RESEARCH AND ANALYSIS METHOD COMPARISON IN FINNISH RELIABILITY WORTH STUDY

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ABSTRACT

In Finland, Helsinki University of Technology and Tampere University of Technology as well as several Finnish distribution network companies worked on a common project concerning the updating of reliability worth values in 2004-2005 [1]. This paper presents the research, analysis and strategic response elimination methods used in this study. There are several methods to calculate and normalize the reliability worth parameters, and the results may differ significantly depending on which method is applied. The principles of the calculating methods are also presented.

INTRODUCTION

Reliability worth and interruption costs are again of great interest. Large blackouts around the world have woken up also customers' interests for electricity distribution and the reliability of distribution networks. In addition to this, in the future reliability worth values will be applied widely in the regulation of distribution companies. Thus reliability worth means real money to companies, and the quality and objectivity of the parameters used for regulation purposes should be assured. For distribution network companies, the reliability worth studies can also offer an excellent tool to focus the network investments in the most critical areas in the network, and so use the assets in the best way to increase the level of reliability.

In the past, distribution system reliability was usually assured by standard design practices and by reactive solutions to historical problems. Today, but even more in the future, reliability is a measured area of performance, reported to regulators and customers, and having an impact on utilities' economics. Reliability must be planned, designed, and optimized with regard to cost. Furthermore, reliability-related risks must be managed. With these respects in mind, reliability optimization requires simulated reliability evaluation, which can be done e.g. with reliability analysis software included in network information system. Reliability evaluation, again, requires defining the fault frequencies for different network components and interruption cost parameters for different customer groups, i.e. reliability worth.

In Finland Helsinki University of Technology and Tampere University of Technology and several Finnish distribution network companies had a project on updating the reliability worth values in 2004-2005 [2], [3]. However, in the context of analyses of interruption costs in a market-based power system, respondents may have incentives to strategic responses to influence the final estimates from the survey [4]. There are several methods to estimate and normalize the reliability worth parameters for different customer groups as well as to eliminate the strategic answers, and the results may differ significantly depending on which methods are applied.

This paper presents the research, analysis and strategic response elimination methods used in the Finnish study.

RELIABILITY WORTH STUDY METHODS

Numerous methods exist for the evaluation of the harm caused for the customer by the interruptions. These can be divided into three more general classes [5]:

- Indirect analytical methods; these estimate interruption costs by drawing conclusions from the value of lost production or lost leisure time, or from other indicators or variables, such as transmission prices.
- Case studies; studies of this type can be carried out after a real interruption situation, mainly a wider disturbance, on the real harm that the interruptions have caused.
- Customer surveys; in these the customers are asked to estimate the costs caused by the electricity distribution interruptions when interruptions of different lengths take place at a certain time of year and day.

The main method used in the Finnish study was a customer survey, where the costs of different interruption scenarios were estimated directly by the customers themselves. The fact that the customers probably know best the harm caused by the interruptions can be considered as the advantage of customer surveys. However, customer surveys are very laborious and the customers' responses, depending on the

purpose of use of the interruption costs, can be purposeful [6].
Principally, the research methods used in the customer surveys can be divided into three groups [7]:

- Direct evaluation of costs (direct costing).
- Preparatory actions made to avoid the harm of interruption (preparatory action method, PAM). In this method the respondents are usually asked to choose from a list actions they would make in order to relieve harm caused by a certain interruption in given conditions.
- Price proportional methods (rate-related methods, RRM). These methods include, among others, willingness to pay (WTP) and willingness to accept (WTA) methods. In WTP the respondents are asked to estimate how much they would be willing to pay for more reliable electricity distribution or to avoid a certain kind of interruption. Correspondingly, in WTA the respondents estimate how big a compensation they would like to have if the reliability of electricity distribution was worse.

CALCULATION METHODS

The methods used in analyzing the results and calculating the final reliability worth parameters can affect the results significantly. During the Finnish study, comparisons have been made between aggregated and averaged values [6]. The experiences have shown that aggregated values are usually smaller than averaged values. The formulae to calculate the aggregated and averaged values in the Finnish study can be given as follows (formula (1) and formula (2)):

$$C_{aggregated,k}(r_i) = \frac{\sum_{x \in k} CIC_x(r_i)}{\sum_{x \in k} L_x} = \frac{\sum_{x \in k} CIC_x(r_i)}{\sum_{x \in k} \frac{W_x(r_i)}{t_k}} \quad (1)$$

$$C_{averaged,k}(r_i) = \frac{\sum_{x \in k} \frac{CIC_x(r_i)}{L_x}}{n} = \frac{\frac{\sum_{x \in k} \frac{CIC_x(r_i)}{W_x(r_i)}}{t_k}}{n} \quad (2)$$

where $CIC_x(r_i)$ are the costs incurred by customer x per interruption of duration r_i, L_x is the customer's peak demand, $W_x(r_i)$ is the annual energy consumption of customer x, t_k is the utilization time of customer group k and n is the number of customers in customer group k.

ELIMINATION OF THE STRATEGIC RESPONSES

Due to the respondents' awareness about the purpose of use of the reliability worth parameters some respondents may resort to so called strategic responses [4]. This is why some kind of elimination should be made among the responses before calculating the final reliability worth parameters. Another reason to apply elimination of responses is to remove those responses that do not fit into the population, i.e. the responses that do not depict an average customer in the customer group. Usually these strategic responses tend to be extremely high or extremely low. On the other hand, if the maximum power of the respondent is low, the €/kW value may become large even though the monetary value responded was not especially large. Probably in some cases these kinds of strategic responses have been eliminated from the data manually so that the biggest monetary values or €/kW values have been removed. In this context, more sophisticated and systematic methods should be applied to remove the strategic responses. During the latest Finnish study [1] some of these methods were also evaluated.
The elimination techniques presented here are:

- strongest effect in average –method (SEA-method). This method takes into account the demand of the respondent and its €/kW-value.
- smallest and largest €/kW-value –method (€/kW-method). The €/kW-method does not take into account the demand of the respondent,

The percentage to eliminate can also be varied. The percentage applied here for aggregated values using SEA-method was 5% of those values, which would have affected most increasingly to results, and also 5% of the most decreasing responses, so in total 10 % of the responses were removed in all the cases. Usually even a rather small elimination percentage is enough to eliminate those responses that do not somehow fit into the population. During the research [1] were made also some studies where 10 % of the smallest and 10 % largest values were eliminated, but these results are not presented here. For averaging process €/kW-method is a natural choice. The experiences during the study showed that a smaller percentage was enough to achieve the desired effect in the case of aggregated values than in the case of averaged values [1].

FINNISH STUDY RESULTS

The results of the Finnish reliability worth study presented here are calculated with the aggregating method. The elimination method applied here has been the SEA-method. [2] and [3] present similar results calculated with the averaging method.
In the Finnish study the respondents were divided into six categories; residential, summer houses, agriculture, industry, public and commercial. The number of respondents in the summer houses category was so small

that these results are not presented here. The direct cost valuation method was used for all customer groups, and both unexpected and planned interruption scenarios were asked about. In addition to this, WTP and WTA questions were asked of residential and agriculture customers.

The Finnish study was implemented with a questionnaire which was sent to the respondents in autumn 2004. The respondents had a possibility either to send the completed questionnaire back in a return envelope or to answer the same questions in the internet by logging in to the page with a respondent-specific code. A relatively low share of respondents used the internet form. The overall response rate in this survey was 29 % (see table 1), but the number of useful numerical responses was somewhat smaller depending on the customer group and interruption scenario.

Table 1: Response rate.

Mail	Internet	Telephone	Sum	Response rate
1324	42	259	1625	29.0 %

In the following chapters the results of the latest Finnish reliability worth study are presented in detail for each customer sector.

Residential

For the residential sector, the interruption durations asked about were 1 s, 2 min, 1 h, 12 h and 36 h for unexpected interruptions, and 1 h and 12 h for planned interruptions. These questions applied the direct cost evaluation method, and the interruptions were meant to occur on a winter weekday at the most harmful time. In the previous Finnish study [8] the shortest durations were not asked about of the residential sector, but this time they were included in the study to estimate also the costs of automatic reclosing occurrences and other short interruptions. On the other hand, the longest durations were asked about to estimate the real costs caused by longest interruptions, and to compare the costs with the standard compensations distribution that companies have to pay in case of interruptions longer than 12 hours. The WTP and WTA questions surveyed a 1 h unexpected interruption scenario. Table 2 shows the results for the residential sector. It is noteworthy that the WTP-value is only a fraction of the direct cost estimate.

Table 2: Study results for the residential sector [€/kW].

unexpected					planned		WTP	WTA
1 s	2 min	1 h	12 h	36 h	1 h	12 h	1 h	1 h
0.23	0.84	5.8	43.8	147.6	3.0	32.1	1.1	8.3

Agriculture

For agriculture sector the durations of unexpected interruptions inquired about were 1 s, 2 min, 1 h, 4 h, 12 h and 36 h, and 1 h for planned interruptions. These questions used direct costs evaluation for interruptions occurring in different seasons (winter, spring, summer, autumn) on a weekday at the most harmful time. WTP and WTA questions surveyed a 1 hour interruption scenario. Table 3 shows the study results for agriculture sector. Two greenhouse respondents were left out as untypical customers. Again, the WTP-value is only a fraction of the direct cost estimate.

Table 3: Study results the for agriculture sector [€/kW].

	unexpected						planned	WTP	WTA
	1 s	2 min	1 h	4 h	12 h	36 h	1 h	1 h	1 h
winter	0.17	0.98	10.6	37.2	102.2	316.5	7.1	1.3	9.6
spring	0.01	0.28	6.0	13.4	54.7	186.6	2.8		
summer	0.04	0.26	3.9	10.6	52.4	159.3	2.9		
autumn	0.47	1.25	13.9	38.3	115.1	321.6	3.1		

Public

In the case of the public sector only the direct cost evaluation method was used, and the interruption durations asked about were 1 s, 2 min, 15 min, 1 h, 4 h, 8 h, 12 h and 24 h for unexpected interruptions, and 2 min, 15 min, 1 h and 8 h for planned interruptions. In both cases the harm was inquired about both for working time and non-working time interruptions. Table 4 shows that in non-working time the planned interruptions would in some cases be more harmful than unexpected interruptions. This is partly due to different kinds of data in the scenarios in question. If, in the case of non-working time planned interruptions, only those respondents are taken into account that have answered also the unexpected interruption question, the monetary harm for a planned interruption is about 80 % of the harm of an unexpected interruption.

Table 4: Study results for the public sector [€/kW].

	unexpected interruption					
	1 s	2 min	1 h	4 h	8 h	12 h
winter, wh	1.9	2.6	13.6	52.1	70.6	91.3
winter, non-wh	0.6	1.0	4.4	13.7	31.5	42.8
summer, wh	1.9	2.7	10.3	22.6	70.6	83.4
summer, non-wh	0.6	1.0	3.8	11.5	28.9	38.6
planned, wh	-	1.3	6.8	-	59.9	-
planned, non-wh	-	1.6	4.5	-	14.0	-

Commercial

The questionnaire formula for the commercial sector was the same as for the public sector, with the exceptions in some questions mapping the background data for the company in question. Table 5 shows the results.

Table 5: Study results for the commercial sector [€/kW].

	unexpected interruption					
	1 s	2 min	1 h	4 h	8 h	12 h
winter, wh	1.8	3.0	27.6	67.8	117.2	163.0
winter, non-wh	0.4	0.5	4.6	10.0	18.2	29.8
summer, wh	1.3	3.2	26.3	58.4	126.3	141.6
summer, non-wh	0.5	0.5	4.1	12.2	17.9	30.3
planned, wh	-	1.2	19.8	-	89.2	-
planned, non-wh	-	0.3	2.5	-	20.4	-

Industry

In order to depict an average small or medium-size industrial customer in the best way, only the respondents having under 1 MW peak demand were considered in the case of industrial sector. The interruption durations asked about were 1 s, 2 min, 15 min, 1 h, 4 h, 8 h and 12 h for both unexpected and planned interruptions, and the questions applied the direct cost evaluation method. Table 6 shows the results for the industry sector. For the industry sector, also the cost for a voltage dip was asked about. The voltage dip scenario depicted a 0,2 s long voltage dip to occur in wintertime during working hours. As can be seen from the table, the cost for a voltage dip seems to be somewhat higher than for a 1 s interruption.

Table 6: Study results for the industry sector [€/kW].

	interruption length					
	dip	1 s	2 min	1 h	8 h	12 h
unexpected, wh	3.7	1.9	2.5	17.0	104.4	132.7
planned, wh	-	0.4	0.5	8.7	61.7	82.3

Comparison of aggregated and averaged values

Table 7 includes also a short comparison of the 1 hour interruption results gathered with aggregating and averaging processes. Here in the aggregating process 5% of those values, which would have affected most increasingly to results, and also 5% most decreasing answers have been excluded. In the case of the averaging process the elimination was done based on the respondents' €/kW-value, and 10 % of both the largest and smallest €/kW-values were eliminated.
From Table 7 we can see that the aggregated process has given for commercial and industry sectors notably lower estimates than averaged values, even in spite of using bigger elimination percentage in the averaging process. An evident conclusion is that, as an average, small customers have stated higher €/kW-values than big customers.

Table 7: Comparison of aggregating and averaging process results [€/kW] of 1 h unexpected interruption in winter.

	Resid.	Agric.	Commerc.	Public	Industry
Aggregated	5.8	10.6	27.6	13.6	17.0
Averaged	6.5	8.6	48.1	34.3	23.6

CONCLUSIONS

There are various purposes of use for the reliability worth estimates. Network companies use them in network planning when deciding which alternatives would be most reliable and cost effective. The deregulation of electricity markets has also brought new uses for the reliability worth estimates. They can be used in calculating the expected and actual interruption costs which are used e.g. in Norway to define the permitted revenues for the network companies.

REFERENCES

[1] Silvast, A., Heine, P., Lehtonen, M., Kivikko, K., Mäkinen, A., Järventausta, P., Costs of electricity supply outages, Report of Power Systems and High Voltage Engineering, TKK-SVSJ-2, Helsinki University of Technology, Espoo, 2005, 175 p. (In Finnish, with English summary).

[2] M. Lehtonen, A. Silvast, P. Heine, K. Kivikko, A. Mäkinen, P. Järventausta. Outage costs in electrical distribution networks – a Finnish study. Nordic Distribution and Asset Management Conference NORDAC 2006. Stockholm, Sweden, 21 – 22 August 2006.

[3] M. Lehtonen, A. Silvast, P. Heine, K. Kivikko, A. Mäkinen, P. Järventausta. Costs of Interruptions of Electricity – A Finnish Survey. International Conference on Harmonics and Quality of Power – ICHQP, The 12th ICHQP. Cascais, Portugal, 1 – 5 October 2006.

[4] Samdal, K., Kjolle, G., Singh, B., Trengereid, F. Customers' Interruption Costs – What's the Problem? Proceedings of the CIRED 17th International Conference on Electricity Distribution. Barcelona, Spain, 12 – 15 May 2003.

[5] Cigre Task Force 38.06.01, Methods to Consider Customer Interruption Costs, August 2001.

[6] Samdal, K., Kjolle, G., Singh, B., Trengereid, F. Customers' Interruption Costs – What's the Problem? Proceedings of the CIRED 17th International Conference on Electricity Distribution. Barcelona, Spain, 12 – 15 May 2003.

[7] Kariuki, K. K., Allan, R. N. Factors affecting customer outage costs due to electric service interruptions. IEE Proceedings of Generation, Transmission and Distribution, Vol. 143, No. 6, November 1996.

[8] Lemström, B., Lehtonen, M. Kostnader för elavbrott. Nordiska ministerrådets serie TemaNord, 1994:627, 165 s. (In Swedish, with English summary)