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Energy, Environmental and Economic Effects of Electric Vehicle Charging on the Performance of a Residential Building-integrated Micro-trigeneration System

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Abstract

The widespread adoption of electric vehicles (EVs) and electric heat pumps (EHPs) would result in radically different electric household demand characteristics, while also possibly posing a threat to the stability of the electrical grid.
Micro-cogeneration (MCHP) is considered by the European Community as one of the most effective measures to save primary energy and reduce emissions. The utilization of EVs and EHPs could be a way to boost MCHP profitability and micro-cogeneration systems can also help in reducing the potential negative effects of EVs and EHPs on electric distribution networks.
In this paper a micro-trigeneration system (composed of a 6.0 kW_{el} cogeneration device feeding a 4.5 kW_{cool} electric air-cooled vapor compression water chiller) serving an Italian residential house was investigated by using the dynamic simulation software TRNSYS. The charging of an electric vehicle was considered by analyzing a set of EV charging profiles representing different scenarios. The simulations were performed in order to evaluate the capability of cogeneration technology in (i) alleviating the impact on the electric infrastructure, (ii) saving primary energy, (iii) reducing the carbon dioxide equivalent emissions and (iv) the operating costs in comparison to a conventional supply system based on separate energy production.

Keywords: cogeneration; trigeneration; electric vehicle; energy saving; TRNSYS; carbon dioxide emissions.

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1. Introduction

The diffusion of electric vehicles (EVs) could help in (i) reducing the large energy consumption of the transport sector and related greenhouse gases emissions [1], (ii) improving the local air quality in urban areas thanks to the reduced emission of local pollutants [2], as well as (iv) lowering the costs per kilometer for the end-users when compared to internal combustion engine vehicles [3]. The number of electric vehicles is still a small percentage of the total fleet. However, this number is increasing exponentially. In addition to the utilization of electric vehicles, it should be highlighted that, since 2009, the RES Directive [4] recognizes aero-thermal, geothermal and hydrothermal energy as renewable energy sources, thus considering electric heat pumps (EHPs) for air-conditioning as a useful tool to achieve European targets concerning energy efficiency and the use of renewable energy.

However, the combination of a widespread adoption of electric vehicles together with the deployment of EHPs at an increasing rate could also pose a threat to the stability of the electrical grid with the need of upgrading the electricity distribution infrastructure in the case of utilities not being able to meet the additional requirements [5,6]. Several possible electric demand-limiting strategies have been investigated [7,8]; one of the most promising option to obtain a reduction of the impact on the electric grid associated to a widespread use of EVs/EHPs is using micro-cogeneration (MCHP) systems, i.e. devices characterized by the combined production of electric and thermal energy from a single fuel source with an electric output lower than 50 kW_{el}. This technology is considered by the European Community as one of the most effective measures to save primary energy and reduce greenhouse gas emissions in domestic and small-scale applications when compared with the conventional separate energy production of electricity and heat [9,10]. The primary function of most MCHP systems applied in residences is to provide heat for space heating (SH) and for domestic hot water (DHW). The micro-cogeneration device generally operates under a heat-load following control strategy, with a large fraction of the electricity usually being produced at times when the electric load of the building is low, requiring substantial amounts of electricity to be exported with low revenues. EVs consume considerable amounts of electricity and are mostly driven during the day and charged at home during the night. The recharging of EVs could thus be a way to drastically increase the own use of electricity produced by the micro-cogeneration devices as well as boost the profitability of the system.

Few papers have investigated the possible synergy between micro-cogeneration and electric vehicle charging [11-15]. Various studies relating to different countries have highlighted how the incorporation of electric chillers/heat pumps to the traditional micro-cogeneration scheme represents an efficient and economical alternative to traditional systems [16-19] thanks to the fact that it allows to (i) increase the use of co-generated electricity enhancing the MCHP profitability as well as reduce the electrical load peaking corresponding to the large cooling loads during the summer and subsequent network congestion and failure events.

In this paper a system composed of a MCHP unit (with 6.0 kW as rated nominal electric output and 11.7 kW as rated nominal thermal output) operating under a heat-led control strategy and coupled with an electric air-cooled water chiller (a system that belongs to the family of EHPs and produces chilled water for space cooling purposes with a nominal cooling capacity equal to 4.5 kW) serving a typical residential multi-family house located in Naples (south of Italy) is investigated by means of the dynamic simulation environment TRNSYS (version 17) [20]. The proposed system is used for (i) heating/cooling purposes, (ii) domestic hot water production, (iii) the electric requirements of domestic appliances, as well as (iv) charging of an electric vehicle. A set of EV charging profiles representing scenarios in which electric vehicles would drive three different daily distances (30 km, 53 km and 75 km) and would be charged at three different power levels (2.2 kW_{el}, 3.6 kW_{el} and 6.6 kW_{el}) is investigated. The simulation results are given and analyzed in terms of (i) capability of micro-cogeneration systems in mitigating the effects of a potential increase in electricity demand at the individual dwelling level due to EVs charging/EHPs utilization, (ii) primary energy saving, (iii) avoided carbon dioxide emissions and (iv) economic benefits that could be achieved in the case of the proposed system being used instead of a conventional plant based on separate energy production.

2. Description of the proposed micro-trigeneration system

Fig. 1 shows the scheme of the system configuration analyzed in this study. The plant is mainly composed of a natural gas fuelled internal combustion engine-based micro-cogeneration device (MCHP), an auxiliary natural gas-