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Role of polygeneration in sustainable energy system development challenges and opportunities from optimization viewpoints

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ABSTRACT

A sustainable energy system can be treated as a development of the distributed generation concept. It meets energy demands locally from renewable energy or/and high-efficiency polygeneration production technologies, and is characterized by energy and cost efficiency, reliability, and environmental-friendliness.

Distributed energy systems typically use renewable energy resources to supply all energy demands, such as heat, cooling, and electric power in an integrated way. However, it seems that too much emphasis is placed on power and associated renewable energy-based power technologies for dealing with sustainability issues in public discussion and the research community. Often, equally important thermal energy (heat and cooling) and polygeneration are ignored. Polygeneration is an energy-efficient technology for generating simultaneously heat and power as well as other energy products in a single integrated process. Energy efficiency contributes significantly to CO_2 emission reduction.

This paper discusses the role of polygeneration in a distributed energy system and the contributions of polygeneration to the development of sustainable energy systems. The paper also stresses that efficient decision support tools for sustainable polygeneration systems are important to achieve sustainability. First, the joint characteristic of a polygeneration plant that defines the dependency between different energy products is reviewed. Then, typical methods for dealing with polygeneration systems are reviewed. The review attempts to highlight the complexity of polygeneration systems and potential of polygeneration systems to adjust output of different energy products. Next, the challenges of sustainable polygeneration energy systems are discussed. Then some practices for operating polygeneration plants are discussed.

Contents

Abbreviations: CGSC, Combined gas and steam cycle(s); CHP, Combined heat and power; DC, District cooling; DES, Distributed energy system(s); DG, Distributed generation; DH, District heating; DHC, District heating and cooling; ED, Economic dispatch; EU, European Union; IEA, International Energy Efficiency; IGCC, Integrated gasification combined cycles; ORC, Organic Rankine Cycles; PTHR, Power-to-heat ratio; RES, Renewable energy source(s); SES, Sustainable energy system(s); UC, Unit commitment

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1. Introduction

The IEA (International Energy Agency) study on energy technology scenarios [1] showed that energy efficiency accounts for the largest share of all options for CO_2 emission reductions, including CO_2 capture and storage. This means that energy efficiency plays an important role in the development of the sustainable energy system (SES). Polygeneration is an important energy-efficient production technology and combined heat and power (CHP) production is the basic form of polygeneration. Polygeneration is the simultaneous generation of two or more energy products in a single integrated process. It can be seen as a generalization of CHP production. CHP production means that electric power and useful heat are produced simultaneously, by utilizing further the excess heat that would otherwise be wasted in conventional condensing power production. Taking CHP as an example, the efficiency of a steam turbine is typically 20-38% for power generation only, but 80-90% when useful heat is also produced. For a fossil-fuel-based CHP plant, the fuel and emission savings vary from 10% to 40% depending on the production technologies originally used by the substituted system [2]. If more useful energy products can be derived from the excess heat (e.g., cooling energy), the overall energy efficiency of polygeneration can be improved further [3,4]. Polygeneration can find wide applications in utilities, district heating and cooling, large buildings, and different industrial sectors, such as pulp, paper, plastic, rubber, steel, chemical, and food.

The utilization of renewable energy sources (RES) such as solar, wind, hydro and biomass energy is fundamental to SES development. A polygeneration plant can be fired by different types of fuels including both fossil fuels and biomass. A polygeneration plant can also be powered by RES. Ref. [5] reviewed different types of RES-based polygeneration technologies, including biomass-based, solar-energy-based, fuel-cell-based and waste-heat-recovery-based. The waste heat recovery aims at reusing the otherwise waste heat in different industrial sectors. Biomass can be either directly used or through gasification to fire polygeneration plants. To reduce CO_2 emissions of a fossil-fuel-based-system, Ref. [6] proposed an innovative dual-gas polygeneration system, which realizes the conversion and utilization of methane and CO_2 that would otherwise be directly discharged into the air. Considering that fossil-fuel-based technologies are currently dominant [7] for supplying heat and power all over the world, and polygeneration is an important technology to improve the overall efficiency of energy production as well as to utilize CO_2, the mix of multiple fuels (including biomass) [7,8] is a viable option for implementing the transition into future sustainable low-carbon energy systems. Encouragement of polygeneration from renewables will help make progress towards both renewable heat (cooling) and electricity targets. As commented by [9], a substantial increase in energy efficiency also forms an important cornerstone of a sustainable energy policy.

Currently, though polygeneration accounts for, on average, only around 10% of global power generation, as shown in Fig. 1, several countries in Europe, such as Denmark, Finland, and the Netherlands have achieved the use of polygeneration to 30-50% of the total national power generation [10]. Ref. [11] presented the implemented policies of the European Union (EU) in the broader field of energy, which includes seven categories: renewable energy, energy efficiency and savings, internal energy markets, security of energy supply, environmental protection, nuclear energy, and research and development. At present, global warming and fossil fuel depletion are driving the development of SES around the world. Consequently, mitigation of environmental impacts and the improvement of energy efficiency become a new focus for energy production and investments. The EU strongly promotes energy-efficient polygeneration technology [12] and treats it as one strategy to combat climate change and to fulfill the EU greenhouse gas emission commitments under the Climate Protection Protocol in Kyoto. In 2008, polygeneration accounted for 9% of the total power generation capacity in the USA. The US government attempts to promote the development of polygeneration on a national level [13] to cut down high energy production costs in the industrial sector, resulting from using traditional, inefficient production technologies. Also, other countries in the world have introduced different support mechanisms to facilitate the deployment of polygeneration [14].

However, the potential of polygeneration is far less utilized as would be expected. There are two reasons for this. First, a majority of companies operate polygeneration plants (e.g. CHP plants) according to a fixed power-to-heat-ratio (PTHR) for easy control. This rigid scheme imposes an excessive restriction between heat and power generation and leaves less room for adjusting power output in the situation where heat generation is fixed. Second, the current energy policy in different countries to drive sustainable energy development places too much emphasis on power generation. Various incentives to promote RES are causing a greater temporal and spatial imbalance between the supply and demand of power. Electric power is a perfect energy form except that it can only be stored directly at an extremely high cost. The storage cost is currently about 170 €/kW for electricity and 0.5–3 €/kW for thermal energy [15]. This means that current design, planning, and policy-making methodologies fail to adequately consider the sustainability of different energy products in the system in coordination. Consequently, the equally important thermal energy (heat and cooling) is to a great extent neglected. In 27 EU countries, 42% of the final energy demand is thermal energy [1]. It seems that the cooling demand in the EU 27 has a tendency to increase, and almost all individual cooling systems (excluding district cooling (DC)) are utilizing electricity now [16]. This demonstrates the

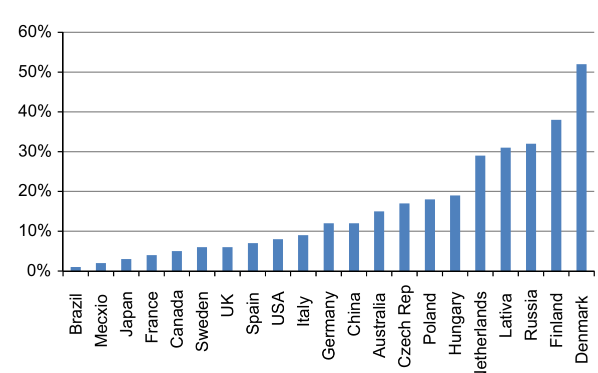

Fig. 1. CHP share of national power production (from [10]).