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Analysis of Methodologies for the Evaluation of Power Outage Costs

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Abstract **- More than three decades now, experts in the field of electrical engineering economics have devised techniques to evaluate power outage costs. In a world that depends so much on electrical energy for virtually all of its activities, it becomes important to correctly quantify the losses arising from power outages especially in view of the economic significance of electricity to the individual consumer, industries and the nation. Accurate assessment of the impact of a power outage depends upon which methodology is employed in its evaluation. The research draws upon secondary data and available scholarly literature to describe the major methodologies and techniques currently available in the power system economics. This paper is significant as it presents different methodologies for adequate and reliable estimation of power outages costs according to data requirements and complexity of the outage incident.**

Keywords - Economic cost evaluation, Electricity consumers, Power outage costs evaluation, Power outages.

I. INTRODUCTION

Every electric power system is expected to provide electricity to its customers at the lowest possible cost and within some acceptable reliability levels. The availability of reliable power supply at reasonable cost guarantees the economic growth and development of a country [1]. However, power outages occur sometimes when least expected thus calling to question the reliability of the power system.

Power outages have engaged the minds of various scholars over the last three decades [2,3,4,5,6,7,8]. A power outage can take any of the following forms:

A Blackout or Full Outage whereby power is lost completely [9,10]. This is a complete or total loss of service arising from causes such as storms, vandalism, car-pole accidents, etc. [11,12].

A Brownout whereby the voltage level drops below the normal and permissible limit for the system [10]. Systems supplied with three-phase electric power suffer brownouts if one or more phases are absent, or at reduced voltage, or incorrectly phased. Some brownouts, called voltage reductions, are sometimes allowed to occur in order to avert a full power outage [9,13]

A Dropout describes a momentary (duration of seconds) loss of power [9,10].

A Load shedding also called rolling blackouts are a way of ensuring that available generation capacity is rotated among various customers. Load shedding is the rationing of electricity by the utility company whereby it intentionally reduces the demand for electricity on the system, usually during periods of peak demand [9,14].

Partial outage is a curtailment of electricity supply due to a utility's public appeal for voluntary load reduction targeted to a particular end-use (e.g. air conditioning or water heating [11,15].

A power failure is an unscheduled and unanticipated outage [9,10].

Three categories of impact arise from power outages [9,16,17,18] : (1) Direct economic costs e.g. restart costs, loss of production, equipment damage and raw material spoilage. (2) Indirect economic costs e.g. cost of income postponement and financial cost due to loss of market share. (3) Social impacts e.g. loss of consumer welfare or discomfort at office/home arising from lack of electricity to power fans, air-conditioners, etc., loss of leisure time, risk of health and safety. Fig. 1 represents a summary of the impacts due to power outage.

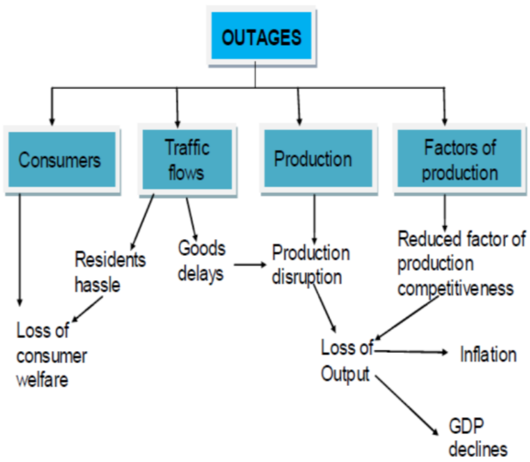

Fig. 1: Summary Impact of Power Outages [9]

It has become vital to prevent power outages due to its severe impacts on economy. Thus studying and correctly estimating power outage costs has become an attractive and popular field of study in the recent years [19]. Power outage is a recurrent phenomenon in many parts of the world especially the sub-Sahara African countries and describes a state of complete absence of electricity at the consumer's end [9,10,20]. Power outage has different consequences depending on whether it is occurring in manufacturing plants, commercial service firms or households [21]. Researches have since the 1950 studied the costs of power outages [22]. In

1995, for instance, a study carried out by the Electric Power Research Institute (EPRI) found that power outages and related issues cost the U.S. economy approximately $30 billion annually. In 2001, however, EPRI reviewed their estimate upward to $119 billion annually. This represented an increase of almost 300 percent over the previous estimate [23].

The assessment of impact of power outages is a hard and rigorous exercise [24]. Numerous attempts to estimate power interruptions costs have yielded wide-ranging and most times inconsistent estimates due to the varying demand characteristics of the electricity end-users [23]. Some of the factors that make the assessment of interruption costs difficult are: The value of the interruption cost can vary significantly depending on different factors such as the magnitude of the failure, duration of the interruption, frequency of interruptions, time, day, the character of interruption (whether it is unexpected or planned), the time that the interruption happens (whether it is at during working hours or outside working hours), the season (summer or winter), and finally the type of the customer (industrial, service, residential or agricultural) [8, 19, 25].

The extent to which power outages affect national economy must be determined. Frequent power outages adversely affect output in productive sectors and prompt firms to disinvest as well as discourage new firms from locating or investing in a country. Lack of adequate electricity supply reduces the rate of job creation, accelerates loss of jobs, reduces households' income and lowers tax receipts at all levels of government. Power outages cost in Zimbabwe in 2009 was found to be as high as US$1.8 billion [26]. Such a huge fund could help diversify production given the state of power under-supply in that country. Proper assessment of the cost of power outages helps both the government, the utility and even the end-users to understand and consciously plan for energy and necessary infrastructural facility needs.

Previous scholarly literature have merely discussed various methods and techniques of power outage costs evaluation, none have considered the comparison of these methodologies in view of their unique uses and application. This paper fills the gap by describing the major methodologies and techniques currently available according to their peculiar uses. This would help in the adequate and reliable assessment of the costs of power outages depending on data requirements and complexity of the outage incident.

II. METHODOLOGIES OF ESTIMATING POWER OUTAGES COSTS

Literature present different methods for the assessment of customer costs of electric power outages [25,27,28]. The major methods, however, are:

A. Proxy methods

Proxy methods make use of an observable behaviour in order to estimate the cost of an outage. These power outage cost assessment approaches consider that an industrial customer would prefer to rely on back-up generation until a time when the marginal cost of additional back-up power would equal the expected marginal cost of an outage event [29]. Such choice by the consumer becomes an evidence of 'revealed preference' towards avoiding an outage [30,31]. Proxy methods are widely known to reveal only a little detail about consumer preferences and sometimes provide only an upper or lower limit on outage cost estimates. In order to obtain an outage cost, proxy methods make numerous assumptions, and usually does not consider such helpful cost assessment factors like the duration of an outage, time or season of the outage, type of customer, etc. [23].

B. Case studies

Case studies are usually carried out after large and significant blackouts as in the case of the 1977 New York City blackout and covers both direct and indirect costs of interruption [23]. Direct costs include loss of sales, loss of food, etc. while the indirect costs are made up of emergency costs and losses resulting from civil disorders in the course of the outage. Case studies have the advantage of dealing with more accurate data due to the fact that the study gets conducted soon after a real interruption. The demerits of the method is the frequency of the large blackout events and the difficulty involved in drawing an analogy between large scale and small scale blackouts [25]. Previous studies indicate that the indirect costs from case studies are usually higher than the direct costs despite being very cumbersome to ascertain [25,37]. Besides, the study findings from case studies are subject to great limitations imposed by geographic constraints as well as the characteristics and duration of the specific outage being studied [23].

C. Indirect Analytical methods

The indirect analytical method uses objective data such as electricity tariffs, gross national product of a country and the country's annual electricity consumption to estimate the power costs. The advantages of this method include: its objectivity in using publicly declared and easily accessible data like electricity prices and turnovers in the costs assessment. Also, the method is straightforward and cheap in estimating the value of interruption costs. The method, however, suffers from the big disadvantages of its inability to sufficiently capture many direct costs its tendency to overlook the indirect costs. Besides, results from indirect analytical studies are usually too broad and not very useful for planning purposes [25,27].

D. Customer Surveys methods

Customer surveys methods involve of asking questions in order to ascertain the likely costs of power outages. This method involves one-to-one interviews, e-mail correspondences and telephone calls. Customers are often asked about the time of day when the outage occurred (whether during working hours or outside working hours), the duration of the outage, the time or season of the year (whether summer or winter). The customer surveys methods are the commonest methodology (See Fig. 2) for calculating outage costs because it affords more accurate and sufficient outage cost data for planning purposes [25,33]. The methods have the disadvantages, however of being very costly as it usually involves reaching out to large number of customers in order to obtain accurate data and reliable results. Besides, it requires much time and effort to design the survey, retrieve and analyse the respondent data [23].

S/N	Study	Country	Sector	Methodology
1.	Ukpong (1973)	Nigeria	Industrial	Proxy method
2.	Ontario Hydro (1980)	Canada	Industrial	Survey
3.	Bental and Ravid (1982)	USA and Israel	Industrial	Proxy method
4.	Billinton, Wacker and Wojczynski (1982)	Canada	Industrial	Survey
5.	Billinton, Wacker and Wojczynski (1982)	Canada	Residential	Survey
6.	Iyanda (1982)	Nigeria	Residential	Survey
7.	Bernstein and Heganazy (1988)	Egypt	Industrial	Proxy method
8.	Doane, Hartman and Woo (1988)	Canada	Residential	Survey
9.	Lee and Anas (1992)	Nigeria	Industrial	Survey
10.	Caves, Herriges and Windle (1992)	USA	Industrial	Proxy method
11.	Uchendu (1993)	Nigeria	Industrial	Survey
12.	Matsukawa and Fuji (1994)	Japan	Services	Proxy method
13.	Beenstock, Goldin and Haitovsky (1997)	Israel	Business & Public	Proxy method
14.	Adenikinju (2005)	Nigeria	Manufacturing	Marginal costing
15.	Kaseke (2014)	Zimbabwe	Agricultural, Mining, Industrial & Households	Direct & Indirect Assessment

Fig. 2: Methodologies of Power Outage Cost Assessment

Variations of the customer surveys methods are: The preparatory action method (PAM), that directly evaluates outage costs in terms of costs of mitigation measures required to avoid outage, the direct worth (DW) approach that evaluates the outage costs in terms of avoiding the impact of the outages [33] and the price proportional method that involves both the willingness to pay (WTP) and willingness to accept (WTA) techniques [25,34]. In WTP, the survey asks the customers how much they are willing to pay for uninterruptible electricity supply. But in WTA, the survey seeks to understand how much the customers are willing to accept as compensation in case of an interruption in service supply [35]. Studies, however, show a pattern among the respondents to demand more compensation while unwilling to pay the amount of money that would otherwise be needed to provide them with the desired service for the same outage scenario. This causes much disparity between WTP and WTA results such that it is often advised that WTP and WTA results be never used in isolation while making outage cost evaluations.

There are several variations of the aforementioned major methodologies for estimating power outage costs. These include: The marginal cost technique, the value of leisure method, the simple value added method, the adjusted value added and the willingness to pay methods.

A. The Marginal Cost Technique [38]

Reference [36] argues that by observing a firm's behaviour with respect to the acquisition of own generating power, the marginal cost of unsupplied electricity may be inferred. A competitive risk-neutral firm equates, at the margin, the cost of generating a kwh on its own to the expected gain due to that kwh. This expected gain is also the expected loss from the marginal kwh which is not supplied by the utility [38]. Therefore, the marginal cost of generating its own power may serve as an estimate of the marginal outage cost.

The cost to a firm of generating its own power consists of two elements [38]. The first is the yearly capacity cost of the generator represented as follows:

K(c) = annual capital cost (depreciation + interest cost) of a generator with capacity in kva

In addition,

VC = variable cost per Kwh, consisting mainly of fuel cost

l = hours of outages

The marginal cost, MC of self-generation per Kwh is given by

$$MC = \frac{\partial K(c)}{\partial c} + vc \ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

On the assumption that the MC is constant, the total cost, of power outage is given by

$$TC = MC.\, l \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

This approach has the disadvantage of not yielding proper estimates in cases [38] where:

(i) There exists some economies or diseconomies of scale in capital cost of generators such that:

$$\frac{\partial K(c)}{\partial c} \text{ is not constant.}$$

(ii) The capital market becomes so imperfect that a firm cannot even borrow to acquire a generator.

B. The Value of Leisure Method [38]

The Value of Leisure method estimates the costs of outages to residential consumers, as the value of leisure foregone [37]. The approach assumes that the principal outage cost imposed on a household is proportional to the loss of leisure during the evening hours when electricity is essential. It presupposes also that during the day time, sufficient slack occurs in the execution of household activities due to interruptions that warrants rescheduling of activities such as cooking or cleaning to more convenient times. The monetary value of this lost leisure, therefore, is equated to the income earning rate on the basis of the consumers' labour–leisure choice. Consequently, the cost per Kwh of unsupplied electricity is expressed by [38] as:

$$C = \frac{y}{k} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where y is the hourly income and k the normal level of electricity consumed per hour in the absence of outages. Therefore, the total cost of outages to residential consumer is, C, where

$$C = \frac{y}{k} .\, l \quad \ldots\ldots\ldots\ldots\ldots (4)$$

This method is most useful for estimating outage costs for residential consumers and has the advantage of involving a relatively easy-to-obtain data. A disadvantage of the method is that it requires the electricity consumption levels for different income level within the household sector. Again, this power outage costing approach supposes that the income earner in the household has flexible working hours that allows them to effectively exercise some labour-leisure choices. The approach ignores also the presence of household economic activities like cottage industry or sewing/embroidery work by women, especially in lower income households.

C. The Simple Value Added Method [38]
This approach is most suitable to the production sectors of the economy i.e. agriculture, industry and commerce. It is not appropriate for estimating domestic consumption of electricity. Unfortunately, this approach often leads to a high estimate of load shedding costs for the following reasons:

(i) It makes no distinctions between the average and marginal productivity of the electricity input.
(ii) It assumes that output lost is proportional to the extent of unsupplied electricity and firms not apply adjustment measures to recover at least part of the output.

The Simple Value Added method is expressed by [38] as:

$$C_i = \frac{Vi}{Ei} l_i \quad \text{......(5)}$$

Summing across sectors, the total cost of power outages is given by:

$$C = \sum_{i=1}^{n} \frac{V_i}{E_i} l_i \quad \text{......(6)}$$

Where:

C_i = the cost of power outage
n = the number of sectors
V_i = value added by sector i in the absence of power outage
E_i = electricity consumption in the absence of power outage
l_i = the quantum of electricity not supplied due to outages

Unlike the above, another approach yields a low estimate due to the fact that it focuses only the wage cost based on the assumption that the idle factor during outages is labour. In which case:

$$C_i = \frac{W_i}{E_i} l_i \quad \text{......(7)}$$

Where W_i is the wage bill.

D. The Adjusted Value Added Method [38]
This approach assumes that the marginal cost of unsupplied electricity differs from the average cost as given in (1) above. Accordingly,

$$\frac{\partial V_i}{\partial E_i} = \beta \frac{V_i}{E_i}, \text{ where } \beta > 0 \quad \text{......(8)}$$

β is often estimated on the basis of historical relationship between value added and electricity consumption. Generally, $\beta < 1$.

This technique of estimating interruption costs has the disadvantage that it neglects the spoilage costs arising from damages to materials during the outage incident, especially if such outage was unanticipated or unplanned.

E. Willingness to Pay Method [38]

The willingness to pay approach provides the basis for determining the subjective valuation by households of the cost of outages to them. A major disadvantage of this method, therefore, is a household may understate their willingness to pay on the expectation that other households may reveal a sufficiently high WTP to justify investments to improve the reliability of the power supply.

This can be estimated as follows [38]:

$$\text{SOCKW} = \left(\frac{WTP}{100}\right)\frac{AEB}{ENS} \quad \text{......(9)}$$

Where,
SOCKW = Subjective valuation by household of the outage cost per kwh
WTP = % higher tariff that the household is willing to pay for improved reliability of electricity supply (with minimal outages)
AEB = Annual electricity bill paid to the distribution company
ENS = Electricity not supplied in the outages

III. CONCLUSION AND RECOMMENDATION

This paper has evaluated the most prominent methodologies to successfully evaluate the losses which an electricity consumer many incur due to an electricity supply failure. As represented in the paper, each methodology has its own limitations such that it makes greater sense sometimes to combine two or more techniques in order to obtain a better, more revealing and more reliable power outage cost estimates.

REFERENCES

[1] Singh, H. and Mangat, H.S. Impact of Unreliable Power on a Paper Mill: A Case Study of Paper Industry of Punjab, India. Proceedings of the International Multi-Conference of Engineers and Computer Scientists 2012 Vol II, IMECS 2012, March 14-16, 2012, Hong Kong.

[2] Ukpong, I.I. 1973. The economic consequences of electric power failures. The Nigerian Journal of Economic and Social Studies, volume 15, no. 1, pp.53-74.

[3] Ontario Hydro. 1980. Ontario Hydro survey on Power System Reliability: Viewpoint of Farm Operators. Final Report No. R&U 78-5, December.

[4] Bernstein, M. & Heganazy, Y. 1988. Economic costs of electricity shortages: Case study of Egypt. The Energy Journal, Special Electricity Reliability Issues, volume 9: pp.173-88.

[5] Lee, K.S. & Anas, A. 1992. Impacts of Infrastructure Deficiencies on Nigerian Manufacturing: Private Alternative and Policy Options. Washington DC, USA: Infrastructure and Urban Development Department.

[6] Tierney, K. 1997. Impacts of Recent Disasters on Businesses: The 1993 Midwest Floods and the 1994 Northridge Earthquake. In Jones, B. (Ed.).Economic Consequences of Earthquakes: Preparing for the Unexpected. Buffalo, NY: National Center for Earthquake Engineering Research.

[7] Adenikinju, A. 2005. Analysis of the cost of infrastructure failures in a developing economy: The case of the electricity sector in Nigeria. Nairobi, Kenya: African Economic Research Consortium. Available:www.aerc.org/publications/index.asp.

[8] Bose, R.K., Shukla, M. Srivasta, L. & Yaron, G. 2006. Cost of unserved Power in Karnataka, India. Energy Policy, volume 34, No. 12, pp. 1434-1447.

[9] Kaseke, N., An Estimate of the Cost of Electricity Outages in Zimbabwe. Thesis. Nelson Mandela Metropolitan University, June, 2011.

[10] CEIDS, 2001. The cost of power disturbances to Industrial and Digital economy companies.pp.1-27.

[11] Woo, C. and R.L. Pupp. "Costs of service disruptions to Electricity Consumers." March 1991.

[12] Keane, D.L., MacDonald and C.K. Woo (1988), "Estimating Residential Partial Outage Cost with Market Research Data," Electricity Reliability – Special Issue, Energy Journal, 9:151-160.

[13] ZESA. 2008.Harare, Zimbabwe: Annual Report.

[14] Jyoti, R., Ozbafli, A. & Jenkins, G.P. 2006. The opportunity cost of Electricity outages and Privatisation of Substations in Nepal. Queen's University, Department of Economics.

[15] Khatib, H. (1978), Economics of Reliability in Electrical Power Systems, Technicopy Limited.

[16] Linares, P. and Reyy, L. The costs of electricity interruptions in Spain. Are we sending the right signals? Alcoa Advancing Sustainability Initiative to Research and Leverage Actionable Solutions on Energy and Environmental Economics. 2012.

[17] Targosz, R., and J. Manson (2008). "Pan European LPQI Power Quality Survey." 19th International Conference on Electricity Distribution. Paper 0263.

[18] Munasinghe, M. 1979. Costs incurred by residential electricity consumers due to power failures. *The Journal of Consumer Research*,volume 6, no. 4, pp. 361–369.

[19] Carmona,J.D. and J. C. Gómez. Evaluation of Power Interruption Costs for Industrial and Commercial Sectors in Argentina. VII Simposio Internacional sobre Calidad de la Energia Electrica. 2013.

[20] Amadi, H.N. (2015). Impact of Power Outages on Developing Countries: Evidence from Rural Households in Niger Delta, Nigeria. Journal of Energy Technologies and Policy, Vol.5, No.3.

[21] Mbohwa, C. 2002. The potential for co-generation in Zimbabwe. Nairobi: AFREPREN/FWD.

[22] Cerny, M. (2013). Economic and Social Costs of Power Outages: The Case of Pakistan. B.Sc. Charles University in Prague.

[23] Balducci, P.J., Roop, J.M., Schienbein, L.A., DeSteese, J.G. and M. R. Weimar. Electrical Power Interruption Cost Estimates for Individual Industries, Sectors, and U.S. Economy. U.S. Department of Energy. February 2002.

[24] Pultarova, T. 'Counting the cost: the economic and social costs of electricity shortfalls in the UK'. Report prepared for the Prime Minister's Council for Science and Technology. 27 November 2014.

[25] Kufeoglu, S. (2011). Evaluation of Power Outage Costs for Industrial and Service Sectors in Finland. MS Thesis. Alto University School of Electrical Engineering, Finland.

[26] Kaseke, N. (2014). A Comparative Cost Assessment of Electricity Outages and Generation Expansion in Zimbabwe. International Journal of Advanced Research in Management and Social Sciences. 3 (4), pp.1-22.

[27] Cigre Task Force, 2001, Methods to Consider Customer Interruption Costs in Power System Analysis, 38.06.01.

[28] Centolella, P. (n.d). "Estimates of the Value of Uninterrupted Service." The Mid-West Independent System Operator.

[29] Bental, B. & Ravid, S. A., 1982. A simple method for evaluating the Marginal Cost of unsuplied electricity. The Bell Journal of Economics, volume 13, no. 1,pp. 259-253.

[30] Beenstock, M., Goldin, E. & Haitovsky, Y. 1997. The cost of power outages in the business and public sectors in Israel: Revealed preference vs. subjective valuations. The Energy Journal, volume 18, no.3, pp. 39-61.

[31] Matsukawa, I., and Y. Fujii. 1994. "Customer Preferences for Reliable Power Supply: Using Data on Actual Choices of Back-up Equipment." Review of Economics and Statistics, 76 (3): 434-446.

[32] Kariukki K.K., Allan R.N.: "Factors Affecting Customer Outage Costs due to Electric Service Interruptions", IEE Proc., Gener. Transm. Distrib., 1996, 143, pp. 521 – 528.

[33] Kjolle, G.H., Samdal, K., Singh, B. And Kvitastein, O.A. (2008), "Customer costs related to interruptions and voltage problems: methodology and results", IEEE Transactions on Power Systems, 23(3):1030-1038.

[34] K. Kivikko, A. Makinen, P. Jarventausta, A. Silvast, P. Heine, M. Lehtonen, Comparison of Reliability Worth Analysis Methods: Data Analysis and Elimination Methods, IET Gener. Transm. Distr., Vol. 2, No. 3, pp. 321 – 329 / 321.

[35] M. J. Sullivan and D. M. Keane, Outage Cost Estimation Guidebook, EPRI, Palo Alto, CA, Tech. Rep. TR – 106082, December 2005.

[36] B. Bental, 'A simple method for evaluating the marginal cost of unsupplied electricity', The Bell Journal Economics, 1982, JSTOR.

[37] M.Munasinghe', 'Costs incurred by residential electric consumers due to power failures', Journal of Consumer Research, 1980, JSTOR.

[38] Pasha, H.A. and Saleem, W. (2012). The Impact and Cost of Power Load Shedding to Domestic Consumers. [ONLINE] Available at: http://www.pide.org.pk/psde/pdf/AGM29/papers/Dr.hafiz Pasha.pdf.