Study for Determination of Projected Maximum Unit Demand Case Study: Cuenca–Ecuador

S. A. Moscoso,
UCACUE
Cuenca, Ecuador
smoscoso@ucacue.edu.ec

D. X. Morales,
Univ. Grenoble Alpes, CNRS, Grenoble INP*, G2Elab, F-38000
Grenoble, France
Diego.Morales-Jadan@g2elab.grenoble-inp.fr

D. A. Balarezo
UCACUE
Cuenca, Ecuador
Diego.electri@hotmail.com

Abstract –This paper aims to propose a methodology for the capacity estimation of transformers within Centrosur concession area in Cuenca. The study is based on measurements made with quality equipment, records of electrical energy consumption of the users involved, demographic data, growth rate, socioeconomic conditions collected from different official bodies such as Ministries and National Agencies.

Index Terms **– Transformer Capacity, Coincidence Factor, Projected unit maximum demand**

I. Introduction

The local Utility in Cuenca (CENTROSUR), in 2004 standardized tables of Maximum Projected Unit Demand based on technical studies, which allowed to categorize customers of the Urban and Rural sector according to their consumption, basically these tables are based on the property area. This information have been used by professionals of the engineering, in order to size both transformers and secondary networks to provide energy for the customers.

It is necessary to determine if the demand values assigned to each categories of the clients are adequate, since the energy efficiency of current appliances is better than years ago. For instance, the TVs, refrigerators have been reduced their consumption by up to 50%. Also the massive replacement of electric showers by gas and solar heaters, government campaigns for replacing incandescent lamps by Energy Saving ones have allowed to reduce the demand of electrical energy in the country. Another important key factor to be considered is the public policy of replacing gas stoves by induction cookers [1].

Taking into account the aforementioned, it is vital to update and to validate the Maximum Projected Unit Demand defined 13 years ago. Since, it seems those values does not reflect anymore the reality. In addition, a right size determination of transformer capacity will able a better use of energetic and economic resources, as well as, an optimization within the distribution network.

This work was supported by Smart Grid Research Group of the Universidad Católica de Cuenca, Cuenca - Ecuador.

Therefore, it is worth to perform a new study for determining the new projected unit maximum demand.

II. Background

A. Method to determine Demand according CENTROSUR

The design demand for distribution networks is calculated as follows.

$$DMp = DMup \times N \times Fcoin$$

Where

DMup Projected unit maximum demand (kVA).
N Clients number
Fcoin Coincidence Factor
DMp Projected maximum demand

The DMup for CENTROSUR is calculated in function of the geographic location (urban or rural) and the property area. The Table I shows the current classification.

TABLE I
CLIENT TYPES FOR URBAN AND RURAL SECTORS WITHIN CENTROSUR

Location	*Average Property Area (m^2)*	*Category*	*DMup 10 years*	*DMUp 15 years*
Urban	A >400	A	7,47	7,99
	300<A<400	B	3,93	4,29
	200<A<300	C	2,23	2,48
	100<A<200	D	1,36	1,55
	A<100	E	0,94	1,09
Rural	City outskirts	F	1,02	1,16
	Parish center	G	0,84	0,98
	Rural	H	0,65	0,76

SOURCE [2]

The coincidence factor is calculated in function of the clients number connected to the network, for CENTROSUR the calculus is given by [2].

$$Fcoin = N^{-0.0944} \quad (1)$$

Additionally, must be considered the load due to Street lighting and especial loads. Hence, the design demand is calculated as:

$$DD = DMp + A + Ce \quad (2)$$

Where

DD Design Demand (kVA).
A Street Lighting load (kVA).
Ce Special Loads (kVA).

In order to determine the transformer capacity, it is need to apply the next factors for considering overload.

TABLE II
OVERLOAD FACTOR.

Category	*Factor*
A	*0,9*
B y C	*0,8*
D…H	*0,7*

SOURCE [3]

In addition, the Agency for the Regulation and Control of the Electricity – *ARCONEL* – establishes a method for projecting demands based on the correlation between macroeconomic and demographic variables and the variables of interest (energy and customers), together with the application of analytical methods, the next figure depicts the described.

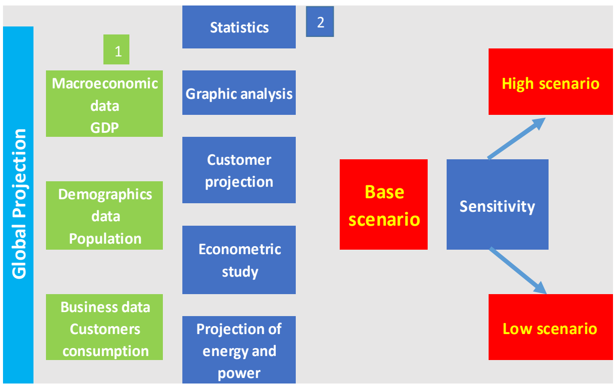

Fig. 1. Analytical balance of energy and power [4]

III. FUNDAMENTALS

A. *Electrical System*

The electrical system consists of a set of equipment and processes destined to supply electrical energy to the consumption points [5]. The electrical system is constituted by three different subsystems such as generation, transmission and distribution.

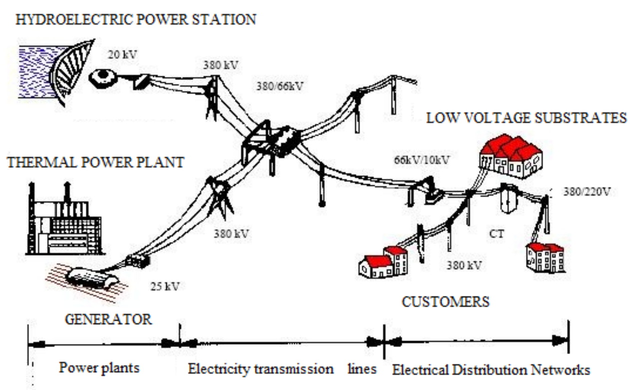

Fig. 2. Electrical System elements [6]

B. *Customer*

The client is any natural or legal person who hires the electricity supply service. Normally, they are classified in residential, industrial, street lighting and others such as *i)* Sports scenarios, *ii)* Social assistance, *iii)* Water pumping among others.

C. *Concidence and Diversity Factors*

When considering a group of homogeneous loads, there is a diversity in the use of electrical equipment due to the variety of customs and needs. The diversity factor *–Fdiv-* can be defined as the ratio between the sum of the individual maximum demand of each client and the maximum demand of the system [7].

$$F_{div} = \frac{\sum_{i=1}^{n} Dmáxi}{Dmáxs} \qquad (3)$$

Where
Dmáxi Maximum Demand of the i*th* load.
Dmáxs Maximum Demand of the system.

The coincidence factor *–Fcoi-* is the inverse of the Fdiv and it is expressed as:

$$F_{coi} = \frac{1}{F_{div}} \qquad (4)$$

Another empirical equation that could be used is

$$F_{coin} = F_{coi\infty} + \frac{1 - F_{coi\infty}}{N} \qquad (5)$$

Where
$F_{coi\infty}$ Infinite Coincidence

D. *Power Factor – Fp-*

This value indicates the relationship between active and apparent power.

$$FP = \frac{P}{S} = \cos(\theta) \qquad (6)$$

Where
FP Power Factor
P Active Power
S Apparent Power
θ Offset angle between voltage and current.

E. *Load Factor – Fc-.*

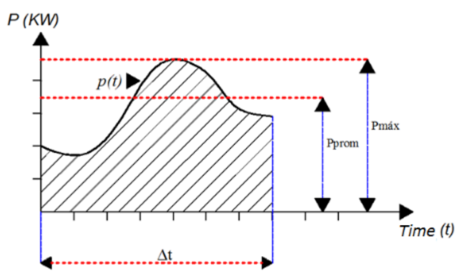

Fig. 3. Average and maximum Power.

Considering *p(t)* function , which represent an instantaneous load curve, the load factor for an interval Δt, is given by the next equation, [8].

$$FC = \frac{1}{Pmax} \int_0^{\Delta t} \frac{p(t)dt}{\Delta t} \qquad (7)$$

Where

$\frac{p(t)}{\Delta t}$	Indicates the average value of the function
$\frac{1}{Pmax}$	Indicates the reciprocal of the maximum value of the maximum power – *Pmax-*

The load factor can be defined as the ratio between the average demand and the maximum demand. Thus, the Fc is calculated by dividing the average power for the maximum power [9].

F. Demand

Demand is the power required by a system, averaged over a time interval Δt , that interval is usually 15, 30 and 60 minutes [10].

$$Demand = \frac{\int_0^{\Delta V} P\,dt}{\Delta t} \qquad (8)$$

Where
P Instantaneous Power

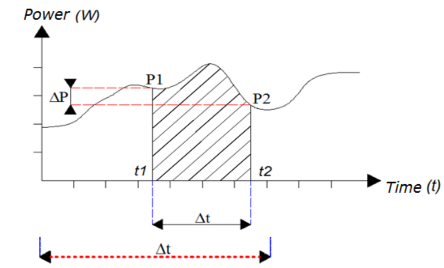

Fig. 4. Demand Curve

G. Maximum Demand

It is the maximum power value of all loads, which occurs in a time interval. By means of the maximum demand we can determine the thermal capacity of the conductors and other elements of the distribution system [10].

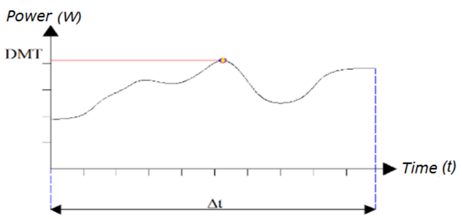

Fig. 5. Maximum Demand

IV. PROPOSAL METHODOLOGY.

A. Sample Selection

Taking into account the number of transformer stations installed by CENTROSUR in Cuenca and the heterogeneity in both urban and rural parishes, it is possible to understand the difficulty of carrying out measurements and registers of each one of these. For this reason, the sampling technique is used.

The formula for calculating the sample size when the population size is known is the following [11]:

$$n = \frac{k^2 Npq}{e^2(N-1) + k^2 pq} \qquad (9)$$

Where
n Sample size
N Size of the Universe
k constant that depends on the level of trust assigned
p proportion of individuals that have the study characteristic in the population
q proportion of individuals who do not have the study characteristic in the population
e desired sample error

B. Stratification of urban parishes of Cuenca

CENTROSUR has 325.849 clients throughout its concession area, of which 262.731 clients are in the province of Azuay and 187.691 are located exclusively in Cuenca city. The 86% corresponds to the residential category [12].

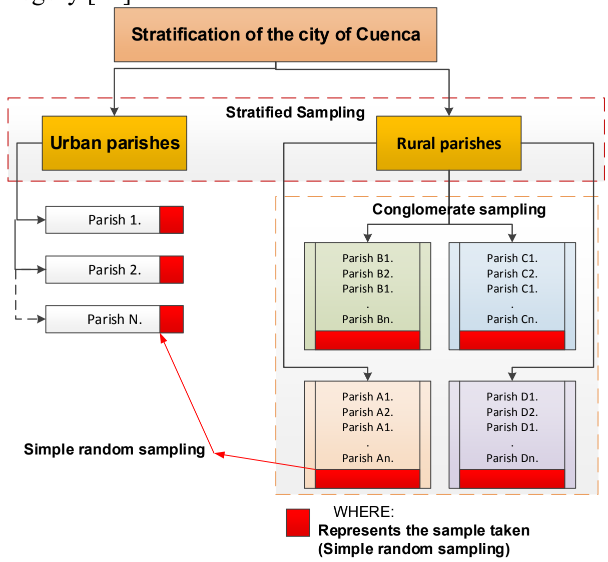

Fig. 6. Stratification Process

C. Stratification of rural parishes of Cuenca

The rural parishes of the Cuenca canton are geographically distant from the city. Cuenca has 22 rural parishes, taking into account the significant heterogeneity and that are geographically distant, it will be used sampling by clusters.

The technique will basically allow to divide rural parishes into conglomerates that have some similarity, considering criteria such as population growth rate, household number in each parish, number of inhabitants per house, number of households with internet access, number of households with computer and economic growth [13].

For the final stratification a correlation by range is used, based on the previous stratifications (qualities and attributes) among the rural parishes of the canton Cuenca, in summary the method basically consists of taking into account all the previous stratifications and based on these to define the final stratification using as tool of selection the statistic known as Mode.

TABLE III
RURAL STRATUMS

Stratum A	***Stratum B***	***Stratum C***	***Stratum D***
Baños.	*Paccha.*	*Chiquintad.*	*Chaucha.*
El Valle.	*Sayausí.*	*Cumbe.*	*Checa.*
Ricaurte.	*Sinincay.*	*Llacao.*	*Molleturo.*
San Joaquín.	*Turi.*	*Nulti.*	*Octavio Cordero P.*
		Quingeo.	
		Santa Ana.	
		Sidcay.	
		Tarqui.	
		Victoria del Portete.	

D. Determination of Maximum Unit Demand –DMU-.

The DMU correspond to an average value of demand in a group of users, to determine this demand is taken into account the Sum of Individual Maximum Demands $\sum_{i=1}^{n} Dmáxi$ and the number of customers that record consumption. This result will present the DMU in kW, in order to get this demand in kVA we divide this value for the power factor, which is provided by the quality registers.

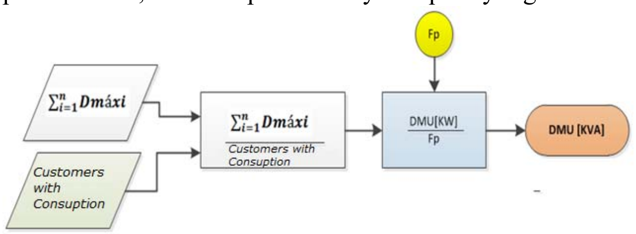

Fig. 7. Process to determine the DMU

With the demands obtained by transformer station and with the purpose of having a single demand by parish and stratum for the urban and rural sector respectively the average of the demands is considered.

With the results of this process and the use of the Range concept, the urban sector was separated into stratums, maintaining the same stratification for the rural sector. See Fig. 8

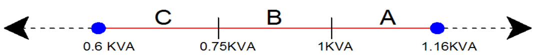

Fig. 8. Ranges for urban stratification

The following table shows the parishes involved within each urban stratum.

TABLE IV
URBAN STRATUM

Stratum A	***Stratum B***	***Stratum C***
Sucre	*El Batan*	*Bellavista*
Gil Ramírez	*Totoracocha*	*Monay*
San Blas	*Huayna Cápac*	*Yanuncay*
El Sagrario	*El Vecino*	*Machángara*
	San Sebastián	*Hermano Miguel*
	Cañaribamba	

The DMU per stratum value is assigned according to the maximum unit demand within the stratum in order to avoid under-dimensioning.

TABLE V
DMU BY STRATUM.

Location	***Stratum***	***DMU [kVA]***
Urban	*Stratum A*	*1,16*
	Stratum B	*0,94*
	Stratum C	*0,69*
Rural	*Stratum A*	*0,68*
	Stratum B	*0,63*
	Stratum C	*0,53*
	Stratum D	*0,42*

As you can see in Table V in Stratums A and B of the rural sector there is a very small (negligible) difference. Hence, these extracts were unified, predominating the one with the highest demand (Stratum A); On the other hand, the extracts were renamed to avoid later confusions. The Tables 6 and 7 depicts the mentioned.

TABLE VI
FINAL STRATUMS

Location	***Original Stratum***	***Renamed Stratum***	***DMU [kVA]***
Urban	*Stratum A*	*A*	*1,16*
	Stratum B	*B*	*0,94*
	Stratum C	*C*	*0,69*
Rural	*Stratum A*	*D*	*0,68*
	Stratum B		
	Stratum C	*E*	*0,53*
	Stratum D	*F*	*0,42*

TABLE VII
STRATUMS AND PARISHES

Urban			**Rural**		
Stratum A	**Stratum B**	**Stratum C**	**Stratum D**	**Stratum E**	**Stratum F**
Sucre, Gil Ramirez San Blas, El Sagrario.	*El Batán, Totoracocha Huayna Cápac, El Vecino, San Sebastián, Cañaribamba.*	*Bellavista, Monay Yanuncay, Machángara, Hermano Miguel.*	*Baños, El Valle, Ricaurte, San Joaquín, Paccha, Sayausí, Sinincay, Turi.*	*Chiquintad, Cumbe, Llacao, Nulti, Quingeo, Santa Ana, Sidcay, Tarqui, Victoria del Portete.*	*Chaucha, Checa, Molleturo, Octavio Cordero P.*

E. Determination of DMup

The results shown previously correspond for the base scenario, which is based on real measurements. It is then time to define unique factors in order to perform a demand projection.

a) Electrical Demand Projection for the concession area of CENTROSUR

The growth of energy demand was taken from the Electrification Master Plan 2013-2022 [4]. For the projection, historical behavior and demographic and macroeconomic variables are evaluated. Thus, CENTROSUR has an average growth rate in electricity demand of 4,45% per year.

b) Electrical Demand Projection for Cuenca

In [14] is proposes a model for forecasting in the long-term the electrical demand, the most important contribution is about the determination of where and when the demand will grow, by means of micro areas (1Km^2), through geoprocessing considering factors such as *i)* degree of restriction to construction, *ii)* use and slope of land and *iii)* proximity to the city.

The results of this study show that there is an annual energy demand growth rate of 4,5%. From the results obtained for each stratum depicted in the Table 6 and taking as reference a 4,5% growth in demand [14], a projection for 10 years is presented in the Table 8.

TABLE VIII
DMUP PROPOSAL

Location	*Stratum*	*DMU [kVA]*	*DMup [kVA]-10 years*
Urban	*A*	*1,16*	*1,68*
	B	*0,94*	*1,36*
	C	*0,69*	*1,00*
Rural	*D*	*0,68*	*0,99*
	E	*0,53*	*0,77*
	F	*0,42*	*0,61*

c) National program of efficient cooking.

The National Government of Ecuador, in compliance with the established in the Constitution of the Republic, in articles 15 and 413, has decided to implement an aggressive plan to improve the use of energy resources. In this regard, the Ministry of Electricity and Renewable Energy –MEER- has announced that the National Plan for Efficient Cooking is ongoing, for which Utilities must prepare their infrastructure to be able to supply the service with this important increase in the load and with the service reliability required.

On the other hand, the norm NTE INEN 2567 establishes the requirements of energy efficiency of all the induction cookers that are commercialized in Ecuador. Also indicates that induction cooker category D has heating units of 1200 W. Considering an average of four heating units per induction cooker, it is then determined that the installed capacity per induction cooker is about 4800 W [15]. In [16] an extensive analysis is carried out on the impact of induction cookers on the demand for electrical energy, which serves as reference for the present study

TABLE IX
DAILY CONSUMPTION BY CLIENT (kWh)

Breakfast	1,6	Lunch	2,0	Dinner	1,4

SOURCE [16]

d) Final DMup

In order to determine DMup, two factors were taken into account. The DMup without induction cooker (DMups/c) and the DMup with induction cooker (DMuC). The results of the sum of the two demands are shown in the following table.

TABLE X
DMUp PROPOSAL

Location	*Stratum*	*DMup [kVA] (DMups/c+DMuC)*
Urban	*A*	*4,07*
	B	*3,75*
	C	*3,39*
Rural	*D*	*3,38*
	E	*3,16*
	F	*3,00*

F. Coincidence Factor Determination

e) Coincidence Factor of the System - FScoin

For the determination of Coincidence Factor the following data is considered *i)* Sum of maximum demand non coincident and ii) maximum system demand.

In order to determine the equation that best approximates the behavior of these factors, the interactive adjustment tool (cftool) of MATLAB was used.

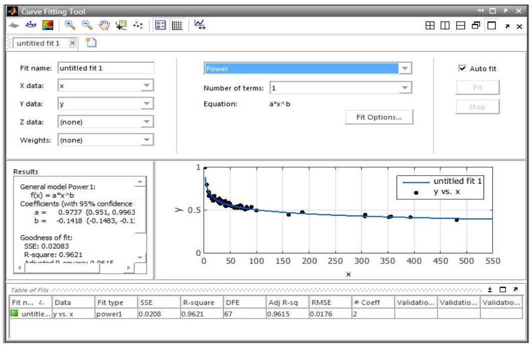

Fig. 9. Cftool within MATLAB

When evaluating the results, it was determined that the power curve is the best fit. After some process and executions of the tool, the following values are obtained: a = 1 y b = -0.1498. It is depicted in the Fig. 10. Thus, the final equation is $N^{-0.1498}$

f) Coincidence Factor for Induction Cookers - FCcoin

For the determination of the Coincidence Factor for induction cookers, the following equation was used:

$$F_{coin} = F_{coi\infty} + \frac{1 - F_{coi\infty}}{N}$$

Where
N number of clients

In addition, it is assumed the probability of simultaneity described in [15]. In the use of induction cookers of 69.9% for the preparation of breakfast, 77.7% for lunch and 88.2% for the dinner. Fcoi∞ is assumed equal to 0.882. Thus, $FCcoi = N^{-0.035}$

g) Final Simultaneous Factor considering induction cooker -Fcoin-

With the support of CFtool , the FS_{coin} and $FCcoi$ values were adjusted in order to obtain a single equation that fitted these two factors.

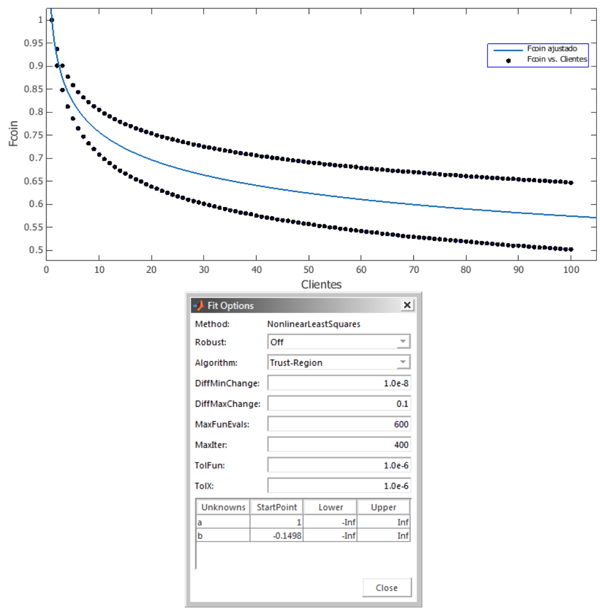

Fig. 10. Final Curve considering $\boldsymbol{FC_{coin}}$ y $\boldsymbol{FS_{coin}}$.

The final equation is $Fcoin = N^{-0.1221}$

V. Final Design

For the determination of the distribution transformer capacity the following equation is proposed:

$$\mathrm{DD} = (\mathrm{DMup} \times N \times F_{coin}) \times \eta + \mathrm{AP} + \mathrm{CE}$$
$$F_{coin} = N^{-0.1221}$$
$$\mathrm{AP} = \frac{\sum_{i=1}^{Nl} \mathrm{PLmax}_{(i)}}{\mathrm{Fp}_{Lum}}$$
$$\mathrm{TRAFO} \cong \mathrm{DD}$$

Where

η = Overload Factor
AP = Street Lighting Load
CE = Special Loads
$\sum_{n=1}^{Nl} PLmax_{(i)}$ = Sum of the street lighting unit powers of the system
Fp_{Lum} = Power factor for lighting concept (0,92).

$TRAFO$ = Distribution transformer capacity [kVA].

The overload factors suggested are shown in the next table.

TABLE XI
OVERLOAD FACTORS SUGGESTED

Sector	η
Urban	0.8
Rural	0.7

VI. Conclusions.

The factors used for calculating DMup oversize the demand taking into account that they do not consider the load of induction cookers, additionally the coincidence factor employed currently does not reflect the reality. According to the analysis performed the average demand for induction cooker will be 2,38 KVA, and the proposed coincidence factor is better adjusted to the current situation of the canton Cuenca, also considers the possible behavior in terms of energy consumption in cooking food.

The incursion of electric induction cookers into the electrical system will have a huge impact on distribution networks; the values and methods for the determination of the proposed demand are adjusted to the reality, these values are based on real measurements, besides considering several parameters such as: the population growth rate, the socioeconomic conditions among others.

The proposed method offers a good degree of precision for transformers with a clear predominance of residential clients, both when DMup values with and without induction cookers. The proposed model has been validated both analytically and mathematically as a function of the measurements performed, obtaining a very high degree of precision and reliability.

VII. Bibliography

[1] D. X. Morales, Y. Besanger, S. Sami, and C. Alvarez Bel, "Assessment of the impact of intelligent DSM methods in the Galapagos Islands toward a Smart Grid," *Electric Power Systems Research,* vol. 146, pp. 308-320, 5// 2017.

[2] EERCS, "Clasificación de abonados en función de las demandas máximas unitarias proyectadas para el sector urbano y rural,," Empresa Eléctrica Regional Centro Sur, Cuenca,Ecuador2009.

[3] S. A. Moscoso, "Recategorización de clientes para el correcto dimensionamiento de redes de distribución," *UCACUE - INVESTIGACIÓN & INGENIERÍA,* vol. I, p. 37, 2012.

[4] CELEC, "Plan Maestro de Electrificación 2013 - 2022," Corporación Eléctrica del Ecuador, Quito - Ecuador, 2013.

[5] S. A. Moscoso and D. Balarezo, *ALTA TENSIÓN* vol. I. Cuenca, Ecuador: EDUNICA - Universidad Católica de Cuenca, 2014.

[6] S. A. Moscoso, "Introducción a la Distribución Eléctrica," U. C. d. Cuenca, Ed., ed. Cuenca,Ecuador, 2013.

[7] J. A. Y. Morón, *Sistemas Eléctricos de Distribución*. Barcelona, España: Reverté, 2012.

[8] H. Enríquez, *El ABC del Alumbrado y de las instalaciones eléctricas en Baja Tensión*. México D.F. : LIMUSA S.A., 2005.

[9] L. Calvo, "Comparación de Demandas de Diseño en Sistemas Eléctricos de Distribución - Aplicación en el Área Urbana de Quito," Departamento de Potencia, Escuela Politécnica Nacional Quito,Ecuador, 1990.

[10] J. Pilamunga and P. Freile, "Análisis del Factor de Carga y del Factor de Diversidad para el Diseño Eléctrico en Centros Comerciales del Municipio de Quito," Escuela Politécnica Nacional, Quito,Ecuador, 2009.

[11] D. X. Morales, D. Icaza, L. Lliguin, S. Melgar, and V. A. Vimos, "Acceptability determination of electric vehicles: Case study in a typical distribution transformer," in *2016 IEEE International Conference on Automatica (ICA-ACCA)*, 2016, pp. 1-6.

[12] ARCONEL. (2014, March 11, 2017). *Estadística del Sector Eléctrico Ecuatoriano*. Available: http://www.centrosur.gob.ec/?q=conelec.

[13] INEC. (2017, March 11,2017). *Ecuador en Cifras*. Available: http://www.ecuadorencifras.gob.ec/estadisticas/

[14] D. X. Morales, "Desarrollo de un módulo para la estimación especial de la demanda eléctrica," *Colegio de Ingenieros Eléctricos y Electrónicos del Azuay -CIEELA-,* vol. 22, 2013.

[15] INEN, "NTE INEN 2567: Eficiencia energética en cocinas de inducción de uso doméstico," ed. Quito - Ecuador: INSTITUTO ECUATORIANO DE NORMALIZACIÓN 2009.

[16] H. Alfonso, *Gestión de la Demanda a través de la sustitución de la energía en la cocción residencial: Región Metropolitana de Costa Rica*. Costa Rica, 1996.