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Role of power-to-gas in an integrated gas and electricity system in Great Britain

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ABSTRACT

Power-to-gas (PtG) converts electricity into hydrogen using the electrolysis process and uses the gas grid for the storage and transport of hydrogen. Hydrogen is injected into a gas network in a quantity and quality compatible with the gas safety regulations and thereby transported as a mixture of hydrogen and natural gas to demand centres. Once integrated into the electricity network, PtG systems can provide flexibility to the power system and absorb excess electricity from renewables to produce hydrogen. Injection of hydrogen into the gas network reduces gas volumes supplied from terminals.

In order to investigate this concept, hydrogen electrolysers were included as a technology option within an operational optimisation model of the Great Britain (GB) combined gas and electricity network (CGEN). The model was used to determine the minimum cost of meeting the electricity and gas demand in a typical low and high electricity demand day in GB, in the presence of a significant capacity of wind generation. The value of employing power-to-gas systems in the gas and electricity supply system was investigated given different allowable levels of hydrogen injections. The results showed that producing hydrogen from electricity is capable of reducing wind curtailment in a high wind case and decreasing the overall cost of operating the GB gas and electricity network. The northern part of GB was identified as a suitable region to develop hydrogen electrolysis and injection facilities due to its vicinity to a significant capacity of wind generation, as well as the existence of gas network headroom capacity, which is expected to increase as a result of depletion of UK domestic gas resources.

Introduction

The UK government has ambitious plans to deploy renewable sources of energy and reduce greenhouse gas (GHG) emissions from the energy sector. As part of the EU 2020 target [1], the share of electrical energy generated from renewables needs to increase to approximately 30% by 2020. Furthermore, the UK is committed to reduce its GHG emissions by at least 80% (from 1990 levels) by 2050 [2].

Wind generation is projected to play an important role in achieving the UK's renewable and emissions targets. The onshore installed wind capacity is expected to increase to

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21 GW by 2035 from 5.5 GW in 2012 [3]. Offshore wind capacity is expected to increase to 12 GW by 2020, 28.6 GW by 2025 and up to 37.5 GW by 2035 [3]. As the penetration of renewable power increases, periods of excess generation will become more frequent and of larger magnitude. Previous studies [4,5] suggest electricity curtailment could reach 2.8 TWh per annum by 2020 and as much as 50–100 TWh per annum by 2050 depending on the amount of installed renewables. If storage is used the monetary value of storing this excess energy could be as high as £10 bn/year by 2050 [4].

The integration of large capacity of wind generation into the grid poses a number of challenges. Given that large wind farms (especially offshore wind farms) are located far away from demand centres, significant investment is required to build or reinforce the electricity transmission network to transport the power generated. The variability of wind power, which results in an annual capacity factor of 27%–35% [6], makes it difficult to justify the expansion of transmission capacity to accommodate the maximum wind power produced. Previous studies [6] showed that the curtailment of wind power is sensitive to insufficient transmission capacity, low consumer demand and installed must-run generation units such as nuclear. Currently, UK wind curtailment is 0.1 TWh/annum [5] and occurs primarily due to transmission line constraints. In a future scenario where the UK increases its nuclear power generation capacity alongside wind, curtailment will increase further.

Owing to a number of financial incentives supporting efficiency improvements (Green Deal, Energy Company Obligation) and a shift to electrified heating [7], the demand for gas to domestic dwellings is projected to decrease over the next few decades [3]. The decrease in gas demand combined with the depletion of the UK domestic gas resources is changing the pattern of gas flows in the National Transmission System (NTS), as shown by Fig. 1. In particular, the north-south gas flow is projected to decrease further despite the large capacity of the gas transmission network in Scotland.

Power-to-gas (PtG) converts electricity into hydrogen using the electrolysis process and uses the gas grid for the storage and transport of hydrogen. This method is different from conventional electrical energy storage systems, which absorb and output electrical energy (pumped storage, batteries). PtG systems produce hydrogen that can be blended with natural gas in a quantity and quality compatible with the gas grid. Fig. 2 shows a schematic of a PtG system. In a

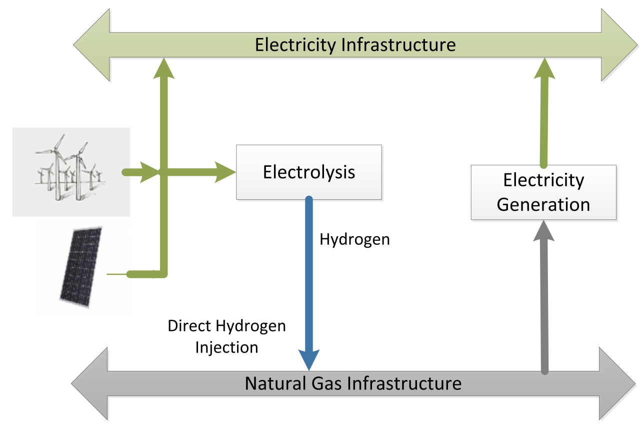

Fig. 2 – Power-to-gas system schematic.

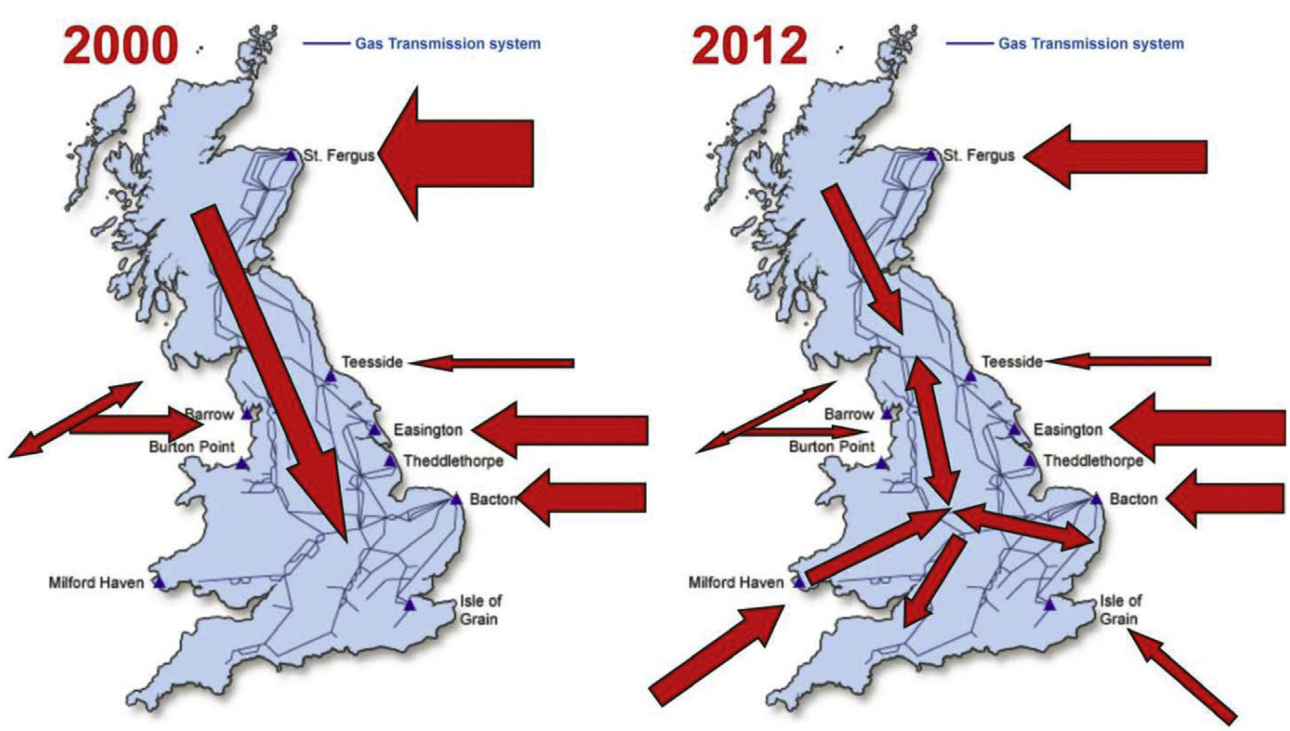

Fig. 1 – Gas flow pattern in the NTS [8].