THE USE OF RELIABILITY ECONOMIC ANALYSIS IN ALEXANDRIA DISTRIBUTION NETWORK

Nazineh EASSA
Alex. Elect. Dist. Co. – Egypt
nazineh@hotmail.com

Mervat ELNAHASS
Alex. Elect. Dist. Co. – Egypt
mervat_nahass2006@yahoo.com

Amani ATTIA
Alex. Elect. Dist. Co. – Egypt
amibrahim2001@yahoo.com

ABSTRACT

Modern competitive electricity markets ask for power systems with the highest possible economic efficiency. Higher efficiency can only be reached when accurate and flexible analysis tools are used. In order to relate investment costs to the resulting levels of supply reliability, it is required to quantify supply reliability.

The calculation of performance indicators in respect to supply reliability is the task of the reliability assessment. This task can be divided into the calculation of interruption statistics and the calculation of reliability worth indices.

The paper briefly illustrates the philosophies adopted by Alexandria Electricity Distribution Company (AEDC) in the collection of component and system outage data. A report of delivery quality in various distribution zones and in the whole company is presented.

Interruption valuation enables the cost of interruption to be valued in a simplified manner. A calculation is made of the interruption cost. The customer outage model is evaluated. The outage cost is calculated using the Customer Damage Function.

The concept of the Quality Function is discussed as an assessment of the company's way of running its operations.

INTRODUCTION

Electric utilities have always been concerned with the need to provide a high level of continuity and quality of supply to their customers. This concern manifests itself in the planning, design and operation of their systems and the judicial selection of appropriate equipment. This can be achieved by quantitatively assessing the reliability of the power system.

It is very important to analyse exhaustibly the statistics and the failure rates in order to direct with precision the investments to those installations which their marginal contribution to the indices of interruptions have more relative weight.

In that line AEDC works with the continual improvement criteria in analyzing the interruption statistics supported by informatics tools that allow determining indicators with different criteria. Consistent collection of data is essential as it forms the input to relevant reliability models, techniques and equations. Consistent data are required to continuously monitor the performance of an electric power system and to measure its ability to provide reliable service to its customers. Equipment and system benchmarking cannot be performed in the absence of consistent data collected under comprehensive and agreed definitions and protocols.

RELIABILITY EVALUATION CRITERIA

AEDC created a system for collection, processing and reporting of reliability and outage statistics for the medium voltage distribution system. In addition to the equipment reliability information system, AEDC has also initiated an electric power system reliability assessment procedure that is designed to provide data on the past performance of the system. It contains systems for compiling information on system disturbances, system delivery point performance and customer service continuity statistics.

In respect to the effects of interruption of supply on a customer, the interruptions are classified in planned and unplanned interruptions.

A comprehensive report of delivery quality in various distribution zones and in the whole company is developed. The report includes the common practice reliability indices i.e. System Average Interruption Frequency Index (SAIFI), System Average Interruption Duration Index (SAIDI) and Customer Average Interruption Duration Index (CAIDI).

These indicators are available for the whole company, for each distribution zone, both for planned and unplanned interruptions.

The overall annual service continuity indices for the year (2005/2006) are shown in table 1.

The major causes of interruptions to the system and to the customers are assessed; Figure 1 shows the classification of interruptions by cause.

Figure 2 shows the relation between reliability of supply indices.

TABLE 1- Service continuity indices (2005/2006)

Index		Distribution zone					AEDC
		Montaza	East	Central	West	Coast	
SAIFI	Planned	1.812	1.143	1.83	1.72	0.45	1.44
	Unplanned	2.28	1.16	2.04	2.54	1.63	1.87
	Overall	4.12	2.32	3.86	4.24	2	3.31
SAIDI	Planned	200.87	146.3	186.7	162.7	48.67	153.19
	Unplanned	73.74	35.12	59.51	66.73	40.97	54.65
	Overall	274.64	181.4	246.33	229.4	89.65	207.84
CAIDI	Planned	110.85	128.0	102.02	94.64	108.1	106.62
	Unplanned	32.34	30.28	29.17	26.27	21.23	29.22
	Overall	66.66	78.23	63.81	54.12	46.45	62.85

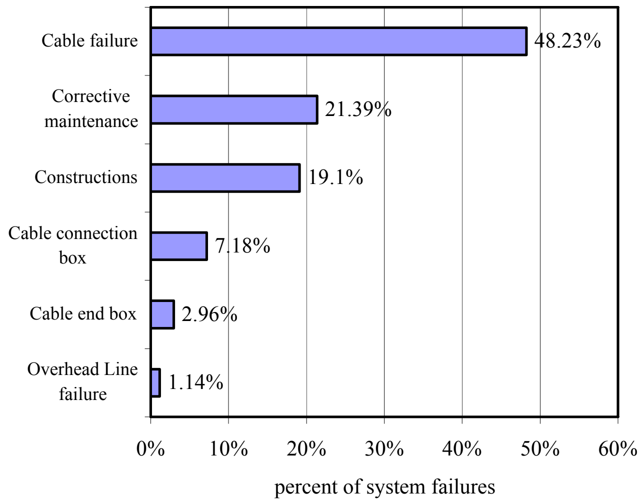

Fig. 1 Classification of interruptions by cause

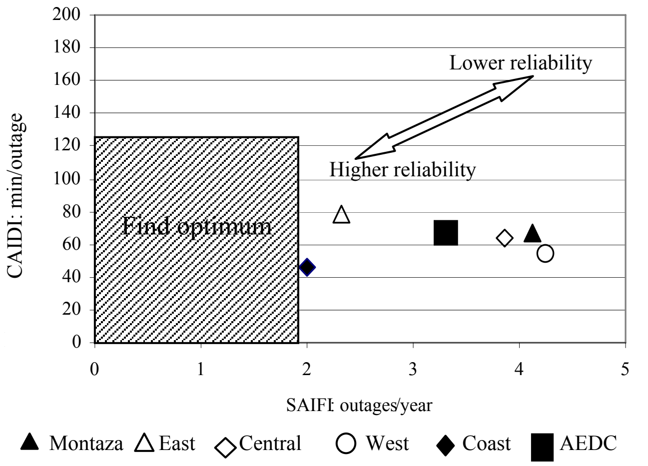

Fig. 2 Relation between reliability of supply indices

Generally, it could be said that the values of interruption indices have a great dispersion and there is a great variety between different distribution zones even when they have similar networks. Therefore, a range of influential factors can be determined which may explain the variations of indices.
In short, these factors can be separated into two classes: inherited and inherent factors. The most important inherited factors are: feeder length, voltage level in MV, percentage of underground network, sectionalizing, rate of automation and rate of interconnection between feeders. The inherent factors include: lightening, air pollution, climatic factors, animals, vegetation and customer density.

OUTAGE COST STUDY

One of the main tasks of each utility is to provide and supply reliable electricity to customers at reasonable prices. The prices of electricity normally vary in accordance with the level of utility's reliability standards.

Utilities try to maximize efficiency. They have to find the best balance between performance and cost. The highest level of efficiency can only be reached by comparing the increase of performance with the required investment costs. The calculation of performance indicators in respect to supply reliability is the task of the reliability assessment.
The reliability worth evaluation is usually done through the evaluation of reliability indices, which indirectly reflects the reliability worth. The worth is generally known as the outage cost.
The impacts of interruptions are classified as direct vs. indirect and economic vs. otherwise (social). Short interruptions in a small residential area will normally only cause direct damage. More widespread interruptions with a longer duration will cause indirect damage. The classification into direct and indirect costs, and into economic and non-economic costs, is not further discussed here. It is assumed that the impacts of interruptions can be quantified into cost functions.
The evaluation process is divided into two main stages:
1- Outage cost model, which is developed according to electricity tariff that classifies customers into several categories e.g. residential, small industry, large industry, commercial, specific business and government organizations.
2- Outage cost estimation.
Data used in the outage cost study had been gathered from direct surveys and interviews with power consumers and concerned persons in different agencies and households.

Customer damage function

To develop the customer damage model, we have to calculate the total damage cost, which comprises several types of damages. For example, for industrial and business customers, the damage cost of each customer comprises the following damages: cost of loss of profit opportunity, cost of loss of raw material, salary or work payment, cost of damaged equipment and cost of re-starting the process.
These damage costs may vary with interruption duration.
The evaluation process starts from defining the distribution zones required for the outage cost evaluation. In AEDC, there are five distribution zones: Montaza, East, Central, West and Coast.
Data collected from customer surveys is used to create damage functions for certain classes or "sectors" of customers.
These surveys give information about the perceived interruption costs for each specific customer separately, and may contain information about the effect of the duration of the interruption, the time of occurrence, the amount of interrupted power or energy, etc.
The raw data from the customer surveys has to be processed and transformed in order to create customer damage functions (CDF), which can also be projected upon customers, which have not been surveyed. All raw damage functions are grouped according to customer classifications.

Then, they are normalized per group by using a specific customer parameter.
This normalization parameter may be the measured yearly peak demand, the yearly energy consumption. When the normalization parameter is known for each raw damage function, then averaged sector customer damage function (SCDF) can be calculated.
The SCDF is not used in the actual reliability assessment itself. It is only used to create damage functions for single customers or for mixes of customers.

Composite customer damage function

By weighting the average model of each sector, classified by electric tariff, the customer damage function can be obtained. We can see that the CDF, which is in the units of LE/kW_{avg}, is the function of interruption duration.
To create damage functions for a mix of customers, we have to create a composite customer damage function (CCDF). The CCDF is basically the sum of the individual customer damage functions in the customer mix.

$$CCDF(t) = \sum_{i=1}^{n} \frac{W_i * SCDF_i(t)}{LF_i} \qquad LE/kW_{avg} \qquad (1)$$

Where,
i : customer type.
n : number of each customer type.
W_i: energy consumption of customer type i.
$SCDF_i$: sector customer damage function of customer type i.
LF_i: load factor of customer type i.

The average CCDF(t) is shown in table 2.

TABLE 2- Average customer damage model

Interruption duration	Average CCDF (t) (LE/kW_{avg})
1 min	2.025
30 min	6.975
1 hr	14.565
2 hr	26.685
4 hr	50.535
8 hr	92.505

Interruption costs calculations

The obtained CCDF and the actual interruption statistics are used to evaluate the outage cost for each distribution area and for the whole AEDC.
The outage costs are divided into:

1- Interrupted Energy Rate (IER)

$$IER = \frac{\text{Interruption Cost}}{\text{Energy not supplied}}$$

$$= \frac{\sum_{k=1}^{n} CCDF(t_k) * p_k}{\sum_{k}^{n} p_k * t_k} \qquad LE/kWh \qquad (2)$$

2- Interruption Cost Per Event (ICPE)

$$ICPE = \frac{\text{Interruption Cost}}{\text{Number of outage events}}$$

$$= \frac{\sum_{k=1}^{n} CCDF(t_k) * p_k}{\sum_{k}^{n} k} \qquad LE/event \qquad (3)$$

Where,
CCDF: Composite Customer Damage Function.
t_k : interruption duration of k^{th} interruption.
p_k : load loss of k^{th} interruption.
n : number of interruptions.

The results of IER and ICPE are shown in table 3.

TABLE 3- Interruption energy rate and interruption cost per event.

Distribution zone	Index	
	IER (LE/kWh)	ICPE (LE/event)
Montaza	16.32	57,145
East	15.405	45,978
Central	15.69	35,209
West	15.81	37,534
Coast	15.255	44,251
AEDC	15.90	43,593

QUALITY ADDITION

To assess the company's way of running its operation the concept of the quality addition is introduced. The quality function is added to the sum of all the costs of network performance. The quality function is evaluated on the basis of the interruption statistics and outage cost. It takes into account both the redundancy adjustment and the valued quality.

System design and component reliability are two critical factors to consider in determining the right level of redundancy for a system.
Premium power system design can be categorized into three general levels of redundancy:

- System – plus – system redundancy.
- Component level redundancy.
- Single point of failure.

System – plus – system redundancy means that the power system is designed with two identical, completely redundant systems. Component level redundancy means that each critical component of the system is designed with an additional, like-kind, component to carry the load if one of the components fails. Single point of failure means that some portions of the system may be hardened against failure, however, when taken as a whole, the system is susceptible to failure if only one component fails.
The redundancy adjustments specify the magnitude of additions in percent to the conductor lengths or transformers that are made at each network level. In simple terms, they describe the percentage addition to the new procurement value for each network level.
The sum of interruption costs for every node in the network is calculated. This interruption cost is compared with the cost of providing a reserve conductor or a reserve transformer for each node. If the cost of the reserve component is lower than the total interruption cost of the node, the reserve is established in the network, it is then assumed that the total interruption cost at this particular node will cease.
The valued quality is defined as (quality achieved – expected quality).
The reported interruption values measured in SAIFI & SAIDI, which are the interruption frequency and interruption time, are the basis for the calculation of the quality achieved.
For a redundancy–adjusted network, the number of interruptions and their durations an average customer will experience, measured in LE/kWh average costs are evaluated. The result is the expected quality.

CONCLUSION

The objective of reliability monitoring is manifold and is as follows:

- Furnish management with performance data regarding the quality of customer service on the electrical system as a whole and for each voltage level and operating area.
- Provide a basis for utilities to establish service continuity criteria. Such criteria could then be used to monitor system performance and to evaluate general policies, practices, standards and design.
- Provide data for analysis to determine reliability of service in a given area (geographical, political, operating, etc.) to determine how factors such as design differences, environment or maintenance methods and operating practices affect performance.

The assessment of the reliability worth is perceived as being a major aspect in providing the additional detail in justification of new system facilities and operating reliability levels. Customer outage costs are a key indicator of customer expectations and therefore reliability worth.
The outage cost evaluation presents the Interrupted Energy Rate and Interrupted Cost Per Event. Both costs require two main types of information, i.e. customer damage models, outage statistics.

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