Battery Reserve Sizing for Fibre-In-The-Loop Equipment Based on AC Outage Data

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SUMMARY

Telstra Corporation is currently deploying Fibre-In-The-Loop (FITL) facilities in Australia for pay-TV, and the potential future requirements of Video-on-Demand and Multimedia services. FITL equipment located at the curb or customer's premises is expected to be powered from a local AC line connection, and hence it will be subject to AC outages. This paper discusses the use of typical metropolitan outage data recorded by Australian electricity supply utilities to assist in the optimum design of curb located FITL equipment. A FITL powering availability model is used to determine the power outage contribution to system unavailability for a given battery reserve time.

INTRODUCTION

Two previous papers presented at INTELEC by the Telstra Research Laboratories have discussed powering options[1] and cost structures[2] for various FITL architectures. These investigations have assumed that an 8 hour battery reserve time would cover most of the planned and unplanned power outages.

Recently, Bellcore have analysed outage data[3] from a US based site survey[4] and estimated average FITL service unavailability attributable to power disturbances. Bellcore have estimated service availability for 4, 8 and 12 hour battery reserve times, but indicate that the majority of the unavailability is caused by a minority of long duration events that occur mainly in rural and disaster-prone locations.

The metropolitan AC outage data recorded by Australian electricity utilities is extensive and provides an excellent base for estimating AC availability at various elements in the power distribution system. Thus the analysis of outage data can be used to derive strategies for battery reserve sizing for FITL facilities.

This paper focuses on battery reserve sizing for curb located FITL equipment, however customer premise located FITL equipment is also under investigation. Results from this analysis will also augment assessment of exchange power system availability using the reliability modelling technique presented by Telstra Corporation at last year's INTELEC[5].

AUSTRALIAN AC OUTAGE DATA

Australian electricity utilities have been collecting AC outage statistics for a number of years to help benchmark their "quality of supply" performance. Presently, the only technical indicators reported on a yearly basis are:

- system average outage frequency (No. per customer per year).
- average customer outage duration (minutes per customer per year).
- system average outage duration (minutes per year).

Each of the 8 Australian state utilities has its own reporting process for outages affecting its customers. The outage data recorded typically includes outage time, restoration time, region, number of customers affected, distribution level (that was affected by the fault, as shown in Figure 1), and fault cause category, where:

- outage time is the time manually recorded when the first affected customer telephones the utility to report a fault or automatically generated by remotely monitored utility equipment.

- restoration time is the point at which the resumption of service is reported by the utility fault repair staff.
- the number of customers affected by a fault is determined from the fault distribution level and a customer information database.
- a fault cause category includes cause categories such as planned/accidental outages, equipment failure modes and extrinsic disturbance failure modes.

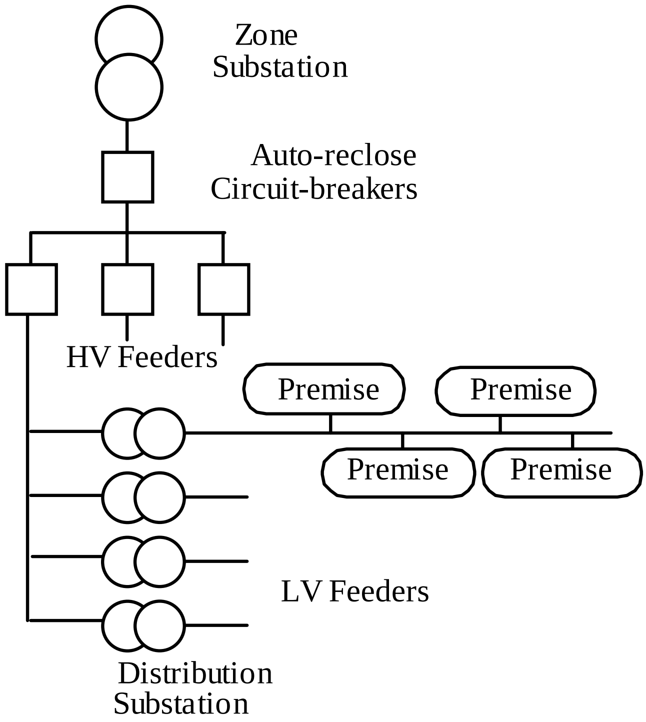

Figure 1. Typical AC distribution levels.

RAW DATA PROCESSING

Large databases derived from a predominantly manual reporting process are highly likely to contain a small percentage of records that contain invalid data, despite automatic validation procedures. The main types of errors found in the database analysed for this paper, and the likely cause of violations of data integrity were:

- null fields, where a data field is empty.
- negative outage durations, where the outage date and time appears to occur after the restoration date and time.
- zero outage durations, where the restoration date and time is equal to the outage date and time. This type of record is generated when either, an outage was planned to occur but did not, or a real outage did not occur but a report was entered to record preventative maintenance actions, or finally, the disturbance was very short (<1 minute).
- excessively long outage durations. This type of record occurs when the restoration time has been recorded significantly after the customer(s) is reconnected. This type of record also occurs when a fault is isolated and customers reconnected to an alternate source, but the fault was repaired some later time.

For the analysis presented in this paper, the raw data was processed to remove those records with null fields, negative outage durations, zero outage durations and outage durations longer than 3 days.

The decision to remove records with outage durations longer than 3 days was taken after consultation with utility staff. It was noted that the frequency of this type of record had decreased markedly in the last year of data, which may result from improved reporting quality and accuracy. It is also noted that these data are from a metropolitan region not subject to major supply disturbances more likely in rural areas.

A small number of seemingly associated record groups were also identified, in which each record in the group had the same outage and restoration date and time, and the same fault category and location, but a different number of affected customers. After discussion with utility staff, these records were left unaltered under the assumption that any similarities were coincidental.

AC AVAILABILITY ANALYSIS

Curb located FITL equipment is subject to outages occurring at distribution levels down to low voltage feeders, as shown in Figure 1, i.e., not including outages occurring at the premise level. The database for this analysis contains a total of 28,124 records for 1217 consecutive days.

The AC availability for a given outage duration derived from this data is shown in Figure 2. The plot shows a distinct change in slope for outage durations longer than about 8 hours, indicating that any increase in battery reserve time longer than 8 hours may have only a marginal effect on power system availability.

To determine the number and extent of worst case outages, a scatter plot of all outage records is shown in Figure 3. This figure shows that the large majority of all outages have durations less than about 5 hours. Although most outages beyond this point affect less than 0.4% of the customer population this maybe an unacceptable rate for provision of an essential FITL service.

The relative frequency of all outages occurring for a given outage duration is shown in Figure 4. The distribution is bimodal. The large peak occurring near 1 hour can be attributed to the time taken to reach the fault location, and depending on the severity, either fix the fault, or reconnect customers to an alternate source. The peak occurring around 8 hours is related to the nominal number of hours in a working day. These effects are reflected more clearly in Figures 5 and 6, showing the relative frequency of accidental and planned outages respectively.

Figure 5 shows a strong correlation with known fault repair practices. The planned outage frequency plot is more complex in structure, showing a strong correlation with the nominal 8 hour work day and less distinct peaks that may be associated with segmenting the work day into hourly or 2 hourly blocks.

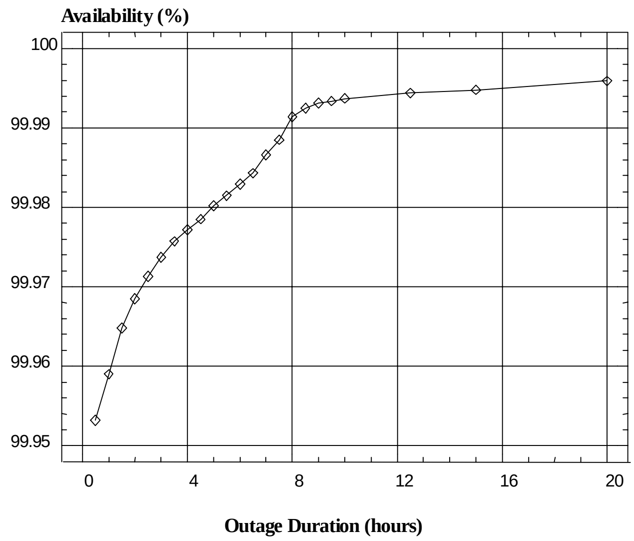

Figure 2. AC Availability

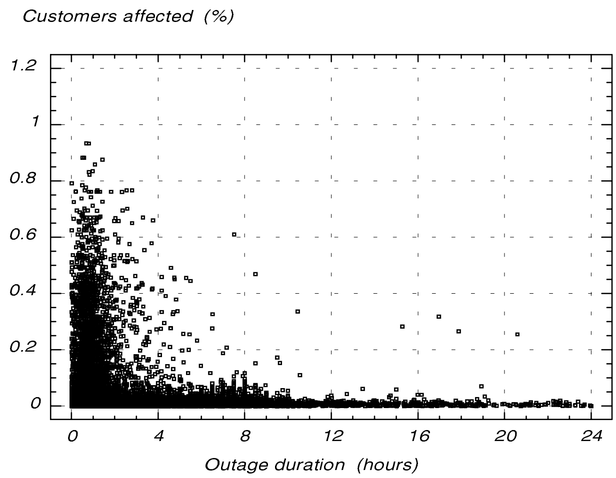

Figure 3. Customer base affected by AC power outages.

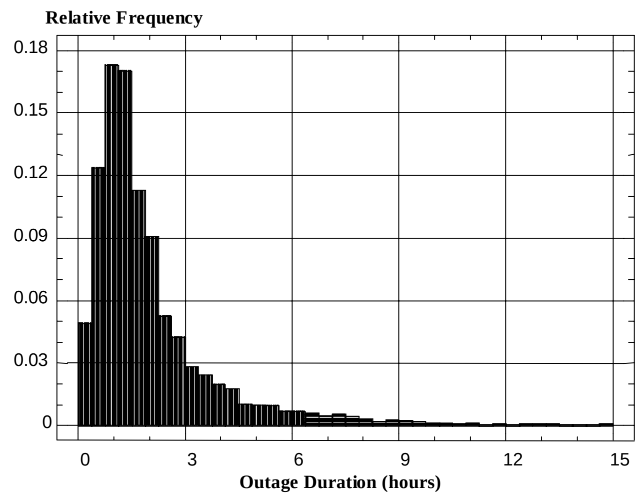

Figure 4. Relative frequency distribution of all outages.

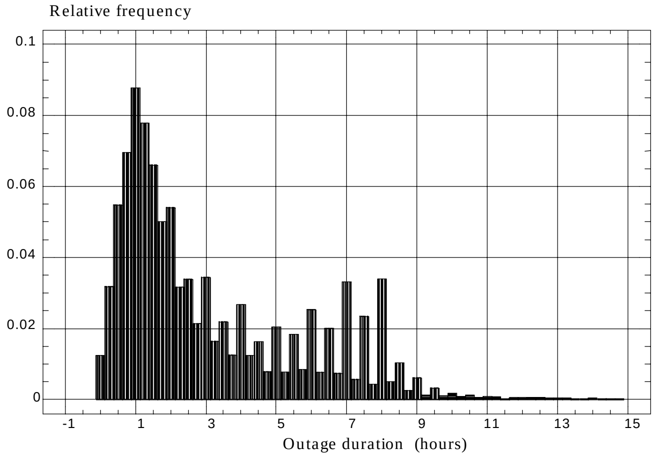

Figure 5. Relative frequency of accidental AC power outages.

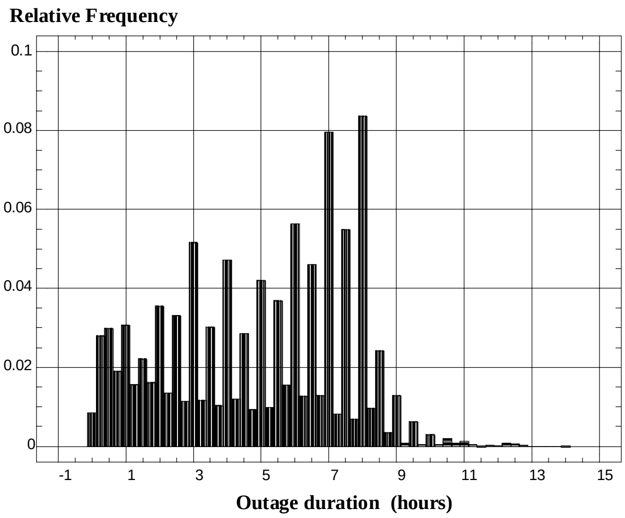

Figure 6. Relative frequency of planned AC power outages.

FITL POWER SYSTEM MODEL

The steady-state unavailability of a system is defined as the proportion of total system time where it is not available for use[6]. Thus, for constant failure and repair rates :

$$\text{System Unavailability} = U_s = \frac{MSRT}{MTBF + MSRT} \quad (1)$$

Where,

$MSRT =$ The Mean Service Restoration Time

and

$MTBF =$ The Mean Time Between Failures

If MTBF>> MSRT, then :

$$U_s \approx \frac{MSRT}{MTBF} \quad (2)$$

Furthermore, since the system failure rate, • • is defined as the reciprocal of the system Mean Time Between Failure, equation (2) may be rearranged as:

$$U_s \approx \lambda \times MSRT \qquad (3)$$

The availability of power at the remote unit depends on several conditions. These are the availability of AC mains power, the availability of the rectifiers, the availability of the batteries, and the reserve battery capacity. Thus, the remote unit will be unavailable if either the AC Mains power or the rectifiers are unavailable and the battery has failed. In addition, the remote unit will also be unavailable if either the AC mains power or the rectifiers are unavailable and the duration of the AC mains outage exceeds the reserve capacity of the battery[7]. Refer to equation (4).

$$\begin{aligned} U_{remote\,-\,unit\;power} &= (U_{AC} + U_{\mathrm{Re}\,ctifiers}) \times U_{Battery} \\ &+ (U_{AC} + U_{\mathrm{Re}\,ctifiers}) \\ &\times (1 - U_{Battery})\, e^{-\frac{t}{MSRTAC}} \qquad (4) \end{aligned}$$

Where

$t =$ the reserve capacity of the batteries

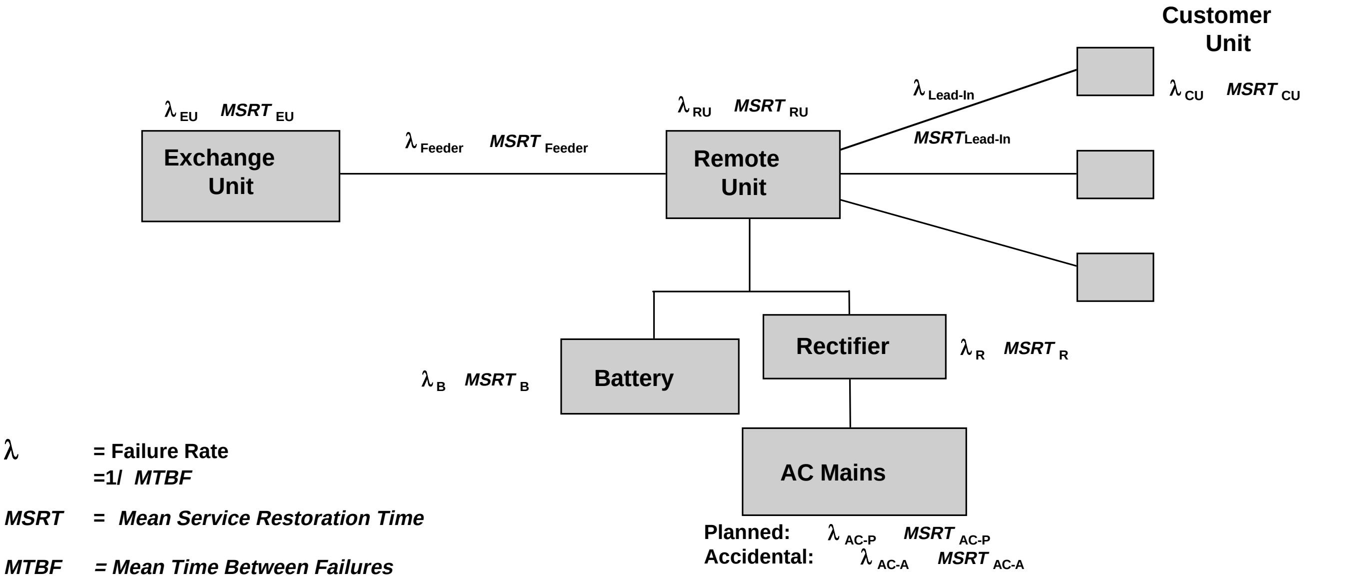

Figure 7. FITL system reliability block diagram

$$
\begin{aligned}
U_{\text{Customer}} = {} & \lambda_{CU} \times \text{MSRT}_{CU} + \lambda_{Lead-In} \times \text{MSRT}_{Lead-In} + \lambda_{RU} \times \text{MSRT}_{RU} \\
& + \lambda_{Feeder} \times \text{MSRT}_{Feeder} + \lambda_{EU} \times \text{MSRT}_{EU} \\
& + (\lambda_{AC-P} \times \text{MSRT}_{AC-P} + \lambda_{R} \times \text{MSRT}_{R}) \times (1 - \lambda_{B} \times \text{MSRT}_{B})\, e^{-\frac{t}{\text{MSRT}_{AC-P}}} \\
& + (\lambda_{AC-A} \times \text{MSRT}_{AC-A} + \lambda_{R} \times \text{MSRT}_{R}) \times (1 - \lambda_{B} \times \text{MSRT}_{B})\, e^{-\frac{t}{\text{MSRT}_{AC-A}}} \\
& + (\lambda_{AC-A} \times \text{MSRT}_{AC-A} + \lambda_{R} \times \text{MSRT}_{R} + \lambda_{AC-P} \times \text{MSRT}_{AC-P} + \lambda_{R} \times \text{MSRT}_{R}) \\
& \times \lambda_{B} \times \text{MSRT}_{B} \qquad \text{(equation 5)}
\end{aligned}
$$

Where;

t = the battery reserve capacity

Sub-Unit	Mean Time Between Failures (yrs)	Mean Service Restoration Time (hrs)	Component Unavailability (mins/line/yr)
Customer Unit	114.0	8.0	4.21
Service Lead-In	28.5	8.0	16.84
Remote Unit	5.4	8.0	88.89
Rectifier	2.3	8.0	208.70
Battery	228.3	8.0	2.10
AC Mains:			
Planned	3.8	4.9	76.66
Accidental	0.5	2.7	310.45
Feeder	85.6	8.0	5.61
Exchange Unit	5.2	1.0	11.54

Table 1. FITL reliability parameters

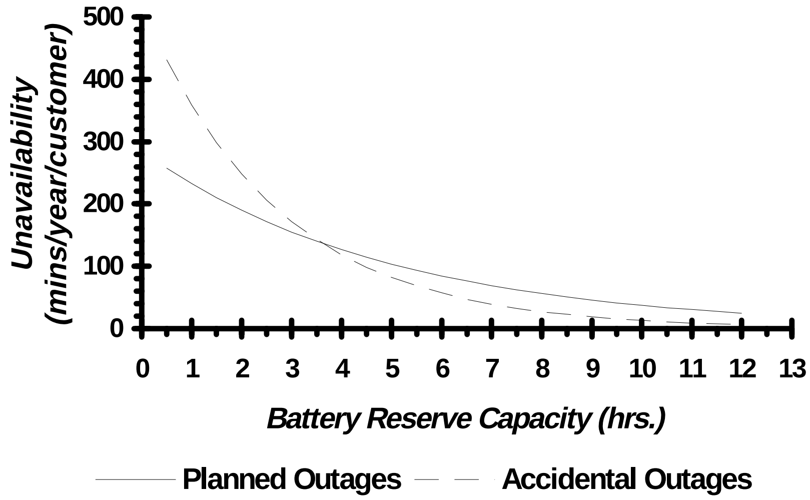

Figure 8. Power outage contribution to system unavailability versus battery reserve

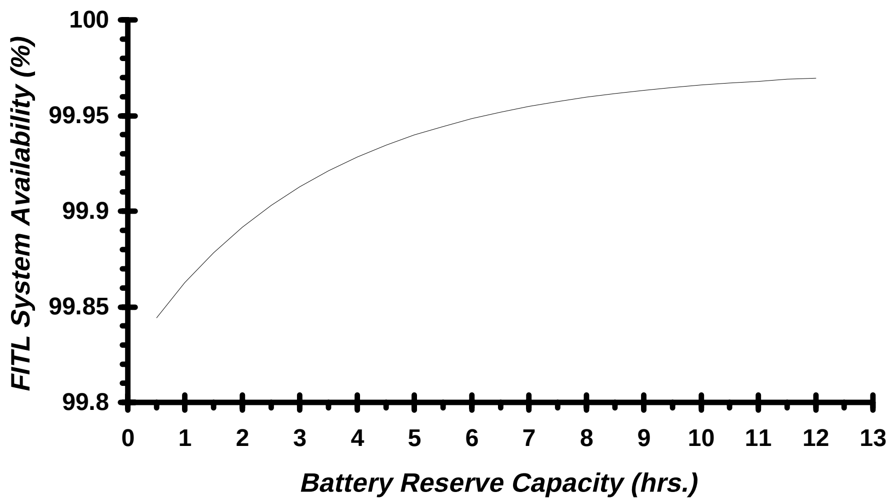

Figure 9. FITL system availability versus battery reserve capacity.

This situation is further complicated by the multi-modal nature of the observed AC mains power outage distribution as discussed earlier. Consequently, restoration times for planned and accidental outages have been individually analysed and separately included in the FITL availability model. The FITL system reliability block diagram is shown in Figure 7 and the power availability model is given by equation 5.

Some nominal reliability parameters for FITL systems based on Telstra field trial equipment are given in Table 1 together with their sub-unit unavailabilities. It is apparent that without back-up power to remote unit, AC mains failure would be the major contributor to system down-time. The relative contributions of planned and accidental AC mains outages to the FITL system unavailability are shown in Figure 8. This indicates that outages less than four hours have predominantly accidental causes. Planned outages are expected to contribute less to power system unavailability because of their less frequent occurrence.

The variation of overall system availability with battery reserve capacity is shown in Figure 9. This suggests that while moderate levels of customer service (system availabilities of 99.90%) may be achievable with relatively low battery reserves, high levels of service (availability • 99.99%) will not result by increasing battery capacity alone.

Thus the end-to-end model has considerable application in the investigation of FITL powering performance and availability, the analysis of risk in service delivery, and cost-benefit analysis of power system configurations and components.

BATTERY RESERVE SIZING STRATEGIES

Battery reserve size is determined on the basis of the various levels of quality of service that may be offered for various FITL services. For example, the provision of a non-essential FITL service compared with an essential FITL service may justify a lower level of FITL power availability, allowing the use of a smaller battery reserve. An alternative strategy is to augment the AC mains availability with mobile AC back-up, for example a petrol driven generator delivered and operated on site by fault repair staff. This could be implemented in a number of ways, such as:

- when notification of a planned outage is received, the generator can be used during the entire AC outage, or supplement the battery reserve, thereby minimising the generator on-time and staff time.
- when an accidental outage is indicated by an alarm, service staff could be called to the site only after a certain outage duration has elapsed (say 2-3 hours), as the majority of accidental outages would have been restored by this time.

CONCLUSION

In conclusion, this paper describes the type of outage data available from Australian metropolitan electricity utilities, the processing typically required to provide accurate and relevant data, the analysis of data to determine the availability of the AC supply, the application of a FITL powering availability model to determine the power outage contribution to FITL system unavailability, and strategies for battery reserve sizing.

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