

New concepts of reliability in powering the customer access network

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Introduction

Broadband and multimedia telecommunications are here. Optical-fibre based architectures and equipment are out of the labs and now commercially available for deployment in the customer access network. Telecommunications operators around the world are having to decide, with their cheque book, to what degree they will embrace this brave new world. The success of new services is base on consumer acceptance and demand, and thus forces operators to focus on the access network infrastructure and performance. Many telecommunications operators continue to undertake significant field trials of new networks and services in small towns or sample residential populations. These trials are not only to verify design expectations but also to test the ability to provide service activation and assurance, end-to-end system performance, and acceptance from the customer's point of view. Customer expectations of service are every bit as critical in determining the viability of these new services as the technical sophistication which makes them possible.

The plain old telephone service (POTS) is generally seen as an ubiquitous service with a high degree of reliability which is often epitomised by community notions of a "life-line" telephone. Many operators now wish to provide POTS over these new multimedia networks. There appears to be a fundamental expectation that POTS over these new networks will demand service reliability at least as high as customers presently experience from their traditional residential telephone service. However, due to use of mature power back-up methodologies for central office equipment, there is no significant powering contrib-ution to the reliability of traditional POTS. New powering architectures and methodologies are required to power the broadband networks. Powering is now seen as a major contributor to reliable provision of multimedia services and the traditional experience with telecommunications powering may be inadequate.

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The challenge therefore, is to face the powering aspects of new access networks and broaden the traditional view of power system reliability and its influence on service delivery.

Telephony Reliability

In Australia, telecommunications has been undergoing staged deregulation so as to achieve a wide and open competitive environment by mid-1997. Telstra is the original common carrier and now operates about 9 million lines across Australia. The public switched telephone network (PSTN) includes a vast rural and remote solar powered network but most of the lines are installed in a classical telephone exchange infrastructure throughout metropolitan residential areas.

The traditional telephone service is characterised by a very fault-tolerant telephony exchange infrastructure and a less fault-tolerant copper-pair distribution network. The reliability of POTS has been measured by the basic hardware reliability of the system which is dominated by field failures in the access network. In Telstra, telephony via the PSTN is very reliable with an estimated end-to-end service unavailability of less than a few hundred minutes per customer per year averaged across all Telstra's POTS including rural and remote services. This basic unavailability is dominated by service restoration times and is expected to decrease as competitive pressures force more efficient and effective work practices. The powering contribution to this service unavailability is estimated to be less than about 1 minute per customer per year. That is, loss of telephony service due to power failure is very rare for Telstra. This is primarily due to the traditional approach to tele-power provisioning of the central office. Powering has been considered critical, particularly in the context of life-line services, and network power architectures are conservatively designed. Typical power plant design utilises component redundancy to reduce the opportunities for single point failures and most of Telstra's telephone exchanges have both battery and diesel back-up to provide energy during loss of ac mains power supply.

Implementation of conservatively designed power systems for a very high level of availability is known to be expensive. However, the traditional telephony central office infrastructure allows much of the relatively high costs of power back-up and redundancy to be amortised over a relatively large number of customers. Maintenance procedures and life-cycle support strategies can be optimised for the centralised plant and tailored to an expectation of standard performance for plant operating under controlled environment conditions.

New and Emerging Networks

Penetration of optical-fibre based transmission systems into the customer access network has been occurring for some time. Fibre-in-the-loop (FITL) technologies such as Telstra's remote integrated multiplexer (RIM) distribute telephony-based communications over smaller customer areas compared to the traditional central office infrastructure. This hybrid fibre copper-pair technology provides a platform to support new and emerging broadband services such as ISDN, ADSL, and VSDL. Some telecommunications carriers and cable operators are introducing or upgrading hybrid fibre coax (HFC) networks to support both telephony and new and emerging broadband services. These technologies require active electronics for optical-electronic conversion, line interface circuitry and signal distribution amplification. Many customer access networks can now be generically represented as a distributed network of active elements serving groupings of residential customers, as shown in *Figure 1*.

As fibre extends closer to the customer, these newer networks exhibit:-

- a greater distribution of active electronic elements
- significant multiplicity of equipment
- an increase in the number of active elements as seen by the customer
- an increasingly distributed, rather than concentrated, infrastructure to maintain
- increasing use of equipment in less controlled operating environments
- a greater degree of localised powering networks to power the active elements.

Since these new types of access network architectures are clearly fundamentally different to the classic copper-pair telephony network, the end-to-end reliability can be expected to be influenced by much more than just copper-pair hardware component failure. In Australia, performance indicators suggest that services provided over distributed plant involving active electronics in the customer loop may not be as reliable as the traditional central office POTS.

Performance indicators such as operating equipment in uncontrolled environments, distribution architectures, provision for traffic congestion, multiplicity of equipment and cost limitations on provision of

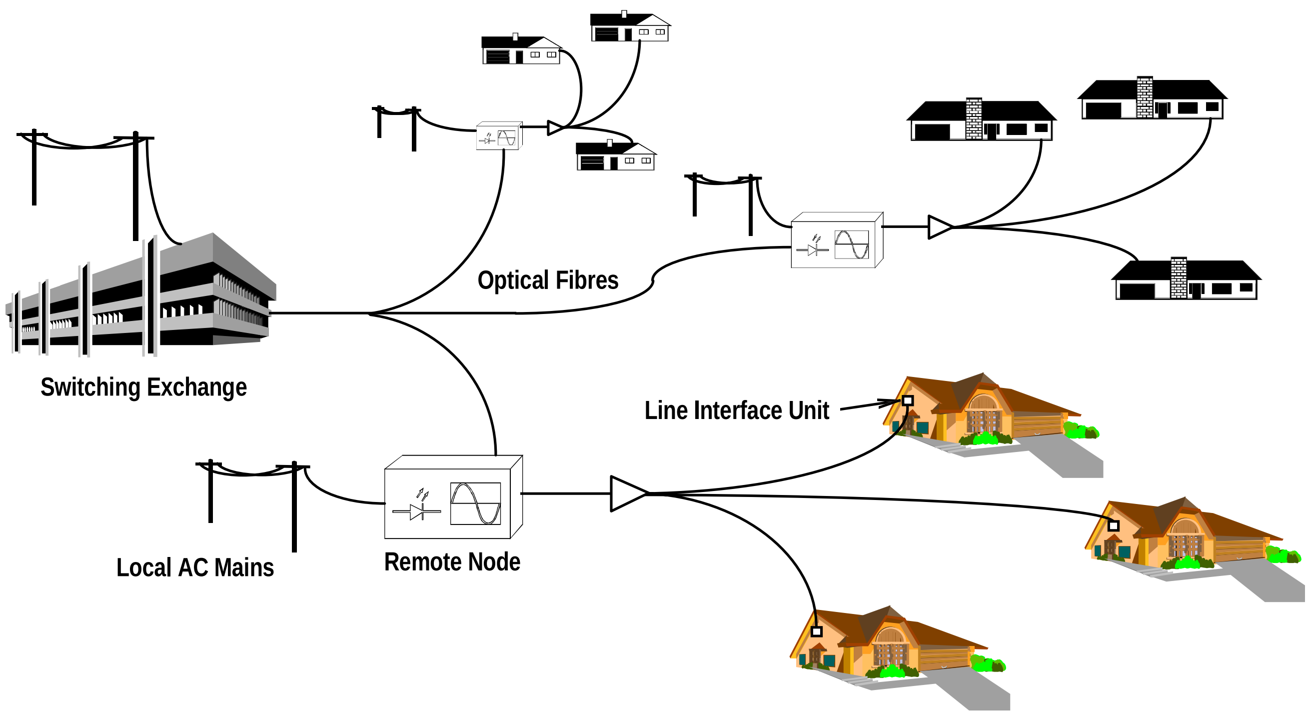

Figure 1. Generic FITL (fibre-in-the-loop) customer access network

redundancy all contribute to the total system reliability as never before. Local ac mains power supply is typically used in these distributed networks, thereby invoking all the historical arguments for the need for power-backup redundancy for high service reliability. However, commercial an1d competitive pressures will not allow traditional approaches of providing "gold-plated" telepowering infrastructure to be applied to great multiplicity of power supplies. It becomes necessary to focus powering requirements on *grade-of-service* targets. To do this requires a better understanding of the elements of the power infrastructure that influence grade-of-service and quality-of-service at the customer level.

Service Reliability

Service availability depends on the reliability of critical elements and service restoration times. Service restoration times will depend on both the frequency of failure of the elements and the sophistication of maintenance procedures. For power-related customer down-time, service unavailability is a combination of the reliability of the primary power supply and the reliability of the powering elements needed to support the active network. As discussed below, the reliability of supply of primary ac power in the customer access network is complex and depends on many factors. The inherent reliability of the powering elements will vary significantly. For instance, power supply equipment such as rectifiers or inverters can be considered to be relatively mature technology and thus expected to display predictable failure rates. Operation in varying temperature and humidity environments in the access network should increase the basic failure rates to some degree, but the MTBF should be reasonably estimated. On the other hand, the valve-regulated lead-acid (VRLA) batteries typically used as energy storage elements are considered less mature and exhibit greater performance variations in uncontrolled operating environments, and are thus less predictable in contribution to system reliability. Maintenance effort is affected by multiplicity and distribution geography. Metrics and monitoring of the power system status or performance will greatly improve the efficacy of required actions. Automatic alarming and targeted actions will generally result in shorter service restoration times (and higher *customer perception* of service availability) than circumstances where service loss failure is only identified and actioned after customer complaint.

AC Power Reliability

Power is critical to all telecommunications services. The power contribution to service reliability is therefore strongly linked to the likelihood of loss of the primary power supply. AC outage characteristics themselves are complex, at least in Australia, and influenced by high and low voltage electricity distributions architectures, accidental and planned outages, weather patterns and major disasters. The influence of ac power outages on service delivery in a distributed network depends greatly on the customer serving area, and with cascaded signal distribution architectures, failure of upstream components may have ramifications down stream. The point here is that power-related service availability in the new access network architectures depends on the meshing of two active networks - the ac distribution network which is the source of primary power supply, and the power continuity strategies in the distributed telepower network design. As such, it is inherently different to traditional POTS delivery.

While concentration of effort in the central office allows amortised cost of effort across many customers, failure of these standby power systems is all that more catastrophic in that the same large number of customers will lose service. However, for distributed active elements in the access network, customer serving areas may be considerably smaller than that represented by the traditional telephony infrastructure, and the ramifications of power failure might only need to be considered at the very local level. *Figure 2* shows the relative frequency and duration of accidental ac mains outages compiled over five years for residential customers in an Australian metropolitan region. Of particular interest is that the majority of ac supply outages to domestic customers are less than 1-1.5 hours in duration. These types of outage statistics can be used in distributed power system models, and it can be shown that while moderate levels of system availability (due to powering) - around 99.90% availability - can be achieved with relatively low battery reserves, high levels - around 99.99% availability - can not be attained with an increase in battery capacity alone [1]. Thus, the battery reserve times traditionally used to ensure highly reliable power supply in the telephone exchange may be less appropriate as backup reserve times at the customer level. That is, does the customer really see a difference between active loop equipment

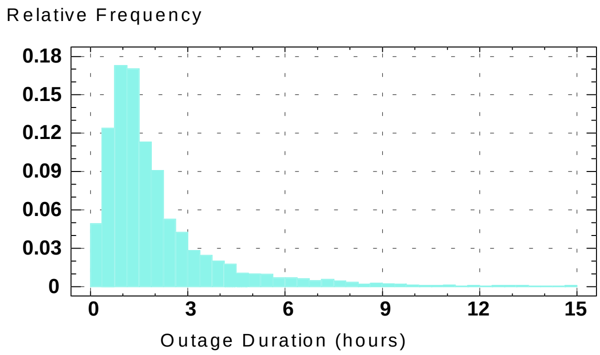

Figure 2. Accidental ac mains outage statistics

battery backed for 1 hour and a network battery backed for 8 hours? Put another way, does a marginal increase in the calculated service availability from powering (say, from 99.90% to 99.95%) justify the cost of a powering infrastructure with 5-8 times the designed reserve capacity? What is the *customer perceived* grade-of-service?

Customer Perceived Grade-of-Service

A customer may or may not experience a loss of service when the service is actually unavailable. This may be due to a number of reasons, such as the customer was not accessing the service at the time of outage, or the customer was not aware that an attempted service event failed. For instance, a customer might be unaware of a failed telephony call attempt from a friend which was blocked by the network. The service unavailability may also be linked to loss of other residential facilities, and thus not interpreted as loss of service. Thus, a customer receiving PayTV service may not actually consider it a matter of poor PayTV grade-of-service (GoS) if there is no ac power for the TV set due to an electricity blackout. Similarly, a customer's notion about GoS may be more influenced if the service is disrupted frequently or for a long duration compared to infrequently or for a short duration. In the traditional telephony network there are a few well known contributors to a customer's GoS, such as inter-network call loss (ie. blocking), access network failure and customer premise equipment failure. The customer may perceive each of these contributors very differently. Customer satisfaction with a service, that is, the *customer perceived* GoS, can therefore be quite different from the "actual" GoS or unavailability metric. In new and emerging networks there are many likely new contributors to "actual" GoS, such as power supply failure and power distribution "low end-of-line" voltage induced failure. Non-power related contributors may be call blocking due to concentration over the fibre link, or due to loss of available bandwidth in the access network during noise ingress periods. Each type of network will require an understanding of the GoS contributors and how these contributors will impact on the customer perceived GoS.

How customers perceive the level of performance they experience is very important for a service provider operating in a competitive environment, and may cause a shift in focus and target in the provisioning of technical solutions in the access network. Provisioning infrastructure that operates on the management of the *likelihood* that an unavailability event (if and when it might occur) actually results in a degradation of service from the customer's point of view is in principle different from provisioning engineering effort to reduce the likelihood of the event in the first place.

Batteries and Back-up Reserves

Lead-acid batteries have historically been used in telecommunications power back-up, and given the cost of alternative energy storage devices, it is unlikely that this situation will change in the foreseeable future. However, there are a few corollary issues with the use of lead-acid battery back-up which particularly affect the reserve times of remote active elements in the access network.

First, in the design process, battery reserve times are assumed to be available. That is, in unavailability determinations, loss of power to service occurs in circumstances where the ac outage duration exceeds the battery reserve time. The reliability of the battery as a powering element is typically calculated as the series contribution of the reliability of individual cells which make up the battery string. The inherent reliability of the lead-acid battery has been quoted as being very high [2], and thus does not contribute significantly in failure rates. That is, the reserve time is considered available. In traditional central office powering, particularly using vented lead-acid battery technology, this is a valid approach. Routine maintenance procedures, conservative use of battery performance data, and operation of the batteries at or near optimum controlled conditions, all help to ensure that designed reserves times are achieved. For exchanges with diesel back-up, the actual battery capacity performance is masked, and the standby power availability is dominated by diesel failure-to-start statistics (which are usually caused by failure of the starter battery anyway!).

However, it is not valid to assume that the same factors apply to standby batteries used in the remote elements of the access network. That is, it is not valid to assume the design reserve time is available. Due to a higher energy density and inherent equipment compatibility, VRLA batteries are now the technology of choice in most standby applications. Yet VRLA battery performance is not mature, and increasing evidence suggests that battery reserve capacity is not assured. Further, VRLA technology can not be subjected to the traditional maintenance routines which contributed to the reliability of central office battery reserve. VRLA battery technology is known to be less robust than vented technology when subjected to non-optimimun operating conditions. Operation of VRLA batteries outside the benign and controlled environment of the telephone exchange can be expected to exasperate any inherent poor performance.

Recently reported statistics of capacity failure of VRLA batteries in standby telecommunications applications suggests concern for the assumption of available capacity [3]. The Telstra Reserach Laboratories (TRL) has a program of study into the capacity retention of VRLA battery strings [4], and early indications are that battery strings of fewer series-connected cells exhibit better float conformance, and hence capacity retention, than strings containing a larger number of series-connected cells. That is, the evidence to date is that a 12V VRLA battery string floats “better” than a 48V string. An improvement in the “inherent” reliability of use of the VRLA batteries may therefore come from not operating the battery float regime at the equipment voltage rails.

The affect of poor performance of VRLA batteries on reserve dimensioning can be tackled by statistical approaches. Battery reserve design determinations could be weighted with a confidence level statistical characteristic for VRLA batteries operating in uncontrolled environments. This is shown in *Figure 3* where the likelihood of available capacity of a large population of VRLA is represented by a probability distribution function which changes with time. There is a high level of confidence that most new batteries (say, greater than 95%) exhibit a distribution about the rated, or "fit-for-purpose", capacity. This confidence level characteristic will age (decrease) with time, and thus form the basis for both reserve design calculations and battery replacement strategies. The traditional methods of derating battery capacity for age are typically based on cell deterioration rates (lead corrosion) under specific conditions. The confidence level characteristic described here can be statistically derived from the available capacity determinations of a sample population, and is thus independent of assumptions about individual cell failure modes. In reality, the battery population in the access network will exhibit a spread of service age, site dependent discharge frequency and duration, and perhaps even a variety of battery types from different manufacturers. A statistically significant sample of the battery capacity measurements in the battery population would provide confirmation of this capacity confidence statistic. Application specific discharges will occur normally due to ac mains outages, and this provides a convenient means to validate the battery population performance.

Improvement in power-related reliability is closely coupled to efficient maintenance and restoration efforts which depends on accurate knowledge of the power system status, including the standby VRLA batteries. TRL has a program of development of battery impedance technology to provide useful, real-time estimates of the likelihood that the standby batteries are actually "fit for purpose" [5]. Deployment of low cost automated, remote power system monitoring with basic available battery capacity estimation is seen as a necessary step in bringing the realm of tele-power into the metrics and metering of system parameters for basic GoS determination.

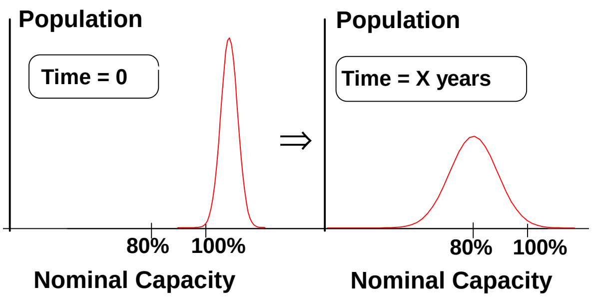

Figure 3. Battery population capacity change over time

Summary

The powering-related contribution to service unavailability on new and emerging distributed broad band networks in the customer loop is complex and there is a need to broaden the traditional view of the influence of tele-power provisioning on service delivery. Concepts of *customer perceived* service availability can be used to balance design options and reliability targets with powering costs and acceptable levels of grade-of-service due to power. At the residential customer level, it is unproductive to consider powering reliability in isolation or independent of the total service availability, and power reliability effort must be consistent with the total reliability requirements. In summary, this requires a top-down process, rather than the existing and traditional bottom-up style of power system reliability engineering.

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