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Coordinated scheduling strategy to optimize conflicting benefits for daily operation of integrated electricity and gas networks ☆

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HIGHLIGHTS

- The models of electricity and gas networks are presented.
- A coordinate scheduling strategy (CSS) is proposed to optimize conflicting benefits of the two networks.
- The CSS is proved to be effective for the optimization problem.
- The interdependency between the electricity and gas networks is analyzed.

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ABSTRACT

The increasing share of variable renewable energy sources and the improving requirements on system security and reliability are calling for important changes in our energy systems. The synergies between energy supply networks are of great importance to satisfy the development of the integrated energy system (IES). Hence this paper presents the study of the coordinated scheduling strategy (CSS), in which, the models of the electricity network and gas network are developed in detail, and the operation constraints of the networks are fully considered. The purpose of the CSS is to optimize the conflicting benefits of the electricity network and gas network for daily operation of the IES, while satisfying the operation constraints. In the CSS, a multi-objective optimization algorithm is applied to obtain a Pareto-optimal solution set, and a multiple attribute decision analysis (MADA) using interval evidential reasoning (IER) is developed to determine a final optimal daily operation solution for the IES. Simulation studies are conducted on an IES consisting of a modified IEEE 30-bus electricity network and a 15-node gas network to verify the effectiveness of the CSS, and to evaluate the interdependency between the electricity network and gas network.

1. Introduction

Until now, worldwide demand for natural gas has increased from 32% in 2007 to 39% in 2009 [1], and it is estimated to grow at a rate of 2.9–3.2% per year until 2030 [2]. With the high integration of natural gas in electricity power systems, the synergies between the gas network and electricity network are dramatically increasing in order to reduce the operation cost and satisfy the stringent environmental regulations [3].

As a significant kind of gas consumers, the gas-fired generator keeps a rising proportion of the total generating capacity in power systems in the last decades, owing to low cost, low carbon emission and fast response [4]. As an energy conversion equipment transforming natural gas to electricity power, the gas-fired unit serves as a linkage between the electricity network and gas net-

Abbreviations: AC, Alternative Current; CCHP, Combined Cooling Heating and Power; CHP, Combined Heating and Power; CSS, Coordinated Scheduling Strategy; CT, Computation time; DC, Direct Current; DHC, District Heating and Cooling; D-S, Dempster-Shafer; ER, Evidential Reasoning; GSC, Gas Supply Cost; HV, Hypervolume; IER, Interval Evidential Reasoning; IES, Integrated Energy system; MADA, Multiple Attribute Decision Analysis; MED, Mean Euclidian Distance; MGSO-ACL, Multi-objective Group Search Optimizer with Adaptive Covariance and Lévy Flights; NPS, Number of Pareto-optimal Solution; NSGA-II, Non-dominated Sorted Genetic Algorithm II; PGC, Power Generation Cost; SCUC, Security Constrained Unit Commitment; SI, Spacing Index; SOO, Single Objective Optimization; TC, Total Cost; UC, Unit Commitment.

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work. More importantly, with the development of distributed renewable resources and district energy demands [5,6], the interconnections between the electricity network and gas network extend from the gas-fired generators to various types of connectivity nodes, such as distributed heating and cooling loads [7,8], combined heating and power (CHPs), combined cooling heating and power (CCHPs) [9,10]. Therefore, the interactions between the two networks are playing more and more important roles along with the development of IES.

The synergies between the electricity network and gas network have great influence on the two networks from the viewpoint of economics and security [11]. From the economics point of view, the gas contracts of price and total generation could affect the unit commitment, economic dispatch and daily scheduling of the electricity network. From the security point of view, pressure losses, pipeline contingencies, compressor outages or supply disruptions might lead to forced outages of thermal units or load shedding [12]. Consequently, the synergies between the electricity network and gas network embedded in the IES are worth being investigated for the purpose of economics and security.

Extensive research has conducted on the planning and operation of the combined electricity and gas networks. In [13], the authors presented the development of a security-based methodology for short term security constrained unit commitment (SCUC) considering the impact of natural gas transmission constraints. Pricing flexible natural gas supply contracts under uncertainty in hydrothermal markets was discussed in [14]. However, these papers considered either the unit commitment (UC) of power system or the pricing of natural gas supply contracts as the master problem rather than treated the electricity network and gas network equally.

The natural gas and electricity optimal power flow was discussed in [15]. Combined gas and electricity network planning of expansion and energy hubs were presented in [16] and [17], respectively. In [18], an interval optimization based operating strategy for gas-electricity integrated energy systems was proposed. The demand response and wind power uncertainties were taken into consideration. The authors of [19] proposed a long-term interdependency of natural gas and electricity infrastructures, incorporating the natural gas transportation planning objective in the co-optimization planning of power generation and transmission systems. In most of the previous research, only the gas-fired generator has been considered as the linkage between the electricity network and gas network [14–19].

With the increasing of the types of renewable energy resources and energy demands, it is of great importance to extend the synergies of the two networks from the single type to various other types like distributed generators and district heating and cooling loads [7,8,20]. Moreover, as the proportion of gas consumption rise, the gas network plays a significant role as the electricity network from the perspectives of economics and security. Hence it is wise to treat the gas network and the electricity network coordinately.

This paper proposes a CSS to optimize conflicting benefits for the daily operation of the electricity and gas networks embedded in the IES. In the combined electricity and gas networks of the IES, we regard both the gas-fired generators and distributed district heating and cooling systems (DHCs) [21,22] as the interconnections between the two networks. In the case that the two networks are managed by one company operating electricity and gas networks together, the CSS could be achieved without any further effort. In the case that the two networks are managed by two different companies separately, the CSS could be achieved by a joint effort provided by a third party with negotiation between the two companies considering their own business interests and being committed to their social duties. In addition, the linkages of the two networks, gas-fired units, serve as gas consumers of the gas network, but electricity power suppliers of the electricity network, which means that the optimal daily operation of the integrated electricity and gas networks must make compromise of their own benefits through the synergies.

The CSS consists of a multi-objective optimization procedure and a MADA for the daily operation scheduling of the IES. Based on the multi-optimization model developed in this paper, the multi-objective optimization procedure is adopted from the Multi-objective group search optimizer with adaptive covariance and Lévy flights (MGSO-ACL), which is proved to be efficient for the multi-objective optimization of the IES [22]. After the Pareto-optimal set obtained by the multi-objective optimization procedure, the MADA using an IER is utilized to select a final operation solution with adequate evidence fully considering the multiple criteria of the electricity and gas networks and the society interests. In this way, the daily operation of the two networks with conflicting benefits can be tackled with a compromised scheduling solution.

The rest of the paper is organized as follows: Section 2 formulates the models of the electricity and gas networks interconnected in the integrated energy system. The coordinated scheduling strategy for the daily operation of the IES is developed in Section 3. Section 4 carries out the simulation studies to verify the performance of the CSS developed for the daily operation of the IES, and to evaluate the interdependency between the two networks. Finally, the last section draws the conclusion of this paper.

2. Integrated electricity and gas networks modeling

The proposed model of electricity network and gas network integrated in the IES can be illustrated in Fig. 1. The system includes electricity transmission system, gas supply system, gas-fired generator, electricity load, gas load and heating and cooling load. The electricity network and gas network are closely interconnected by the gas-fired generator and distributed DHC, which can be treated as energy converters between these two energy networks. Noted that the distributed DHCs addressed in this paper consider the energy input of electricity power and natural gas to serve the heating and cooling load. The models of the electricity network and gas network are described in detail as follows, respectively.

2.1. Gas network model

The gas network is most commonly composed of gas well, gas pipelines, gas compressors, interconnection points, gas storage stations and gas loads [23,24]. In this paper, gas pipelines, compressors, gas loads and interconnection points are taken into consideration. The gas well is treated as a constant pressure interconnection point, and it is assumed that the compressors are dri-

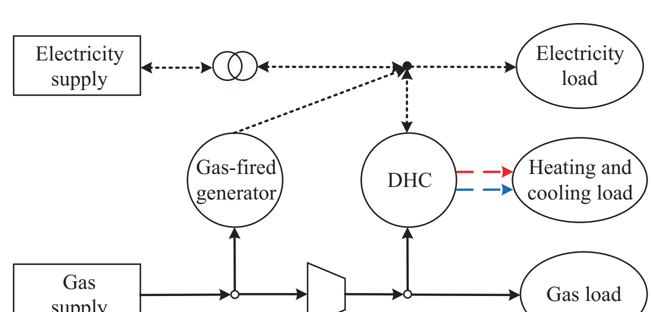

Fig. 1. A framework of an IES with electricity and gas networks embedded.

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