Annex O

Interruption Costs, Consumer Satisfaction, and Expectations for Service Reliability

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Interruption Costs, Customer Satisfaction and Expectations for Service Reliability

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***Abstract* — This paper summarizes results of a comprehensive study of the economic value of electric service carried out by Duke Power Company in cooperation with the Electric Power Research Institute. In the study, customer interruption costs were estimated for generation, transmission and distribution outages of differing lengths occurring under varying circumstances. Interruption costs for momentary outages and voltage disturbances are also reported. In addition to these economic indicators of customer value of service, customer expectations for service reliability and power quality and their satisfaction with the service currently offered are reported. Statistical methods and procedures used in estimating interruption costs are described.**

I. Introduction

Some electric utility customers experience significant economic losses when power is interrupted or when power quality problems occur. These customers need and expect the highest quality and reliability of service that the utility can supply. On the other hand, the vast majority of utility customers experience relatively little inconvenience or cost as a result of electric outages or power quality problems. They do not desire, and are not willing to pay for, significantly improved reliability and power quality.

Increasingly, utilities are being squeezed between the conflicting demands of customers who require higher quality (and more costly) service and those who demand lower rates.

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To compete effectively given this situation, it is important for utilities to establish a balance between the costs of improving service reliability and quality, and the economic benefits that these improvements bring to customers. This approach to reliability planning is generally called Value Based Reliability Planning (VBRP).

Value Based Reliability Planning directly takes account of the value of reliability and power quality to customers in assessing the cost effectiveness of proposed investment alternatives. Typically, VBRP planning procedures incorporate customer value of service in the planning process at the point at which investment alternatives are subjected to cost-benefit analysis. This is done by including avoided customer losses (due to outages and poor power quality) in the stream of benefits that arise from utility investments to improve reliability or power quality.

Fig. 1. provides an example of the relationship between service reliability, utility investment cost and customer interruption cost [1]. The objective of value based reliability planning is to balance the utility's investment cost against the interruption costs experienced by customers [2,3]. These costs are balanced by investing in reliability so that the Total

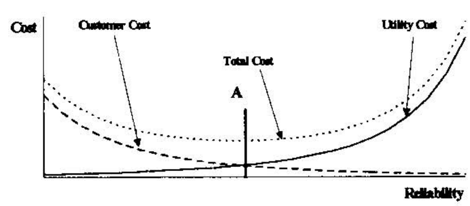

Fig. 1. Minimizing the Total Cost Of Reliability

Cost of service reliability (i.e., investment cost plus customer interruption costs) is minimized. The line A in Fig. 1. is the point on the Total Cost curve at which the Total Cost is a minimum. All utility investments with Total Costs appearing on the left side of line A are cost effective and reasonable. All those on the right side of line A are investments which increase the total cost and are unreasonable. Investment cost estimates are obtained through conventional engineering cost estimation techniques. Customer interruption cost estimates are obtained by directly surveying customers to determine the costs they experience as a result of different kinds of reliability and power quality problems.

As part of a larger effort within Duke Power Company to establish value based reliability planning, a comprehensive value of service study of Duke Power Customers was carried out in cooperation with the Electric Power Research Institute in 1992-93. In addition to interruption costs, the study measured customer satisfaction with and expectations for service reliability and quality.

II. Approach

Customer interruption costs are the economic losses customers experience as a result of interruptions of electric service or power quality problems. These costs vary from customer to customer as a function of a number of factors including:

- the customer's dependence on electricity;
- the nature and timing of the electric supply disturbance; and
- the economic value of the activity being disrupted.

Consequently, to estimate customer interruption costs it is necessary to statistically survey representative samples of customers.

Procedures for statistically surveying customer interruption costs have been developed and refined by a number of utilities over the past 15 years; and in the late 1980s the Electric Power Research Institute (EPRI) co-sponsored several large scale efforts to demonstrate the estimation of outage costs using state of the art survey techniques [4]. The basic methodology used in these studies involves directly asking random samples of customers in different market segments (i.e., residential, commercial and industrial) to estimate their economic losses as a result of power reliability and quality problems commonly considered in utility planning.

Using the methods that had been developed and tested over the years by EPRI and others, information was collected from customers concerning the economic and operational impacts of a number of reliability and quality conditions. The seven outage scenarios outlined below comprise the minimum set of conditions for which information is required to support VBRP at Duke Power Company. These conditions included:

1) a one-hour Generation outage (i.e., an outage occurring at the time of system peak with advance notice;
2) a one-hour summer afternoon T&D outage;
3) a four-hour summer afternoon T&D outage;
4) a two-hour winter morning T&D outage;
5) a 1-2 second momentary outage (clear weather);
6) several 1-2 second momentary outages (occurring during a summer storm); and
7) a 15 to 20 percent voltage sag (large customers only).

Customers cannot distinguish between outages resulting from generation capacity shortfalls (generation outages) and those resulting from failures on the transmission or distribution system (T&D outages). Nevertheless, the conditions that customers experience during outages originating in the generation system are very different from the conditions they experience for outages originating on the transmission or distribution system; and as will become clear below, these different conditions result in very different outage costs.

Outages originating on the transmission and distribution system generally occur without warning and can last anywhere from microseconds to many hours (even days). Outages resulting from generation capacity shortfalls are different in several important respects. Generation capacity shortfalls do not cause the collapse of the utility system because the operation of the system during generation shortfalls is governed by emergency operating procedures. These procedures dictate ameliorative actions that the utility will take when operating reserves are forecasted to fall below specified levels. Among the actions that are usually called for are public appeals for voluntary curtailments and if the situation continues to worsen, interruption of randomly selected retail circuits preceded by radio and television announcements. These interruptions are designed to last a fixed period of time (usually one hour) and are imposed in rotating fashion. Because the duration of the outage is fixed and known and because the customer receives advance notice of its onset, the costs resulting from generation outages are significantly lower than the costs that customers would otherwise experience.

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Table 1. summarizes critical features of customer interruption cost surveys conducted during the study. The survey designs, sample designs and study procedures differed by market segment and customer size. Residential customers were surveyed by mail. Small and medium sized industrial and commercial customers were surveyed using a combination of telephone and mail; and large industrial and commercial customers were surveyed in-person by experienced cost estimators.

III. Interruption Cost Summary

In the event of a generation outage, the average cost per kWh of unserved energy on the Duke Power System is estimated to be $7.79 (1992). Table 2. summarizes average customer interruption costs per event and per kWh for summer afternoon outages of one hour duration. The generation outage occurs with one-hour advance notice via radio and television announcements by the utility. Using the sample sizes and measurement techniques applied in this study, there is only a five percent chance that true system-wide generation outage costs are below $5.38 per kWh or above $10.10 per kWh.

Commercial and industrial customers experience much higher interruption costs than residential customers. In Table 2, it is apparent that residential customer interruption costs are significantly lower than those of either commercial or industrial customers. For an outage lasting one hour on a summer afternoon originating in the transmission or distribution system, the average residential customer would experience an interruption cost of $5.39 (or about $2.07 per coincident kWh of residential customer load). For the same outage, the average commercial customer would experience a cost of $1,317 (or about $45.82 per coincident kWh of commercial customer load). For industrial customers, the average cost of this outage is estimated to be $9,404 (or about $7.61 per coincident kWh of industrial customer load). Overall the average customer cost per unserved kWh for a one hour outage without advance notice is estimated to be $16.15 (1993).

Interruption costs vary from customer to customer depending on a number of factors. Fig. 2a. and Fig. 2b. display the distribution of customer interruption costs for residential, commercial and industrial customers for a one-hour outage on a summer afternoon without advance notice. Residential customer interruption costs range from $0 to $64. Commercial customer interruption costs range from $0 to over $100,000, and industrial customer interruption costs range from $0 to over $1,000,000.

Differences in interruption costs among commercial and industrial customers are systematic and can be predicted from related production factors (i.e., the customer's business type, size and production technology). Using these production factors, multiple regression models were developed for predicting customer interruption costs. Fig. 3. shows the relationship between predicted and actual interruption costs for a multiple regression model predicting customer interruption costs from these factors. Predictions from the regression model are not perfect, but they are significantly more accurate than predictions based only on

Table 1. Duke Power Company - Value of Service Study Approach and Methodology

Duke Power Customer Class	Customer Class Characteristics	Sample Design	Outage Cost Estimation Methods	Customers Contacted	Customers Responded	Response Rate
Residential	All Residential Customer Accounts	Random Sample Stratified by Geographic Location and Prior Reliability	Mail Survey, using Willingness to Pay measures with High Control and Low Control variations	2,187	1,584	72%
Large Industrial and Commercial	Customers that Receive Power at Non-Residential Rate Schedules with Demand > 1MW or Receiving Power at Transmission Voltages	Random Sample Stratified by Business Type and Transmission or Distribution Voltage Levels	On-Site Surveying Using Direct Worth Outage Cost Calculations	299	210	70%
Small and Medium Industrial and Commercial	Customers that Receive Power at Non-Residential Rate Schedules with Demand <1MW and are on Distribution Circuits	Random Sample Stratified by Business Type and Electrical Demand	Combination of Telephone and Mail Survey Using Direct Worth Outage Cost Estimates	2,797	1,080	40%

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Table 2. Customer Outage Cost Summary

Market Segment	Generation Outage Mean Outage Cost	Transmission or Distribution Outage Mean Outage Cost
Residential Customers		
Cost Per Event	$4.91	$5.39
Cost Per Peak kWh	$1.88	$2.07
Commercial Customers		
Cost Per Event	$604.19	$1,317.21
Cost Per Peak kWh	$21.02	$45.82
Industrial Customers		
Cost Per Event	$4,443.00	$9,403.55
Cost Per Peak kWh	$3.60	$7.61
System Wide		
Cost Per Event	n/a	n/a
Cost Per Peak kWh	$7.79	$16.15

Michael J. Sullivan, "Volume Five: Outage Cost Summary", in Final Report For Value Of Service Study, December 1992

market segment means (i.e., the mean for commercial or industrial customers). For example, multiple R^2s for regression models predicting outage costs arising from different kinds of outages ranged from .67 to .34. That is, these models explain between 34 and 67 percent of the variation in outage costs about the averages for the market segments — a statistically significant improvement over the predictive power arising from market segment alone.

Since much less information is required to estimate customer outage costs from the parameters in the regression model, it is possible to calculate customer specific outage cost estimates for all large customers (from regression models) and thus to obtain detailed estimates of customer outage costs without the expense of on-site surveys of all customers. This approach is being used by Duke Power Company to calculate circuit specific outage costs including unique estimates for each of its 1,000 largest customers.

Although less of the variation in residential interruption cost is accounted for by variation in other household attributes, significant statistical associations are found between residential customer interruption costs, the size of the household and the age of its inhabitants. In general, the older the members of a household, the lower the household's average interruption cost. When children are present, customer interruption costs are significantly higher.

Circuit level interruption costs should be used when applying interruption cost information to transmission and distribution planning problems. While system average interruption cost estimates are meaningful and useful for generation planning, significant errors can be made by applying system average figures to particular circuits. Because of the variation that exists across circuits in the distribution of customers by market segment and size, customer interruption costs for particular circuits may deviate dramatically from system averages.

From the individual customer's point of view, generation outages (i.e.,. those including advance warning) are inherently less costly than transmission and distribution outages (i.e., those without warning). Advance warning significantly lowers the costs of outages for commercial and industrial customers. Table 3. illustrates the effect of advance notice on customer outage costs.

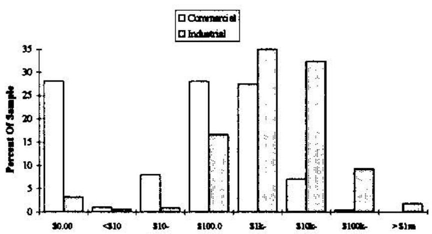

Fig. 2a. Commercial and Industrial Customers

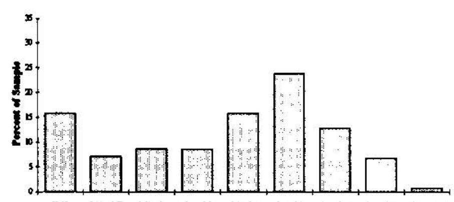

Fig. 2b. Residential Customers

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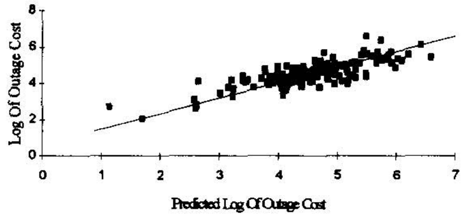

Fig. 3. Prediction of Customer Outage Costs

Given one hour advance notice, the average large commercial customer can reduce its interruption cost by 35 percent, from $22,506 to $14,574. For large industrial customers the savings due to advance notice are even greater. Given one hour advance notice, the average large industrial customer can reduce its interruption cost by 43 percent, from $46,695 to $26,582.

Voltage sags of 20 percent for less than 30 cycles can result in significant interruption costs for about 10 percent of Duke Power's largest industrial and commercial customers. On average, large commercial and industrial customers estimated that a voltage sag would cost about $7,694. However, slightly less than 50 percent of the large customers surveyed said that they would experience no losses as a result of a voltage sag. The interruption costs estimates provided by the remaining 50 percent of customers ranged from a low of $13 to a high of about $285,000. Ten percent of the large customers surveyed estimated their losses from a voltage sag would be in excess of $23,600. For customers who said that they would experience costs as a result of a voltage sag, the average cost was estimated to be $60,407.

Momentary interruptions can result in significant interruption costs for most of Duke Power's large commercial and industrial customers. On average, large customers estimated they would experience costs of $11,027 as a result of a 1 to 2 second momentary interruption on a summer afternoon. Approximately 35 percent said they would experience no losses as a result of a 1 to 2 second outage. Fifty percent of the large customers said that a momentary interruption of 1 to 2 seconds would result in outage costs in excess of $1,500; and ten percent of large customers said that their costs in the event of a momentary outage would exceed $45,130. For customers who said that they would experience costs as a result of a momentary outage, the average cost was estimated to be $72,426.

Table 3. Customer Interruption Costs With and Without Advance Notice

Customer Class	With Notice	W/O Notice
Large Commercial	$14,574	$22,506
Large Industrial	$26,582	$46,695

IV. Customer Expectations For Service Reliability

Most customers understand that it is virtually impossible to provide perfect power supply reliability and power quality. However, they differ dramatically in their expectations for the utility's performance along these dimensions.

Large commercial and industrial customers expect nearly perfect service reliability. Most of the large commercial and industrial customers in the study were served at transmission voltages. These customers experience almost no outages. From their reactions to the survey, it is reasonable to conclude that most large commercial and industrial customers probably do not consider any number of outages of any duration to be acceptable.

Small and medium sized commercial and industrial customers expect significantly higher reliability than residential customers. Customers on primary and secondary distribution circuits were asked to indicate the number of outages (of different durations) that they consider to be acceptable in a given year. The objective of this battery of questions was to measure the customer's desired level of service reliability in non-economic terms. The outage durations studied included momentaries, short outages (i.e., less than one hour) and long outages (i.e., outages lasting one to four hours). In the survey, respondents could indicate that they thought outages of the above durations would be acceptable at one of the following intervals: daily, weekly, monthly, every few months, twice a year, once a year, and none of the above.

Fig. 4a. and Fig. 4b. compare the answers to the above question given by residential and small and medium sized commercial and industrial customers. The figures show that residential customers have significantly lower expectations for service reliability than commercial and industrial customers. For example, Fig. 4a. shows that fifty percent of residential customers consider two or less extended outages per year to be an acceptable level of service. On the other hand, fifty percent of commercial and industrial customers expect one or fewer outages per year. That is, the median

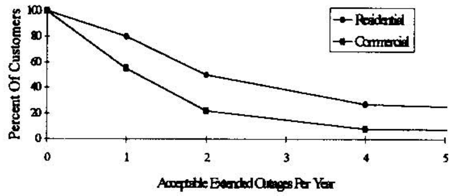

Fig. 4a. Acceptable Number of Extended Outages

commercial and industrial customer expects service to be about twice as reliable as the median residential customer.

The difference between expectations for service reliability for non-residential and residential customers is even more pronounced for momentary outages. Fig. 4b. shows that the median residential customer considers service to be acceptable if the number of momentary outages is less than about 38 per year -- about once every ten days. On the other hand, the median non-residential customer expects fewer than 12 outages per year -- about one per month. Here non-residential customers expect or desire service that is about three times as reliable as that desired by residential customers.

V. Customer Satisfaction

The satisfaction of customers with service reliability was measured in all three studies to ensure that the issue of customer satisfaction could be addressed. The customer satisfaction measures used in the surveys were comparable to those used on other studies of Duke Power customers.

The relationship between the reliability of utility service and

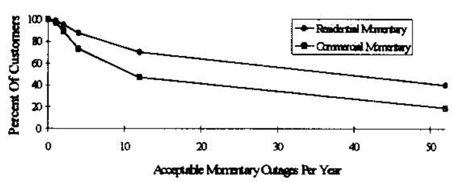

Fig. 4b. Acceptable Number of Momentary Outages

residential customer satisfaction is more complicated than it might appear at first. The results of this survey indicate that reliability history has no direct effect on a customer's satisfaction with utility service. That is, customers who receive relatively less reliable service are no less satisfied than other customers who receive higher reliability service. Fig. 5. shows that there are relatively small differences in the levels of satisfaction for customers in the survey sampled from circuits with dramatically different prior reliability histories.

Residential customer satisfaction is determined by the customer's perception of their service reliability, not by their actual service reliability. Residential customer's perception of the reliability of their service is highly correlated with their satisfaction. Customers who perceive that they are experiencing relatively high numbers of momentary or sustained outages are significantly less satisfied than customers who believe that they are not receiving relatively high numbers of outages.

Customer's perception of the reliability of their electric service is influenced by the reliability of their service, but most residential customers cannot distinguish high reliability service from low reliability service. Customers who experience relatively small numbers of momentary and sustained outages are significantly more likely to say that the number of outages they experience is very low than are customers who experience these kinds of outages more frequently. However, the relationship between perceived service reliability and actual service reliability is tenuous. Only customers in the extremes of the reliability distribution appear to be able to discriminate their level of service reliability, and then only imperfectly.

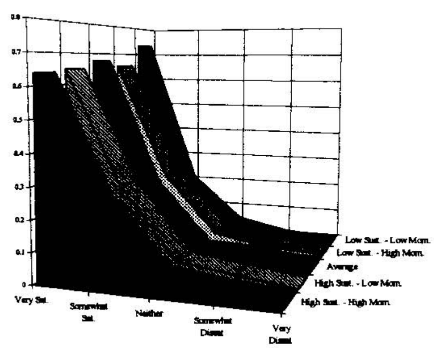

Fig. 5. Residential Satisfaction

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The effect of actual service reliability on customer satisfaction is indirect, based on the customer's perception of the reliability of its service. Many other factors affect the customer's perception of the reliability of their service besides the actual level of reliability that they experience.

VI. Conclusions

This study shows that customer interruption costs vary systematically and predictably as a function of customer type and size and within commercial and industrial customers by the processes, equipment and products being made and sold. It documents the ameliorative effects of advance warning on interruption costs arising from generation outages and suggests that electric emergency planning may be a highly cost effective alternative to investment in new generation. Because there are significant differences across utility circuits in the numbers and types of customers served, this study suggests that it is inappropriate to apply system wide interruption cost estimates to transmission and distribution planning problems. Work is ongoing at Duke Power Company and the Electric Power Research Institute to develop interruption cost estimates that are appropriate for these applications.

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Biographies

Michael J. Sullivan has a Ph. D. in Sociology from Washington State University. Prior to founding Freeman, Sullivan & Co., he was Operations Coordinator for Load Management at Pacific Gas and Electric Company and a Lecturer at the Hass Business School at the University of California, Berkeley. He has over 20 years experience directing large scale statistical surveys designed to estimate population parameters for use in engineering and scientific modeling and forecasting. He is currently Vice President of Practice at Freeman, Sullivan & Co.

Terry Vardell has an MBA from the University of South Florida. He has over 25 years experience as a market researcher in the utility, banking and retail service markets. He joined Duke Power Company as a project manager in Market Research in 1991 and is now Manager of Market Research.

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