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Probabilistic analysis of climate change impacts on timber power pole networks

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ABSTRACT

The IPCC, a collection of 800 of the world's leading climate change scientists, state that future climate related risks to society and infrastructure are likely to change. It is therefore important for the power industry to consider the possible impacts of future climate change on infrastructure performance. However, very few studies have been published to date examining the potential impacts of climate change on power distribution poles networks, which constitute large and valuable infrastructure assets worldwide. The work presented in this paper builds on the limited research in this area by developing a framework for examination of the possible impacts of climate change on timber power pole networks. The time-dependent event-based model developed herein allows network maintenance and predicted climate change effects to be considered, while also incorporating uncertainty associated with both climate change predictions, and structural reliability modelling of infrastructure networks over time. The results of a case study which examined notional power pole networks for five Australian cities revealed that the effects of climate change on predicted power pole performance can be significant. Wind failures for the Brisbane location were predicted to increase by approximately 60% when considering a period from 2015 to 2070, under the severe climate change scenario. However, the predicted impacts are also highly regionally variable, with one location considered experiencing positive climate change impacts for a medium climate change scenario.

Introduction

The latest International Panel on Climate Change Assessment Report (IPCC 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 [1]. These observed changes in climate, and perhaps more importantly projected future changes, may lead to increased risk to human life and infrastructure. The Working Group II of the IPCC 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 [2]. Some effects of a changing climate are already being felt by industry managers worldwide. This year the UK Institute of Civil Engineers stated that Great Britain's infrastructure is beginning to struggle to cope with increasingly frequent extreme events, and warned that the UK public should be primed to expect more failures in the future as climate change will make it increasingly difficult to run power and transport networks in all weather conditions [3].

One of the key means of dealing with increased climate change related risks is implementation of effective climate change adaptation strategies. This mode of thinking is beginning to penetrate into infrastructure management and policy across the globe [2]. For instance, the US military have recently announced that the Pentagon is undertaking sweeping changes to operation systems and installations to adapt to climate change impacts now and in the future [4]. However, in order to implement effective climate change adaptation for infrastructure it is essential to first understand the nature and magnitude of predicted climate change impacts on our infrastructure networks. This is not straight forward for the power industry in particular for two main reasons: (1) the influence of climate change on the power infrastructure performance is a relatively complex interaction of a number of

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different climactic effects (i.e. temperature, rainfall, wind speeds, etc.) manifesting in changes in deterioration rates and loading conditions, and (2) there is considerable uncertainty associated with future climate change projections. These issues make it difficult for power infrastructure asset managers to quantify impacts, and thus ascertain if adaptation is required, and if so, what adaptation strategy is most appropriate.

The work presented in this paper sets out a framework for assessment of climate change impacts on power distribution infrastructure. The performance of notional timber power pole networks under various climate change scenarios for five different regions of Australian was considered over a period of over 50 years. Importantly, the framework is developed in a probabilistic context. This approach, which uses Monte Carlo simulation in the assessment of structural reliability of poles, allows climate change uncertainty to be incorporated into the assessment, together with the other forms of uncertainty associated with structural reliability modelling of infrastructure elements over time. It is widely recognised that such probabilistic methods are the most appropriate tool for the representation of processes which have high levels of uncertainty [5], and examination of infrastructure networks, which have high variability among network elements [6,7]. The probabilistic approach utilised in this study is event-based time dependent modelling. This allows maintenance actions to be incorporated into the assessment, an important consideration for realistic modelling of power pole networks, as illustrated in [6].

To date, a number of studies have employed probabilistic methods to examine the existing risk and vulnerability of timber power poles [6,8–13], and indeed electrical networks as a whole [14], however very few power pole studies have considered possible changes in future risk due to climate change. Existing publications in this area limited to the work of Bjarnadottir et al. [10]. This is somewhat surprising given the International scientific community's predictions about future climate [1,2], and the scale and value of timber power pole networks worldwide. For instance, it is estimated that there are between 120 million and 200 million treated timber poles in service in the United States [15]. In Australia there are over five million timber power poles, with a net worth of over $10 billion [16]. The study by Bjarnadottir et al. [10] examined climate change related increases in risk for timber power poles in a United States context. The work in this paper builds on this existing literature in three main ways. Firstly, the framework presented in this paper considers the impact of climate change on both wind loading and on deterioration rates. Existing studies considered climate impacts in terms of wind loading alone, but as shown in Section 'Results – impact of climate change' of this paper, changes in deterioration rates constitute a major component of climate change impacts for timber power pole networks. Secondly, the case study presented in Sections 'Case study – Australian timber poles in five cities and Results – impact of climate change' of this paper examine the regional variation of climate change effects for five cities in Australia. Regional variability of impacts has not been examined in the relevant power pole literature to date. However, a recent study by Wang and Wang [17] highlighted the importance of regional considerations for climate impact studies when they found the impacts of climate change on timber decay rate to vary widely across Australia. Finally, as previously mentioned the probabilistic framework herein also considers the effects of network maintenance, an important consideration when attempting to realistically model power pole vulnerability in a working power network over time [6], and something overlooked in the relevant literature to date.

The following section of this paper presents the most up to date regional climate change predictions which will be used in the case study herein. The probabilistic framework utilised in the study is then developed in Section 'Assessment methodology'. Section 'Case study – Australian timber poles in five cities' provides the details of the case study for climate change impacts on notional power distribution pole networks in five Australian cities. The results of this case study for three climate change scenarios are then presented in Section 'Results – impact of climate change', first for a single location, followed by regional comparison of climate change impacts.

Climate change predictions

The case-study presented later in this paper examines climate change impacts on power distribution poles across five different Australian cities. Consequently, the most up-to-date regionally specific climate change predictions developed by the Australian Commonwealth Scientific and Industrial Research (CSIRO) body were used in this study [18]. The five Australian cities considered were: Brisbane, Sydney, Canberra, Melbourne and Perth. Three climate change scenarios were examined for each city: (a) no climate change, whereby climactic conditions remain at 1990 levels, (b) the IPCC B1 (median) climate change scenario, and (c) the IPCC A1FI (worst) climate change scenario. Table 1 presents the median, 10th percentile, and 90th percentile predicted changes in temperature, rainfall and wind speed for the B1 and A1FI climate change scenarios for the five Australian cities. The values represent the total change to the year 2070, relative to 1990 levels. In line with the framework set out by Stewart et al. [19,20], truncated normal distributions were used to represent the uncertainty associated with climactic predictions, whereby the 50th, 10th and 90th percentiles provided by CSIRO [18], allow the standard deviation of two truncated normal distributions, each with a cumulative probability of 50%, to be calculated as shown in Fig. 1. In the absence of yearly data resolution for regional climate change predictions (CSIRO provide total change predictions at year 2070), a time-dependent linear change in climactic conditions for the B1 and A1FI scenarios was assumed [19,20]. A Monte Carlo simulation approach was used to incorporate the climactic uncertainty in the probabilistic model, with one million Monte Carlo iterations carried out for each of the cities considered.

Examination of the prediction patterns in Table 1 reveals two important points. Firstly, the predicted climate change effects vary

Table 1
Statistical parameters for climate change predictions for five Australian locations.

Parameter	B1 10th P	B1 50th P	B1 90th P	A1FI 10th P	A1FI 50th P	A1FI 90th P
Brisbane						
Temperature (°C)	+1.1	+1.6	+2.3	+2.1	+3.1	4.4
Rainfall (%)	−18	−5	+9	−33	−9	17
Wind speed (%)	−1	+3	+10	−2	+6	19
Sydney						
Temperature (°C)	+1.1	+1.6	+2.2	+2.1	+3.0	+4.3
Rainfall (%)	−14	−4	+5	−25	−8	+10
Wind speed (%)	−8	0	+6	−15	−1	+12
Canberra						
Temperature (°C)	+1.1	+1.6	+2.2	+2.1	+3.0	+4.2
Rainfall (%)	−14	−5	+4	−26	−9	+8
Wind speed (%)	−10	−1	+7	−20	−2	+13
Melbourne						
Temperature (°C)	+1.0	+1.4	+2.0	+1.9	+2.8	+3.8
Rainfall (%)	−14	−6	+1	−25	−11	+3
Wind speed (%)	−9	−1	+6	−18	−1	+12
Perth						
Temperature (°C)	+1.0	+1.4	+2.0	+1.9	+2.7	+3.8
Rainfall (%)	−21	−11	+1	−37	−19	+2
Wind speed (%)	−5	0	+4	−9	−1	+7