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Efficacy of options to address balancing challenges: Integrated gas and electricity perspectives

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HIGHLIGHTS

- Variability of wind power poses operational challenges to power system.
- Roles of three options to address the operational challenges were evaluated.
- Electricity storage was shown to minimise energy losses due to wind curtailment.
- The flexibility options reduce the gas and electricity networks' operating costs.

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ABSTRACT

Integration of a large capacity of wind generation in the Great Britain (GB) electricity network is expected to pose a number of operational challenges. The variable nature of wind generation necessitates introduction of technologies that can provide flexibility to generation portfolios and therefore compensate for intermittency of wind generation. In this paper, the efficacy of three options to address electricity balancing challenges was evaluated: flexible gas-fired plants, electricity storage and Power-to-Gas system. The combined gas and electricity network model (CGEN) was enhanced and through adopting a rolling optimisation approach the model aims at minimising the operational cost of an integrated gas and electricity networks that represents a GB system in 2030. The potential impacts of employing each of the flexibility options on the operation of the integrated electricity and gas networks were investigated. The analysis showed that amongst all the flexibility options, the deployment of grid-scale electricity storage will achieve the highest reduction in the operational cost of the integrated system (£12 million reduction in a typical winter week, and £3 million reduction in a typical summer week). The results of this study provide insights on the system-wide benefits offered by each of the flexibility options and role of the gas network in the energy system with large capacity of wind generation.

1. Introduction

UK is committed to increase the share of renewable sources in the total energy consumption to 15% by 2020 [1] and 27% by 2030 [2], in order to achieve a longer term CO_2 reduction target of 80% in 2050 (to 1990 level). Given the significant wind energy resources across UK, wind generation will play a crucial role in achieving the renewable and emission reduction targets [3]. According to a number of low carbon scenarios studied by academics, industries and governmental bodies, capacity of wind generation in 2030 is expected to span between 52 GW and 65 GW [1].

Due to the variable nature of wind generation, increasing trend of wind farms integration into the GB power grid is expected to make the balancing of electricity supply and demand even more challenging [4–6]. Consequently, gas-fired generation will play increasingly important role in supporting balancing of demand and supply given that nuclear generation is inherently inflexible [4].

Gas-fired generation links gas and electricity networks. In the gas network, a gas-fired plant can be seen as a gas load, and in the electricity network this plant is an electricity supplier. Thus, utilising gas-fired plants to compensate for wind variability leads to variable gas demand for power generation [4].

Unlike electrical power, gas takes time to travel from supply sources (terminals and storage facilities) to demand centres. Linepack which is within-pipe storage capability of gas network is

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Nomenclature

Superscripts

i	gas injection into a storage facility
ω	gas withdrawal from a storage facility
ue	unserved electricity
ug	unserved gas
su	start-up
sd	shut-down
f	fuel cost of power generation
var	variable cost of power generation
av	average
$ecom$	electrically-driven compressors
dem	demand
$supp$	supply
inj	injection of electricity into storage
$avail$	this superscript indicates available wind power
abs	this superscript indicates the wind power absorbed by the electricity grid
cur	this superscript indicates the wind power curtailed

Subscripts

t	time
S	gas storage facility
b	electrical busbar
i	power generating unit
k	thermal generating unit
n	gas node
g	gas terminal
q	gas pipe
c	gas compressor
l	transmission line
e	electrolyser

Parameters & variables

C	cost (£)
P	electrical power (MW)
Q	volumetric gas flow rate in standard temperature and pressure (m^3/h)
$Ramp$	ramp rate (MW/h)
ρ	density of gas in standard temperature and pressure (0.8 kg/m^3)
p	gas pressure (bar)
$\overline{P}$	power generation capacity (MW)
$\underline{P}$	minimum stable generation (MW)
T	standard temperature (288 K)
$\underline{Z}$	gas compressibility (0.95)
$\overline{p}$	upper pressure bound (bar)
$\underline{p}$	lower pressure bound (bar)
v	ON and OFF state of a thermal generating unit (1/0)
UT	minimum up time for a thermal generating unit (h)
DT	minimum down time for a thermal generating unit (h)
r	spinning reserve (MW)
V	volume of a pipe (m^3)
η	efficiency (%)
LP	linepack (m^3)
α	polytropic exponent (1.27)
CPR	compressor pressure ratio
τ	amount of gas trapped by a compressor (m^3/s)
β	gas turbine fuel rate coefficient of a compressor
E	level of energy storage (MW h)
D	diameter of a pipe (m)
L	length of a pipe (m)
R	gas constant (518.3 J/kg K°)
H	the constant to convert energy content of hydrogen to its equivalent natural gas volume (90.9 m^3/MW h)
ts	length of time step (1 h)
$WindP$	wind power (MW)

therefore a key factor that enables gas network to deal with rapid changes of the gas demand locally. Gas network operators tend to maintain a certain level of linepack, for example National Grid balances linepack of the GB National Transmission System (NTS) every 24 h.

Growing variability and unpredictability of gas demand for power generation, caused by increased penetration of intermittent wind and inflexible nuclear generation will adversely affect linepack and make its management more difficult. Real operational data from National Grid shows that the within-day linepack of the GB NTS in 2012 fluctuated with larger magnitude compared to 2002 (Fig. 1). This is due to increased wind generation capacity and also partly as a result of closure of several gas holders in gas distribution networks [7].

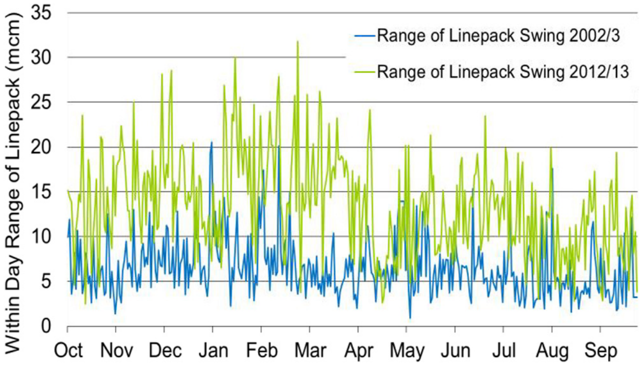

Fig. 1. Comparison of within day Max-Min range of NTS linepack (mcm).

In addition to flexible gas-fired plants, there are other flexibility options that can be employed for addressing balancing challenges such as demand-side response, electricity storage and power-to-gas system. Electricity storage can facilitate integration of wind to the grid and also affect the operation of gas network through smoothing variation of power output from gas-fired plants. Power-to-gas concept is to utilise electrolysers to convert electricity to hydrogen and then inject it into the gas network. Power-to-gas system can enhance the ability of system to integrate variable wind generation and reduce its curtailment through converting the excess wind and nuclear power to hydrogen, and affect the gas network operation by introducing new sources of gas in the network [8].

Several studies have investigated the role of flexibility options in addressing the balancing challenges. Ref. [9] studied and quantified key parameters of thermal power plants that influence their flexibility in future power systems with a large capacity of variable renewable generation. It was shown although the flexible plants will have a crucial role in balancing electricity supply and demand in future, significant changes in the current market design needs to be made in order to encourage investments in flexible plants. In [10], the effectiveness of demand side response to deal with adverse impacts of the large integration of wind generation into power systems was investigated. Using real option analysis, authors in [11] evaluated optimal investments in hydrogen storage