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Low Voltage Tariffs in the Context of Decentralized on Grid Photovoltaic Generation

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HIGHLIGHTS

- Business model for electrical energy distribution utilities.
- Distributed photovoltaic generation impacts in current Brazilian tariffs.
- Binomial tariffs for Brazilian costumers at low voltage.

Abstract: Distributed photovoltaic generation (DPVG) has become a worldwide trend and is experiencing great growth in Brazil, although at a later rate than most of the more developed countries. Brazil has an incentive tariff for distributed electricity generation based on a compensation system, i.e. net metering, therefore DPVG is becoming increasingly popular for low voltage consumers. However, the business model of Brazilian electrical energy distribution utilities is primarily a function of the trade and distribution of energy in addition to the maintenance and expansion of the distribution grid. The objective of this study was to evaluate the business model of electric power distribution utilities and to propose possible improvements in order to make it more robust and maintain the viability of electric distribution utilities, in a context of increased utilization of distributed energy resources. Data and tariff compositions from a Brazilian distribution utility at low voltage were studied. Considering different consumptions possibilities, the annual tariff costs for different types of consumers were simulated, the percentages of tariff reduction for the consumers and for the utilities, if these consumers opted for DPVG. Finally, based on tariff proposals for other countries, a tariff was proposed. With the proposed binomial tariff, which includes charging demand and energy consumption, there was greater attractiveness for smaller consumers to adopt DPVG and reduced bills for consumers with less demand, making the system fairer and more balanced.

Keywords: decentralized energy resources; electricity tariffs; electricity sector; externalities.

INTRODUCTION

Distributed generation, using photovoltaic technology (PV), has become a worldwide trend and has been applied on a large scale, mainly in the more developed countries [1]. Among the factors that enabled the expansion of distributed photovoltaic generation (DPVG), we can mention significant electricity costs, the need to reduce greenhouse gas emissions, increasing demand for electricity and high fossil fuel costs [2].

In 2018, the installed capacity of PV systems in the world increased by around 100 GWp, representing 55%, of the total installed renewable energy sources built in that year. Projections indicate that in 2030 the capacity of PV systems is close to six times that recorded in 2018 [3]. Such an expansion of PV systems has brought challenges to the electricity sector since the 1990s, when the traditional centralized generation system started to give way to new distributed generation systems (DG) [4].

The insertion of DG in the electrical system provided a new relational structure between consumers and electrical distribution utilities. Under the power system with increased decentralized energy resources, the flow of power became bidirectional. This paradigm shift can also be considered as one of the external effects or impacts related to the use and implementation of PV technology, to these external impacts is attributed the term externality.

This externality introduced additional challenges in the management and control of energy distribution systems. Thus, new tariff models were needed in order to guarantee the maintenance of the electrical energy sector, since the contribution paid for maintenance of the electricity distribution service is, in general, a small portion in most tariffs in force in 2020 [5].

The DG imposes an increasing dissociation between the flow of electricity and money since the traditional tariff model generally provides for remuneration for consumption [4]. In the new model, the flow of electricity could be in both ways, and then the tariff must differentiate the energy flow direction. With distributed generation growing significantly, several countries have adopted new tariff models, always based on, basically, two priorities: maintaining the viability of the activities of electric energy distribution utilities and attracting investments in DG, especially in renewable ones, such as PV.

DPVG's worldwide regulatory models, mainly in Europe, were drivers of technology through direct incentives for the acquisition of equipment or at premium rates. Both aimed to increase the attractiveness of PV systems. The incentives were mostly capital, tax, credit improvement, soft loans and public funds [6]. Among the tariffs, we can mention feed in tariffs (FIT) or Renewable Portfolio Standard (RPS). Those of the FIT type are based on price regulation while those of the RPS type force a greater generation of electric energy through renewable technologies, requiring a minimum percentage of these [7].

FIT premium rates have proven to be one of the most effective ways to ensure the development of PV technology. Such tariff provides greater viability to the consumer, since the electric power utility is obliged to purchase electricity in its concession area, at a tariff determined by the government and for a specified period [6]. As a result, such tariffs contribute significantly to the development of DG through PV technology.

Brazil, unlike many developed countries, has a predominantly renewable electrical matrix. Among the sources of generation that contribute to this achievement, we can mention the large hydroelectric plants. In the last 10 years, the share of renewable sources increased from 43.6% to 48.4% [8]. The growth trend was only observed from 2014 onwards, which can be attributed mainly to the results of programs to encourage alternative sources of electricity, such as small hydroelectric, wind and biomass thermoelectric projects, were encouraged through the Program of Incentive to Renewable Energy Sources [9].

In Brazil, distributed PV generation was regulated late, in 2012 only, through normative resolution 482, issued by the Brazilian Regulatory Agency. The resolution established an electric energy compensation system, known as net metering, which defined the general conditions for DG access to electricity distribution systems under two modalities, micro generation less than 100 kW and mini-generation greater than 100 kW and less than 1 MW [10].

Until 2017, the regulation of distributed generation in Brazil was modified through new normative resolutions 687 and 786 issued in 2015 and 2017, respectively. With the new regulations, micro generation was limited to 75 kW while the mini generation for powers defined as greater than 75 kW and limited to 5 MW, for PV DG. The energy compensation system introduced credits to be used in up to 60 months, in case of surplus electricity generated by the DG systems, then the consumed locally, in a given period of time.

However, normative resolutions do not allow the consumer to stop paying electricity bills, even if the generation is equal to or exceeds the consumption itself. Resolution 687 established that at least the cost of availability for the group B consumer or the contracted demand for group A consumers must be billed [11]. However, for group B consumers, consumption can be much higher than the minimum consumption related to the availability cost. Group B consumers are those served at low voltage, such as residential consumers. Group A consumers are served at medium or high voltage, like large companies [12].

The discussion of new tariff models for DPVG in Brazil has become a priority, given the exponential growth of DG since its regulation in 2012. In Brazil, between 2019 and 2020, there was an increase of 70% in PV sources [8].

Along these lines, the National Electric Energy Agency (ANEEL) is considering revising the DG regulations again. The proposed amendments are in the public consultation stage and should be finalized by 2020. The new proposal for DG proposes the change to the current rule, in which group B consumers can offset the energy consumed by the energy injected into the electrical system, provided the availability bill is maintained. This new proposal aims, according to the regulatory agency, to balance the rule, so that the costs related to the use of the distribution grid and its respective charges are paid by consumers with distributed generation [13]. Despite current regulations being in constant progress, it is important to consider that new changes are expected, which may result in further regulation actualization.

The regulation of DG, although recent, already presents challenges, given the pace of accelerated growth of this technology in Brazil. The DPVG growth projections according to the electrical energy distribution utility, CEMIG-D data indicates that the need for restructuring the electrical system must be taken as a priority. Figure 1 shows the growth projections for the micro and mini-generation distributed PV, referring to the period from 2018 to 2035 in Minas Gerais [14].

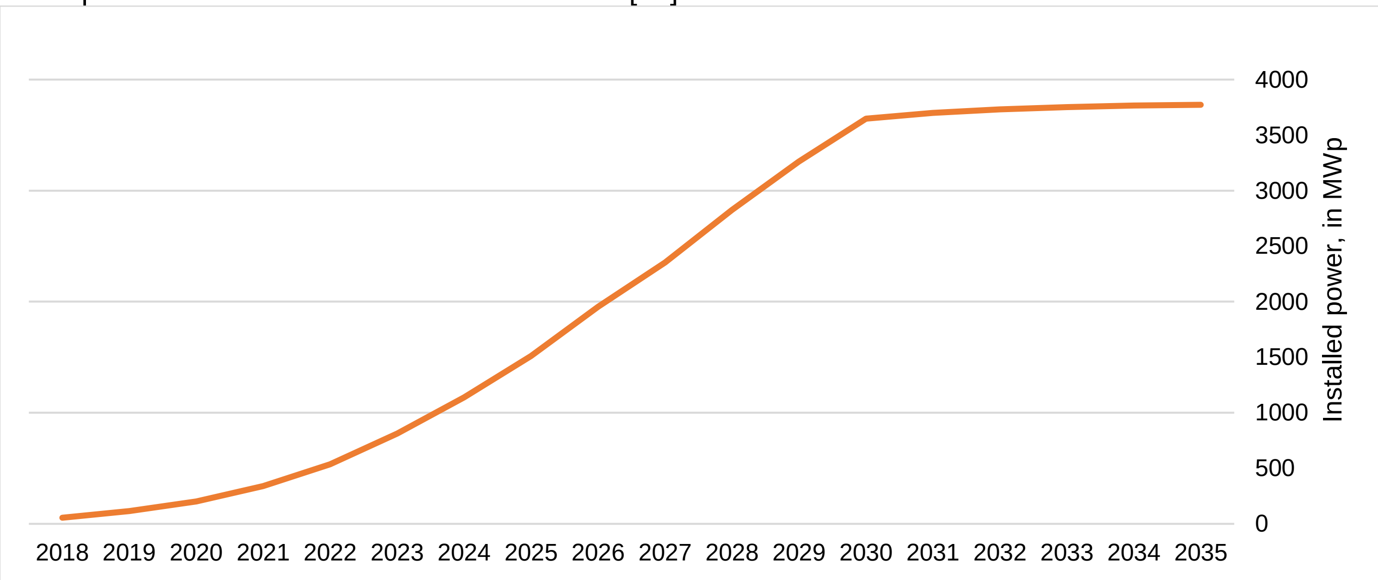

Figure 1. Projection of growth of distributed photovoltaic micro and mini-generation for low voltage consumers of the distribution utility, CEMIG D in Minas Gerais, in relation to 2018. Source: [14].

Figure 1 shows the growth of insertion of DPVG, where the first 1000 MWp will be reached around 5 years after 2018 and the 2000 MWp after an extra 2 year, i. e. around 2025. The data was provided by the CEMIG-D distribution utility, however, the reality of other utilities in Brazil does not differ, since Brazil regulates the same tariff structure for all distribution utilities. Other countries, especially the more developed ones, already have higher insertion percentages of PV than Brazil and, for this reason, they are studying changes in the sector, mainly with regard to regulations in general and to new tariff models [15].

Based on the growth prospects for the implementation of distributed generation and the need for continuity of services provided by the electricity sector, the intention is to evaluate the current model and provide inputs for the conception of a new business model that is viable for the electricity distribution utilities. Thus, the objective was to evaluate a possible change in the business model of the electricity distribution utility in the context of a much greater participation of decentralized photovoltaic generation.

MATERIAL AND METHODS

This research was carried out at the Energy Laboratory of the Agricultural Engineering Department of the Federal University of Viçosa, Viçosa, Minas Gerais State, Brazil. To prepare the results, the data made available by the Brazilian Electrical Energy Agency, ANEEL and relevant international scientific literature were used. Data relating to the electricity distribution utility Cemig Distribution (CEMIG-D) was used. The company in question has the largest network in Brazil [14]. The data obtained were analyzed using Microsoft Excel software.

Distributed photovoltaic generation under the tariffs in force in 2020

The effects of the insertion of DPVG, specifically for low-voltage consumers, classified as group B, were evaluated. In order to enable the assessment of the current business model between electricity distributors and consumers, initially, the tariffs in force in 2020were considered. Two types of tariffs were studied: (i) B2, for rural consumers, classified as subgroup B2 by ANEEL and (ii) B1 and B3, which include residential, industrial, commercial and other consumers, respectively classified as subgroup B1 and B3 by ANEEL [12].

Table 1 shows the data used for the tariffs applied by CEMIG-D in Minas Gerais State for the two types of consumers under study. The plain tariff rates of 2019 were used, without taxes or incentives, as these are independent of DG [12].

Table 1. Electrical energy tariffs of distribution utility CEMIG-D applied to low voltage consumers without taxes.

Consumer	Type of connection	Cost per kWh (US$/kWh)*	Minimum tariff (kWh/month)	Cost of minimum tariff (US$/month)
	Single phase	0.12339	30	3.70
B2	Two-phase	0.12339	50	6.17
	Three-phase	0.12339	100	12.34
	Single phase	0.16236	30	4.87
B1 and B3	Two-phase	0.16236	50	8.12
	Three-phase	0.16236	100	16.25

*The quotation of 1 US dollar was used for 3.87 BR$, on October, 2018 - Source: [12].

The value of the minimum tariff must be paid regardless of consumption, if consumption exceeds the minimum value, it will be charged by multiplying consumption by the value of kWh, as shown in Table 01.

The tariff applied to consumers, seen in Table 1, can be roughly subdivided between different groups [12]. The different percentages that make up the tariff structure for consumers classified as belonging to group B were also evaluated, as shown in Table 2. The tariff composition was used to estimate the percentages of revenue by the distribution utility.

Table 2. Composition of electrical energy tariffs for low voltage consumers, excluding taxes

Use of resources	Portion (%)
Charges	8.29
Transmission	6.48
Distribution	31.52
Losses	7.39
Energy	46.31

Source: [16]

To assess the effects of DG on the distribution utility market, different possibilities were considered for consumers of types B2 and also B1 and B3, with the types of connection: single-phase, two-phase and three-phase, with monthly consumption of: 30, 50, 100, 220, 350, 500 and 1000 kWh / month. Those figures represent, somehow, the monthly electricity consumption for dwellings of different economic classes in Brazil.

It was considered three possibilities that these consumers can be:

(i) without DG, that is, those who do not have DPVG;

(ii) self-sufficient consumer, i.e. with DPVG equal to consumption; and

(iii) consumer with partial generation i. e. consuming from the utility only the minimum that refers to the availability costs and complementing energy supply through their own DPVG.

For each of the possibilities described, annual electricity costs were estimated. These estimates allow us to understand, according to the current DPVG tariff regulations, how the revenue variation occurs for electricity distribution utilities. For this, the portion of the amount to be paid by consumers was estimated by the distribution company, for the different possibilities mentioned above.

New tariff model for low voltage consumers

In section Distributed photovoltaic generation under the tariffs in force in 2020 , the tariffs in force in 2020 model for consumers supplied with low voltage was considered, however, the current model adopts availability cost regardless of the consumer demand. The non charging of the consumer's demand is considered to be a limitation, another possibility for the cost of availability was evaluated based on different studies, mainly those aimed at countries with greater insertion of DPVG [15,17].

Based on international models and on the Brazilian tariff model for consumers powered by voltage levels, i.e. between 13.8 to 34.5 kV, a new tariff model was proposed. This was proposed considering the need to maintain the viability of distribution utilities and the criteria that may be fairer to consumers of electricity.

New tariff application

Based on the previous theoretical proposition, section New tariff model for low voltage consumers, the bill estimates for annual electricity bills for consumers of types B2 and also B1 and B3, without their own DPVG, were reworked. Connection types were considered: single-phase, two-phase and three-phase, with consumption of: 30, 50, 100, 220, 350, 500 and 1000 kWh / month.

Such estimates of annual tariff values have been redone considering that the average amount paid by consumers were unchanged. For this purpose, the simple arithmetic average of the amounts paid to consumers B2 and for B1 and B3 was calculated, considering the different types of connection and consumption for the current Brazilian tariff model. The value provided is the average paid by each of these two groups of consumers. Thus, the consumption tariffs proposed in the new model were readjusted in order to maintain the same average tariff value as the current model.

RESULTS

Distributed photovoltaic generation with the tariffs in force in 2020

The application of CEMIG tariffs in force in 2019 for consumer groups B2 and for B1 and B3, are shown in Table 3, for the consumption of 30, 50, 100, 220, 350, 500 and 1000 kWh / month. Consumers with and without DPVG were considered, since the tariff for consumers supplied with low voltage is based on the consumption tariff, regardless of whether these consumers have their own DPVG. The analysis was made without considering the taxation on the value of the electricity. The goal was to evaluate the possible utility revenue percentage variations, as shown in the following Tables.

Table 3. Annual electricity bill for different consumers and consumption with and without distributed photovoltaic generation (DPVG), without taxes.

Consumers by type of connection	Estimated electricity bill for different consumption in kWh / month (US$/year)							Electricity bill with DPVG (US$/year)
	30	50	100	220	350	500	1000	
B2, single-phase	44.42	74.04	148.07	325.76	518.25	740.36	1480.71	44.42
B2, two-phase	74.04	74.04	148.07	325.76	518.25	740.36	1480.71	74.04
B2, three-phase	148.07	148.07	148.07	325.76	518.25	740.36	1480.71	148.07
B1 and B3, single-phase	58,45	97.42	194.83	428.63	681.91	974.16	1948.31	58.45
B1 and B3, two-phase	97.42	97.42	194.83	428.63	681.91	974.16	1948.31	97.42
B1 and B3, three-phase	194.83	194.83	194.83	428.63	681.91	974.16	1948.31	194.83

In Table 3, the tariff results for consumers with DPVG were analyzed considering 2 possibilities: consumer with self-sufficiency, i.e. generation equal to consumption and consumer with partial DPVG, i.e. consumers who consume the equivalent of the minimum tariff from the company. However, in these two situations the rates are the same and were summarized in the column called: Electricity bill with DPVG. The results for the consumer were the same, since the existence of the minimum tariff, which acts as a kind of availability bill, means that the consumer must pay monthly, at least, a value corresponding to a fixed number of kWh.

However, when analyzing the percentage of tariff reduction for different consumers, it is observed that the percentages are independent of the type of consumer, because consumers differ only in terms of the consumption tariff. Table 4 shows the percentages of reduction in bills for the three different types of connection, in the current rates.

Table 4. Electric energy bill reduction of for consumers with distributed generation, in %

Type of connection	Electricity bill reduction estimated for different consumption in kWh / month (%)						
	30	50	100	220	350	500	1000
Single-phase	0.00	40.00	70.00	86.36	91.43	94.00	97.00
Two-phase	0.00	0.00	50.00	77.27	85.71	90.00	95.00
Three-phase	0.00	0.00	0.00	54.55	71.43	80.00	90.00

The data in Table 4 show that the insertion of DPVG can result in different percentages of bill reduction, depending on the type of connection.

The percentages of reduction in the revenue of the distribution company were calculated, considering a customer who purchases a distributed generation system. Two situations were considered: self-sufficient consumer and partial generation consumer. Again, the tariff model used was the one presented in Table 2, which is generic for group B consumers. Table 5 shows the percentages of reduction in the revenue of distribution utilities for consumers who choose to use their own distributed generation.

Table 5. Distribution utilities revenue reduction for consumers with distributed generation, in %.

Own generation	Type of connection	Reduction in the revenue (income) of the estimated distribution company for different consumption in kWh / month						
		30 (%)	50 (%)	100 (%)	220 (%)	350 (%)	500 (%)	1000 (%)
Total	Single-phase	0.00*	0.00*	25.92	66.33	78.84	85.18	92.59
	Two-phase	0.00*	0.00*	0.00*	43.88	64.73	75.31	87.65
	Three-phase	0.00*	0.00*	0.00*	0.00*	29.45	50.62	75.31
Partial	Single-phase	0.00	40.00	70.00	86.36	91.43	94.00	97.00
	Two-phase	40.53	0.00	50.00	77.27	85.71	90.00	95.00
	Three-phase	54.39	46.00	0.00	54.55	71.43	80.00	90.00

* Situations in which there was no reduction in revenue.

New tariff model for low voltage consumers

It is not only in Brazil that DG presents challenges. In many other countries, the insertion of DPVG in even higher percentages challenges the renewal of the electricity sector, mainly to ensure the viability of electricity utilities. The importance of maintaining the structure of the distribution system can be justified, since it must provide reliability, backup power, electricity supply in the non-generation periods and guarantee the supply with reliability to those consumers who do not choose the distributed micro or mini-generation plan, as well as ensure the grid expansion.

We suggest a more elaborate tariff model than the current one. The proposed tariff model can be summarized by Equation 1:

$$E = I_{DT}I_D + D_CP_D + O_DO_P + I_{CT}I_C + I_{CT}I_C + C_TO_P \quad (1)$$

where:

E = expenses with electricity, in US$ / month;
I_{DT} = intermediate demand tariff, in US$ / kW;
I_D = intermediate demand, in kW;
D_C = demand charge at the peak, in US$ / kW;
P_D = peak demand, in kW;
O_D = off-demand demand rate, in US$ / kW;
O_P = off-peak demand, in kW;

I_{CT} = intermediate consumption tariff, in US$ / kWh;
I_C = intermediate consumption, in kWh per month;
P_{CT} = peak consumption tariff, in US $ / kWh;
P_C = peak consumption, in kWh per month;
C_T = consumption tariff off-peak, in US$ / kWh; and
O_P = off-peak consumption, in kWh per month.

The proposed tariff would be a binomial tariff (charging as a function of the monthly energy consumption and the monthly demand), depending on the time-of-use, and with three tariff intervals: off-peak, intermediate tariff one hour before and after the peak and peak hours - with three-hour duration. The three intervals, or steps are shown in Figure 2 in green, yellow and red, in general the demand and consumption tariffs follow the same behavior illustrated in the figure, with a lower value in the off-peak and higher in the peak interval. In Brazil, since 1986, because of the insertion of time-of-use rates, the peak period is considered to be within three hours duration, applied for consumers connected in medium voltage levels.

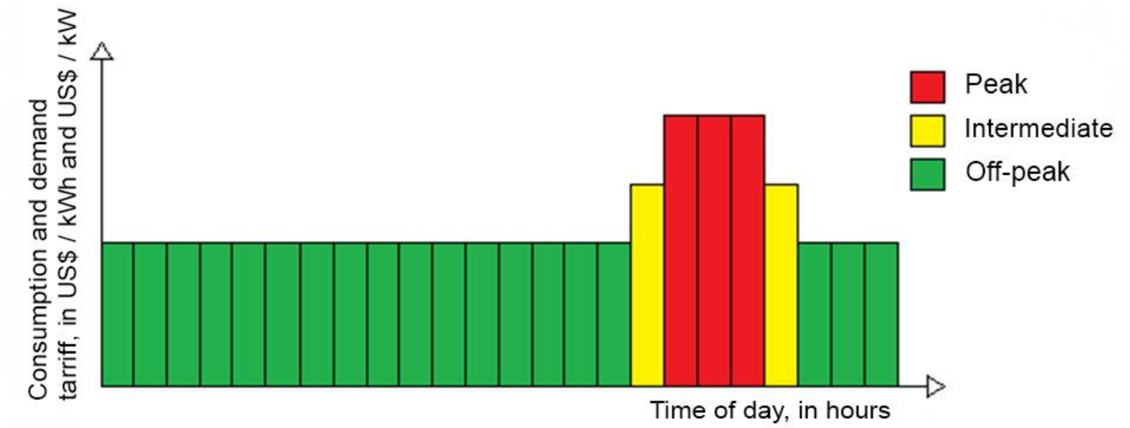

Figure 2. Illustration of the proposed tariff model.

Application of the new tariff

In order to apply the proposed tariff, demand and consumption tariffs were considered to be the same at any time-of-use. The proposed value for the demand tariff was based on the current minimum single consumer tariff, however, other values for the demand tariff can be adopted. The demand of a single-phase residential consumer tends to be close to that of the most consumed equipment, which would be at least equal to that of the most powerful equipment, which is the electric shower, in most cases. Thus, assuming that the demand for this equipment is 5 kW and knowing that the minimum tariff, according to the tariffs in force in 2020, corresponds to 30 kWh, the demand tariff is proposed equal to the price, in reais, of 6 kWh for each kW demanded.

For consumption considerations, different demands were assumed: 5, 7.5 and 10 kW for single-phase consumers, 10, 15 and 20 kW for two-phase and 15, 27 and 38 kW for three-phase consumers. These demand possibilities were considered to enable the assessment of the binomial tariff model proposed here, however, there may be other demand possibilities.

After these considerations, the average value of consumer tariffs was recalculated to a value that would provide, on average, the same price as the annual tariffs obtained by the current model. This amount was 0.09644 and 0.12690 US$ / kWh for B2 consumers and for B1 and B3, respectively. These amounts are approximately 78.16% of the kWh tariff practiced by CEMIG-D in 2019. Such reduction was considered to offset the cost of the demand tariff.

Table 6 shows the annual prices that would be paid to consumers B2 and for B1 and B3 following the new tariff model proposed. The results obtained show, on average, the same amount that would be paid by the tariffs in force in 2020, as for the consumption of 30, 50, 100, 220, 350, 500 and 1000 kWh / month, which would be 485.8 US$ / year and US$ 639.27 / year for B2 consumers and for B1 and B3, respectively. In the last column, there are the amounts that would be paid by a customer with self-sufficient distributed PV generation.

Table 6. Annual electricity bill for different consumers and consumption with and without distributed photovoltaic generation (DPVG) according to the proposed new tariff model.

Consumer, connection (demand, in kW)	**Estimated electricity bill for different consumption in kWh / month, in US$ / year**							**Electricity bill with DPVG (US$/year)**
	30	50	100	220	350	500	1000	
B2 Single-phase (5)	69.44	92.59	150.46	289.34	439.80	613.40	1192.08	34.72
B2 Single-phase (7.5)	86.80	109.95	167.82	306.70	457.16	630.76	1209.44	52.08
B2 Single-phase (10)	104.16	127.31	185.18	324.06	474.52	648.12	1226.80	69.44
B2 Two-phase (10)	104.16	127.31	185.18	324.06	474.52	648.12	1226.80	69.44
B2 Two-phase (15)	138.88	162.03	219.90	358.78	509.24	682.84	1261.52	104.16
B2 Two-phase (20)	173.60	196.75	254.62	393.50	543.96	717.56	1296.24	138.88
B2 Three-phase (15)	138.88	162.03	219.90	358.78	509.24	682.84	1261.52	104.16
B2 Three-phase (27)	222.21	245.36	303.23	442.11	592.57	766.17	1344.85	187.49
B2 Three-phase (38)	298.60	321.74	379.61	518.50	668.95	842.56	1421.23	263.88
B1 and B3 Single-phase (5)	91.37	121.83	197.97	380.71	578.68	807.11	1568.53	45.68
B1 and B3 Single-phase (7.5)	114.21	144.67	220.81	403.55	601.52	829.95	1591.37	68.53
B1 and B3 Single-phase (10)	137.06	165.51	243.65	426.40	624.37	852.79	1614.21	91.37
B1 and B3 Two-phase (10)	137.06	165.51	243.65	426.40	624.37	852.79	1614.21	91.37
B1 and B3 Two-phase (15)	182.74	213.20	289.34	472.08	670.05	898.48	1659.90	137.06
B1 and B3 Two-phase (20)	228.43	258.88	335.03	517.77	715.74	944.16	1705.58	182.74
B1 and B3 Three-phase (15)	182.74	213.20	289.34	472.08	670.05	898.48	1659.90	137.06
B1 and B3 Three-phase (27)	292.39	322.84	398.98	581.73	779.70	1008.12	1769.54	246.70
B1 and B3 Three-phase (38)	392.89	423.35	499.49	682.23	880.20	1108.63	1870.05	347.21

Table 7 shows the tariff reduction percentages for consumers who have DPVG. In this case, as the types of consumers B2 and B1 and B3 differ only by the cost per kWh, they present the same percentages, thus, the data depends only on the type of connection and the consumption range.

Table 7. Electricity bill reduction for consumers with distributed generation, based on the proposed binomial tariff, in %.

Type of connection (demand, in kW)	**Electricity bill reduction, in (%), estimated for different consumption, in kWh/month**						
	30	**50**	**100**	**220**	**350**	**500**	**1000**
Single-phase (5)	50.00	62.50	76.92	88.00	92.11	94.34	97.09
Single-phase (7.5)	40.00	52.63	68.97	83.02	88.61	91.74	95.69
Single-phase (10)	33.33	45.45	62.50	78.57	85.37	89.29	94.34
Two-phase (10)	33.33	45.45	62.50	78.57	85.37	89.29	94.34
Two-phase (15)	25.00	35.71	52.63	70.97	79.55	84.75	91.74
Two-phase (20)	20.00	29.41	45.45	64.71	74.47	80.65	89.29
Three-phase (15)	25.00	35.71	52.63	70.97	79.55	84.75	91.74
Three-phase (27)	15.63	23.58	38.17	57.59	68.36	75.53	86.06
Three-phase (38)	11.63	17.99	30.49	49.11	60.55	68.68	81.43

DISCUSSION

For the same consumption range the current Brazilian tariff for the consumers at voltage up to 1 kV, or low voltage level, the single-phase connection tends to be more attractive in case of the installation of DPVG system, while the three-phase connection tends to be less economically attractive. This difference is explained precisely by the definition of the minimum amount to be paid, in the tariffs in force in 2020 system, in Brazil, which does not depend on demand or consumption profile. This value, according to the current bylaw, depends exclusively on the type of connection (single, two or three phase system). Another limitation of the current Brazilian tariff may be demonstrated, considering that, in the electricity bill reduction estimated for different monthly consumption, the percentages increase sharply due to the increase in consumption, so the current regulation means that larger consumers are, in a way, the most benefited. This happens because the availability cost presently is not a function neither of the consumption nor the demand, but is only dependent on the type of connection.

So, in general, the more attractive to the consumer, the more revenue reduction to the distribution utility will be. On the other hand, for consumers with smaller electricity consumption, DPVG could even be advantageous to the company. However, DG is not a reality in this range of consumption, due to the low attractiveness to the consumer, who would perhaps achieve a small reduction in its tariff. For consumers who opt for partial generation, the situation becomes even more severe, resulting in a revenue decrease for the utility. When the consumer opts for partial generation, the reduction can reach 97%.

The tariffs in force in 2020 has limitations because the charge for consumers is only as a function of the electrical monthly consumption and not the demand. The binomial tariff, that is the charge as a function of the consumption and demand, may help to minimize the limitations, such as to charge the availability cost. The inclusion in the tariff system of the charge of the demand tariffs could consider the supply costs of the electric energy utilities that are associated with: (i) maintenance; (ii) availability; and (iii) reliability. Thus, the inclusion of the demand tariff could guarantee remuneration to utilities in situations where the consumers have or haven't DPVG.

In recent years, in Australia, the maximum demand, mainly from residential consumption, has grown, impacting greater needs to strengthen the electrical system and, consequently, increasing the final costs for the consumer. An alternative has been the proposition of tariffs based on consumption and demand [15]. [17] assessed the need for new tariffs because the growth of distributed generation may result in higher costs for consumers without DG. The author concluded that tariff proposals based on demand and consumption profile may be more equitable and their application may reduce tariffs for consumers without DG and raise them to a fairer level for consumers with their own generation.

In the society point of view, the time-of-use tariffs that consider the demand and consumption can be a good alternative for Brazilian consumers who have DG or no. The white tariff, is a time-of-use, voluntary adherence, which was implemented in 2018 for Brazilian residential consumers, establishes monomial tariffs, taxing only electricity consumption, depending on the time-of-use (TOU) [18 11]. Attempts such as the implementation of the white tariff may help to modify the consumer load curve, even if charging only for the consumption of electricity. The white tariff may not provide a complete solution, as time-of-use tariffs may not be as effective in reducing demand as binomial tariffs, i.e. that charge according to consumption and demand. There are studies showing that despite the tariff model for residential consumers may not reduce demand always in response to the increasing tariffs for different reasons, such as high income, difficulty in changing consumption habits and even misinformation [19]. This highlights the complexity of implementing new tariff models.

Thus, we concluded that the cost of availability of the electrical system [9] currently charged is not such an effective strategy to guarantee the viability of electric energy utilities, mainly with the advent of distributed generation. In addition, the availability cost of the electrical system corresponds to the value of 30, 50 and 100 kWh / month for single-phase, two-phase and three-phase consumers, respectively [9]. These values do not seem to be fair, since the demand of a single-phase consumer will not necessarily be less, and possibly, the demand will not follow exactly the same proportions of the minimum values charged among the different types of connections.

In this scenario, the main positive feature of the binomial tariff is taxation based not only on the profile of electricity consumption observed, but also on the profile of the load curve in relation to the demand. The joint taxation of consumption and demand allows consumers who consume the same amounts of electricity in a given period, but who have different load curves, requiring more or less system capacity, to be charged differently. In Brazil, this type of tariff already exists for medium voltage consumers.

For the application of this proposed tariff model, second generation energy meters will be necessary, which can be programmed to attend a TOU tariff proposed. As for the replacement costs of conventional meters, these would already be necessary for the white tariff, TOU tariff charging only the consumption, since the electricity meter would have to be replaced, for this tariff modality too. Thus, what is intended is to propose a fairer tariff model for consumers and electricity distribution utilities. In this way, the planning of electrical energy systems will be more reasonable.

The proposed model may offer some externalities resulting from its implementation, in addition to the main objective of enabling the maintenance of electricity distribution utilities. The following externalities can be mentioned: (i) contribution to demand reduction; (ii) making the implantation of distributed generation feasible to small consumers; and (iii) contribution to the reduction of electricity consumption at the most critical moments in the electrical system.

Demand reduction can be achieved as consumers look for more efficient equipment, for example, solar water heating systems to replace the common water heating system used in Brazil, that is electric tankless water heater. In addition, the reduction in demand can be achieved by promoting this new tariff to encourage the insertion of DPVG with energy storage. It should be noted that energy storage systems are currently not allowed for consumers who wish to benefit from the compensation system, i. e. net metering for the use of DPVG systems. It should be noted that, since the vast majority of current energy meters do not have the ability to record when consumption occurs, but only the total amount per month. Then the energy storage systems still are neither advisable nor be used with the present net metering tariff for residential customers, in Brazil. In reality, the energy storage systems in Brazil are not allowed in any case, with the net metering system. So, revision in this matter is needed since there exists a major pressure to spread energy storage systems for load curve adjustments and because of the advent of electric cars.

With the new proposed binomial tariff enabling distributed generation, for both players, the customers and the distribution utilities, would be a possibility for small consumers. Currently, the tariff system establishes a minimum charge corresponding to a given consumption as a way of charging availability costs. Therefore, small consumers would not have a fair advantage when installing a distributed generation system, as they would achieve, at most, small reductions in their bills, in many cases.

Finally, as the model can enable differentiated consumption tariffs, depending on the time, it is possible to stimulate less consumption at more critical times for the electrical system. As a consequence, there may be changes in consumption patterns, that is the load curve, benefiting the electrical system and the consumers who make this transition.

It is worth mentioning that the current Brazilian tariff for the low voltage customer is of the monomial type, which are tariffs that charge only in function of the monthly energy consumption. Monomial tariffs have disadvantages compared to binomial tariffs, that are tariffs that charge in function of the consumption and the demand, as well.

To add another dimension in the tariff structure will distinguish customers by consumption and by demand. One example of that will be two customers may have the same consumption, same type of connection, single phase and different demands. Here we may add that the demand values that may occur due to: a) the load demand itself and/or b) the effect on demand by the photovoltaic generation. Note that, the effect on demand by the photovoltaic generation could be either to increase or decrease the demand. In any case a specific study will be necessary. So, the account of those changes must be considered for the Integrated Resource Planning, IRP.

Finally, it is worth noting that the present research has its own limitations, the results of the simulations carried out may require adjustments to adapt the binomial tariff, i. e. to charge as a function of the monthly consumption and demand to the Brazilian reality. The definition of values for the composition of a new tariff also depends on regulations by the Electrical Energy Brazilian State Agency, ANEEL. Studies for other regions of the country can also contribute to complement the proposed model.

CONCLUSION

In this paper, the limitations of Brazilian electricity tariffs for low-voltage consumers were presented. These consumers pay a tariff based exclusively on consumption, however if consumption is below a given threshold, the minimum tariff is applied. Under the tariffs in force in 2020, Distributed Photovoltaic Generation, DPVG can result in serious reductions in the income of the electricity distribution utilities, as well as low attractiveness for small consumers to install PV systems. Through the proposal made here, we do not expect to obtain a complete tariff description to meet the demand for a new business model to support DG in the electricity sector. However, we intend to contribute towards exploring new possibilities to enable the sustainable development of DPVG, from the point of view of both electricity distribution utilities and consumers.

The application of a new binomial tariff charge according to the consumption and demand for electric energy, can provide a fairer and more favorable scenario, both for increased implantation of the PV technology, and for the maintenance of the electric energy distribution utilities. These companies are fundamentals for the electric energy supply, guaranteeing, as well the reliability and the maintenance of the system.

A proposal for a new binomial time-of-use tariff model was proposed, similar to the white tariff for low voltage consumers in Brazil, but with the inclusion of demand and not only consumption as parameters to charge the consumer. This tariff aims to discriminate consumption and demand costs, differentiating consumers according to their load curves, making the system fairer. The new tariff can increase the attractiveness for distributed generation for utilities and consumers, especially small ones, without harming non-participants and society.

The simulations presented were carried out in order to present, as directly as possible, the nuances of the proposed tariff, including the consumption and the low voltage consumer group, as well as those that have distributed generation and those that do not. The simulated tariff values need more in-depth studies before their implementation to ensure balance for consumers and utilities.

When including demand as a tariff parameter to charge it is expected to recognize and remunerate the electricity distribution utility. This remuneration is justified, as the company is much more than exclusively an energy supplier, since it guarantees reliability, system expansion, maintenance, backup energy and standardization of the low voltage electrical system.

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