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Reliability cost Assessment for upgrading feeder by using customer surveys

C. Bhargava, Imran, P.S.R. Murty

Abstract: Reliability cost/worth analysis involves an assessment of the costs of providing reliable service and a separate quantification of the worth of having that service. Uninterrupted electric power supply is a desire of a customer, although it is not realistic. For interruption costs assessments to be specific, they should obtain information that is customer specific. The customer survey approach is based on the assumption that the customer is in the best position to estimate the losses resulting from a power interruption. This customer survey approach presents a method to quantify the loss of the customers into monetary terms, due to electric power interruption. the major contribution of this paper, using survey method it is not only possible to obtain absolute power interruption costs for different customers but also shows the variation in interruption costs with the variation in interruption duration for each type of customer. Hence, these cost calculations can be further be used for the evaluation of other cost worth indices which will be useful for the future/reinforcement options for the reliability worth.

Keywords: reliability worth assessment, customer surveys, interruption cost assessments

I. INTRODUCTION

The reliability of power supply to industrial, commercial and residential customers gained renewed importance during the last several years as outages shutdown power in several regions in the country. Energy companies need to ensure that the reliability of the energy supply to their customers corresponds to the importance of reliability and so energy providers seek to quantify the impact of outages. Furthermore, in the current deregulated, regulated, reregulated electricity market environment, it is becoming increasingly important to justify capital, operating and maintenance expenditures based on the benefits derived by the utility and the customer. Quantitative reliability assessments permit a cost benefit analysis for every system reinforcement plan by including customer outage cost into the planning model before the reinforcement plan is implemented Power companies aim to provide electricity to their customers using the optimum amount of investment. Supply reliability is an important criterion for the decision of optimum power supply. In the past, power companies decided the level of acceptable supply reliability based on their judgment or experience. But in recent years, approaches that allow more reasonable and rational decision of the level of acceptable supply reliability have been used due to energy price hike and environmental change as well as government and consumer demands. The most important one of these approaches is the assessment of the value of system reliability that allows comparison with the cost of reliability level. The most important measure for the assessment of a selected reliability level is to compare personal and social costs resulting from electric service interruption.

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Reliability cost/worth assessment:

Reliability cost/worth analysis involves an assessment of the costs of providing reliable service and a separate quantification of the worth of having that service. The objective of reliability worth study is to estimate or assign a value to the worth of electric power service to the consuming public. This value can then be used in the cost/benefit analysis of an electric power system for planning purposes. This economic analysis is fundamental to establishing a balance between expenditures required to obtain a certain level of reliability and the worth of having that level as shown in fig1. Direct assessment of power system reliability worth is a difficult task. Earlier work in this area indicates that the worth of reliability in monetary terms cannot be obtained directly. The cost associated with unreliability of the supply system, however, can be estimated and considered as an indirect indicator of the reliability worth. A common approach used in quantifying reliability worth of an electric system is to estimate the customer costs or monetary losses resulting from power supply interruptions. It is therefore essential to have some understanding of the ways that an interruption affects the customer. Interruption effects can be broadly classified as direct and indirect effects [1]. Direct effects are those arising directly from the electrical interruption and relate to such impacts as lost production, spoiled food or raw materials. Paid staff unable to work lost personal leisure time, injury or loss of life. Indirect effects are related to impacts arising from response to the interruption. Such as crimes during blackouts (short term effect) or businesses moving to areas with higher reliability (long term effect). The consequences of an interruption are highly dependent on the characteristics of the interruption as well as that of the customer concerned. Interruption characteristics include frequency, duration, time of occurrence, advance warning. and the extent of the interruption. Customer characteristics include the type of customer, size of operation, demand and energy requirements and advance preparation for the outage. Additional factors such as the outside temperature or the occurrence of the interruption during special events also affect the impact. The level of reliability the users have experienced in the past and expect in the future may have a significant effect on the interruption costs [1].

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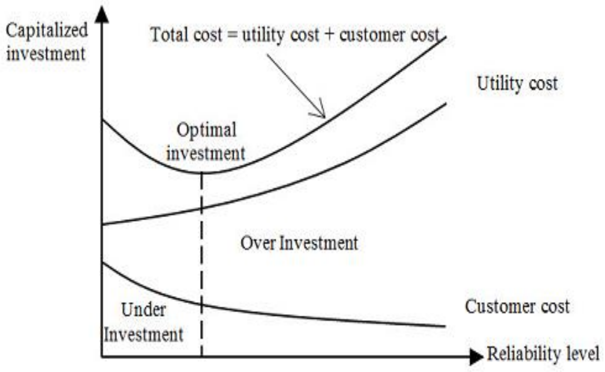

Fig1.Cost benefit analysis of reliability investment

II. INTERRUPTION COST METHODOLOGIES

Obtaining customer interruption costs are a complex and often subjective task. The impacts of interruptions can be evaluated using a variety of approaches [2]. These methods can be grouped into three basic categories: analytical methods, case studies of actual blackouts and customer surveys.

Analytical Methods

There is a large number of methods which can be classified as analytical. Analytical methods generally evaluate the interruption costs from a theoretical economic viewpoint. Many of the methods attempt to be market-based, while others utilize readily available secondary data, such as global economic indices. An example of this approach is a method which attempts to estimate the interruption cost based on the ratio of the Gross National Product (GNP) and the consumption of electrical energy from the viewpoint of the nation as a whole [3]. The main advantage of these methods is the relative simplicity of the assessment. The inability to provide assessments other than for only large geopolitical regions limits the use of most analytical methods. In general, these approaches do not reflect the actual consumer's needs.

Case Studies of Actual Blackouts

The case study approach attempts to estimate losses caused by an actual power interruption. Both direct costs as well as indirect consequences can be addressed. For example, the study of the 1977 New York blackout [4] considered a wide range of societal and organizational impacts along with the direct and indirect consequences of the events. The results also suggest that a widespread blackout has more serious consequences than local power outages. Valuable information can be obtained from case studies of actual blackouts. Unfortunately, this information is restricted to the specifics of the individual interruption event and its location. The costs associated with specific interruptions cannot be generalized to other locations and other interruption characteristics.

Customer Surveys:

The results from both the analytical methods and the case studies indicate that for interruption cost assessments to be realistic, they should obtain information that is customer specific. Customer specific costs are the losses that the customer experiences due to the unavailability of the functions, products and activities that are dependent upon electricity. The customer survey approach is based on the assumption that the customer is in the best position to estimate the losses resulting from a power interruption. Moreover, the survey questions can be framed in a number of ways depending upon the type of customers, the locations, the resources available and the utility's needs.

Customer survey methods can be grouped into the three categories of contingent valuation methods, direct costing methods, and indirect costing methods [5]. Most customer surveys incorporate a combination of all three approaches. The choice is largely dependent upon the type of customer being surveyed.

Contingent Valuation Methods

Contingent valuation methods are based on two basic concepts of electricity use. The first concept is that customers consume electricity in a predetermined pattern which has characteristics based on time of the day, day of the week and season of the year. The pattern evolved so as to provide the greatest benefit to the consumer. An electric power outage interrupts this pattern of usage and either eliminates, diminishes or postpones the activity that is dependent on electricity. The second concept is that some uses of electricity are worth more to the consumer than others. The difference between the amount paid for the electricity and its worth to the consumer is lost when the supply is interrupted. The value or worth of electricity can therefore be quantified by either the customer's willingness to pay to avoid an interruption and have the benefit or by the customer's willingness to accept (WTA) compensation for having an interruption and deprived of the benefit of electricity uses.

Theoretically, the WTP and WTA methods should yield the same cost value. But typically they do not. This is probably due to customer bias regarding electricity rates, or it may simply be a reflection of the difference between the "bid" and "asked for" price. These costs, however, can be considered as two bounds on reliability worth for a given type of customer surveyed. This approach being based upon the fundamental principal of electricity use is suitable for any type of customer. The limitation is the costs evaluated may be comparatively very rough compared to other costing methods.

Direct Costing Methods

Direct costing methods ask the customer to identify impacts of a particular outage scenario and then to evaluate the monetary losses of those impacts. Customers are guided to evaluate the monetary losses by suggesting possible impacts such as loss of production or sales, raw material spoilage, paid staff unable to work, etc..This approach provides reasonable and consistent results in those situations where most losses tend to be tangible, directly identifiable and quantifiable. Independent researchers have derived valuations which are reasonably similar in magnitude [6-9].This approach is particularly suitable for customers where the Losses are of an economic nature, such as in commercial and industrial sectors.

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Indirect Costing Methods

Indirect costing methods are based on the economic principle of substitution (EPS).

In which the value of a replacement product or service is used as a measure of the worth of the product or service that was replaced. This approach is particularly useful when social impacts or other less tangible consequences are expected to comprise a significant portion of the overall interruption effects, such as in the residential sector. One form of this approach is to offer customers a choice from a series of preparatory actions that they might take in the event of recurring interruptions. The actions may range from doing nothing to installing a back-up supply capable of handling the entire load. The value of the preparatory actions provides a means to evaluate the financial burden that the customer would be willing to bear to alleviate the consequences of outages. The value of the choice(s) that the customer makes represents the value or worth of electric supply.

In this paper, both the contingent valuation method and the indirect costing method were used for residential customers and the direct costing method was used for commercial and industrial sectors.

III. SURVEY METHODOLOGY

The investigation was conducted using the following three main stages:

1. Background Information and Preparation;
2. Conducting the Surveys in the region of Andhra Pradesh; and
3. Data Analysis.

Background Information and Preparation

The investigation began with an extensive literature search in the area of customer surveys. Substantial time was spent in collecting and reviewing dominant literature in the study area.Initial work began with the development of survey questionnaires for the, following three main categories of electric consumers in developing countries:

1. Residential
2. Commercial
3. Industrial

Specific questionnaires and approaches used by others were thoroughly investigated. The questionnaire contents and formats developed by the Power System Research Group were considered to be the most suitable and were used as the basis for the survey.

All sector questionnaires begin with questions related to the respondents' experience with electrical service. This is important as it establishes the context for the remaining questions. As respondents begin to consider how many interruptions they have experienced. They also begin to consider what happens during an interruption.

The next set of questions then asks about the specific effects of an interruption. Respondents are asked to rate the negative effects of an interruption using a list of activities or equipment that are electricity dependent. These questions move the respondent from general thoughts about interruptions to the more specific effects of an interruption.

After the negative effects of an interruption are identified and considered, respondents are asked to rate these effects in terms of different interruption scenarios. Such as an outage frequency, duration, time of the day, day of the week. and season of the year. This is a shift from the evaluation of user characteristics to an evaluation of interruption characteristics. The last section of the questionnaire contains the cost questions. This is the most important section of the questionnaire and seeks to obtain information about the monetary values associated with the effects of the interruption on the respondent.

IV. QUESTIONNAIRE CONTENT

Questionnaire for residential customers [10]

The questions were as simple as possible to minimize the inconvenience to respondents. The following items were included in the questionnaire.

(1) Interruption characteristics

Interruption characteristics by area, Interruption duration and frequency, Interruption season, Interruption day, Interruption time, Interruption impact by scenario,- average costs

(2) Customer characteristics

Number of household members, Age of the head of household, Education level of the head of household, Residence type (Apartment or house), Area type, monthly power use, monthly electric fee, monthly income of household, having or not having interruption experience

Questionnaire for small industrial customers

To summarize the kinds of data collected and the considerations for evaluation and survey of interruption costs are follows:

i) Interruption characteristics
 Interruption duration, frequency, occurrence time, Worst, the greatest damage resulted, interruption season/ week / day/ time, Interruption area (partial or complete)

ii) Customer characteristics [11]
 Characteristics of manufacturing activity by SIC, Customer size by the monthly consumption of electricity, Type of works stopped by interruption etc.

iii) Cost factors - Damage on manufacturing facilities, Loss of raw materials and finished Product damage, Stat up costs, Production loss, over time cost to take make up lost production etc.,

iv) Mitigating or standby facility for interruption
 To reduce the impact and economic loss from interruption customers install various facilities such as DVR (dynamic voltage regulator), UPS, SSTS (solid state transfer switch), battery energy storage systems, engine driven system etc., but these are not included in the calculating cost in this time.

Questionnaire for small commercial customers

Paid staff to unable work, Loss of sales, starts up costs, Spoilage of food, Damage to equipment/supplies, other costs or effects. The main objectives of the survey were to understand losses to commercial consumers resulting from service interruptions and to identify variables that contribute to these losses.

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Survey procedure

Customer surveys can be conducted by mail, telephone or using in person interviews. The survey conducted in India was mainly through in person interviews and partially through mail surveys. Telephone survey was not considered because of the fact that the customers may not have sufficient knowledge about it. The survey was conducted in the regions of Hyderabad. The following service areas were considered for conducting surveys.spm moula Ali, mangapuram, Krishna nagar, NFC Bridge, OU.C GHMC. The survey was conducted for 2653 customers out of whom 2306 customers were residential, 246 were commercial and 67 were industrial.

Both the contingent valuation method and the indirect costing method were used for residential customers. The survey data was divided into useful and unusable data were compiled using Microsoft excel. Most of the survey results are presented in concise form. All values quoted are from the combined responses of the customers. the residential survey response for the survey questionnaire can be grouped as follows:

1. Electricity Supply Service and Outages
2. Demand and monthly consumption
3 .Outage undesirability as a household activities 'function
4 .Variation of outage without age characteristics
5. Cost estimate from preparatory action approach
6 .Willingness to pay for uninterrupted supply
7 .Willingness to accept increased level of outage.

1) Electricity Supply Service and Outages:

More than 85% of the respondents feel that the service provided by the supply Company is poor or fair and nearly 75% feel the price of Electricity high or moderate. Regarding outage frequency, 47% said very high, 37% said high or moderate and 6% said low or very low.

2) Monthly Electricity Consumption:

The average house- hold monthly consumption of residential customers based on customers 'responses was found about170 units which is similar to the figures regarding average monthly consumption of residential customers.

3) Outage Undesirability as a Function of Household Activities:

The residential customers rated loss of lighting as most undesirable effect followed by disruption in leisure activities, and also the loss of perishable items like foodstuffs stored in refrigerators, fans and heaters not usable. Kitchen appliances not usable, computer not usable, pump-motor not usable, fear of crime. Washing machine not usable were given least undesirability.

4) Variation of Undesirability with Outage Characteristics:

Residential respondents indicated that there are several variations in undesirability when outage characteristics like frequency, duration, time of day, season, etc are considered. Outages during festival seasons are most undesirable. The results also indicated that longer duration outages have greater undesirable consequences than shorter ones. Most respondents consider outages of 4hrs and longer as extremely undesirable where as a 30minute outage during day time does not pose any problem. Outages after 5pm and outages in weekends and other public holidays are regarded as undesirable.

5) Preparatory Actions:

Customers were asked to choose from series of preparatory actions they might take in case of recurring supply outage. The following options with their approximate hourly costs were provided to the respondents to estimate their valuations:

- Make no preparation
- Use candles that cost Rs 10(2candles) per hour
- Use emergency/charging light that cost Rs25 per hour
- Use Inverters to light two bulbs or tube lights and a fan Rs80 Per hour
- Use emergency electric generator that costs Rs250 per hour.

Fig.2 depicts the customers' response regarding their preparatory actions if outage occurs daily after 6:00PM in weekdays and lasts for 30min to 4-hours.Fig.3 and Fig.4 show the responses for customer preparedness against monthly total outages ranging from 8-hours to 48-hours in winter and summer respectively. It was found that the customers tended to choose costlier options as outage frequency or duration increased. Most of the residents did not choose "make no preparation "and "rent a large generator" options.

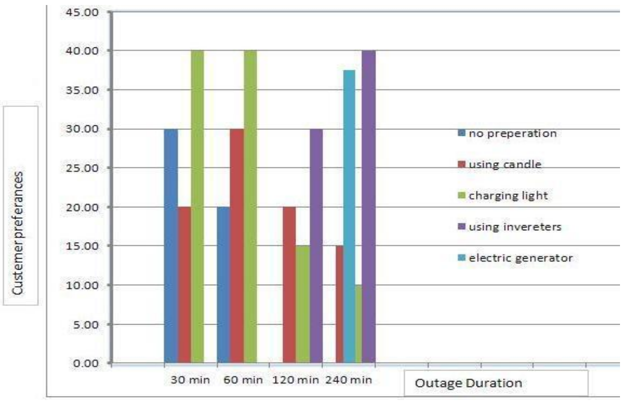

Fig 2: Customers preparedness against outages in weekdays

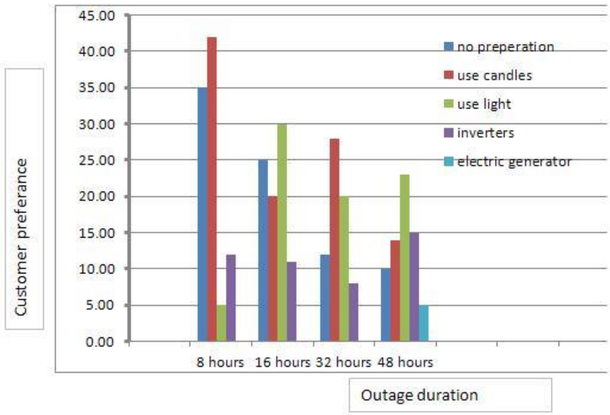

Fig 3: Customers preparedness against outages in winter weekdays

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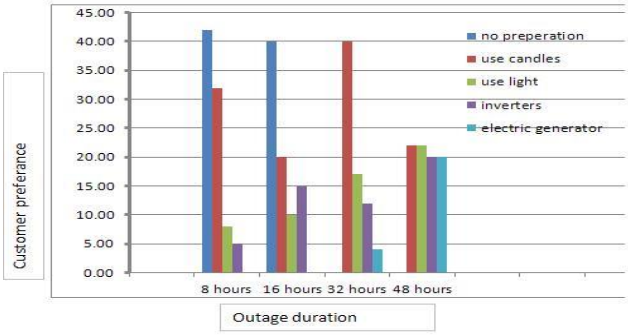

Fig 4: Customers preparedness against outages in summer weekdays

6) Response on Willingness-to-Pay:

Respondents were asked to suppose the scenario where by failures occur without prior notice at different hours of the day and at the same instant, there was an Independent Power Supplier from where the respondents can buy electricity. How much the customers were willing to pay (WTP). Fig.5 shows the customers' response on WTP extra amount monthly as a function of outage duration and time. It was found that customer response differed for different duration and customer category. More than 95% of the respondents were willing to pay extra money for electricity from alternate supply to avoid outage if the outage was in between 6AM to 9AM or 6PM to 9PM. Only about 20% of the respondents were ready to pay extra for an outage after the midnight and in the midday.

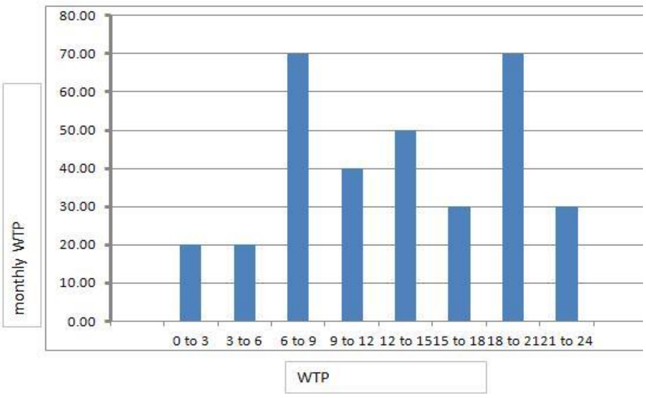

FIG5: Customers response on WTP Question

7) Response on Willingness-to-Accept:

This is basically indication of customers' willingness to accept inferior reliability of power supply for reduction in the price of electricity. The customers are asked to reduce the price of electricity with increase in number of outages .Respondents were also asked to indicate the minimum percentage reduction in price for them to accept the given increased number of outages. About 85% customers want 30% or more reduction in rate for outage in between 6 PM to 9 PM. Fig.6 presents customers' response for accepting monetary compensation for increased supply outages.

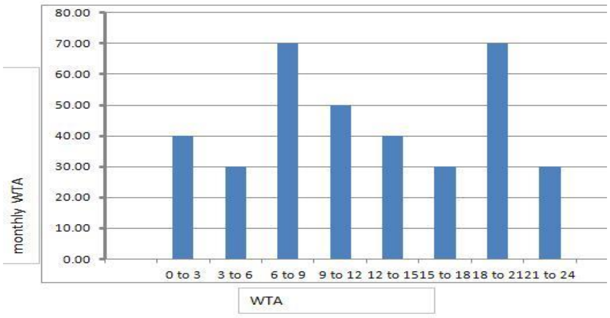

FIG6: Customers response on WTP Question

The direct costing method was used for commercial and industrial sectors. The ultimate aim of the survey is to provide customer outage costs due to electric service interruptions on the basis of the underlying principle that these costs are indicative customer expectations and therefore reliability worth. These customer outage costs can be used in planning, design and operation and are calculated in two steps [12]:

(i) The values of CIC are normalized by the peak demand (kw) or energy consumed (MWh) to give customer damage functions (CDF).

(ii) The CDF are used as input to calculate COC. Most of data are CDF, i.e. the interruption costs after normalizing.

Customer Damage Functions:

$$CDF = \frac{NO.\ OF\ UNITS\ CONSUMED \times COST\ PER\ UNIT\ CONSUMPTION}{PEAK\ LOAD}$$

A) Sector customer damage functions (SCDF)

$$SCDF = CDF \times CCDF$$

B) Composite Customer Damage Functions (CCDF)

$$CCDF = \frac{PEAK\ LOAD\ OF\ A\ LOAD\ POINT}{TOTAL\ PEAK\ LOAD\ OF\ THE\ SYSTEM}$$

Data analysis

The final stage of the work involved data compilation, analysis and interpretation of results. The results of the survey are discussed in next section.

V. CASE STUDY

A 33/11 KV Urban radial distribution system from Moula ali Substation, Hyderabad, Andhra Pradesh is taken into consideration, reliability of this system is assessed. The system consists of 19 distribution transformers with 2653customers with an overall average load consumption of 313.173 MW [12]. Both the contingent valuation method and the indirect costing method were used for residential customers and the direct costing method was used for commercial and industrial sectors.the number of respondents for the survey are as shown in table1 the number of respondents for industrial sector were more regarding the other two customers,because the impacts of power interruptions will be more for industrial customers and normally they maintain a record for it[9].

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the percentage of respondents for industrial was 87% comparing to residential which was 35.7% and commercial was 73.9%. for the number of customers the number of respondents are also shown in the fig8.

TABLE: I
Distribution of survey respondents

Customer group	Number of customers	Respondents	Percentage of respondents
Industrial(I)	67	58.29	87
Commercial(C)	246	181.794	73.9
Residential(R)	2306	823.242	35.7
Total	3112	442.9413	14.23333

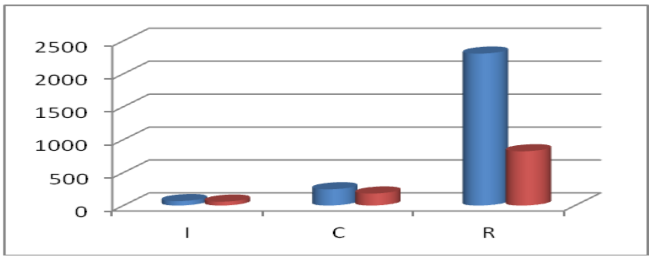
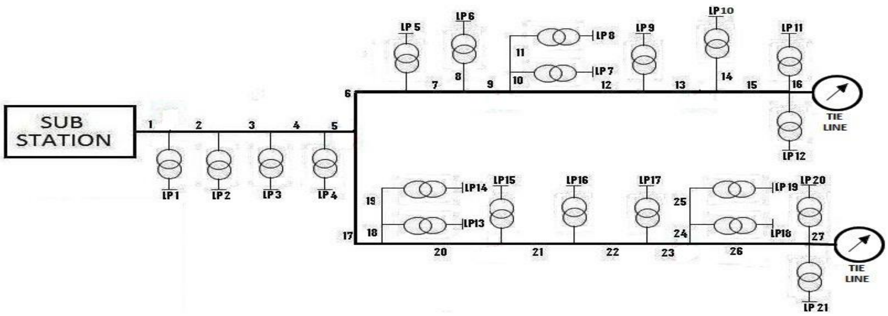


Fig. 8 distribution of survey respondents graph

Customer survey was carried out in that region and the respondents were as shown above.The obtained data from the respondents is used for further calculations.the customer



damage function and composite customer damage function
Fig.7 HCL Feeder of 33/11 kv Moula Ali Substation

was evaluated for several number of interruptions tabulated in Table II,Table III and respected graphs are as shown in figure 9&10

TABLE: II
Interruption cost estimates (CDF) in kw of annual peak demand (Rs/kw)

Interruption duration	residential	commercial	Industrial
1 min	0.23023	0.1833	0.4841
20 min	4.604	11.00	9.682
1 hr	13.814	33.00	29.046
2 hr	27.63	66.00	58.092
4 hr	55.26	132.62	116.184
8 hr	110.52	264.00	232.368
24 hr	331.56	792	697.104
48 hr	663.12	1584.00	1394.208

TABLE III
Interruption Cost Estimates (Ccdf) In Kw Of Annual Peak Demand (Rs/Kw)

Type of customers	CCDF
Residential	0.14578
Commercial	0.16158
Industrial	0.273640

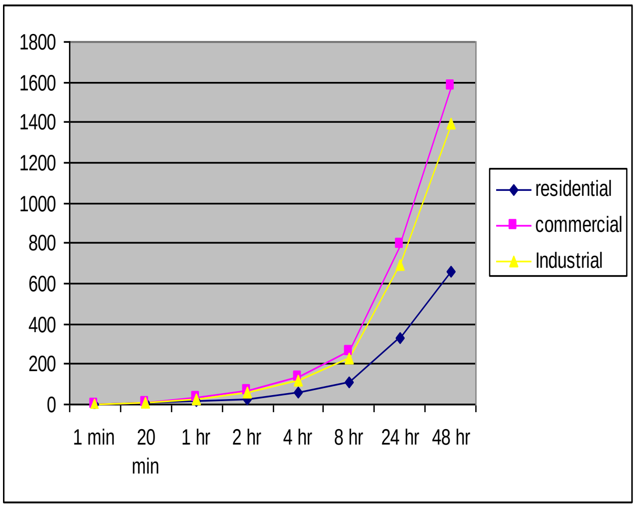


Fig.9Interruption Cost Graphs (Cdf) In Kw Of Annual Peak Demand (Rs/Kw)

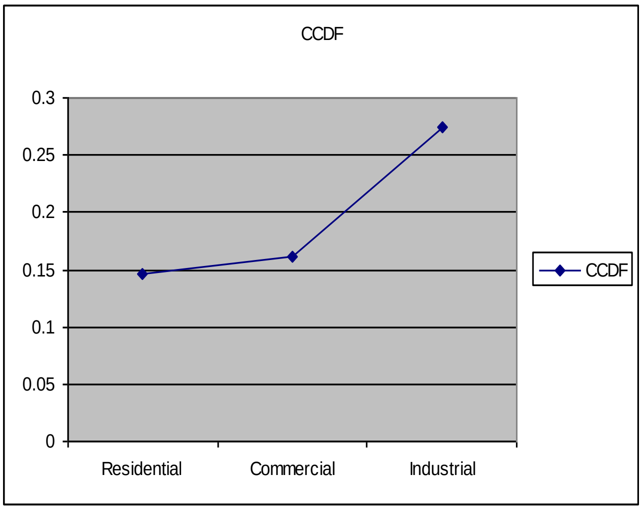


Fig. 10 Interruption Cost Graphs (Ccdf) In Kw Of Annual Peak Demand (Rs/Kw)

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The results determined were used to create sector customer damage functions (SCDF).Table IV and figure 11show the customer damage functions for the residential, commercial and industrial sectors of this region.
The costs are aggregated average and normalized according to annual peak demand and presented as a function of outage duration.
Now, this functions are then used in reliability cost/worth evaluation to determine the optimum reliability level for the service area and also helpful in future expansion/reinforcement

TABLE IV
Sector Interruption Cost Estimates (Scdf) In Kw Of Annual Peak Demand (Rs/Kw)

Interruption duration	residential	commercial	Industrial
1 min	0.23023	0.1833	0.4841
20 min	4.604	11.00	9.682
1 hr	13.814	33.00	29.046
2 hr	27.63	66.00	58.092
4 hr	55.26	132.62	116.184
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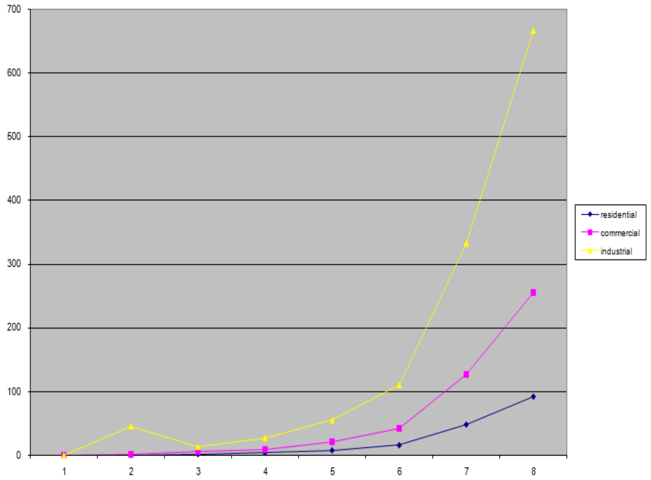

Fig. 11 Sector Interruption Cost Graphs (Scdf) In Kw Of Annual Peak Demand (Rs/Kw)

VI. CONCLUSION

There is now a growing recognition of the need to consider the economic link between the cost of providing a certain level of reliability and its value to customers. Evaluation of the costs associated with future expansion/reinforcement options is a standard planning procedure amongst power utilities. Hence, calculating the loss incurred from the point of utility is not at all accepted as the customer is in the best position to answer the loss of interruption. The major contribution of this paper is obtaining the power interruption costs for different customers in a developing country and also shows the variation in interruption costs with the variation in interruption duration for each type of customer. These costs calculations can be further used for the Evaluation of the cost worth indices associated with future expansion/reinforcement options for the reliability worth.

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