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Climate change mitigation with integration of renewable energy resources in the electricity grid of New South Wales, Australia

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ABSTRACT

The implementation of climate change mitigation strategies may significantly affect the current practices for electricity network operation. Increasing penetration of renewable energy generation technologies into electricity networks is one of the key mitigation strategies to achieve greenhouse gas emission reduction targets. Additional climate change mitigation strategies can also contribute to emission reduction thereby supplementing the renewable energy generation participation, which may be limited due to technical constraints of the network. In this paper, the penetration requirements for different renewable energy generation resources are assessed while concurrently examining other mitigation strategies to reduce overall emissions from electricity networks and meet requisite targets. The impacts of climate change mitigation strategies on the demand and generation mix are considered for facilitating the penetration of renewable generation. New climate change mitigation indices namely change in average demand, change in peak demand, generation flexibility and generation mix have been proposed to measure the level of emission reduction by incorporating different mitigation strategies. The marginal emissions associated with the individual generation technologies in the state of New South Wales (NSW) are modelled and the total emissions associated with the electricity grid of NSW are evaluated.

1. Introduction

Fossil fuel based conventional power plants produce a large amount of greenhouse gas (GHG) emissions. To mitigate climate change disorder in electricity generation, deployment of mitigation technologies for reduction of GHG emissions is essential [1–4]. Climate change mitigation techniques such as use of renewable energy resources in power generation including change in fuel mix, energy efficient appliances, demand side management strategies, and smart appliances can be applied to reduce emissions from electricity infrastructure [1,2]. Mitigation strategies are required to be developed for introducing such a transition in the well-established power sector. Assessment and quantification of the emission reduction ability for an electricity system with varying penetration of renewable power generation are required to achieve the national and international emission targets [5].

Several economic theories, such as integration of renewable energy resources in the grid, have been reported in the literature to assess the impact of climate change mitigation strategies on the electricity infrastructure. In Ref. [3], the author has presented a comparative analysis of the costs associated with and without implementation of GHG emission reduction policies for the Australian electricity sector. The authors in Ref. [4] have presented the simulated results detailing impacts of climate change mitigation technologies on power system. In Ref. [4], electricity generation cost, energy price, emission rate and transmission congestion are used as the performance indicators for the different technologies. However, cost may not be a suitable indicator of the mitigation ability of an electricity network, especially in the presence of different government incentive schemes and consumer willingness to pay for enacting climate change mitigation.

A composite GHG emission reduction model has been developed in Ref. [6] considering emission savings from renewable energy resources, and transmission and distribution efficiency improvements. The integration of renewable generation systems and adoption of carbon price are considered as the climate change mitigation strategies; and marginal emission is used as the performance indicator. In Ref. [7], marginal emission of the conventional generation system is used to compute the emission offset from the installation of wind generation systems. Variation in annual emissions is shown as the mitigation indicator for different installed capacities of wind generation systems. In Ref. [8], linear

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programming model is developed to assess the optimal generation mix for the electricity network with high penetration of wind power generation. The different options of generation mix are evaluated with the aid of different ramp rates of the associated generation technologies, transmission interconnection flexibility and energy storage flexibility in the network. In Ref. [9], the emission rate of coal and gas power plants is modelled and impact of system flexibility constraints on the penetration of intermittent generation systems in the electricity network is assessed. The authors of [10] have assessed the impact of system flexibility factor on the penetration of solar photovoltaic (PV) generation systems. It considers surplus energy, capacity factor and energy cost as the mitigation indices of the system. In Ref. [11], the effects of climate change mitigation technologies on the penetration of the solar PV system are investigated. System flexibility, energy storage systems and peak load shaving schemes are considered as the mitigation techniques, and the unit cost of energy is used as an indicator for the mitigating of the electricity system.

The emissions from different generation technologies are modelled in Ref. [12] considering the variations in the loading levels of the generating units. Emission factor, which is the average GHG emission associated with the per unit energy generation from the plant, is used to estimate the emission from the generation plant corresponding to the net energy generation [13–15]. In Ref. [14], emission factor of the input fuel is used to calculate the CO_2 emission from combined heat and power plants. In Ref. [15], emission factor is used to evaluate the emissions of the pollutant gases from the distributed cogeneration power plants. However, the GHG emissions from generation plants depend on the output of the generators and emission factor of the plant cannot incorporate the fluctuations in GHG emissions due to the varying output of the generators [16,17]. The dependency of CO_2 emissions of the coal fired power plant on the efficiency of the plant is considered in Ref. [16] in order to estimate the CO_2 emissions. In Ref. [17], an empirical function of generated power from the generators is used to estimate the emissions from the thermal power generation plants. A number of unit commitment algorithms can be found in the literature [1,17–20] to determine economic dispatch of generating units for emission reduction. In the emission constrained unit commitment presented in Refs. [1,17–20], empirical models of emissions have been formulated to estimate the total emission from electricity generation. In Refs. [1,17,21,22], constant emission factor and nonlinear functions of power output have been used to model the emission from generation plants.

The New South Wales (NSW) state government in Australia has set targets to contain emissions to the 2000 levels by 2025 and reduce emissions by 60% by 2050 [23]. In order to achieve the emission reduction target, mitigation strategies are set for different sectors such as energy generation, agriculture, transportation and industrial production. In order to reduce emission from electricity generation, renewable energy generation targets (RET) are set and additional schemes such as carbon tax, incentives on renewable generation systems, energy storage integration, introducing electric vehicles, use of energy efficient appliances are planned to be introduced [23]. These mitigation schemes have impacts on the NSW electricity network such as change in load demand, generation mix, generation flexibility, etc. Depending upon the changes in NSW electricity network, the emissions from electricity generation would be altered, and required renewable generation penetration to achieve NSW emission reduction target from electricity generation would be different. Hence, it is necessary to assess the impacts of climate change mitigation strategies on NSW electricity network and possible emission reduction from electricity generation systems with the increased penetration of renewable generation systems need to be investigated [24].

In this paper, the impacts of climate change mitigation strategies are assessed to achieve emission reduction targets with the increasing penetration of renewable energy generation in the electricity network. The mitigation indices based on the impacts of the mitigation strategies on the demand and generation mix are developed. Change in average demand, variation in peak and off-peak demand, generation flexibility and generation mix index are considered to evaluate the impact of climate change mitigation strategies on facilitating the renewable generation growth in the electricity network. The marginal emission of the individual generation plant is modelled using thermodynamic model of the plant. The emission model for the energy supplied in the grid from different generation plants is developed based on the fuel mix of the grid. The penetration levels of different renewable energy resources have been evaluated to achieve the set emission reduction target for NSW electricity grid.

2. Impacts of climate change mitigation strategies on electricity networks

The extensive usage of renewable energy resources within technical constraints can be one of the attractive options to reduce GHG emissions in the electricity networks. The penetration level of renewable energy generation and the emission offset from conventional i.e. non-renewable generation systems can be considered as indicators to examine climate change mitigation performance of the electricity infrastructure. It is noted that the relationship between emission reduction and penetration of the renewable energy generation is nonlinear [25]. For higher penetration, the emission reduction per unit installed capacity becomes lower due to the curtailment of excess energy. The penetration of the renewable resources can be expressed in terms of their installed capacity with respect to the peak load demand of the network. The emission offset due to the integration of renewable generation systems can be expressed by the fraction of emission reduced from the base case emission.

The conventional strategies and practices in electricity networks may not be significantly beneficial for achieving the emission curtailment target [1]. The uncertainties associated with the power availability from renewable resources, such as solar PV and wind generation, could be one of the major barriers for accommodating renewable generation systems in the electricity infrastructure. In order to accommodate high penetration of renewable energy resources in the electricity infrastructure, novel climate change mitigation strategies need to be developed. The implementation of energy efficient equipment, electric vehicles, demand side management schemes and fuel efficient generation plants can be considered as some of efficient strategies of climate change mitigation. The mitigation strategies can affect the load demand of the network and the operation of conventional, non-renewable generating resources. The effects of various mitigation strategies on the relationship between emission reduction and penetration level of renewable generation are required to be quantified for assessing the effectiveness of their applicability.

2.1. Impacts on electricity demand

Implementation of the energy efficient appliances, electric vehicles and demand side management can influence the average daily load demand in the network [26,27]. These mitigation strategies can change the daily energy consumption and hence the average daily load demand as shown in Fig. 1. The changes in daily load pattern of the network due to 10% increase and 10% decrease in average daily load are shown in Fig. 1. The average load demand shift can be expressed using (1).