EVALUATION OF POWER OUTAGE COSTS FOR INDUSTRIAL SECTORS IN FINLAND

Sinan KÜFEOĞLU
Aalto University – Finland
sinan.kufeoglu@aalto.fi

Matti LEHTONEN
Aalto University – Finland
matti.lehtonen@aalto.fi

ABSTRACT

Estimating the customer interruption costs is a challenge for the electric power society. In this paper the results of a customer survey on power outage costs for industry sectors conducted in Finland have been presented. In addition, the problem of strategic responses has been investigated and an elimination method for the zero and extreme responses has been proposed.

INTRODUCTION

Electric power business has changed dramatically for the past 30 years. There has been a considerable change in the structure and electric power system operation throughout the world. As the world gets more and more dependent on the electric power and since the reliability concerns have been increased, studying power interruptions and their economic worth attracts more attention. Having a moderate scale economy and the competitive electric power market make Finland a proper country to study power outage costs for industrial customers.

There are several methods used in assessing the customer costs of electric power outages. Three major classes; indirect analytical methods, customer surveys and case studies, are commonly used in the power business and academic studies [1]. Among all, for being regarded as the one containing more accurate data, the customer surveys are the most preferred ones by the electric power society [2]. Nevertheless, there are some concerns such as subjectivity of the results and strategic responses, regarding the customer surveys for estimating customer interruption costs (CICs) [3], [4]. In this paper, the authors have focused on handling the strategic responses matter only. The analysis of the subjectivity, and therefore the reliability of the customer surveys, and moreover, proposing an analytical method to estimate CICs are to be done by the authors in a later study. Interpreting the obtained data and handling the biased responses is another challenge to the researcher. A study conducted in Finland proposes three different methodologies to overcome strategic response problem [5]. Another study [6] utilizes a statistical approach to eliminate outliers in the data set.

In this paper, the authors chose to follow the z-score technique for interpreting the customer survey data.

A z-score, or a standard score (the z value of the standard normal distribution), indicates how many standard deviations a data point is from the mean. It is simply calculated as follows:

$$z = (x - \mu) / \sigma \qquad (1)$$

Where; z is the z-score, x is the value of the data point, μ is the mean of the data set and σ is the standard deviation of the data set.

An outlier (an extreme outlier) is an extreme point that is outside the range of typical data values in a data set. If the absolute value of the z-score of an element is equal or greater than 3.0, then that point is called an extreme outlier. After the customer survey, the z-score elimination has been applied to each data set, and the outliers have been censored during the statistical analysis.

THE CUSTOMER SURVEY

In this study, the material of a customer survey conducted to evaluate the customer interruption costs of industry sector in Finland has been used. A total number of 126 customers were involved and about 73% of the response rate had been reached. In the customer survey the Direct Worth approach model has been utilized. Direct worth approach (DW) or direct costing is a method that presents different outage scenarios and asks the customers to estimate a rough cost in case of the scenarios [4]. By one-to-one interviews, telephone calls and e-mail questionnaires, the power outage cost information had been collected by a study conducted at Aalto University, School of Electrical Engineering [7].

There are many factors affecting the industry sector customer interruption costs. Among all, the duration of the interruption and the character of interruption (whether it is unexpected or planned) are the two major ones that directly affect the monetary impacts of the power outages.

The power consumption changes in considerable amounts among customers depending on the size, the production amount, the field that the company works in and the equipments that are being used by those facilities. Therefore, when estimating outage costs for the large industrial facilities for utility planning purposes, using average cost estimation techniques for whole industry and service sector is not advised. Instead of using average values, each industrial sector must be analyzed separately

[8]. Due to the reasons explained above and regarding the power consumption characteristics, to get more reliable results, the facilities are divided into subcategories. The industrial sector subcategories are: food, chemical, glass, paper, metal, timber, construction and electrical.

By the aid of the survey, each respondent was asked to estimate his/her amount of power outage cost in Euros for different time periods (for 1 sec, 15 min, 1 h, 4 h, 8 h and 12 h). And then two Customer Damage Functions (CDF) were defined as:

$$CICp = \frac{\text{Reported cost for t hours}}{\text{Peak power of the customer}} \text{ in } €/kW$$

$$CICe = \frac{\text{Reported cost for t hours}}{\text{Annual energy consumption}} \text{ in } €/kWh$$

Before going to regression analysis, the data of reported unexpected outage costs for one hour for all industry sectors has been presented as a histogram in the below figure. As it is seen, the distribution of the responses is highly right skewed. This results in difficulty in reaching a typical value to represent the skewed outage cost distribution. Therefore elimination is imperative to carry out healthy statistical analysis to reach a sound conclusion for estimating CICs of the industry sector customers.

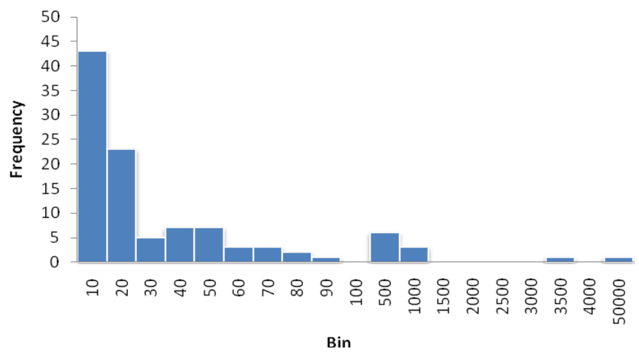

Figure 1.Uncensored distribution of the industry sector unexpected outage costs for 1hour in €/kW

The uncensored histogram shows that there are more than 40 responses at the bin range of 0-10 and a considerable amount of these are zero responses. On the other hand, there is a response at the bin point 5000, which is an extreme response for the customer survey study and it must be censored for the sake of reliable analysis.

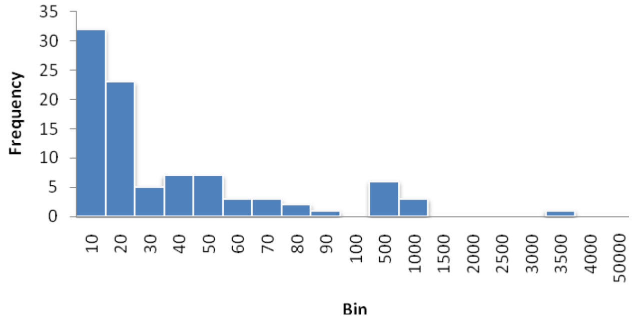

Figure 2.Censored distribution of the industry sector unexpected outage costs for 1hour in €/kW

After eliminating the data points corresponding to the strategic responses with the z-score elimination technique, a new data set for the customer survey analysis was reached. As it can be seen from the figure, the zero responses and the extreme response have been removed from the data set in order to proceed with the regression analysis.

RESULTS

Typical values have been defined as the censored average values which are the CDFs **Reported cost in kW of peak power** and **Reported cost in kWh of annual energy consumption**. At this section, only the CDFs of Reported cost in kW of peak power (CIC*p*) have been plotted and analyzed. A regression technique was needed to come up with a characteristic that can be utilized to estimate the CICs for the desired time span. To get more precise results, instead of linear regression, a second order polynomial regression has been preferred. For the volume concerns of the paper, among all the industry sectors only metal and paper industry results have been shown here. Rest of the results is given as a summary. Furthermore, Table 5 and Table 6 give typical values of CIC*e*'s in €/kWh for each industry sector.

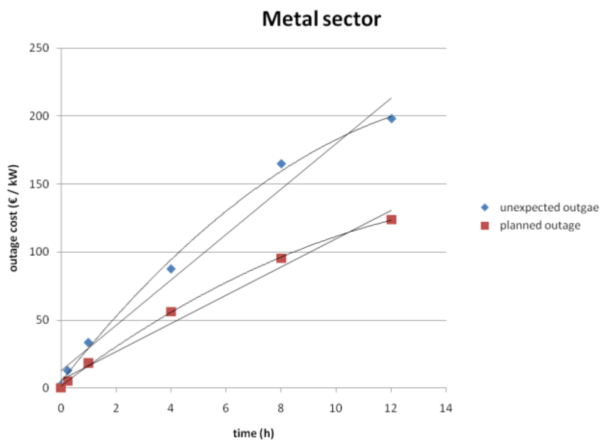

Figure 3.Metal sector CIC*p* characteristics for both unexpected and planned outage scenarios in €/kW

Unexpected outage:
Polynomial regression result:
CICp = -0.7756t^2 + 25.577t + 4.5357, R^2=0.9969
Where *CICp* is in €/kW peak power of the customer and *t* is the time of the outage.
Linear regression result:
CICp = 16.712t + 12.749, R^2 = 0.9769
Planned outage:
Polynomial regression result:
CICp = -0.4221t^2 + 15.213t + 1.616, R^2 = 0.9995
Linear regression result:
CICp = 10.389t + 6.0854, R^2 = 0.9841

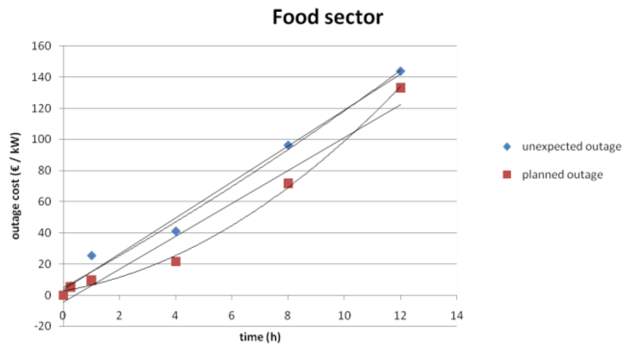

Figure 4.Food sector CICp characteristics for both unexpected and planned outage scenarios in €/kW

Unexpected outage:
Polynomial regression result:
CICp = 0.1323t^2 + 10.027t + 4.8271, R^2 = 0.989
Linear regression result:
CICp = 11.54t + 3.4259, R^2 = 0.9877
Planned outage:
Polynomial regression result:
CICp = 0.6557t^2 + 3.0589t + 2.7897, R^2 = 0.9969
Linear regression result:
CICp = 10.553t – 4.1536, R^2 = 0.9617

The comparison of the R^2 values of the second order polynomial and linear regression results clearly shows that, to reach more accurate estimation for the power outage costs, it is better to use polynomial regression instead of linear one. Nonetheless, making use of higher order polynomial regressions could be claimed to be unnecessary since it will not bring much of improvements in the R^2 results and it will result in a more ambiguous analysis procedure.

The rest of the results for each sector are given only for the second order polynomial function case. For the sake of simplicity, the polynomials are expressed in the format: $CICp = at^2+bt+c$ and the corresponding coefficients and the R^2 values are tabulated as follows:

Table1.Second order polynomial regression coefficients of industry sector CICp's in €/kW and R^2 values for unexpected outage scenario

	a	b	c	R^2
chemical	-0.2063	12.244	2.5008	0.9894
glass	2.5376	49.847	10.559	0.9732
paper	-0.4351	27.105	4.7851	0.9885
timber	-0.5044	19.993	-0.4905	0.9976
construction	-1.2472	43.806	3.477	0.9967
electrical	-0.4688	14.488	4.8309	0.9927

Table2.Second order polynomial regression coefficients of industry sector CICp's in €/kW and R^2 values for planned outage scenario

	a	b	c	R^2
chemical	-0.1762	5.6816	4.0775	0.9543
glass	0.501	2.0898	3.661	0.9845
paper	-0.2562	23.065	3.1196	0.995
timber	0.0935	8.8116	-0.3399	0.9811
construction	-1.3965	41.74	-1.4846	0.9912
electrical	-0.1294	6.6701	1.5281	0.993

The typical values used in the regression analysis for only 1h, 4h and 8h time spans are presented in the tables 3 and 4.

Table 3.Typical values of CICp's for industry sectors in € /kW of peak power for unexpected outage scenario

	unexpected outage		
	1h	4h	8h
metal	33.37	87.5	164.9
food	25.34	40.99	96.15
chemical	20.85	41.01	92.42
glass	48.94	197.16	221.74
paper	28.09	124.44	176.72
timber	15.40	67.87	131.75
construction	53.84	145.92	284.12
electrical	20.05	49.18	96.40

Table 4.Typical values of CICp's for industry sectors in €/kW of peak power for planned outage scenario

	planned outage		
	1h	4h	8h
metal	18.33	56.05	95.34
food	9.64	21.70	71.81
chemical	16.77	20.28	39.69
glass	7.30	27.07	45.09
paper	24.40	102.04	160.97
timber	7.29	26.56	86.04
construction	40.89	124.35	260.86
electrical	9.07	22.76	49.57

To illustrate the results in a different perspective, the second CDF (CICe), the monetary loss of certain power outage for certain time span divided by the annual energy consumption was defined. The annual working hours was defined to be 3000 hours [9]. To avoid carrying out further regression analysis and presenting those on the paper, only the censored average values were calculated. The following typical values are tabulated in € cents/kWh for each industry sector.

Table 4.Typical values of CIC*e*'s for industry sectors in € cents/kWh of annual energy consumption for unexpected outage scenario

	unexpected outage		
	1h	4h	8h
metal	1.07	2.92	5.50
food	0.65	1.37	3.21
chemical	0.83	1.37	3.08
glass	1.63	6.57	7.39
paper	0.94	4.15	5.89
timber	0.51	2.26	4.39
construction	1.62	4.86	9.47
electrical	0.67	1.64	3.21

Table 5.Typical values of CIC*e*'s for industry sectors in € cents/kWh of annual energy consumption for planned outage scenario

	planned outage		
	1h	4h	8h
metal	0.58	1.87	3.61
food	0.32	0.72	2.39
chemical	0.67	0.68	4.86
glass	0.24	0.90	1.50
paper	0.81	3.40	5.37
timber	0.24	0.89	2.87
construction	0.95	3.77	7.90
electrical	0.30	0.76	1.65

CONCLUSIONS

Estimating the power outage costs is of great value and importance. The customer survey method is considered as the best way of handling the calculation of the interruption costs problem. The scale of the Finnish economy avoids excessive time demands and high monetary expenditure when doing a customer survey. The response rate of the survey was satisfactory to reach solid conclusions about the rough estimations of the economic worth of the electric power outages in Finland for the industry sector. After eliminating the outliers, the remaining data has been plotted and second order polynomial regression analysis has been carried out for the different industry sectors. Although z-score elimination technique is a successful one to handle the zero responses and extreme responses, the problem of biased answers persists. It could be claimed that some responses had been given in a rush without too much of consideration, and some respondents had given highly rough figures as responses to the questions. In addition, there is no doubt that the respondents sometimes feel to exaggerate their losses. After taking account these concerns, the authors believe that the correctness and the credibility of the direct worth approach is questionable. Therefore, the authors now work on another comprehensive study following the indirect analytical methods to come up with a solid conclusion and recommendation for estimating the customer interruption costs.

REFERENCES

[1] G. Wacker, R. Billinton, 1989, "Customer Cost of Electric Service Interruptions", *Proceedings of the IEEE*, Vol. 77, No. 6, 919-930.

[2] R. Billinton et al., 2001, "Methods to Consider Customer Interruption Costs in Power Systems Analysis", *CIGRE Task Force,* Report.

[3] R. Herman, T. Gaunt, U. Minnaar, R. Koch, 2007, "Direct and indirect estimation of domestic customer interruption costs: considerations and preliminary results", *CIGRE SC-C6 (COLL 2007),* Working Group C6-13. Rural Electrification, Topic A.

[4] G. Kjølle, K. Samdal, B. Singh, O. Kvitastein, 2008, "Customer Costs Related to Interruptions and Voltage Problems: Methodology and Results", *IEEE Transactions on Power Systems*, Vol. 23, No. 6, 1030-1038.

[5] K. Kivikko, A. Makinen,P. Jarventausta, A. Silvast, P. Heine, M. Lehtonen, 2008, "Comparison of reliability worth analysis methods: data analysis and elimination methods", *Generation, Transmission & Distribution, IET,* Vol.2, No. 3, 321-329.

[6] M. Sullivan, M. Mercurio, J. Schellenberg, M. Freeman, 2009, "*Estimated Value of Service Reliability for Electric Utility Customers in the United States*", Energy Analysis Department, Ernest Orlando Lawrence Berkeley National Laboratory, Berkeley, CA, USA, 11-12.

[7] A. Silvast , P. Heine, M. Lehtonen, K. Kivikko, A. Mäkinen, P. Järventausta, 2005, "*Sähkönjakelun keskeytyksestä aiheutuva haitta* (Customer Interruption Costs in Finland)", Teknillinen korkeakoulu, Tampereen teknillinen yliopisto.

[8] M. Sullivan, T. Vardell, M. Johnson, 1997, "Power Interruption Costs to Industrial and Commercial Consumers of Electricity", *IEEE Transactions on Industry Applications*, Vol. 33, No. 6. 23-35.

[9] M. Lehtonen, P. Heine, A. Silvast, K. Kivikko, A. Mäkinen, P. Järventausta, 2006, "Customers´outage costs in electrical distribution networks" *5th International Conference Electric Power Quality and Supply Reliability*, Viimsi, Estonia, 87-91.