical and economic point of view. And with the variables inserted HOMER Pro Energy, the software determines how each simulated case can be specific considering the combination of the components with the respective powers and the strategy of operation, and such strategies dictate how the components inserted in the software work together during the period analyzed [8].

Through a complex optimization system considering the specific characteristics of each component of the electric system under study and considering the costs of the energy tariff, several operational situations can be simulated, and the results made available individually. Fig. 2 shows the system modeled in the computational program mentioned above.

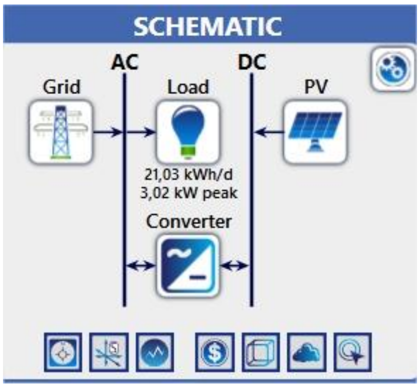

Fig. 2. Modeling System in HOMER PRO

The optimization process basically determines which, among the numerous simulations, meets the specifications entered by the user, being that the unprofitable options are discarded and the most profitable have staggered each other to obtain the case that is more attractive [8].

Eight sets were designed to carry out the studies proposed in this paper. Table I summarizes the characteristics of each case.

Table I – Simulated Cases

Cases	Characteristics
01	Conventional Tariff, with GCPS and shower
02	Conventional Tariff, with GCPS and SHS
03	Conventional Tariff, without GCPS and shower
04	Conventional Tariff, without GCPS and SHS
05	White Tariff, with GCPS and shower
06	White Tariff, with GCPS and SHS
07	White Tariff, without GCPS and shower
08	White Tariff, without GCPS and SHS

The different cases seek to obtain the best parameters for the residential consumer, for this purpose the first set to be considered was the alternative for different tariffs, the white tariff and the conventional tariff. The second scenario alternates the presence and absence of a grid-connected photovoltaic system (GCPS) aiming to measure the benefits of implementation to a residential consumer, both economically and environmentally. The third analysis is based on the replacement of the water heating of the bath by the electric shower, so common in Brazil, by a Solar Heating System (SHS), also to analyse the economic and environmental

A. Modelling in the HOMER PRO Energy system

The system under study consists of a residential consumer unit whose load curve was obtained through measurements performed over a period of seven days as shown in figure 3.

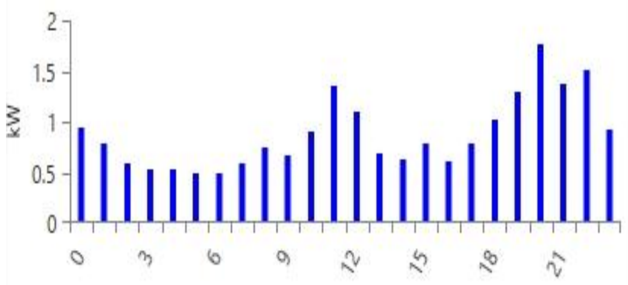

Fig. 3. Annual load curve for residence without SHS (7,675kWh/year).

It is important to emphasize that the consumer uses electric shower for the bath water heating system. For the analysis considering the same consumer unit, however, replacing the electric shower with a solar heating system, we have the load curve shown in figure 4.

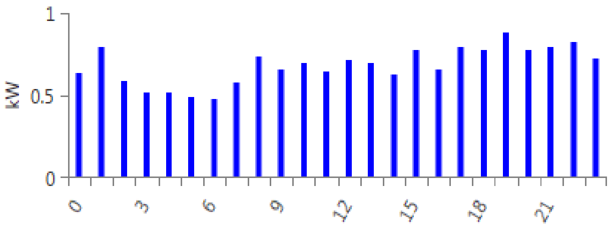

Fig. 4. Annual load curve for residence with SHS (5,978kWh/year)

The reduction of consumption with the replacement of the type of heating of the bath water was of the order of 24% considering the time in which the use of this type of load occurs.

B. Economic Analysis

The HOMER Pro program after the optimization process, classifies the results found by means of levelized cost of energy (COE). The COE [$/kWh] is the average cost per kWh consumed, whether produced by the generation system or purchased from the grid. Equation (1) presents the formulation used by the program to calculate the COE.

$$COE = \frac{C_{an\_tot}}{E} \quad (1)$$

Where:

C_{an_tot} – Total annualized cost of system [$/yr].

E – total electrical load served [kWh/yr].

The program uses several factors to calculate the total annual cost of energy, such as the base cost of kWh, various financial factors (Inflation, discount rate), among others.

To scale the capacity of the PV system is the equation (2) provides the maximum power of the photovoltaic generation system.

$$Pp = \frac{E}{DP \cdot FSH} \quad (2)$$

Where:

Pp – Peak Power [Wp]
E – Energy consumed daily [kWh/day]
DP – Dashboard Performance Rate [%]
FSH- Full sunshine hours [h/day]

For the system under tudy, the daily energy consumption is of the order of 21.03 kWh. The performance of the photovoltaic panel is equal to 0.8 and the number of hours of full sun, as [8] is 5.31 h / day, which resulted in a photovoltaic system with a peak power of approximately 5 kWp

The results of the case studies were abbreviated in acronyms, COE, IC, CO_2 mean levelized cost of energy (kWh/year), Investment Capital or Invested Capital (R$), and Carbon Dioxide Emission (Kg / year). And such acronyms are responsible for dynamizing optimized results that depend on variables such as solar radiation, solar module and converter power [10].

The economic analysis will be done in such a way that the main factor analyzed is the levelized cost of energy, since this parameter is a variable that indicates how much the kWh will decrease, on average, with the investments made in the project, that is, the investment in solar energy generates a compensatory system capable of reducing the cost of energy according to production.

Investment Capital is the other main factor capable of considering the feasibility of installing an GCPS, since cheaper systems result in a shorter time to return the investment of the project and consequently greater profit for the consumer.

On the other hand, the Carbon Dioxide Emission is presented to foment the discussion on new forms of producing energy that impact less the environment and lead humanity to a sustainable growth.

It is noteworthy that this research does not take into account the price of installing a solar heating system to replace the shower. All lower prices are valid in the Brazilian territory.

5. Result and Discussion

After performing the computer simulations, considering the cases above mentioned in Materials and Methods, is presented initially the results in the tables I and III, considering the values practiced by CELG in September 2017.

From the tables II and III the most advantageous case for the residential consumer who opted for the Conventional Rate is the case 02, with GCPS and absence of electric shower, which was able to zero the COE, presents a cost of investment of R$ 23,035 and lower CO_2 emissions.

Table II. Cases Practiced in Celg for conventional tariff

Cases	COE	IC	CO_2
01	0.136	24,035	191
02	0.004	24,035	-882
03	0.767	0	4,850
04	0.767	0	3,778

*1 euro equal 3.808 brazilian real (R$)

Considering Table II, no case with GCPS absence is practicable, because this photovoltaic system is almost able to compensate for all the electricity consumption of the simulated residence, in the case 02, to the point that practically all the energy consumed from the grid throughout the day it is returned to the grid only with the energy production of the solar modules during the hours of full sun. This would imply in an energy bill that basically charged rates of public lighting and/or taxes in general. It is noticed that the withdrawal of the shower in a consumer with GCPS beyond to reducing the average cost of energy by R$ 0,132 causes a decrease in the emission of CO_2 in the atmosphere of about 1073 kg/year.

Some tables below show a negative CO_2 emission, because due to the withdrawal of the shower, the system produces more solar energy than necessary in the residence, with that, it sells more energy to the grid, avoiding the emission of carbon dioxide in the production of energy by the power plants

Both case 01 and case 02 compare to the cases 03 and 04, respectively, take about 4.46 years to obtain a return on the investment in GCPS, with an annual rate of return of 22%.

From the COE of case 01 and case 02 it is possible to understand the real impact of an electric shower in a residence. The showers in the house studied increased the energy price by R$ 0,132 for each kWh consumed during the year.

Simulation for cases 05 to 08 are expressed in tables IV and V, which also take into consideration the prices of the White Tariff regulated by ANEEL (National Electric Energy Agency, in Portuguese) bases on the CELG-D tariff.

A From the tables, it is noted that the most advantageous case for a residential consumer who opted for the White tariff is case 06, which presents the lower CO_2 among the White tariff, an IC of R$ 24,035 and lowest CO_2 emission.

Table III. Cases Practiced in Celg for White tariff

Cases	COE	IC	CO_2
05	0.218	24,035	191
06	0.107	24,035	-882
07	0.741	0	4,850
08	0.707	0	3,778

*1 euro equal 3.808 brazilian real (R$)

Considering tables III, it is possible to note that the absence of a GCPS remains financially uninteresting to the residential consumer, because the GCPS continues to be able to reduce the COE drastically despite the different tariff system. It is noted that the withdrawal of the shower in a consumer with GCPS and white tariff in addition to reducing the average cost of energy by R$

0.034, causes the same decrease in the emission of CO_2 in the atmosphere of the previous cases, about 1073 kg/years

Both case 05 and case 0.6 with respect to cases 07 and 08, respectively, take about 5.71 years to obtain return on investment mad in GCPS, with an annual rate of return of 17%.

The comparison of cases 02 and 06, it is contemplated that the same GCPS with SHS is able to zero the COE in case 02, but it does not zero in case 06, this fact is justifiable due to the time seasonality of the white tariff. In other words, the moment the photovoltaic system produces and sells energy to the grid, it is the moment when energy is cheaper, that is, the COE does not reset because the consumer stops selling energy at R$ 0.767 in case 02 and sells at R$ 0.6036 in case 06. Such a price difference also explains why the white-rate GCPS takes 1.25 years to obtain return on investment.

The price of white tariff in cases 07 and 08 are different due to the reduction of electricity consumption to power the shower during the peak and intermediate times that raise the average price of the tariff. This price difference for different profiles feeds the discussion about energy saving possibilities for consumers who are not in their own homes during peak and intermediate times.

However, analyzing cases 03 and 07, it is observed that the COE is that for the consumption profile analyzed, the white tariff option was financially attractive to residential consumers without GCPS. This fact observed between cases 04 and 08, where the white tariff became even more attractive.

To highlight how much a micro-generation system can reduce the consumption of residence figure 5 shows the amount of energy that is purchased from the grid in the studied residence and the excess of solar energy sold to the grid.

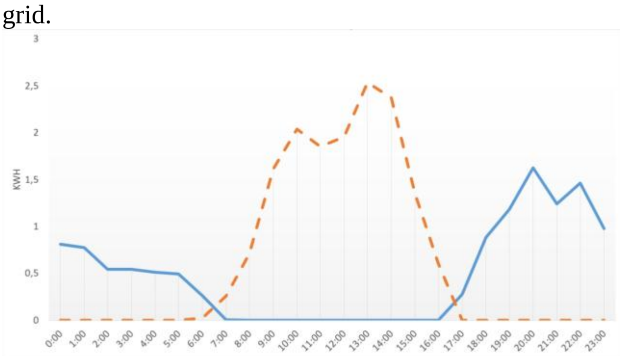

Fig. 5 – Energy purchased and sold from the grid.

The GCPS studied has a self-consumption rate of 61.2% for electric shower cases and 68.2% for SHS cases, and this value represents how much energy produced by the solar modules is destined to load. The system produces 7,540 kWh/year, it sells to grid 4,669 kWh / year, already the load demands 7,675 kWh/year and purchase of the grid 4,367 kWh/year.

Comparing cases 02 and 03 and cases 06 and 07 it is possible to note that the GCPS with SHS is able to reduce the annual emission of carbon dioxide in 5732 kg in the studied residence.

6. Conclusion

It concluded that there was a reduction of around 24% in energy consumption during peak hours, meaning a decrease in annual consumption from 7,675 kWh to 5,978 kWh, according to the studies carried out and simulated in the above-mentioned computer program. The reduction of the consumption of electric power directly reflects on the reduction of the emission of carbon dioxide.

The most favorable scenario indicated in the studies is associated with the one in which the conventional tariff practiced in the state of Goias was considered. In this condition, there are greater financial advantages with the replacement of the electric shower by the solar heater associated with the implementation of an GCPS.

It is important to emphasize that the computational simulations showed that the option for the White Rate considering the load curve of the consumer unit chosen in the studies, resulted in financial advantages over the conventional tariff for absence of a GCPS with both electric shower and solar heating system (SHS). However, in the case of white tariffs with GCPS, the conventional tariff has proved to be of interest to the consumer, since the photovoltaic system sells energy with higher price in this type of charging.

Acknowledgement

The authors wish to thank the Federal Institute of Goias (IFG) and the research group NupSOL.

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