



Study Committee B3

SC B3 Substations

Paper B3_205_2018



Modelling Substation Control and Protection Asset Condition for Optimal Reinvestment Decision Based on Risk, Cost and Performance

T. VU, M. PELEVIN, D. GIBBS, J. HORAN, C. ZHANG

POWERLINK QUEENSLAND

Motivation

- Challenges: Meeting customer and consumer expectations on affordable energy cost while maintaining system reliability and availability.
- Aim of this Research: Optimise asset reinvestment decision and replacement timing based on risk, cost and performance (availability and reliability) of protection and control systems (secondary systems).
- Enable the utility to quantify the trade-off in investment against protection and control reliability and availability.

Method/Approach

- Developed an Asset Risk and Value Management Framework.
- Developed a High Level Transmission Network Assets Decision Framework.
- Analysed protection and control system assets' performance (functional failures, reliability and availability) based on historical data.
- Modelled protection and control system assets' Failure Rate, Probability of Failure, Network Exposure Factor, Network Consequences and Risk Costs.
- Modelled Equipment Health Indices, Effective Age and Optimal Replacement Timeframe.

Objects of Investigation

- Optimise Secondary System Assets' replacement timeframe based on risks, cost and performance.
- Review and apply Corporate Risk Matrix to the Risk Model.
- Understand the risk costs associated with transmission network element outages.
- Study historical data (15 Years) - maintenance and fault data.
- Investigate the impact of environmental conditions on Operational Assets e.g. heat and dust.

Experimental Setup & Test Results

- Secondary systems reliability and availability do not correlate with the average physical age and their performance is not linear with the physical age of equipment.

- Secondary Systems' Availability Versus Asset Age:

> 99.6 %: Asset's age = 1 – 10 years

98.5 % - 99.6 %: Asset's age = 10 - 15 years

95.5 % - 98.5 %: Asset's age = 15-20 years

91.3 % - 95.5 %: Asset's age = 20-25 years

Powerlink's Min. Target: 95.5 % - 20 Years Life

- Model Projection: For an increase in the Mean Replacement Age by six percent (6 %) of the total asset population from 20 to 25 years, the annual secondary system maintenance cost increases by 19.4 % and system's availability reduces from 95.5 % to 91.3 %.

Discussion

- Transmission network risk, availability and reliability are directly linked to the increase of secondary systems functional downtime, which is directly related to equipment and systems' effective ages (i.e. after taking into account environmental conditions e.g. heat, dust and humidity).
- Recommended Replacement Timeframe is optimised based on systems' reliability, availability, spares and obsolescence issues (both hardware and software).

Conclusion

- Delaying the replacement of Powerlink's Secondary System Assets beyond the Optimal Replacement Timeframe (Around 20 Yrs) does not always result in higher mal-tripping of network elements but definitely lowers secondary systems availability.
- The significant decrease of system functional availability coupled with forced network element outages for extended periods of time increases the risk that such failures will occur coincidentally with other network events, whether planned or unplanned, and result in reduced reliability outcomes for consumers. The conclusion is based on Powerlink data and is a direct reflection of Powerlink's environment, including the types of relays purchased, the conditions in which they are installed, the maintenance regime used, and the quantity of spares held.



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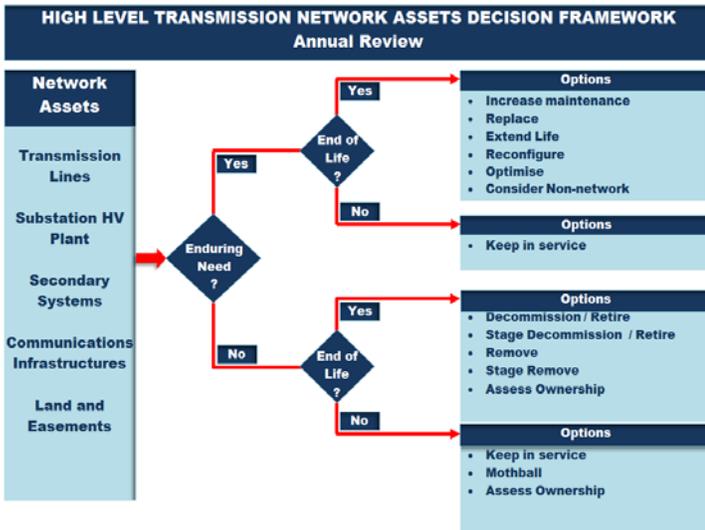


Figure 1

High Level Transmission Network Assets Decision Framework

EXAMPLE - EQUIPMENT FAILURE RATE					
Functional Location	Descriptio	Manufactur	Model	Age (λ
H002-SSS-407--BAYCONT	RTU	FOXBORO	C50	5.47	5.79%
H002-SSS-407--XPROT	DIG RELAY	GE	C60 (VER 2.93)	5.47	4.11%
H002-SSS-407--YPROT	DIG RELAY	SCHWEITZER	SEL-351-1 (1A)	5.47	1.30%
H002-SSS-4811-BAYCONT	RTU	FOXBORO	C50	5.98	5.79%
H002-SSS-4811-POWAVE	POW RELAY	ABB	WITCHSYNC E21	5.98	1.75%
H002-SSS-4811-XPROT	DIG RELAY	GE	C60 (VER 2.93)	5.98	4.11%
H002-SSS-4811-XPROT	DIG RELAY	ABB	SPAJ160C	5.98	0.38%
H002-SSS-4811-XPROT	DIG RELAY	ABB	SPAJ140C	5.98	0.51%

$$Failure_Rate = \lambda = \frac{No.Failures}{Total_Operating_Time} = \frac{r}{\sum_{i=1}^n t_i}$$

Over 14,000 Pieces of Equipment

Table 1
Samples of Equipment Failure Rates

Analyse Secondary Systems Performance – Equipment Failure Rate and Systems’ Availability Based On Historical Fault Data Over the last 17 Years

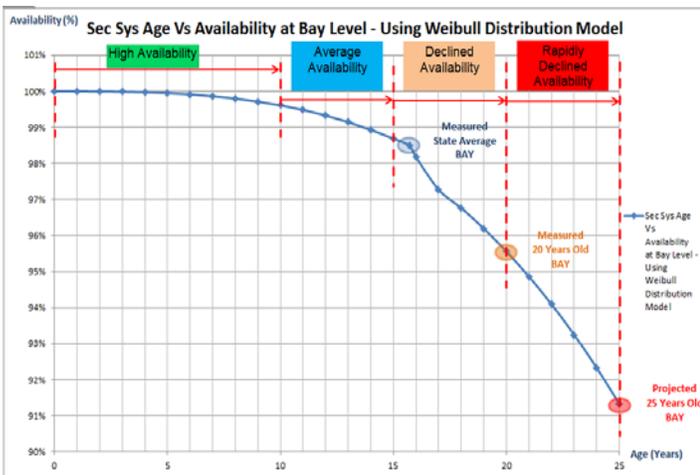


Figure 2

Secondary System Age Vs Availability at Bay Level Weibull 2 Parameters Distribution Model

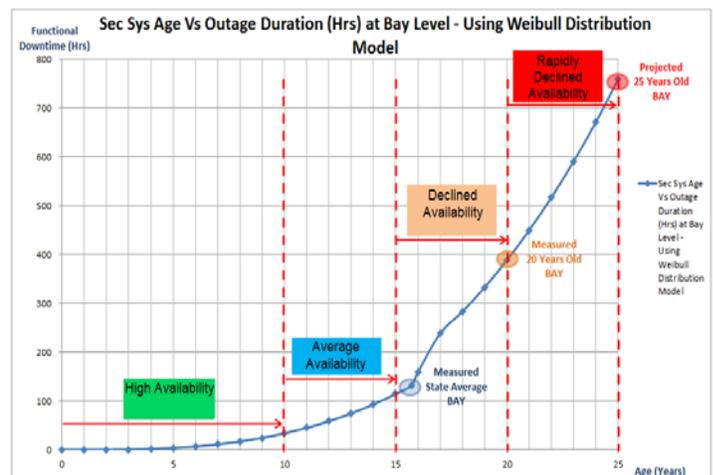


Figure 3

Secondary System Age Vs Outage Duration (Hrs) at Bay Level Weibull 2 Parameters Distribution Model

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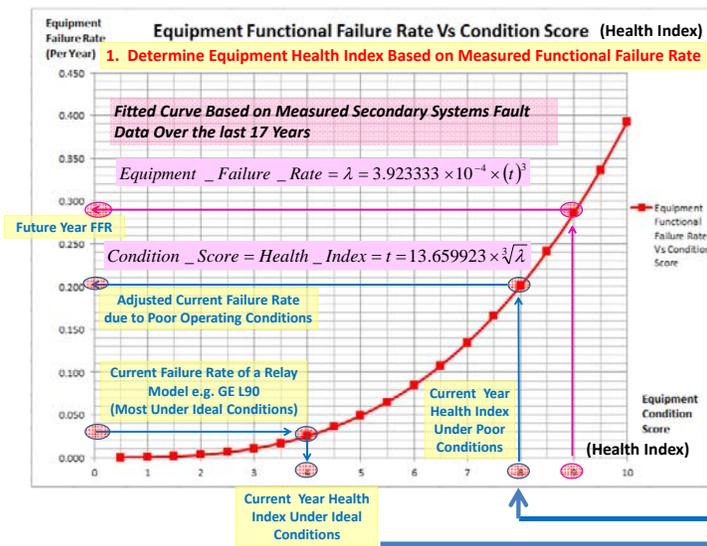


Figure 4
Equipment Health Indices Vs Effective Age – 20 Years Lifespan

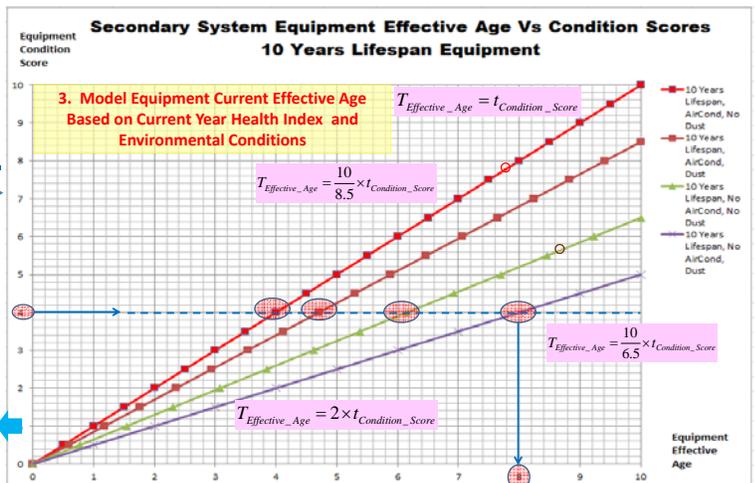
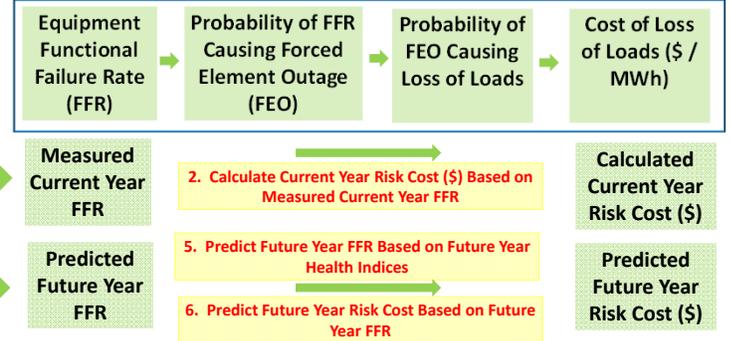


Figure 5
Equipment Health Indices Vs Effective Age – 10 Years Lifespan

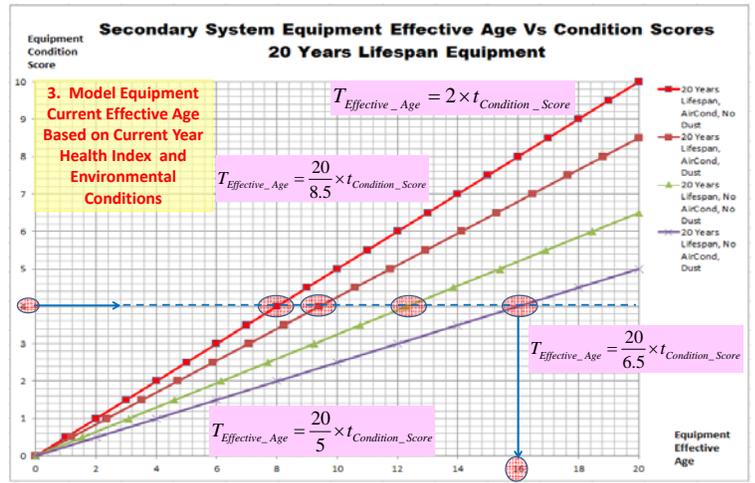


Figure 6
Equipment Health Indices Vs Effective Age – 20 Years Lifespan

4. Model Future Year Health Indices (Current Year HIs + Increment of HIs) Based on Future Effective Ages (Current Year Effective Ages + Increment of Ages)

Operating Environment		Increment of HIs Based on Increment of the Effective Ages		
		$\Delta t_{HI, Yr(x)} = \frac{Max_HI \times \Delta T_{Eff_Age, Yr(x)}}{LifeSpan \times (1 - Reduction_Factor)}$		
Air Condition	Dust	20 Years Lifespan	10 Years Lifespan	Reduction Factor
Yes	No	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{2 \times 10}$	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{10}$	0%
Yes	Yes	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{2 \times 8.5}$	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{8.5}$	15%
No	No	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{2 \times 6.5}$	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{6.5}$	35%
No	Yes	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{2 \times 5}$	$\Delta t_{HI} = \frac{10 \times \Delta T_{Eff_Age, Yr}}{5}$	50%

Table 2

Increment of Health Indices based on Increment of Effective Ages

7. Enable Powerlink to:
- Quantify the trade-off between Reinvestment Cost Versus Risk Cost Derived From Secondary System's Availability and Reliability.
 - Prioritise Projects based on the highest ratio of Risk Cost Over Reinvestment Cost.