Maintenance Optimisation at Western Power

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Abstract

Western Power has commissioned this report through their Maintenance Optimisation Department. The thesis brief was to review the maintenance planning, maintenance data collection, maintenance data analysis and maintenance procedures for a sub-section of Western Power's distribution system. The intention of this presentation report is to review the reliability merits of the current policy of replacing overhead distribution with underground distribution. It will identify reliability challenges within the underground network and make suggestions to enable Western Power to improve the current underground maintenance systems.

1.0 Introduction

The Western Power Corporation (WPC) operates and maintains an extensive and diverse power generation, transmission and distribution network. The maintenance of the distribution network plays a crucial role in the uninterrupted operation of the electrical distribution service. WPC is currently fast tracking the replacement of the ageing overhead distribution network (OH) with new OH assets and establishing an underground (UG) distribution network. WPC aims to increase the reliability of the South West Interconnected Service (SWIS) network. The OH network describes the distribution method of suspending conductive cables overhead on poles. The UG network involves burying the conductive cables below ground.

Despite higher initial capital costs incurred by placing the distribution network underground, WPC believes that these higher intital costs are offset by the many advantages and cost savings that result from an UG network [1]. The author of this report has not been able to locate any detailed study or life cycle cost comparison of these systems in the WPC context. This report seeks to:

1. compare OH and UG reliability data to establish the reliability advantages and disadvantages of an UG distribution network.
2. outline improvements to current maintenance policies for the UG network which may result in improved reliability and decreased costs to WPC in the future

As shown in the main thesis, the reliability of the WPC SWIS network has decreased in recent times whilst the cost of maintenance due to unplanned failures has increased. The requirement to obtain the greatest reliability improvement from a limited maintenance budget is increasingly important. The main body of this thesis will identify the reasons behind the decreasing reliability of the network in addition to reviewing and analyzing current maintenance data. It also explores an outline of changes to maintenance systems that may enable more appropriate and targeted maintenance.

2.0 Background

The yearly costs of maintaining the WPC distribution and transmission networks are illustrated in Figure 1. This data was obtained by reviewing multiple reports from WPC and collating the maintenance costing data into a unified format. As shown, the costs of both planned and corrective maintenance have increased dramatically since 1995 and the ratio planned:unplanned expenditure has increased from 46% to 171%. This means that despite the increase in planned maintenance expenditure over this period, the cost of unplanned failures has increased at an even higher rate over the same period. This issue is addressed further in the main body of the thesis.

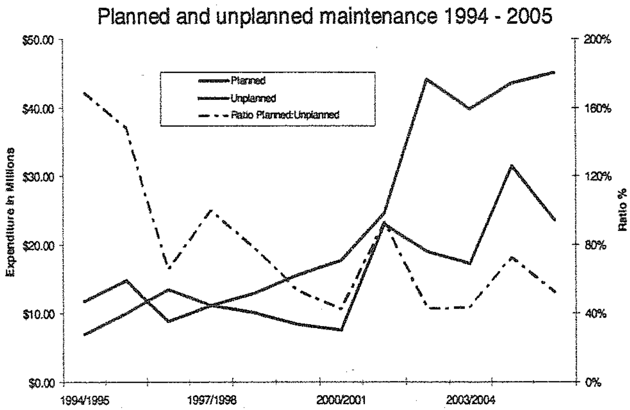

Figure 1 – Maintenance Costs

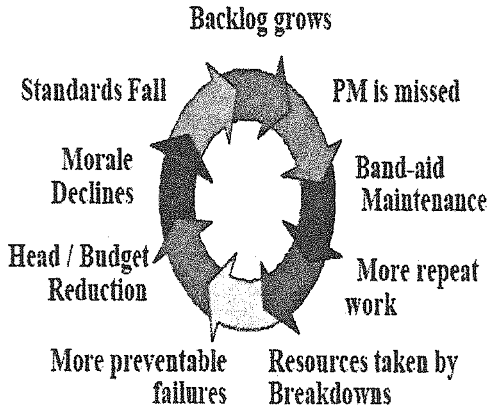

Figure 2 – Maintenance Cycle

The implication of this data is that WPC is experiencing a deteriorating cycle of maintenance [2] as illustrated by Figure 2. Scarce maintenance resources are stretched and unplanned failures consume an increasing amount of maintenance resources. As a result, preventative maintenance suffers which results in more unplanned failures and the cycle continues. The cycle is further compounded by rushed or temporary repairs that can exacerbate the maintenance situation. This maintenance cycle continues to deteriorate and organisations can become entirely reactive in their maintenance instead of proactive, which increases costs and decreases reliability. As part of a utility wide effort to break from this cycle, WPC is looking to its expanding UG network for increased reliability and maintenance savings. WPC has a target of 50% of metropolitan power lines being relocated underground by the end of the decade [1]. This report seeks to investigate the UG risk profile and outline improvements in UG maintenance that may affect the long-term reliability of the UG network.

3.0 The Underground Distribution Risk Profile

Anecdotal evidence suggests that there are several quantifiable advantages in an UG network as well as potential negative consequences. This report will explore both these factors in order to establish an model for an improved maintenance regime for the UG network.

3.1 The Likelihood of Failure in an Underground Network

A review of WP's data on the failure causes across the distribution network reveal that a large majority of failure modes relate specifically to the OH network. This data was collated from WPC internal failure reporting system known as TCMS and manually reviewed for obvious errors and incorrect entries. As illustrated in Figure 3, over 28% of failure causes only affect the OH network.. These specific failure modes were 'wind-borne materials', 'pole-top fires', 'trees in mains', 'pollution', 'pole down', 'fallen tree' and 'clashing conductors'. Other failure modes such as 'lightening' may affect UG in some small way but would usually have an increased of affecting the OH network. An UG distribution network is likely to be more reliable than its equivalent in the OH distribution network simply because there is a greater chance of external failure causes impacting on the OH assets.

By reviewing the respective availablility and utilisation measures for both the UG and OH network across a range of WPC feeders it was also possible to compare reliability trends between OH and UG distribution methods. The average availability[1] of the UG network across five diverse feeders over a three year period was calculated to be 99.09% whilst the same measure for the overhead network was calculated to be 97.99%.

[1] Defined as *Availability % = (Calendar Hrs – Maintenance D/Time)/Calendar Hrs * 100*

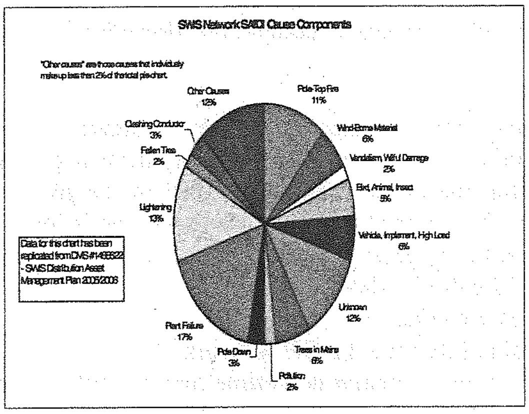

Figure 3 - Causes of Network Outages

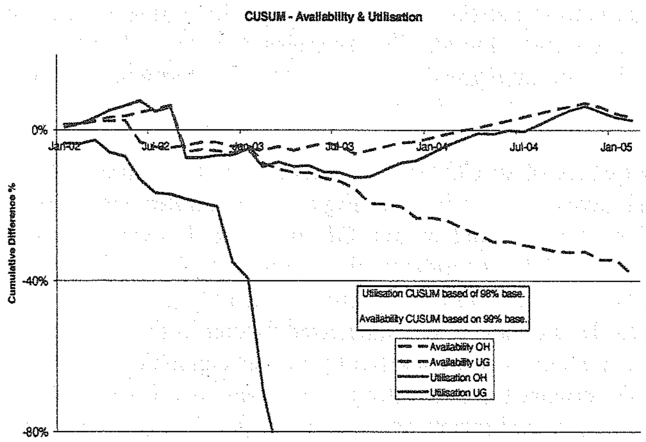

Figure 4 - CUSUM Plot

The utilization[2] measure for the same feeders and time period showed an average respective utilisation of 98.08% versus 93.84%. This difference indicates that the OH network is affected to a much greater extent by non-mainteance related failure events, and indicates that the WPC UG is currently more reliable than the WPC OH distribution network.

Figure 4 trends the availability and utilisation for the OH and UG networks across five feeders over several years. This figure illustrates that the OH network has shown a trend of decreasing availability and utilisation over several years when compared to the same base comparison as the UG network. A further review of the data, as discussed in the main body of the thesis, shows that the gap between availability and utilisation in the UG network is consistently lower than the same gap in the OH network. This indicates that a high proportion of UG downtime is caused by equipment faults and other maintenance related failure modes. The higher gap in the OH network shows that a substantial proporation of downtime is due to external factors which, as discussed above, often do not impact on the UG network.

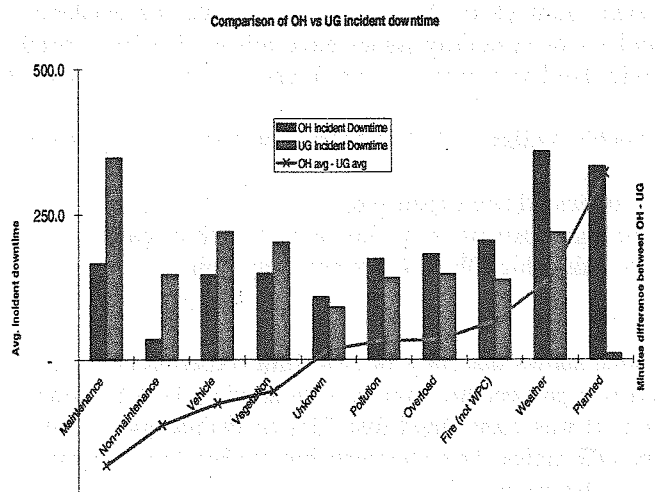

Figure 5 - Relative downtime for failure events

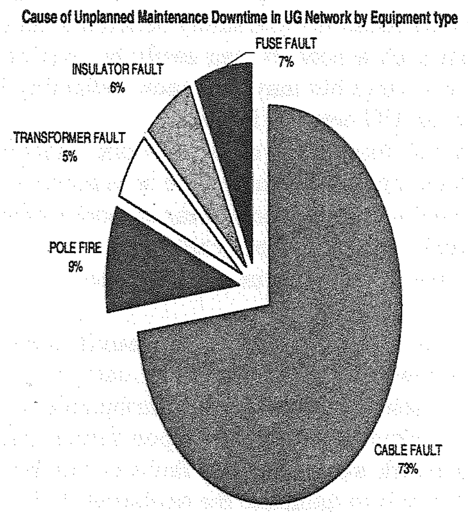

Figure 6 – Causes of UG downtime

Figure 5 depicts the differences (in average downtime) for both networks for different failure modes. The data for this plot was collated by an interrogation of WPC TCMS system for specific feeders. Failure modes were checked

2 Defined as *Utilization % = Operating Hrs/Calendar Hrs * 100*

for each downtime incident and the average downtime for UG and OH failures as well as the difference between these averages was plotted. The averages for the "Maintenance downtime" failure mode (far left on the plot) indicates that an unplanned failure in the UG network usually results in nearly double the downtime of the equivalent failure in the OH network.

The consequence of an UG failure in terms of outage time and customer impact is much higher than a similar failure in the OH network. In addition, Figure 5 illustrates that certain failure types (such as weather) have a greater average downtime impact on the OH network. It must be noted that the downtimes represented in the plot are averages only and do not indicate the frequency of each failure type. The planned maintenance downtime is low on the UG network as the WPC procedure is to run the UG network to failure with no planned repairs or maintenance. The data, as detailed above and discussed further in the main body of the thesis, shows that

1. UG network has a consistently higher availability than the OH network,
2. UG network has a smaller gap between its utilisation and availability than the OH network,
3. An unplanned maintenance event on the UG network incurs an much greater downtime than a similar event on the OH network.
4. Both OH and UG availability is trending downwards which indicates that both networks are becoming less reliable as time progresses. UG is trending downwards at a decreased rate to OH.

3.2 Safety Benefits of an Underground Network

When the real cost of underground power is calculated by incorporating additional factors such as the societal cost incurred from loss of life, the real cost of undergrounding equates very favourably with the real cost of traditional overhead power lines. The real savings in terms of lives lost has been calculated in several journals [3] which measured fatality statistics and revealed that an OH network causes 57.9 times as many fatalities than an UG network. Another similar survey found 22.9 times as many fatalities for people were caused by OH networks compared to UG networks. While these survey results were calculated from different definitions and in different circumstances, they serve to illustrate that an UG has marked safety benefits when compared with OH networks. There is no cause to think that the WPC network would exhibit any real safety differences from those surveyed. Although difficult to quantify in dollar terms, the costs to the public for loss of life due to an OH distribution network is many orders of magnitude greater than the loss incurred from an UG distribution network.

4.0 Possible future problems with the Underground network

Although the reliability and safety benefits of an underground network can be illustrated as above, the problems that arise from such a network can easily be overlooked until major reliability issues have arisen. This may result in short term savings but may also cause reliability issues with the UG network in the future. The main problems that arise from an UG network include

1. visual monitoring of the network assets is not possible, unlike an OH network, and hence maintenance and locating faults is more time consuming and expensive,
2. condition based monitoring is more technically complicated and expensive,
3. replacement of worn cables is also time consuming and expensive as the entire length of cable has to be physically dug up unless the cables are laid in a conduit, which WPC is not currently doing.

4.1 Failure profile of Underground Networks

Figure 6 shows an analysis of failure data from WPC which shows that 39% of downtime experienced by the UG network in selected feeders were attributable to maintenance preventable events, with another 19% of downtime having an unknown root cause. Upon further examination, it was established that 73% of maintenance failures in the UG network were caused by faults or failures with the UG cables. This indicates that the key to maintaining the UG reliability is to minimise the unplanned failures in the underground cables.

4.2 Failure parameters of Underground Cables

While data is not available from WPC to construct a failure profile of UG cables, research conducted [4] into the failure rates of UG cables indicates a strong wear-out failure profile with a mean life of approximately 30 years. Other published research [5] gives details of reliability data for a range of distribution components including UG cables. Glasser [6], in a seminal journal, quantifies a method with which to base timed replacements of assets with wear out failure modes. Failure rates must increase over time if benefits are to be obtained from timed replacements. UG cables have been found to have an increasing failure rate [7] (a β value greater than 1 in a Weibull function) and so may benefit from time based or aged based replacement.

5.0 Age Based Replacement Model

The available data detailing reliability of insulated UG cables carrying less than 600V is presented[8] as an exponential Weibull function where $R(t) = e^{-\lambda t}$. Further manipulation reveals an expected time to failure (μ) of 37.5 years for that particular cable type. We can use this result, along with the knowledge that an exponential Weibull distribution (β=1) has a standard deviation (σ) equal to 1, to utilise a Glasser Chart to establish the benefits of aged-based replacement for UG cables. While the actual cable Weibull function would be expected to have a β>>1, by using the available base parameters we can establish the upper boundary of timed replacement to explore the benefits that could be obtained by aged based replacement. A "Glasser chart" can establish the likely benefits that would be obtained by WPC from an timed replacement policy instead of the current run to failure (RTF) procedure. We can establish the benefits obtained for a range of cost ratios ($k = C_f/C_p$) where C_f is the cost of failed asset replacement and C_p is the cost of planned asset replacement .

The total cost of a timed replacement program can be calculated by:

$$C(t_p) = \frac{C_p.R(t_p) + C_f.[1 - R(t_p)]}{t_p.R(t_p) + M(t_p).[1 - R(t_p)]} \quad (1)$$

By iterating t_p through a range of time periods and assuming that $C_f = k * C_p$ we can test a range of cost ratios to establish optimum replacement times that would maximise cost savings for each value of k. Figure 7 illustrates the cost profiles for a range of 'k' values from 2 to 10 using a calculated WPC C_p for UG cable of $196p/m and $\nu = \frac{\mu}{\sigma} = \frac{37.5}{1}$.

Figure 7 indicates that the higher the value of 'k' (the greater the cost of failure to cost of planned replacement) the less the optimal duration of timed replacement (t_p).

Figure 8 illustrates a 'Glasser Chart' with 'υ' on the x-axis and 'k' on the y-axis. Within a k value range of 1.5 to 5 the Glasser chart indicates that a savings multiplier ρ of 0.20 to 0.75 could be achieved. To establish the true cost of failure (C_f) it is necessary to include non-financial factors such as public image, safety and enviromental damage caused by the failure. Due to the location of UG cables, the additional enviromental and safety costs associated with cable failure have been calculated as having no impact (or zero cost). However, the public image cost needs to be included by WPC when calculating the cost of each failure and hence the savings obtained from a timed replcement mainteance policy. The true cost of failure calculation is investigated further in the main body of the thesis.

If we test a σ equal to 2, υ reduces to approximately 18 (as indicated in Figure 8) but the estimated savings 'ρ' are not significantly affected. However, as $t_p = \mu + Z\sigma$, the new estimated optimal replacement time with σ = 2 is 15 years (given a k value equal to 5). Given this variation in replacement times, if WPC was to utilise this model it is imperitive that the correct μ and σ values are obtained for WPC cables. Nonetheless, savings would be expected by replacing the current RTF policy for a timed replacement policy for UG cables in addition to reliability improvements to the UG network.

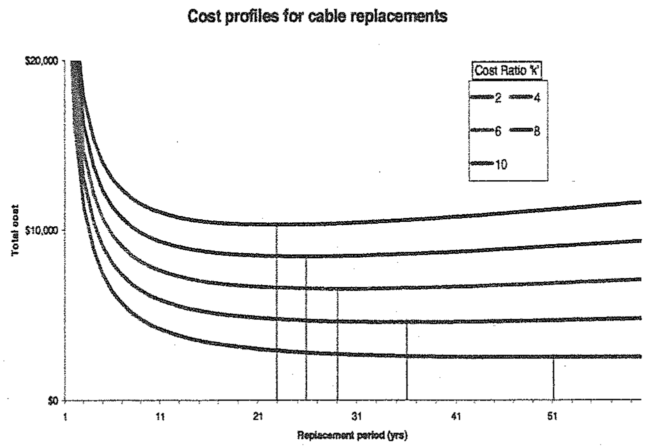

Figure 7 – Cost profiles for varying 'k'

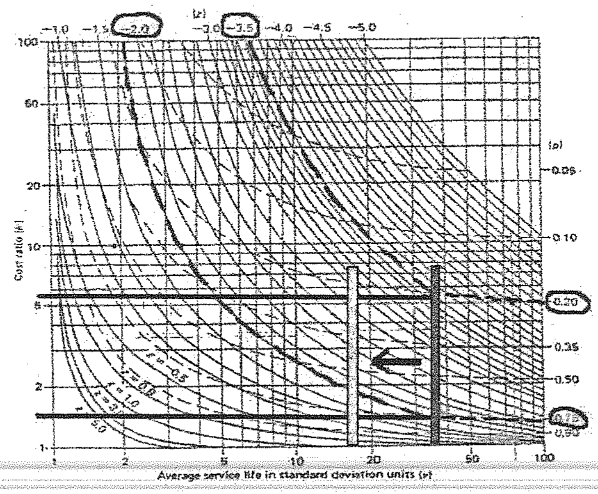

Figure 8 – Glasser Chart

As large areas of WPC UG cable were laid at the same time, it becomes increasingly likely that areas of the network will fail due to wear after the same approximate time period. Without a cable replacement policy, WPC could again experience the deteriorating maintenance cycle it currently finds itself, with increasing unplanned maintenance leading to pressure being placed on planned maintenance activities along with increasing maintenance costs and decreasing reliability. The increased public expectations of utility performance would also increase the focus on the maintenance systems within WP and increase the cost of failure, making aged-based replacement even more beneficial.

6.0 Conclusion

In this report it was illustrated that:

- There are reliability and safety benefits in replacing OH networks with UG networks.
- Underground failures have a higher average downtime than overhead failures.
- The major cause of underground failures at WP is cable failure.
- Underground cables exhibit wear-out failure characteristics and hence economic and reliability benefits can be obtained be implementing an aged-based replacement policy for UG cables.
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It is recommended that WPC explore and investigate the true costs of failure in the UG distribution network to establish to optimal replacement period for UG cables and seek to implement an aged-based replacement policy for the UG network.

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