Transmission Efficiency Test (TET)

Why the TET could require modelling of unassisted transmission failure to optimise the balance between capital costs and operating costs due to maintenance

Answer to Question for stakeholders 10.

What views do you have on these elements and is there any other guidance that should be included in the TET guidelines to be developed by the Regulator?

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Executive Summary

The Transmission Efficiency Test could assess projected capital costs and operating costs of transmission projects in a statement of future cash flows that is based on sound engineering design principles, models, and analysis. An example could be sizing wires in a manner that minimises the overall cost of transmission when considering the up-front cost of the wires as well as the replacement cost of the wires as they fail. Transmission and distribution assets are prone to temperature dependent modes of unassisted failure. Common causes of unassisted failure include corrosion, fatigue, and annealing. Electricity infrastructure heats up as electricity is transported. The temperature of conductors can be decreased by increasing their cross-sectional area. This would increase capital costs as more material is required for conductors and supporting structures. However, these larger conductors could decrease maintenance costs as the electricity system will be less prone to unassisted failure. The ideal conductor size will be dependent on the generation profile of the Renewable Energy Zone (REZ) associated with the transmission infrastructure and the load profile of the National Electricity Market (NEM). Hence, design of the transmission system should coincide with modelling of the generation profile of each Renewable Energy Zone. The Transmission Efficiency Test could require an independent engineering assessment of the supplier's design work. This could ensure transmission infrastructure is designed in a manner that reduces the overall combined cost of transmission infrastructure, not just the initial capital costs.

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1. About the Author

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Alexander's specialization is in providing Australian solar investors with site-specific business cases and engineering designs that add value to a customer's investment. Since founding Anamise in 2015, the consulting work delivered by the Anamise team has been well received by high profile Australian organizations.

Testimonials:
"Alex has worked with SFS and Brilliant Energy for the past year. He has been instrumental in developing analytical tools for the development of our energy contracting business. He has a good business sense which enables him to make commercial decisions that back up his analytical intellect." – Kevin Heydt, Solar Financial Solutions

"Hats off to the Anamise team for their comprehensive analysis of energy data, application of innovative research and unique mathematical models to produce easy to understand visual data models and representations of the most financially and energy beneficial implementation of solar to buildings." – Karin Wunsch, Townsville City Council

Experience:
Alexander has extensive experience in the solar industry having worked as a quality assurance team member at the 100MW First Solar Pilot Project. He has been educated at the prestigious University of New South Wales School of Photovoltaic and Renewable Energy. Furthermore, he has worked as a project manager for MPower Group on the SP Ausnet residential battery energy storage project.

2. Introduction

The Transmission Efficiency Test is being introduced as part of the Electricity Infrastructure Investment Act 2020 (EII Act). The aim of the TET is to ensure the efficient design and construction of transmission networks in Renewable Energy Zones. Under the EII Act the Regulator will approve financial incentives to the Network Operator that promote economic efficiency. This incentive is a generous solution to overcoming one of the principal-client dilemmas that exist in the National Electricity Market.

Currently, transmission and distribution network service providers may only generate revenue through the Australian Energy Regulator's cost recovery scheme known as the Cost Allocation Method (CAM). Counter-intuitively, network service providers have an inefficient financial incentive to increase expenditure. The electricity network is a natural monopoly and essential service. Hence, there is no external market pressure on network service providers to ensure they operate in an efficient manner.

Under the EII Act the Regulator will be able request information from the Network Operator to ensure they are operating in an efficient manner. Overall, the Transmission Efficiency Test is an excellent initiative. Network Operators should be rewarded for providing a high quality, reliable, safe, and efficient service. The Regulator should also be able to request information from the Network Operator to maintain transparency.

One improvement to the TET guidelines would be to expand the point

"the process and approach by which the Regulator will undertake a capital cost assessment"

to include a maintenance and operating cost assessment. This could be included as a combined process. Engineering design decisions often have a trade off between capital cost, lifetime of an asset, and expected maintenance of the asset. This is evident in the case of many of the sources of unassisted failure that occur in transmission and distribution assets. One example that will be explored in this paper is whether increasing the cross-sectional area of a wire efficiently increases the asset lifetime. The model presented below could highlight the need for this amendment to be included in the TET guidelines. For example:

"The Regulator will undertake an assessment that ensures the Network Service provider has optimised the electricity network design parameters to minimise the combined capital costs and maintenance costs as illustrated in a statement of future cash flows."

3. Unassisted Failure in Electricity Networks

Causes of Unassisted Failure in Electricity Networks

Research from Queensland University shows the chance of failure in Australian electricity network wires from unassisted sources (Naranpanawe, Ma, & Saha, 2018).

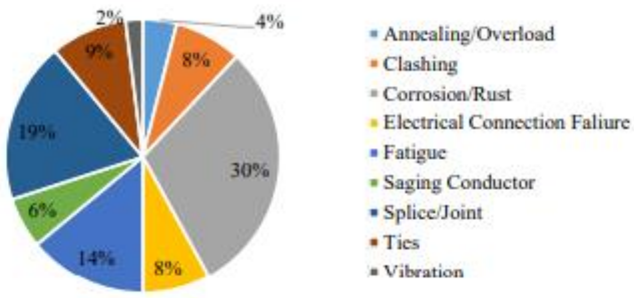

Figure 6 Different cause of conductor failure in unassisted failure mode

Figure 1: Chances of conductor failure by unassisted causes (Naranpanawe, Ma, & Saha, 2018)

Many of these causes are highly affected by temperature. For example, corrosion, the highest cause of failure, is exponentially dependent on temperature. The Materials Technology Institute (based in the US) shows this relationship between corrosion and temperature quoting:

"*There's a rule of thumb that the corrosion rate of a metal doubles for every 10°C increase in temperature* (Materials Technology Institute, 2012)*.*"

Temperature of Electricity Assets vs. Load

The temperature of electricity assets increases with the more they are loaded. An example of this can be seen in the following graph of electricity protection equipment.

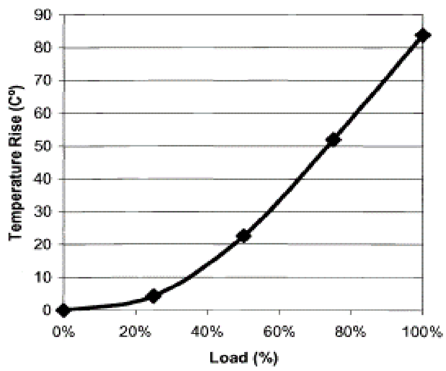

Figure 5. Temperature Rise as a Function of Load

Figure 2: Graph showing the temperature rise of protective equipment in the electricity grid vs. load% (Lyon, Orlove, & Peters)

Load Frequency in the National Electricity Market

One method the Australian Energy Market Operator (AEMO) uses to model the load on the National Electricity Market is the five load block method. This is visualised in the following graph.

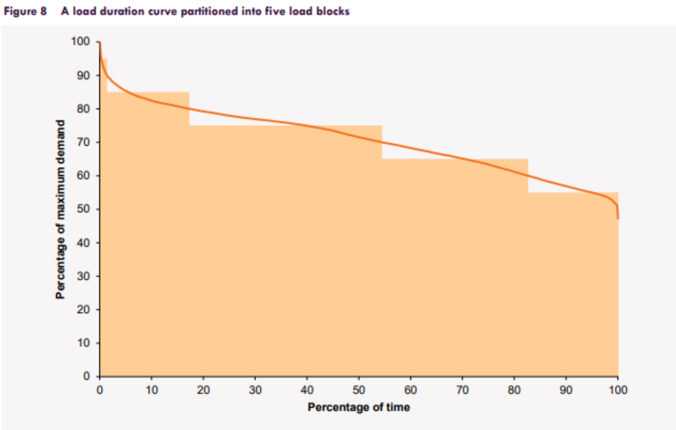

Figure 3: The load% on the electricity grid (Australian Energy Market Operator, 2018)

4. Example Model for Optimising Conductor Size to Minimise Overall Cost

The following model and experimental process provides an example to how the size of a transmission wire can be optimised. This example only takes into consideration the size of the wire and the rate of corrosion. The TET could request that the Network Service Provider submits similar calculations considering all modes of unassisted failure. Furthermore, it could draw upon more accurate sources of data to complete the calculations. The work completed here by Anamise Pty Ltd is conducted over 3 days and in kind, and hence assumptions must be made to complete the work in the allowed time. A Network Service Provider bidding to construct and maintain an asset as large the transmission network required for renewable energy zones could present the work in a much more thorough manner.

Hypothesis

Conductors in the National Electricity Market (NEM) are undersized. This results in increased unassisted degradation of conductors (wires) due to corrosion. An optimal conductor size may be determined to minimise the overall cost of a conductor when considering both up-front and replacement costs.

Aim

Create a model to calculate the cost of a wire based on its capital cost and replacement cost due to corrosion. Determine whether increasing the cross-sectional area of a wire efficiently increases the asset lifetime.

Method

- Create a database showing the temperature rise in the conductor as a function of load %.
- Use the "corrosion rule of thumb" to model the rate of corrosion as a function of temperature when compared to an unloaded conductor.
- Model National Electricity Market load profile wire subjected to an AEMO load profile.
- Use solver to minimise the cost of the wire with respect to cross sectional area.

Results

Temperature Rise As A Function of Load			
Load (%) Min Segment	Load (%) Max Segment	Temperature Rise (K)	Corrosion Rate Multiple
0	5	1	1.071773463
5	10	2	1.148698355
10	15	3	1.231144413
15	20	4	1.319507911
20	25	5	1.414213562
25	30	6	1.515716567
30	35	10	2
35	40	13	2.462288827
40	45	16	3.031433133
45	50	20	4
50	55	25	5.656854249
55	60	30	8
60	65	36	12.12573253
65	70	42	18.37917368
70	75	50	32
75	80	56	48.50293013
80	85	62	73.51669472
85	90	68	111.4304721
90	95	75	181.019336
95	100	82	294.0667789

A Load Duration Curve Partitioned into Five Load Blocks						
Percentage of Time (%)	Original Percentage of Maximum Demand	Old Replacement Rate	Weighted Old Rate Calculation	New Percentage of Maximum Demand	New Replacement Rate	Weighted New Rate Calculation
2%	90	111.4304721	2.228609442	45	3.031433133	0.060628663
14%	80	48.50293013	6.790410218	40	2.462288827	0.344720436
36%	70	18.37917368	6.616502525	35	2	0.72
29%	60	8	2.32	30	1.515716567	0.439557804
19%	50	4	0.76	25	1.414213562	0.268700577
Total			17.95552218			1.83360748
Conductor Size:	2					
Replacement Ratio New vs. Old:	10.2%					

Rated Voltage of Powerline	500	kV			
Max Power on Powerlines	2000000	kW			
Max Current through Wires	4000	A			
Max Current Per Circuit	1333.333	A			
Estimated Minimum Possible Cross Sectional Area of Cable	600	mm^2			
Radius of Cable	14	mm			
Diameter of Cable	27.63953	mm			
Corrosion Rate of Aluminium at Ambient Temp	0.03	um/year			
Minimum Allowable Conductor Diameter For Maximum Transmission Load	27639	um	New Allowable Conductor Diameter For Maximum Transmission Load	55278	um
Corrosion Rate under AEMO Load Profile	0.538666	um/year	Corrosion Rate under New Load Profile	0.055008	um/year
Total reduction in Diameter under AEMO Load Profile	1.077331	um/year	Total reduction in Diameter under New Load Profile	0.110016	um/year

Discussion

- The total amount of wires required to be replaced is unknown, so whilst Figure 1: Chances of conductor failure by unassisted causes lists corrosion as the most common occurrence of unassisted failure, unassisted failure itself could be minimal.
- The maintenance logs of transmission or distribution service providers are not easily accessible. Studies and models would be easier to assess if they were publicly available.
- The model assumes the load% of the grid matches the load% of the infrastructure.
- A proper optimisation process was not carried out as corrosion appeared to have minimal impact. Doubling the conductor size was left in as an example to demonstrate how it would impact the rate of corrosion.

Conclusion

The model suggested corrosion would have a negligible effect on the lifetime of transmission cables. This seems to be in opposition to the data on the causes of unassisted failure. Further analysis of the data that showed corrosion causes 30% of unassisted failure is required.

5. Conclusion

A maintenance schedule could be considered in the design of projects. This assessment could help the regulator determine if changing design parameters to minimise maintenance can minimise the overall cost of the project. In the model created for corrosion, it appeared to be insignificant. Other factors such as annealing could be investigated. Annealing is due to temperature changes in conductors. This could be a more appropriate problem to investigate as the intermittent nature of renewable energy zones means wires regularly heat up and cool down. Despite the results of the model, the cost and likelihood of failure in any engineering design should be investigated.

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7. Contact Information

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