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Interruption costs of service sector electricity customers, a hybrid approach

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ABSTRACT

A power outage brings in economic losses for both the customers and the utilities. Studying these unwanted events and making solid predictions about the outcomes of the interruptions has been an attractive area of interest for the researchers for the last couple of decades. By making use of a customer survey study conducted in Finland, this paper benefits from both the reported cost data collected from customers and from the analytical data that are available and then presents a new hybrid approach to estimate the customer interruption costs of service sector customer segment. Making use of Value Added information of the customers is a common practice for the cost normalization purposes. This paper verifies the approach by comparing the findings of the customer survey and the econometric model suggested here. This study is a unique source in terms of providing a reliable, easy to apply, and a straightforward model for calculating the economic impacts of power outages.

Introduction

Starting from 1980s many countries restructured their power sector putting aside non-competitive, monopolistic and regulated model. Along with this revolutionary change came the emphasis on the significance of electric power reliability and therefore its economic worth. The authorities, the utilities and surely the costumers are asking for continuous electric supply with a certain level of power quality. However discussions arise with the questions of "What is the monetary worth of this?" and "Who is going to pay for it?" The answer of the second question is not in the scope of this study. To answer the first question, there have been numerous studies done so far [1–21]. However, there is no widely accepted methodology to come up with a credible and acknowledged solution to estimate the worth of electric power reliability yet. This makes studying the estimation of the electric power interruptions an attractive area of interest for the members of the electric power society.

The electric power customers could be divided into customer sectors of industrial, service (or commercial), residential, etc. regarding their power consumption characteristics. To make better estimations and to reach sector specific results, this paper focuses on estimating the costs of power outages for the service sector customers only. Before going through detailed analysis, understanding the nature of the power interruptions is compulsory. The interruptions could roughly be grouped into three types. Momentary interruptions, as the name calls, are the ones that last for a very short time, typically some seconds, or even less than 1 s. Sporadic interruptions, on the other hand, are caused by severe weather conditions such as floods, hurricanes or thunder storms. These types of interruptions pose great dangers for all the parties that benefit from the electric power system since they tend to last longer durations and they end up with quite high economic damages in the power infrastructure. The last type is the chronic interruptions. There are many factors that might end up with chronic interruptions. Insufficient power generation, faults in the power system due to aging or lack of maintenance, the faults resulted from power system operation or overloading of the system are of some examples that end up with an unwanted and unexpected interruption [22]. The duration of these interruptions might be from minutes to hours depending on the severity of the fault that occurred. Since the frequency of these interruptions is much higher than the others, in this paper, the authors focused only on the chronic interruptions and sought for a methodology to come up with credible and sound estimates about the economic consequences of these events.

To fully understand the results of the interruptions, the impacts caused by these events must be analysed and classified thoroughly. In the case study report of the 1977 New York blackout by the US Department of Energy the impacts of interruptions were grouped into two main categories: direct and indirect impacts [23]. The

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direct impacts include the direct effects of power cuts that cause economic losses such as sales loss, lost manufacturing, interruption of services, suspension of transportation, spoiled materials, damages on the electric equipment and on electronic data, other damages and accidents resulted from interruptions or, worst of all, injuries and deaths. The analysis of these events is relatively easy when they are compared to the indirect impacts. The indirect effects of power outages compose of arsons, looting, public disorder and crimes due to blackouts, possible sharp increases in the insurance rates, property losses, overtime payments, cancellation of social activities, lost tax revenues, the costs for recovering from looting and so on. When these indirect impacts are checked, it is obvious that the effects of some of those can only be seen after a considerable amount of time passes after the interruption. These long time effects make the analysis of the indirect impacts rather a challenging and a difficult task. The comprehensive report [23] and the significant study focusing on factors affecting customer outage costs [24] show that the economic worth of the indirect impacts can be much higher than that of direct ones. Nevertheless, as pointed out earlier, to analyse indirect economic results of the power interruptions is a tedious and demanding task, which can only be achieved by a large scale and extensive study that will take place after a major blackout event such as the infamous New York City blackout of 1977.

There are two main aspects when the customer interruption cost (CIC) assessments are done. The first matter is the methodology of collecting necessary input data and corresponding tools for the estimations and suggestions about the economic correspondence of the CICs. When the proper tool for the data collection is selected, another challenging point arises. How the raw data can and should be interpreted to get as bias free as possible results is the second phase of a complete and credible CIC analysis.

Section 'Customer interruption cost analysis approaches' of this paper presents different methodologies that are used to estimate the economic impacts of the power interruptions. Section 'The customer survey' includes the finnish service sector customer survey study and presents several customer damage functions (CDF) that are adopted throughout the paper. Moreover, the problem of strategic responses is pointed out and a remedy for zero and extreme responses is proposed. The hybrid model that combines the indirect analytical method and customer survey methodology is suggested in Section 'The hybrid model'. Comments, discussions and conclusions are summarized in Section 'Discussion and conclusions'.

Customer interruption cost analysis approaches

Being a popular area of interest, there are many proposed CIC assessment methodologies. Among all, three approaches are a step forward and they have been extensively preferred by the electric power society. In CIGRE Task Force report of 2001 these are grouped as indirect analytical methods, customer surveys and case studies [25].

Indirect analytical methods

The key idea behind this approach is to make use of publicly declared and available, easy to reach and objective data to study CICs. These data include the gross domestic product (GDP), the annual energy consumption, the peak power reached, the turnover or the created Value Added of a country, region or a customer group [26–28]. This method can be favoured in terms of being easy and straightforward, demanding much lower times to follow, being much cheaper and most importantly, resulting in highly objective estimations when compared to the other ones. For instance, defining a customer damage function (CDF) by dividing the GDP to the annual energy consumption of a country gives a rough idea about the monetary losses experienced by that country within a certain time of period. Nevertheless, the proposed customer costs via this method yield average results since all customer segments with distinct electric power consumption characteristics are analysed together. The market dynamics demand for customer specific results with as low error margin as possible. This fact makes the analytical methods less attractive and less preferable by the researchers and professionals.

Customer surveys

These are by far the most popular tools chosen and utilized by the electric power society and utilities to make estimations about outage costs [29–37]. In customer surveys, the customer, who is in the best position to assess his/her losses, is taken as the correspondent. This achieves the goal of being customer specific and thus the approach is regarded as superior to the other ones. By designing hypothetical outage scenarios with a carefully prepared questionnaire, the customer is asked to estimate the economic losses incurred during that predefined scenario. There are three main ways to collect the desired data. The first one is the Willingness to Accept (WTA) method. In WTA, the customer is asked to define an amount of compensation that he/she is willing to accept to experience a hypothetical outage. The other one is the Willingness to Pay (WTP) method. Here, in order to avoid a defined outage, the customer mark out an amount of money that he/she is ready to pay. In theory, an objective evaluation of the WTA and WTP results are expected to be identical. The economic value of a certain interruption in a certain environment must be unique by nature since, for example, the worth of one specific spoiled material is the same and it should be independent from whoever evaluates the costs of it. Nevertheless, author experiences and another customer survey study [38] show that there is a considerable gap between WTA and WTP figures. This is a quite an expected situation when the behavioural bias of a human being is considered. It can be expected that one tends to exaggerate his/her losses and he/she is ready to demand a higher compensation in case of the same situation while the same one is willing to pay much less to avoid it. This phenomenon makes the credibility of these methods quite low. However, by setting lower and higher bounds to the expected outage costs, it is a valuable tool to make use of WTA and WTP studies [38]. The third and the final way of data collection tool for the customer surveys is the Direct Worth (DW) approach. With the DW approach the customer is directly asked to provide answers for the economic value of the distinct outage scenarios. Directly assessing the economic loss reduces the biases that are resulted from the correspondent. Therefore, this technique is considered as more reliable when compared to the first two ones. However, there are major concerns about the credibility of this process as well. The problem of zero responses and strategic responses is a critical challenge for the ones carrying out these studies. A further inspection and the possible remedies offered to handle these challenges are presented in Section 'The customer survey' of this paper in detail.

Case studies

The last and the least preferred technique by the researchers to mention is the case study approach. The case studies are done after massive and major blackouts that affect large areas and large populations causing serious and severe economic losses. Among others, this type of study yields most accurate and reliable data since they are carried out just after the actual events. The correspondents are in a better situation to estimate the losses when the event is recently experienced. On the other hand, however, since these types of major blackouts are seen rarely, for example Northeast blackouts of 1965 and 2003, New York City blackout of 1977 and the California Electricity Crisis of 2000–2001, and since to conduct such extensive studies is highly expensive, this method is less attractive and thus less preferred by the professionals. A thorough study conducted in Sweden after infamous storm Gudrun of 2005 can be found at Ref. [39].

In this paper, the results of a customer survey to estimate power outage costs conducted in Finland has been used [40]. An attempt has been done to join the outcomes of this survey with the Analytical methods to reach and propose a more objective, easy to carry out and asses and a more credible hybrid methodology. The details of this approach are discussed and the results are presented in the sections Part 3 and Part 4 of the paper.

The customer survey

A carefully designed customer survey questionnaire is the first condition for a reliable CIC study. There are many factors determining the economic losses dues to interruptions. These include the duration and the frequency of the power outage, the season that the interruption is seen in (summer or winter), the time of occurrence (during or outside working hours) and the character of the outage (whether or not a notification is given beforehand, unexpected or planned outage. In the customer survey, the respondents were asked to predict their losses via e-mails in case of different outage scenarios that differ with the factors explained above. A total of 236 commercial sector customers joined to the survey and 54% of response rate was reached. The questionnaire for the service sector includes the following for each customer:

- Annual energy consumption.
- Turnover per year.
- Value Added created per year.
- The income and expenses per year (profit, salaries, material costs, depreciation and other expenses).
- Cost estimations for 1, 4 and 8 h of unexpected outages during working hours.
- Cost estimations for 1, 4 and 8 h of unexpected outages outside working hours.
- Cost estimations for 1 and 8 h of planned outages during working hours.
- Cost estimations for 1 and 8 h of planned outages outside working hours.
- Cost estimations for 1, 4 and 8 h of unexpected outages in summer.
- Cost estimations for 1, 4 and 8 h of unexpected outages in winter.
- Cost estimations for 1 and 8 h of planned outages in summer.
- Cost estimations for 1 and 8 h of planned outages in winter.

In the literature, most of the studies make use of sector customer damage functions (SCDF) by categorizing the customers in the sectors of industrial, service (or commercial), residential, agricultural and so on [7,19,31,41,42]. A SCDF is created by averaging the outage costs data collected via customer surveys and then normalizing the value with either average annual energy consumption or with the average peak power demand of the same customer group. When creating unique SCDFs, the ultimate purpose is to get customer specific assessment results. However, among the same sectors, there are customer segments that have totally different electric power utilization characteristics with quite distinct consequences of possible outage scenarios. That is why the authors believe that adopting the SCDF tool will yield quite broad and average calculations. To reach more customer specific estimations, in this survey, the service sector customers in Finland have been divided into sub-sectors of whole sale, department store, other retail, hotel, restaurant, sports, health and others. By following this logic, throughout the analysis process, sub-sector customer damage functions (SSCDF) [36] have been defined and used. In this study, the annual energy consumptions of the customers were chosen as the normalizing factors the following SSCDFs have been defined:

$$\mathrm{CICt} = \frac{\text{Annual turnover of the customer for } t \text{ hours}}{\text{Annual energy consumption of the customer}} \; in\ €/\mathrm{kW\,h} \tag{1}$$

$$\mathrm{CICva} = \frac{\text{Annual Value Added of the customer for } t \text{ hours}}{\text{Annual energy consumption of the customer}} \; in\ €/\mathrm{kW\,h} \tag{2}$$

$$\mathrm{CICpo} = \frac{\text{Reported cost of the customer for a planned outage for } t \text{ hours}}{\text{Annual energy consumption of the customer}} \; in\ €/\mathrm{kW\,h} \tag{3}$$

$$\mathrm{CICuo} = \frac{\text{Reported cost of the customer for an un expected outage for } t \text{ hours}}{\text{Annual energy consumption of the customer}} \; in\ €/\mathrm{kW\,h} \tag{4}$$

The indirect analytical approach adopts CDFs by collecting all customer sub-sectors in the same group. This brings the criticisms that are mentioned in Section 'Indirect analytical methods'. In this paper, the authors preferred to follow more customer specific analysis and the resulting SSCDFs (CICt and CICva) are called econometric model damage functions.

In the normalization process of the outage costs, the annual working hours for the service sector customers has been chosen as 3000 h and the calculations have been done accordingly [43]. For each sub-sector of the customers, the CIC assessment analyses have been carried out.

In this paper only one scenario yielding the highest outage cost results is being processed and analysed. Since Finland has a cold climate due to its geographical position, the country has mild summers. This results in the usage of air conditioning relatively less than other countries where the power consumption peaks are seen during summer times. Hence the preferred outage scenario is the reported/planned outages in winters during working times which corresponds to the summer afternoon interruptions for the majority of the other countries. The cost analysis of the other scenarios have been done and presented in a previous study done by the authors [35].

The second phase of challenge starts at this point. As mentioned briefly earlier, there are certain concerns and uncertainties with the customer survey method. The most trivial one is the quality of the respondents. The customers with large amount of electricity consumption hires eligible personnel who are aware of the electric power dependency of their businesses. The possible economic outcomes of potential power interruptions. Although an exact prediction about losses is impossible, these professionals are able to inform the surveyors about the consequences of power outages with as credible as possible responses. However, it is seen that the majority of the customers are mid-level and low-level customers in terms of the amount of electric energy consumption. Whether or not the respondents from these consumers are qualified enough to be fully aware of the economic reflections of the power interruptions is questionable. In addition, it is seen that some respondents specify the losses as zero loss just to finish the questionnaire as quickly as possible although it is known that there must be at least some amount of economic loss in case of the suggested hypothetical outage scenarios. Again the surveys show that some respondents come up with unreasonably high monetary figures to express their losses. These responses are called and grouped as zero responses and extreme responses respectively. Another crucial point with the surveys is the strategic response problem [31]. During the surveys, some respondents might give intentionally wrong answers to affect and change the results of the survey. These answers are called strategic responses and they pose a considerable threat to the overall reliability of the studies. And finally, another shortcoming about customer surveys is the tendency towards exaggerating losses. This brings the suspicion that a considerable amount of reported costs might be higher than they actually are. All these observations bring along the criticism for the customer survey methodology to be highly subjective and thus yielding unconvincing results for the estimation of the CICs.

In order to handle the problem of zero responses and extreme responses, the raw data sets must be censored so that the unwanted and unreliable data points would be removed. To achieve this goal, there are numerous statistical tools which are proper for this task. Being a straightforward and an easy to apply tool, the authors chose to utilize the standard score test, or the z-score test, to eliminate these zero and extreme responses. In a standard normal distribution, 99.7% of the data values will fall within 3 standard deviation of the mean in either direction. When the z-score is chosen as 2.0, the percentage of the uncensored data drops to 95%. In order to eliminate the mild outliers as well as the extreme outliers, in this study the z-score has been chosen to be 2.0 to censor the raw data set. However, one obstacle emerges when the histogram of the collected data is checked. When Fig. 1 is observed it is obviously seen that the histogram of the responses of the customer survey is highly right skewed. To apply an elimination method to censor the outliers of a response distribution which is right skewed will result in censoring too many data points most of which are relevant in the analysis process. To overcome this trouble the following procedure has been applied to the data set. Since the standard score test is meaningful when it is applied to the normal distribution, first of all the data set has been converted into natural logarithm values. When Fig 2. Is checked, it is seen that the histogram of the natural logarithms roughly fits to the normal distribution, which enables healthy elimination process on the data set. After setting the z-score to 2.0, the outliers have been detected and censored. Finally, the remaining data points have been transformed back to the normal values. The histogram of the censored and uncensored logarithms of response distributions and the histogram of the censored and the uncensored response distributions are presented in Figs. 1 and 2 respectively.

As it can be seen in Fig. 2, after the data elimination process, the remaining data set fits better to the normal distribution better, which means that the remaining data is more appropriate to carry out further analysis.

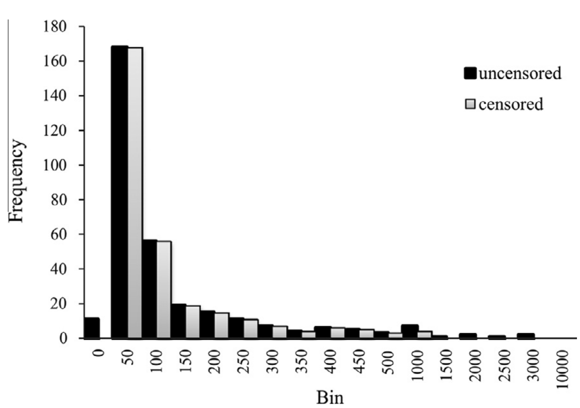

Fig. 1. Uncensored and censored distributions of the service sector customers' unexpected outage costs for 1 h in €/kW h.

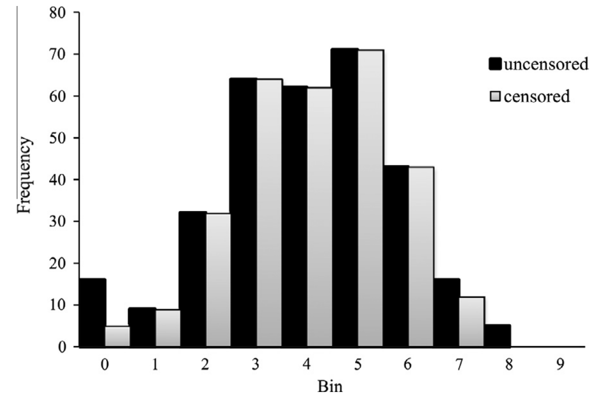

Fig. 2. Uncensored and censored distributions of the logarithms of the service sector customers' unexpected outage costs for 1 h in €/kW h.

The hybrid model

After careful truncation, the problem of zero and extreme responses has been solved substantially. However, the dispute with the strategic responses still persists. The strategic responses that lie in the uncensored region of the data distribution cannot be removed with the aid of statistical tools. A finnish study proposes three different approaches (strongest effect in average method, smallest and largest monetary values method and smallest and largest CIC/L-value method) to overcome the strategic response problem [44]. Another study conducted in the US utilizes tobit regression to reach more reliable estimations [45]. In reality, it is impossible to tell if a response is a healthy one or a strategic one if it is not detected as an outlier in the elimination process. This fact poses a threat to the reliability and the objectivity of the outcomes of the customer survey studies. That is why, the authors sought for a new methodology that will make use of the customer surveys, and then to combine the findings of these surveys with the analytical data to reach a hybrid model. By the aid of the publicly available, objective and bias free data, the final aim is to reach estimations that will be easy to calculate and are customer specific. To establish a link between the analytical data and the CIC estimations, the following statistics have been collected from the service sector customers.

The incomes and expenses of the service sector customers have been grouped and summarized in Fig. 3. When the reflections of power outages on the businesses are considered, one can link the expenses and losses to the CICs with the following straightforward logic.

In case of an interruption, although the business is not running properly, the personnel still receive their working time payments which can be regarded as an unnecessary expense. This means salary payments are directly related to the power outage conse-

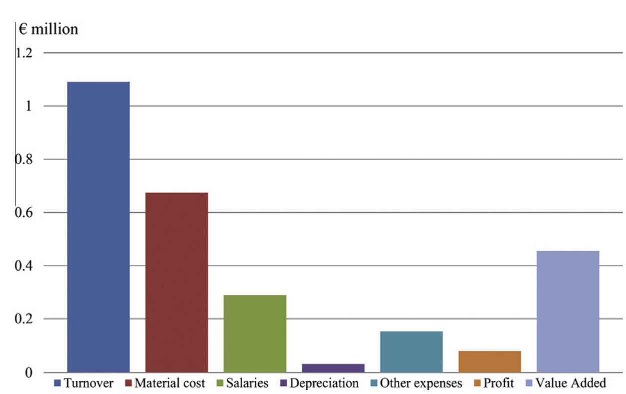

Fig. 3. Income and expense distribution of the service sector customers.

quences. In addition, by assuming that there is no sales during a blackout, since the materials are not used and sold, the material costs are irrelevant to the CICs. At this point, it is reasonable to focus on profit instead of sales costs by noticing that the materials stay in the business during the outage but the profit is lost since there is no sales available. Then the CIC could be summarized as:

$$\mathrm{CIC} = \mathrm{Salaries}(\mathrm{Salary\ costs}) + \mathrm{Profit} + \mathrm{Perishables}(\mathrm{Spoiled\ materials\ and\ damages}) \quad (5)$$

where all costs are calculated during the interruption time. On the other hand, it is known that:

$$\mathrm{Turnover} = \mathrm{Value\ Added} + \mathrm{Material\ costs} + \mathrm{Other\ expenses} \quad (6)$$

And,

$$\mathrm{Value\ Added} = \mathrm{Salaries} + \mathrm{Profit} + \mathrm{Depreciation} \quad (7)$$

If it is assumed that the depreciation amount is negligible, in case of an unexpected outage, one can deduce:

$$\mathrm{CIC} = \mathrm{Value\ Added} + \mathrm{Perishables} \quad (8)$$

In case of a pre-reported outage (a planned outage), the customers are allowed to take precautions to minimize the effects of the interruption. This means the amount of the perishables will be negligibly small. Therefore, the CIC estimation for the planned outages will roughly be:

$$\mathrm{CIC} = \mathrm{Value\ Added} \quad (9)$$

i.e., the outage costs are equal to the lost Value Added due to interrupted activities in the time span of the outage.

The hybrid approach simply makes use of indirect analytical methods to calculate the loss of Value Added and it utilizes customer surveys to find out the cost of Perishables that will be seen during an interruption. Theoretically the CIC results of the hybrid model that is suggested here should be quite close to the ones acquired from extensive customer survey findings. However, in reality, due to the strategic responses; the responses from ineligible customers and the human nature of overstating of the losses, there will be an amount of error between hybrid CICs and the customer survey CICs. This observation can be summarized as:

$$\mathrm{Customer\ Survey\ Model} = \mathrm{Hybrid\ Model} + \mathrm{Strategic\ Response\ Factor} \quad (10)$$

where the Strategic Response Factor (SRF) is simply defined as the difference between the CIC estimations of customer surveys and the calculations of the hybrid approach. For planned outages, the hybrid approach CIC is equal to CICva and for unexpected outages the hybrid approach CIC is equal to the summation of CICva and the normalized cost of Perishables.

To illustrate the idea, the CICs of the Customer Survey Model (CICuo and CICpo) and CICs of the the econometric model, (CICt and CICva) have been calculated for each customer segment. The results of the Whole Sale and Department Store customers are shown in Figs. 4 and 5 respectively.

As it can be seen in Figs. 4 and 5, attempting to assess the outage with the econometric model by utilizing the turnover figures of the customers yields unacceptably high estimations. On the other hand, in consistency with the relations (8)–(10), the econometric model SSCDF findings of CICva is comparable to the customer survey outcomes of CICuo and CICpo. Consequently the following relations could be claimed and recommended:

$$\mathrm{CICuo} = \mathrm{CICva} + \mathrm{Perishables}/\mathrm{Annual\ energy\ consumption} + \mathrm{Strategic\ Response\ Factor} \quad (11)$$

$$\mathrm{CICpo} = \mathrm{CICva} + \mathrm{Strategic\ Response\ Factor} \quad (12)$$

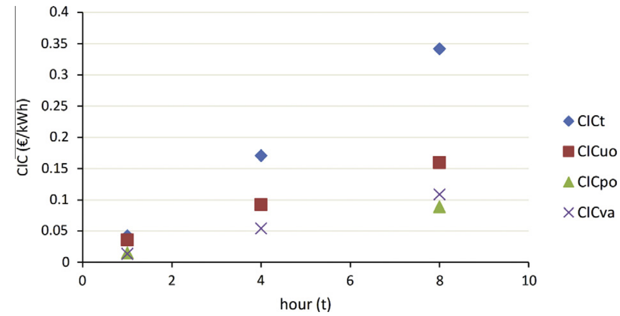

Fig. 4. Results of SSCDFs for the whole sale sector customers in €/kW h.

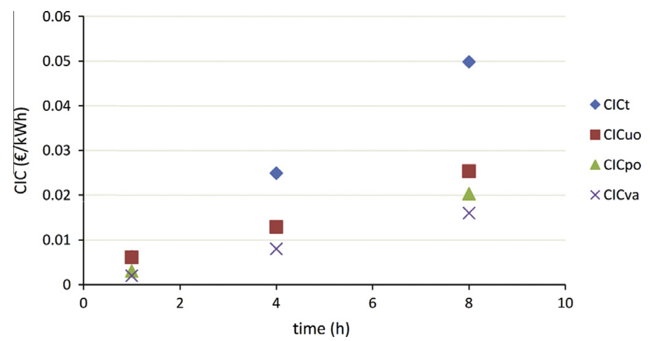

Fig. 5. Results of SSCDFs for the department store sector customers in €/kW h. *There is no data in the customer survey for the planned outages for the time span of 4 h.

Through the hybrid model that combines and benefits from the econometric method and the customer surveys, instead of carrying out an extensive and detailed customer survey, a survey which will focus only on the economic worth of the spoiled materials and the damages, i.e., the perishables, will be sufficient to calculate and recommend sound estimations for both unexpected and planned electric power interruptions. By this way, responding to the questionnaire will be much easier for the respondent whether or not he/she is an eligible person to do it. Moreover, since the cost of a spoiled or damaged material is well known, the level of subjectivity in the answers will be considerably low. In that case the Strategic Response Factor (SRF) will be minimal. Therefore, for the sake of decreasing the subjectivity of the analysis process and to provide objective CIC estimations, the SRF could be neglected by the ones who carry out the corresponding studies. By this way, with less effort and less money spent on customer surveys, more objective and more customer specific estimations will be achieved faster than the conventional approaches. To summarize:

For the unexpected outages;

$$\mathrm{CICuo} = \mathrm{CICva} + \mathrm{Perishables}/\mathrm{Annual\ energy\ consumption} \quad (13)$$

And for the planned outages;

$$\mathrm{CICpo} = \mathrm{CICva} \quad (14)$$

To verify the theory a regression analysis has been applied to the findings of the department store sector customers. A report by Ernest Orlando Lawrence Berkeley National Laboratory [46] claim that during the first 8 h of outage, the CIC characteristics is almost linear. This observation is consistent with the findings of this paper, therefore the authors chose the linear regression technique for CIC estimations.

To have a more sensitive regression analysis process, the reported outage data for the 2 min and 15 min have been used. Let the calculated linear equations be in the format of $y = mx + n$.

The coefficients of the equations and the coefficient of determinations are presented on Table 1.

The relation between customer survey CICs and the econometric model CIC with respect to time has been calculated and the result is shown in Fig. 6.

As it is seen in Fig. 7. the hybrid approach that attempts to link the customer survey findings to the econometric model fails at the short interruption times. One explanation for this result might be that the customers are not well aware of their economic losses in case of short interruptions, and therefore they report much higher outage costs than it should be for the interruptions shorter than 2 h. On the other hand, however, as the outage time increases the variation ratio stabilizes around 20% and 40% for the planned and unexpected outage scenarios respectively. In accordance with the relation (14) the 20% difference could be claimed as the SRF which covers the strategic responses. In addition, by the relation (13), the gap between two lines stands for the cost of perishables. As it can be observed, after a certain time, the relative cost of perishables is slightly decreasing. This is quite logical since it is known that if the power interruption time gets longer, the customers start to take precautions to diminish the adverse effects of the event. This helps to reduce the amount of damages and spoiled materials. And thus, it ends up in a decrease in the costs of the total losses.

The rest of the results of other service sector customers have been summarized and tabulated for an outage of 1 h on Table 2.

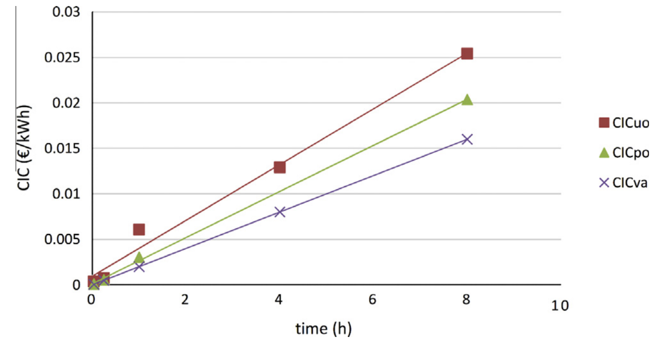

Fig. 6. The CIC linear regression analysis for the department store sector customers.

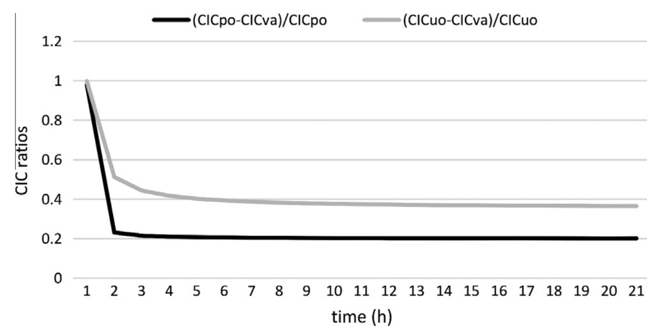

Fig. 7. CIC ratios of different SSCDFs for the department store sector customers.

Table 2
Typical values for service sector customers for one hour in € Cents/kW h of annual energy demand.

Sub-sectors	CICuo	CICpo	CICva
Other retail	1.90	1.52	0.59
Whole sale	0.04	0.02	0.01
Hotel	0.60	0.15	0.12
Restaurant	0.31	0.25	0.21
Sports	4.86	3.89	2.26
Department store	0.006	0.003	0.002
Health	3.12	0.94	0.79
Other	3.65	2.47	2.17
Average	1.81	1.15	0.77

Discussion and conclusions

It is practically impossible to present a 100% credible and concern free power outage cost estimation tool with the current methodologies. Since understanding the economic worth of the electric power reliability is vitally important for power system planning, operation and electric power market structure, there has been increased emphasis on the customer interruption cost assessments for the last 30 years.

The customer survey method is the most popular and the most favoured tool for reliability worth assessments among the electric power society. On the other hand, there are some efforts to study the phenomena by following the indirect analytical methods by expressing the CIC directly using the Value Added (GDP) of a customer segment with the annual energy consumption [26–28]. It is clear that both approaches possess certain advantages and disadvantages. In this paper, the authors attempted to create a hybrid econometric approach that will benefit from both tools, and tried to minimize the shortcomings of these models. For each party of the electric power business; the authorities, the utilities and the customers, what is wanted for the CIC assessments is obvious: a method which is customer specific, bias free, easy to apply, not so time consuming and finally reasonably low-priced. This paper proposes the utilization of publicly declared and available Value Added data of the customers with a simple customer survey which is solely focused on the perishables in case of unwanted power interruptions. When the focus is only on the monetary correspondence of the perishables, then the SRF will be minimal since estimating the value of spoiled materials and dangers on the equipment is a straightforward task that even uneducated or ineligible personnel can achieve it easily without too much biases. Another benefit of this approach is that since the assessment of the perishables will be based on actual events, or experience, the survey results will be more reliable. Although suggested statistical elimination tool is successful in censoring the zero and extreme responses, the proposed methodology is the only way to cope with the strategic responses that lie in the uncensored region of data distribution. As a consequence, it can be claimed that the hybrid model is the most reliable way of calculating the economic worth of the power interruptions for service sector customers.

Table 1
The CIC regression coefficients for the department store sector customers.

	m	*n*	R^2
CICuo	0.0031	0.001	0.98
CICpo	0.0025	0.0001	0.99
CICva	0.002	2.00E−18	1

Momentary interruptions have been omitted in the analysis process because their nature in cost affecting is quite different than the other interruptions with longer durations. The authors believe that these outages should be studied along with another research that will focus on the economic worth of the power quality events. These events are not so significant for the service sector and for the domestic customers. However, they pose a serious danger on the manufacturing process for the industrial customers. The references [47–49] study the economic impacts of harmonics, voltage sags, flickers, transients, etc. and attempts to explain the consequences of such events. Moreover, one significant discussion over the CIC estimations is the frequency of the outages. In the current questionnaire format, the emphasis has been given on the duration of the outages. Nonetheless, by considering the restart losses and damages, it is comprehensible that the economic consequences of two interruptions with half an hour of duration each will be more severe than one interruption lasting one hour. Clearly certain modifications are needed in the customer surveys. Finally, when the literature is reviewed, it is seen that the majority of the studies are done for the industrial and service (commercial) sector customers [36], while there are few studies only for the residential sector customers. The authors believe that further research is needed to come up credible interruption costs assessments for the residential sector as well.

The final crucial observation is that the concept of reliability worth is not fully covered by the interruption cost estimations done by customer surveys, analytical methods or by the hybrid method suggested here. The reason lies beneath the fact that only the direct impacts of the interruptions are dealt with via the above mentioned tools. However the reliability worth corresponds to all outcomes of both direct and indirect impacts. It is known that most of the indirect impacts are seen in the mid-term or in the long-term. The only way to identify these and then make a reliability worth analysis is to carry out an extensive case study which can only be done after major and rarely seen blackout events.

This paper is a unique work by distinguishing itself from the others by combining the widely adopted and popular model of customer surveys with an econometric model. That way it presents a novel hybrid approach that can be utilized to cope with the challenge of the customer interruption costs. The authors believe that the logic behind the hybrid approach is well-grounded and the reasoning is quite sound. The econometric model that makes use of the Value Added created by a customer group in a year is a practical way of estimating the costs of the planned outages. Nonetheless, proposed methodology for the unexpected outages can only be verified after another customer survey which will be designed solely on the costs of spoiled materials and damages for the service sector customers. In addition, since this study focuses on the interruption scenario that will yield the highest outage costs, it only covers winter afternoon outages and it excludes the effects of time of the day and season differences. That is why further extensive studies are needed to fully cover all interruption scenarios and all customer types.

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