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Article

Methodology for characterization and planning of electricity demand in an isolated zone: Mitú Approach

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Abstract: This paper aims a model for the characterization and planning of electricity demand in isolated networks when there is no information from the measurement system, a typical scenario in the Colombian Non-Interconnected Zone. This research is based on the Arvidson method of the publication entitled: "Diversified demand method of estimating residential distribution transformer loads". This study proposes consumption indices for typical household appliances based on a statistical analysis of load censuses. Then, a timely contrast is made between the curves of the Arvidson study and the generation curves of the isolated network because there is no direct measurement in the end-users and by macrometers associated with the transformers. With this information, we proceed to complement the validated Arvidson curve with its own index; this index allows the proposed curve to be readjusted to a similar curve, per unit, with the generation profile. The main contribution is to propose a new factor to contextualize and diversify the Arvidson method to specific case studies in building daily electricity demand and diversified demand curves as tools for planning the electrical system and managing the electrical infrastructure.

1. Introduction

Energy policies and regulatory scenarios worldwide are created under the need for continuity in supply, security, and reliability in each area [1]. Regulatory considerations are tied to technical and economic scenarios. Around 70% of electricity, supply interruptions occur at voltage levels between 1kV and 22kV [2] which indicates that the distribution networks are the section of the electrical system where the majority of interruptions to users originate. For voltage levels below 1kV, the average interruptions in Colombian distribution systems range between 13 and 18 hours per year. For levels between 1 and 36kV, the average interruptions are between 10 and 15 hours [3]. Based on the above information, distribution

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systems are recognized as the most vulnerable link in the electrical system, with or without catastrophic consequences such as the disconnection of users, technical energy losses [4], non-technical [5], and low power quality [6]. Therefore, it is of vital importance to generate solutions that allow an increase in the quality and reliability of the electricity supply. Measurement and communication systems are essential for the timely management of assets in an electrical distribution network. Characterization of the demand, reduction of losses, and the optimal sizing of equipment are some of the transversal characteristics of the planning, design, operation, and commercialization of electrical energy.

Within the panorama of complex analysis of the load in distribution systems of localities with low or high population density, two determining methodologies can be distinguished to characterize the demand for electricity consumption [7]. The first has to do with an exhaustive statistical analysis from the management of the information obtained by means of the measurement of electrical parameters in strategic places, with the aim of finding operational similarities to carry out a respective sample grouping where consumption trends can be visualized. and prospective expansion. The second methodology proposes an analysis of the demand from the inference by experience and trend through load censuses, a determining tool in the characterization of demand when there are no robust systems of measurement in place, as is the case of the Colombian ZNI. Therefore, the relevance of the electricity demand forecast is focused on reducing the uncertainty in decision-making for the effective and timely management of the electricity grids and the assets associated with them.

For its part, the analysis of electricity demand has three transversal axes: time horizon, mathematical technique, and type of demand. The time horizon, in turn, is classified as short, medium, and long-term. The short-term forecast focuses on an operating environment on an hourly basis or for up to a week. The medium-term forecast can range from a month to a year and corresponds to the complex analysis of incident factors such as economic growth, possible climatic variations, and the increase or decrease of the population census. Finally, the long-term forecast corresponds to the expansion planning of the entire electrical system. Mathematical techniques, meanwhile, are divided into three strategic moments in the prospect of complex characterization of electricity demand [7]; the first moment corresponds to the statistical analysis of historical information on user consumption and its subsequent grouping to recognize similar consumption profiles and formulate diversification curves. The second moment corresponds to the analysis of micro areas that allow visualizing trends in demand behavior from the geographical division taking the existing electricity system. And, finally, a third moment in which the importance of information as a strategic input is recognized to carry out modeling, prediction, and validation exercises using artificial intelligence methods. The effective management of the information, obtained from the analysis of electricity demand, will be decisive so that the network operators can plan optimal dispatch of load flows, strengthen the reliability of the system, and ensure the continuity and quality of the electric power service. On the other hand, the dynamics of the electrical systems are not represented as adaptive systems, therefore, it is necessary to have the characterization of demand in order to make modifications and adjustments in accordance with the quality requirements of service provision [7, 8].

2. Antecedents

In the 1940s, Arvidson CE, in its publication entitled "Diversified demand method of estimating residential distribution transformer loads," developed a method to analytically estimate loads of distribution transformers in residential areas by the diversified demand method, which is based on the diversity between similar loads and the non-coincidence of the peaks of different types of loads [9]. The non-coincidence of the peaks of different types of loads is highlighted. Arvidson introduced the "hourly variation factor," defined as the "relationship between the demand of a particular type of load coinciding with the maximum demand of the group and the maximum demand of that specific type of load" [9]. Figure 2 shows the curves of at least 12 types of household appliances to determine the average diversified maximum demand per consumer in kW / load. Each curve represents a 100% saturation level for a specific demand. Some other works, such as Bartel in Australia and Capasso's research in Italy, have been guided by Arvidson's research [10]. However, few end-use-based models address both demand and diversity.

3. Methodology

As shown in figure 1, the methodology is based on the Arvidson method of the publication entitled: "Diversified demand method of estimating residential distribution transformer loads," complemented with its adjustments using the S factor. This allows contextualizing the model of interconnected networks to isolated networks. It is planned to migrate from the scarcity of data to generating trends from load censuses and generation type curves for the planning and management of electrical networks.

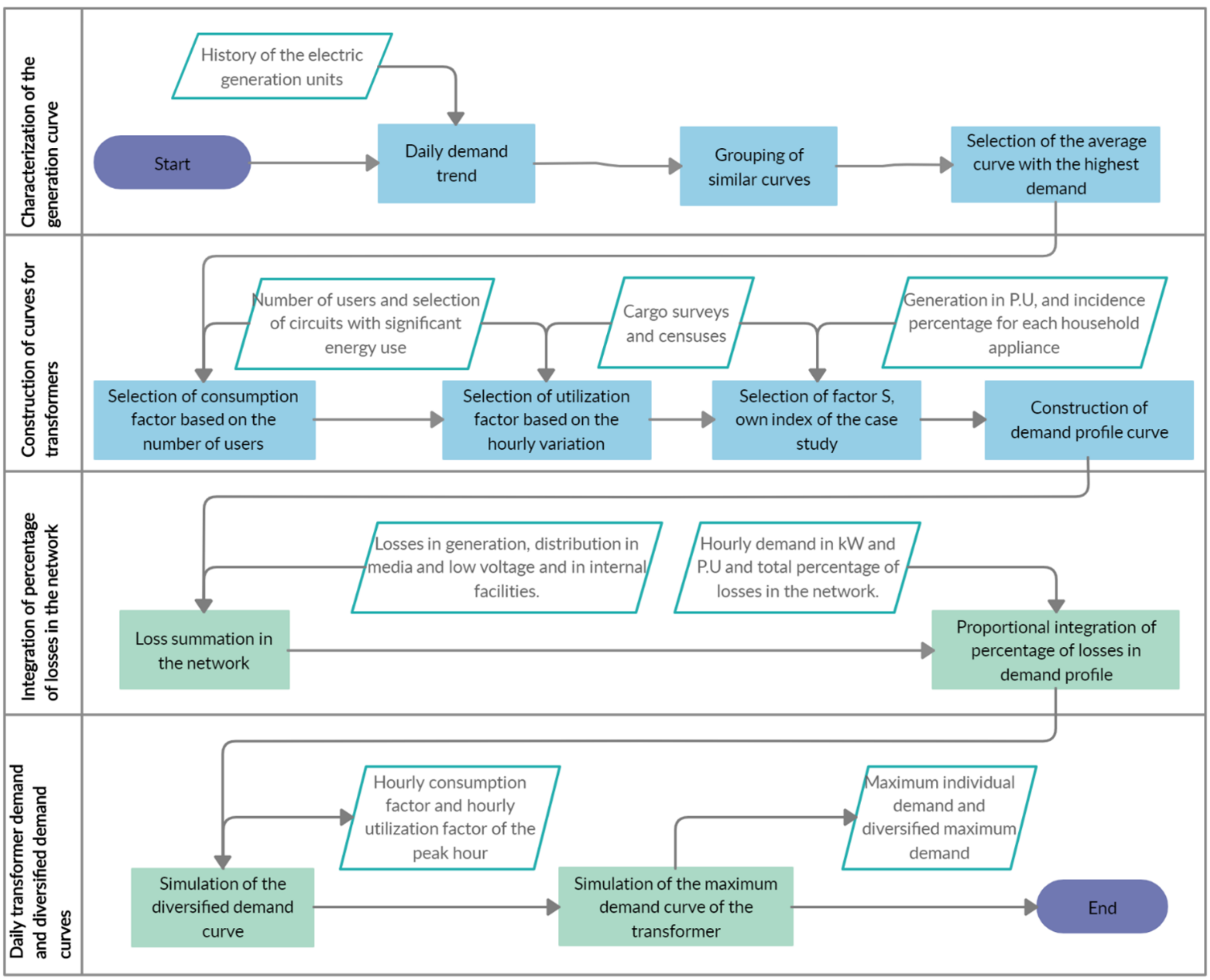

Figure 1. Methodological guide for analyzing and characterizing the demand in conditions of absence of direct measurement in end users.

3.1. Characterization of demand curve

The demand curve is estimated from the trend in the generation system. Intra-hour historical electrical energy production is taken in all the machines that contribute to the system, then the hourly sum of all of them is made, and daily demand lines are built. Finally, similar lines are grouped, and the average curve with the highest consumption index is extracted, with which the analysis will be made to characterize the demand.

3.2. Characteristic curve construction for transformers

For the construction of the characteristic demand curve, four factors are used that represent the complex incidence of the hourly variation factor, the number of associated users, the utilization factor based on the time slot, and an additional factor derived from a previous study for each network of study, referring to the characterization of significant energy uses through the application of surveys and load censuses.

To determine the total intra-hourly demand, the following equation is applied,

$$Dth_i = N * F_1 * F_2 * S, \tag{1}$$

where N corresponds to the number of users connected to the transformer. Understanding as a user that the connection between the transformer and the home through the electrical connection. F_1 the consumption factor based on end-users corresponds to diversified consumption according to the type of appliance and the number of users associated with the transformer [11]. Thus, for example, for a transformer with 20 users, the demand for lighting devices and miscellaneous electrical outlets will be taken as the product between 0.53 kW and 20 users, as shown in figure 2. F_2 the utilization factor based on hourly variation corresponds to a diversified value between 0 and 1 according to the hourly use of each appliance. Thus, for example, the stove will have the highest use rate at noon, while the air conditioner will have the lowest rate at dawn. And S, the proper index factor based on load census for the case study Mitú corresponds to the additional dimensionless factor that contextualizes the analysis of the characterization of the demand to the case study The calculation of the factor S is made from the value in PU of the hourly generation and a percentage by the degree of importance, according to the load census, for each appliance.

3.3. Integration of losses percentage in the network

Since the losses are proportional to the load, the hourly consideration of losses is made following the following equation,

$$D_d = Dh - Dh * (L * Dh_{p.u}), \tag{2}$$

where D_d Are Hourly demand with losses, L is the Percentage of total losses in the network, Dh are Hourly demand without losses, $Dh_{p.u}$ is Hourly demand in P.U in generation.

3.4. Daily demand curves of the transformer and diversified demand

The daily demand of a transformer is calculated by dividing the maximum demand by an end-user by the diversified maximum demand [6], as

$$Fdiv_n = \frac{D_{\max - \text{individual}}}{D_{\max - \text{diversified}}}. \tag{3}$$

On the other hand, the diversified demand is carried out according to the parameters recognized in the hour of greatest consumption or peak hour of the day [6], as follows

$$\sum Fh_1 * Fh_2 = Fdh_n, \tag{4}$$

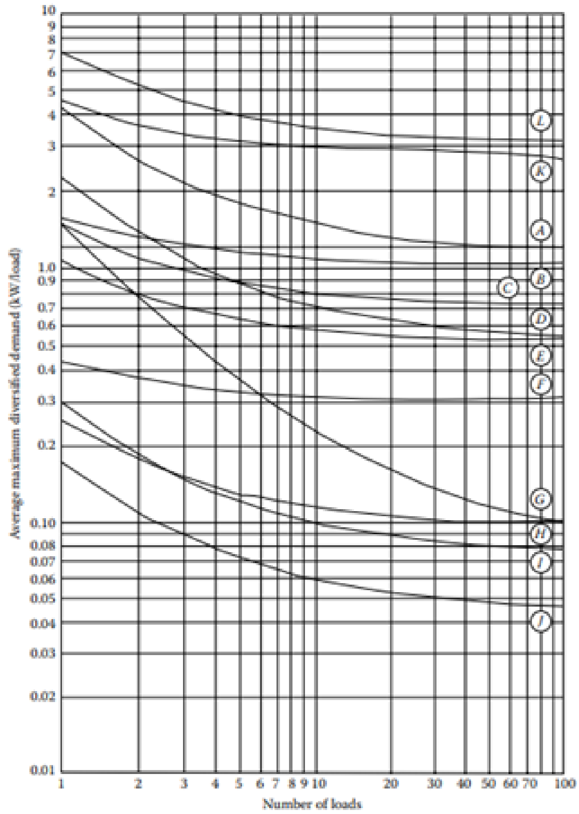

Figure 2. Maximum diversified demand characteristics of various residential loads: A, clothes dryer; B, off-peak water heater, "off-peak" load; C, water heater, uncontrolled, interlocked elements; D, range; E, lighting and miscellaneous appliances; F, 0.5-hp room coolers; G, off-peak water heater, "on-peak" load, upper element uncontrolled; H, oil burner; I, home freezer; J, refrigerator; K, central air-conditioning, including heat-pump cooling, 5-hp heat pump (4-ton air conditioner); L, house heating, including heat-pump-heating-connected load of 15kW unit-type resistance heating or 5hp heat pump. Reprinted with permission from [9] under the terms of the CC BY-NC 4.0 license.

where Fh_1 is the Arvidson consumption factor as a function of hourly consumption by the number of users [kW * n users] (Figure 2), Fh_2 is the peak hour hourly utilization factor, Fdh_n is diversification factor for n users.

4. Case study

Mitú is in the south of Colombia in the department of Vaupés. It is one of the five capitals of the Non-Interconnected Zone, with an approximate population of 10,400 people [12]. Its generation system is made up of 4 hydraulic generation units that contribute a maximum of 2MW to the system and 5 diesel generation units with a total maximum capacity of 5,052 MW. On the other hand, the demand does not have an individual measurement system or macro measurement by transformer, which makes the dimensioning and planning of the distribution system difficult. The decrease in the quality and continuity of the electricity service is part of the lack of asset management, also reflected in the high percentage of technical and non-technical losses.

5. Simulation and results

5.1. Characterization of the demand curve

For the case study, Mitú, the information of the generation units contributing to the system is assumed to determine trends in demand behavior. Then a percentage plot (P.U) is made that can be easily extrapolated to the modeling of each distribution system transformer according to factors such as the number of users and time zone trends.

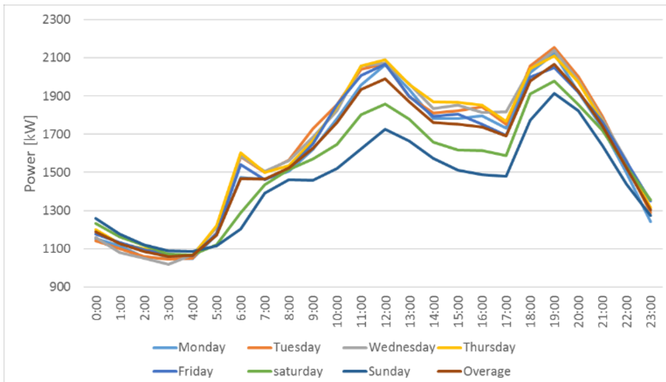

Figure 3. Average hourly generation curve for the year 2017 for the municipality of Mitú. Information provided by the generator (Source: Gestión Energética Colombian utility).

Figure 3 shows the mean of the sum in the generation of all units for the year 2017 with a time precision of 1 hour for each day of the week. The trend curves are divided into two groups, the first one corresponds to the weekdays from Monday to Friday, and the second group corresponds to the weekend days, Saturday and Sunday.

For the analysis of demand, the scenario of higher consumption corresponding to the average in the generation curve of the weekdays is taken. Then, based on the maximum value, the values are transported to P.U, as shown in Figure 4.

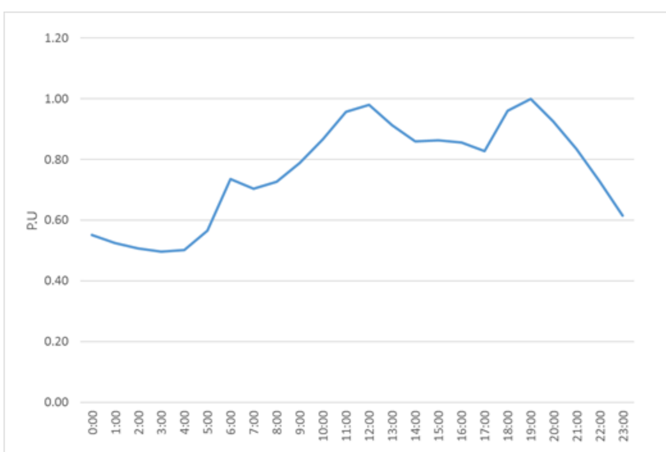

Figure 4. Average hourly generation curve in P.U for weekdays of the year 2017.

5.2. Construction of the transformers' characteristic curve

According to a previous study by the electricity generating company in Mitú, the distribution transformers have approximately 40 associated end-users, on average [13]. Therefore, an example of the analysis process will be made to characterize the demand based on that number of users.

5.2.1. Number of users

We chose $N = 40$ end-users.

5.2.2. Consumption factor based on end users

The circuits selection criteria were made based on the results of load censuses and surveys carried out on the population by the generating company [14]. The results show that around 95% of the energy consumed in the residential sector corresponds to the electric stove, air conditioning, refrigeration and lighting, and miscellaneous outlets.

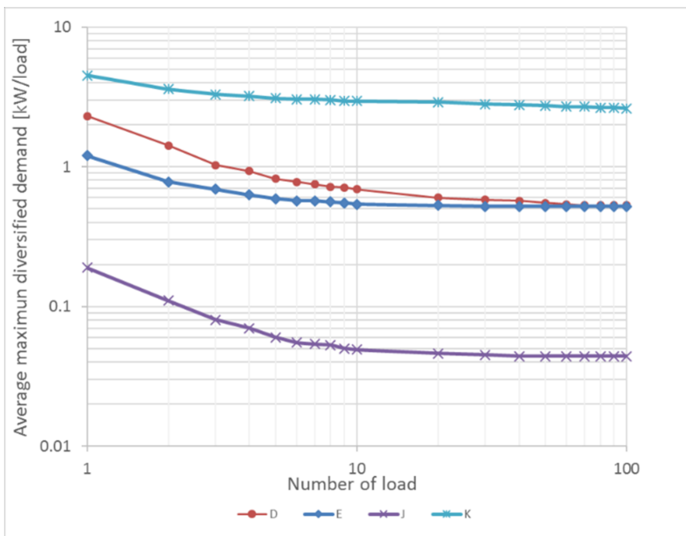

Figure 5. Maximum mean demand curves, according to Arvidson, for electric stove (D), lighting fixtures and miscellaneous outlets (E), refrigerator (J), and air conditioning (K) circuits.

5.2.3. Utilization factor based on hourly variation

Table 1 shows the consumption trend in the main circuits of Mitú end-users.

5.2.4. S factor, proper index based on load census for the case study, Mitú

The calculation of the S factor takes into account the value in P.U of the hourly generation and a percentage by the degree of importance, according to the load census, for each appliance,

$$S = 1 + (G * P)/100, \tag{5}$$

where G is generation in P.U, and P is the appliance's incidence percentage.

According to the surveys and load censuses carried out previously, it was found that the circuits with the highest energy consumption corresponded to the stove, air conditioning, refrigeration and lighting circuits, and miscellaneous outlets; therefore, the incidence percentage for the calculation of the S factor is 30%, 25%, 25%, and 20% respectively.

Table 1. Vp and Vs. for different frequencies.

Hour	Electric stove	Air conditioning	Refrigerator	Lighting and miscellaneous outlets
00	0.02	0.40	0.93	0.32
01	0.01	0.39	0.89	0.12
02	0.01	0.36	0.80	0.10
03	0.01	0.35	0.76	0.09
04	0.02	0.40	0.79	0.08
05	0.05	0.65	0.72	0.10
06	0.55	0.70	0.75	0.19
07	0.47	0.60	0.75	0.41
08	0.28	0.61	0.79	0.35
09	0.22	0.62	0.79	0.31
10	0.22	0.72	0.79	0.31
11	0.85	0.90	0.85	0.30
12	1.00	1.00	0.85	0.28
13	0.90	0.94	0.87	0.26
14	0.50	0.85	0.90	0.29
15	0.40	0.84	0.90	0.30
16	0.50	0.85	0.90	0.32
17	0.70	0.85	0.90	0.70
18	0.80	0.95	0.90	0.92
19	0.95	0.99	0.95	1.00
20	0.90	0.87	0.95	0.95
21	0.75	0.71	0.95	0.85
22	0.04	0.68	0.88	0.72
23	0.02	0.55	0.88	0.50

To determine the total intra-hourly demand, the following multiplication of factors is applied

$$N * FA_1 * FA_2 * S = Dth_i, \tag{6}$$

where N is the number of users, Fh_1 is the Arvidson consumption factor as a function of hourly consumption by the number of users [kW * n users] (Figure 2), Fh_2 is peak hour hourly utilization factor and S is proper factor index based on load census for the case study, Mitú.

Finally, we estimate losses in the network with the information provided by GENSA. The procedure carried out consisted of finding the difference between the energy generated and the energy delivered to each circuit and then adding the percentage estimate of losses in the distribution network.

For 2017, there were, on average, 11% losses between the energy generated and that which is delivered in the circuits (According to generation reports, by GENSA, for 2017); not counting the losses in the medium and low voltage network for the municipality's distribution system. According to the survey and redesign of the distribution network carried out by GENSA in 2017, it was found that, on average, about 0.5% is lost in the medium voltage network, and an additional 22% in the transformers and the low voltage electricity network [13]. In addition, through visual inspection carried out during visits to the site, an additional 10% of losses is estimated due to the precariousness of the internal facilities of each user. Based on the losses that are proportional to the load, the hourly consideration of losses is made with equation (2), with $L = 44\%$.

In addition, the maximum demand curve of the transformer is determined, according to equation (3), and diversified demand, according to equation (4), as shown in Figure 6 and Figure 7, respectively, from

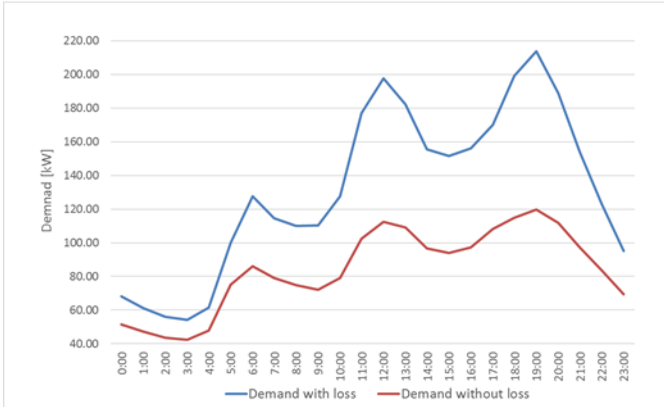

Figure 6. Comparison of average hourly demand curves for weekdays of 2017 by integrating the percentage of losses.

the most relevant household appliances in consumption significant amount of electrical energy. The choice is made under the criteria validated by surveys of the target population.

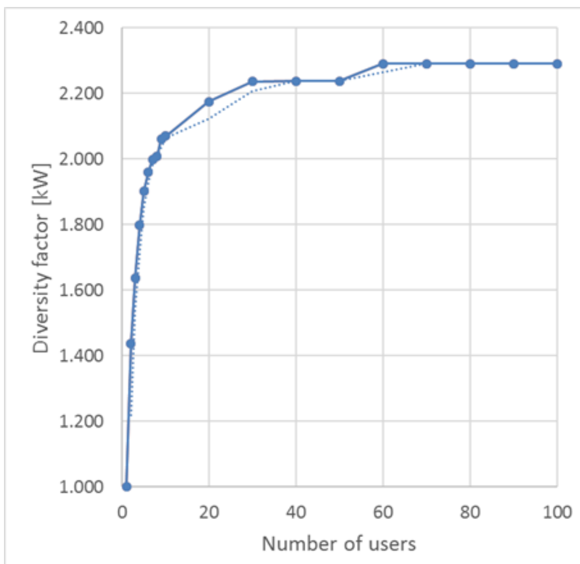

Figure 7. Maximum demand curve of distribution transformer with 40 associated users.

The diversified demand, divided into time bands and as shown in figure 7, is carried out according to the parameters recognized in the hour of highest consumption, or peak hour of the day, according to equation (4) [9].

Thus, for the average of 40 users per transformer, there will be a diversification factor of 4.24. Therefore, the demand for the planning of the electrical system will be 169.4 kW, which is the result of multiplying 40 (end-users) by 4.24 (Diversity factor).

It is clarified that the present analysis is made under the current conditions of the electrical infrastructure of Mitu. For future analysis, it is recommended to consider population growth and the expansion of the electricity system to communities near the municipal seat.

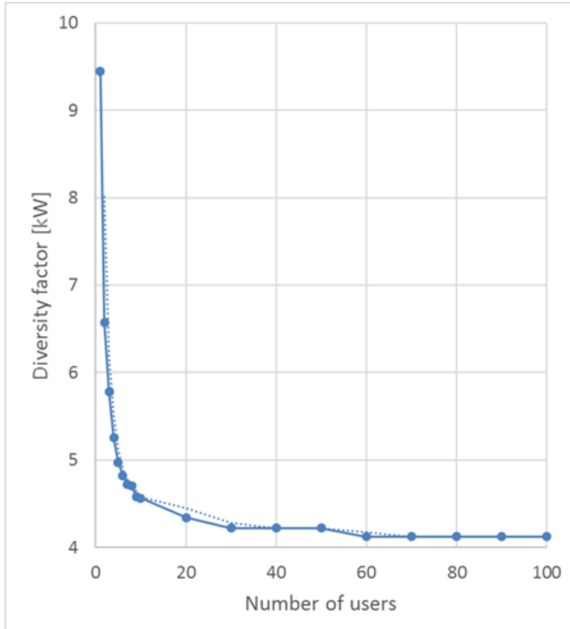

Figure 8. Diversified demand curve for a distribution transformer with 40 associated users.

6. Conclusions

Asset management is imperative to foresee maintenance and resource optimization strategies. The present study was able to adapt and generalize the Arvidson model to characterize the demand for isolated networks by inserting the S factor under the criteria of surveys and load censuses carried out on the target population. This model is easily extrapolated to other cases with isolated networks that do not have centralized and decentralized measurement systems.

For its part, the construction of the curves of diversified demand and maximum demand of the transformers was carried out, which will serve as planning tools for the due dimensioning of the electrical distribution system where there is no direct measurement in the users and macro measurement. The reduction of electrical losses and the optimal sizing of the equipment will be some of the benefits that lead to the electrical system's continuity, efficiency, and reliability, which also transcends the optimization of economic resources for sustainability.

The Mitú case study shows a high per capita consumption due to the high losses present in the medium and low voltage networks. According to the model, it is estimated that the losses amount to 44% of the total generation without counting on the low-efficiency level of the diesel generation units. Therefore, regulation and energy efficiency policies must be oriented not only toward the end-user but also towards the operator and administrator of the system.

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