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Optimization of Heat Sector Decarbonization Strategy through Coordinated Operation with Electricity System

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Abstract

Heat networks (HNs) and heat pumps (HPs) are potential low-carbon heating technologies that can deliver the 2050 carbon target reduction in the UK. The optimal design of the heating system on a national scale to maximize the economic benefits while satisfying carbon target remains an open question. By applying the HN investment model and the integrated heat and electricity system model, this paper compares the decomposed system cost of HNs, hybrid HP-Bs (HPs and gas boilers) and air source HPs (ASHP), analyzes the impact of different heating strategies on the operation and investment of the electricity system, and presents the optimized strategy for heat sector decarbonization. According to the cost assumption, hybrid HP-Bs based approach may have significant economic advantage over the other two heating technologies when each of these is applied individually, while HNs in urban areas play an important role in the optimized heat technology portfolio.

Keywords: Integated energy system; Heat networks; Hybrid heat pumps; Thermal energy storage; Optimization

1. Introduction

Heating accounts for approximately half of total energy consumption and one third of carbon emission in the UK. To meet the target of 80% carbon reduction by 2050, alternative heating technologies are required to replace gas boilers that currently predominate in UK. HNs and HPs are two of the potential low-carbon heating technologies. As links between heat systems and electricity systems, the investment strategy of HNs and HPs can be influenced by the

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investment and operation of the electricity system. Therefore, it is essential to analyze the advantages of each heating technology in the integrated heat and electricity system.

An HN dispatch model is presented in [1], showing that benefits can be achieved through the cooperation of different components in HNs (e.g. CHP, TES, electric boilers, etc.), concluding that HNs have the potential to alleviate the curtailment of wind. An integrated heat, gas and electricity operation model, which focuses on the dispatch strategy of CCHP to accommodate more renewable energy is developed in [2]. Reference [3] proposed a whole-system model of the electricity system which can optimize the investment and operation cost of generation, transmission, distribution and demand side on a national level. The economic and operational features of different types of hybrid HPs is compared in [4] within an multi-energy system model on Irish level, indicating that hybrid HP-B system has an advantage over the other types of hybrid HPs. References [5] and [6] present different model to optimize the investment and operation cost of HNs on local level, while the application of industrial HPs in HNs is investigated in [7] and [8].

This paper compares the decomposed system cost of HNs, hybrid HP-Bs and air source HPs in an integrated heat and electricity system on a national level, optimizing the total system operation cost and investment of generation, transmission/distribution networks, HNs and heating devices, analyzing the impact of different heating strategies on the investment of electricity system, and presents the optimized strategy of heating technology investment.

2. Modelling methodology

2.1. Integrated electricity and heat system model

This section presents the novel integrated heat and electricity system model with Fig. 1 illustrating all the components and energy flow in this model. The model is formulated as an MILP problem with hourly time resolution across a whole year. The objective function (1) is to minimize the total system operation cost and investment of generation, transmission/distribution networks, HNs and heating devices (including end-use and industrial HPs, TESs as well as CHPs):

$$Min\ \varphi = \sum_{t=1}^{T}\sum_{j=1}^{L} C_{t,j}^{op} + \sum_{i=1}^{G}\sum_{j=1}^{L} \pi_{\mu_i} \cdot \mu_{i,j} + \sum_{i=1}^{F} \pi_{f_i} \cdot f_i + \sum_{i=1}^{DN} C_{dn} + \sum_{i=1}^{L}\sum_{k=1}^{A} C_{hn} + \sum_{j=1}^{L} hd_{t,j} \tag{1}$$

Where *T, G, L, F, DN, A* and are sets of operating snapshots, generation types, locations, transmission paths, distribution networks, area types respectively; π_μ and π_f are unit investment cost of generators and transmission lines; μ and f are installed capacity of generators and transmission lines; C^{op}, C_{dn} and C_{hn} are the functions of operation cost, distribution network reinforcement cost and HN investment cost respectively; hd denotes the investment cost of heating device.

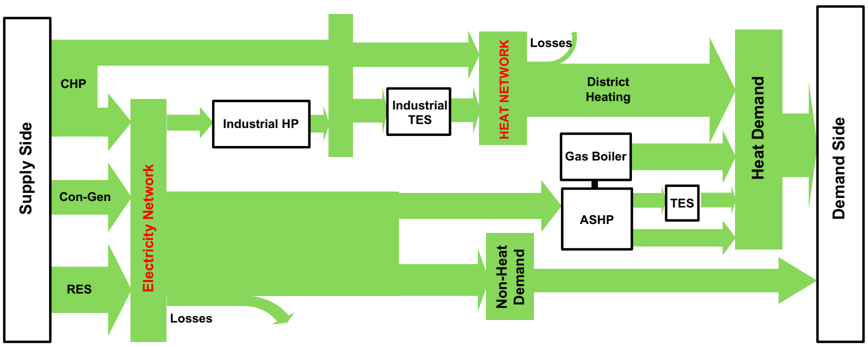

Fig. 1. Energy balance of the integrated heat and electricity system

Electricity balance constraints: Electricity supplies comprise renewable energy source (res) (including wind and PV generation), conventional generation (g) (including nuclear power, conventional power and CCS plants) and CHP