Reliability worth assessment of electricity consumers: a South African case study

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Abstract

This paper discusses the results obtained from a customer survey conducted in Cape Town, South Africa, using in-person interviews with approximately 275 sample business customers. The survey included customer interruption cost estimation questions based on the direct costing method. The results obtained show that customer interruption cost for business customers varies with duration and time of occurrence of power interruptions. The variation was shown to be dependent on customer segment. Furthermore, it revealed that business customers can be grouped in terms of the investment they make to mitigate the impact of power interruptions on their activities, such as the use of backup power supplies.

Keywords: Energy Bill, customer interruption cost

1. Introduction

South Africa is a developing country with large industrial and commercial consumers. For the overall development of the country, it is important that all resources are used optimally to ensure all sectors of the economy have a sustainable and continuous growth. Availability of reliable power supply at reasonable cost is essential for the economic growth of a country. Power suppliers therefore face particular challenges such as building new supply capacity and distributing energy to manufacturing and service industries to meet growing customer demands as economically as possible.

In recent years, the level of power supply reliability in South Africa has changed. Power supply failure figures have increased and the supply authorities regularly implement curtailment (NERSA, 2008a; NERSA, 2008b). This power supply scenario is common in other parts of Africa where the development of power system facilities has not kept pace with the demand. Significant investment is needed to expand power system facilities and raise the power supply reliability level. It is therefore important that electricity regulators and utilities balance the costs of utility to develop, operate, and maintain the power system against the economic value of supply to customers. This has yet to become a consideration in South Africa where development plans are based on traditional deterministic measures such as the largest single contingency or fixed percentage reserve margin. These criteria cannot be used to measure the economic impacts of changing reliability levels on the utility as well as on the customers and therefore cannot lead to an optimum expansion plan for the power system (Alvehag, 2008). Generally, investment, operating and maintenance costs are obtained using standard engineering cost estimation procedures (Sullivan et al, 1997). The economic value attached by electricity customers to the service provided by the power utility is measured by their customer interruption cost (CIC) (Chowdhury and Koval, 2001; Tiedmann, 2004). Many studies to assess CIC have been conducted internationally (EPRI, 2000). In South Africa, the estimated cost for an interruption, as reported in the Governments IRP2010 policy report (IRP, 2010) was simply R75/kW interrupted. The motivation for this study, therefore, was to develop appropriate methods to determine the CIC models associated with various levels of unreliability in a developing country.

Methods to obtain CIC data can be convenient-

ly grouped into three categories: (i) indirect analytical evaluations, (ii) case studies of actual blackouts, and (iii) customer surveys. Over the past years, the Power System Research Group at the University of Cape Town has developed theoretical structures and conducted various customer surveys to determine the impacts of power interruptions on South African electricity consumers. The group conducted a study of the interruption costs in the residential and commercial sectors in 2008 (Herman and Gaunt, 2008; Jordaan, 2006). The customer survey approach is again utilised as the basic methodology of this study. The basis of the approach is that customers are in the best position to understand and assess how the costs associated with power supply interruptions impact their activities.

This paper presents a general overview of the customer survey methodology utilised in this study, cost data that has been obtained and the analyses which have been performed (Dzobo, 2010). No attempt is made in this paper to present the results from all questions in the survey questionnaire, but solely to give an indication of the general results, especially in the area of cost evaluation.

For the purpose of the present research: interruption means – any outage, planned or unplanned; business customers – industrial and commercial customers combined and all costs are in South African Rand (R). 1 US$ is equivalent to R7 approximately.

2. Methodology

The CICs can be classified as direct and indirect costs (Chowdhury and Koval, 1999). Direct costs are further classified as economic and social. Direct economic costs include cost due to lost production, product spoilage and damage to equipment. The direct social costs include risk of injury or health etc. Indirect costs are associated with the losses incurred subsequently to the power interruption. This includes economic, social and relational effects such as changes in business plans, schedules, looting etc. The magnitude of all these costs is highly dependent on the characteristics of the customer and interruption events (Koskolos *et al*, 1998). Only the direct economic costs were investigated in this research study. This is because direct economic costs are expected to constitute a significant part of the CICs in business customers. The factors contributing to the cost were taken as:

• Wages paid to idle workers
• loss of sales
• overtime costs
• damage to equipment
• spoilage of perishables
• cost of running back-up; and
• cost of any special procedures.

For this research study, business customers of the City of Cape Town constitute the sample for the investigation. The area of Cape Town was chosen because it was the worst affected city during recent power interruptions (Eskom, 2008). Business customers account for about 86% of total energy consumption in Cape Town i.e. about 44% commercial and 42% industrial (City of Cape Town, 2007). The industrial and commercial populations were grouped according to the definition given in SIC (Standard Industrial Code) – StatsSA (1993) (Statistics South Africa, 1993). An industrial customer was defined as a customer engaging in manufacturing of goods and products. A commercial customer was defined as any form of business or commercial activities which are not primarily involved in manufacturing. Mostly small scale industries were considered in the survey. These are normally the majority in Cape Town (City of Cape Town, 2007). The industrial and commercial surveys were conducted concurrently. A business customer with various activities was classified according to the most significant part of that business.

A sample was chosen using a random systematic sampling technique. The actual customers were selected from the list provided in the Cape Peninsula 2008/2009 business directory. Every respondent in the sample was contacted personally. Data for the study was collected through personal contact during the summer months of 2009. Either the owner/partner or manager was asked to answer the questions to ensure the accuracy and reliability of the information. Informed consent was sought from the respondents i.e. permission was obtained from each respondent after the nature of the research study was fully explained. Respondents were informed that their participation was voluntary and the identity of the participants would not be revealed in the reporting and analysis of the results.

2.1 Questionnaire content

Modifications, where necessary, were made to the previously used questionnaire. The questionnaires were designed to progressively lead the respondent in awareness of the effects and costs associated with power supply interruptions and to ask for qualitative and quantitative evaluations at appropriate places. The opening questions seek the respondents opinion and judgment on specific issues. The questionnaire progresses to ask questions about the possible mitigation actions being applied to minimize cost of power interruptions. This set of questions moves the respondent from general thoughts about interruptions to providing valuable information about the things that are used to mitigate interruption costs. A set of specific cost-related questions were then asked and these were the core of the questionnaire. Direct costing questions were used to obtain the customers worst interruption cost estimates for a given set of outage conditions. The

hypothetical scenarios that were provided vary with season, time of day and day of week. The final section contains questions about the demographic characteristics (company size, business activity level and operational characteristics) of the respondent. The questionnaire ends with a blank space for respondents to comment on the improvement they would think their power supplier can implement to reduce impact of power interruptions.

2.2 Modelling approach

The primary purpose of conducting the survey was to identify CIC models that allow reasonably accurate prediction of CICs for various business customer types. The CIC models express CICs as a function of outage duration, season, day of week, time of day and various customer characteristics such as average electricity bill, number of employees, and other variables. Simple linear regression analysis (Navidi, 2008) (standard Ordinary Least Square (OLS)) was used to determine the CIC models. The statistical regression analysis was done using STATA statistical package. Scatter diagrams were used to find the variables that have the highest coefficient of correlation value with CIC. The variable or combination of variables was then used to generate the regression models for specific interruption attributes. The interruption attributes were taken as binary coefficients in the regression models i.e. take the value of 1 if present and zero if not present. Thus, the regression model equations were presented in the form of:

$$CIC\ [d] = a + \beta_1\ \beta_2\ \beta_3\ B\ (X) \tag{1}$$

Where d is the duration of power interruption being studied, a is the regression constant, β_1, β_2 and β_3 are the binary coefficients representing season, day of week and time of day respectively, B is the regression coefficient and X is the predictor variable being investigated.

The accuracy of the regression models prediction R^2 is expressed as:

$$R^2 = \frac{\left[\sum_i (y_i - \hat{y}_i)\right]^2}{\left[\sum_i (y_i - \mu_y)\right]^2} \tag{2}$$

Where y_i is the predicted value from the regression model for observation i, y is the actual value for observation i and μ_y is the mean for all observations.

The coefficient of determination R^2 expresses the strength of the relationship or association between the dependent and independent variables and varies from 0 to 1. When R^2 is 1, there is no prediction error, and the fit of the regression model is exact. When it is zero, the prediction error is very large and the regression model has no predictive

power at all. The results of this analysis are reported in terms of their R^2.

3. Results

3.1 Survey response

The respondents were provided with a list of standard company descriptions and asked to select one that best described their company. Table 1 provides details regarding the samples to which the CQ was applied. This information is presented to illustrate the composition and limitation of the survey. From the results, it is evident that it was difficult to obtain interviews in the industrial sector. The main reason for this is that all the major established industrial companies have strict policies that prohibit employees and managers from disclosing any company information without authority from their directors. Interviews were, however, obtained from smaller, newly established industries. In a few unprecedented cases, managers of large industrial firms did provide CIC estimates. Difficulties were experienced when trying to schedule interviews for the warehousing segment customers. These customers are somewhat busy all the time and only four responses were obtained. It was therefore considered important to remove this category from the analysis of CIC.

Table 1: Survey response

Sector	Business segments	No. of respondents
Industrial	Clothing	22
	Metals	28
	Garages	26
	Warehousing	4
Commercial	Retail	117
	Professional	26
	Office	2
	Hotel	39

In the commercial sector, retail and hotel segment interviews were done with a large variety of businesses. The hotel segment includes family restaurants, fast food establishments, coffee shops, small boutique hotels, and large exclusive hotels. The retail segment constitutes the greater portion of the respondents. Interviews for these segments were easy to schedule and they were more willing to give the information. However, for big establishments similar problems to those experienced in the industrial sector were experienced. Again the office segment was dropped from the analysis of CICs because of the small number of respondents. Interviews for this segment were very difficult to schedule as most of the respondents were not willing to answer the questionnaire because of fear of responsibility. Generally, those establishments where the owner was interviewed were better equipped to estimate possible CICs.

3.2 Power interruption frequency

The questionnaire asks the respondents to indicate the number of power interruptions they had experienced during the past twelve months. Table 2 shows the mean and standard deviation of the number of power interruptions per year experienced by both industrial and commercial samples. Almost 40% of the respondents indicated that they did not have any power interruption for the past 12 months.

Table 2: Number of power interruptions/year for industrial and commercial customers

Type	Mean	Standard deviation	Maxi- mum	No. of respondents
Industry	3.93	4.61	19	91
Commercial	3.40	4.61	22	184

This was to be expected since the period when the customer survey was conducted did not coincide with the large scale load shedding implemented by the power suppliers. Figure 1 shows the distribution of the number of power interruptions per customer per year (SAIFI). The results indicate that there was a higher probability of power interruptions per customer per year in the industrial population than in the commercial sample.

3.3 Satisfaction level

Respondents were asked to give their opinions regarding the quality of service provided by their power utility. More than 45% of the respondents were either very dissatisfied or dissatisfied with the service they were receiving, with about 20% being neutral. Only a third of the respondents were satisfied or very satisfied with the power utility service. This means that both samples regard the service provided by their power utility as generally not satisfying their electricity needs. Analysis of the variation of satisfaction level with respect to power interruption frequency was performed after removing all respondents who had indicated zero power interruptions. It was assumed that those respondents with zero power interruptions were all satisfied with the power supply reliability. Any other satisfaction level indicated by these respondents was regarded as a protest answer to other issues concerning the power utility. Figure 2 shows that business customers become neutral in their satisfaction level if they experience less than four power interruptions per year.

3.4 Power supply reliability preferences

Respondents were asked to rate the acceptability of various interruption scenarios for their companies. In each set of scenarios, only one variable was varied at a time, all the other variables were kept constant. Both duration and frequency were found to affect the reliability preference of business customers. The acceptability decreased as duration and frequency increased. There was no difference in the reliability preferences of both industrial and commercial respondents. Figure 3 shows a two
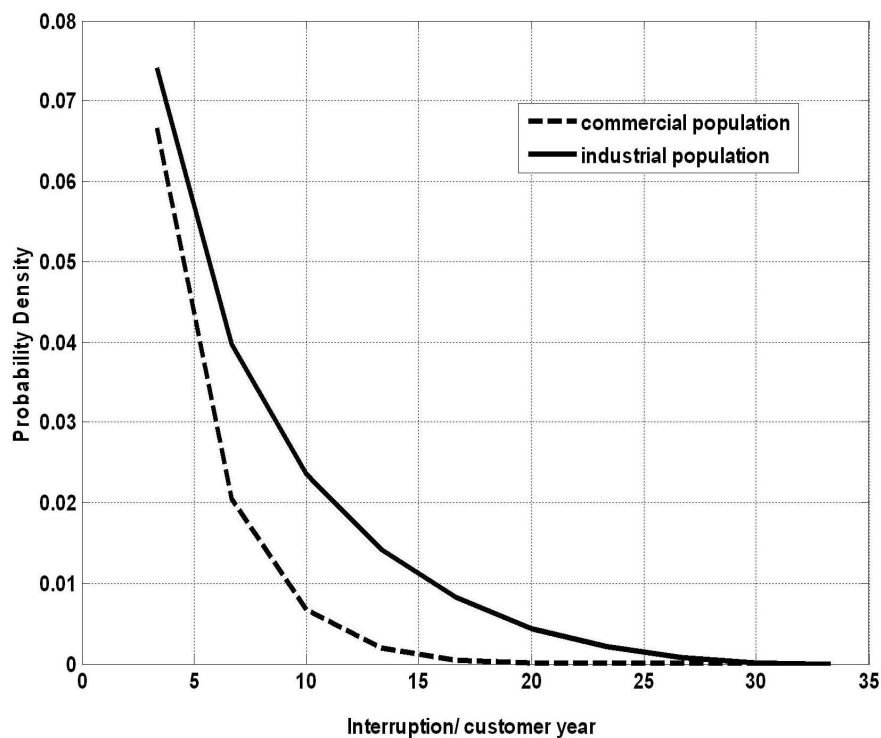

Figure 1: Beta probability function of power interruption/ customer year of both industrial and commercial samples
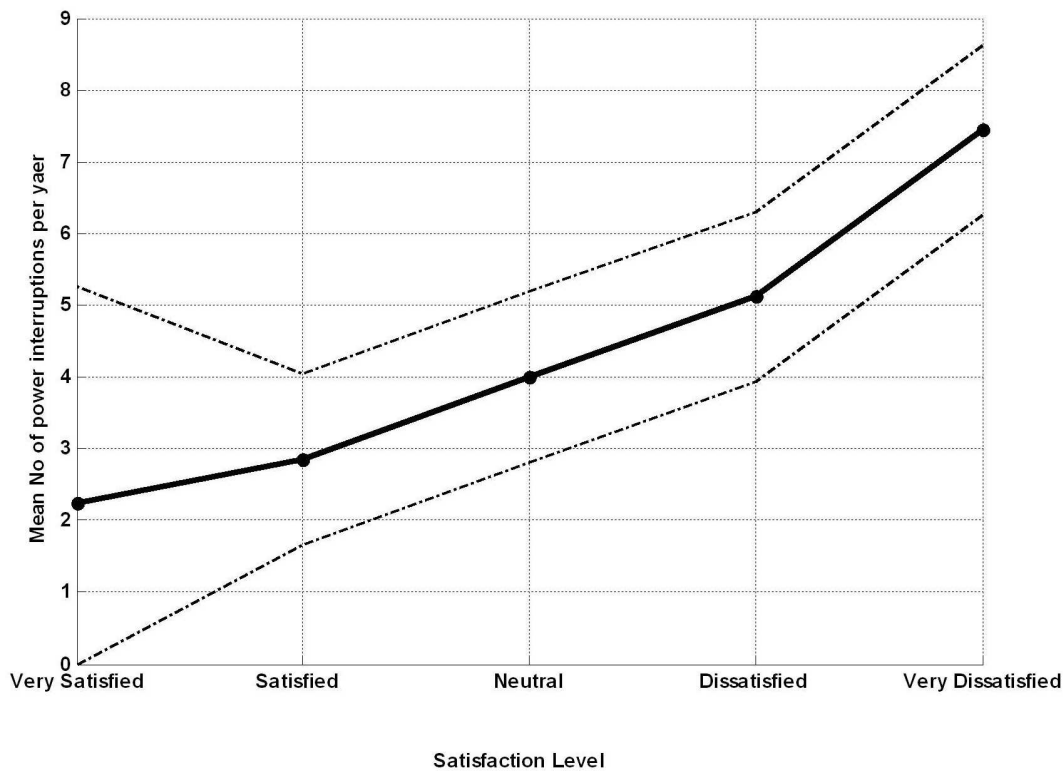
Figure 2: Satisfaction level versus number of power interruptions per year: Mean and 95% confidence interval averaged over all respondents
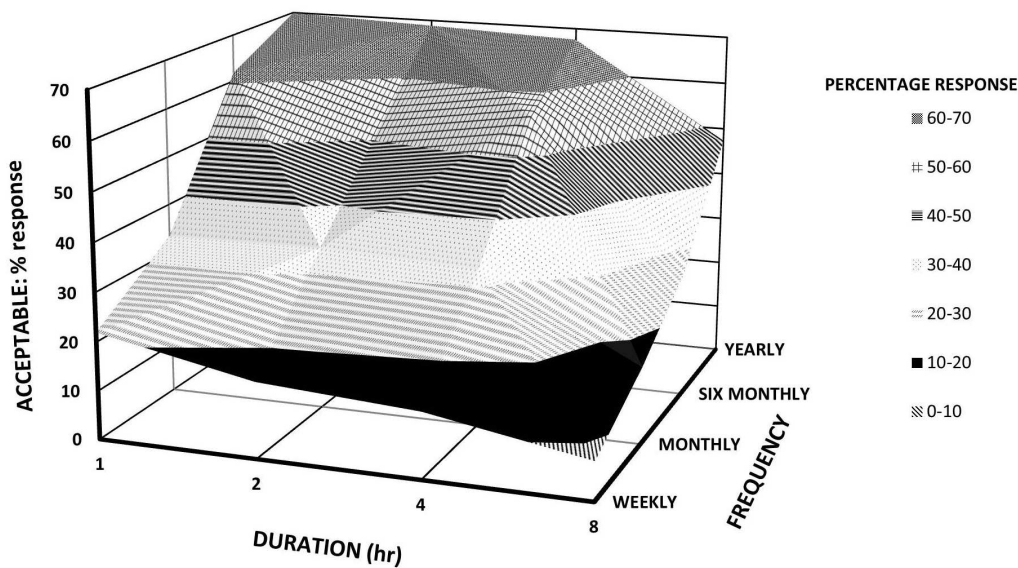

Figure 3: Duration and frequency of power interruptions versus acceptability for all respondents

dimensional distribution of the two factors (duration and frequency) and their effects on reliability preference.

A large majority of the respondents considered weekly failures as undesirable. Over 50% of the respondents considered a 4 to 8 hour failure as unacceptable for all the given duration and frequency scenarios. The majority of respondents stated that a 1 to 2 hour failure is tolerable. Perhaps this is because most business customers are able to

make up for their lost production.

3.5 Ability to make up lost production
Category, duration and time of day were found to affect the ability of business customers to make up for their lost production. The ability to make up for lost production in the commercial sector was found to increase as the duration of power interruption decreases. The worst time of occurrence of power interruption to cause major production loss in both

industrial and commercial sectors was found to be in the afternoon.

3.6 Ownership of backup power supply

Respondents were asked to indicate whether they own a backup power supply at their premises. In addition, the respondents were asked to indicate the type of backup power supply equipment, purpose, size, installation cost, running cost, year of installation and the percentage coverage of the plant by the backup power supply. The results showed that only about 25% of the industrial sample indicated the presence of backup power supply. Thirteen percent of the commercial sample indicated that they had backup supply. The purpose of the backup power supply for commercial customers is mainly to maintain essential business activities e.g. for most retail shops, only the emergency lights, security systems, computers, tills and credit card pay point machines are kept running. More than 50% of the generators were installed between 2008 and 2009 (see Figure 4).

This was expected because 2008 was the year that had most of the load shedding schedules. The size of backup power supply equipment varies from 2.5kVA to 200kVA for the industrial sample and only two respondents indicated the use of UPS i.e. 1.1kVA and 690kVA. For the commercial customers, only three respondents managed to give the size of their backup power supplies – generator i.e. 25, 30, 60kVA.

The difference in both size and percentage coverage of backup power supply (see Table 3) is possibly because industrial customers incur higher interruption costs than commercial customers. Only the industrial customers were able to provide the cost structure of their backup power supply (see Table 4).

Table 3: Percentage of coverage of plant by both industrial and commercial samples

Proportion (%) of coverage of plant	Industry (% respondents)	Commercial (% respondents)
≤ 20	13.04	25.00
20 ≤ 50	17.39	37.50
50 ≤ 80	21.74	4.17
> 80	47.83	33.33

Table 4: Industrial population: Cost structure for backup power supply (generator)

Item	Mean	Standard deviation	No. of observations
Installation cost (R/kVA)	1434.30	444.76	11
Running cost (R/kVA-hr)	7.76	2.14	12

3.7 Customer interruption cost model

The modelling process only uses those predictor variables that contribute significantly (from a statistical point of view) to the prediction of the dependant variable. The variable of interest in the regression analysis is the customer outage cost. Scatter diagrams and correlation values were used to find the predictor variable which contributes significantly to the prediction of the dependent variable. No attempt has been made to presents all the regression models generated from the analysis.

The results showed that there is a high linear correlation between CIC and customer energy bill in both industrial and commercial sectors. The customer energy bill was therefore used to generate
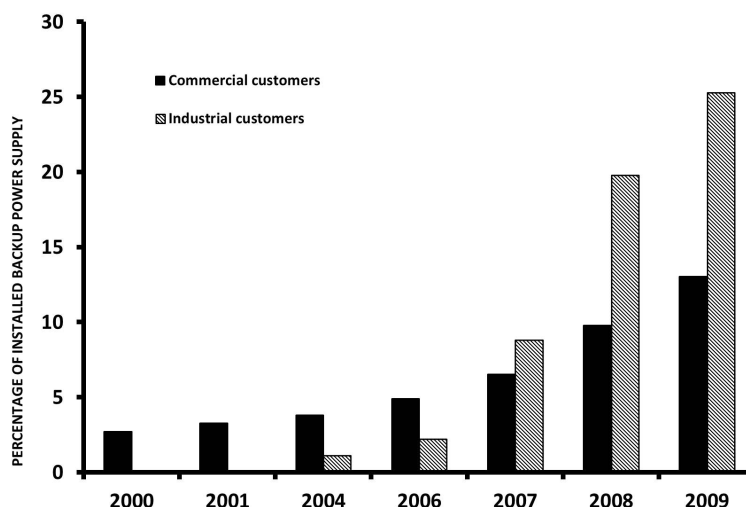

Figure 4: Penetration level of backup power supply installed per year to the total sample surveyed in each group

regression models for business customers presented in this paper. The coefficient of determination ($R2$) values ranges from 0.599 to 0.998 for all the regression models. This means customer energy bill was able to explain more than 59% variance of CIC that was incurred by business customers. This finding therefore implies that the customer energy bill is a useful variable in predicting the CIC incurred by business customers. The positive correlation means that there is an increase in CIC as the customer energy bill increases. Thus, for the same power interruption, business customers who pay high monthly energy bills tend to incur high CICs than those who pay less.

3.7.1 Duration of interruption

The CIC incurred by business customers increases with the duration of power interruption. This means the longer the power interruption the higher the CIC. The rate of increase of CIC also increases as the duration of the power interruption increases.

3.7.2 Time of occurrence

CIC incurred by business customers was affected by season, day of week and time of day. For example, in Figure, 5 the results showed that summer weekday morning costs are higher than winter weekday morning costs for the garages segment. This may be as a result of that, more travelling is done in the summer and usually service starts at the beginning of the day. For the other power interruption durations the results are similar.

3.7.3 Ownership of backup power supply

Respondents were asked to estimate the worst CIC estimates without including the effect of backup power supply. The results showed that business customers who own backup power supply tend to incur higher CICs than those who do not have them (see Figure 6).

This means that respondents own backup power supply in order to reduce the impact of power interruption on their activities. The research clearly identified that backup supplies are a response to frequency of interruption and expectation of continuing. The finding therefore implies that business customers can be grouped in terms of the investment they make to mitigate the impact of power interruption on their activities.

3.7.4 Customer type

The clothing segment customers have their CIC far outstripping those of any other business activity. They incur more than double those in retail and garages segments for the same power interruption scenario. This finding therefore implies that different customer segments experience different CICs for the same power interruption scenario. Therefore combining different customer segments to form one homogeneous group when estimating CICs, may provide overestimate and/or underestimate to some customer segments. This makes customer segment a very important variable to consider in CIC analysis.

3.7.5 Linearity

Nonlinear regression analysis was used in order to try and force the regression line models to pass through the zero point. The nonlinear regression model agrees with the assumption that for a zero energy bill, a business customer would incur zero CIC.
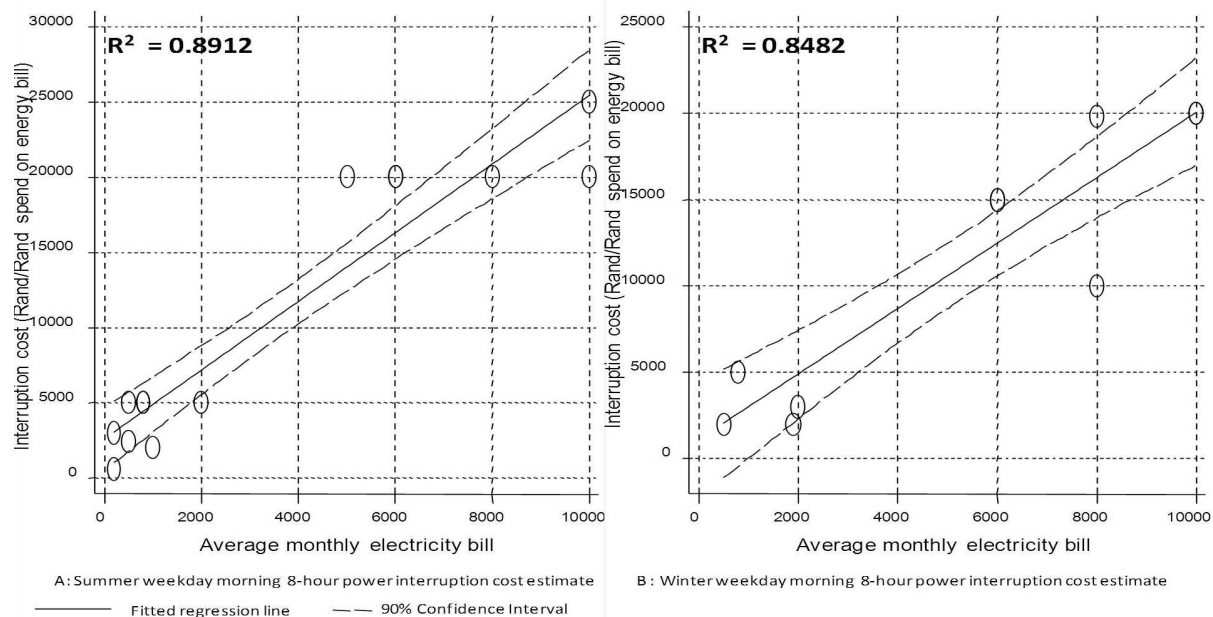

A: Summer weekday morning 8-hour power interruption cost estimate

——— Fitted regression line   — — 90% Confidence Interval

Figure 5: Seasonal variation of interruption cost with average electricity bill of Garage segment

R² = 0.9939

R² = 0.9809

A: Summer 2-hour power interruption cost estimate for Clothing segment with backup power supply

B: Summer 2-hour power interruption cost estimate for Clothing segment without backup power supply

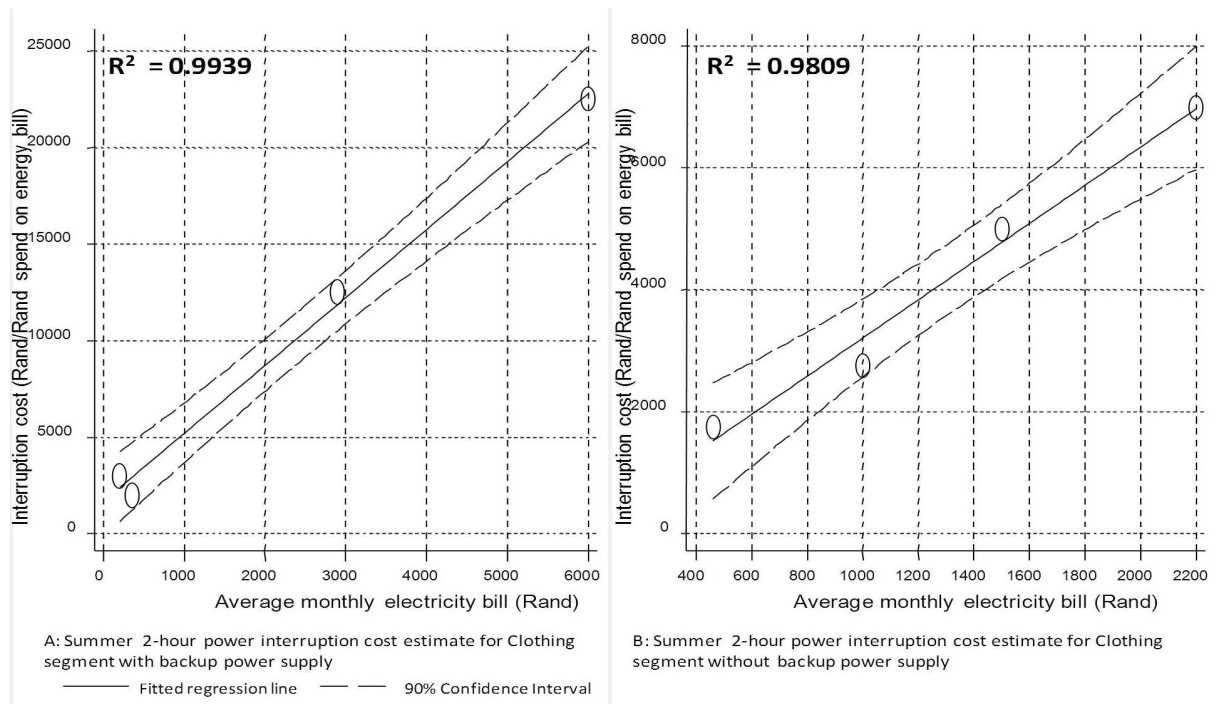———— Fitted regression line   — — — 90% Confidence Interval

Figure 6: Variation of CIC with average monthly electricity bill for clothing segment with and without backup power supply

Figure 7 shows an example of how the linear regression line model would change for the Garages segment. The graph shows that the nonlinear regression model generates lower predicted values for both lower and high values of energy bill. The gradient is high at the start of the graph and it decreases as the average monthly electricity bill increases. Hence, it overestimates the CIC incurred by business customers in the early hours of a power interruption and also later. However, it should be noted that the accuracy of the nonlinear models (R^2) is lower than that of the linear regression models. Thus, the linear regression model can be regarded as the superior model for business customers who have non-zero energy bill.

The relationship between the number of employees and the worst case cost estimates was examined using scatter grams. Scatter grams were prepared for the individual customer segments and levels of other user characteristics variables without
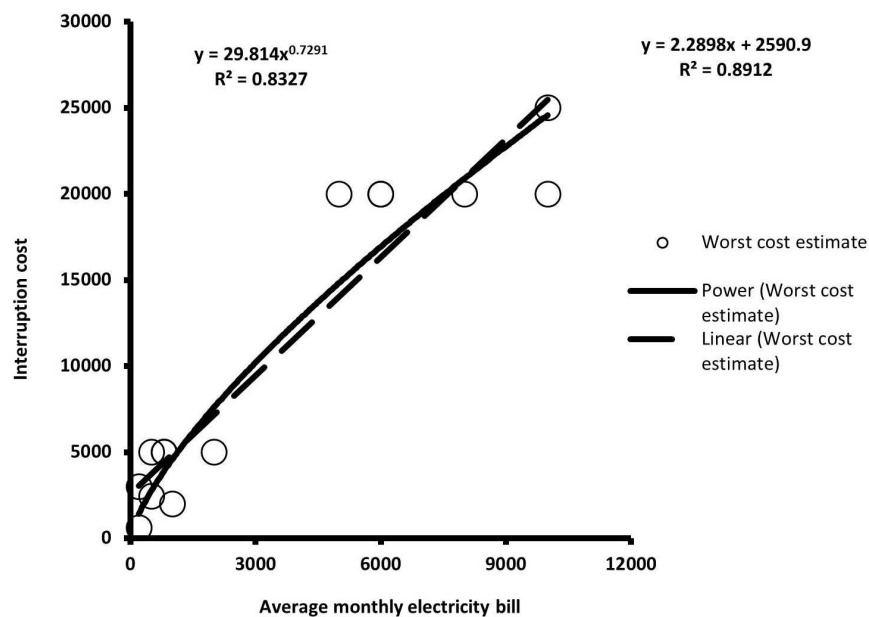

$y = 29.814x^{0.7291}$
$R^2 = 0.8327$

$y = 2.2898x + 2590.9$
$R^2 = 0.8912$

O   Worst cost estimate

——— Power (Worst cost estimate)

——— Linear (Worst cost estimate)

Figure 7: Variation of CIC with average monthly electricity bill for a winter weekday morning power interruption: Garage segment

any success in finding an apparent linear correlation. Therefore, it was concluded that these variables does not have a significant linear relationship with CIC estimates and cannot be used to normalize cost estimates.

4. Conclusions

A probabilistic approach was used to determine the financial impact on customers of a given power interruption allowing for a seasonal variations and time of occurrence. The technique and results obtained from the study demonstrate that CICs can be predicted with a defined level of confidence from the activity category of customer and monthly electricity purchases. Since the time-related CIC values are expressed in a probabilistic manner they can be combined together with probabilistic time-related reliability indices (Edimu, 2009) to give the expected cost impact of power interruptions on customers as probabilistic values associated with different risk levels. Expressing the results in this way will allow non-engineering managers to make meaningful managerial decisions about enhancing power system infrastructure and back-up. It will also assist regulators to determine rewards and penalties necessary to balance cost or tariffs against reliability. Practical applications are being delegated on the basis of the finding of this research project.

It should be noted that the CIC results reported in this paper apply only to the utility under study. Commercial and industrial customers elsewhere, supplied by other utilities, may be affected differently by the same power supply interruption due to difference in tariffs, climate, processes and equipments. Nevertheless, the application of this technique at a single utility demonstrates that CIC are quite predictable and there could be scope to identify more general norms that would be useful for industry regulation. Further survey and modelling efforts will be required to develop realistic probabilistic models for predicting CIC completely for a country or utility.

References

Alvehag, K. (2008). Impact of dependence in risk assessment of power distribution systems, Licentiate Thesis, Royal Institute of Technology, School of Electrical Engineering, Electrical Power Systems, Stockholm, Sweden, 2008.

Chowdhury, A and Koval, D. O. (1999). Value-Based power system reliability planning, IEEE Transactions on Industry Applications ,vol. 35, no. 2, March/April 1999, pp 305 – 311.

Chowdhury, A and Koval, D. O. (2001). Application of customer interruption costs in transmission network reliability planning, IEEE Transactions on Industry Applications, Vol. 37, no. 6, November/December 2001, pp 1590 – 1596

City of Cape Town (2007). State of Energy Report for City of Cape Town 2007, Prepared for the City of Cape Town by Palmer Development Group: www.capetown.gov.za.

Dzobo, O. (2010). Reliability cost and worth assessment of industrial and commercial electricity consumers in Cape Town, M Sc thesis, University of Cape Town, 2010.

Edimu, M. (2009). Evaluation of reliability indices of a composite power system using probability distribution functions, M Sc Thesis, Department of Electrical Engineering, University of Cape Town, South Africa, 2009

EPRI (2000). Customer needs for electric power reliability and power quality, EPRI white paper. Technical Report 2000.1000428, Electrical Power Research Institute, Palo Alto, CA, October 2000.

Eskom (2008). Eskom – Surplus Capacity (visited on 12/08/2008): www.eskom.co.za/live/content.php.

Herman, R and Gaunt, C.T. (2008). Direct and indirect measurement of residential and commercial CIC: Preliminary findings from South Africa Surveys, PMAPS 2008, 2008.

Integrated Resource Plan (IRP) for Electricity (2010). Cost of Unserved Energy (COUE) – IRP 2010 Input Parameter information sheet (Supply input), Department of Energy, South Africa.

Jordaan, G. (2006). Segment specific customer interruption costs in the commercial sector, B Sc (Eng) Project thesis, University of Cape Town, 2006.

Koskolos, N; Megaloconomos, S; Dialynas, E. (1998). Assessment of power interruption costs for the industrial customers in Greece, 8th International Conference on Harmonics and Quality of Power, Anthens, Greece, October 14-16,1998, pp 761-766.

Navidi, W. (2008). Statistics for Engineers and Scientists, Second edition, McGraw- Hill, New York, 2008.

NERSA (2008a). NERSA 2008, Interventions to address electricity shortages, January 2008.

NERSA (2008b). NERSA, Report by the Energy Regulator: Inquiry into the national electricity supply shortage and load shedding, 12 May 2008.

Statistics South Africa (1993). Standard Industrial Classification of all Economic Activities (SIC), 5th edition, Statistics South Africa, January 1993.

Sullivan, M; Vardell, T and Johnson, M. (1997). Power interruption costs to industrial and commercial consumers of electricity, IEEE Transactions on Industry Applications, Vol. 33, No. 6, November/December 1997, pp 1448 – 1458.

Tiedmann, K. (2004). Estimating the value of reliability for business customers, 8th International Conference on Probabilistic Methods Applied to Power Systems, Iowa State University, Ames, Iowa, September 12-16, 2004.