INTRODUCTION

Electricity outages, be they voltage dips or sustained interruptions to supply, generally have an economic impact on the customers affected thereby. The paper describes a recent review of electricity supply interruption performance experienced by and reliability worth to business customers in South Africa and the consequent influence on their investment decisions. The electricity supply industry in South Africa is the largest in the continent, distributing some 186 TWh in 2003, with a maximum demand of 34 GW in mid 2004. The electricity distribution industry is in the process of being restructured into six Regional Electricity Distributors (REDS), combining the distribution networks of Eskom and about 188 municipalities. At present Eskom distributes about 60 per cent of the electricity consumed in South Africa, including that supplied to very large customers.

TABLE 1 – Maximum Interruption Levels – Business Customers

<table>
<thead>
<tr>
<th>Network</th>
<th>Interruptions</th>
<th>Number</th>
<th>Duration (h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead</td>
<td>Planned</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>Forced</td>
<td>6</td>
<td>10</td>
</tr>
<tr>
<td>Underground</td>
<td>Planned</td>
<td>1 every 2 years</td>
<td>6 every 2 years</td>
</tr>
<tr>
<td></td>
<td>Forced</td>
<td>2 years</td>
<td>10</td>
</tr>
</tbody>
</table>

The quality of supply standard NRS 048-2 defines the durations for momentary and sustained interruptions (for MV and LV the sustained interruptions exceed 5 minutes duration) as well as providing comprehensive requirements for power quality, particularly voltage dips [2].

INTERRUPTION PERFORMANCE REPORTING

Evolving procedures for reporting

The quality of supply reporting procedure NRS 048-3 allows forced interruption durations to be weighted by distribution transformer capacities or by energy lost (system-minutes – usually a transmission reliability parameter) depending on what data is available [3]. Importantly the internationally recognised electric distribution reliability indices of SAIFI, SAIDI and CAIDI to IEEE Standard 1366 are also introduced [4].

In mid 2004 the National Electricity Regulator (NER) issued a new specification for the annual reporting of power quality including the reporting of interruption performance in accordance with IEEE Standard 1366 (SAIFI, SAIDI etc) [5]. Elsewhere NER has declared its intention of monitoring reliability indices and establishing targets for improvement. NER also intends to publish an annual report detailing annual power quality statistics, noting that reporting according to the new reporting specification will be due only in year 2005.

Unfortunately at the time of the review few usable statistics on interruptions to supply from electricity distribution systems were found to be available, let alone in the public domain. Consequently the review relied mainly on the responses to questionnaires to provide an indication of the general levels of outages experienced by business customers.

1 SAIFI, System Average Interruption Frequency Index
SAIDI, System Average interruption Duration Index
CAIDI, Customer Average Interruption Duration Index
REVIEW OF RELIABILITY WORTH TO BUSINESSES

Questionnaires issued to distribution licensees and business customers

At the start of the review questionnaires were issued to NER and to distribution licensees to obtain data on interruption performance. Questionnaires were also issued to large business customers to ascertain the reliability of supply experienced and the costs of measures taken to mitigate against dips and interruptions. A particular requirement was to quantify investment lost due to interruptions. The business customers reviewed were restricted to those connected at MV (>1kV) and with a demand in excess of 1MW, in order to keep the review within manageable proportions.

Responses to Questionnaires – interruption performance

Eskom provided SAIFI, SAIDI and other network statistical data from each of its six distribution regions using its Network Equipment Performance System (NEPS). In general Eskom provides bulk supplies to municipalities and supplies very large industrial customers including mines and metallurgical plants from the HV (>44kV) system. Eskom’s MV distribution system is predominantly overhead and supplies sparse rural loads but relatively little urban load. Municipalities supply urban areas including most of the business customers that responded to the questionnaires. This division of supply areas reflects the historic development of the electricity distribution industry that is about to be restructured into six Regional Electricity Distributors (REDs).

However interruption data on urban systems and in a form that could be used for the review was found to be generally unavailable.

Instead data obtained from the responses by business customers to the questionnaires was used to evaluate the interruption performance experienced by the business customers who were mostly supplied at MV from urban networks. Most of the business customers had firm or duplicated supplies including those connected to MV ring circuits. In the event of a supply interruption, communication with the distributor’s control centre would be by telephone although obtaining a response might take a few minutes. In the review the business customers were segregated into those with demands below and above 100MW respectively as the latter included some customers with interruptible supply contracts (hence implying a different value of the reliability of supply). Table 2 summarises data from customers with demands less than 100MW.

Table 2 – Interruptions to business customers (<100MW & >1kV)

<table>
<thead>
<tr>
<th>Units</th>
<th>Min</th>
<th>Max</th>
<th>Average</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Demand</td>
<td>MW</td>
<td>1</td>
<td>71</td>
</tr>
<tr>
<td>Energy</td>
<td>GWh/year</td>
<td>6</td>
<td>331</td>
</tr>
<tr>
<td>Interruptions</td>
<td>No./year</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>Average interruption duration</td>
<td>Minutes</td>
<td>0 (dips)</td>
<td>224</td>
</tr>
</tbody>
</table>

In respect of the business customers (<100MW) that responded, the maximum number of interruptions per year in a number of instances exceeded the maximum number of interruptions (0.5 planned and 2 forced for underground networks) indicated by NRS 047-1. The average duration of interruptions experienced by these business customers was however well below the maximum implied by NRS 047-1.

Table 3 presents the causes of interruptions as attributed by business customers (<100MW).

Table 3 – Attributed causes of interruptions

<table>
<thead>
<tr>
<th>Cause of interruption</th>
<th>Number of times this cause attributed by customer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dips</td>
<td>4</td>
</tr>
<tr>
<td>Lightning</td>
<td>6</td>
</tr>
<tr>
<td>Rain</td>
<td>5</td>
</tr>
<tr>
<td>Grass Fire</td>
<td>4</td>
</tr>
<tr>
<td>Equipment defect</td>
<td>9</td>
</tr>
<tr>
<td>Operator error</td>
<td>1</td>
</tr>
<tr>
<td>System interruption</td>
<td>9</td>
</tr>
<tr>
<td>Supply cable theft</td>
<td>1</td>
</tr>
</tbody>
</table>

Responses to Questionnaires – reliability worth

In the questionnaires business customers were asked to submit information on:

- numbers and durations of interruptions over previous five years
- standby supplies, including number and capacities of diesel generators and uninterruptible power supplies (UPSs)
- estimated value of business lost due to supply interruptions
- estimated value of business shelved due to unsatisfactory quality of supply
- characteristics of load (maximum demand, annual energy consumption, connection voltage and
- interruptible supply contracts.
None of the respondents indicated explicitly either an improved level of quality (reliability/continuity) of supply that they would require or what they would be willing to pay directly towards such improvement. Instead their actual investment in standby generating plant and UPSs was taken as an indication of the value that the business customers would put on the reliability of the supply that they received. The value considered was the annuitised cost of standby plant as well as the cost of loss to business, normalised by annual energy consumption. The resulting costs were plotted against corresponding average interruption duration to derive sector customer damage functions (SCDFs) which was then compared with the results of a more detailed survey undertaken in the United Kingdom [6]. (The SCDF concept is also widely reported in North American papers). The results for business customers (<100MW) are presented in Figure 1 and indicate that the South African values are of the same order as, although in the main lower than, those obtained in the United Kingdom at nominal currency exchange rates.

For large users the South African SCDFs are lower (figure 2), reflecting very large energy consumptions per customer as well as interruptible supply contracts.

From equation (4) of reference [6], the corresponding system customer outage cost (SCOC) may be calculated as:

\[ \text{SCOC} = \text{SAIFI} \times \text{Energy Consumption} \times C(\text{CAIDI}) \]  

The indicative annual cost of interruptions to business customers, as reflected by mitigation measures and costs of loss to business, is about EUR83 million. It is to be expected that marginal reductions in this cost would be compared with costs of reducing both the number and duration of interruptions in order to justify the corresponding expenditure.

**INDICATIVE LEVELS OF ACTUAL INTERRUPTION PERFORMANCE**

Despite difficulties in obtaining interruption data from distribution licensees during the review, the data that was obtained may provide an indication of typical levels of actual interruption performance in South Africa, namely:

- response from business customers
- published data from Eskom and
- data from municipalities.

Analysis of a municipality’s MV circuit interruption data

Figure 3 presents the interruption performance of one medium sized municipality that provided data from some 200 incidents on its MV circuits over a year. The data has been grouped by about 30 load points supplying both business and residential areas and the corresponding system indices due to MV interruptions only are:

- SAIFI = 6.7 interruptions per year
- SAIDI = 817 minutes per year and
- CAIDI = 122 minutes per interruption.
The maximum interruption frequency level is appreciably higher than the levels indicated in NRS 047-1, for both overhead and underground networks supplying business customers. The duration of interruption durations at the MV load points shows a typical lognormal distribution, as shown in Figure 4. 95 per cent of the municipality’s load points experience an annual interruption duration of about 3000 minutes or less, indicating that the ratio between the 95 per cent (i.e. maximum) and average levels is about four to one.

Taking this ratio of maximum to average interruption durations as a proxy for the country as a whole, the system average annual interruption durations (SAIDI) corresponding to the NRS 047-1 maximum limits for networks supplying commercial and industrial customers would be as presented in Table 4.

Table 4 – Indicative average interruption duration limits - business

<table>
<thead>
<tr>
<th>Network</th>
<th>Interruptions</th>
<th>Maximum duration (mins)</th>
<th>Average duration (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overhead</td>
<td>Planned</td>
<td>360</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forced</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>960</td>
<td>240</td>
</tr>
<tr>
<td>Underground</td>
<td>Planned</td>
<td>180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Forced</td>
<td>600</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>780</td>
<td>195</td>
</tr>
</tbody>
</table>

Comparison of SAIDI limits implied by NRS 047-1 maximum limits

Figure 5 presents the implied SAIDI limits for forced and planned outages on underground circuits imposed on a range of SAIDI (customer minutes lost) for distribution companies in OECD countries compared with load densities [7]. The range of load densities depicted are those of the year 2000 loads for the nine provinces of South Africa (SA), ranging from the sparsely populated Northern Cape to Gauteng (which includes Johannesburg).

Indicative actual SAIDI performance

Figure 6 presents a sample indication of the actual level of SAIDI performance in South Africa with respect to load density. The data available is very limited and is based on:

- historic performance data published by Eskom [8]
- data from the medium sized municipality referred to earlier and
- the assumption that the business customers (<100MW) that responded to the questionnaire are located an area where the load density is typical of that of one of the large municipalities.

The contribution to interruptions due to the transmission system is in any case relatively low, corresponding to about 4 system-minutes in 2003. Eskom has stated recently that it is continuing to drive to improve quality of supply on its distribution network, the steps taken including reconfiguration of networks and improvement in equipment performance.

2 OECD – Organisation for Economic Co-operation and Development
A REGULATORY CHALLENGE FOR THE RESTRUCTURED ELECTRICITY DISTRIBUTION INDUSTRY

The electricity distribution industry is in the process of being restructured into six REDs, combining the distribution networks of Eskom and about 188 municipalities. NER has stated the intention of introducing incentive-based regulatory methods, including the “S-Factor” incentive/penalty element in a regulatory price control formula [9]. However before introducing performance-based incentive/penalty regimes, it is important to be able to quantify performance and its value. These considerations will be among the challenges to be faced by the REDs.

Interruption performance targets through network disaggregation

Some regulators elsewhere have benchmarked network interruption performance (numbers of interruptions and durations) at a disaggregated level across distribution licensees and have so taken into account the composition of networks order to set targets. Two particular examples of disaggregation parameters and benchmarking are by:

- type of network (e.g. central business district, urban, short rural and long rural) as in Victoria, Australia [10] and
- voltage level, interruption duration and frequency bands and MV circuit characteristics (customers, length, overhead/underground) in Great Britain [11].

Further research work is presently being undertaken in Great Britain to benchmark interruption performance by considering the influence of switching devices and interconnection points on MV radial circuits.

CONCLUSIONS

The principal conclusions of the review were that no national statistics of distribution interruption performance currently existed, the cost of interruptions to business customers (>1kV) was about EUR80m annually and that the limits for maximum interruption levels in NRS 047-1 for commercial/industrial networks were not unreasonable. These findings provide both a basis and a challenge for the future REDs.

REFERENCES


