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A novel optimization algorithm for efficient economic dispatch of Combined Heat and Power devices

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ABSTRACT

Combined Heat and Power (CHP) units produce heat to warm living spaces, supply hot water and generate electricity. Their normal operation is determined by the building thermal demand. These systems supply hot water on demand from hot water storage tanks avoiding intermittent operation of the machines. A method based on a novel control algorithm is presented to optimize the operating costs of one or a set of CHP units in either commercial or residential buildings. The algorithm uses hot water storage tanks to schedule the daily operation of the CHP devices maximizing the benefits of the electricity that is generated, while ensuring that the heat demand is covered. This is especially relevant for regulatory environments with Time of Use tariffs for electricity. The method comprises an optimization algorithm that minimizes the value of a target function. The target function includes a series of weights that penalize the violation of certain constraints. The outputs of the optimization algorithm define the operating set points of CHP unit/s. The results of the case study simulations demonstrate that the proposed implementation of the algorithm can achieve cost effective savings. Finally, the successful operation of the algorithm is demonstrated in a real building installation.

1. Introduction

There is widespread consensus that Europe needs to embark on a transition “toward a more decentralized power system relying to a larger extent on small-scale (sometimes intermittent) generation from renewable energy sources and Combined Heat and Power units”.

A target of 20% energy savings has been set for 2020 to be achieved through greater energy efficiency, particularly in the residential sector that accounts for 27% of total EU energy consumption. Most existing housing units have high heat demands that Combined Heat and Power (CHP) could satisfy, with the added advantage of local electricity production (COGEN [1]). CHP supplies both heat and electricity from a single energy source. Carbon emissions are reduced by generating electricity at the point of use and increasing the efficiency of the cycle. System losses associated with central power production are also reduced.

Space heating demand is very relevant in European buildings. According to Lapillonne [2] on average, space heating corresponds to 70% of total household consumption in Europe. Consumption differs from country to country. This is due to climatic differences, different construction standards and regulations, and heating technologies that are installed. The comparison of space heating between EU countries usually refers to energy consumption per square meter.

According to the European Environment Agency [3], Austria, Finland, Germany and Latvia consumed more than 160 kWh per square meter in 2010, while Southern European countries such as Italy, Greece and Spain were just below 100 kWh per square meter. CHP technologies for space heating are of greater interest to those Northern countries, but they are also competitive in Southern countries, even if they operate for 30% fewer hours per year. The success of CHP devices will obviously depend on the running time per year and fuel prices, as well as the existing regulatory environment and competing technologies. The German Government established a support scheme whereby CHP devices were subsidized, which promoted the installation of 20,000 residential CHP devices. The UK is also implementing support schemes in which electricity generated in the home is fed back in to the grid at above market prices.

Compared to solar thermal installations, CHP devices provide hot water at a much higher temperature making them applicable

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to a wider range of space heating installation schemes. Security of supply is also enhanced by reducing reliance on centralized power production or intermittent sources.

The use of the control algorithm presented in this paper optimizes the economic operation of CHP devices used in building applications, reducing their payback period, which thereby facilitates their market penetration and contributes to meeting the EU targets.

CHP devices normally operate in response to thermal demand, which also determines their electricity generation rates. The control algorithm exploits the flexibility offered by thermal storage, running the CHP devices at the most profitable operational mode, time intervals and power capacity, while taking dynamic energy prices and electrical and thermal load forecasts into account. The typical optimization period is one day.

This idea has been explored in the past by different authors. Lai [4] and Collazos [5] also proposed algorithms for the economic dispatch of CHP units based on the minimization of cost objective functions. However, the form of the target function to be minimized by the algorithm proposed in this paper incorporates weights and terms that penalize the violation of both constraints on the maximum number of starts of at least one cogeneration unit and constraints on the temperature in the heat storage system and on the dissipated heat in the sink.

Kramer [6] implemented a similar objective function, although it rationalizes the costs with certain electric and thermal production terms. It was proposed to solve the function through the use of fuzzy logic, but no other weighting function was considered.

Other studies, Herbst [7] and Yoshitaka [8], were more focused on controlling CHP operation by means of comparisons that followed a predetermined sequence.

Various authors Marnay et al. [9], Stadler et al. [10], Pruitt et al. [11] considered solutions to similar optimization problems by mixing different Distributed Generation technologies. Some of these algorithms were used for planning purposes at the investment stage. The algorithm that was presented included a very detailed model of the CHP devices and the associated hot water storage system, with highly accurate operation schedules.

The algorithm proposed in this paper presents the following advantages:

- It allows the simultaneous optimization of various CHP devices operating in parallel.
- Its optimization period is flexible.
- It includes a detailed model of the CHP system, and incorporates the modelling of the maximum number of start/stop operations per period as well as a heat dissipation device.
- It is integrated at the building level with a thermal load forecasting algorithm.
- It offers a stable solution using few computing resources, which means that it is easy to implement. The system is presently under development in a test building and its algorithm runs on a standard domestic personal computer.

2. Improved operation of the CHP devices

2.1. Standard Combined Heat and Power thermostat based device operation

Combined Heat and Power (CHP) devices generate electricity and recover heat for other productive purposes. A set of CHP units supplying heat for production processes (in an industrial facility, building dedicated for activities in the tertiary sector such as hospitals, university colleges, or space heating or sanitary hot water in residential or offices buildings) is normally operated following a thermostat based-operation mode.

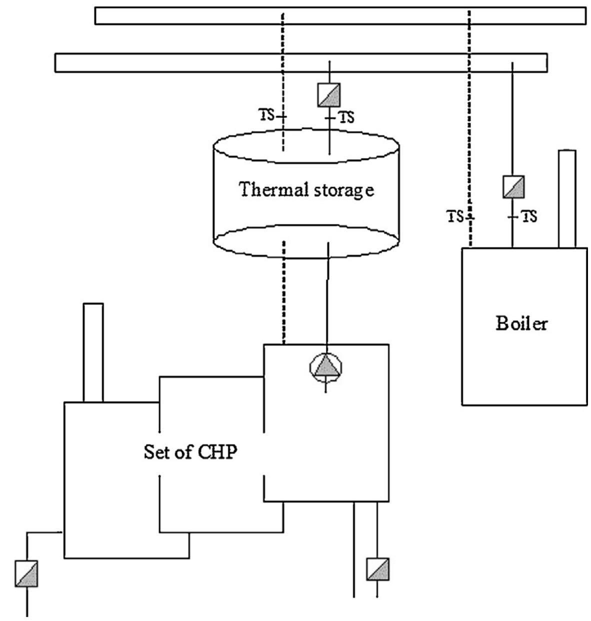

Fig. 1. Set of CHP units supplying heat to a thermal storage tank and in conjunction with a boiler for supplying hot water during peak load periods.

The heat produced by the set of CHP devices is stored in a thermal storage device. The storage device decouples the thermal generation and thermal load. The boiler installed in parallel to the CHP units and water storage tank supplies heat at peak load periods.

A standard installation scheme is shown in Fig. 1.

The water temperature inside the storage unit in relation to certain security (e.g.: a water temperature of 80 °C inside the water tank) and low energy (e.g.: a water temperature of 40 °C inside the water tank) thresholds usually regulates the operational mode of the thermostat, with the main purpose of reducing the number of start/stops. The stored energy would be proportional to water tank volume and the temperature difference between both thresholds. The CHP starts up when the temperature reading is between both thresholds and shuts down when the temperature rises to the upper security limit.

The operation algorithm proposed in this paper improves the operation and the economic dispatch of the CHP devices, because unlike the standard operational mode described above, based on thermostat readings, it takes forecasted energy consumption, stored energy and energy prices into account, with the aim of minimizing the overall energy costs by scheduling the CHP devices running hours and power set points.

2.2. Possible Combined Heat and Power connection

CHP devices are often closely connected to the loads for supplying electric and thermal energy. Hence, in these situations they are grouped under the term 'Distributed Generation'. Differing legislation in each country on available incentives, means that the features of the grid interconnection and, as a consequence, the most advantageous strategies in relation to electric production ("sale" or "self-consumption") will vary. Fig. 2 considers every potential DG interconnection scenario.

The configuration on the left-hand side of Fig. 2 is a system in which the electrical energy produced by the CHP unit/s always feeds the loads where it is consumed. When the production exceeds the demand for electricity, the excess is injected into the grid.