Evaluation of Power Interruption Costs for Industrial and Commercial Sectors in Argentina

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***Abstract*-- Day by day the use of electricity is more important to human activity, in commercial, industrial and residential applications. Electrical Power Business has significantly changed in the last 30 years. A considerable change in the structure and electric power system operation can be seen throughout the world. In spite of an unbundled and competitive electric market, problems of power quality are increasingly significant. Their existence has led to the creation of a regulatory framework for the purpose of monitoring and improving this aspect. In Argentina, power quality control is carried out by penalties for those who break the laws and with rewards for those who respect the normative. Regardless of its psychological effects, preventing power outages presents a vital importance due to its severe effects on economy. Therefore, since it has so many motivating factors, studying and estimating the outage costs has been an attractive and popular field of study in the recent years.**

It is necessary to have appropriate means and methods to identify the different types of problems in electrical systems and also to quantify them in monetary values, that is the cost of losses due to power quality issues. The main purpose of this work is to develop a proper mathematical model to be able to reach a conclusion and to make estimations about customer's outage costs and also to give large power consuming customers an idea about these losses. At this point, it is described a way to find out an almost linear model for this problem. The value of this work is based on in its contribution to the investigations which determine money losses suffered by customers due to the poor quality of the received energy. Such costs, and hence the contribution obtained from this research, could be taken into account in future regulations and/or in investment plans of utilities and by companies that use sensitive equipment. Through this research it is presented a methodology for estimating the cost of power outages to customers in several subcategories of industrial and commercial sectors. The model is applied and validated in a particular case: for the customers of Cordoba Provincial Power Company (EPEC) located in the Zone "Delegation F" of Río Cuarto.

***Keywords*: Interruption Costs, Commercial and Industrial Customers, Customer Interruption Cost (CIC).**

I. Introduction

A modern power system must satisfy load and energy requirements, not only from an economic standpoint, but also provide certain levels of quality and safety. It is usual to measure the quality of the service in terms of acceptable values of frequency, voltage and security, according to the ability to provide an uninterrupted power supply under certain levels of reliability [1] .

The companies involved in the generation and distribution of electricity, especially those that provide distribution services (utilities), are obliged to respect certain minimum standards of quality and service. Maintaining these levels in a certain range involves high investments. In general, it must be achieved an optimum balance between investment and security, which corresponds in theory to minimize the overall cost of investment and operation and failure cost [2].

A continuous power supply is an aspect of quality of the electricity service, which is described by literature as reliability of supply. When the continuity of supply fails, that is, when the supply voltage disappears at the point of connection, it is said that there is an *"interruption"*.

An interruption of power supply can be a big economic loss for those affected consumers.

The cost of power supply interruption is a sum of economical and/or social damages (in monetary values) that consumers have to afford when energy is not supplied. It is important to highlight that an unsatisfactory supply of electricity to the user represents a much bigger value than the price of the energy not delivered, because of the negative social and economic costs of supply restriction.

The interruption cost is difficult to be valued because of several factors that influence on it [3]. The value of the interruption cost can vary significantly depending on different factors such as the magnitude of the failure, duration of the interruption, type of affected user, frequency of interruptions, voltage level of the affected user, time, day and season of failure occurrence.

While assessing the cost of power outages, there are two main challenges. The first one is the method of collecting the required data that has to be chosen, and the second one is the way of evaluating these data.

Current state of methods for estimating the cost of power outages in the world and the few developments made in our country, indicate the need for a comprehensive survey of existing tools for estimating costs.

II. Evaluation Methodology

The most common method that is widely used is customer surveys. Although it is quite expensive, difficult to handle and it requires too much time and effort to collect data, customer surveys are considered to bring the most accurate results [4]. The power outage cost information was collected by a previous study conducted at the National University of Río Cuarto [5]. In that study, surveyors visited each company and/or business and contacted the more skilled persons to answer the questionnaire. The whole data used in this work is based on the mentioned study. There are two main sectors that are of interest in this work, industrial and commercial areas.

III. Approach to Modeling

Modeling this phenomenon needs to lead to an accurate prediction in order to obtain representative results, that is to represent even those customers that were not surveyed.

Data of production/sales were weighted by the coefficients of each type of industry/commerce. After that, estimated cost results were plotted. Finally, the formulas of each data series were obtained by means of regression analysis.

Graph characteristics, coefficients and formulas were evaluated and discussed.

A. Modeling analysis

Modeling aims to identify the models that reasonably allow predicting accurately interruption costs for customers who are not directly examined. They are obtained from the information available, through the analysis of a representative sample of customers brought by the company of electricity distribution.

A good estimation of the interruption cost consists in knowing how the client would afford electricity supply interruptions, considering different failure situations (frequency and duration, season and time, etc.), if the customer has backup equipment systems (stand-by systems), and the costs associated with the interruption [6], [7].

According to what it was presented in past works [5], [8], the results of the average value of interruption cost are a function of the interruption nature, the region, and the types of customers who answered certain proposed scenarios. It can be seen that, the combination of customers and interruption characteristics, may substantially vary depending on the variables that are being examined. To adequately manage the diversity of influences, it must be developed a multivariable analysis of customer prejudice. In this way, information of proposed situations and companies' characteristics are used to estimate a general function of the customer prejudice. This function expresses the cost of disruption that customers suffer, both in commercial and industrial areas, depending on the duration of the interruption, starting time, season, and several customer characteristics such as annual consumption, number of employees and other variables.

The ideal conceptual framework to a prior data detailed analysis is statistical regression [8].

Studying and estimating costs of electrical interruptions have been an attractive field of several notorious publications in the last years. However, although there are many studies on reliability cost analysis, the main problem is the inexistence of an accurate and rigid method to estimate the economic performance of a power outage.

B. Proposed Methodology

In order to find a solution and to develop a methodology for estimating power outages cost, it was necessary to answer the following questions:

'What are the consequences of a power outage?'

'What is the reliability of energy?'

From customers' perspective, reliability is defined as the continuity of the service. Although there are some standards for electrical companies, most customers are interested only in the availability of the service. A relatively small number of customers look for more stringent quality requirements, such as limits on voltage dips and frequency variations. Thus the value of the service continuity, and therefore the cost of a power interruption, changes from client to client in relation to the needs of every particular one.

Power outage costs increase almost linearly during the first eight hours, and then decrease for longer interruptions, according to a study conducted by the U.S. Energy Department, taken as a first step in the lack of consistent data needed to support a better estimate of the economic value of electricity reliability [9]. In this context, twenty studies were conducted by eight electricity companies between 1989 and 2002, studying representative residential and commercial/industrial groups (small, medium and large ones). In those models, data obtained in the different surveys are incorporated into a meta-database in which each interruption scenario (e.g., power outage for one hour on a summer afternoon from Monday to Friday) is treated as an independent case. In this sense, it is possible to make comparisons between the characteristics of the interruption and to increase the statistical power of the test results, and it cannot be used to estimate the damage to individual companies.

A linear mathematical model for the evaluation of CIC (Customer Interruption Cost) was assumed, since the purpose of this work is to find a simple model for calculating the costs of power outages in Argentina. Taking into account that in distribution systems in our study most of the power outages are less than eight hours (except in exceptional cases), and having cost data for power interruption durations of less than 8 hours, it was only employed the data obtained for 3 minutes, one and four hours durations.

In commercial and industrial branches a significant number of respondents said that the costs of interruptions were equal to zero for one second interruption duration. Consequently, to prevent standard regression techniques produce partial parameter estimates, the cost data obtained for outages of a second in duration were discarded.

C. Modeling design

In this study the data used were based on the paper of reference [5]. In the selected sample there were a total of 87 customers, where 45 were commercial users and 42 were industrial.

Instead of using overall average values, each sector, industrial and commercial, was separately analyzed [8]. In addition, each sector was divided into sub-categories, as follows:

i) Industrial sub-categories: Food, Metallurgy, Grains, Meat, Construction and other industries.

ii) Commercial sub-categories: Food, Supermarkets, Fuels, Houseware, Construction, Clothing and other companies.

The main problem in customer surveys, as it was stated in paragraph 2.1.2 b) [5], is subjectivity. Naturally, people and companies tend to exaggerate their losses in case of an interruption event. The Commercial sector analysis and evaluation of the costs of power interruption in Food industries are more difficult than in the Industrial sector. This is due to that the commercial sector does not have a continuous production, and therefore, it is impossible to determine a cost value proportional to production losses.

Moreover, as it was mentioned above, there are many factors that affect the cost of the interruption, like its duration, time of occurrence, character (if unexpected or planned), the size of the company, the season (summer or winter) and, finally, the type of customer (industrial, commercial, residential or agricultural).

According to the analysis in the previous work, it can be seen that the most incident variables, besides the duration of the interruption, are the size of the company and its energy consumption.

For all this, the arithmetic mean is not the most representative value of the cost of the interruption. For the purposes of obtaining more accurate and reasonable results, weight factors were included to consider these variables effects. Logic of weighting factors for the cost of interruptions comes from the data obtained in the survey.

After reaching this conclusion, in order to find the "Estimated Cost", data disruption cost in [USD] were weighted by the coefficients of each type of industry/trade and then normalized to [USD/kWh]. Finally, with the aid of linear regression analysis, it was possible to find the linear formulas for each data series.

The followed steps were:

1) Trough the survey, each respondent estimated the outage cost in Pesos, for different periods of time (3 min, 1h and 4h). Then the CDF (Customer Damage Function) is defined as:

Cost reported per hour “x” = (cost estimate for “x” period)

If the expression above is divided by the annual energy consumed by each costumer, the result is CDF in [$/kWh], that is to say:

Reported Cost in [USD/kWh]= (Cost reported per hour “x”) / (annual comsuption of energy)

This result has a linear trend and can be approximated by the expression:

$$y = a + Bx$$

2) On the other hand, cost estimate is:

Cost estimate for the “x” hour = Weighted Cost for the “x” hour

Cost estimate for the “x” hour = [cost estimate for “x” period] ×[W_i]

were **[W_i]** is the weigth matrix.

If the expression above is divided by the annual energy consumed by each costumer, the result is another CDF in [USD/kWh], that is to say:

Estimated Cost in [USD /kWh]= (Weighted Cost for the “x” hour) / (annual comsuption of energy)

If the linear expression above is analyzed by a simple linear regression model, the variables can be expressed in the form:

$$Y = \alpha + \beta x + \varepsilon$$

were:

x: Independent variable (input level)

Y: Dependant variable (output)

ε: Random error (zero mean)

α, β: Regression Coefficients

This means finding α y β, such that Y can be estimated from the realization of the variable x, through a linear function.

In following sections, for all the sub-categories proposed for the industrial and commercial sectors, it is presented the results of the CIC, reported cost and estimated cost, as well as linear formulas for each data series which have been found with the help of linear regression analysis.

IV. Results

Using the obtained data, a detailed analysis of the several cost components was carried out to determine estimations about customer outage costs, for different subcategories by type of industry or business. For all the values calculated in this work it was assumed an exchange rate of **1.00USD = AR$ 4.55**.

The most outstanding results can be found below.

A. Interruption costs estimate for Industrial sector

A.1 Food industry.

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0111	0.0234	0.0459
Estimated cost [USD/kWh]	0.0121	0.0203	0.0404

Table 1. Interruption Costs for a Food Industry

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.98180686
Determination coefficient R^2	0.96394472
R^2 Adjusted	0.92788944
Typical error	0.00463046

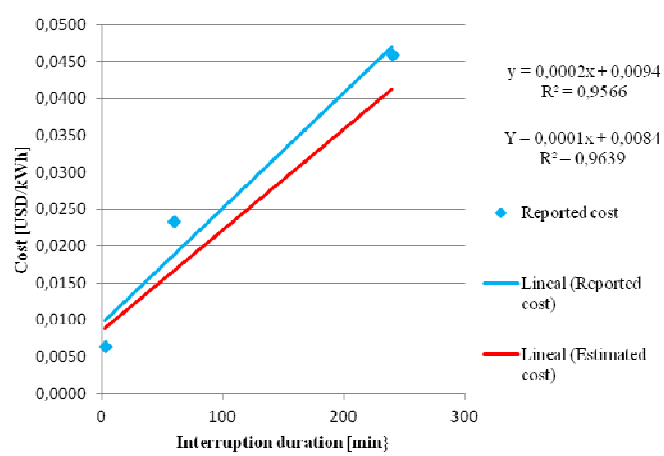

Figure 1. Interruption Costs for Food Industry in USD/kWh of annual energy.

A.2 Metallurgy Industry

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0116	0.0459	0.1117
Estimated cost [USD/kWh]	0.0123	0.0496	0.1171

Table 2. Interruption Costs for a Metallurgy Industry

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99214938
Determination coefficient R^2	0.9843604
R^2 Adjusted	0.9687208
Typical error	0.00939554

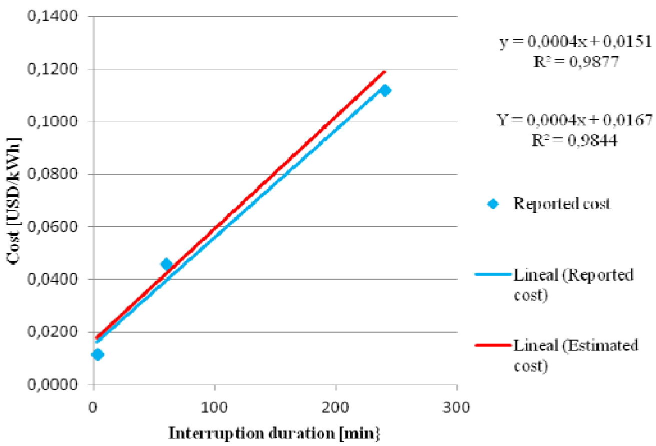

Figure 2. Interruption Costs for Metallurgy Industry in USD/kWh of annual energy.

A.3 Grain Industry.

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0015	0.0041	0.0088
Estimated cost [USD/kWh]	0.0015	0.0037	0.0084

Table 3. Interruption Costs for a Grain Industry

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99700763
Determination coefficient R^2	0.99402421
R^2 Adjusted	0.98804842
Typical error	0.00038213

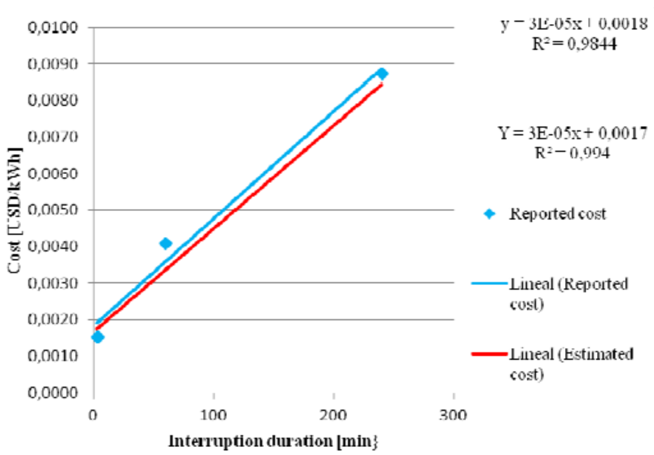

Figure 3. Interruption Costs for Grain Industry in USD/kWh of annual energy.

A.4 Meat Industry.

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0010	0.0029	0.0075
Estimated cost [USD/kWh]	0.0010	0.0025	0.0063

Table 4. Interruption Costs for a Meat Industry

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99866916
Determination coefficient R^2	0.9973401
R^2 Adjusted	0.9946802
Typical error	0.00019833

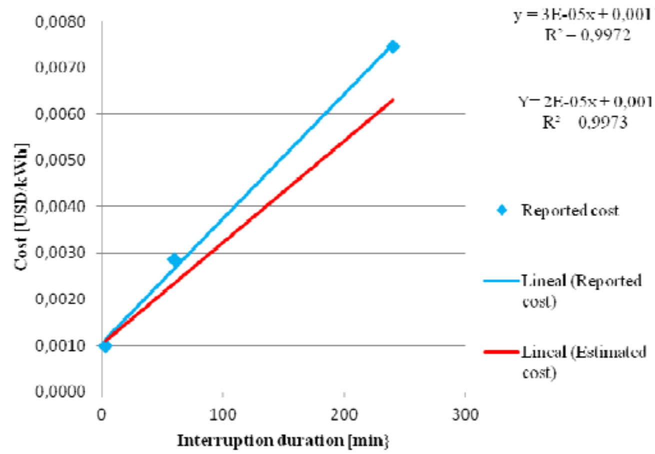

Figure 4. Interruption Costs for Meat Industry in USD/kWh of annual energy.

A.5 Construction Industry.

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0117	0.0440	0.1140
Estimated cost [USD/kWh]	0.0091	0.0350	0.0874

Table 5. Interruption Costs for a Construction Industry

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99527151
Determination coefficient R^2	0.99056539
R^2 Adjusted	0.98113077
Typical error	0.00547782

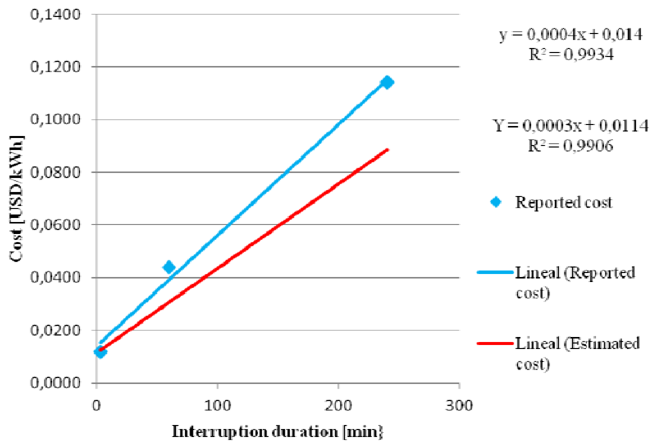

Figure 5. Interruption Costs for Construction Industry in USD/kWh of annual energy.

A.6 Other Industries.

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0020	0.0128	0.0822
Estimated cost [USD/kWh]	0.0019	0.0121	0.0775

Table 6. Interruption Costs for Other Industries

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99424864
Determination coefficient R^2	0.98853037
R^2 Adjusted	0.97706073
Typical error	0.00621495

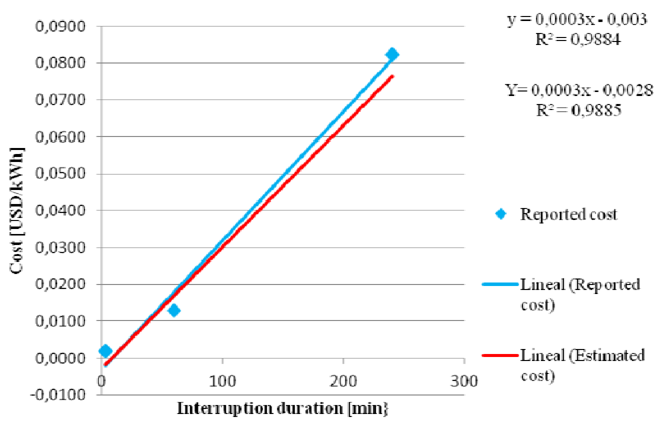

Figure 6. Interruption Costs for Other Industries in USD/kWh of annual energy.

A.7. Cost Estimate Example for an Industry

In a EPEC power supplier station located in the area "F", an unexpected power outage takes place, which lasts an hour and a half. A meat packing plant experiences this interruption. The electricity distributor in that region wants quickly to make a rough estimate of this interruption, knowing that the annual energy consumption of the company is 2,489,990 kWh. Then, what is the cost that the customer has to afford because of the service interruption?

Data needed to estimate the cost are:

- ✓ Type of industry: Meat Industry
- ✓ Interruption duration: 90 [min]
- ✓ Energy annual comsuption: 2,489,990 [kWh]

From the results of previous section for a Meat Industry, CIC is:

Estimated cost: Y = 0.00002x + 0.001

where function Y is the cost of power outage and x is its duration.

Therefore:

CIC = 0.00002 × 90 + 0.001 = 0.0030 [USD / kWh]

Expressing it in [USD]:

CIC = 0.0030 [USD / kWh] × 2,489,990 [kWh] =
=USD 7,501.10

Since the expression of CIC is known, and that the data of annual consumption of energy are easily accessible, the power distribution company would be able to have an idea about the losses of a particular customer, very quickly.

B. Interruption costs estimate for Commercial sector

B.1 Food shops

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0020	0.0128	0.0822
Estimated cost [USD/kWh]	0.0019	0.0121	0.0775

Table 7. Interruption Costs for Commercial sector – Food shops

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99663033
Determination coefficient R^2	0.993272
R^2 Adjusted	0.98654401
Typical error	0.00276371

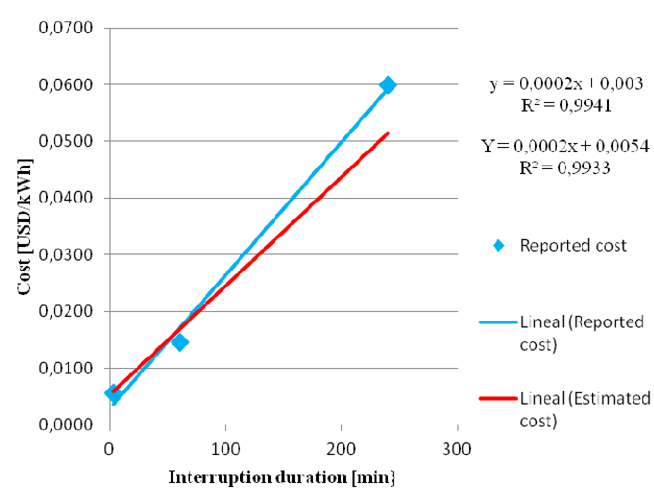

Figure 7. Interruption Costs for a Food Sales Shop in USD/kWh of annual energy.

B.2. *Supermarkets*

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0003	0.0019	0.0112
Estimated cost [USD/kWh]	0,0003	0,0017	0,0104

Table 8. Interruption Costs for Commercial sector – Supermarkets

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99478944
Determination coefficient R^2	0.98990603
R^2 Adjusted	0.97921207
Typical error	0.00081492

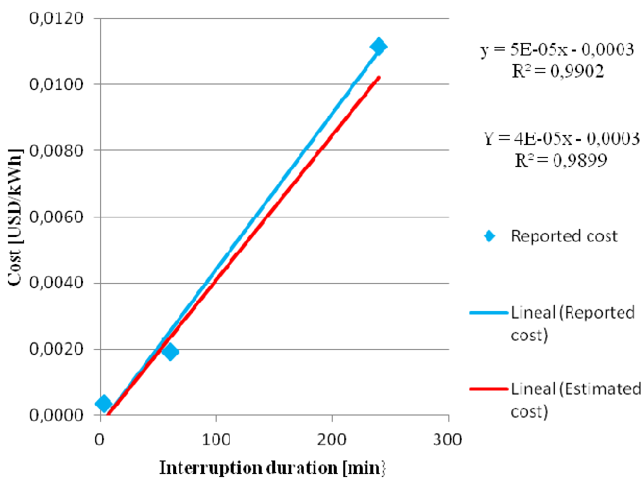

Figure 8. Interruption Costs for a Supermarket in USD/kWh of annual energy.

B.3 *Fuels*

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0005	0.0016	0.0068
Estimated cost [USD/kWh]	0.0005	0.0016	0.0066

Table 9. Interruption Costs for Commercial sector – Fuels

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99701208
Determination coefficient R^2	0.99403308
R^2 Adjusted	0.98806616
Typical error	0.00035707

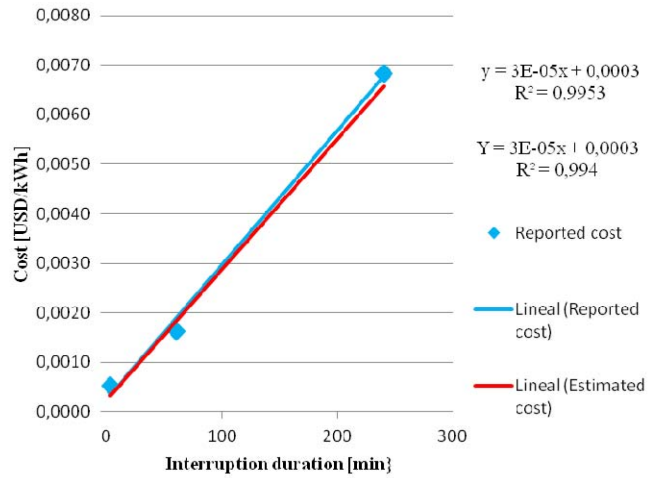

Figure 9. Interruption Costs for Fuels Commerces in USD/kWh of annual energy.

B.4. *Household Goods*

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0023	0.0264	0.1519
Estimated cost [USD/kWh]	0.0015	0.0270	0.1574

Table 10. Interruption Costs for Commercial sector – Household Goods

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.99683284
Determination coefficient R^2	0.99367572
R^2 Adjusted	0.98735143
Typical error	0.00940467

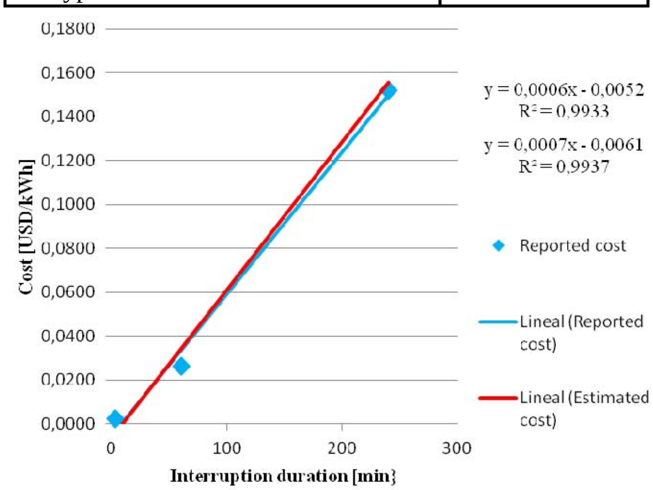

Figure 10. Interruption Costs for Household Goods Shops in USD/kWh of annual energy.

B.5 *Construction Items*

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0061	0.0513	0.1812
Estimated cost [USD/kWh]	0,0065	0,0472	0,1689

Table 11. Interruption Costs for Commercial sector – Construction items

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.9999611
Determination coefficient R^2	0.9999222
R^2 Adjusted	0.99984441
Typical error	0.00110974

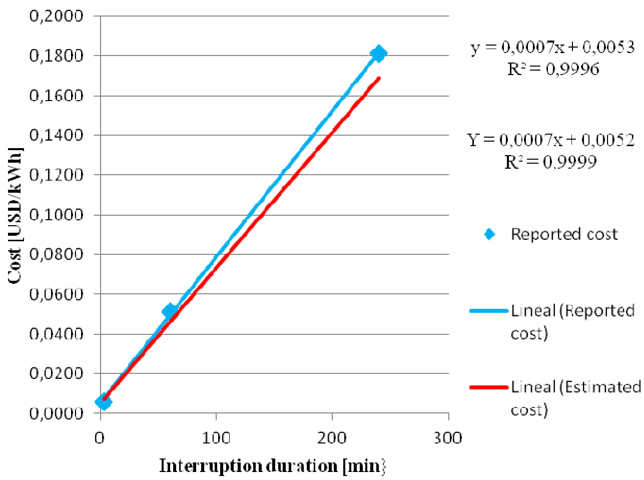

Figure 11. Interruption Costs for Construction Items Shops in USD/kWh of annual energy.

B.6 Clothes

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0012	0.0145	0.0630
Estimated cost [USD/kWh]	0.0015	0.0133	0.0510

Table 12. Interruption Costs for Commercial sector – Clothes

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.9999999
Determination coefficient R^2	0.9999998
R^2 Adjusted	0.9999996
Typical error	1.6379E-05

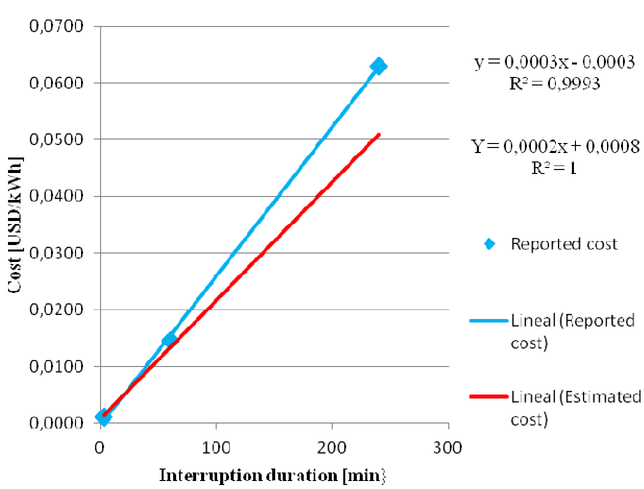

Figure 12. Interruption Costs for Clothes Sales Shops in USD/kWh of annual energy.

B.7. Other Sales

Interruption duration [min]	3	60	240
Reported cost [USD/kWh]	0.0111	0.0645	0.1484
Estimated cost [USD/kWh]	0.0089	0.0603	0.1432

Table 13. Interruption Costs for Commercial sector – Other sales

Regression Summary:

Regression Estatistics	
Multiple correlation coefficient	0.98769153
Determination coefficient R^2	0.97553455
R^2 Adjusted	0.9510691
Typical error	0.01499345

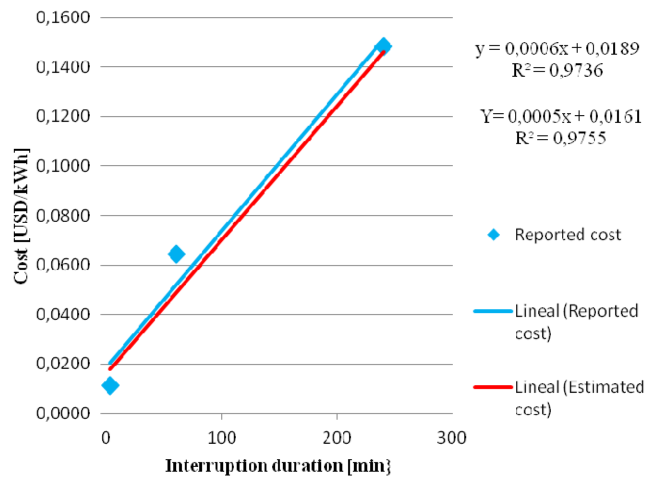

Figure 13. Interruption Costs for other Commerces in USD/kWh of annual energy.

B.8. Cost estimate example for Commercial Sector

A customer, who has a Food Shop, wants to estimate what his losses would be in case of an unexpected power outage, which lasts three hours. An analysis of the service turnover given by EPEC (area "F"), yields an annual energy consumption of 45,000 kWh for this shop.

What is the cost of the power interruption?

Data needed to estimate interruption cost are:

- ✓ Commerce Type: Food Sales
- ✓ Interruption duration: 180 [min]
- ✓ Energy anual comsuption: 45,000 [kWh]

From the results of previous section for a Meat Industry, CIC is:

Estimated cost: $Y = 0.0002\ x + 0.0054$

where function Y is the power outage cost, and x is its duration. Therefore:

$$CIC = 0.0002 \times 180 + 0.0054 = 0.0414\ [USD / kWh]$$

Expressed in [USD], it is:

$$CIC = 0.0414\ [USD / kWh] \times 45{,}000\ [kWh] = USD\ 1{,}863$$

Since the expression of CIC is known, and that the data of annual consumption of energy are easily accessible, customer would be able to have an idea about his losses, very quickly.

C. Comments

As it was expected, each sector, and, particularly, each sub-category has its own unique characteristics in case of a power interruption. In consequence, it is necessary to separately analyze and estimate the costs of outages. Besides this, the parameters that affect the costs of interruptions for different types of customers, and the effects of these parameters on the estimations, change significantly. As a result, the estimation and calculation of such costs become a difficult task for professionals. To facilitate this process, a methodology based on surveys made to customers has been developed to convert the calculations to estimate the interruption cost with respect to such parameters.

The results of this study are quite simple and easy to understand. When professionals working for an electricity distributor want to know the cost of a power outage for a period of time, they can make use of the expressions presented in this study. As they also know how many and what type of customers are being fed by their power system, they can use the results of interruption costs in planning power delivery for future investments, in the design of new facilities to the reconfiguration of networks and in scheduling maintenance activities.

Moreover, several customers, both industrial and commercial, can easily estimate economic losses in case of an unexpected power outage through the steps shown above.

Making an analysis of the graphical results it is found that the relationship between Reported Cost and Estimated Cost, substantially changes over time within each sub-category. For example, Construction branch exhibited the highest difference with a ratio of 1.3 for a 4 hours interruption. On the other hand, Metal industry ratio was less than 1, in all the studied durations, showing an undervalued Reported Cost. In the commercial sector, the Clothes category represents the highest ratio with a value of 1.24 for an interruption of 4 hours.

V. Conclusions

This study was based on the results of surveys made to the customers of a public utility in central Argentina, a country of intermediate development. It was shown a summary of the research conducted to determine the perceived cost estimates or losses for commercial and industrial customers, small and medium, who suffered power outages. On one hand, it was quite obvious and normal that reported costs were higher than the actual CIC cost values. But, on the other hand, the results from the analytical method were expected to be far lower than the reported costs. At the end of this analysis that expectation was confirmed. In order to get more reasonable and more accurate data, some weighing factors were sought with the aid of the questions presented to the respondents during the survey.

It is worth highlighting that the interruption cost data can be used in the planning of the power delivery, in the design of new facilities, in network operation and in maintenance activities. Official departments need to know these results for a correct legislation. And of course, the customers can estimate their true interruption costs in order to see their real losses and to prevent such damages in a future. These facts clearly show the meaning and the importance of evaluating power outage costs.

Interruption costs that have to be afforded by for customers are a key indicator of their expectations to consider in future planning.

The results provided sufficient information to develop a model to predict the cost of power interruptions. The main motivating factor was to find a methodology based on data provided by the customer, which is who really suffers the effects of the power outage. It was necessary to know the size of the company, its peak demand and its annual electricity consumption, which are clear, accurate, easily accessible and what is most important, they are objective.

A linear formula for each sub-category in both sectors was derived for estimating the costs of power outage. The results were compared with average costs reported by surveyed customers.

The methodology exposed in this paper to estimate interruption costs for commercial and industrial sectors (SMEs) in our region, is quite simple, easy to understand and easy to follow. This was clearly shown in the examples developed in the body of this study. Both, utility and customers can use these results to estimate the costs of power outages, in every possible situation, just by following the steps explained above.

VI. References

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