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Increasing thermal plant flexibility in a high renewables power system

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HIGHLIGHTS

- Insufficient attention is given to potential flexibility of existing thermal plants.
- High penetrations of variable renewable generation create curtailment and ramping challenges.
- Strategies to reduce variability impacts using existing generation are identified.
- Fuel switching can accommodate more renewable generation and improve system ramping capability.

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ABSTRACT

Thermal generation is a vital component of mature and reliable electricity markets. As the share of renewable electricity in such markets grows, so too do the challenges associated with its variability. Proposed solutions to these challenges typically focus on alternatives to primary generation, such as energy storage, demand side management, or increased interconnection. Less attention is given to the demands placed on conventional thermal generation or its potential for increased flexibility. However, for the foreseeable future, conventional plants will have to operate alongside new renewables and have an essential role in accommodating increasing supply-side variability.

This paper explores the role that conventional generation has to play in managing variability through the sub-system case study of Northern Ireland, identifying the significance of specific plant characteristics for reliable system operation. Particular attention is given to the challenges of wind ramping and the need to avoid excessive wind curtailment. Potential for conflict is identified with the role for conventional plant in addressing these two challenges. Market specific strategies for using the existing fleet of generation to reduce the impact of renewable resource variability are proposed, and wider lessons from the approach taken are identified.

1. Introduction

As variable renewable energy establishes an ever greater role in global electricity systems, so demands placed on conventional generation are changing. With modern electricity systems expected to place significant reliance on thermal plant for decades to come, there are opportunities to refine the operation of such plant to help deliver energy policy ambitions.

Facing these evolving challenges, smaller country systems such as the island of Ireland are applying system non-synchronous penetration (SNSP) limits to ensure frequency stability and protect against unexpected supply/demand imbalances. Even smaller semi-isolated networks apply rules such as the three unit rule in Northern Ireland [1]. This squeezes out the potential for renewables to operate and drives costly curtailment. The case study of Northern Ireland is of international relevance. The ambitious renewables targets (40% by 2020 [2]) and small mix of generators there emphasise the challenges faced in integrating high levels of variable renewables.

Whilst long-term balancing options include demand response, energy storage or increased interconnection, these are expected to have a limited impact ahead of 2020. The value of storage for addressing curtailment issues has been investigated through a number of stochastic and deterministic modelling approaches. Multiple studies have shown there is value in energy storage technology in reducing wind curtailment [3–5], although they disagree on the economic breakeven points for such a solution. A European wide study by Bove et al. [6] identified that energy storage requirements are strongly influenced by the system's baseload (i.e. combined minimum stable generation level). This result indicates the importance of flexibility of thermal power plants as wind

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penetration increases. The study also indicated that in strongly correlated wind generation areas additional interconnection might not reduce the need for storage.

Curtailing wind is undesirable for a number of stakeholders, reducing renewable energy uptake as percentage of demand and therefore limiting the possibility and increasing the cost of meeting renewable targets. This challenge has been widely acknowledged in recent research, bringing calls for greater power plant flexibility [5,7,8]. Under current Grid Code rules [9], the system operator has to reimburse wind generators for required curtailment. However, eliminating wind curtailment completely is not seen to be economically optimal. A level of curtailment has a role to play in reducing transmission congestion [10–12]. Wind curtailment can also arise for unit commitment or load balancing reasons under high wind penetrations [13,14]. The argument has also been made that in a well-designed market, during periods of excess wind electricity prices would turn negative, giving wind power a signal for voluntary curtailment, or provide an incentive to invest in and operate other flexible technologies [15,16].

Sudden ramping of wind power output, in either direction, can have a substantial effect on the amount of electricity generated and the types and amounts of generating units required to mitigate its variability [17]. Increased cycling of existing generation can also increase wear on units, shorten their lifespans and increase the costs of maintenance [18]. A range of wind integration studies have examined wind ramping implications, using various approaches [19–26]. These studies neglect the detailed impacts and capabilities of conventional generating plant and typically only test short time series that cannot capture the rare significant swings in wind generation. Some studies have bridged generator dispatch and the analysis of wind ramping using stochastic approaches [22,27] but these are based on theoretical systems with simplified and aggregated characteristics, not individual plant parameters of a real system. Foley et al. [28] indicate that the impact of increasing wind ramping on the Irish grid has not received adequate attention.

This paper examines the steps that could be taken to respond to curtailment and ramping challenges introduced by variable renewables through improving existing thermal plant flexibility, a hitherto under explored area. Potentially advantageous plant modification strategies for an incumbent thermal coal plant are identified. An analytical approach is applied that identifies cost and carbon savings for each unit combination. This allows for analysis of local constraint parameters and tests the full range of variability seen across 32 years of wind data, rather than the fixed parameter/single year approach commonly used within power system (unit commitment and economic dispatch) models [14,26,4,29].

2. Analysis approach and energy system simulation method

The technical limit to acceptable wind levels without curtailment is driven by the minimum stable power level that conventional generator units can maintain whilst still satisfying system security constraints. This is known as a generator's *minimum stable generation* (MSG) output. This paper examines options to reduce curtailment within the NI system through reducing the local MSG. Specific attention is not given here to the all island system non-synchronous penetration (SNSP) limit, set to ensure sufficient inertia from synchronous plant to maintain stability. EirGrid and SONI [30] suggest a limit of 75% by 2020 should be feasible, up from a current SNSP of 50%.

2.1. A unit by unit simulation

Despite sharing common market trading arrangements, the Northern Ireland (NI) electricity system is operated separately from the Republic of Ireland (RoI). It consists of only a small number of generators (2.6 GW of dispatchable plant and 586 MW of wind) and no new conventional generation is planned [31]. It has a local peak demand of 1.8 GW and wind energy currently satisfies approximately 20% of annual demand. With limited interconnection, the System Operator (TSO) applies constraints, requiring certain generators to remain on at all times. Whilst there are plans to reinforce an AC tieline with RoI, this has faced repeated delays and uncertainty [32] and NI is effectively a sub-system.

Given these constraints, close examination of must run generation is needed. A system simulation tool has therefore been developed, as detailed in Fig. 1, which allows the analysis of all unit combinations, rather than seeking to solve the unit commitment problem locally e.g. [13,14]. Combinations are sought that reduce wind curtailment by minimising the output of thermal generation. However, lower plant generation levels have the potential impact of reducing thermal efficiency (by increasing the unit's *heat rate*)[1] and reducing system resilience to sudden changes in wind generation. The methodology developed here thus considers the system's ability to achieve suitable ramp rates and the carbon calculations made factor in heat rate increases. Perfect foresight and full ramping capability is assumed for the calculations (i.e. that during times of high wind generation, surplus plant will be taken offline so that only the minimum security *constrained on* plant mix remains).

Key model inputs and parameters are:

D	system demand hourly time series (MW h)
W_{on}	onshore wind generation hourly time series (MW h)
W_{off}	offshore wind generation hourly time series (MW h)
I_m	Moyle interconnector hourly limiting value (MW)
I_{ns}	north–south interconnector hourly limiting value (MW)
G_{msg}	unit minimum stable generation (MW)
G_{max}	unit maximum generation (MW)
R_u	unit upwards ramp limit (MW/min)
R_d	unit downwards ramp limit (MW/min)

Of the above parameters, D, W_{on} and W_{off} are dynamic values, whilst the others are static constraints of either the generation unit in question or of the system, as defined in Section 3.

2.2. Testing for curtailment and ramping

2.2.1. Curtailment calculation

Six input parameters introduced in Section 2.1 are used to determine the necessary balance of conventional generation G_b to create a balance of supply and demand for each half hour:

$$G_b = D - W_{on} - W_{off} - I_{ns} - I_m - G_{msg} \tag{1}$$

When G_b is negative (i.e. there is surplus supply to satisfy demand for any given half hourly period), this is assumed to be resolved by the system operator through curtailment (G_c) of the wind generation:

$$G_c = |G_b| \text{ if } G_b < 0 \tag{2}$$

2.2.2. Emissions calculation

The savings in carbon emissions when moving from one system MSG condition to another are calculated considering both the reduction in conventional generation and the change in carbon intensity of the generation mix. The average annual fuel carbon intensities are taken as those for the Irish SEM in 2010 (Table 1).

[1] Commonly used by generating plant operators, *heat rate* can be thought of as the inverse of efficiency. A higher heat rate infers a low efficiency, as more energy is required to produce a unit of electricity.