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Adapting overhead lines to climate change: Are dynamic ratings the answer?

Lucy C. Cradden*, Gareth P. Harrison

[a] Institute for Energy Systems, School of Engineering, University of Edinburgh, Edinburgh EH9 3JL, UK

HIGHLIGHTS

- A model is created demonstrating the impacts of climate change on overhead line ratings.
- The model accounts for temperature, solar radiation and wind effects on line rating.
- The increased risk to network capacity due to climate change is low.
- Real-time dynamic ratings systems present a cost-effective mitigation strategy.

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ABSTRACT

Thermal ratings of overhead lines (OHL) are determined by the current being carried and ambient climatic conditions. Higher temperatures as a result of climate change will give rise to lower ratings, and thus a reduction in current-carrying capacity across the electricity network. Coupled with demand growth and installation of renewable generation on weaker sections of the network, this could necessitate costly reinforcements and upgrades. Previous UK-based work applying a subset of data from the UK Climate Projections model (UKCP09) has indeed indicated likely reductions in the steady-state OHL ratings under worst-case temperature increases. In the present work, time series data from the full UKCP09 probabilistic climate change modelling framework, including an additional algorithm to incorporate hourly wind conditions, is applied to OHL ratings. Rather than focus purely on worst-case conditions, the potential for an increased risk of exceeding nominal ratings values on thermally constrained OHL is analysed. It is shown that whilst there is a small increase in risk under future climate change scenarios, the overall risk remains low. The model further demonstrates that widespread use of real-time dynamic rating systems are likely to represent the most cost-efficient adaptation method for lines which are frequently thermally constrained.

1. Introduction

The balance of evidence from climate modelling experiments suggests that average temperatures will rise over the coming decades as greenhouse gas concentrations increase (IPCC, 2007). A changing climate has potential to affect electricity systems in many ways, not least the need for low carbon generation. The direct and indirect effects of climate change on electricity distribution and transmission networks may be disruptive and requires analysis.

Many network components such as transformers and overhead lines (OHL) are directly vulnerable to weather conditions. The reliability and safety of these devices are limited by their ability to withstand certain operational temperatures, which are in turn influenced by local ambient environment and loading conditions. In OHL, power flows exceeding defined limits referred to as 'line rating' will cause excess heat gain and damage from sag or a reduction in strength (CIGRE Working Group B2.12, 2006). With the anticipated rise in ambient temperatures in the coming decades, the threshold temperatures for OHL are likely to be reached sooner, leading to reductions in power transmission capacity. Indirectly, networks are required to cope with increasing installations of renewable generators well as demand growth. A combination of reduced capacity with increased loading could necessitate costly network reinforcement.

The issue of changing OHL ratings has featured in the literature on climate change impacts. Consideration has been mainly qualitative or used simple quantitative analysis; this is true of the original impact assessments by the Intergovernmental Panel on Climate

Abbreviations: ER, Engineering recommendation; OHL, Overhead line; PET, Potential evapo-transpiration; UKCP09, UK climate projections; UKMO, UK Met Office; WG, Weather generator; WRF, The weather research and forecasting model

* Corresponding author. Tel.: +44 131 6505612.
E-mail address: lucy.cradden@ed.ac.uk (L.C. Cradden).

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Change (IPCC), for the US (Smith and Tirpak, 1989) and UK (Climate Change Impacts Review Group, 1991) and more recent European assessments (Rademaekers et al., 2011). These used projected mean temperature changes and applied them to standard OHL rating methods. More sophisticated work by the UK Met Office (UKMO) and utilities (Buontempo, 2008; Harrison, 2008) used a subset of the data generated as part of the UK Climate Projections project (UKCP09) to explore impacts on the UK energy industry. The data subset consisted of a version of the UKMO Unified Model driven by an atmospheric climate model, HadAM3P (Buontempo, 2008). Single simulations of hourly weather data for current climate and for a future period indicate reductions in steady state OHL ratings under future climate with 'worst-case' ratings more significantly affected than the mean (Harrison, 2008). The results have been used by UK network operators in their climate adaptation statements (Electricity Networks Association, 2011) and feature in the 2012 UK Climate Change Risk Assessment (McColl et al., 2012). The worst case reductions in OHL ratings are estimated to be 8%–14% for distribution and 2%–4% at transmission by 2099. These arise from sensitivity factors of ~1.6%/°C for distribution and ~0.8%/°C for transmission, with the difference due to higher allowed transmission operating temperatures. The cost of rebuilds of affected circuits is estimated to be £1.3 billion by 2080 and although smart grids are stated to also be part of the solution, this is not elaborated on (Electricity Networks Association, 2011).

An important feature of the UKMO analysis is that due to low confidence in the wind speed output from climate models, potential changes in wind speeds were omitted from the methodology (Buontempo, 2008; Electricity Networks Association, 2011). Instead the focus was on identifying the change in extreme temperatures and lowest steady state rating within the range of possibilities. This is valuable and fits well with prevailing practice in defining OHL ratings. However, it misses an opportunity to gain a much richer picture of the distribution of ratings that occur as weather patterns vary throughout the year and into the future. This is particularly important as emerging experience with dynamic ratings of OHL (Michiorri et al., 2009; Yip et al., 2009) shows much variation in ratings throughout the year and that wind speed plays a major role in determining ratings. With dynamic ratings seen as a key smart grid technology and mooted as a climate adaptation measure (Rademaekers et al., 2011), there is a need for a method that allows the evaluation of dynamic OHL ratings within the framework of future climate change scenarios.

In addressing this challenge, the work described here makes use of the time-varying output from the UKCP09 probabilistic projections (which includes results from the model used in Buontempo (2008), among others), supplemented by additional wind modelling, to explore scenarios of future climate and the implications for the thermal rating of overhead lines. It is set out as follows: Section II provides an overview of the state-of-the-art climate change modelling for the UK, while Section III describes the methodology used for estimating ratings under future climate change and presents a simple temperature-based estimation of changes in static rating assumptions. Section IV presents the changes in climate as depicted by a model based on the UKCP09 weather generator. Section V explores the impact of these changes on OHL ratings and the risk of exceeding current assumed capacities. Section VI concludes the work by discussing the impacts and the scope for climate adaptation in the face of these changes.

2. UK climate change scenarios

Comprehensive, high resolution modelling of potential climate change effects in the UK and surrounding seas is provided by the UK Climate Projections (UKCP09, 2011). These are probabilistic projections of change for a range of atmospheric climate variables over the coming century under several "equally likely" emissions scenarios defined by the IPCC Special Report on Emissions Scenarios (IPCC, 2000). This valuable addition to the available models of future climate data moves beyond established practice in climate impacts analysis that makes use of single values for changes in temperature or other variables by a particular future time period under a given emissions scenario. By combining multiple models, UKCP09 better captures the inherent uncertainty associated with the climate projections for "high", "medium" and "low" emissions scenarios and fits with the trend of applying risk methods to infrastructure challenges.

For specific locations and most climate variables, UKCP09 provides continuous probabilistic estimates of the magnitude of change. For example, Fig. 1 shows the probability function for annual temperature change in the 2050s under a medium emissions scenario, derived for the region of eastern Scotland. The probabilities shown are cumulative, such that if the 10% value is X, it is 10% likely that the change will be less than X (and 90% likely to be greater). If the 90% value is Y, it is 90% likely that the change will be less than Y (and 10% likely to be greater). The 10% and 90% levels can be interpreted as the likely range of changes (i.e. minimum to maximum) expected for a given scenario. For the case shown in Fig. 1 the 10% level corresponds to a rise of around 1.2 °C, the 50% level to 2 °C and the 90% level to 3 °C.

The information can also be presented as a UK-wide map showing changes at a given probability level on a 25 km grid. Considering the 2050s with medium emissions again, the temperature changes at a 50% probability level shown in Fig. 2 indicate that over the whole year, the increase is more-or-less likely to be between 2 and 3 °C, and will be worse in the south than the north. Critically, although UKCP09 does now provide some probabilistic data for future wind speeds, it is accompanied by a 'health warning' concerning the high degree of uncertainty associated with the wind projections (Sexton and Murphy, 2010). Wind speed appears to be one of the most difficult climate variables to understand under conditions of climate change, and any data used must be accompanied by suitable information about the potential errors.

For applications that require coincident changes in multiple weather variables, UKCP09 provides a 'weather generator' (WG) (Jones et al., 2009), which produces synthetic time-series of several weather variables over a small area. Each 'pseudo' time-series are statistically representative of 30 years of weather under a specific set of large-scale scenarios of current or future climate conditions, with the variables being temporally consistent with each other within each simulation. An ensemble of at least 100 weather generator 'runs' of each 30 year period are needed for statistically robust results. The weather generator produces consistent time-series that include temperature and precipitation values, but crucially, the wind speed values are not explicitly provided due to the high degree of uncertainty associated with the future projections.

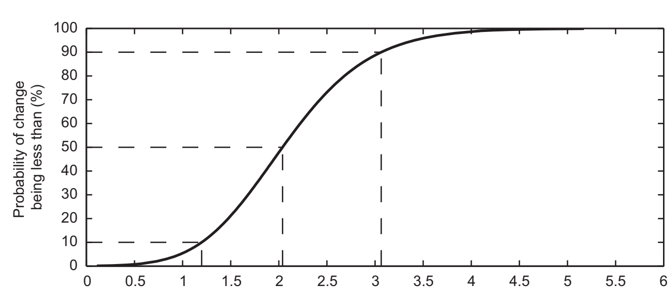

Fig. 1. Cumulative probability distribution for annual temperature change in Eastern Scotland in the 2050s under the 'medium' emissions scenario.