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# Study on the Resilience of the Integrated Energy System

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**Abstract**

Integrated energy system (IES) is the composite infrastructure system with subsystems such as electricity, natural gas, heat/cooling, etc. IES can improve efficiency, reduce pollution emission, and lower the dependence of economy on fossil fuels. IES is directly and physically connected to corresponding energy consumers, therefore it is an essential national infrastructure. With the increasing awareness of the threats from rare events such as extreme natural disasters or man-made attacks to the energy system, the study on energy resilience draws more attention. Still at the starting stage, existing studies on energy resilience is carried out mostly on individual energy system regardless of their interdependence. In the paper, the objective is to investigate the resilience of the IES. Firstly the IES and the interdependence among its subsystems are thoroughly analyzed. Then energy resilience as a concept is systematically discussed, and existing studies, including resilience evaluation methods, are compared and evaluated. Real life experiences of energy systems battling extreme events in enhancing resilience are summarized as well. With the integration of renewable energy and distributed energy resources (DERs), the IES is being reshaped and its resilience face more challenges, which will be investigated in detail. Finally future research trends about IES resilience evaluation, improvement and new technology are presented.



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Keywords: Integrated energy system; Resilience; Distributed energy resources (DERs); Natural gas system;

## 1. Introduction

Electricity, natural gas system and heating/cooling system are the most common energy carriers. With the increasing use of distributed generation, gas-fired units and combined heating and power (CHP), these energy systems are closely coupled. Integrated energy system (IES) is the composite infrastructure system

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with subsystems such as electricity, natural gas, heat/cooling, etc. The deployment of IES is seen as a key option to provide operational flexibility to the energy system and improve its overall efficiency to the users. Traditionally these well-developed energy systems are operated independently. With the advent of IES, however, the combined planning and operation optimization problems of IES have been investigated[1][2].

On the other hand, recently several instances of severe natural disasters have caused serious concerns over the resilience of the energy system. Power outages often occur due to weather or component failures; power systems are designed to resist stochastic component outage, called N-1 security criterion, but not against multiple component instantaneous failures from extreme natural disaster or man-made attacks (e.g. Hurricane Sandy is a N-90 event). Resilience of critical energy infrastructure has been a hot topic. Contrary to reliability evaluation, events considered in resilience study have the following features: 1) high-consequence, low-probability; 2) multiple simultaneous faults due to catastrophic damages. But energy systems are often treated separately, as the interdependence among them are not clearly learnt.

This paper aims to provide a thorough examination of resilience in energy system with a focus on IES. The rest of the paper is organized as follows. Section 2 gives a detailed description of IES; section 3 presents the definition of resilience, and compares the existing qualitative and quantitive evaluation methods; section 4 discusses the resilience of IES; section 5 summarizes the on-going research trends, challenges and opportunities for the future, while section 6 concludes the paper.

## 2. Integrated energy system (IES)

As is shown in Fig. 1, an IES combines electricity distribution network, distributed renewable energy system, natural gas system, cooling and heating systems. IES contains multiple subsystems and has a significant multi-domain feature. Meanwhile, the electricity network is interconnected with the heating system via microturbines (MT) and/or CHP. Many power distribution systems also contain distributed generation system and electricity storage devices. The natural gas system includes gas pipelines and gas boilers. Through gas boilers, chemical energy in natural gas is transformed into heat energy in high-temperature steam, and thus, the gas system is interconnected with the heating system. The high-temperature steam in the heating system can supply heat loads and heat-driven cooling equipment.

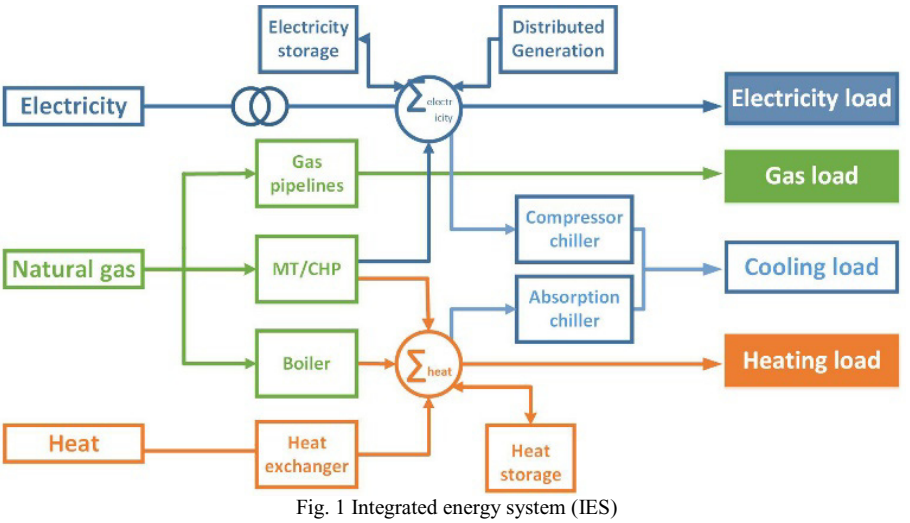


Fig. 1 Integrated energy system (IES)

The concept of IES has been applied in different cases. Several works present the idea of an energy hub[3], which is an energy load point containing multiple energy demands, including electricity, gas, heat and so on. The energy hub envisions a single combined system of all energy forms. Facilities that can be considered as an energy hubs include big building complexes, rural and urban district, or small isolated transportation facilities. At the same time, the concept of polygeneration also appears[4]. Polygeneration can be defined