2018-22
POWERLINK QUEENSLAND REVISED REVENUE PROPOSAL

APPENDIX 4.04 – PUBLIC

Transformer Life Cycle Cost Model

Delivering better value

Transformer Life Cycle Cost Model

Introduction

Powerlink's transformer life cycle cost model assists in determining a spend limit for the repair of component failure and the optimum timing to replace a transformer. The model is based on a technical paper presented at the Asset Management Council's ICOMS 2004 Conference[1]. It works on the basis that there is a limit to how much an asset manager can spend on an existing asset before it becomes cheaper to replace the existing asset with a new one.

$$SpendLimit = Remaining\ life\ of\ old\ asset * (\ Annualised\ cost\ of\ new\ asset - Annualised\ cost\ of\ old)$$

Annualised cost

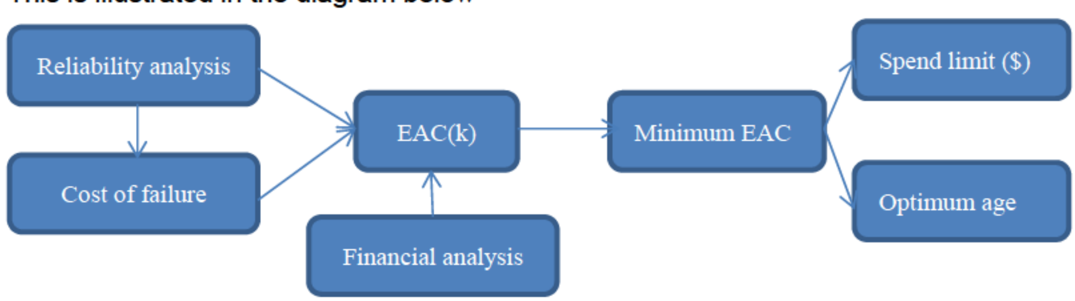
The annualised cost, or Effective Annual Cost (EAC), is the key input into making an efficient repair / replace decision. EAC(k) is the effective cost per annum of keeping a transformer (whether new or old) in service for 'k' years. The goal of the life cycle costing model is to then find the minimum EAC. The minimum EAC then indicates the optimum age to keep the transformer in service.

The model then finds the spend limit by searching for the value of a repair cost for the old transformer that gives the same minimum EAC as for a new transformer. If it is necessary to spend more on repairs than this spend limit, in order for the old transformer to reach the age of the minimum EAC, then prima facie it is better to replace that transformer now.

The calculation of the EAC for both old and new transformers takes into account the following three elements:

- Reliability analysis – the probability of the unit not failing up to year 'k' and the conditional probability of failing in year 'k' given that it has not yet failed;
- Cost of failure – the cost incurred when the transformer under consideration fails plus the probabilistic cost incurred should a second unit failure occur before the first unit failure is rectified; and
- Financial analysis – the costs to recover from a transformer failure, either repairing the failed unit or acquiring a new unit, together with ongoing maintenance and refurbishment costs.

This is illustrated in the diagram below



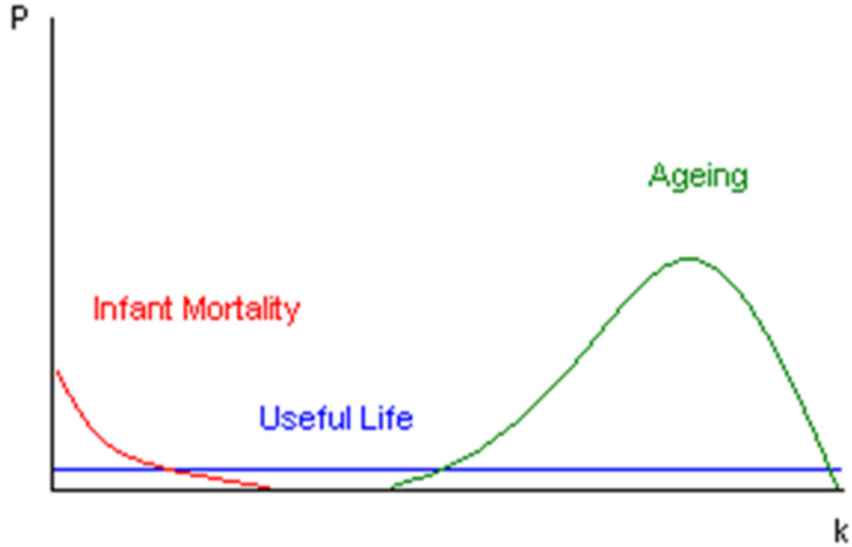
[1] Hastings & Sharp, Spend-Limits and Asset Management, ICOMS 2004

Reliability analysis

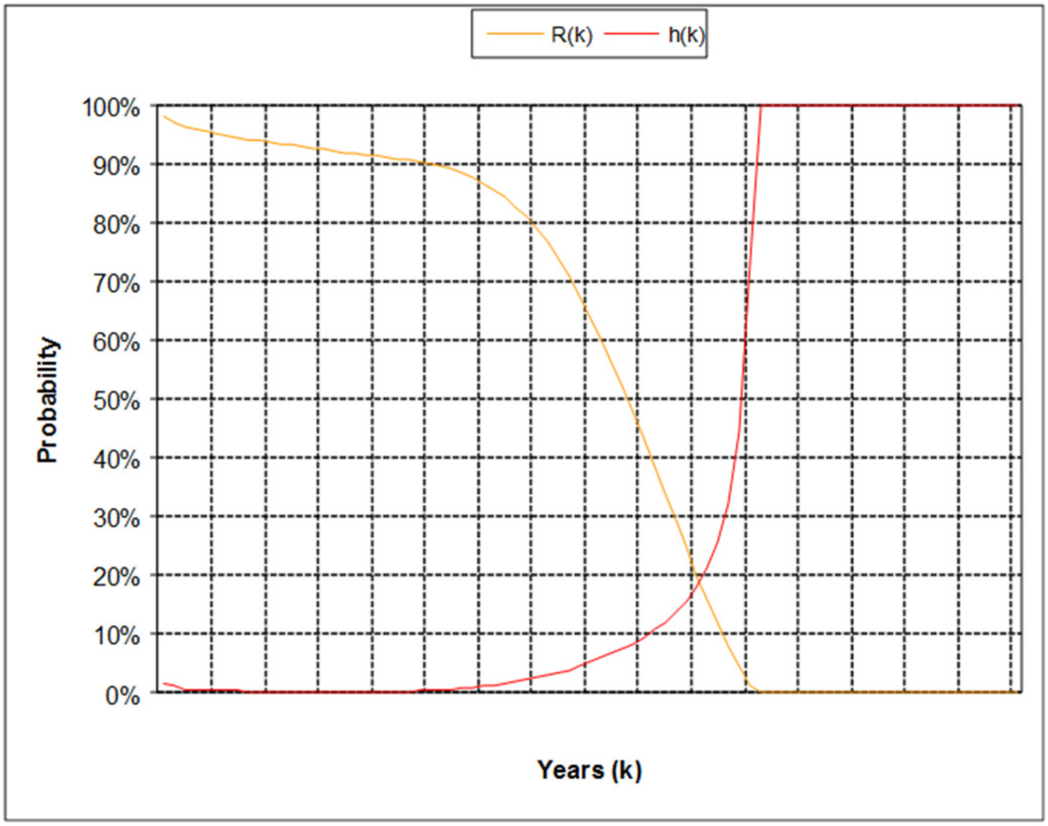
The reliability analysis is based on a transformer life distribution made up of three independent component distributions:

- Infant mortality – caused by problems in the manufacturing process and based on a Weibull function;
- Useful life – a constant risk over the lifetime due to random events;
- Ageing – caused by degradation of insulation and components leading to higher risk of failure and based on a Weibull function.

The overall probability density function (pdf) is illustrated below.



As a transformer ages its reliability (the probability it will survive to that age without failure) falls. As this happens, the hazard rate (the conditional probability that it will fail in the next year) increases. This is illustrated in the diagram below where R(k) is the reliability as a function of age and h(k) is the hazard rate as a function of age.



The above curves are based on the paper samples and investigations associated with Powerlink owned transformers and are applicable to Powerlink's transformers only. These curves are dependent on the way in which the transformers ratings and loading are calculated and managed which will vary from one asset owner to another. They are also dependent on the original transformer specifications and factory tests.

Cost of failure

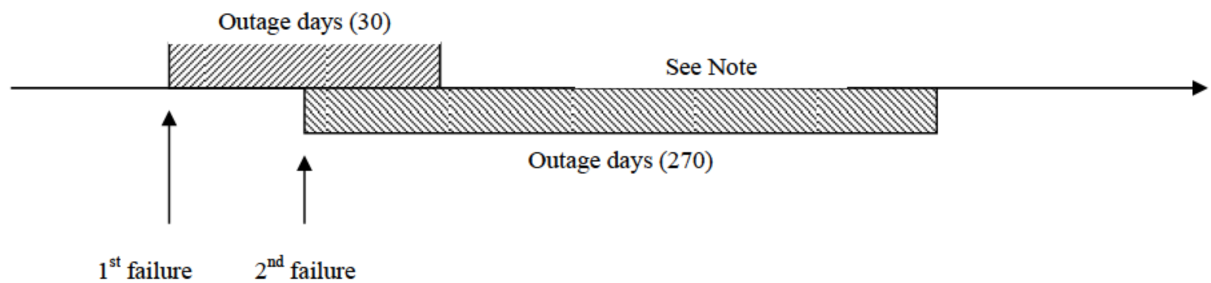
Powerlink's standard assumption is that the first failure of a transformer at a site does not result in any loss of supply, with other transformers at the site able to supply the full load. The only cost is the cost to restore the transformer to service. This in turn depends on whether Powerlink holds a spare of that type of transformer as it will be either the cost to transport and commission the spare transformer, or the cost to repair the failed transformer.

The cost associated with the failure of a second transformer then depends on:

- The cost to repair the transformer, as a spare won't be available to cover a second failure;
- The ages of the other transformers at the site, which determine the hazard rate;
- The duration of the outage due to the first failure, which will depend on whether a spare transformer is available or not;
- The amount of load not supplied due to the second failure; and
- The value of the lost load.

The duration of the first outage, which will depend on whether a spare transformer is available or not, is important because it determines the duration in which a second failure at that site will lead to loss of supply. This is further elaborated below.

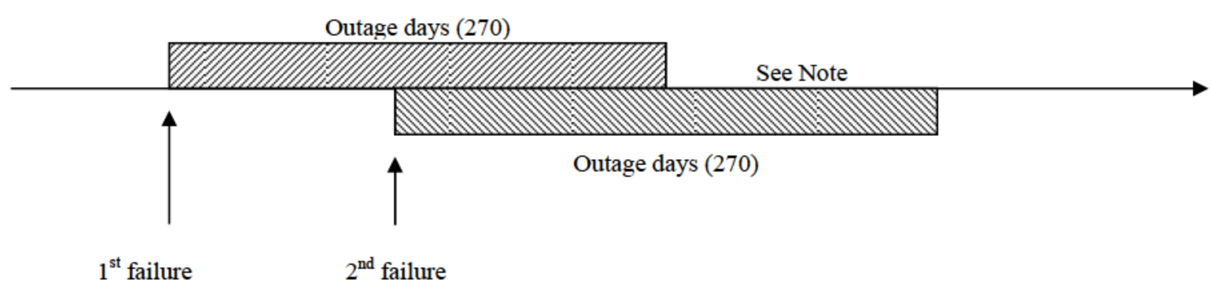
When a spare is available:



If a second failure is to occur, it may fall anywhere in the outage from the first failure. The outage duration is assumed to be 30 days from the initial failure of the transformer and is the time to remove the failed unit, transport the spare transformer to the site, and install and commission the spare transformer. The mean occurrence will fall half way through the outage.

Hence, average number of days that supply is interrupted (upon 2nd failure) = Outage days (30) / 2

When a spare is not available:



If a second failure is to occur, it may fall anywhere in the outage from the first failure. The outage duration is assumed to be 270 days (nine months) from the initial failure of the transformer and is the time to remove the failed unit and either procure a replacement transformer or repair the original failed unit. The mean occurrence will fall half way through the outage.

Hence, average number of days that supply is interrupted (upon 2nd failure) = Outage days (270) / 2

Note: This region is at risk of another failure but is not considered as it would represent the 3rd worst contingency event in a row.

Financial analysis

This element is the present value of the costs associated with keeping a transformer in service into the future. It is made up of four separate cash flow items:

- Replacement transformer – this could be the acquisition cost for a new transformer, or it could be the cost to refurbish an existing transformer to make it suitable as a replacement unit;
- Routine maintenance – costs that occur at regular intervals based on current maintenance policies;
- Refurbishment – specific costs that occur in specific years of the transformers life, such as re-gasketing, based on current maintenance policies; and
- Corrective maintenance – an increasing cost as the transformer ages, using a formula of the form 'a * (k^b)'.

Calculations

The following calculations are used to obtain the EAC. They are difficult to conceptualise and more importantly, it is not necessary to conceptualise them in order to understand the EAC. They can be considered as intermediate formulas and are included only as proof of concept.

- *Reliability R(k)* – This is sourced from the Reliability Analysis.
- *Net Annual Cash Flow for Survivors* – This is equal to (Net Annual Cash Flow * R(k -1)) where R(k-1) represents the proportion of surviving transformers at the start of each year. This is a statistical measure of the cash flow of a transformer given that a proportion of all transformers fail.
- *Risk of Failure (RF)* – This is equal to [Cost of Failure(k) * (R(k-1) – R(k))]. This is a statistical measure of the cost incurred given that a proportion of all transformers fail.

Note that (R(k-1) – R(k)) = f(k), the risk of a transformer failing in year k.

- *PV(Survivor Cash Flow + RF)* – This is equal to the Present Value of (Net Annual Cash Flow for Survivors + RF).
- *Cumulative PV(Survivor Cash Flow + RF)* – This is the cumulative total of PV(Survivor Cash Flow + RF).
- *PV(R(k-1))* – This is equal to the Present Value of R(k-1).
- *Cumulative PV(R(k-1))* – This is the cumulative total of PV(R(k-1)).

The important calculations in this section are:

- *Effective Annual Cost (EAC)* – This is equal to [Cumulative PV(Survivor Cash Flow + RF) ÷ Cumulative PV(R(k-1)]. This represents the effective cost per annum of keeping a transformer for k years. **The theory behind this is explained in detail in Attachment 1.**
- *Minimum EAC* – This identifies the most economic age for keeping a transformer.
- *Optimum Age* – This is the length of time a transformer should be kept to achieve the Minimum EAC.

Attachment 1 – Derivation of EAC

The mathematical form of the model is set out below.

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

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[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

$$[redacted] = \sum_{i=[redacted]}^{k} \frac{[redacted]}{([redacted] + r)^{i}}$$

[redacted]

[redacted]

$$[redacted] = \frac{[redacted]}{[redacted]}$$

[redacted]