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Integrated Analysis and Planning of Energy Conversion and Storage Devices in Multi-vector Energy Systems

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Abstract

Multi-vector energy systems take into account synergies between different energy vectors (cooling/heat/electricity/gas), which will increase the flexibility for equalising the fluctuations from the renewable energy, and thus facilitate the penetration of renewable energy. This paper focuses on developing whole-system analysis and planning methods of energy conversion and storage devices in multi-vector energy systems, to achieve an overall optimum of energy systems.
Various energy conversion and storage devices (such as photovoltaic, CHP, gas boilers, battery energy storage systems (BESS), ice storage and so forth) are planned coordinately as an integrated whole. According to the electricity demand during the planning period and the power and energy balance between supply and demand, the size of energy conversion and storage devices are determined to improve the energy efficiency and the energy supply reliability, as well as mitigate carbon emissions.

Keywords: multi-vector energy systems; energy flows; power system planning;electric power distribution networks; energy storage

1. Introduction

Recently, with the burgeoning "energy Internet" concept, the integrated energy system analysis and planning researches put forward a new demand for the future development of the grid. Multi-vector energy systems considering the cooling / heat / electricity / gas and other energy synergies, contribute to the local energy consumption of renewable energy and improve energy efficiency. In "China Energy development for 13th Five-Year Plan" report [1], the

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integration of cooling/heat/electricity/gas supply system is vigorously promoted, the construction of "Internet +" smart energy will be accelerated, providing a strong foundation for the development of multi-vector energy systems. Currently energy systems are regulated in such a way that they have to be planned independently. However, in the future energy system, closer and more complex interactions between networks are set to emerge. The integrated supply of various energy sources such as cooling/heat/electricity/gas in urban areas from the regional energy service providers, is one of the important reform on energy production, transmission and consumption system.

The problem of the design and planning of multi-vector energy systems is to identify the optimal combination of energy supply, conversion and storage technologies as well as the network infrastructure required to meet the estimated energy demand and its future evolution. A transition to a decarbonised energy system is constrained by the difficulty of obtaining energy balance between fluctuating demand and the intermittent, non-dispatchable power supply delivered by most renewables. Integrated design and planning of multi-energy systems is beneficial compared to the independent development practiced today, since it takes into account synergies between the different energy vectors (cooling/heat/electricity/gas), which will facilitate the penetration of renewable energy.

The importance of multi-vector network interaction is growing in research and practical applications, as demonstrated by recent work on multi-energy systems [2, 3], energy hubs [4], intelligent energy systems [5], community energy [6], smart energy systems [7], and integrated energy systems [8, 9]. The development of multi-vector energy systems in US, Europe, UK and China were reported in a special column on IEEE Power & Energy Magazine [10, 11]. Various methods have been developed to investigate combined electricity and natural gas networks [4, 12-19], mostly with focus on transmission systems whereby gas turbine generators provide the linkage between gas and electricity networks. Likewise, there have been a few studies that have investigated combined electricity and heat networks [18, 20]. Integrated energy analysis has been performed in [3, 9], however with limited applications considering PV and energy storage. Regarding conversion devices, the optimal scheduling of smart homes' energy consumption is studied using a mixed integer linear programming (MILP) approach [21]. A microgrid system including a mix of renewable generation technologies, energy storage and demand response systems has been modelled [22]. Furthermore, chains of conversion can be visually mapped in Sankey diagram form [23], with the possibility to identify areas with largest energy flows and largest energy efficiency potential.

This paper has been focused on developing whole-system analysis and planning methods of energy conversion and storage devices in multi-vector energy systems, to achieve an overall optimum. Various energy conversion and storage devices (such as photovoltaic, CHP, gas boilers, BESS, ice storage, air conditioner, and so forth) are planned coordinately as an integrated whole. According to the electricity demand during the planning period and the power and energy balance between supply and demand, the size of energy conversion devices and storage are determined to improve the energy efficiency and the energy supply reliability, as well as mitigate carbon emissions.

A real case study of a multi-vector district energy system in a demonstration project of Guangzhou industrial park is planned in a quantitative manner the implication of the multi-vector interactions through energy conversion and storage devices to participate in system optimisation. The aim is to improve energy efficiency and facilitate the penetration of renewable energy through the cooling/heat/electricity/gas system optimisation. The model is used to provide energy arbitrage to maximise synergies between multi-vector energy systems. In addition to gain economic benefits, the aim is to achieve 20% peak load shaving target.

2. Integrated modelling

The objective function is to minimise the lifetime levelised annual cost shown as Equation (1), which includes: the annualised capital cost of energy conversion and storage devices (CHP, gas boiler, PV, BESS and ice storage); the annual cost of electricity purchased from the grid minus the annual revenue from electricity sold to the grid [24, 25]. Intuitively, a BESS is able to control the power flow flexibly, which could facilitate increased penetration of PV systems by minimising their intermittency. The coordination between PV, BESS charging/discharging strategy and ice storage determines the operational cost at a large extent.

$$Min\ C_{total} = LF_n \cdot C_{Capex} + C_{Opex} = LF_n \cdot C_{Capex} + \sum_{t=1}^{T} C_e P_{import}(t) + \sum_{t=1}^{T} C_g v_{g_{total}}(t) \quad (1)$$

where C_{total}—lifetime levelised annual cost, C_{Capex}—up-front capital expenditure cost of all system components. For