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ASSESSMENT OF COST OF UNSERVED ENERGY FOR SRI LANKAN COMMERCIAL SECTOR

By

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Assessment of Cost of Unserved Energy for Sri Lankan Commercial Sector

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Abstract— The investments for the improvements of power system to fulfill the energy requirements of electricity customers need to meet the reliability improvement targets. Thus, it is essential to obtain a clear and accurate assessment of Cost of Unserved Energy as an input to the power system planning process. Sri Lanka is currently using an approximated value of Cost of Unserved Energy calculated in 2002 considering only the Industrial Sector. It is important to update this value. This research was conducted to assess the Cost of Unserved Energy based on consumer survey method. The survey and analysis parts are conducted in three separate categories as Industrial, Commercial and Residential. This paper presents the results for Commercial sector, separately for momentary, planned and unplanned non-momentary interruptions. It is expected that the results of this study helps the power sector to provide a better service, taking the views of the customers and the national importance of electricity as an esential input for economic growth.

Keywords—Cost of Unserved Energy; Electricity Interruptions; Momentary interruptions; Consumer Survey

I. INTRODUCTION

The core activity task of the Power System is to provide electricity to its customers at the least possible cost and at an acceptable level of reliability. Access to reliable electricity supply increases the productivity of the nation and thus most of the countries make efforts to increase the system adequacy by expanding and upgrading generation, transmission and distribution systems. For this, Cost of Unserved Energy as an economic indicator plays a major role. The definition and the role of Cost of Unserved Energy can be defined as the economic value of the price consumers would pay to avoid a service disruption [1]. Alternatively, the cost of unserved energy is defined as the value placed on a unit of energy based on the sum of all losses, arising due to an unplanned outage of a short duration. Investment decisions to improve supply sensitively depend on the cost of unserved energy. Thus the Cost of Unserved Energy is one of the key economic parameters influencing the need for investments to upgrade and refurbish the network both at Transmission and Distribution. Further, generation planning requires Cost of Unserved Energy to assess the extent of economic damage caused by generation capacity inadequacy. Capacity inadequacy can also slow down the future economic growth. Distribution planners use Cost of Unserved Energy for deciding on investments to strengthen the distribution network. The cost of the project to the electricity utility is compared against the cost impact to consumers if the project is not done [2].

The research is conducted for three separate categories. These categories are based on Tariff Categories of Sri Lanka. Industrial tariff category was taken as one category and the research was conducted for the Category. Domestic and religious tariff categories were taken under Domestic category. General purpose, Hotels and Government tariff categories were considered under Commercial Category and results from the commercial category are presented in this paper. Commercial Category represents 10.54% share of 5,964,194 total number of electricity customer accounts of Sri Lanka [3].

II. CONSUMER SURVEY

Consumer survey method is widely used to estimate Cost of Unserved Energy and is adapted in this study as well. Consumer surveys help to identify and determine the effects of electricity interruption on the utility itself and national economy as whole. Responses to the surveys have been based on either historical or hypothetical outage experiences and it can be classified as the main advantage of this method. Further this methodology will give a feedback from utility side on their satisfaction on the Service of the supply. Researcher should be more careful to take sincere responses from the customer because entire results may contain errors if the false data is obtained through the survey.

A. Sampling the Customers

The Commercial sector contains a variety of electrical customers including supermarkets, retail shops, hotels, restaurants, communication-based places, government and private offices, schools, hospitals, banks etc. Commercial Consumers sub divided into seven sub categories according to the categorization mentioned in the service section in Central Bank Report of Sri Lanka in order of their percentage contribution to the national economy [4]. This classification is used in the research because it is easy to obtain the GDP contribution from each sub category. Among the seven sub categories of Service Sector of Sri Lankan economy, "Ownership of Dwellings" sub category was omitted from the research scope because of its complexity and low contribution to the electrical consumption. Thus six sub categories were considered for the research of Commercial sector and listed in order of their absolute and percentage contribution to the GDP as presented in Table I. The survey sample comprised 155 total responses including 30 responses each from Wholesale and Retail Trade, Hotels and Restaurants, Banking Insurance and Real Estate Categories; 25 responses from Transport and

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TABLE I GDP CONTRIBUTION OF THE COMMERCIAL CATEGORIES

Categories	Abbreviation	GDP LKR million	%
Wholesale and Retail Trade	Wholesale	739,826	40.72
Hotels and Restaurants	Hotel	25,715	1.41
Transport and Communication	Transport	476,721	26.23
Banking, Insurance and Real Estates	Bank	285,750	15.72
Government Services	Government	213,439	11.74
Private Services	Private	75,946	4.18
Total	Total	1,597,261	100.00

Source: Central Bank of Sri Lanka: Annual Report 2015 [4]

Communication Category; 20 each from the remaining two categories. It is a challenging task to decide the sample size because the population size of the relevant sub category is not presented in the suppliers' side database.

B. Designing the Questionnaire

Examining the costs incurred due to electricity interruptions is a challenging task. Each customer has own distinct electric power consumption and dependence characteristics. It is difficult to predict or comment for periodical characteristics of interruption data. The impacts of an electricity interruption for Commercial customers are different from the Industrial or Domestic Customers. Similarly, the impacts are different with utilization pattern of electricity, Type, duration and time of interruption and the availability of backup sources.

A questionnaire was designed specifically for the commercial sector. Questions were formulated to gather information on the cost of electricity interruptions to the consumer, variations of the cost with the duration of interruption, advance warning time required to minimize the costs, availability of stand by generators, vulnerability of consumer products to interruptions.

Group of undergraduate students of Department of Electrical Engineering, University of Moratuwa have conducted a survey to assess the Cost of Unserved Energy for Sri Lanka in 1998 [5]. They have conducted the survey for G1, G2 and G3 tariff categories and presented final answers. The values may not be a justified value because it will not consider the difference of each consumer. Different characteristics of sub categories had not considered and the answer is not a god justification for each individual respondent [5]

C. Categorization of interruptions

In order to capture the dependence of the cost on the duration of the interruption, all interruptions are first grouped into momentary and non-momentary categories. Momentary interruptions are those of very short duration of about six seconds. The reasons for considering six seconds duration for momentary interruptions, Ceylon Electricity Board is storing interruption data for this duration. All the other interruptions not counted under the momentary category fall into the non-momentary category. Non-momentary interruptions are further subdivided into six categories based on the duration of the interruption. Each of the six categories are further divided into the categories of planned and unplanned interruption. Thus, altogether there are twelve subcategories of non-momentary interruptions. The different categories and their respective probabilities of occurrence, derived from electricity interruption data records of CEB, are given in Table II.

D. Pilot Survey

A pilot survey on a smaller sample of 30 customers was conducted through prearranged meetings to check whether the questionnaire is well-formulated. However, the fact that the enumerator meets the interviewee face to face further explanations could be given whenever necessary. The pilot survey confirmed the suitability of the questionnaire and that the meaningful answers can be gathered.

E. Final Survey

The questionnaire in the final survey was posted or handed over to the interviewee in advance. Majority of the interviews were conducted face to face and some interviews were conducted over the phone. Out of 155 total responses, 84 were taken through face to face interviews and 71 through telephone interviews. Information provided was validated using the crosschecking method [6]. As examples, cross checks were done between average electricity bill and average amount of energy, between the capacity of the stand-by generator and the average fuel consumption, and between the generator capacity and average demand.

III. AVERAGING THE COSTS

A. Cost of Unserved Energy for Non-Momentary Interruptions

After completing survey, data is computerized according to the sub category assigning each individual respondent a separate spread sheet. The Cost consists of the values of spoilage of products, discomfort, loss of man power and the cost of backup generation. By taking the summation of all these Costs of interruptions Total cost occurred due to the electricity interruption is calculated. The obtained value is divided by total average estimated electricity consumption of the consumer during the same period if the electricity supply were to be available. This result provides the average Cost of Unserved Energy for the Consumer k denoted by C_{ki} due to an interruption in category i.

$$C_{ki} = \frac{\text{Total cost incurred due to category i interruption}}{\text{Total estimated energy not served during the interruption}} \quad (1)$$

If the customer has used fully or partially backup sources, it can be assumed that interruption has no impact on the production and the summation of capital, running and maintenance costs given in LKR/kWh is taken as the Cost of Unserved Energy. All kinds of losses are managed with the backup generation units and as a result of that no losses occurred, but an additional cost is added with backup units.

Probability of interruption occurrence of category i is defined in Equation (2) and the results obtained probability values are given in Table II. These values are used for averaging the cost of unserved energy for individual customers.

$$P_i = \frac{\text{No of interruptions in category } i \text{ within a year}}{\text{Total No of interruptions occured within a year}} \tag{2}$$

Averaged Cost of Unserved Energy for the Consumer k denoted by C_k, is obtained by summing up the products of C_{ki} and respective P_i. Cost of Unserved Energy for a consumer can be obtained separately for planned and unplanned interruptions. In this case, six time durations are considered.

$$C_k = \frac{\sum_{i=1}^{r} C_{ki} P_i}{\sum_{i=1}^{r} P_i} \tag{3}$$

Where, r is the no. of interruption durations (here r = 6).

Having obtained the cost of unserved energy for each of the customers in a commercial category s, average value for the same category C_s is obtained by weighting the individual values by x_k, the average electricity consumption of the respective consumer as given in (4).

$$C_s = \frac{\sum_{k=1}^{P} C_k x_k}{\sum_{k=1}^{P} x_k} \tag{4}$$

Where, P is the number of customers in the survey sample in the respective commercial category. There are two separate values of C_s each for planned and unplanned non-momentary interruptions. Considering the contribution to the national economy by each of the commercial categories, commercial average C_{cm} is derived by weighting the cost of each commercial category with its percentage contribution to the GDP presented in Table I.

$$C_{cm} = \frac{\sum_{s=1}^{N} C_s N_s}{\sum_{s=1}^{N} N_s} \tag{5}$$

Where, N_s is the percentage of the contribution to national GDP made by the commercial category s and N is the total number of such commercial categories (here N=6). This way, two different values for the cost of unserved energy for planned an unplanned interruption are obtained.

To obtain a single value for non-momentary Interruptions, costs due to planned and unplanned interruptions are combined together. For this, the average costs corresponding to planned and unplanned interruptions are multiplied from the probabilities given in Table II and added together.

In order to estimate economic losses from these results which represent the financial losses, a conversion factor of 0.76 is used. This factor has been calculated by the Ministry of

TABLE II. OCCURRENCE PROBABILITIES OF NON MOMENTARY INTERRUPTION CATEGORIES

	Probability						
Duration (hrs)	0.25	0.75	1.5	3	6	16	Total
Unplanned	0.547	0.104	0.037	0.026	0.011	0.015	**0.740**
Planned	0.151	0.005	0.008	0.014	0.050	0.032	**0.260**
Total	**0.698**	**0.109**	**0.045**	**0.040**	**0.061**	**0.047**	**1.000**

Finance and Planning of Sri Lanka in early 1990s [7] and has not been revised since then.

B. Cost of Unserved Energy for Momentary Interruptions

A different method is used to estimate the cost of momentary interruptions. Since all the losses happen within a very short duration, (here it is considered as six seconds) Cost of Unserved Energy for momentary interruptions is presented in LKR/kW. Total Normalized Cost during a momentary interruption per customer is referred as $C_{k,m}$ and Cost of Unserved Energy for momentary interruptions for the relevant sub category s is referred as $C_{s,m}$. The mathematical equations can be written as;

$$C_{k,m} = \frac{\text{Total Cost to customer k due to a momentary interruption (LKR)}}{\text{Average Demand of the Customer (kW)}} \tag{6}$$

$$C_{s,m} = \frac{\sum_{k=1}^{p} C_{k,m} d_k}{\sum_{k=1}^{p} d_k} \tag{7}$$

Where, p is the number of consumers in the sub sector and d_i is the Average Electricity Demand of Consumer k. Commercial average for the Cost of Unserved Energy due to momentary interruptions is calculated by using the same method as given in (5).

$$C_{cm,m} = \frac{\sum_{s=1}^{N} C_{s,m} N_s}{\sum_{s=1}^{N} N_s} \tag{8}$$

The values of Momentary interruptions are presented also in LKR/kWh to find out whether the final results of non-momentary and momentary interruptions can be combined together. From the results it is seen that such a combination is inappropriate because the results are varying in an unacceptably large range.

IV. RESULTS

The cost of unserved energy values for non-momentary interruptions is presented in Table III. The combined cost is given in the last column of the table and the respective economic costs are also presented within brackets below each financial cost value. It is confirmed, that the costs are generally higher if the interruption is unplanned. But in the commercial sector Cost of Unserved Energy for Planned interruptions are higher than Cost of Unserved Energy for Unplanned interruptions in Wholesale and Retail Trade, Hotels and Restaurants, government sector categories. This irregular pattern can be defined separately for the corresponding three sub categories.

Wholesale and Retail Trade sub category consists with supermarkets, shopping complexes, retail shops, kiosk shops etc. Household retail shops show a similar electricity consumption pattern with domestic category. Thus the priority of the research was given to the shopping complexes and supermarkets. All of respondents in the sample were using backup units. Thus their Cost of Unserved Energy is equal for the capital, running and maintenance costs of backup units. Their backup sources will be switched on within few seconds (Switching time is different from place to place) and the disturbances with electricity interruptions are successfully managed whether the interruption is planned or unplanned. These respondents use electricity for lighting, cooling in refrigerators, air conditioning purposes etc. Neither as industry categories, have commercial categories had the ability to manage the effects of interruption. Thus interruption costs are similar for Planned and unplanned interruptions.

Hotels and Restaurants sub category may be justified with the reasons mentioned with the Wholesale and Retail Trade.

In the government sector most of the places have office environment. Sri Lankan state sector process with manual paper based and machine based or computerized works. In an electricity interruption most of the workers in state sector can continue their work with manual activities. Government offices are fully or partially using backup sources. Thus in an interruption they may use electricity for turn on the machines including computers. Some offices may fully or partially air conditioned. Throughout the survey no government office was encountered that they turn on air conditioning machines within an interruption period. They have to face with discomfort situations which are difficult to measure in economic terms.

Schools are considered under government sector. It is observed that Cost of Unserved Energy for schools is nearly zero. All the schools in Sri Lanka are using day time, for their comfort they may use electricity for lighting and cooling. No significant disturbance occurs with electricity interruptions except computer laboratories and office works. Interruption costs associated with computer laboratories are negligible.

Hospitals need electricity in surgical activities, refrigerators for keeping medicine and bio parts in relevant environment etc. Sometimes they may use chilled water system for air conditioning especially in blood banks. These conditions are considered in the calculations.

The costs for momentary interruptions are presented in Table IV. For comparison the costs are given in terms of LKR/kW and LKR/KWh. As all the losses occur during a very short spell of time presenting in terms of LKR/kWh lead to an unnecessary escalation and thus the alternative approach of presenting in terms of LKR/kW is adopted.

TABLE III. COST OF UNSERVED ENERGY DUE TO NON-MOMENTARY INTERRUPTIONS – AVERAGE FOR DIFFERENT COMMERCIAL CATEGORIES

Industrial category	Financial Cost in LKR/kWh (Economical Cost in LKR/kWh)		
	Planned	Unplanned	Combined
Wholesale	832.09 (632.39)	822.53 (625.12)	825.02 (627.01)
Hotel	176.68 (134.28)	101.62 (77.23)	121.14 (92.06)
Transport	119.55 (90.86)	122.61 (93.18)	121.81 (92.58)
Bank	294.08 (223.50)	336.22 (255.53)	325.06 (247.20)
Government	145.78 (110.79)	141.93 (107.87)	142.93 (108.63)
Private	261.46 (110.79)	330.46 (107.87)	213.52 (237.52)
Combined	**453.49 (344.65)**	**418.19 (317.82)**	**427.37 (324.80)**

TABLE IV. COST OF UNSERVED ENERGY DUE TO MOMENTARY INTERRUPTIONS - AVERAGE FOR DIFFERENT COMMERCIAL CATEGORIES

Industrial category	Cost of Unserved Energy Financial Cost (Economical Cost)	
	LKR/kW	LKR/kWh
Wholesale	0.00 (0.00)	0.00 (0.00)
Hotel	0.00 (0.00)	0.00 (0.00)
Transport	8.65 (6.57)	2,603.45 (1,978.62)
Bank	485.59 (369.05)	308,133.40 (234,181.40)
Government	0.00 (0.00)	0.00 (0.00)
Private	0.00 (0.00)	0.00 (0.00)
Combined	**78.62 (59.75)**	**49,130.83 (31,736.80)**

V. VARIATION OF COST OF UNSERVED ENERGY VERSUS INTERRUPTION DURATION

Fig. 1 to Fig. 6 show the variation of Cost of Unserved Energy due to Non-momentary interruptions versus interruption duration for different sub categories in the Commercial sector. It is easy to identify that six categories show a very similar variation pattern.

The total cost due to an interruption can be broken down into three components. They are 1. Shutdown cost 2. Cost of lost services and production, and 3. Startup cost. The shutdown cost occurs once per interruption and is distributed over the duration

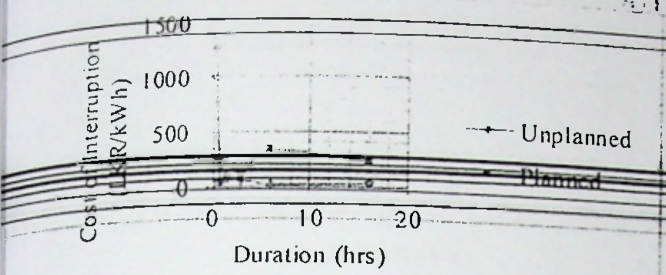

Figure 1 : Variation of Cost of Unserved Energy due to Non-momentary interruptions versus Interruption duration - Wholesale and Retail Trade

of interruption and takes a value inversely proportional to the duration as shown in Fig. 9. The cost per kWh of lost service or production is constant over time as shown in Fig. 8, while the startup cost usually increases with the duration to reach saturation after about five hours as shown in Fig. 7.

Addition of all these three costs gives a total cost variation as shown in Fig. 1 to Fig. 6. The average cost is high for the shorter periods as the shutdown costs are distributed over the smaller period. Then after a short duration of low cost the total starts to increase to reach a saturation level. It is observed that this pattern is common for all subsectors with variations in the magnitude of the maximum, minimum and saturation levels.

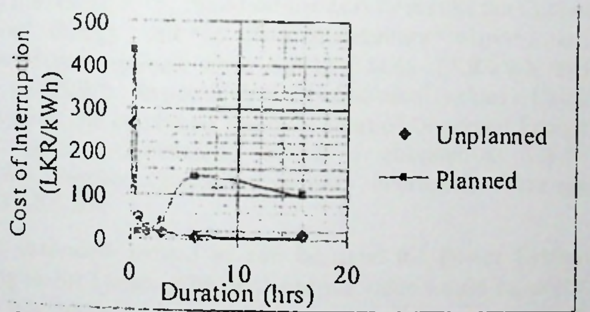

Figure 2 : Variation of Cost of Unserved Energy due to Non-momentary interruptions versus Interruption duration – Hotels and Restaurants

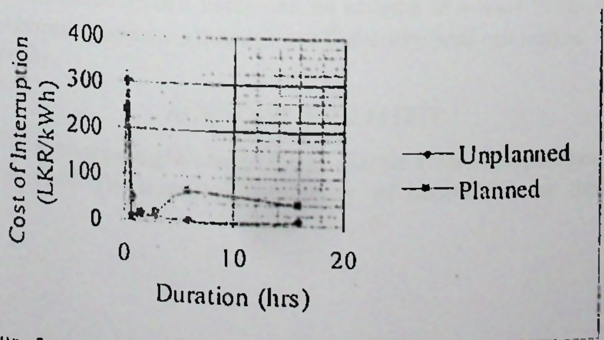

Figure 3 : Variation of Cost of Unserved Energy due to Non-momentary interruptions versus Interruption duration – Transport and Communication

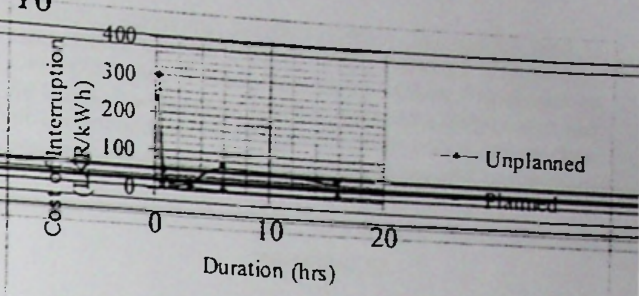

Figure 4 : Variation of Cost of Unserved Energy due to Non-momentary interruptions versus Interruption duration – Banking and Real Estates

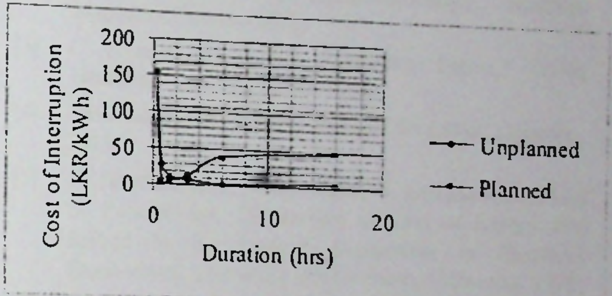

Figure 5 : Variation of Cost of Unserved Energy due to Non-momentary interruptions versus Interruption duration – Government Sector

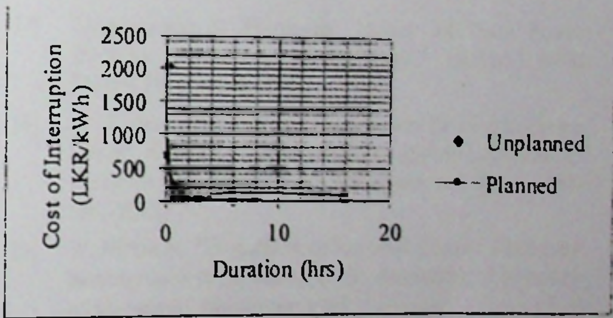

Figure 6 : Variation of Cost of Unserved Energy due to Non-momentary interruptions versus Interruption duration – Private Sector

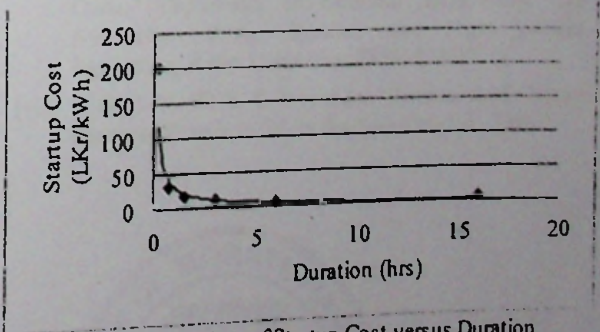

Figure 7 : Variation of Startup Cost versus Duration

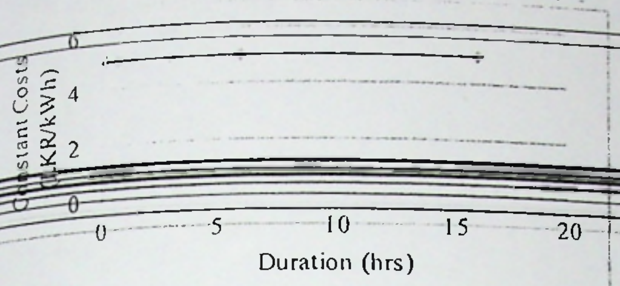

Figure 8 : Variation of Constant Costs versus Duration

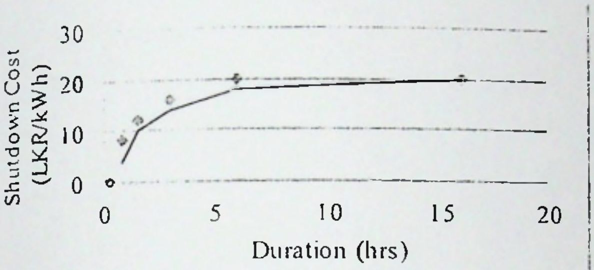

Figure 9 : Variation of Shutdown Cost versus Duration

VI. Conclusion

Out of several methodologies introduced by different authors, consumer survey method is the most popular method among the researchers. Based on the survey results the Cost of Unserved Energy due to Non momentary planned and unplanned interruptions work out to 344.65 LKR/kWh and 317.82 LKR/kWh respectively (in economical values). Using those values, the combined value of Cost of Unserved Energy for Sri Lankan Commercial sector is obtained as 324.80 LKR/kWh. Further, Cost of momentary interruptions average to 59.75 LKR/kW

The estimates arrived at can be used for Power System Planning in Sri Lanka. The final output value would be useful for the regulatory and planning purposes. Here, the unserved energy value is given for each category of commercial entities separately. However, a single value averaged over all categories is more helpful for effective and efficient planning. The indices produced based on this value can be utilized in a wide range of management decisions throughout the utility and not limited to the utility.

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References

[1] "Investigation of the Value of Unserved Energy- Stage 1," Concept Economics Pvt Ltd, Australia, 2008.

[2] U. Minnaar, "Cost of Unserved Energy," *WattNow Magazine*, October 2015.

[3] C. S. a. R. A. Branch, "Statistical Digest," Ceylon Electricity Board, Colombo, 2016.

[4] "Annual Report," Central Bank of Sri Lanka, Colombo, 2015.

[5] H. Nandasena, J. Nanayakkara, P. Liyanaarachchi and N. Punchihewa, "Evaluation of Cost of Energy Not Served In Sri Lanka," Department of Electrical Engineering, University of Moratuwa, Moratuwa, 1998.

[6] H. S. H. V. H. K. Matthias Hofmann, "Study on Estimation of Costs due to Electricity interruptions and Voltage Disturbances," in *SINTEF Energy Rearch*, 2010.

[7] "Assessment of Economic Impact of Poor Power Quantity on Industry - Sri Lanka," USAID- SARI Energy Programme, 2002.

[8] M. L. Sinan Kufeoglu, "Interruption Costs of Service Sector Electricity Customers, a Hybrid Approach," *Electrical Power and Energy Systems*, vol. 64, pp. 588-595, 2015.

[9] W. Methsiri, "Evaluation of National Cost of Electricity Interruptions in Sri Lanka (MSc Research)," University of Moratuwa, Moratuwa, 1990.

[10] S. Kufeoglu, "Economic Imacts of Electric Power Outages and Evaluation of Customer Interruption Costs," Department of Electrical Engineering and Automation Power Systems and High Voltage Engineering, Aalto University, Finland, 2015.

[11] P. D. C. W. W. L. S. Fernando, "Evaluation of Cost of Unserved Energy in Sri Lanka," pp. 208-216, 1996.