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Small scale impact of gas technologies on electric load management – μCHP & hybrid heat pump

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ABSTRACT

To face winter electricity peaking issues the authors proposes an analysis of the potential of distributed gas technologies for demand side management. This impact has to be analysed at small scale before any large scale extrapolation. Bi-energy technologies (gas and electricity) are a path to transfer loads from one system to another. Indeed, the flexible gas infrastructure adapts to load while electricity demand variations cause risk of black-out. The impacts of two hybrid technologies are studied at transformer level with 1-min experimental load profiles of 40 dwellings equipped with micro Combined Heat and Power (μCHP) boilers over a year in France. An absolute peak load reduction by 17% at small scale is found. Different technology mixes are then simulated to assess the effect on local infrastructure. Finally a methodology for temperature dependence analysis of load is used to assess different potential benefits of gas technologies.

1. Introduction

1.1. Electricity and gas interactions

1.1.1. Climatic impact on electric system

Electricity demand is driven by several variables such as gross domestic product, demographics and local weather conditions. Climate, especially ambient temperature, plays a significant role on seasonal energy demand as clearly demonstrated by [1] for two capital cities in the south and north of Europe: London, UK and Athens, Greece. Investigation of 1997–2001 load data for both cities showed that the annual electricity peak demand occurred during the winter-time. Even though development of air-conditioning systems might reverse this phenomenon in southern countries of Europe, the northern countries will still have to deal with winter peak loads; especially if electric heat pumps are deployed in those countries.

The European Network of Transmission System Operators for Electricity (ENTSO-E) publishes every year a system adequacy forecast to ensure that future generation supply is adequate [2]. According to the latest forecast, it would appear that the Seasonal Peak Load increases faster than reference load under normal conditions. This trend is observed in France, which has the highest electricity peak load according to ENTSO-E. The French Transmission System Operator (TSO) adequacy forecast [3] shows that French peak loads have been increasing on average by 2% per annum over the past decade, whereas the annual load growth rate has been inching upward by nearly half that amount (1.2% according to the available data). Due to the widespread use of electric heaters, the fall of 1 °C of ambient temperature over France induces an increase of national consumption by up to 2100 MW. Winter-time national hourly loads tend to be similar across European countries, with peaks occurring in the evening-time hours when residential consumption due to cooking and lighting gets aggregated to commercial and industrial uses. As a consequence, the 7 pm winter electric load is driving the entire electricity system, from power plant to transport, distribution and interconnection capacities with neighbouring countries. Security margins (secondary and tertiary reserves) are also driven by winter-time diurnal temperature variations. According to the study of 2009-10 winter

Abbreviations: μCHP, micro Combined Heat and Power; DER, Distributed Energy Resources; TSO, Transmission System Operator; DNO, Distribution Network Operator; ADMD, After Diversity Maximum Demand; ADmD, After Diversity Minimum Demand; ADML, After Diversity Maximum Load; ADmL, After Diversity Minimum Load; LF, Load Factor; HP, Heat Pump.

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performance data by the French TSO [4], in the event of a prolonged period of cold weather conditions, electricity imports would be very close to the maximum system transmission capacity. To relieve this situation, either an increase in capacity generation (and interconnection) or implementation of Demand Response and Demand Side Management would be required.

1.1.2. Development of generation capacity and role of distributed solutions

On the generation side, gas technologies such as combined cycles are expected to grow by up to 8% in the European mix [2]. A combined cycle power plant is a flexible and more efficient way to generate electricity than conventional fossil fuel power plants. Smaller decentralized gas combined heat and power (CHP) units represent an even better opportunity to increase global efficiency. The deployment of CHP, linked to heating needs, can be easily achieved without major consequences on gas infrastructure as large storage capacity allows for seasonal variations. Large CHP plants can be used in district heating applications or to supply the needs of large apartment complexes and hospitals. Mini and micro-CHP technologies can be employed in smaller dwellings to provide heat while also generating electricity locally.

Micro-combined heat and power (μCHP) systems typically refer to units generating less than 50 kWe according to [5]. It is a promising technology for use in Europe, especially in the UK where environmental benefits could be significant [6]. Stirling engine-based CHP is already a commercially viable technology. Stirling μCHP typical characteristics are 1kWe generation with a heat to power ratio varying from 5 to 8 for most residential applications. When a μCHP is coupled with a condensing heat exchanger and an auxiliary burner, global efficiencies can reach as high as 96% (107% if based on lower calorific value). Distributed gas technologies are more profitable than central gas power plants, as these are not constrained by the precise location of the gas network and micro-generation tends to limit electricity transit and network losses [7].

Distributed Energy Resources (DER), such as μCHP, is gaining increasing momentum thanks to the development in the information and communication technology fields. Central load dispatch of a multitude of small units can help TSOs to manage electricity transits. Geographically scattered load balancing, based on local electricity needs, has been studied in Denmark [8]. Using different CHP control strategies to decrease transits on high voltage transport lines, Østergaard showed that transmission transits are reduced, which in turn results in higher transmission capacity margins. In his analysis Østergaard investigated electricity balance with dispatchable load systems: district heating heat pumps and electrical vehicles. The first system can dispatch electrical loads through the use of large heat storages, but is constrained by demand and system capacity (storage and heat generator).

To alleviate this constraint, the use "hybrid" heat pumps, consisting of a combination of a heat pump and gas boiler (this is described later) could be an adequate solution. There is abundant literature on the integration of DER, including CHP systems, and a review of this topic, presented in next section, will focus on the temporal resolution, which is a parameter of major importance.

1.2. Review of μCHP impact on electricity demand

Modelling of thermal and electrical load profiles is quite sensitive to the choice of time resolution, as demonstrated in the study by Hawkes and Leach [9], who considered optimal dispatch, economic and environmental strategies for typical Stirling μCHP power plants. The same methodology applied to the determination of optimal capacity revealed large design criteria uncertainties. In their study they concluded that a 10 min resolution for average profiles was an adequate modelling interval, with little improvement for shorter time periods. Larger time periods were insufficient to capture actual constraints, and resulted in large deviations between predicted and measured profiles. According to an analysis by the IEA [10], electricity peak loads were underestimated by a factor of three when the time sampling resolution interval was increased from 1 min to 5 min. When estimating typical domestic electricity consumption rates in Europe, the IEA report assumed a 5 min interval in their assessment. Other studies [9] [11], and [12] have assumed a reference interval of 1 min. In our opinion, a 10 min resolution interval is likely to be the coarsest acceptable time resolution for modelling electrical load profiles.

When dealing with bi-energy technologies, the heating load time resolution should be adequate (fine enough) to obtain the same precision as the electricity profile. In the μCHP impact study by Peacock and Newborough [14], the authors noted that weather conditions, building design, occupancy rate and occupant behaviour were all contributing factors in predicting an accurate heating load profile. In their assessment they used a time step of 1 min for describing both the electricity and gas profiles. A gas to heat load conversion is operated to model electricity generation through a control logic scheme implemented for a Stirling engine of 15% electrical efficiency. And a reduction of 44% of aggregate peak load on a winter's day is presented. In [11], Boait et al. proposed a heating load model to assess exported electricity from a dwelling, considering μCHP regulation, internal heat gains, thermal capacities in the house and in the radiator circuit. Their 5-min step model gives confidence when compared with experimental and modelled export electricity. They have estimated a range of 2–3.4 MWh of electricity generation for 3 types of houses, and concluded that exported electricity was around 40–50%. As part of the European project "More Microgrids", an optimisation of μCHP has been studied with an emphasis on occupancy pattern [15]. The study used four different electricity demand patterns but only one heat demand for each case. Hourly profiles were utilised, which is a limit to performance analysis.

Control command strategies from an aggregator have been studied in EUDEEP [16]. Large thermal storage was set up to give a degree of freedom on electrical load dispatch. Different types of control strategies to modulate electrical load are also investigate in [17]. Different operating modes are described in [6] but such considerations are out of scope.

Detailed modelling studies on the influence of distributed generation are notoriously complex in nature, especially when considering local issues such as electrical constraints (voltage rise, for example), which, of course, depend on the distribution network architecture details. Trichakis et al. [18], used key electrical characteristics such as network symmetry, length, lines, distribution transformer, and so forth to predict the impact of embedded generators. Network characteristics coupled with geographic load dispatch lead to different possible configurations. Thomson and Infield [12] pointed out the limitation of current impact studies of μCHP regarding generation and demand analysis by noting that both geographical and temporal considerations must be addressed when modelling the effect of micro-CHP on distribution networks. Once these previous issues are addressed, potential benefits on distribution network can be assessed. In [19] and [20], the authors evaluate the economic impact of microgeneration (CHP and PV) on the total network costs, losses and infrastructures.

1.3. Scope of the study

Power plant and network capacities are typically over-sized to accommodate seasonal load variations, which inevitably leads to a low utilization factor of the installed infrastructure. The aim of this