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Benefits of demand-side response in combined gas and electricity networks

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HIGHLIGHTS

- Availability and cost of gas are crucial factors in power system planning.
- CGEN+ was developed to analyse expansion of combined gas and electricity systems.
- The model was enhanced significantly to take into account electricity DSR.
- The benefits of electricity DSR to GB gas and electricity networks were quantified.

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ABSTRACT

Active demand side response (DSR) will provide a significant opportunity to enhance the power system flexibility in the Great Britain (GB). Although electricity peak shaving has a clear reduction on required investments in the power system, the benefits on the gas supply network have not been examined. Using a Combined Gas and Electricity Networks expansion model (CGEN+), the impact of DSR on the electricity and gas supply systems in GB was investigated for the time horizon from 2010 to 2050s. The results showed a significant reduction in the capacity of new gas-fired power plants, caused by electricity peak shaving. The reduction of gas-fired power plants achieved through DSR consequently reduced the requirements for gas import capacity up to 90 million cubic meter per day by 2050. The cost savings resulted from the deployment of DSR over a 50-year time horizon from 2010 was estimated to be around £60 billion for the GB power system. Although, the cost saving achieved in the gas network was not significant, it was shown that the DSR will have a crucial role to play in the improvement of security of gas supply.

1. Introduction

The power system is increasingly integrating generation from renewable energy sources in order to reduce the reliance on import fossil fuels and to mitigate the Green House Gas (GHG) emissions. Electrification of heat and transport in the Great Britain (GB) is expected to have a substantial contribution to the reduction of the total GHG emissions [1]. However, these changes in generation mix and electricity demand will lead to an increasing peak demand and consequently network congestions which challenge the system security. Therefore, more capacity of peaking generation plants such as the fast start and flexible gas-fired generation is required. It is estimated in [2] that, around 1 MW of new peaking plant is required for every 8 MW of wind generation installed.

As expected in the GB Gone Green Scenario [3], the gas-fired generation capacity will increase from 27.5 GW in 2009/10 to 34.6 GW in 2020/21. The increases in the gas-fired generation capacity will cause increasing gas consumption in the GB. As illustrated by the GB system operator, National Grid, the percentage of GB import gas will rise to 62–83% by 2020 [4]. However, reliance on imports is usually expensive and may cause concerns over the security of energy supply.

An alternative solution to mitigate the pressure of peak demand on future GB electricity and gas supply networks is the implementation of Demand-Side Response (DSR) [5]. DSR is a set of measures that uses loads, local generation and storage to support network operations and also to enhance the quality of power supply. DSR encourages customers financially to lower or shift their electricity use at peak times. This will help manage the load and voltage profiles on the electricity network [6]. DSR is also able to manage the power consumption of demand in response to supply conditions.

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Nomenclature

Superscripts

y	type of power generating technology (e.g. nuclear, wind, CCGT)
l	location
t	planning time step
n	new infrastructure
d	decommissioned infrastructure

Variables

$\overline{C}$	capacity of infrastructure
$\overline{P}$	capacity of power generation

Parameters

A	winter availability of power plants
ACS	average cold spell electricity peak demand
τ^{peak}	number of hours representing peak period (2 h)
$\tau^{off-peak}$	number of hours representing off-peak period (11 h)
δ^{-}	average power shaving during peak hours (GW)
δ^{+}	average power increase in off-peak demand, shifted from peak hours (GW)

Abbreviations

CCS	Carbon Capture and Storage
CCGT	Combined Cycle Gas Turbine
DSR	Demand-side response
OCGT	Open Cycle Gas Turbine
Capex	Capital expenditures
Opex	Operating expenditures

Research and projects have been undertaken to develop different DSR mechanisms. At present, DSR mainly from the large-size industrial loads, is able to provide ancillary services at the transmission level, for instance, frequency response services [7] and operating reserves [8]. The employment of DSR will reduce the reliance on partly-loaded fossil-fueled generators to provide spinning reserve for the maintenance of the balance between supply and demand. National Grid has started to turn DSR into actions through the 'Power Responsive Campaign' [9] across the GB power system. It is admitted that DSR is able to reduce the conventional generation capacity, to maximize the low carbon generation, to contribute to short-term system balancing and to defer the network reinforcements [10]. By 2014, DSR has provided approximately 1.6 GW of reserve services to the GB power system [11]. Carbon savings will also be obtained through DSR. In [12], the carbon savings were quantified by applying DSR for different balancing services in the GB power system including the Short Term Operating Reserve, Triad and Fast Reserve.

The roll-out of smart meters will provide the opportunity to introduce time varying price schemes such as Time-of-use price to customers [13]. It is therefore expected that customers will change their power consumption as a result of the financial savings offered by the time varying price schemes. This will contribute to the reduction of peak demand. Different optimization problems were established in [14–19] to shave the system peak and therefore alleviate the distribution network congestions. The rescheduling of demand minimizes not only the total system costs but also reduces the user payments. As discussed in [20], using smart meter with the price-responsive demand response programs will make long term electricity markets more competitive and will enhance the system reliability. Refs. [21,22] integrate the residential demand response, which is a real-time control of shiftable appliances such as the electric water heaters, Heating, Ventilating and Air Conditioning (HVAC) loads, with locational marginal price in a distribution energy market. It is shown that the distribution network congestions and the GHG emissions were alleviated while the customers achieve cost savings in using electricity. Although there are certain regulatory barriers in applying DSR at the distribution level in terms of network tariffs, DSO remuneration, consumer protection, etc. that slow down the involvement in DSR especially from the small consumers in the distribution network as discussed in [23], the benefits of implementing DSR are still worth to be investigated in order to facilitate the transition to a low-carbon power system.

The impact of DSR in the operation of combined electricity and gas network was briefly discussed in [24,25]. These studies show that DSR is an effective way in improving the operational efficiency of the integrated networks, and can reduce the network congestions during the peak demand period. The benefits of DSR to gas supply networks in terms of long-term planning have not been investigated in the literature.

In this study, an integrated approach based on the Combined Gas and Electricity Networks expansion model (CGEN+) [31] was adopted to investigate the long-term value of electricity DSR to the GB power and gas supply systems. The dynamic coevolution of gas and electricity systems up to 2050s was taken into account to quantify the value of electricity DSR in terms of capital costs, operating costs and security of gas supply.

2. Potential flexible demand for DSR

Flexible demand for DSR refers to the loads varying the energy consumption in response to system needs with minimal disruption to load owners. Fig. 1 depicts the electrical demand sectors across the GB power system [26]. The domestic sector represents the sin-

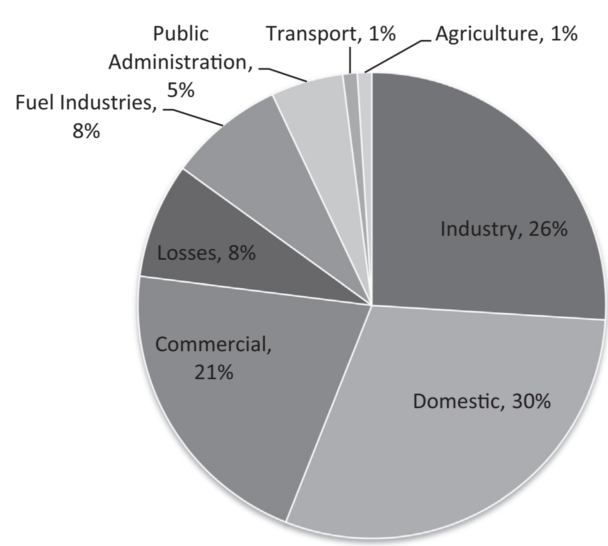

Fig. 1. Electricity demand of GB power system by sectors in 2012 [26].