ELECTRIC SERVICE INTERRUPTIONS: IMPACTS AND COST ESTIMATION

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INTRODUCTION

Service interruptions in electric supply can arise from severe power outages due to inadequate generating, transmission, or distribution capacity. During these periods of inadequacy, interruption costs will be borne by the utility and its consumers. The utility costs usually form only a small part, while the greater part is that borne by the consumers.

The major aspect of interruption costs estimation is an attempt to assess the worth of power system reliability, in order to compare it with the cost of the power system needed to establish the appropriate system reliability level. In this regard, numerous methods have been used to estimate the cost to customers of interruptions [1–8]. Different approaches and modeling techniques have been developed and adopted.

CASE STUDY

This work presents a summary of a study conducted to explore the impact of power interruptions upon the major consumer sectors in the city of Riyadh. Riyadh is the capital of Saudi Arabia and the largest city within the Saudi Consolidated Electric Company (SCECO) service area. The methodology is thoroughly described and documented in reference [9]. It represents a customer survey which is considered to yield relatively definite results and can estimate the real impact of energy shortages upon the various types of consumers, *e.g.* residential, commercial, or industrial. The breakdown of respondents to the samples of questionnaires by consumer sector is provided in Table 1.

Residential Survey Results

A difficulty associated with residential losses is due to the fact that in this sector, activities are not productive and most of its output is consumed within the household and not valued in the market. Interruptions may disrupt housekeeping activities such as cooking, washing, using air conditioners, entertainment, lighting, *etc.* Residents may incur tangible losses such as food spoilage and intangible losses in terms of inconvenience, discomfort, and anxiety. Most of the effects of interruption are intangible and cannot be measured in terms of monetary values. Therefore, a single complete measure of residential interruption cost is difficult if not impossible to obtain. However, the method depends on the specific purpose and theoretical structure of the analysis. In general, it is the author's opinion that the most suitable estimate of the worth of reliability is willingness-to-pay. This approach is theoretically sound and more pertinent to the perception of the residential customer and to his needs.

The survey aims to measure the attitude among the respondents towards tariff increases, and how much they are willing to pay to avoid interruptions. It is suggested that the power system has become subject to more frequent power interruptions. To increase system reliability, the company may add new generating units and/or reinforce its networks,

Table 1. Survey Response Information

Number of Questionnaires	Number of Responses	Residential (By Personal Contact)					
		Villa		Duplex			Apartment
500	340	174		31			135
		Industrial (By Mail)					
		Metal	Beverages	Carpets	Dairy	Food	Chemicals
120	31	13	2	1	3	8	4
		Commercial (By Mail)					
		Public Services		Food			Small Businesses
50	25	5		11			9

which may result in tariff increase. Hence, the question hypothesized a daily power interruption in the summer period for a duration of 20 minutes, 1 hour, and 4 hours. The question then suggested a range of possible tariff rate increases and asked the respondents to estimate the inpact of these interruptions and thus to discern the fair and appropriate rate increases, as a percentage of the present tariff structure. The information reported by the respondents is displayed in Figure 1, which shows that a reasonable percentage is willing to pay up to 20% of the present tariff to avoid the 4 hours per day interruptions. The willingness-to-pay (rate increase) decreases when higher rate increases are suggested or less frequent failures occur. The average value of the amounts that the respondents are willing to pay per interruption for a more reliable system is based on their annual energy consumption and is estimated as SR/kWh. To show more clearly the non-linear nature of the interruption cost, another cost is estimated as the average cost in SR per respondent for the same interruption duration. These costs are presented in Table 2.

Table 2. Residential Average Interruption Cost Estimation

Interruption duration	SR/kWh	SR
1 min	–	–
20 min	0.000007	0.15
1 h	0.000078	2.83
4 h	0.006241	18.53

Industrial Survey Results

The objective of the industrial survey was to obtain information on costs of interruption for electrical users involved in assembling and manufacturing. This sector was delineated using the RCCI definition [10]. The effects and direct costs of interruptions to industry during working hours may be classified into two main categories: (*a*) spoilage of material in the process of being produced or in storage; and (*b*) reduced production during the interruption and the following restart period. The economic value of spoiled products depends on the extent to which they have been processed and must include the value of all embodied inputs used in their production.

To estimate the impact of interruptions upon this sector, the respondents were asked to estimate the costs to their company for interruptions of various durations. The interruptions were to occur without warning at a time of full production, at 9 am near the end of July. They were told to include in the estimation: plant and equipment damage; raw material and finished products spoilage or damage; and the cost of restarting production, the cost of operating standby equipment, and paid overtime to make up lost production. Each respondent's cost estimates were divided by their annual kWh consumption. The resulting averages in SR/kWh are presented in Table 3 and depicted in Figure 2. The variation of costs with respondent category indicates that interruption costs vary greatly from respondent to respondent within each category. Other average interruption

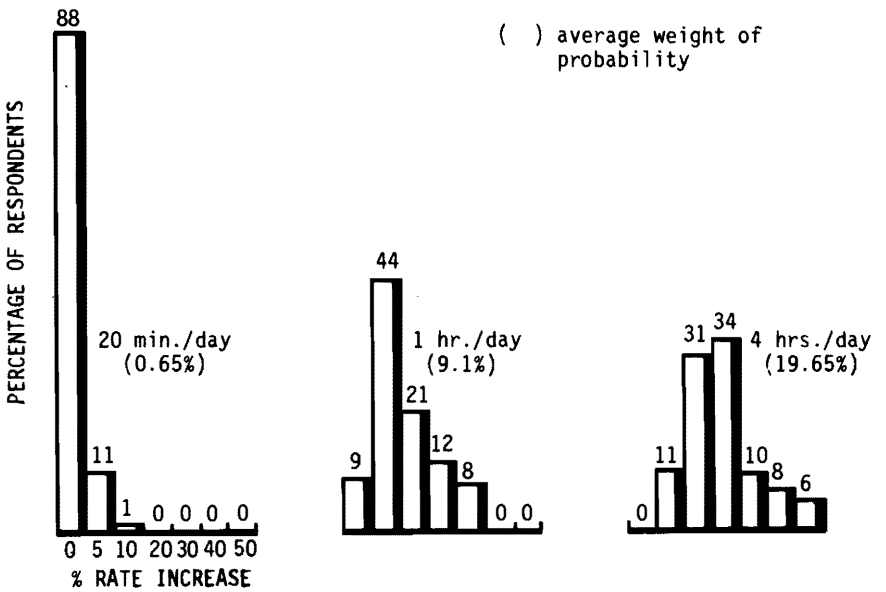

Figure 1. Respondents' Willingness-to-pay as a Percentage of Rate Increase.

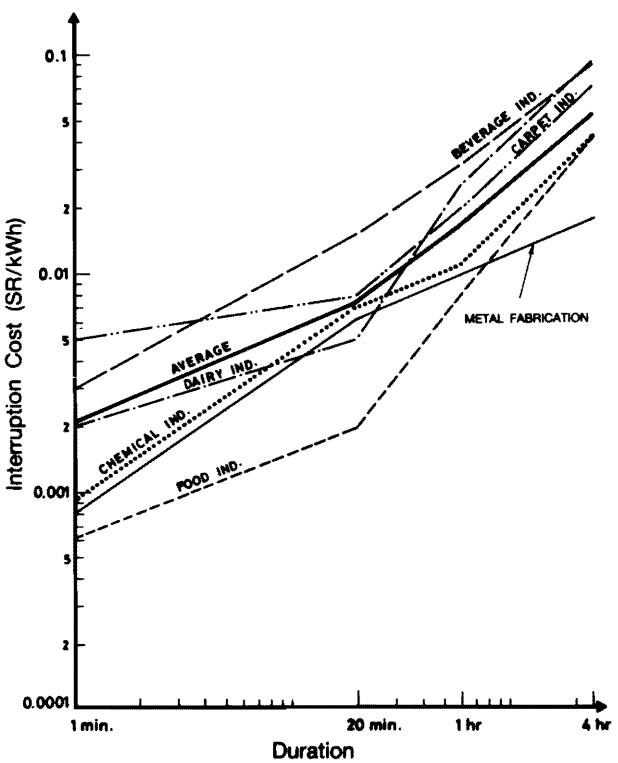

Figure 2. Industrial Sector Cost versus *Interruption Duration.*

costs, as SR per respondent, are evaluated and shown in the same Table to indicate the variation of these costs as a function of interruption duration. As reported by most of the respondents, this showed that a significant cost saving can result from information regarding interruption duration and from advance warning.

Table 3. Industrial Average Interruption Cost Estimation

Interruption duration	SR/kWh	SR
1 min	0.002063	5431
20 min	0.007232	10242
1 h	0.016510	16352
4 h	0.056331	32542

Commercial Survey Results

The commercial sector covers a variety of electricity consumers [11]. Interruption costs suffered by such consumers may generally be analyzed within a framework similar to that described for the industrial sector. Since much of the commercial activity could be classified as in the service-oriented sector such as shops, offices, and small businesses, the possibility of making up work lost by interruptions is much greater, by using existing manpower and equipment more intensively during normal working hours. Generally, the more commercial consumers rely on electricity-using equipment, the larger the corresponding interruption costs tend to be. Spoilage costs resulting from interruptions are likely to be most important to commercial users such as supermarkets,

restaurants, and hotels who use refrigeration to store perishable items.

The results of investigations are basically similar to those of the industrial sector. The commercial survey was divided into three subgroups: food stores, public service, and small business. Respondents were asked to estimate the cost to their establishments for interruptions of various durations. The interruptions were to occur without warning in summer, and specifically in Ramadan (the peak shopping season) between 9 pm and 1 am. They were told to include in their estimates loss of sales, wages paid to staff who are unable to work, goods and equipment damage, spoilage of food, start-up cost, and other cost effects. Table 4 displays the average of the cost estimates reported by the respondents, normalized by dividing by the respondent's annual energy consumption. As noted from Figure 3, some commercial users' estimates as SR/kWh have different cost estimates from the average. For example, although the average cost due to a one minute interruption is small, some

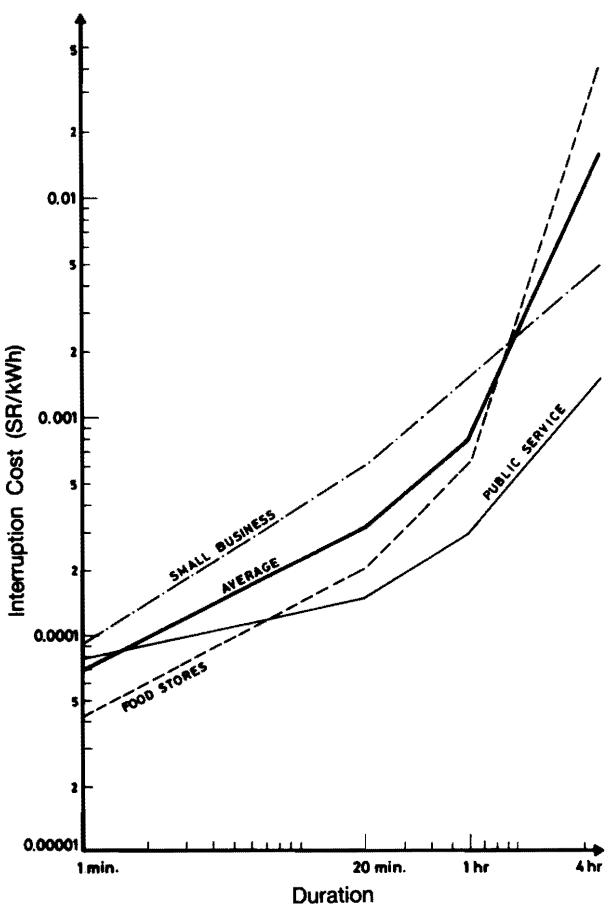

Figure 3. Commercial Sector Cost versus *Interruption Duration.*

categories have larger losses associated with potential damage to some major equipment. In the same Table, the average interruption cost per respondent in SR is shown to indicate the size of the monetary loss to the users as a function of interruption duration. A number of respondents reported that their interruption costs would be small or negligible. These involved businesses not operating during the evening or suffering less effect of interruption on their business production. Another observation is that food related businesses such as supermarkets and cold stores are the most affected by the interruption durations due to the great loss from of food spoilage. As in the industrial case, an overwhelming majority indicated that a significant cost saving can be achieved if adequate warnings as well as information on interruption durations are available in advance.

Table 4. Commercial Average Interruption Cost Estimation

Interruption duration	SR/kWh	SR
1 min	0.000076	5
20 min	0.000318	152
1 h	0.000853	471
4 h	0.015510	1246

CONCLUSIONS

Interruption costs estimation for the residential, industrial, and commercial sectors in the city of Riyadh were obtained for interruptions of various durations, which were to occur without warning in summer time. The intangible losses sustained by the residential customer include loss of comfort and convenience. These are difficult to convert to monetary values. To reflect the role of customer discomfort and inconvenience in his perception of the value system reliability (defined as least interruptions), the residential cost estimation was based on his willingness-to-pay to avoid service interruptions. The industrial and commercial costs estimation resulted from respondents' evaluation of interruption losses to their companies and establishments, normalized by dividing by their annual energy consumptions (kWh). Some essential factors that influence interruption costs and mitigate their effects have been discussed. The outcome of this study is a key input in power-system planning and reliability criteria, using cost–benefit assessments.

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