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Controlling micro-CHP systems to modulate electrical load profiles

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Abstract

As micro-CHP systems move towards mass deployment an increasing emphasis will be placed on their effect on time-varying demands for network electricity. A 50 dwelling data set of heat and power demands was employed to investigate the implementation of various penetrations of μCHP system on the resultant electrical load profile using two control methodologies: heat-led and a proposed method for modulating the aggregate electrical load. The first caused the daily load factor of the net load profile to decrease from 42.5% to 28.6% on a January day and the after diversity maximum demand to decrease from 2.0 to 1.2 kW. The second caused the daily load factor to increase from 42.5% to 48.6% and the after diversity maximum demand to decrease from 2.0 to 0.9 kW. The extent to which these improvements in load factor can be achieved was investigated in detail and maximum resultant load factor values were identified for a day in January, April and July. Further improvements in the modulating capability of this control approach may be realised if prime movers capable of rapid start-up, shut-down and cycling can be developed. The control of micro-CHP systems in this manner offers a mechanism for managing the load at distribution transformers.

Keywords: Combined heat and power; Control; Distributed generation; Electrical load

1. Introduction

Much of the UK's existing electricity generation plant will reach the end of its useful life during the next two decades [1]. Across this period, buildings-integrated micro-generation systems and distributed renewable power sources may be deployed to provide a significant proportion of the replacement generating capacity [2,3]. These types of generation are generally considered to be non-dispatchable from the perspective of network control. As their penetrations increase the mean value and variance of the net load profile placed on central thermal power plant will decrease and increase respectively [4]. The subsequent effect on supply/demand matching protocols is the subject of substantive research and the precise impacts have not yet been quantified. However, in combination with rising demand for electricity it is likely to increase the need for energy balancing [5]. At present, energy balancing is principally provided by the supply side through the flexible operation of thermal power plant i.e. requiring it to be part-loaded or idling for long periods in anticipation of changes in load. This flexibility of operation reduces both asset life and efficiency leading to increased costs and carbon intensity of electricity generation.

The forecasted changes in network generation capacity have heightened the importance of demand side solutions for energy balancing [6]. Options for achieving this (with respect to peak clipping and valley filling) have been investigated previously [7] and numerous programmes are in operation, principally in the commercial and industrial sectors. However, the domestic sector is currently responsible for a large part of the load variations. Several options exist to modulate demand in domestic dwellings by modifying operation or technology of end use equipment [8,9]. Indeed control options abound; their achievement is however constrained by the number of actors involved in their successful implementation and by the relationship between the service provided by the specific load and the expectations of end users.

Abbreviations: ADMD, after diversity maximum demand from the stated group of dwellings, kW; ALC, aggregate load control; ESI, electricity supply industry; LV, low voltage; SE, Stirling engine

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Nomenclature

CF_d	Capacity factor desired, the ratio of the total rated capacity of the activated μCHP prime movers to the installed capacity at any given time, %
CF_g	Capacity factor generation, the ratio of the total electrical output of the activated μCHP prime movers to the installed capacity at any given time, %
E	Electricity requirement of the stated group of dwellings, kW
e	Electricity requirement of the stated group of dwellings, kW h
e_{exp}	Electricity generated by the stated μCHP systems that is exported to the network by the group of dwellings during a period of one day, kW h
e_{gen}	Electricity generated by a group of μCHP systems during a period of one day, kW h
e_{imp}	Electrical energy imported from the network by the stated group of dwellings employing the stated μCHP systems, kW h
EC_{max}	Maximum capacity of embedded generation that can be fitted to the low voltage network without the magnitude of the export flow exceeding the peak demand, kW
LF_o	Daily load factor, the ratio of the average electrical demand to peak demand across a period of one day, %
LF_r	Resultant daily load factor, the ratio of the average electrical load to peak load across a period of one day for a group of dwellings with a given penetration of μCHP systems, %
L_{max}	Maximum load placed on the network by the stated group of dwellings, kW
L_{min}	Minimum load placed on the network by the stated group of dwellings, kW
N	Number of μCHP systems activated under the aggregate load control methodology
n	Penetration level, proportion of homes with a μCHP system, %
P_a	Aggregate load threshold above which a number of μCHP systems within the group will be activated, kW
P_i	Installed electrical capacity of μCHP systems within the stated group of dwellings, kW
P_{oe}	Electrical power output of the prime mover, kW
P_{ot}	Recovered thermal output of the prime mover, kW
s	Number of prime mover switching events per day

In this context, the development of micro-CHP (μCHP) systems presents an additional approach for modulating domestic sector load profiles. Micro-CHP systems are being designed and developed to enter an existing marketplace, i.e. the domestic boiler market. The potential UK market has been estimated as 13.5 million individual units, which is a penetration level equivalent to 75% of the stock of domestic gas-fired boilers [10,11]. At low penetrations, electricity generation will be almost incidental and the primary role of μCHP will be to reduce costs and CO_2 emissions attributable to energy provision in individual dwellings. However, understanding the time-varying nature of electricity generation from μCHP systems will become more important as the penetration levels within networks increase. Numerous control strategies are feasible, especially if systems are packaged to include both a prime mover and a conventional boiler, i.e. a cogeneration and heating system. Systems of this configuration permit electricity production to be partially de-coupled in time phase from the thermal demand profiles of individual dwellings, which provides an additional degree of freedom with respect to their control. Assuming favourable economic and legislative conditions for rapid growth, high penetrations of μCHP system may be reached across the aforementioned period of transition for the electricity supply industry (ESI).

Most previous research attention has concerned benefits to the individual household with respect to financial and carbon savings. Some research attention has been given to the relationship between μCHP operation and the nature of the resultant electrical load placed on the network by a group of dwellings for various μCHP penetration levels [12–14]. Previous studies have concluded that when μCHP systems are controlled primarily to match the space heating demand of the dwelling (i.e. heat-led control), substantial export flows will occur during periods of high heat demand but low electrical demand. This is caused by the dislocation between heat and power demands in domestic dwellings; this occurs especially at times immediately prior to waking/breakfast and to arriving home from work/school when heat-led control causes μCHP electricity generation to lead demand. In common with the general effect expected from embedded generation, μCHP systems operated under heat led control will cause daily load profiles of lower mean load and greater variability to be placed on low voltage (LV) transformers.

The mass deployment of μCHP systems that are controlled using a heat led strategy i.e. one that considers only the requirements of the individual dwelling, is likely to reduce the CO_2 emissions and cost attributable to energy provision in the dwelling. However, it is also likely to (i) exacerbate supply/demand matching of central generation (i.e. increase costs and potentially the CO_2 emissions of