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Editorial

Synergies between energy supply networks

1. Introduction

The increasing share of variable renewable energy sources, strict targets set for the reduction of greenhouse gas emissions and the requirements on improvement of system security and reliability are calling for important changes in our energy systems. Energy systems have been in transition, extending their boundaries beyond the energy systems themselves, the 3-D interactive extensions, that relate to the dimensions of physical **S**pace, **T**ime scale and **H**uman behaviors – STH extension. Under the new circumstance of the STH-demission, we need new approaches and solutions to solve the challenging issues associated with new transitions of future clean energy systems [1]. The next generation of competitive technologies and services that will create or enhance synergies between energy supply networks are being developed and matured. Facing these challenges and opportunities, energy supply networks (e.g. electric power networks, natural gas networks, hydrogen production and transportation, district heating and cooling systems, electrified transportation, and the associated information and communication infrastructure) are undergoing a radical transformation with massive investments in infrastructure and technologies [2]. This provides a window of opportunity. This transition is significantly increasing the coupling and interactions between energy supply networks via network coupling technologies, e.g. Combined Heat and Power units (CHP), Power to Gas (e.g. using excess renewable energy to produce hydrogen, which can be injected to the gas network or converted to synthetic natural gas, SNG, and then injected into the gas network) and Power to heat (e.g. heat pumps) processes. There is an urgent need to develop the next generation network coupling technologies and energy system integration methods which will make optimal use of synergies between energy networks to increase the hosting capacity and flexibility of distributed energy resources (DERs), enhanced demand response and support Smart Grid operation.

2. Synergies between energy supply networks

Conventionally different energy supply networks have relatively few interactions and were designed and operated independently. However, these diverse energy networks are increasingly interconnected with each other via network coupling technologies. The interactions mainly take place through conversion of energy between different energy vectors in order to provide services and ensure that each energy vector is managed in an optimal way. Fig. 1 shows some possible interactions between various energy supply networks and it can be seen that the network coupling technologies play a critical role in the energy system integration [3].

Energy system integration is urgently needed which uses a whole-system approach to optimize the synergies between energy supply networks in order to facilitate and coordinate the grid integration of DERs, while enabling the synergies and conflicts between the local distribution networks and the national level objectives to be understood and optimally coordinated. Innovative and competitive solutions of network coupling are also urgently required to enable and enhance the synergies and provide a significant amount of flexibility to energy networks. Some of the key challenges of exploiting the synergies between energy supply networks include:

- The complicated interactions and interdependencies between energy supply networks (technical, economic and markets) have not been clearly understood.
- There is no standard available for network coupling technologies and their network interfaces have significantly different characteristics.
- Design and operation planning of energy supply needs to consider the interactions and interdependencies between energy supply networks, to which there are no commercial tools available.
- The fragmented institutional and market structures of different energy systems is often a barrier to realise the benefits of synergies between energy networks.
- Integration of multiple energy supply networks would result in a more complex energy system to manage and operate. The interdependencies between different energy networks and the ICT (Information and Communication Technologies) infrastructure that facilitates interoperability would require powerful software models and analysis tools. It is argued that the integration of multiple energy supply networks may result in an energy supply system that is more susceptible to cascaded failures affecting reliability of supply.
- Network coupling technologies and solutions have been generally considered in the context of objectives and constraints at the distribution level, not necessarily reflecting on the impact on the design and operation of energy systems at the national level. Ignoring the interaction between distribution level energy networks and national infrastructure and objectives, will lead to significant cost and carbon inefficacies and may compromise security of supply.

3. The Special Issue

This Special Issue in Applied Energy provides the latest research outcome in this promising and dynamic area of research and development, which focuses on the technological aspects.

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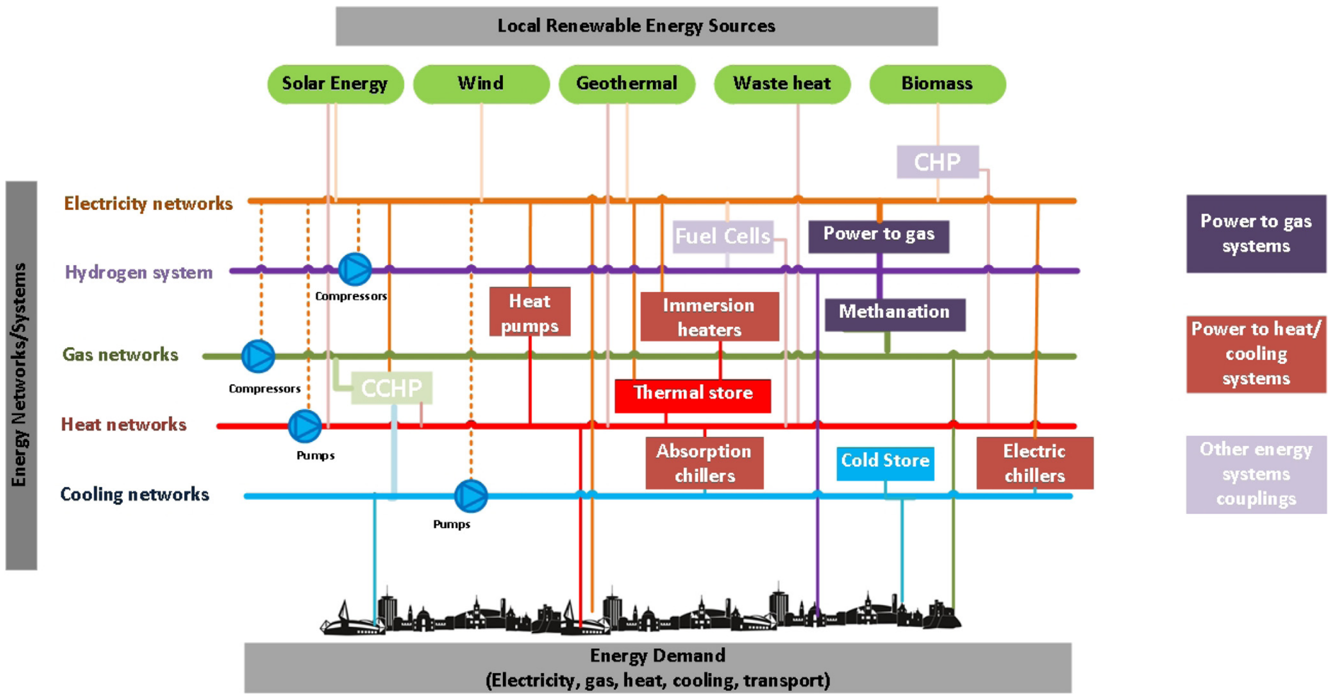

Fig. 1. Possible interactions between different energy networks and integration of local renewables.

A total of 12 papers have been accepted for this Special Issue. The papers address a great variety of issues that can be put into three categories: (1) network coupling technologies; (2) analysis of synergies between energy supply networks; and (3) optimal use of synergies in network operation. The individual papers under each category are presented in detail below.

3.1. Network coupling technologies

The network coupling technologies physically link different energy supply networks and provide possibility and flexibility to optimize their synergies.

Power to Heat/Cooling technologies allow utilizing low cost electrical power for heat and/or cooling generation in periods of excess renewable electricity. A typical Power to Heat/Cooling system can be considered either a centralized system where energy conversion takes place in a large-scale plant and the thermal energy distributed using a pipeline network or a decentralized system where the energy conversion takes place closer to end user (see Fig. 2). In both systems, thermal energy storage facilities are used to decouple the time of heat production from demand. In centralized systems the storage facilities are integrated with heat/cooling distribution infrastructure such as district heating and district cooling networks. Power to Heat/Cooling systems are capable of utilizing surplus electricity from renewable plants and act as a controllable load that can ramp up/down or shut down quickly and provide interruptible capacity to the electrical power system.

Heat pumps have been recognized as one of the key technologies for decarbonizing the heating of domestic and non-domestic buildings. Paper [4] assesses and quantifies in a probabilistic way the impact of heat pumps and PV on the low-voltage distribution grid, as a function of building and district properties. The Monte Carlo approach is used to simulate an assortment of Belgian residential feeders, with varying size, cable type, heat pump and PV penetration rates, and buildings of different geometry and insulation quality. Modelica-based models simulate the dynamic behavior of both buildings and heating systems, as well as three-phase unbalanced loading of the network. Stochastic occupant behavior is taken into account. It is shown that air-source heat pumps have a greater impact on the studied feeders than PV, in terms of loading and voltage magnitude. Furthermore, rural feeders are more prone to overloading and under-voltage problems than urban ones.

Power to Gas technologies convert electricity into hydrogen using an electrolysis process and subsequently to methane (SNG). The gas (hydrogen/methane) can be injected in the gas grid for energy storage and generation of power again or in the transport sector. Hydrogen and methane can be utilized in all well-established natural gas facilities (e.g. heating systems, CHP) and for heavy duty vehicles (trucks, trains, ships) as liquefied fuel (LNG). In addition, hydrogen can be utilized directly in industrial processes as chemical (e.g. ammonia synthesis) feed stock. Power to Gas is recognized as a long-term storage option, and it also provides additional benefits for power grid management. The conversion of surplus electricity into gas facilitates the transport of energy over long distances with low losses and makes effective use of the existing network of gas pipelines and underground storage facilities, as shown in Fig. 3.

In paper [5], techno-economic and Life Cycle Assessment of methane production via the combination of anaerobic digestion and Power to Gas technology were applied to sewage sludge valorization. Sensitivity analyses were carried out on biogas upgrading technologies, electricity prices, annual operation time and composition of the electricity mix with also a comparison between Power to Gas and direct injection. From an environmental point of view, continuous Power to Gas generates more greenhouse gases than direct injection, but intermittent operation with use of renewable electricity can significantly reduce emissions. Impact from continuous Power to Gas are higher than biogas upgrading, but much lower than fossil energy. Future development of low electricity consumption of the electrolysis process, and integration of renewable credits from CO2 valorization can increase the competitiveness of this technology.