SETTING OF TARGETS FOR CONTINUITY OF SUPPLY THROUGH BENCHMARKING

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INTRODUCTION

Electricity regulators in a number of countries [1] are focusing increasingly on the measurement of outputs such as continuity of supply, in addition to the control of revenues of distribution companies - historically based on input measurands such as investment and operating expenditures. Targets and incentive/penalty regimes are being introduced progressively. Using information from OECD countries, the paper examines the fundamental linkages between continuity performance (average frequency and duration of long supply interruptions) and network characteristics as well as the methods used and proposed by regulators to set quality of supply targets.

INDICES

In American terminology [2] the indices for system average interruption frequency and duration of long or sustained supply interruptions are known as SAIFI and SAIDI respectively and are weighted by customer numbers. Although these indices are used widely, the indices used in different countries may differ in detail:

- EN50160 indicates that long interruptions are longer than 3 minutes’ duration
- IEEE P1366 –2000 defines sustained interruptions as longer than 5 minutes’ duration
- Spain, Portugal and Latin American countries (CIER) weight the indices by transformer capacities instead of by customer numbers; e.g. in Spain the parameter used is TIEPI (tiempo de interrupción equivalente de la potencia instalada)
- in Australia and New Zealand (long) interruptions are those exceeding 1 minute duration
- in Great Britain [3] with effect from April 2001, under the Information and Incentives Programme (IIP), (long) interruptions are those exceeding 3 minutes instead of 1 minute duration,
- selective exclusion of interruptions due to severe weather, load shedding, transmission interruptions, pre-arranged outages or LV outages [4]
- in New South Wales, Australia, interruption data sets are classified as “Overall, Raw, Standard and Modified Standard”, depending on which measure is used [5] and
- in Great Britain improved information on customer connectivity (numbers) has tended to increase the “count”.

As a consequence the availability and quality of data on continuity of supply performance is found to vary.

COMPARISON OF CONTINUITY OF SUPPLY PERFORMANCE BY LOAD AND CUSTOMER DENSITY

It is important that any benchmarking or comparison method should provide both a means of normalising measures and a reasonable correlation. Different measures of load density or customer/circuit utilisation may be considered, GWh/km², MWh/MV-km [6], Customers/km² and Customers/MV-km. Figs 1 and 2 below show a comparison of interruption duration performance (SAIDI) for the distribution networks of individual companies in a selection of OECD countries (Australia, Ireland, Japan, New Zealand, Spain, United Kingdom, and United States) as a function of load density (GWh per km²) and of customer/circuit utilisation (customers per MV km).

Fig 1. Average duration of interruptions v load density

![Graph 1](image1.png)

Fig 2. Average duration of interruptions v Customer per MV-km

![Graph 2](image2.png)
Whilst there is more data available (i.e. published) for the load density comparison, the customer/circuit utilisation comparison may be considered to provide a closer reflection of the effect of MV circuit lengths and hence topography of the networks. (In general most customer interruptions and minutes lost are incurred at the MV level). Both comparisons show however that there is a general consistency between reliability and load density. The use of energy distributed or demand instead of customers as a parameter may also give some weighting to commercial and industrial customers which would otherwise be absent in purely customer weighted comparisons.

Other findings are that there is less variation in the customer average interruption duration index (CAIDI), typical values being 100 minutes per interruption. The highest reliabilities however generally require networks to be solidly interconnected at MV level (e.g. Manweb – Merseyside area in Great Britain with only 16 customer minutes lost in 2000/01.) and the comparison would suggest that about 40 customer minutes of interruption would be representative of “best practice” in urban areas. The frequency and duration indices used in the paper are averages for the operating zone concerned and in practice there may be individual areas (circuits) within a zone that display a reliability significantly different from the average. As a consequence there is increasing attention on the part of regulators to the performance experienced by worst-served customers.

COMPARISON OF CUSTOMER AVERAGE INTERRUPTION DURATION AND SYSTEM AVERAGE INTERRUPTION FREQUENCY INDICES

Fig 3 presents a comparison of the CAIDI index and the number of interruptions per 100 customers (SAIFI) using data from operating zones within distribution companies in a number of countries [7].

From the British data, operating zones in high load density areas (London, Merseyside) tend to show high CAIDI and low SAIFI, which may reflect relatively low fault rates of predominantly underground networks but longer interruption times due to time to undertake fault location and corrective switching operations on an urban network. This characteristic may change as more remote controlled switching is introduced. Conversely the instances of high values of SAIFI reflect predominantly overhead networks.

(Contour lines are drawn for lines of constant SAIDI = SAIFI x CAIDI)

The data for Italy and New Zealand shows that CAIDI is substantially constant for a wide range of SAIFI, which may reflect arrangements for system control.

SETTING OF CONTINUITY OF SUPPLY TARGETS BY LOAD DENSITY

Examples of countries that have recently introduced continuity of supply targets based on customer or load density include Italy, Ireland and Victoria, Australia.

Italy

In Italy customer density and territorial area are used with targets and incentives/penalties being set by load concentration of the municipalities concerned, namely high (50,000 inhabitants), medium (<5,000 inhabitants) and low (>5,000 inhabitants) [8].

Ireland

In 2001 the Commission for Energy Regulation (CER) in Ireland set distribution network continuity of supply targets after consideration of a benchmarking of network continuity performance against load density data from a number of distribution companies in different OECD countries [9]. Both the load density (GWh/km²) and circuit utilisation criteria (MWh/MV-km) were used in the assessment of an appropriate target level.
CER set targets for minutes lost per customer per year for 2005 as follows:

<table>
<thead>
<tr>
<th>Network</th>
<th>2005 SAIDI target (mins/year)</th>
<th>Improvement on 2000 level (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urban</td>
<td>50</td>
<td>60</td>
</tr>
<tr>
<td>Rural</td>
<td>350</td>
<td>38</td>
</tr>
<tr>
<td>Average</td>
<td>275</td>
<td>40</td>
</tr>
</tbody>
</table>

The corresponding incentive/penalty clause in the regulatory price control formula is based on a value of lost load (VOLL) of about €6/kWh, whilst also providing an element of “policing” the allowed investment on network reinforcement and refurbishment.

**Victoria, Australia**

For the purposes of monitoring continuity performance and setting targets the regulator, now the Essential Services Commission (ESC), has categorised MV feeders as follows:

<table>
<thead>
<tr>
<th>Feeder category</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central business district (CBD)</td>
<td>A feeder supplying Melbourne CBD as determined from zone substation coverage maps.</td>
</tr>
<tr>
<td>Urban</td>
<td>A feeder, which is not a CBD feeder, with load density greater than 0.3 MVA/km</td>
</tr>
<tr>
<td>Short rural</td>
<td>A rural feeder with total length less than 200 km.</td>
</tr>
<tr>
<td>Long rural</td>
<td>A rural feeder with total length greater than 200 km.</td>
</tr>
</tbody>
</table>

Targets have been set in Victoria, by circuit category and by distribution company, for each of the years 2001 to 2005 for the following indicators:

- planned minutes off supply
- unplanned interruption frequency and
- unplanned interruption duration.

Overall the targets for 2005 would represent a reduction in minutes off supply over year 2000 levels of 20% for the state average, 17% for rural networks and 25% for urban networks. A Service Adjustment Factor has been incorporated in the regulatory price control formula in which incentives and penalties are calculated according to an incentive rate and the gap in performance between actual and target levels, by indicator and customer category (CBD, urban and rural) [10].

Furthermore each distribution business is required to report on the performance of low reliability distribution feeders, limits for which were initially set (1999) such that approximately 95% of customers could expect on average that level of service or better [11]. Accordingly the following benchmark levels were set for low reliability feeders:

<table>
<thead>
<tr>
<th>Feeder category</th>
<th>Minutes off supply per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBD</td>
<td>65</td>
</tr>
<tr>
<td>Urban</td>
<td>280</td>
</tr>
<tr>
<td>Short rural</td>
<td>710</td>
</tr>
<tr>
<td>Long rural</td>
<td>1010</td>
</tr>
</tbody>
</table>

Similar concepts are being developed in South Australia and Tasmania whereas New South Wales is not presently setting mandatory standards and instead is requiring the distribution companies to nominate performance targets and report against these.

**Great Britain**

In 1999 under the Distribution Price Review the British energy regulator Ofgem set targets for continuity of supply performance for 2004/5. These targets and the associated penalties/incentives have since been formalised under the IIP [3] but, following discussions with the industry, Ofgem is presently consulting on establishing a framework to make more robust comparisons of continuity performance [12].

The continuity targets set in 1999 were based only on current performance and trends and hence both they and the incentives and penalties in the IIP may not necessarily reflect the:

- inherent characteristics of networks
- economic benefit of improvements or
- costs of improvements [13].

![Fig 4. British interruption duration target 2004/5 v load density](image_url)

Fig 4 shows the 2004/5 targets (before IIP revisions) for duration of interruptions to supply against customer density. The regression trendline indicates that at least one company with comparatively good performance, for example, may have been set a tight target whereas there may be justification for further improvements in those with

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comparatively poor performance. Similar comparisons of both customer interruption and interruption duration targets against other load and customer density measures were consistent with this finding.

A standard for multiple interruptions experienced by an individual customer has also recently been introduced in Great Britain.

**FACTORS AFFECTING CONTINUITY OF SUPPLY PERFORMANCE**

Ofgem recently considered the factors affecting continuity of supply performance as falling into three categories: inherited (e.g. network configuration), inherent (topography) and incurred (operational practices) [12]. Inherited factors could have a varying time horizon whereas inherent factors were considered permanent.

**DISAGGREGATION OF THE INTERRUPTION DURATION (SAIDI) INDEX**

Systematic order of the interruption duration index

The influence of inherent, inherited and incurred factors may be illustrated by considering the disaggregation of the interruption duration index.

\[
\text{SAIDI} = \frac{\text{customer minutes}}{\text{customers}} = \frac{\text{minutes lost}}{\text{km of network}} \times \frac{\text{km of network}}{\text{customers}} \quad (1)
\]

The “minutes lost” term can be divided into those minutes lost due to planned outages and those due to faults. A high level of minutes lost due to planned outages for example may indicate significant work being carried out on the network, particularly where there are limited means of providing an alternate supply. However live working techniques and the provision of standby generators should mitigate planned outages.

The term “minutes lost per km of network” indicates that part of the performance of the network over which the distribution company has control (inherited and incurred factors), whereas the term “km of network per customer” reflects the inherent factor of geography (population density) that the distribution company cannot control.

**Term: Minutes lost per km of network**

From the distribution system performance data for 2000/01 published by Ofgem (this data includes the effects of severe weather) the following comparison in Figs 5 to 7 is obtained of the interruption performance due to faults only of the 14 distribution companies in Great Britain.

**Fig 5. Great Britain – Customer minutes lost in 2000/01, due to faults**

![Graph of customer minutes lost in 2000/01 due to faults]

As reflected in Fig 6, some distribution companies reported performance levels worse than their long-term averages and trends, due mainly to severe weather. With regard to length of network per customer (an inherited factor), the two outliers are London with an underground network serving an area of high load density and Hydro-Electric with a mainly overhead network supplying an area of low load density including mountains and submarine crossings.

**Fig 6. Minutes lost due to faults per km of network**

![Graph of minutes lost due to faults per km of network]

**Fig 7. Length of network per customer**

![Graph of length of network per customer]

Further disaggregation of the term “minutes lost per km of network” is presented below, where minutes lost/km

\[
= \frac{\text{Cust. Interruptions}}{\text{Faults}} \times \frac{\text{faults}}{\text{km}} \times \text{duration} \quad (2)
\]
The range of ratios of customer interruptions (CIs) to faults (namely the average number of customers affected by a fault) reflects system configuration and protection policy (inherited factors which a company may ameliorate in the longer term). To reduce this ratio requires investment to increase the number of circuits and/or protected zones, including investment in switchgear, protection equipment, auto-sectionalising and remotely controlled switching.

The fault rate (faults per km of network) reflects construction and condition of assets as well as the weather conditions encountered. On open-wire overhead systems, faults may be considered as “damage” or “non-damage” (transient) and the impact of the latter may be reduced substantially through improved auto-reclosing techniques as well as the use of arc suppression coils. Fault rates may be reduced through effective refurbishment, replacement and maintenance policies, including the replacement of open-wire systems with covered conductor systems or underground cables. Under severe weather conditions, fault rates may rise to many times the long-term average. Fault rates are therefore influenced by inherited and incurred factors, although it may be argued that severe weather is inherent. (Resilience of networks to severe weather conditions is receiving considerable attention following severe storms in recent years.)

The average duration of a customer outage (CAIDI) is influenced by operational procedures, communications, fault passage indication facilities and telecontrol systems and as such may be considered largely as an incurred factor being under managerial control (subject to constraints of geography and travel times). Restoration times may increase many times under severe weather conditions where widespread damage is encountered and the operator’s resources are finite. The high average interruption duration for ScottishPower in the chart above reflects severe snow and ice storms in 2001 – excluding these would reduce the company’s average interruption duration by about half. (The company has since undertaken extensive remedial work in the area affected.) Where targets are set purely in terms of annual interruption duration (SAIDI), it is the reduction in restoration times that generally offers the most improvement for a given cost.

The above disaggregation enables the inherent, inherited and incurred factors to be compared and arguably is more objective for a distribution company for the purposes of forming strategic policy than comparison of only the overall average interruption frequency and interruption duration indices. Further comparison on a year-by-year basis may also reflect the past expenditure policies of the companies concerned.

**DETAILED COMPARISON OF INTERRUPTION FREQUENCY BY LENGTH OF MV PROTECTED ZONES**

In most networks the MV level has most influence on interruption frequency and duration indices. From more detailed data, the estimated average length of an MV protected zone (i.e. circuit or protected section thereof) may be estimated by considering the number of customer interruptions per MV fault (for which data is compiled in Great Britain) as representing the average number of customers per MV protected zone.
The average length of an MV protected zone is taken as being

\[ \text{average length} = \frac{\text{network length} \times \text{customers/MV zone}}{\text{total customers}} \]  

(3)

For 2000/01 the comparison in Fig 11 is obtained.

Fig 11. MV customer interruptions 2000/01 v protected zone length

Fig 11 indicates those companies with higher fault rates and protected zone lengths as well as the increased number of protected zones that would be required in order to reduce interruption frequency to a required target level.

CONCLUSIONS

The paper presents different approaches to benchmarking of continuity performance as might be used by both regulators and distribution companies, particularly in those jurisdictions where no targets presently exist. In the latter case the concept of the disaggregation of the interruption duration (SAIDI) index and in particular the detailed comparison by protected zones requires the necessary data to be available and compiled on a systematic basis. The benchmarking methods as described provide a high-level indication of inherent, inherited and incurred factors and therefore an indication of where improvements can be made. The methods provide a starting point for more detailed optimisation studies as might be carried out by a distribution company, say, by using a generic model such as the Reference Network Model being developed by UMIST [14].

REFERENCES