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Evolution of primary frequency control requirements in Great Britain with increasing wind generation

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ABSTRACT

With the increase of renewable generating capacity following the ambitious targets set by many governments for the next decades, there will be major changes in power generation and challenges for balancing transmission grids. In particular, primary frequency control requirements will be increased following a potential reduction of system inertia.

An assessment of the frequency response reserve needed is made through use of a simple model of the Great Britain transmission grid for different loads and wind power penetration. This model analyses the effect of changing the system inertia and the effectiveness of standard frequency response as well as dynamic frequency control support.

It is observed that an increased wind power generation requires substantial additional reserves for primary frequency control if the wind turbines do not contribute to the overall system inertia. However, it is also shown that these reserves can be dramatically reduced if the system is provided with fast acting response by dynamic frequency control support.

Introduction

Traditionally, electricity grids are dominated by synchronous generators linked directly to the grid, and the mechanical inertia in the rotating machinery provides inertia to the grid frequency such that imbalances in supply to demand result only in a relatively slow change of the grid frequency which can easily be corrected. However, with globally increasing contribution of power from wind and PV through inverters, this inertia is effectively reduced as inverters do not provide any intrinsic inertia. Furthermore, most renewable power can only be controlled through curtailing output, which is useful if supply exceeds demand, but not in the other case where demand exceeds supply. A critical case of the latter situation arises if there is a sudden loss of generation.

The British government (DECC) has set a target of delivering 15% of its energy demand from renewable energy sources by 2020 [1,2]. This is dictated by the Climate Change Act of 2008 setting a target of 80% reduction of CO_2 emissions (compared to 1990) by 2050, with at least a 34% reduction by 2020 and 60% reduction by 2030. In particular, the UK government is confident to achieve a 30% electricity generation from renewable energy sources [2]. This means that the installed generating capacity is likely to change dramatically over the next years and even further by 2030. Based on different scenarios, it is expected that transmission connected variable renewable generation will exceed the minimum load (and possibly even peak load) by 2030 as shown in Fig. 1 (further details provided in Table 1).

In all scenarios, the instant proportion of renewable generation on the grid, in particular wind power in the UK, will increase. Since the characteristics of this generation differs from conventional generation, it is important to study the need for changes in power system operation at times with high instant penetration level of wind power. As a reminder, the instant share of wind generation at time *t* is defined as the ratio of combined wind power fed into the network to the total output of all grid-connected generators at the particular point in time. This instant penetration level is key when assessing the impact of wind power generation on the grid.

One of the key challenges is to maintain the grid frequency within specified limits. In traditional large transmission systems, the combined electro-mechanical inertia of the rotating machinery directly linked to the grid provided frequency inertia which allowed enough time for corrective action [4–6]. The nature of both, the resource and the technology to convert wind power, do not necessarily contribute to that frequency inertia and additional reserve generation or control strategies have to be used [7–11]. The same also applies to other variable resources, such as PV [12].

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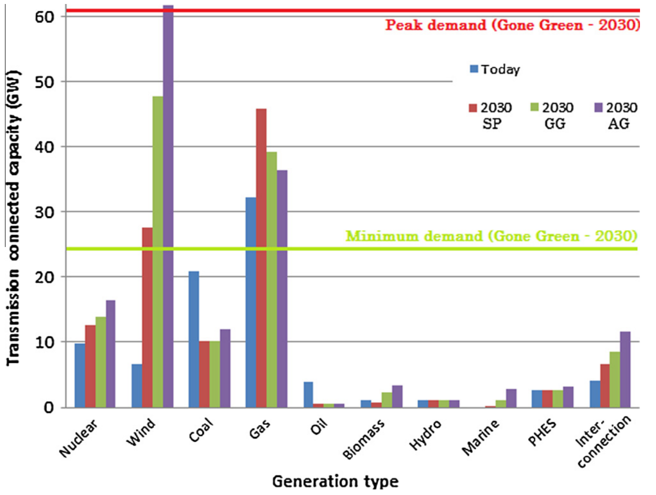

Fig. 1. Evolution of transmission connected capacity in Great-Britain by 2030 under various scenarios (data: National Grid [3]).

Table 1
Predictions of installed transmission-connected capacity evolution (data: National Grid [3]).

Type	Scenario	Installed capacity (GW)		
		2013	2020	2030
Nuclear	SP	9.9	9.5	12.6
	GG		9.5	13.9
	AG		8.7	16.4
Conventional thermal	SP	57.8	57	57.2
	GG		55.6	52.3
	AG		57.4	52.3
Hydro	SP	1.1	1.1	1.1
	GG		1.1	1.1
	AG		1.1	1.1
Wind	SP	6.8	13.4	27.6
	GG		25.6	47.7
	AG		33.0	61.6
Pumped storage	SP	2.7	2.7	2.7
	GG		2.7	2.7
	AG		3.3	3.3
Inter-connection	SP	4.2	5.2	6.6
	GG		6.6	8.6
	AG		6.6	11.6
Total (transmission-connected)	SP	82.7	88.9	101.8
	GG		101.1	127.5
	AG		110.4	149.3

When trying to reduce greenhouse gases emissions, not only generation directly feeding into the grid has to be considered, but also generation kept into reserve for system balance mechanism. In particular, part loaded conventional plants contributing to primary frequency control run at lower efficiencies, and the consequence is that the associated greenhouse gases emissions are increased [8]. It is therefore important to understand the effectiveness of frequency control strategies and their demand on the plant providing this to find ways to reduce their environmental impact as much as possible while providing security and quality of supply.

Aims and objectives

From all these impacts, this article focuses on the particular aspect of response capacity needed to cope with the loss of the largest generating unit on the UK transmission grid. This aspect of security of supply is particularly important for keeping the system operating within safe limits preventing blackouts due to cascading trip of generating units. With this focus in mind, the objectives of this work are to simulate and analyse the response of the grid following loss of generation under a range of demand and wind power conditions for a choice of frequency control strategies for the wind power. From these simulations, the required power level of response action to keep the grid frequency within the legal range is determined as the key measure.

The remainder of this section will first state the projected electricity generation targets and power quality constraints for the UK and then provide an overview over Great Britain's current power system and wind turbine generator technologies. Frequency regulation strategies and actions to ensure compliance with power quality constraints are introduced in Section "Frequency control stages". The model to investigate the response of the grid to primary frequency control actions is developed in Section "Simulation model". The simulation results are presented in Section "Results", and conclusions drawn for the future of frequency regulation in Section "Discussions and conclusion".

Future electricity generation in Great Britain

National Grid has published three reference scenarios [3] for future electricity requirements in Great Britain by 2030:

Slow progression (SP): the economy is restarting slowly after the crisis, with environmental targets met late.
Gone green (GG): the economy is restarting slowly with environmental target met according to schedule.
Accelerated growth (AG): the economy is restarting fast with significant growth and focus on environmental targets being met on schedule.

Fig. 1 and Table 1 show the associated changes in generating capacity to be expected by 2030 according to these scenarios. These three scenarios form the basis of the load and wind power conditions for our model.

Frequency standards in Great Britain

The nominal value of the grid frequency on European grids including that of the UK is $f_0 = 50$ Hz. Frequency standards are described in National Grid's *Security and Quality of Supply Standard* [13]. In particular, two requirements are of particular interest for this study, namely those concerning the power frequency following a *normal* or *infrequent* loss of generation, which are classified according to the magnitude of loss of power [14]:

- Following a normal loss of generation, specified as 1320 MW from April 2014, the frequency must not fall below 49.5 Hz.
- Following an infrequent loss of generation with a loss of 1800 MW, the frequency must return above 49.5 Hz within 60 s.

In line with the study's aims, these two threshold values of loss of generation were used in the model to investigate the level of generation response required to comply with these regulations for ranges of load-wind power situations expected within the scenarios outlined in Section "Future electricity generation in Great Britain".

Great Britain's transmission grid

National Grid is responsible for the system operation in Great Britain, in accordance with the terms of the Transmission Licence granted by the British regulator OFGEM. This transmission system