Availability Modelling of POTS on a Hybrid/Fibre Coax Network - A Power Perspective

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Abstract

This paper outlines the contribution that powering makes to the *plain old telephone service* (POTS) availability on an integrated hybrid/fibre coax (IHFC) customer access network. POTS reliability is recognised as a highly important performance metric by Telstra. Thus, new technologies such as those of the IHFC architectures will need to exhibit an availability performance that maintains the public's confidence and perception of POTS as a lifeline service.

1. Introduction

The delivery of POTS on IHFC architectures will involve the formulation of new telephony powering strategies for Telcos. Thus, there is significant potential for the widespread deployment of powering equipment into a relatively hostile environment by comparison with exchange-based equipment. Furthermore, considerable investment in standby power sources is expected in order to counteract against less reliable AC mains supplies. Accordingly, the design of reliable powering systems is critical in both customer service and the cost-effective operation of the customer access network.

2. Reliability Model

2.1 IHFC Network Reliability Model

A reliability model of an IHFC Customer Access Network (CAN) has been developed as shown in Figure 1. The model represents the main elements effecting POTS availability on an IHFC network. The model contains the following components: exchange node, fibre cable, fibre hub, two power supplies, High Voltage (HV) AC and Low Voltage (LV) AC distribution connections, coax cable sections, a maximum of three line extender amplifiers per coax leg, taps, curb side unit, coax / twisted pair / siamese drop cables, set top unit and telephone.

This model is representative of a fibre hub that serves between 600-1200 homes passed. Reliability parameters for the network model have been derived from both Telstra databases and other industry sources.

2.2 Power Supply Reliability Model

A reliability model of the power supply has been developed, as shown in Figure 2. The model is a logical representation of the power supply element functionalities. A physical model of the power supply is shown in Figure 3. The power supply reliability model is made up of component blocks which a are characterised by reliability parameters, such as Mean Time Between Failures (MTBF) and Mean Time To Repair (MTTR). On failure of a component associated with a block, the power supply either fails or the supply integrity is maintained by the use of redundant components, eg. batteries. The inclusion of dummy (non-failing) blocks to serve as conditional switches permits the modelling of multiple system paths on the failure of particular blocks. This allows the mimicking of "real-life" failure mechanisms. The battery block is also characterised by an on-line operating time (capacity), discharge rate and a recharge rate.

Thus, under normal operating conditions, the supply path comprises the Start, HV AC, Circuit Breaker (CB), Metal Oxide Varistor (MOV), LV AC, Rectifier, Switch, Transformer, Capacitor and Fuse blocks. On failure of the high or low voltage AC distribution network, or the CB and MOV components, the supply path changes to comprise the battery, inverter, transformer, capacitor and the fuse. Failure of the rectifier results in the system path by-passing the rectifier via dummy blocks 1 and 3. However, in this case the batteries stop accumulating charge until the rectifiers are repaired . The switch is assumed to fail open circuit and the resulting supply path depends on the state of the rectifier. That is, if the rectifier is operational, the system path includes the LV AC, rectifier, dummy blocks 2 and 3, while maintaining charge to the batteries. However, failure of both the switch and the rectifier results in the system path including the LV AC, dummy block 1, the batteries *etc*.

The power system contribution to customer service unavailability has been modelled as shown in Figure 1. It is estimated that, in the worst case, a single customer will be supported by two power supplies with separate LV connections a common HV connection. In the subsequent discussion, this double power supply configuration is referred to as the power system.

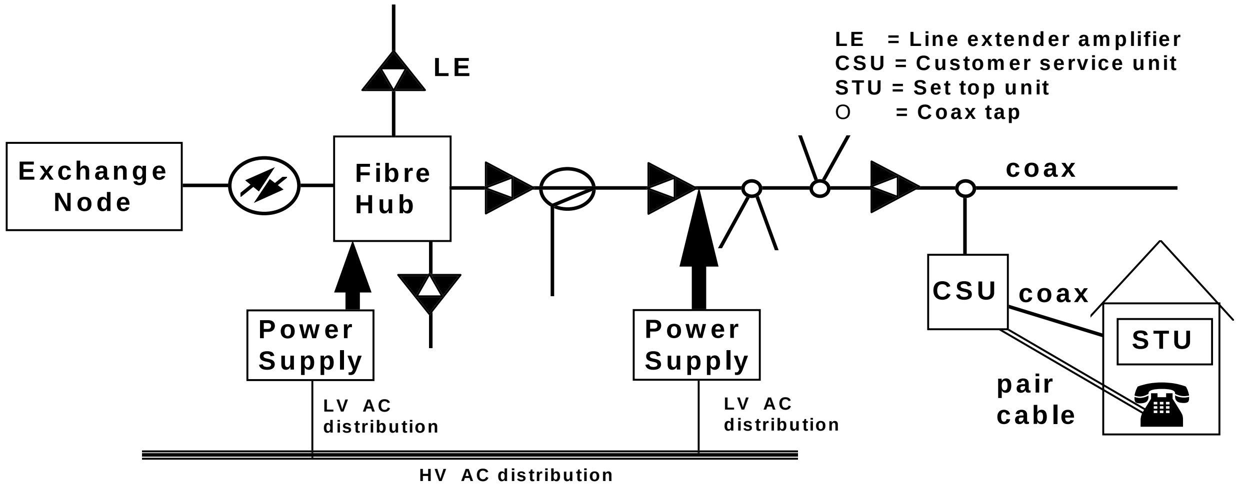

Figure 1. Integrated Hybrid Fibre Coax Network Reliability Model

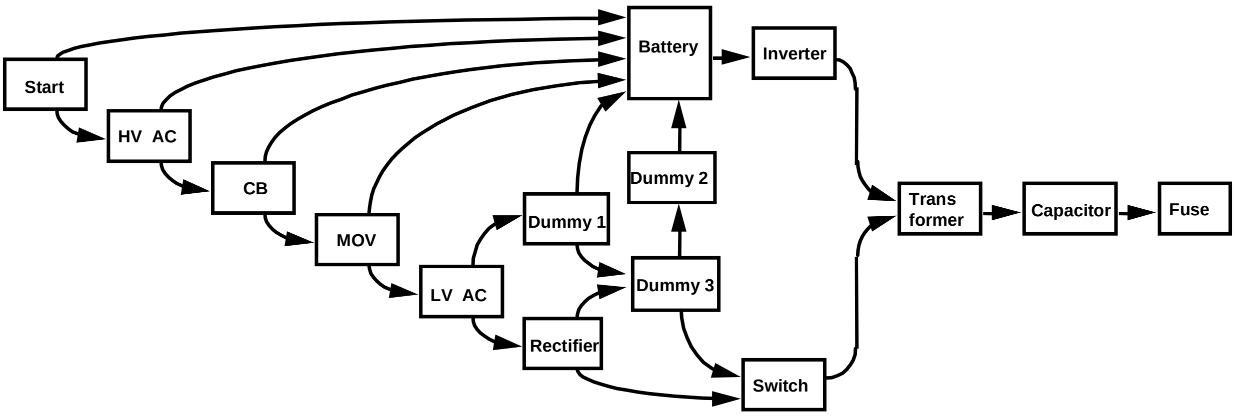

Figure 2. Power Supply Reliability Logical Model

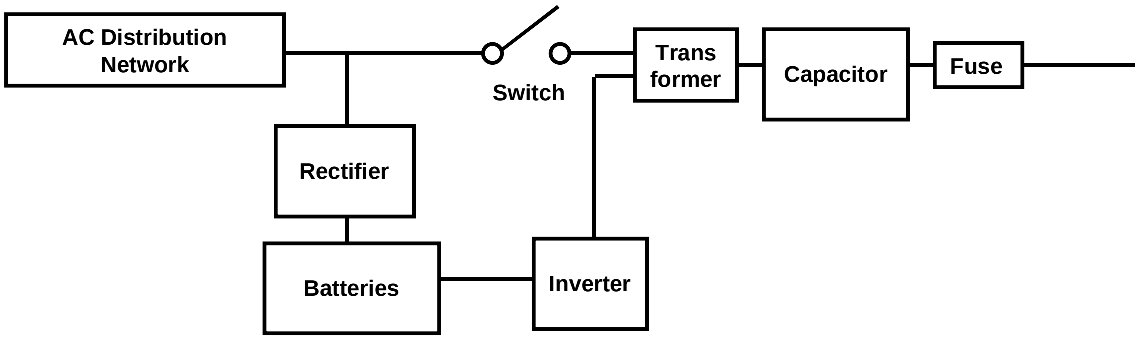

Figure 3. Power Supply Model

Aggregate reliability parameters, *ie*. power system availability and MTBF, were calculated for the power supply using an event simulation technique [1].

Component	MTBF (hours)	MTTR (hours)
HV AC mains	5,375	4.52
LV AC mains	29,354	4.89
Circuit Breaker	2,222,000	4
MOV	1,333,000	4
Rectifier	175,320	4
Battery	219,150	4
Switch	3,333,000	4
Inverter	175,320	4
Transformer	2,667,000	4
Capacitor	74,074,000	4
Fuse	66,667,000	4

Table 1. Power Supply Model Component Reliability Parameters

The reliability parameters of some of the components in the power supply (circuit-breaker, MOV, switch, transformer, capacitor and fuse) were calculated from data presented in [2]. Calculations were based on commercial quality components in a stationary, non-weather protected environment. The reliability parameters for the rectifier, inverter and battery are estimates derived from Telstra field return data of functionally equivalent components and are adjusted to reflect environmental conditions. Note that these parameters represent failures from randomly distributed stresses to the components rather than end-of-life wear-out failure mechanisms. In this sense, it is implicitly assumed in this analysis that equipment is replaced before its end of life. This assumption is relaxed in Section 5 where the Operations, Administration and Maintenance (OAM) implications of maintenance strategies are discussed.

The AC mains outage characteristics of a typical Australian metropolitan electricity supply utility for kerb located equipment were presented at INTELEC'94 [3]. In this work the power outage characteristics related to the high- and low-voltage elements of the power distribution network have been derived. The power supply model reliability parameter values are given in Table 1.

3. Unavailability of the Power Supply System

Figure 4 shows the simulated unavailability of a single power supply and a dual supply power system with respect to battery capacity. As expected, at low levels of battery reserve the power system exhibits poor availability performance as AC mains outages on average exceed the battery capacity. As more reserve capacity is introduced into the power supply, the power system unavailability decreases. However, the power supply exhibits diminishing availability returns to battery reserve capacity. Thus, a single power supply with reserve capacity of 8 hours indicates a power unavailability of approximately 20 minutes/customer/year.

In contrast, the insertion of an additional power supply with a common high voltage mains distribution network is predicted to increase the power system unavailability to approximately 70 minutes/customer/year.

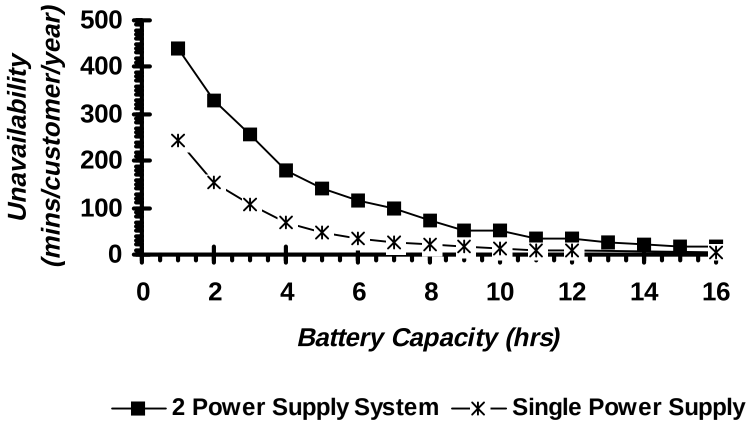

Figure 4. Power supply unavailability versus battery capacity for all High- and Low-Voltage AC mains outages.

Maintaining the same level of customer service is expected to be difficult in situations where the coax distribution network comprises more than one power supply in the powering system. Figure 4 implies that multiple power supply systems will require increased investment in battery capacity per individual supply unit in order to achieve the same levels of power availability as with a single power supply.

For example, Figure 4 indicates that a power unavailability of 100 minutes/customer/year can be achieved with approximately three hours of battery reserve. However, it is estimated that the dual power supply system will require a reserve capacity of approximately eight hours at each supply location in order to achieve the same level of power unavailability.

4. The Dependence of Power System Unavailability on Equipment Reliability and Repair Times

As discussed in the previous section, the capacity of the reserve batteries is a major contributor to the overall power system availability. However, there are also several other potential drivers of the power system availability performance. These are the intrinsic reliability of the power supply equipment and the time taken to respond to equipment failure and restore power outages.

Accordingly, the sensitivity of the power system to changes in the MTBFs of power supply components was investigated. It was found that both halving and doubling the MTBFs of the batteries and rectifiers did not greatly influence the power system unavailability. Thus, the reserve battery capacity has greater overall impact than the intrinsic equipment reliability.
This suggests that a many fold increase in equipment reliability would be required before any significant gains in unavailibility could be realised.

Figure 5 shows the effects of varying component mean repair times for the field-based power supply components from two to twelve hours. Again, the influence of reserve battery capacity dominates the power system unavailability. However, there is considerable variation of system unavailability with repair times.

Furthermore, as the battery capacity increases the relative differences in unavailability for different mean repair times appears to decrease. This suggests that, in terms of overall power system unavailability, repair times become less critical once an adequate battery reserve capacity has been established.

In summary, these simulation results indicate the potential areas of maximum availability leverage for power system designers. That is, the parameters which have the greatest scope for increasing power system availability and the quality of customer service. Thus, changes in battery capacity will have the greatest proportional changes in power system unavailability. Next, decreases in equipment repair times will produce moderate proportional system unavailablity gains. Finally, considerable increases in equipment reliability will be needed to achieve similar availability gains.

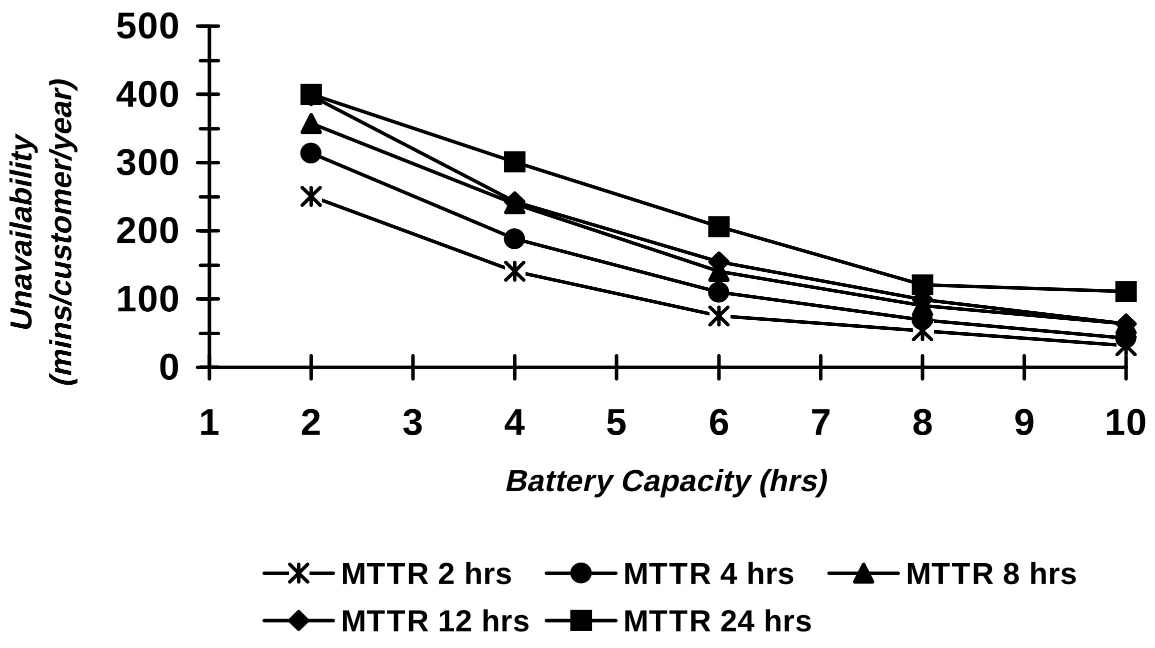

Figure 5. Customer Unavailability Vs Power Supply Element Repair Times

5. Reliability and Operations, Administration and Maintenance Issues

As the traditional telecommunication service providers face increasing competition and declining unit revenues there will be ever greater pressures on costs and an overarching need for cost containment strategies. The use of reliability techniques as tools for analysing the cost effectiveness of AOM issues is discussed in this section.

The following discussion illustrates the manner in which reliability methodology can be applied to network maintenance problems based on distributed power supply systems, such as those implemented in the HFC architectures. The analysis is based on nominal equipment lifetimes and nominal costs, thus this discussion should be viewed as descriptive rather than prescriptive.

It is assumed that battery life can extended by introducing a program of preventative maintenance in which the batteries are removed from service to undergo maintenance for one hour every six months. It is also assumed that the battery life is increased by two years as a result of these maintenance actions.

However, during the battery preventative maintenance period there is the risk of an AC mains failure or the failure of a supply component that results in the need for reserve capacity. Thus, as well as preventative battery maintenance prolonging battery life and reducing power system outages, it may also increase the number of power system outages by periodically removing the battery redundancy.

Figure 6 shows the incremental availability results from the preventative maintenance program against the original battery lifetime. Thus, if the original battery life is less than approximately 5.5 years, the six monthly preventative maintenance cycle decreases the power system availability. For example, given an original battery life of two years may be extended to four years with preventative maintenance, Figure 6 compares the power system availability comprising battery back-up with a four year lifetime and preventative maintenance with that for a system containing a battery with a two year lifetime and without any maintenance.

This indicates that additional reliability gained from extending the life of the battery does not outweigh the additional outages that occur while the batteries are under maintenance. Furthermore, availability benefits do not accrue to the power system until the original battery lifetime is approximately six years.

As discussed above a preventative maintenance strategy can provide some availability leverage depending on battery lifetime. However, the additional reliability generated by the preventative maintenance program incurs additional costs associated with additional scheduled site visits.

Figure 7 shows the incremental direct variable costs to the preventative maintenance strategy discussed earlier. These costs are based on nominal costs for replacement batteries, nominal hourly wage rates, and travelling and site-visit times.

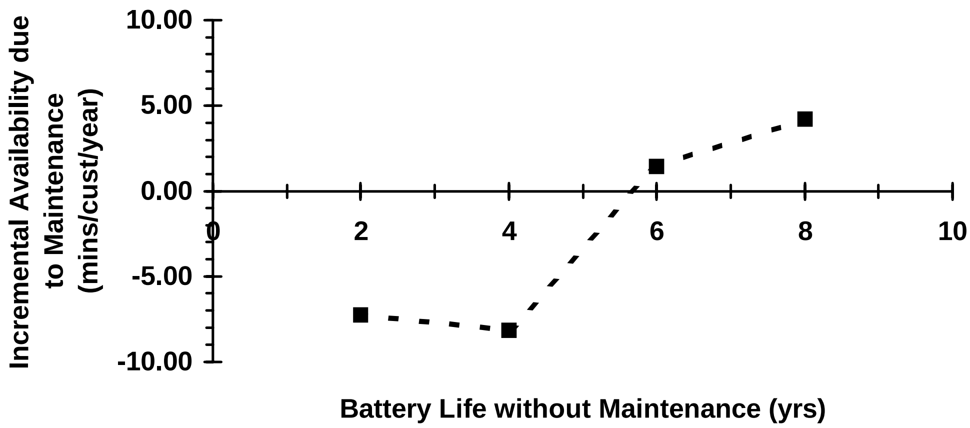

Figure 6. Incremental Power System Unavailability for a Nominal 2 Year Improvement in Battery Life

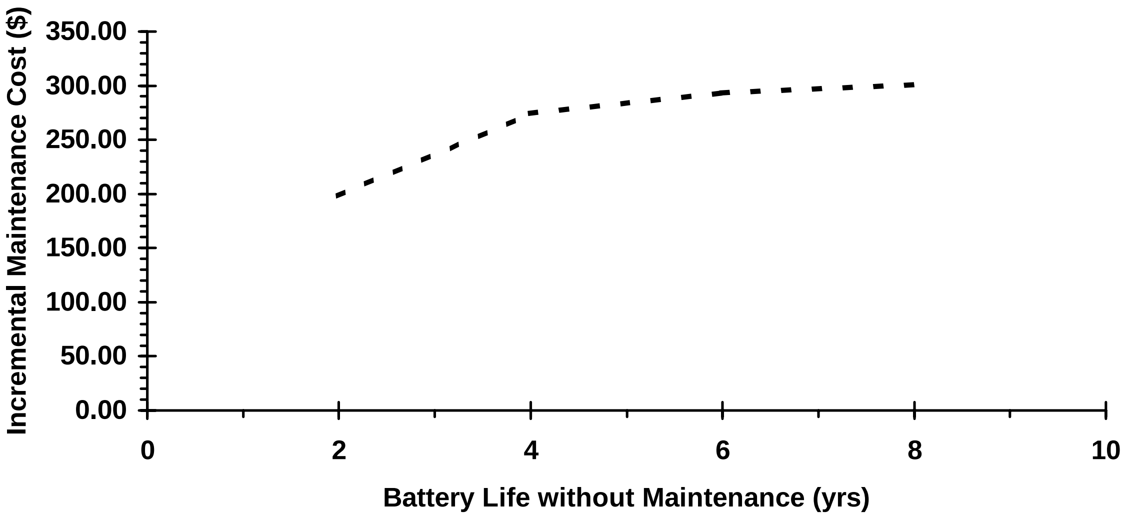

Figure 7. Incremental Maintenance Cost for a Nominal 2 Year Improvement in Battery Life

Thus, in order for a preventative maintenance regime to achieve cost parity with an un-maintained regime, the cost of the additional site visits for maintenance must exactly offset the cost of battery replacement. Figure 7 shows the difference in costs for the situation where preventative maintenance extends battery life by a nominal two years and where the battery is un-maintained. Thus, Figure 7 indicates that the variable cost difference between a power supply system with a four year lifetime under a six monthly preventative maintenance cycle is approximately $ 200 *pa*. greater than for a system with un-maintained battery with a two year life expectancy.

Furthermore, the cost of the preventative maintenance regime is always greater than that for the un-maintained case. This indicates that the direct labour costs are of considerable importance in planning preventative maintenance strategies.

Overall, while OAM strategies may provide some availability advantages, they will need to demonstrate superior cost effectiveness over existing methodologies. Accordingly, the above example suggests preventative maintenance may not be as economically feasible a strategy as the direct investment in higher quality batteries with enhanced lifetimes.

6. Conclusion

The HFC power system reliability has been investigated using simulation techniques. The collation of power system component Mean-Time-Between-Failure (MTBF) data and the sensitivity of their mean-time-repair-times (MTTR) on system unavailability have been discussed. It appears that ensuring adequate back-up capacity is vital in establishing a highly reliable service. Power system components repair times will have an important but less vital influence over power system availability. Equipment reliability has the least impact.

Reliability and availability techniques also provide power system designer with powerful tools for the analysis of OAM issues and generate the potential to optimize system parameters such that maximum cost effectiveness for both customer service and operations may be achieved.

Acknowledgments

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