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PROBABILISTIC ANALYSIS OF CLIMATE CHANGE IMPACTS FOR POWER POLE NETWORKS

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According to the most recent International Panel on Climate Change (IPCC) report, warming of the climate system is unequivocal, and this warming may lead to increased risk of breakdown of infrastructure networks due to extreme weather. A key means of reducing future risk exposure is implementation of effective climate change adaptation strategies for critical infrastructure assets. However, before such strategies can be put in place, we must first understand the extent of potential climate change impacts on our infrastructure. The work described in this paper examines climate change impacts for timber power pole networks. These power pole networks represent important critical infrastructure assets worldwide, with five million timber power poles currently in service across Australia worth over $10 billion, and approximately 200 million treated power poles in service in the United States. Despite the scale and value of these critical infrastructure assets, limited research has been carried out examining climate change impacts for power pole networks. The study described herein examines this area using a Monte-Carlo event-based sequential model, which incorporates structural reliability, deterioration, climactic effects and network maintenance. The hazards of interest are storm winds and timber decay - both of which may worsen due to a changing climate. The results are presented in the context of a notional network of one million power poles. Impacts are examined across five Australian regions. The analysis indicates that climate change impacts can be significant, however, the impacts were also found to be highly regionally variable.

Keywords: Timber power pole networks, climate change, critical infrastructure, vulnerability

1 Introduction

The latest International Panel on Climate Change (IPCC) Assessment Report 5 (AR5) has stated that warming of the climate system is unequivocal, with many of the observed changes since the 1950s unprecedented over decades to millennia (IPCC, 2013). These observed changes in climate, and perhaps more importantly projected future changes, may lead to increased risk to life, infrastructure and eco-systems. The IPCC Working Group II has identified a number of key risks or 'dangerous anthropogenic interfaces with the climate system'. These include risks due to storm surges, inland flooding, sea level rise and systematic risks due to extreme weather events leading to breakdown of infrastructure networks and critical services (IPCC, 2014). One of the key means of dealing with these climate change related risks is implementation of climate change adaptation. However, before we can implement efficient climate adaptation strategies we must first understand the nature and extent of impact on our infrastructure. The work presented in this paper represents such an assessment for timber power pole networks in five regions in Australia.

These power distribution pole networks represent considerable national assets, both in Australia, and throughout the world. There are an estimated five million timber power poles currently in service in Australia, with a net worth of over $10 billion (Crews and Horrigan, 2000). The level of investment in timber power poles in other countries is even greater. For example, there are between 120 million and 200 million treated timber poles currently in service in the United States (Bolin and Smith, 2011). Given the scale of these infrastructure networks it is clear that any possible climate change induced increases in power pole failure rates or maintenance requirements could lead to considerable direct and indirect costs. Thus, there is a need to investigate the possible impacts of climate change on power pole networks. The work presented in this paper addresses this need through utilization of a probabilistic event-based time-dependent model to assess the possible impacts of climate change on power distribution infrastructure across five Australian cities.

2 Methodology

The basis for the model used herein has been developed in detail in previous papers by the authors (Ryan et al., 2014, Ryan et al., 2016), which explored existing vulnerability and climate change impacts under AR4 climate change predictions. This section presents a brief description of the model. The reader is referred to the previous papers for more detailed discussion on the model development and probabilistic model parameter selection.

2.1 Sequential Event-based Modelling

The sequential event-based modelling approach used herein allows power pole network performance over time to be assessed, considering both maintenance and climate change effects. The uncertainty and variability associated with a) climate change predictions, b) structural capacity, c) structural loading, and d) deterioration with time, are incorporated in the analysis. The sequential aspect of the model relates to the fact that each Monte Carlo iteration runs on a year-by-year basis from the year 2015 to 2090. Each yearly step includes; calculation of time dependent resistance $R(t)$ and time dependent load $S(t)$, accounting for climate change effects on deterioration and wind load, in addition to simulation of network maintenance if appropriate. The event-based aspect of the probabilistic model refers to the fact that the occurrence of certain events over the monitoring period can influence the course of a given sequential Monte Carlo simulation. The two key events which can occur are a) violation of the limit state, whereby the annual wind load exceeds the deteriorated pole bending capacity and the pole fails, and b) the condemning of a pole as a result of the network inspections and maintenance program. Upon occurrence of a wind failure or the condemning of a pole, the pole in question is replaced by a new pole in the Monte Carlo simulation. This pole is assigned new properties generated from the appropriate distributions. The process of deterioration then restarts for this new pole, and the sequential Monte Carlo process continues for the iteration in question up to the year 2090. This sequential event-based approach means that, in effect, each Monte Carlo iteration represents one pole location in a network of poles, whereby if this pole fails at a given location it must be replaced to prevent a break in the power supply system.

2.2 Time Dependent Load and Resistance

The initial bending resistance (R(0)) of a timber power pole at time t = 0 can be represented based on established bending theory as follows;

$$R\ (0) = f_b \,.\, {}^{\pi.\, D^3}\!/_{32} \tag{1}$$

where fb is the bending strength of the timber, and D is the ground line diameter of the distribution pole. It is noted however that this initial bending resistance (R(0)), will tell us little about the performance of timber power poles in service, which undergo significant deterioration over their service life. Thus, for timber power pole networks, as with any infrastructure network analysis, infrastructure element deterioration must be incorporated into the probabilistic model. Timber deterioration was incorporated herein based on the work of Wang et al. (2008), who developed a timber decay model based on 35 years of field data for 77 timber species which considers timber type, timber treatment, temperature and rainfall. The implementation of this model in the context of timber power pole networks, both in existing environmental conditions, and under climate change conditions, is discussed in detail in previous publications by the authors (Ryan et al., 2014, Ryan et al., 2016).

2.3 Time Dependent Wind Loading

The most common failure mode for timber power poles is bending failure under wind loading (Winkler et al., 2010). In the context of climate change, it is thus important to consider time dependent changes in wind speed under various climate change scenarios. The wind field for the five Australian locations (Sydney, Melbourne, Canberra, Brisbane and Perth) examined in this paper are dominated by non-cyclonic synoptic weather systems. These non-cyclonic gust wind speeds are modelled using the Gumbel distribution. The probabilistic parameters for the pre-climate change wind field distributions for the Australian locations were adopted from Wang et al. (2013). Climate change impacts on the wind field and subsequent wind load was incorporated into the assessment using the climate change predictions presented in Section 2.4 in accordance with the procedure outlined in detail in (Ryan et al., 2016). The work of Henderson and Ginger (2007) was used to calculate the time-dependent wind load S(t), based on the generated wind speed, again as described in detail in Ryan et al. (2014). This model allowed uncertainty and variability to be incorporated into predictions for the wind load on the power poles, conductors etc. for a given wind speed v, at a given time t.

2.4 Climate change Projections

This study uses the latest IPCC Assessment Report (AR5) climate change predictions for five regions in Australia (Webb and Hennessy, 2015). In line with the large uncertainty and variability associated with long-term climate predictions, climatic changes were modelled probabilistically using Monte Carlo simulation. Wind speed, rainfall and temperature changes were considered for the no climate change scenario, and the RCP4.5 (medium) and RCP 8.5 (severe case) emission scenario. In line with the framework set out by Stewart and Deng (2015), and utilized in Ryan et al. (2016, 2015), truncated normal distributions were used to represent the uncertainty associated with climactic predictions provided by CSIRO (Webb and Hennessy, 2015).

2.5 Power Pole Network Details

The aim of this study was to determine the likely climate change impacts on a notional network of one million newly installed CCA treated timber power distribution poles, for the period 2015 to 2090 (76 years), across five Australian cities. To facilitate fair comparison between locations, both the new 2015 poles, and replacement poles, were designed for each location in accordance with existing standards (AS/NZS 1170.2:2011 and AS/NZS 7000:2010). A typical Australian power distribution pole layout, as detailed in Ryan et al. (2014) was used for the Australian case studies herein. Appropriate sizing grades were also utilized in line with those provided by pole suppliers in each region. Spotted Gum (corymbia citriodora, corymbia henryi & corymbia maculate) is the most common timber species used for treated poles in Brisbane, Sydney, Canberra and Melbourne (2009, Francis and Norton, 2006), and thus was utilised in the design and modelling for these locations. The majority of newly installed poles used in Western Australia, however, are CCA treated Radiata Pine, and thus this pole type was used in the design and modelling for Perth. Poles were assumed to be CCA treated in line with current practice in the Australian power industry. Inspection intervals were set at 5 years, with first inspection at 20 years (Standards Australia/New Zealand, 2010). In accordance with common industry practice in Australia, inspection failure or pole condemning criteria was set at 50% of original pole capacity based on loss of section modulus (Z), meaning if inspection revealed that the pole moment capacity was less than 50% of the original pole moment capacity the pole failed the inspection and was condemned and replaced.

3 Results

The impact of the three climate change scenarios on the average annual pole condemning rates for the five Australian cities is shown in Figure 1. Figure 2 presents the percentage increase in pole condemning rates for the three scenarios, for each of the locations i.e. increase relative to "no change", or baseline condemning rates for each location. As can be seen from Figure 1, the predicted climate change impact can be significant with Brisbane experiencing the largest impact. The RCP8.5 climate scenario for Brisbane results in an increase in average annual condemning rates over the monitoring period of approximately 0.11%, representing an 11.2% increase in pole condemning rates when compared to the Brisbane "no change" scenario. Sydney also experiences a notable proportional increase in pole condemning rates due to climate change under the RCP8.5 scenario, with a 10.7% increase when compared to the no change scenario. In contrast to Brisbane and Sydney, Melbourne actually experiences a slight reduction in annual pole condemning rates for both the RCP4.5 and RCP8.5 emission scenarios, while the climate change impacts for Canberra were relatively small. The Perth pole network experiences a low annual condemning rate for the three emission scenarios. This was due to the influence of pole timber species utilized, with the Radiata Pine poles resulting in far less poles condemned than the Spotted Gum poles over the 76 year monitoring period for a given location. As shown in Figure 2 however, the small increases in pole condemning rates due to the RCP8.5 emission scenario represents a notable proportional increase in condemning rates, with a 15.9% increase observed when compared to the no change scenario.

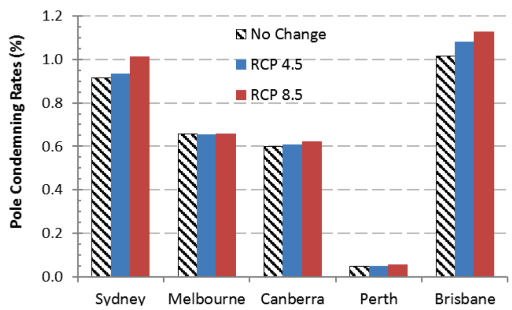

Figure 1. Annual pole condemning rates for three climate change scenarios for the five locations

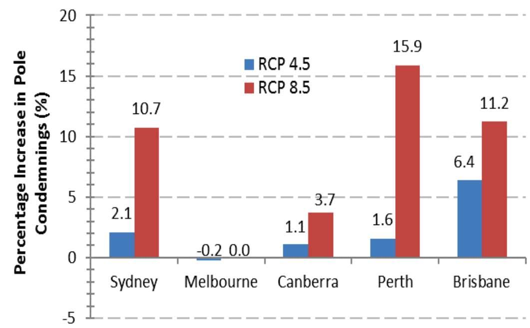

Figure 2. Percentage change in annual pole condemning rates due to climate change for five locations

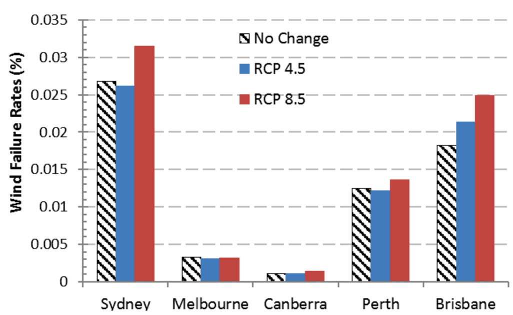

Figure 3. Annual pole wind failure rates for three climate change scenarios for the five locations

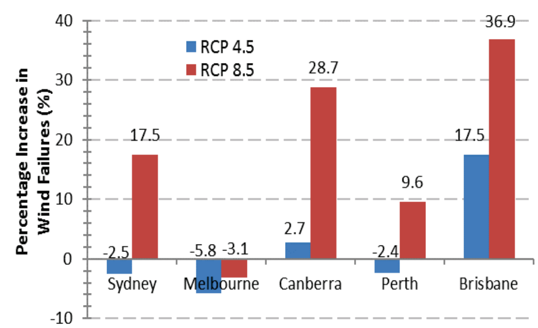

Figure 4. Percentage change in annual pole wind failure rates due to climate change for five cities

Figure 3 shows the average annual wind failure rates for the three emission scenarios for each of the five Australian locations, with Figure 4 showing the percentage change in annual wind failure rates for the RCP4.5 and RCP8.5 emission scenarios for each location. Brisbane can be seen to experience the most severe increase in annual wind failures, which is partially due to the fact that Brisbane is the only one of the five cities examined to experience a notable median increase in wind speed. Sydney also experiences a significant increase in average annual wind failure rates for the RCP8.5 scenario, with a rise of 0.047%, representing a 17.5% increase in the average annual wind failure rates when compared to “no climate change” scenario. This is primarily related to increased decay and increased variability in wind speed caused by climate change uncertainty. Canberra experiences a small increase in average annual wind failure rates, but a significant proportional increase in wind failure rates. This is due to the fact that Canberra city experiences low wind failures for the “no change” scenario as median wind speed for this location is approximately 20m/s, 9m/s less than Sydney, despite both locations having the same wind speed classification from a design perspective (Standards Australia/New Zealand, 2011). It is also interesting to note that Melbourne experiences a decrease in wind failures for both emission scenarios.

4 Conclusions

This study indicates that impacts on power pole networks are likely to be substantial for some locations in Australia, with Brisbane experiencing a projected 11% increase in pole condemning rates, and an approximate 37% increase in wind failure rates over the period 2015 to 2090 under RCP8.5. Such increases could have substantial societal impacts when one considers the consequences of power pole failures, which range from interruptions of power for businesses and homes, to loss of life due to wildfires. However, the predicted impacts of climate change were found to be highly regionally variable. In addition to the interaction between three climatic change parameters (temperature, rainfall and wind speed), predicted climate change impacts are also influenced by a regions baseline climatic conditions, type of timber used in a region, and the uncertainty associated with climate change predictions, something that can only be captured in a probabilistic assessment. This complex regionally variable nature of impact emphasizes the need for detailed regional specific probabilistic analysis before effective climate adaptation strategies can be put in place, with neither impacts, nor regional effects intuitive i.e. Sydney experiences an increase in predicted wind failures despite a median reduction in wind speed, and Canberra and Sydney experience very different condemning rate impacts, despite having very similar temperature and rainfall climate change predictions. Thus, Sydney and Canberra are likely to require different adaptation strategies, while the analysis indicates the implementation of an adaptation strategy for Melbourne based on perhaps a national assessment would have been a waste of finances.

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