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Analysis of the Generation of Photovoltaic Solar Energy Connected by Electricity Energy Network Using the Software *Energyplus*

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Abstract.

This article aims to analyze through computer simulation the energy sustainability and Economic Feasibility of a residence with Photovoltaic Power Generation System, using an Integrated Electricity Networks and the Software *EnergyPlus*. For this end the Physical Characteristics of the building (size, thickness and color of the wall, type of coverage, number of occupants any environment, climate conditions of the region, etc.) and Power Generation (type Plates, Cell Number, Income boards and inverter yield, etc.) are considered. The benefits of using the Integrated System for Electric Power Network, its dimensioning and improving energy sustainability of the building, are also discussed.

Key words

Solar Photovoltaic Energy; *EnergyPlus*; Software Simulation; Building modeling;

1. Introduction

Increasing consumption of electrical energy and it´s rational use have been recurring themes, considered in several national and international documents in discussions involving the limitations of energy resources, along with major environmental impacts caused by new generation projects.

Seeking to attenuate the energy sector crisis, many countries, including Brazil, have diversified their energy matrix, aiming to provide for growing demand, without losing sight of the lowest possible environmental impacts through alternative energy sources.

Among the renewable energy sources that can be installed in homes, there is the photovoltaic solar energy, where photovoltaic panels generate electricity from solar radiation, which is abundant throughout Brazil.

2. Photovoltaic Solar Energy

The photovoltaic systems are able to generate electricity through photovoltaic cells. These are made from materials that transform solar radiation directly into electric energy by means of "photovoltaic effect". Nowadays, the material most used for this is the silicon [1].

These systems can be classified into two main categories: isolated or connected to the grid. They can work as pure photovoltaic sources or associated with other energy sources, called hybrids. The figures 1 and 2 show the block diagrams for each system.

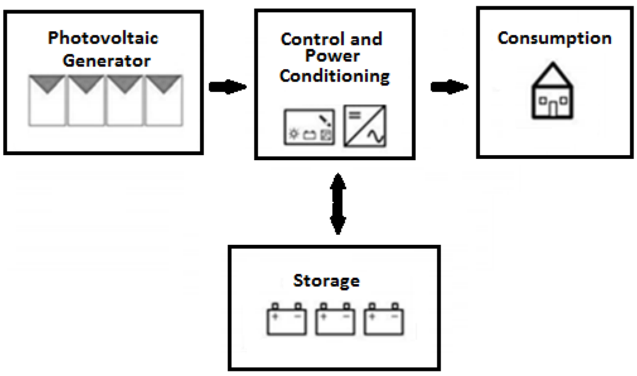

Figure 1: Photovoltaic system block diagrams: Isolated to single electrification;

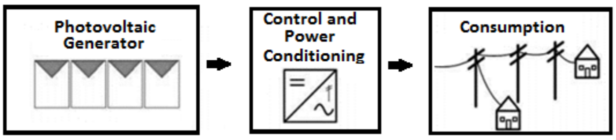

Figure 2: Photovoltaic system block diagrams: Connected to the grid.

Energy accumulators (battery banks) are needed for an isolated system in order to feed the charges at the moments there is no solar generation, while in the Connected System Network, these batteries are dismissed and the generated energy is "stored " on the grid.

The publication of Normative Resolution Nº482 of the National Electric Energy Agency (ANEEL) propitiated the connected generation into the network, April 2012, that established the general procedures for mini and micro generators connecting into the grid, also creating the power compensation system, internationally known as *net metering*, where the owner of a small renewable generator can store the produced energy surplus and use this credit for a period of 36 months [2].

3. Economic Viability of the Photovoltaic Solar Energy

Depending of factors as availability of solar radiation, performance and cost of the photovoltaic panels, the cost per kWh of installed solar energy has been decreasing. It happens because of the high incidence of solar radiation in Brazil and the equalization of the prices between the electrical energy generated by photovoltaic systems and the conventional [3].

Rising tariffs, associated with tariff flag surcharges, since when it is red flag there is an additional monthly fee to the consumer that costs R$5,50 for each 100KWh (no taxes) have made electricity more expensive, turning photovoltaic solar energy into an interesting alternative.

In a standard scenario solar energy generation is economically viable in all brazilian capitals. In an alternative scenario the economic viability is also present in most cases, even with fees increasing below inflation.

For cases that the fees increase in line with inflation, there is economic viability in most cities. Finally, in the scenarios that tariff adjustment is above inflation, there is economic viability in all capitals of Brazil.

Therefore, photovoltaic micro generation can be considered as an interesting alternative compared to traditional sources at the Brazilian electrical system, even in economic terms.

4. EnergyPlus

A computational program called *EnergyPlus* was used for the simulations, created from BLAST and DOE-2 programs, distributed for free by the Energy Department of United States of America [4].

It was developed for thermal load simulation, consumption of active electricity, estimation of active power demand, suitable tariff framework and energy analysis of buildings and their systems. Through the Plug-in OpenStudio, SketchUp, creation program of electronic models in 3D, is integrated into EnergyPlus, which enables edition and 3D visualization of the simulated building.

5. Building Modeling

Annual average daily consumption (in Wh / day) of the building is necessary for the sizing of Photovoltaic Connected Network System (SFCR) which was accomplished by *EnergyPlus* software, adopting a popular home of Residential Jamil Boutros Nadaf, located in the city of Cuiaba-MT in Brazil. This residential comprises a total of 322 houses with about 36,60m2 each, with 10 of them having been adapted for people with special needs.

Two simulations will be done, one for obtaining the estimated consumption of the building type and the other covering the appropriately size of SFCR.

For the simulation of the building consumption estimates, building characteristics were portrayed, such as their construction materials and occupation routines. The Figure 3 shows the floor plan of the building used in the simulation and its facade.

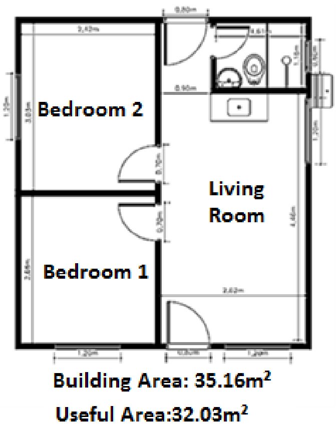

Figure 3: Floor Plan of the building.

The construction of the building is in brickwork, with walls 14 cm thick, painted in light color. The roof is made up of ceramic tiles and PVC liner. The floor has ceramic tiles and living room windows are made of glass, while the dorms are made by shutter with glass. The Figure 4 shows the construction details of the brickwork and the roof.

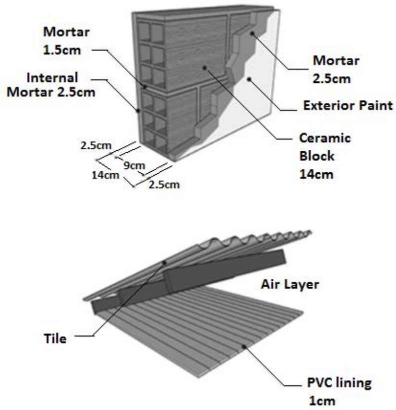

Figure 4: Constructive detail of the wall and the cover.

6. Modeling of the Building to estimate Consumption

The popular house simulation passed through several stages, among them modeling in Google SketchUp software, which through the plug-in OpenStudio, has been joined with the *EnergyPlus*. For the modeling, the house was divided into heating zones, which is the region with a volume of air where the temperature is uniform, as shown on Figure 5.

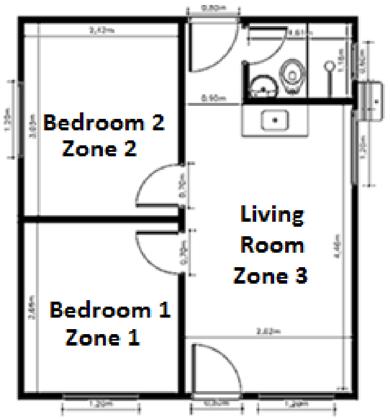

Figure 5: Thermal zones of the building.

The zones were modeled as a drop shadow object. The Figure 6 shows a 3D computer model of the popular home.

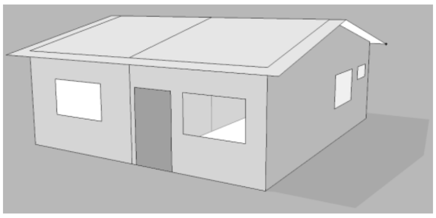

Figure 6: 3D Computer model of the building.

After the geometric modeling of the house, a file has generated with the extension .idf containing the information of the modeled surfaces of the building.

The monthly average temperature of the soil in the area where the building is located is required for the EnergyPlus to perform the simulation. EnergyPlus recommends using an auxiliary program called Slab for the calculation of temperatures [5]. The Table 1 shows the monthly average soil temperature used in the simulation, obtained from Base Simulation Technical Report for the RTQ-R.

Table I. - Monthly Average of Soil temperature used in the simulation.

MONTH	TEMPERATURE (ºC)	MONTH	TEMPERATURE (ºC)
January	26,98	July	23,64
February	26,61	August	25,20
March	26,71	September	25,87
April	25,88	October	27,26
May	25,20	November	26,82
June	24,82	December	27,14

The construction materials of the building were also registered in EnergyPlus, with thermal properties as showed in the Table 2 [6].

Table II. - Thermal characteristics of the building materials type.

MATERIAL	APPARENT BULK DENSITY (P) (KG/M^3)	THERMAL CONDUCTIVITY (Λ) (W/MK)	SPECIFIC HEAT (C) (J/KGK)	SOLAR ABSORTION(A)	THERMAL ABSORTION (E)
Grout	2100	1,15	1000	0,97	0,9
Concrete	1400	1,75	1000	-	-
PVC Liner	1400	0,19	-	-	-
Ceramic Tile	1600	0,9	920	0,8	0,95
Ceramic Brick	1600	0,9	920	0,8	0,95

During the modeling phase, partial simulations were performed to identify and correct any parameterization errors reported in the EnergyPlus simulation report, until a consistent simulation model was obtained.

Occupancy standards is interesting for simulations issues, operation of equipment and lighting operation for the simulation approaches the reality. The Regulation Quality Technician for Energy Efficiency Level Residential Buildings (RTQ-R) establishes parameters of routines that can be used in simulations to obtain the building consumption estimate and are presented in Tables 3-6 [7].

Table III. - Occupation Standard for week days and weekend.

HOUR (H)	DORMS		LIVING ROOM	
	WEEK DAYS (%)	WEEKEND (%)	WEEK DAYS (%)	WEEKEND (%)
1-7	100	100	0	0
8-9	0	100	0	0
10	0	50	0	0
11	0	0	0	25
12	0	0	0	75
13	0	0	0	0
14	0	0	25	75
15-17	0	0	25	50
18	0	0	25	25
19	0	0	100	25
20	0	0	50	50
21	50	50	50	50
22-24	100	100	0	0

Table IV - Installed power density lighting.

ENVIRONMENT	DENSITY POWER LIGHTING (W/M^2)
Dorms	5,0
Living Room	6,0

Table V - Lighting usage pattern.

HOUR (H)	DORMS		LIVING ROOM	
	WEEK DAYS (%)	WEEKEND (%)	WEEK DAYS (%)	WEEKEND (%)
1-6	0	0	0	0
7	100	0	0	0
8	0	0	0	0
9	0	100	0	0
10	0	0	0	0
11-12	0	0	0	100
14-16	0	0	0	0
17-20	0	0	100	100
21	100	100	100	100
22	100	100	0	0
23-24	0	0	0	0

Table VI. - Interior equipment loads.

ENVIRONMENT	PERIOD	POTENTIAL (W/M2)
Living Room	24h	1,5

For the dorms, an artificial air conditioning system was set in the period from 9pm to 8am, and natural ventilation in the period from 9 am to 8pm. The thermostat cooling system was set at 24 ° C.

Figure 7 shows estimated consumption of the construction. The consumption decrease on June and July coincide with the low temperature conditions period, while the consumption peak on October reflects the high temperatures.

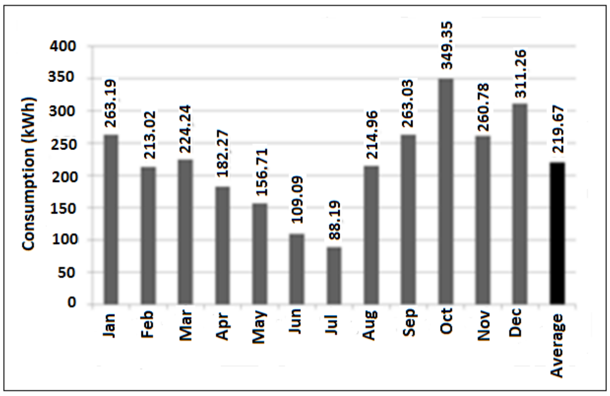

Figure 7: Consumption Expected of the building

7. Photovoltaic Connected Network System (SFCR)

The SFCR was carried out as provided by the Engineering Manual for Photovoltaic Systems.[8]

8. Full Sun Time (HSP)

This parameter shows the number of hours that the solar radiation reamins constant and equal to 1 kW / m², where the resulting energy is equivalent to the energy provided by the sun into the area concerned, totaled throughout the day. The value of HSP according to the albedo (reflection coefficient) defined for the plane at 16 ° inclined in the city of Cuiabá is during 5.5h [9].

9. Location and System Configuration

Model analysis was considered for installed signs on the roof and how the house type is located in a residential area, there is no presence of shading elements.

10. Sizing of Photovoltaic Generator

The surplus of power compensation system (net metering) of the generated energy is "stored" on the network. A meter capable of measuring the power generated and consumed. At the end of the cycle a reading is carried out of the analysis of the energy flow (energy consumed minus the energy generated). If the balance is negative, the excess energy is converted into energy credit that can be used during 36 months. If consumption is bigger than the power generated, the surplus of energy consumption is charged according to the current rate.

However, each month the availability charge will be charged to the consumer of the group B (low voltage) even if the electricity generated is greater than the energy consumed. This rate is equivalent to the consumption of 50kWh per month.

Thus, the design of the photovoltaic generator takes into account the annual daily consumption average of the building (Wh / day) minus the value of the minimum energy availability. For existing buildings, this value may be obtained by the consumption history contained in the electricity bill of the consumer. In the case of a new building, this value can be obtained through computer simulation.

The power of the micro generator that makes up the SFCR can be calculated using the formula:

$$P_{FV}\,(Wp) = \frac{E/_{TD}}{HSP_{MA}} \quad (1)$$

Such that:

- P_{FV} (Wp) = Peak power of PV panel;
- E (Wh / day) = Annual average daily consumption of the building or fraction;
- HSP_{MA} (h) = Annual daily average of HSP incident on the PV panel plan;
- TD (dimensionless) = Performance fee. For residential SFCRs, well ventilated and unshaded, can use a TD between 70% and 80%.

Estimation of consumption of the building for a typical year was possible through simulation on EnergyPlus, as shown in Figure 7.

Thus, average daily consumption of the building around the year is given by:

$$E = \frac{Annual\ Average\ Consumption\ (kWh)}{30\ days}\ x\ 1000 \quad (2)$$

Substituting values:

$$E = \frac{219{,}67\ (kWh)}{30\ days}\ x\ 1000$$

$$E = 7.322(Wh/day)$$

Thus, the power of the solar photovoltaic panel is:

$$P_{FV}\,(Wp) = \frac{7.322/_{0{,}75}}{5{,}5}$$

$$P_{FV}\,(Wp) = 1.775W$$

A. Inverter sizing for connection to the network

Keeping the idea that the inverter costs are higher than those of the photovoltaic panels seeks to optimize the use in order to the inverter does not operate for long periods at low powers and not overloaded.

The inverters Scaling Factor (FDI) represents the relationship between the AC inverter rating and the peak power of the photovoltaic generator, as shown in Equation 3.

$$FDI = \frac{P_{Nca}\,(W)}{P_{FV}\,(Wp)} \quad (3)$$

Where :
FDI (dimensionless) - The inverter scaling factor;
P_{Nca} (W) - Rated power into AC power inverter ;
P_{FV} (Wp) - Power peak of PV panel .

The *PNca* (W) with lower commercial value and closer to the peak power of the photovoltaic panel is 1.500W. Then the FDI system is given by:

$$FDI = \frac{1.500(W)}{1.775(Wp)}$$

$$FDI = 0{,}85$$

As the lower limit of FDI recommended by manufacturers and installers are in the range of 0.75 to 0.85, found FDI meets this requirement.

B. How the photovoltaic panel was chosen

The panels were chosen motivated by their high efficiency. Polycrystalline photovoltaic panel 250Wp was adopted. Six panels will be used of 250Wp, totaling 1.500Wp.

TableVII - Technical specifications and dimensions.

TECHNICAL SPECIFICATIONS	
Maximum power (Pm):	250 Watts
Tolerance:	0 / 5 Watts
Maximum power voltage (Vm):	30,4 Volts
Maximum power current (Im):	8.24 Amps
Open circuit voltage (Voc):	38.4 Volts
Short circuit current (Isc):	8.79 Amps
Maximum Voltage of the System:	1000 Volts
Panel efficiency:	15,0%
Dimensions	
Panel size:	(1650 x 990 x 40) mm
IP code of the junction box:	IP 65
Cells number and type:	60, Polycrystalline silicon
Module Weight:	19,1 kg
Glass, type and thickness:	High transmissivity, Low Iron, Tempered Glass 3.2mm

C. Modeling SFCR into EnergyPlus

The created file to obtain the estimate of consumption and demand was used for modeling the SFCR in EnergyPlus.

The file is imported into SketchUp, where it will start modeling the SFCR. A shaded surface is created on the roof to include photovoltaic panels to the model. This surface is located on the roof facing the solar north, with a 16 ° inclination for a better yield.

The size of the shading surface corresponds to the area of the six juxtaposed panels, which corresponds to 5,94m width by 1.65 m length, as illustrated in Figure 8.

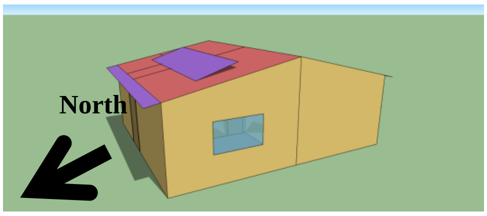

Figure 8: Computer model with the solar plate location.

The shading surface should be renamed to be easily found. The file is saved in *idf* and may be opened through the *IDF Editor* for final parameterization, which basically consists to inform the respective surface where the panels will be located, the efficiency of the panels and the inverter.

Some settings also were made in order to define the power compensation system and performed the simulation. The Figure 9 shows the comparison between the monthly consumption of the building and the energy provided by the grid.

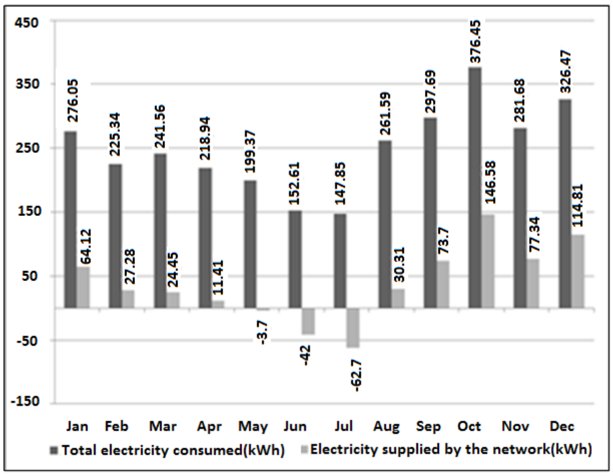

Figure 9: Electricity consumed and provided by the grid.

The Figure 9 demonstrates how much energy would be paid to the utility company (in kWh) without installing the SFCR and how much the consumer unit will pay. The Negative values represent energy credits to be offset in subsequent months. The difference between total electricity consumed and the electricity supplied by the grid is the energy generated by photovoltaic panels.

Another interesting factor is that for power consumption less than 100kWh the consumer unit is exempt of Tax on Sales and Services Circulation (ICMS), according to Law 7,098 of December 30 1998(BRAZIL).

The Figure 10 compares the annual consumption of the building with the generation of photovoltaic solar energy.

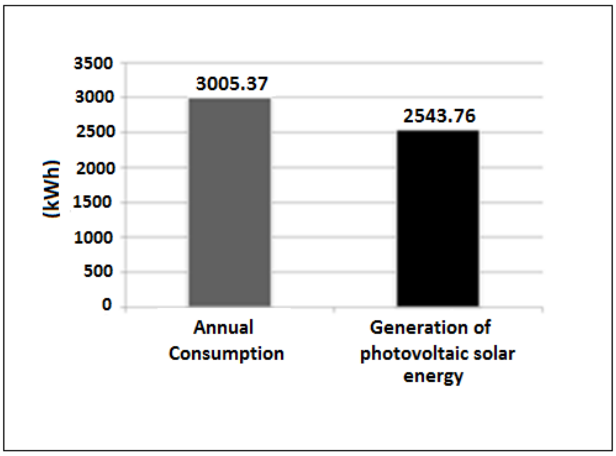

Figure 10: Annual Consumption and Annual Generation of the Photovoltaic Solar Energy.

Comparing the annual consumption of building energy and the energy generated, it can be seen that the SFCR accounts for 84% of the energy consumed of the building, bringing its energy sustainability.

11. Conclusion

Generation of photovoltaic solar energy is an interesting alternative for systems connected to the grid, as utilization of energy stores is unnecessary, and it allows the growing of the energy sustainability of the building.

The EnergyPlus is a powerful tool because it allows calculation of building consumption estimates as well as an assessment of the generation of photovoltaic solar energy.

The rising increases in electricity prices combined with lower costs of the systems have made photovoltaic solar generation more competitive.

However, the efficiency of solar panels is still low, which makes a gap for the creation of new technologies that increase yield at more affordable costs.

The dimensions of the photovoltaic system were done satisfactorily, supplying almost 85% of the energy consumed by the building in a year.

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