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Proposal of an On-Grid Photovoltaic Electric Power Generation System and Economic Viability Study: Application in Multi Family Residence

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ABSTRACT
The need to search for alternative sources of energy is increasingly evident, in this context, this work presents a solution based on renewable energy by means of photovoltaic panels for electric power supply in residence of the multi-family type.

The energy supply is obtained by the local utility that is connected to the (SIN) National Interconnected System, with a strong predominance in conventional energy sources.

The proposed photovoltaic system is grid-tie type (connected to the grid) composed by photovoltaic (PV) generator and inverter (DC / AC). Residential microgeneration has its centralized installation location, with capacity to power other consumer units using the energy compensation benefit.

The objective is to propose a solar generation system with topology favorable to the reduction of the cost of implantation when compared to the traditional individual systems presenting the technical and economic viability.

Keywords
Electricity generation, Renewable energy, Multi-family system.

1. INTRODUCTION
The residence set that is the object of research of this work has 4 consumer units entitled RES1, RES2, RES, 3 and RES4, with approximately 75 m² each unit, connected to the same owner and serviced within the same concession area of an energy distributor.

It is located in the Paraíba Valley region in the city of Porto Real, state of Rio de Janeiro, Brazil.

The families that make up this group can be considered class E. According to ABEP [1], they are classified as (lower class); Between 2 and 5 minimum wages.

Households have equipment such as: internal lighting, external lighting, refrigerators, electronic equipment, resistance heating systems, where one can cite the shower as the largest consumer.

The multi-family residence can be understood as a structure composed of a set of residences located in the same land and address, also known as multifamily. The buildings, condominiums and housing complexes can be mentioned [2].

The multi-family system is an electric power generation system designed to power multifamily structures.

The problems related to the environment are of worldwide concern and the source of photovoltaic renewable energy has gained attention as one of the possible solutions for the reduction of greenhouse gases [3].

Renewable energies are those that are obtained through natural resources like the sun, rain and wind, in which even after being used in a process, it has the capacity to regenerate, and that, when compared with the conventional ones the base Of fossil fuels has a reduced environmental impact [4].

Solar energy can be divided into thermal and photovoltaic. Thermal energy is directly associated with temperature and consists basically of the transformation of solar radiation into energy in the form of heat. Photovoltaic energy makes the direct transformation into electric energy [5].Figure 1 shows the front view of the residences.

Figure 1: Multi-Family Residence

The conventional method is one in which each residence has its own generation. The centralized sizing method using energy compensation, adopts a compact configuration where the panels are grouped, connected to a single energy reversal system.

In 2016, Brazil again faces challenges in terms of electric power generation, leading to a tariff increase with the use of the red flag, justified by the activation of thermoelectric power plants [9].

This work presents a microvolt generation proposal with a GRID TIE configuration applied to multi-family residence, which allows to supply electricity to four residences (RES 1 RES 2, RES 3 and RES 4) with a reduced installation cost when compared to traditional installations. The expected physical components are: photovoltaic panel, electric cables and inverter, which will be connected to the connection point of the local utility.

2. PROCEDIMENTOS

For a proposal of a suitable photovoltaic system, it starts with preliminary steps such as: solar resource assessment, location, configuration choice, demand survey and energy consumption [6].

The city of Porto Real is located in the southeast region of the state of Rio de Janeiro, at 385m altitude, with an area of 50.7km². Its geographic coordinates have the following data: Latitude: 22º 25 '11 "S, Longitude: 44º 17' 25" W [7].

The level of solar irradiation in the horizontal plane and in the inclined plane, in the closest locality, where the city of Resende was considered with 3.28 kWh / m in the most critical period.

As it is an urban locality, the installation area is limited, so it will be indicated the rooftop type, the closest to the distribution panel, to take advantage of existing infrastructure and material savings.

The configuration chosen will be a grid-connected system, consisting of: i) photovoltaic generator (energy source that converts light energy into electricity), ii) distribution board (responsible for energy distribution), iii) bidirectional meter with the function of measuring the energy consumed and sent to the grid), (iv) inverter (module designed to convert direct current to alternating current).

Figure 2 shows an example of grid-connected photovoltaic system connected to a distribution panel with its consumer loads.

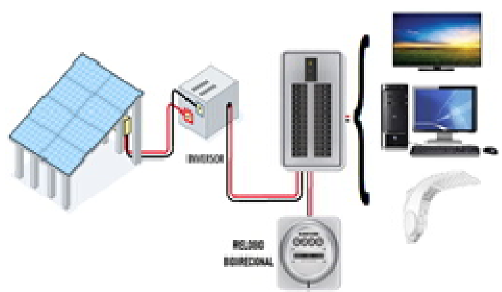

Figure 2. [8] (adapted).

In order to estimate the demand for the installation and the consumption of electric energy, the field loads were surveyed, and each equipment was connected, or it could be connected at some point to the photovoltaic system.

For a better understanding of the lifting of loads, it should be borne in mind that the basis of the design of the photovoltaic system in order to reduce the energy bill to the maximum is to generate more electricity than the limit established for consumption [6].

Table 1 shows the relation of the loads of the houses (RES1, RES2, RES, 3 and RES4) connected to the alternating current (AC) distribution board, containing the amount of each equipment, nominal individual power, and total Watts (W), the individual ampere working current (A), the individual and total consumed current in (Ah), the safety factor, and the system voltage, 24 (Vdc) continuous voltage.

The equipment (column load AC) of worksheet 1 were classified into loads with small daily consumption (household appliances), moderate daily consumption (television and computer washing machine, constant consumption (refrigerator), lighting and large daily consumption (electric shower).

Table 2 shows the 7 weekly days considered, hours of use per day, weekly consumption days, daily consumption in Wh (watt / hour), total daily consumption in Wh (watt / hour) and average consumption monthly.

For the sizing of the photovoltaic panel, the critical month will be considered, where the most unfavorable conditions occur during the period of the year.

The month of June with 3.28 kWh / m, in this case is considered the period of lowest solar irradiation, that is, the intuitive month for the design. If the proposed fixed-load isolated system works in perfect condition, it will also occur over the eleven subsequent periods and with excess energy compared to the critical month.

In order to calculate the power of the photovoltaic panel (Pm), the amount of energy consumed daily (Li) presented in table 2, hours of full sun in the plane of the panel (HSPi), considered 5 hours per day, Of modules (Red1), loss factor in the system (Red2).

The active power of the panel (Pm) can be defined by equation 1 [6].

$$Pm = \max_{i=1}^{12} (Li/HSPi \; X \; RED_1 X RED_2) \qquad (1)$$

For the analysis of the results consider initially the design of a photovoltaic system for each residence (RES1, RES2, RES, 3 and RES4) understood as a traditional individual system. This first scenario each household has its own generation.

In the second scenario it is considered a centralized system, where for the purpose of calculation the loads of the residences are unified, that is, it is understood as a single charge connected to photovoltaic microgeneration.

In order to evaluate and compare the traditional individual photovoltaic system and the proposed multi-family centralized system, it measures both systems and compares itself in technical terms such as: installed power, number of solar panels used and mainly the design efficiency in the reduction of materials and service.

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Table 1: Loads, power and individual / total current of residences 1, 2, 3 and 4

Casa 1- Potência e Corrente Individual					
Tensão do Sistema 24V					
Cargas AC	Quantidade	Potencia(w)	Potencia Total	Corrente(A)	Corrente (Ah)
Eletrodomésticos	3	200	600	1,57	3,37
Computador	1	200	200	1,96	1,68
Televisão	1	220	220	1,73	1,48
Chuveiro	2	5200	10400	40,9	40,90
Geladeira	1	300	300	2,36	16,52
Máq.Lavar	1	1000	1000	7,8	1,11
Lâmpada	7	15	105	0,2	0,70
Total	16		12825	56,52	65,77
	DSS	2	ator de seguranç	1,2	157,85

Casa 2- Potência e Corrente Individual					
Tensão do Sistema 24V					
Cargas AC	Quantidade	Potencia(w)	Potencia Total	Corrente(A)	Corrente (Ah)
Computador	1	200	200	1,96	3,36
Eletrodomésticos	4	300	300	2,36	8,10
Televisão	2	220	440	3,46	13,86
Chuveiro	1	5200	5200	40,9	32,76
Geladeira	1	300	300	2,36	16,52
Máq.Lavar	1	1000	1000	7,8	3,34
Lâmpada	8	15	120	0,20	0,80
Total	18		7560	59,09	78,74
	DSS	2	Fator de segurança	1,2	188,97

Casa 3- Potência e Corrente Individual					
Tensão do Sistema 24V					
Cargas AC	Quantidade	Potencia(w)	Potencia Total	Corrente(A)	Corrente (Ah)
Computador	1	250	250	1,96	1,96
Eletrodomésticos	1	300	300	2,36	1,18
Televisão	2	220	440	1,73	10,38
Chuveiro	2	5200	10400	40,9	40,90
Geladeira	1	300	300	2,36	16,52
Máq.Lavar	1	1000	1000	7,8	4,46
Lâmpada	7	15	105	0,20	1,40
Total	15	7285	12795	57,31	76,80
	DSS	2	Fator de segurança	1,2	184,32

Casa 4- Potência e Corrente Individual					
Tensão do Sistema 24V					
Cargas AC	Quantidade	Potencia(w)	Potencia Total	Corrente(A)	Corrente (Ah)
Computador	2	200	400	3,149606	9,00
Eletrodomésticos	3	300	900	2,36	2,53
Televisão	1	220	220	1,73	6,93
Chuveiro	1	5200	5200	40,9	40,94
Geladeira	1	300	300	2,36	16,52
Máq.Lavar	1	1000	1000	7,8	5,57
Ar condicionado	0	1500	0	0,00	0,00
Lâmpada	10	15	150	0,20	6,00
		Total			
	DSS	2	Fator de segurança	1,2	209,99

Table 2: Current and daily consumption of residences 1, 2, 3 and 4

Casa 1			
Hora/dia	Dia/semana	Consumo diário (Wh)	mês
1	5	429	
1	6	171	
1	6	189	
0,5	7	5200	
7	7	2100	
1	1	143	
0,5	7	52,5	
Total		8284	
Total kWh		8,28	249

Casa 2			
Hora/dia	Dia/semana	Consumo diário (Wh)	mês
2	6	343	
1	6	257,1428571	
2	7	880	
0,8	7	4160	
7	7	2100	
1	3	429	
0,5	7	60	
Total		8229	
Total kWh		8,23	247

Casa 3			
Hora/dia	Dia/semana	Consumo diário (Wh)	mês
1	7	250	
0,5	7	150	
3	7	1320	
0,5	7	5200	
7	7	2100	
4	1	571	
1	7	105	
Total Wh		9696	
Total kWh		9,70	291

Casa 4			
Hora/dia	Dia/semana	Consumo diário (Wh)	mês
2	5	571	
0,5	5	321,4285714	
4	7	880	
1	7	5200	
7	7	2100	
5	1	714	
4	5	0	
3		450	
Total Wh		10237,14	
Total kWh		10,24	307

3. INDIVIDUAL TRADITIONAL PHOTOVOLTAIC SYSTEM

According to the values of efficiency of the inverters and values of total daily consumption of table 2, it is considered 8.28kW for house 1 (Li), 8.23kW for house 2 (Li), 9.70kW for house 3 (Li), 11.24 kW for house 4 (Li), 5 hours of peak solar irradiance, recommended values of (Red 1) of 0.75 and (Red 2) of 0.9 for all households. These values are a factor of reduction of the power of the modules and factor of reduction of the power due to losses in the system like wiring and diode. The active power (Pm) found according to equation 1:

- House 1: 2454 W
- House 2: 2438 W
- House 3: 2873 W
- House 4: 3033 W

The current with maximum power of 8.36 A and load capacity per module of 40.25Ah / day as reported by the manufacturer.

The module to meet the calculated power will be 250W, 24V with dimensions of 99cm x 164cm x 3.5cm.

The ratio of the working voltage (Vsist) 24VDC and the maximum power voltage over high temperatures (VmaxTmax), defines the number of modules in series. As the value found considering the charging voltage 20% above the nominal working voltage, is less than 1, the system will have only 1 module in series.

The ratio of the working current to the minimum current at maximum power defines the number of panels in parallel series, reported in Table 3.

Table 3: Number of panels per residence

Painel fotovoltaico Casa 1	
Corrente Máxima	8,36
Capacidade de carga	41,8
Corrente gerada pelo painel	102
Número de painel	4
Painel fotovoltaico Casa 2	
Corrente Máxima	8,36
Capacidade de carga	40,25
Corrente gerada pelo painel	102
Número de painel	5
Painel fotovoltaico Casa 3	
Corrente Máxima	8,36
Capacidade de carga	40,25
Corrente gerada pelo painel	120
Número de painel	5
Painel fotovoltaico Casa 4	
Corrente Máxima	8,36
Capacidade de carga	40,25
Corrente gerada pelo painel	126
Número de painel	6

The design of the inverter is based on the minimum power of the generator with an increase in the safety factor of 15%.

The minimum power of each inverter are:

- House 1: 3000 W
- House 2: 3000 W
- House 3: 4000 W
- House 4: 4000 W

4. PLURIFAMILIAR CENTRALIZED PHOTOVOLTAIC SYSTEM

In scenario 2, we add the consumption values of each daily residence of table 2, we consider 12,418.66W (Li), 5 hours of solar radiation peak, recommended values of (Red 1) of 0.75 e (Red 2) of 0.9 for all households. As the power is considered as single charge, a panel of 325 (wP) with current value could be used with a maximum power of 9.05 A. The active power (Pm) found according to equation 1:

- Power of multi-family microgeneration: 10798,84 W

The module to meet the calculated power will be 325wP, 24V with dimensions of 99cm x 195cm x 4.5cm.

The number of panels in parallel is defined as in scenario 1 and presented in table 4.

Table 4: Number of panels for proposed multi-family microgeneration

Painel fotovoltaico Microgeração	
Corrente Máxima	9,05
Capacidade de carga	45,25
Corrente gerada pelo painel	450
Corrente total	308,8012
Fator de segurança	1,2
Corrente total painel	539,9418
Número de painel	17

The inverter sizing is carried out with global values adopted in the calculations of the photovoltaic panels with an increase in the safety factor of 15%.

- Micropower inverter power: 12,418.66W

The residences of approximately 75m2 have a length of 10 meters and gable roof with approximately 4 meters wide each, allowing the installation of up to 9 panels in each one.

The design contemplates the installation of the 17 photovoltaic panels resulting from table 4 in two units, (RES 1 and RES 2), 9 in the first and 8 in the second.

As the residences belong to the same owner and are in the same concession area. Residences 3 and 4 (RES3, RES4) will benefit from the electricity compensation system.

The surplus energy generated by the microgenerator consuming unit in the case of the RES 1 and RES 2 study is injected into the distribution network, which will function as an accumulator. This surplus energy returns to the owner by means of energy credit (kWh) to be used to reduce consumption at another tariff point corresponding to RES 3 and 4. The energy credits generated are still valid for 60 months.

5. PLURIFAMILIAR CENTRALIZED PHOTOVOLTAIC ARCHITECTURE

The architecture shown in figure 3 consists of 6 blocks. Block 1, called photovoltaic microgeneration, represents the installation of the multi-family solar system, block 2 (REDE), represents the

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utility and the connection point, blocks 3, 4, 5 and 6 illustrate the consumer loads of the respective homes.

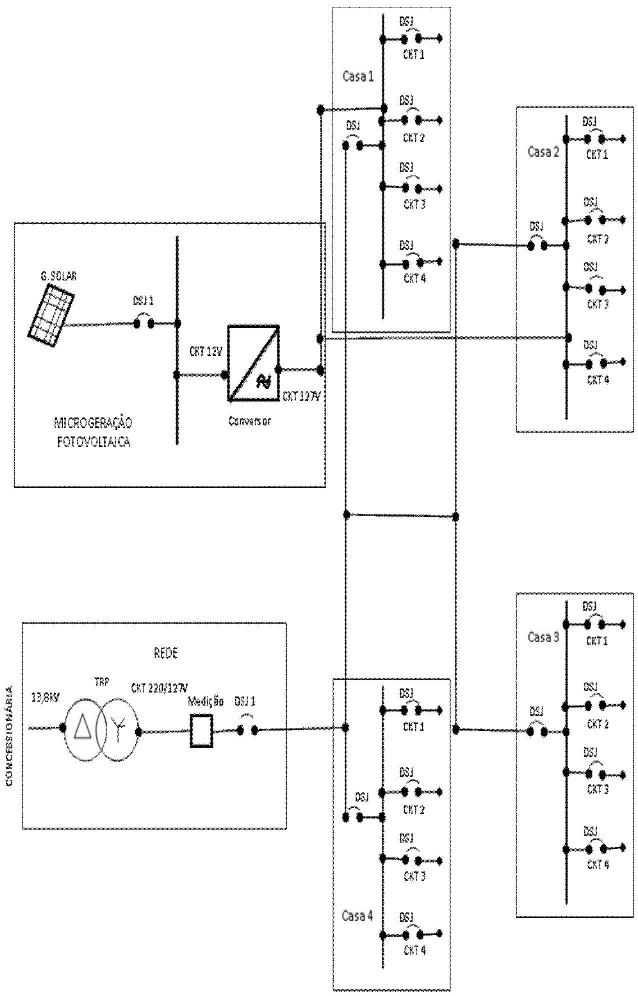

Figure 3: Proposed Architecture

6. TECHNICAL ANALYSIS AND ECONOMICAL FEASIBILITY

In relation to the technical feasibility analysis, there was a reduction in the number of panels and consequently a reduction of materials such as connectors and cables reflecting in the installation time and cost.

Another interesting factor worth mentioning is the contribution in the generation, transmission and distribution system, allowing the postponement of investments in expansion.

The reduction of greenhouse gas emissions, since the proposal uses renewable sources.

The reduction of the impacts caused by the increase of the energy tariff, especially when the red flag is activated.

For economic feasibility analysis, a prior budget of residential panels and inverters, panels and microgeneration inverter is required. The consumption of electric energy and the cost of energy, in this case was considered the year of 2017, with average cost per kWh consumed of R $ 0.74. Each residence will have an annual savings of: RES 1, R $ 2,206.8, RES 2, R $ 2,192.1, RES 3, R $ 2583.1 and RES 4, R $ 2,727.2.

6.1 Budget Photovoltaic System (RES 1, RES 2, RES 3, RES 4 and Microgeneration).

Table 5 shows the values for acquisition of the individual residential system and the multi-family microgeneration system.

Table 5: Budget

Orçamento Projeto fotovoltaico RES1, RES2, RES3 e RES4			
Paineis	Valor Unitario	Quantidade	Total
Painel fotovoltaico casa 1	R$ 1.139,90	4	R$ 4.559,60
Painel fotovoltaico casa 2	R$ 1.139,90	5	R$ 5.699,50
Painel fotovoltaico casa 3	R$ 1.139,90	5	R$ 5.699,50
Painel fotovoltaico casa 4	R$ 1.139,90	6	R$ 6.839,40
Inversor casa 1	R$ 6.502,50	1	R$ 6.502,50
Inversor casa 2	R$ 5.095,00	1	R$ 5.095,00
Inversor casa 3	R$ 5.095,00	1	R$ 5.095,00
Inversor casa 4	R$ 6.502,50	1	R$ 6.502,50
Miscelâneas	5%	1	R$ 2.299,65
Serviço	10%	1	R$ 4.599,30
Total			R$ 52.891,95
Orçamento Projeto Microgeração fotovoltaica plurifamiliar			
Painel Microgeração	R$ 1.490,90	17	R$ 25.345,30
Inv Microgeração	R$ 8.000,00	1	R$ 9.550,00
Miscelâneas	5%	1	R$ 1.744,77
Serviço	10%	1	R$ 3.489,53
Total			R$ 40.129,60

According to the values of the projects in worksheet 5, the choice of centralized photovoltaic configuration of the multi-family type, when compared to the traditional configuration used in the market, generates a reduction in the implementation cost of 24.13%.

The amortization time of the investment will be realized by the calculation of (PRS), simple return period, dividing the purchase value of the proposed system and the amount that will be saved over the years.

The cost of availability is added in the calculations, which in the case of residences with a two-phase profile is R $ 1065.6 / year, considering 30kWh / month at R $ 0.74.

The traditional individual configuration results in a recovery of approximately 6.2 years, when compared to the 4.6 years of the unified multi-family system.

Configuration using power credits can reduce turnaround time by approximately 1.4 years.

Networked systems have a service life of 30 to 40 years [4].

Initially the amortization result found is higher than the market accepted, but the tariff increases contributed to reduce this return compared to previous work.

7. CONCLUSION

The generation of energy by solar system presents a challenge in technological terms, but the values of the panels already are in slope, leaving the system more competitive in the market when compared with the conventional sources of energy.

The proposal meets the estimated loads, leaving only the value of the contribution with the lighting system and cost of availability in the value of the electricity bill.

The multi-family GRID-TIE photovoltaic system shows a considerable depreciation, but when compared to the traditional ones it is more attractive in the technical / commercial view.

Photovoltaic systems go beyond energy savings, it is considered as an inexhaustible source that contributes mainly to the reduction of greenhouse gases.

REFERENCES

[1] BEP, Brazilian Association of Research Companies. Criterion Brazil 2015 and update of class distribution for 2016. Available at: http://www.abep.org/criterio-brasil. Accessed on 16 May 2017.

[2] Brazil. Complementary law (2004). It provides for the consolidation of legislation that governs the zoning of urban land use and provides other measures. São Paulo, SP: State of 2007.

[3] F Dinçer.The analysis on photovoltaic electricity generation, potential and policies of the leading countries in solar energy.RenewableandSustainable Energy Reviews 15 (2011), 713-720.

[4] Neosolar, Renewable energies or alternative energies. Available at: http://www.neosolar.com.br/aprenda/saiba-mais/energias-renovaveis-ou-energias-alternativas. Accessed on 05/16/2015.

[5] Cresesb, Tutorial of photovoltaic solar energy. Available at: http://www.cresesb.cepel.br/index.php?section=com_content&cid=tutorial_solar. Access on 05/05/2015

[6] Cresesb - Reference Center for Solar and Wind Energy Sérgio de Salvo Brito. Engineering manual for photovoltaic systems. Updated and updated. Rio de Janeiro, 2014, 529p.

[7] Geography. Brazilian municipality located in the southeastern region of Brazil. Available at http://www.geografos.com.br/cidades-rio-de-janeiro/porto-real.php. Accessed on 1/05/2017.

[8] Connected photovoltaic system Available at http://sasfotovoltaico.com.br/index.php/energia-fotovoltaica/. Accessed on 4/3/2017.

[9] https://www.canalenergia.com.br/

