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Techno-economic assessment of battery storage and Power-to-Gas: A whole-system approach

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Abstract

The power systems in many countries are undergoing a radical transformation through employing a large capacity of renewable generation technologies such as wind turbine and solar photovoltaic. The power generation by wind and solar resources are variable and difficult to predict. Therefore, growing capacities of such technologies is expected to introduce challenges regarding balancing electricity supply and demand. This paper investigates the role of battery storage and power-to-gas systems to accommodate large capacity of intermittent power generation from wind and solar and therefore facilitates matching electricity supply and demand. The Combined Gas and Electricity Networks (CGEN) model was used to optimize the operation of gas and electricity networks in GB for typical weeks in winter and summer in 2030. The role of different capacity of battery storage and power-to-gas systems in reducing the wind curtailment and operating cost of the system were quantified and compared with the annualized cost of these technologies.

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Keywords: Energy Systems Integration; Gas Networks; Power Systems.

Nomenclature

$CAPEX$	Capital Cost
CRF	Capital Recovery Factor
i	Discount rate (%)
n	life time (years)

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1. Introduction

The United Kingdom has legally binding targets to increase the share of renewable sources in electricity generation mix. Due to the abundant wind resources across the country, wind is expected to play a very important role in the future generation mix [1].

The intermittent nature of wind speed and the resultant electric power output poses challenges to the balancing of electricity supply and demand. In Great Britain (GB) in particular, gas-fired generators are expected to compensate for the variations in wind generation, and therefore accommodate increased integration of wind generation. However, the frequent ramp up and ramp down of gas-fired generators caused by wind intermittency is transferred to the gas network and result in more variable gas demand for power generation [2].

There are number of potential solutions to address the supply and demand balancing challenge, from which battery storage and power-to-gas were assessed in this paper. The value of these options in the operation of integrated electricity and gas networks were quantified for a low carbon energy system in 2030.

1.1. Battery storage

Battery Energy Storage Systems (BESS) have seen significant growth in recent years. Though some of this will be research-driven, it can be assumed that in many regions of the world, the benefits of battery storage now outweigh the significant capital investment costs.

The need for energy storage has increased with the increasing deployment of renewables. For power system security to be maintained, demand and generation need to be matched at all times. With traditional thermal generation, output can be varied to match demand. Given the recent success of lithium-ion, this paper will focus on that technology.

Much of the interest in lithium-ion battery costs has focused on battery cells for electric vehicles because of the interest in when electric vehicles may become cost-competitive with combustion engine vehicles. The capital costs in 2030 is estimated to range from $150 to $300 per kWh, a reduction of approximately 50% from 2014 prices [3].

1.2. Power-to-Gas (P2G)

Power-to-Gas is the use of excess renewable electricity from power grid to produce hydrogen via electrolysis process and inject the hydrogen into the existing gas network. The structure of P2G is shown in Fig. 1 [4]. P2G systems can be operated to [5]:

- absorb otherwise curtailed wind and solar electricity
- use a combination of grid electricity and local renewable electricity to produce low carbon gas and consequently contribute to decarbonizing heat sector
- operate on a time base that meets load levelling and balancing services objectives.

The potential of large scale integration of hydrogen technologies in balancing the Spanish power system was studied in reference [6]. Qadrdan et al [4], investigated the role of P2G in an integrated gas and electricity system in Great Britain, and showed that P2G has a significant potential to reduce wind curtailment that caused by insufficient power transmission capacity. Furthermore, it was shown that injecting the hydrogen produced from renewable electricity into the gas network contributes to the reduction of gas import dependency.

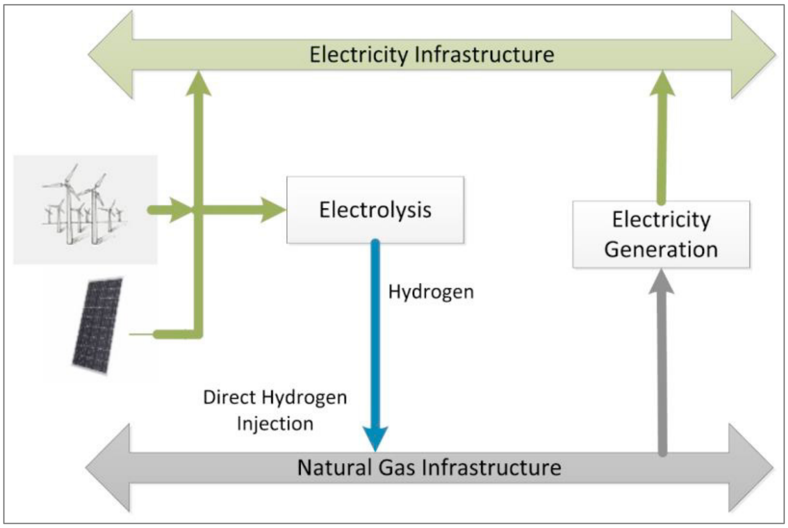

Fig. 1. Structure of a P2G in integrated gas and electricity system [4]

2. Methodologies

In this study, the Combined Gas and Electricity Networks model (CGEN) [7], was used to assess the role of BESS and P2G in the operation of electricity and gas networks in GB. CGEN model investigates the optimal operation of gas and electricity networks and quantifies the reduction in the operating cost of the system achieved through the employment of BESS and P2G. In order to assess the economic feasibility of BESS and P2G, the reduction in annual operating cost for each of these options were compared to their annualized capital cost of these technologies.

2.1. Combined Gas and Electricity Networks model (CGEN)

CGEN is an optimization model that simultaneously minimizes the operational costs of gas and electricity transmission system. The objective function of the optimization problem includes fuel and variable operation and maintenance costs of power generation, in addition to the cost of gas supply and cost of unserved energy.

The operating characteristics of gas and electricity networks such as maximum generation and ramping limits of power plants, gas flow along pipes, fuel consumption by compressors were considered in CGEN model as constraints. The components considered in CGEN is shown in Fig. 2. Detailed descriptions and formulation of CGEN model is reported in [7].

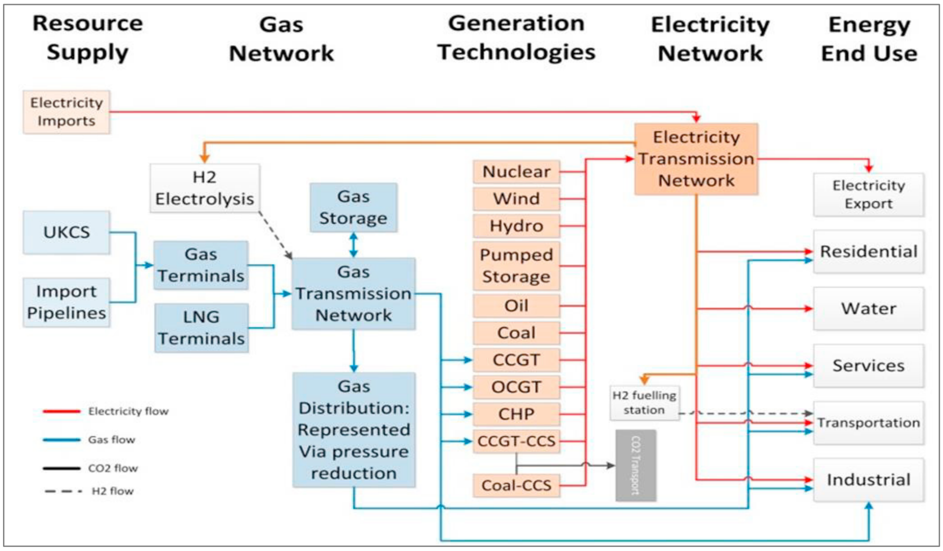

Fig. 2. The structure of CGEN model [7]

2.2. Annualized cost of BESS and P2G

In order to assess the economic feasibility of BESS and P2G in gas and electricity networks, the annualized costs of these technologies were calculated and compared with annual saving in the operating cost of the gas and electricity networks. Eq. 1 was used to annualize the capital cost of technologies:

$$Annualized\ Cost = CAPEX \times CRF \tag{1}$$

where, *CAPEX* is capital cost of the technologies and *CRF* stands for Capital Recovery Factor. *CRF* is calculated using Eq. 2:

$$CRF = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{2}$$

where, *n* is the life time of the technologies, and *i* is discount rate which was assumed 10% in this study.

For BESS, from reviewing different literature and in particular reference [8], the cost of a 4MWh BESS with inverter size of 1 MW was assumed to be around £0.7 million in 2030. For P2G, the capital cost also was assumed to be £0.7 million per MW hydrogen production [5].

3. Case Studies

The role of BESS and P2G in meeting the balancing challenges of supply and demand was studied in typical summer and winter weeks in 2030 in GB. To quantify the value of BESS and P2G in the operation of gas and electricity networks, different capacities of these technologies (i.e., 5 GW, 10 GW, and 15 GW) was installed in the power system. The input data including available wind, gas and electricity demands have been taken from [7].

3.1. Gas and electricity networks

A future GB electricity and gas networks were represented using Fig. 3 [9]. The figures illustrate the topologies and spatial granularities of gas and electricity networks.

3.2. Power generation mix

The operation of a GB integrated gas and electricity system with large capacity of wind generation (Table 1) was modelled over typical winter and typical summer weeks in 2030. The value of different capacity of BESS and P2G to address electricity balancing challenges and reduce the operating costs of gas and electricity networks was evaluated.

Table 1. Power generation mix and marginal cost of electricity generation [1].

Generation technology	Capacity (GW)	Marginal cost (£/MWh)
Nuclear	9	7
Coal with CCS	4.5	22
Gas	33	2.3* + Locational gas price
Wind	52	0
Pumped storage	2.7	NA
Interconnector	11.5	100

* £2.3/MWh is variable operating cost for gas-fired generating plants

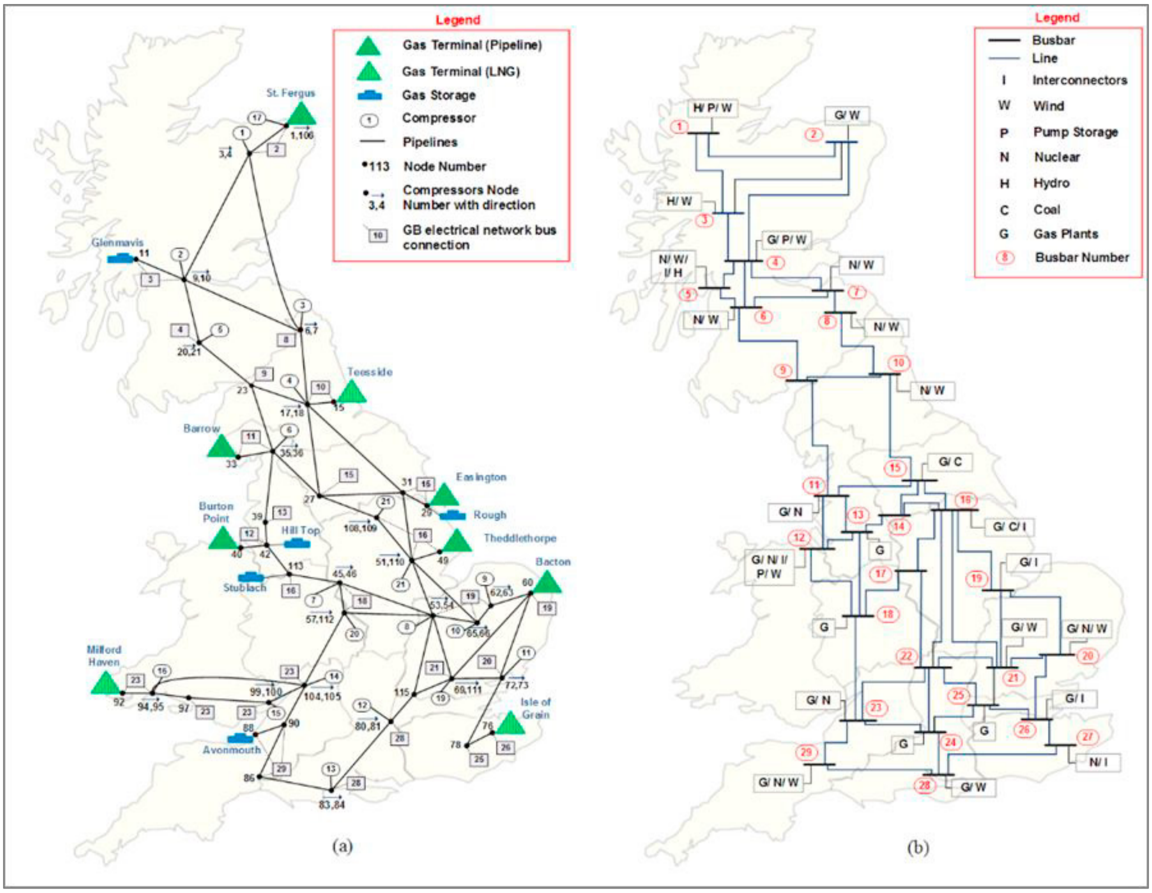

Fig. 3. GB transmission networks [9] : (a) gas network (b) electiricty network

4. Results and Discussions

In Fig. 4, the curtailed wind generation in different cases is presented. Through employment of BESS and P2G technologies, the wind curtailment is reduced and more wind is injected to the grid. Additionally, it is concluded that the P2G technology could play an important role in accommodating more wind in the system. It is shown that in summer and winter weeks almost the wind was completely absorbed by the grid and no wind curtailment was occurred.

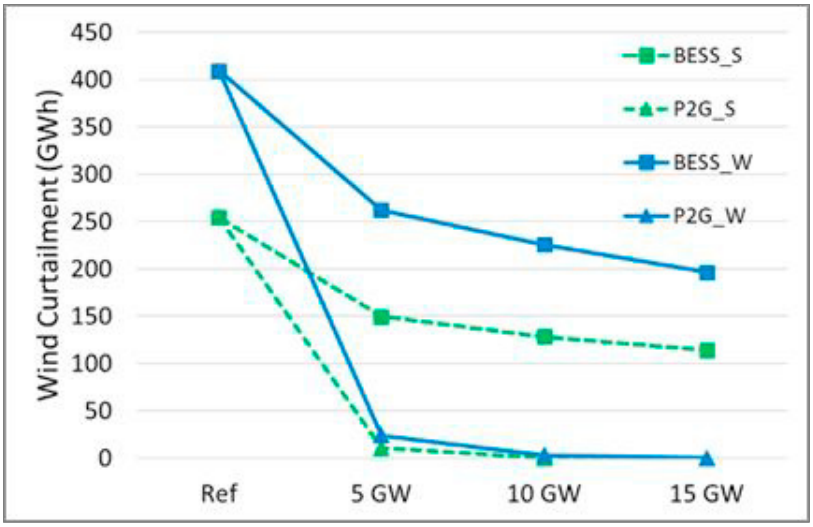

Fig. 4. Cumulative wind curtailment in different case studies

Fig. 5 shows the saving in operating cost achieved by different size of BESS and P2G in a winter typical week and in a summer typical week. The BESS offers promising cost savings in particular in the winter week, and its contribution in saving operating cost increase by increasing its capacity. The larger saving in operating cost of the gas and electricity system in winter is due to the reduction of the share of the peaking power plants in which has high marginal generation cost in meeting electricity demand.

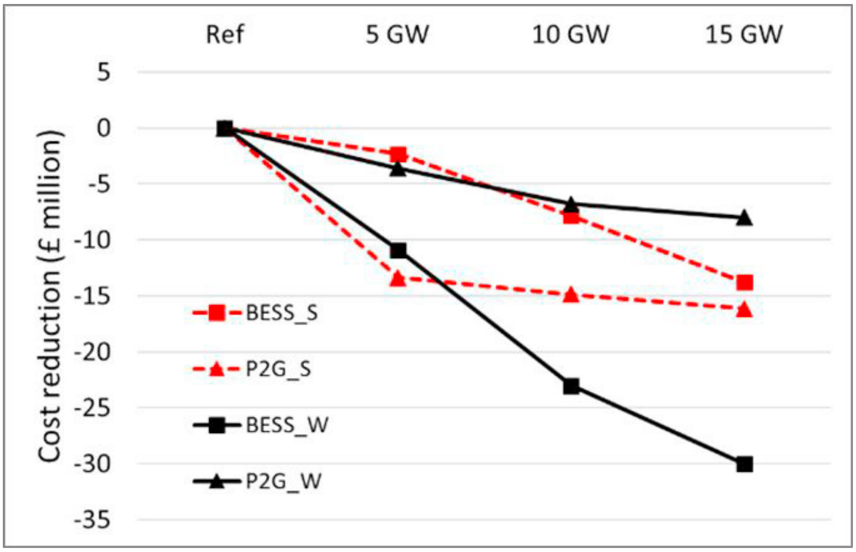

Fig. 5. Saving in operating cost achieved by BESS and P2G in a week in summer and a week in winter

In the case of P2G, the cost saving in the winter week is lower compared to the summer week. This is because in the summer week demand is low and wind curtailment is larger compared to the winter week, therefore, the P2G is utilized more extensively in the summer week and avoids the waste of the electricity from wind and produce free gas.

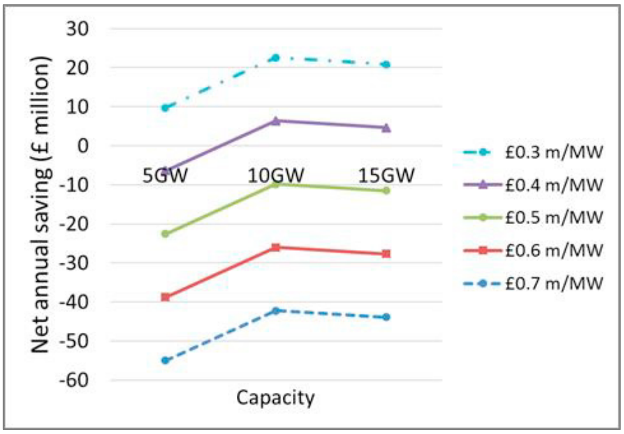

Fig. 6. Net annual savings by different capacity of BESS

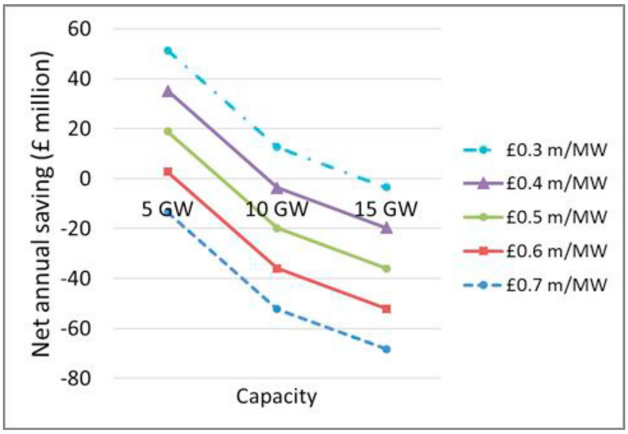

Fig. 7. Net annual savings by different capacity of P2G

Fig. 6 and 7, present net annual saving in operating cost of the gas and electricity system for different assumptions of capital cost and different capacities. It is shown that employment of BESS and P2G is economically feasible, when the annualized capital cost of these technologies is less than £0.4 m/MW and £0.5 m/MW, respectively. In this study, the optimal size of BESS was 10 GW since through increasing the size of BESS to 15 GW, the annual savings was decreased. Moreover, through increasing the capacity of P2G facilities, the value of this option was reduced due to the high capital costs compared to the operational cost savings.

5. Conclusions

This paper investigated the role of battery energy storage system (BESS) and power-to-gas (P2G) system in addressing electricity balancing challenges. The value of these technologies in reducing operating costs of the gas and electricity systems in GB was quantified for different capacity and capital cost assumptions. Both technologies offer promising contributions to reducing the operating cost, however their investment can be justified only when the capital cost of the technologies reach a threshold. This threshold is £0.5 m/MW for P2G, and is £0.4 m/MW (and 2 MWh storage capacity) for BESS.

Acknowledgements

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