Journal of Energy & Environment 3 (2004) 119 - 131

Evaluation of Power Interruption Cost for Residential and Industrial Sectors

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(Received on 27 Apr 2004, revised on 26 May 2004)

Abstract

Uninterrupted electric power supply is a desire of a customer of electricity, although it is not realistic. However, the electric power interruption may create a significant loss to a customer. This paper presents a methodology to quantify the loss of the residential and industrial customers, into monetary term, due to electric power interruption with a view to creating awareness among the customers and the utility of the actual amount of loss inflicted on the customers.

Introduction

Each electric power interruption incurs a loss to a customer. It is not realistic that a system would be completely uninterrupted one, but the frequency and duration of power interruption should be limited to an acceptable level. Generally, the utility requires more money to invest to improve its system reliability. The quantification of the effects of power interruption into monetary term can make a customer of the actual loss inflicted on him. This will also help the utility to justify higher investment to improve its system reliability.

A list of publications relating to the theory and surveys concerned with determining the impacts and estimating the costs to customers of electrical service interruptions is presented in [1-2]. Those evaluated losses by surveying respondents and the losses are expressed in terms of their monthly salary. R. Billinaton et. al. [3] introduces an approach of customer cost calculation recognizing that the interruption cost data is dispersed in nature. K. K. Kariuki and R. N. Allan [4] identify the factors that affect customers' perceived costs caused by interruption of supply. They collect opinions of customers on various issues, such as price and quality. The paper observes that the customers are only concerned about their inability to use their equipments and the costs of likely damages from interruption of supply. In most of the cases in [1-4] the cost of power interruption is evaluated without presenting a generalized model of it.

This paper proposes a methodology of evaluating the loss of residential and industrial customers due to electric power interruption. To accommodate all possible losses of a customer due to a power interruption the methodology introduces five cost components; (i) the damage of the appliances, (ii) the cost of alternative sources, (iii) the damage of perishable goods. (iv) the cost of inconveniences and (v) additional wage. The first four components are applicable for residential customers and all five components except the cost of inconvenience are applicable for industrial customer. The study reveals useful results for both the customers and the utility. The initial results of the study are presented in [5-6]. The significant difference of this paper from [5-6] is that it presents the global model for the quantification of power interruption into monetary term instead of presenting a model specific for a class of consumers. Moreover, it presents a comparison of losses of two classes of consumer with a view to providing guidance to the utility where to invest more.

Methodology

The methodology to quantify the loss of a customer, into monetary term, due to electric power interruption is based on the identification of the types of losses a customer may face. A residential customer usually faces the following four types of losses due to the interruption of power:

a. Damage of electrical appliance,
b. Cost of alternative electrical source to meet the emergencies,
c. Damage of perishable goods and
d. Loss due to inconvenience.

The contribution of inconvenience towards the loss of interruption is insignificant in case of industrial customers. However, the wages for additional labors compensating the production, hampered due to power interruption, may contribute significantly. In what follows, a mathematical model incorporating the above five types of losses is developed.

Cost due to the damage of appliances

The frequent power interruption causes serious damage to some of the electrical/electronic appliances. This may also shorten the life of the appliance. Some of the damages are repairable and some are not. Therefore, the cost of the damage of the appliances, J_1, may be expressed as

$$J_1 = \sum_{i=1}^{N} \left[J_{11} I(da) + J_{12} \perp(da) \right]_i \tag{1}$$

where,

J_1 = cost component due to the damage of appliances
J_{11}= cost component due to the damage of the repairable item
J_{12}= cost component due to the damage of the irreparable item and
N = total number of the damaged appliances
I(da) and $\perp$(da) are characteristic functions and these are defined as

$$I(da) = \begin{cases} 1 & \text{if da is a repairable appliance} \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$\perp(da) = \begin{cases} 1 & \text{if da is an irreparable appliance} \\ 0 & \text{otherwise} \end{cases} \tag{3}$$

To evaluate J_{11}, it is required to estimate the number of interruptions during the rest of the life of the appliance. The estimated number of interruptions during the life of the appliance, NI may be expressed as

$$\mathrm{NI} = (\mathrm{NI_s} + \mathrm{NI_{ns}})\hat{\tau}_R \mathrm{k} \tag{4}$$

Where, k is a function of the uncertainty in interruption due to seasonal variation and the change of the quality of the supply of electricity.

In equation (4), NI_s is the number of interruptions during the sampling period and NI_{ns} is the number of interruptions during the rest of the period of a time interval. The time interval may be a year or season or any convenient period. $\tilde{\tau}_R$ is the reduced life of the repairable appliance. This decrease in the length of the life of an appliance is because of the interruption of electric power. This decrease depends on the frequency of interruption. NI_{ns} may be evaluate as

$$NI_{ns} = (T - T_S)\frac{NI_s}{T_S} \quad (5)$$

In equation (5), T and T_S represent the time interval and the duration of sampling period, respectively.

Two components of cost constitute J_{11}; one due to the repair of the appliance and the other one arises due to the decrease of the life span of an appliance.

If C is the average cost per repair of an appliance, the cost of repair C_R may be expressed as

$$C_R = NRC \quad (6)$$

NR is the total number of possible repair during the lifetime of an appliance. The value of NR may be estimated by considering the number of repair required for NI_s.

The loss due to the decrease of the life span of the repairable appliance, CRL, may be expressed as

$$C_{RL} = \frac{P_R}{\tau_R}(\tau_R - \hat{\tau}_R) - s_R \quad (7)$$

In equation (7), P_R is the capacity cost, τ_R is the life span and S_R is the salvage value of an appliance. Therefore J_{11} can be expressed as

$$J_{11} = C_R + C_{RL} \quad (8)$$

The cost of the irreparable appliance, J_{12}, involves the loss due to the reduced life of the appliance only and this may be expressed by an equation similar to equation (7) as

$$J_{12} = \frac{P_{IR}}{\tau_R}(\tau_{IR} - \hat{\tau}_{IR}) - S_{IR} \quad (9)$$

In equation (9), the subscript, IR, corresponds to the irreparable appliance.

Cost due to the use of alternative sources

The alternative sources, the customer may use during the power interruption, are of different types including charger light, IPS, UPS, generator, candle, kerosene lamp etc. The use of an alternative source during power interruption involves capacity cost and fuel cost. Some of the alternative sources have only capacity cost. For example, the cost of a candle is its capacity cost only. The cost due to the use of alternative sources may be expresses as

$$J_2 = (P_{Al} - S_{Al}) + C_{FAL}\,NIT_1 \quad (10)$$

In equation (10), the subscript AL corresponds to alternative source. C_{FAL} is the cost of the fuel for an unit duration of use. This may be the fuel cost of the generator or the charging cost of IPS, UPS and changer. T_1 is the mean duration of an interruption. This may be evaluated by calculating the mean of the probability density function of interruption duration developed through sampling. Note that the value of NI depends on the life span of an alternative source.

Cost of perishable goods

The damage of perishable goods is a function of the duration of power interruption. Some items get perished in a refrigerator or oven for a short duration of power interruption but some item may stay longer without being perished. The cost of the loss of perishable goods is

$$J_3 = C_{PG} \mathrm{I}(D) \tag{11}$$

In equation (11) and in what follows, D represents the duration of interruption. C_{PG} represents the cost of perishable goods. I(D) is a characteristic function given as

$$\mathrm{I}(D) = \begin{cases} 1 \text{ if } \mathrm{D} \geq \overline{\mathrm{D}} \\ 0 \text{ otherwise} \end{cases} \tag{12}$$

$\overline{\mathrm{D}}$ is the duration required for an item to be perished.

Cost of inconvenience

The inconvenience to a residential customer may arise from the disturbance in study, dinning, computer works, cooking, sewing, accounting, amusements etc. In a residence, all members may not feel inconvenience for the same kind of disturbance. The magnitude and the cause creating inconvenience depend on the psychological and physical condition, the age, profession and the gender of a resident.

The disturbance in the work during night due to interruption of power may force an incumbent to work late in the night. The incumbent may fail to catch the regular transport to reach his work next day. The repetition of this phenomenon may create sickness. Therefore, the loss due to the inconvenience from the disturbance in study, computer works and or accounting may be expressed as

$$\mathrm{J}_{\mathrm{IN}_1} = \sum_{i=1}^{M} \left(C_{TR} + C_M \right)_i \tag{13}$$

where,

J_{IN_1} =cost relating to the loss due to inconvenience in study or in computer works or in accounting
C_{TR} = additional charge for transport
C_M = cost of medication
M= number of members of a residence suffered from the inconvenience due to disturbance in study or computer works or accounting

Due to power interruption the sewing may be disturbed. This disturbance may require getting the job done by a professional tailor. The loss due to this inconvenience is

$$\mathrm{J}_{\mathrm{IN}_2} = \sum_{i=1}^{K} \mathrm{CT}_i \tag{14}$$

where,

J_{IN_2} = cost relating to inconvenience in sewing
CT= the charge of the tailor
K=number of members of a residence suffered from this inconvenience

A longer duration of the interruption of power during cooking or dinning may cause wastage of food and the family members may have to get food from outside. This inconvenience may be assessed by estimating the price of outside food and the wastage of cooking material. This may be expressed as

$$J_{IN_3} = (C_F + C_{OF}) \perp (D) \tag{15}$$

where,

J_{IN_3} = equivalent cost of inconvenience in dinning or cooking
C_F = cost of the cooking material run to waste
C_{OF} = cost of outside food

In equation (15), $\perp(D)$ is a characteristic function. It is expressed as

$$\perp(D) = \begin{cases} 1 \text{ if } D \geq ID \\ 0 \text{ otherwise} \end{cases} \tag{16}$$

where,

ID is the interruption duration creating wastage of food.

Since inconvenience for the disturbance in amusement is intangible, it is not considered here for quantification. However, the disturbance in family function may be assessed as

$$J_{In_4} = C_D + C_F + C_A \tag{17}$$

where,

J_{IN_4} = loss in the family function
C_D = cost of decoration
C_F = cost of food
C_A = charges of outside artist

Therefore, the total inconvenience cost J_4 may be written as

$$J_4 = \sum_{i=1}^{4} J_{In_i} \tag{18}$$

Cost of additional wages

The cost due to additional wage, J_5, may be expressed as,

$$J_5 = \sum W_i L \qquad (19)$$

where,

W_i = The wage of i^{th} worker per unit time
L = Duration of running an industry to compensate power interruption

The total cost of interruption of power is the sum of all four cost components J_1, J_2, J_3 and J_4 for residential customers and the sum of cost components J_1, J_2, J_3 and J_5 for industrial customers.

Data Collection

The methodology proposed before is applied to the different residential areas of Dhaka Metropolitan City and two different types of industries, garment and tannery. The majority of these two types of industries are located in Dhaka or in its suburb. The product of these industries is mainly exported to different countries, earning foreign currency.

Questionnaire

Separate questionnaire is developed for residential and industrial customers to collect the information of interruption of electric power. The first page of the questionnaire asks the respondent to fill up the general information like the address, the monthly electric bill, the size of the house/industry, the types of electric appliances and their number. Its second page requires mainly the information regarding the date and duration of interruption, the type of alternative source used during the interruption and the duration of its use. It also requires the type of inconveniences suffered by the respondents and its severity for residential customers.

Response of the respondents

Residential customer

The questionnaire was distributed among the customers of electricity of four different residential areas of Dhaka Metropolitan City, Dhanmondi, Kallanpur, Mirpur and Bashabo. The areas are selected randomly. The questionnaires were distributed among 75 families. The data collection starts in the first week of August and it ends at the last week of December.

During the sampling period the respondents were requested, by visiting their houses or by phone, to fill up the questionnaire. However, the response was very poor. Only 26 families filled up the questionnaire. Almost all the 26 respondents did not record the data throughout the complete period. Some of them started taking data even one and a half-month later and some did not continue till the end of the sampling period.

Industrial customer

The questionnaire was distributed among 38 garment and 12 tannery industries. The sampling period was December to February. During the sampling period the respondents were requested, by visiting the industry or by phone, to fill up the questionnaire. However, the response is very poor. Only 20 garment and 6 tannery industries filled up the questionnaire. Four garment industries provided partial information.

Information from the respondents

Residential customers

Table 1 presents the total number and duration of interruptions corresponding to each respondent during the sampling period. Table 1 also presents the total number of samples observed by each respondent and the average duration of an interruption.

Table 1 shows that the number of data collection days by a respondent are as low as 7. As the residences of the respondents are not located close to each other, the average duration of interruption corresponding to different respondents is not same. The average duration of interruption varies from 0.45 hours to 2.44 hours. Among the 26 respondents 6 reported more than one interruption in a day. The average interruption rate is 0.564 per sample.

Table 1 Interruptions of electric power for residential customers

Identification No. of respondent	Number of samples	No. of interruptions	Total duration of interruption (Hours)	Average duration of an interruption (Hours)
1	17	12	9.50	0.79
2	13	13	9.50	0.73
3	59	17	13.66	0.80
4	34	17	9.58	0.56
5	55	23	16.95	0.74
6	24	22	18.88	0.86
7	24	08	3.58	0.45
8	30	14	34.00	2.44
9	08	17	12.92	0.76
10	58	11	6.25	0.75
11	17	17	23.25	1.36
12	24	14	12.10	0.86
13	07	07	5.33	0.76
14	14	14	16.00	1.14
15	09	04	2.16	0.54
16	10	10	10.16	1.02
17	24	14	12.17	0.87
18	12	30	20.6	0.68
19	25	14	8.00	0.57
20	66	22	19.60	0.89
21	27	14	13.50	0.96
22	17	17	18.42	1.08
23	37	18	13.17	0.73
24	14	09	12.65	1.41
25	37	08	6.42	0.80
26	17	17	12.60	0.74

As reported by the respondents, the duration of interruption varies from 10 minutes to 5 hours 20 minutes. The relative frequency of the interruption of different durations is depicted in Fig. 1. The Fig. 1 shows that mostly the interruptions are of duration 30-60 minutes. Note that the scheduled load shedding during the peak period is around an hour.

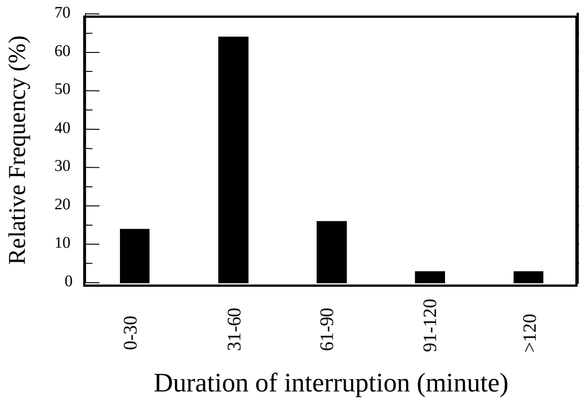

Fig. 1 Relative frequency of interruption of different duration for residential customers

<u>Industrial customers</u>

Although the sampling period ranges from December to February the maximum number of observation days is 31 and the minimum is 24. The operating hours of a garment industry in a day is 10 hours, from 8 a.m. to 6 p.m. The tanneries operate 24 hours a day in three shifts. It is observed from the collected information that only four garment and all the tanneries have alternative sources of electric supply. Longer duration of power interruption or frequent ones causes the damage of raw material or materials under process in tanneries only. All the industries reported the damage of electric appliances due to power interruption

The responding industries are grouped into three according to the number of samples recorded by them. This is presented in Table 2. The Table 2 also presents the average number of interruptions observed by an industry and the average duration of an interruption. The relative frequencies of interruptions of different duration are depicted in Fig. 2. The Fig. 2 shows that the highest frequency is of the interruptions of around one hour duration. Note that the usual duration of load shedding is about an hour in the areas where these industries are located. It indicates that the dominating factor of the frequency of power interruption is load shedding.

Table 2 Average number and duration of power interruption for industrial customers

Sampling range	Number of industries sampled in this range (%)	Average Number of interruptions (interruptions/industry)	Average duration of an interruption (Hour/ interruption)
200-300	33.33	32.70	1.09
301-500	46.67	44.43	0.95
501-750	20.00	57.67	1.00

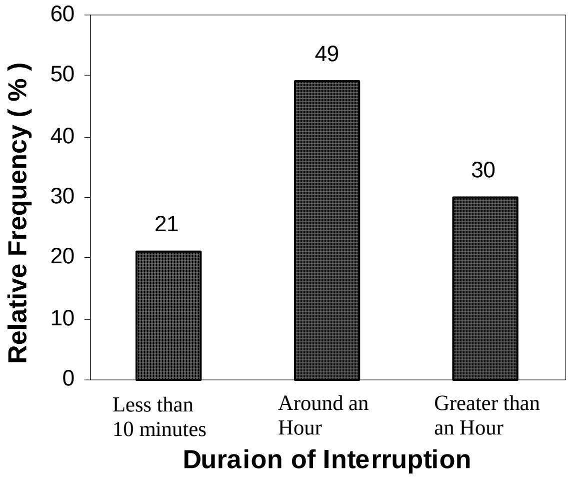

Fig. 2 Relative frequency of interruption of different duration for industrial customers

Quantification of Loss and Its Analysis

Residential customers

The data of power interruption presented in Table 1 is used to evaluate the loss following the methodology presented before. The evaluated cost (in Bangladesh currency i.e. Taka) corresponding to each respondent is presented in Table 3. It should be noted that one US dollar is equivalent to 58.00 Taka (Tk).

Table 3 shows all 4 cost components due to interruption for each respondent. From 2nd up to fifth columns present the average value of cost components for an hour of interruption. None of the 26 residential respondents except Respondent #1 reported the loss relating to perishable goods. Therefore, the evaluation shows the cost of perishable component zero for all respondents except Respondent #1. Sixth column of this Table 3 presents the sum of all cost components from columns 2 to 5. In the seventh column of the Table 3 the average cost for an interruption corresponding to each respondent is presented. This was computed by multiplying the sixth column value by the average duration of interruption to the respondent.

Table 3 shows that among these 26 respondents the 26th respondent suffered the highest cost of inconvenience. Although his loss due to the damage of appliance and the use of alternative source are not higher compared to other, however, the cost of inconvenience makes his loss higher.

The overall average interruption cost, evaluated considering the average cost of interruption of all 26 respondents, is compared with the average electricity bill in Table 4. The average electricity bill is computed by considering the monthly electricity bill of all respondents.

The comparison of columns 1 and 2 with 3 and 4 clearly shows that the inclusion of the cost of inconvenience increases the cost of interruption 3 to 4 times. The Table 4 also clearly shows that the interruption cost, presented in different forms, is much higher than the average electricity bill paid by the respondents.

Table 3 Evaluated different cost components and the total cost of interruption for residential customers

Respondents	Cost due to damage of appliance (Tk / hour of interru-ption)	Cost of alternative source (Tk / hour of interruption)	Cost of perishable goods (Tk / hour of interruption)	Cost of inconveniences (Tk / hour of interruption)	Total cost (Tk / hour of interru-ption)	Average cost per interru-ption (Tk)
1	20.00	29.42	16.31	45.60	111.33	87.95
2	4.08	1.39	0	51.36	56.83	41.48
3	3.61	4.53	0	41.29	49.43	39.00
4	7.05	4.06	0	58.33	69.44	38.88
5	2.27	1.44	0	133.33	137.04	87.70
6	2.13	2.41	0	64.00	68.53	50.71
7	19.19	1.00	0	66.70	86.80	39.06
8	2.63	7.65	0	12.35	22.63	55.21
9	13.38	1.77	0	56.40	71.55	53.00
10	11.70	5.70	0	22.00	39.40	29.55
11	2.18	1.60	0	36.72	40.59	55.20
12	7.90	4.07	0	38.60	50.57	43.49
13	5.23	4.00	0	33.77	43.30	32.9
14	2.42	2.07	0	2.00	6.49	7.41
15	8.30	2.16	0	59.40	69.86	37.72
16	1.96	1.98	0	35.00	38.34	38.34
17	2.17	0.86	0	7.86	10.89	9.36
18	5.15	1.12	0	68.17	74.80	50.86
19	6.16	15.36	0	64.22	85.74	48.87
20	4.96	2.20	0	24.50	31.68	27.24
21	3.98	2.16	0	29.21	35.35	33.93
22	2.60	0.01	0	26.94	29.55	31.91
23	2.64	1.75	0	44.89	49.28	34.98
24	2.07	1.69	0	24.48	28.24	42.36
25	2.40	1.97	0	26.66	31.03	23.89
26	2.70	3.20	0	139.60	145.50	107.8

Table 4 Comparison of interruption cost with the electricity bill for residential customers

Average cost of interruption					Average electricity bill (Tk / hour of energy consumption)
Incorporating all cost components		Without inconvenience cost		Without inconven-ience and damage of appliance costs	
Tk / hour of interruption	Tk / interruption	Tk / hour of interruption	Tk / interru-ption	Tk / hour of interruption	
57.08	44.18	10.39	8.38	4.66	0.9

Industrial customer

The data obtained from the respondent are used to evaluate the loss following the methodology presented before. The evaluated four components of costs associated with the power interruption are presented in Table 5. These cost components and the total cost of interruption are compared with the electricity bill in the Table 5. The values in this Table 5 are average ones, which are computed considering the interruption costs of all the industries and the corresponding total duration of interruption.

Table 5 Comparison between the cost of interruption and the electricity bill for industrial customers

Cost components	Average cost (Tk / hour of interruption)	Total of all cost components (Tk / hour of interruption)	Average Electricity Bill (Tk / hour of operation)
Additional Wage	1859.00	2379.06	136.72
Alternative Source	363.44		
Damage of Appliance	82.37		
Perishable Goods	74.26		

Table 5 clearly shows that the total cost of interruption is much higher compared to the electricity bill paid by the industries to the utility. The cost corresponding to alternative source of electricity is two and a half times higher than the electricity bills. The cost due to the damage of electrical appliance is not high since the garment industries or the tanneries do not use sophisticated electrical appliance sensitive to power interruption. Among the four cost components, the cost of perishable goods is the lowest and that is only applicable to tanneries. The costs of interruption of different categories of industries are depicted in Fig. 3. Category A represents the garment industries with back up power system. Garment industries without back up power system fall in category B. Category C represents the tanneries only.

Fig. 3 clearly shows that the cost of interruption of garment industries without back up power system, group B, is the highest. Note that these industries usually operate outside the normal working period to meet the dead line of export. This requires the additional wages for the workers. The highest cost of interruption of this category clearly matches with the highest cost component of Table 5. The cost of interruption of other two categories, A and C, are very close indicating that the cost component due to perishable goods does not offset other two components of cost due to alternative source and damage of appliances. Moreover, these two components in case of tanneries are lower than those of garment industries.

The ratio of interruption cost and electricity bill is compared between residential and industrial customers in Table 6. The ratio is much higher in case of residential customers. However, if the inconvenience cost component is not considered, the two ratios are close.

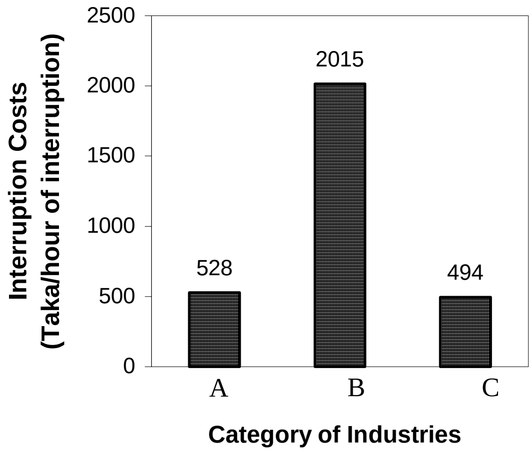

Fig. 3 Comparison of interruption costs of different categories of industries

Table 6 Comparison of cost of interruption between residential industrial customers

Type of Customers	Average cost (Tk / hour of interruption)	Average Electricity bill (Tk / hour of energy consumption)	Ratio: Interruption cost to electricity bill
Residential	57.08	0.9	63.4, 11.5(without inconvenience component)
Industrial	2379.06	136.72	17.4

Conclusions

This paper presents a methodology to quantify the loss of residential and industrial customers due to electric power interruption. It incorporates all possible tangible losses. The domain of sampling of data was narrow and also the responses of the respondents were poor. However, the evaluation of the cost of power interruption even with this narrow band of data clearly reveals that it is much higher than the amount a customer pays for its electricity bill.

The results of the investigation should be able to create awareness among the customers by finding a severe impact of electric power interruption. These results, especially the comparison between the loss due to power interruption and the electricity bill collected, also give a clear message to the utility to give a serious consideration to the reliability worth in its expansion analysis. Moreover, it will be easy to convince the consumers to pay higher charges for electricity.

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