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Micro combined heat and power home supply: Prospective and adaptive management achieved by computational intelligence techniques

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ABSTRACT

Micro combined heat and power (CHP) systems for single residential buildings are seen as advantageous to combine both decentralized power supply and rather high overall efficiency. The latter presupposes flexible and adaptive plant management which has to mediate between energy cost minimization and user comfort aspects. This is achieved by use of computational intelligence (CI) techniques; structure and performance of the management system are shown.

1. Introduction

Micro combined heat and power (CHP) systems powering up to approximately 10 kW_{el} are considered as a future key technology for the energy supply of buildings and settlements from the viewpoints of both heating systems manufacturers and energy suppliers; such CHP plants can be based on conventional diesel, gas or biomass engines, gas or steam turbines, as well as Stirling engines or fuel cells [1]. In combination with public gas and electricity supply these technologies are well suited for primary provision of electric and thermal energy in single or multi-family residences and buildings with mixed occupancy of private residents and business establishments. It is evident that reasonable economic operation of CHP systems requires both limitation of device power rating and peak demand (the first comprising the investment, and the latter the fixed operational costs); for covering electrical peaks the public grid connection provides a sound basis, whereas thermal peaks can be smoothed out by both thermal storage and an auxiliary boiler. Efficient operation of such plants pivotally depends on both their sound design for the particular building as well as on powerful strategies for energy and load management. *Energy management* in this context means cost-efficient supply of all (electrical and thermal) loads by intelligent and anticipatory operation of all interacting system components, in particular the CHP unit. *Load management* means the controlled arresting and releasing of the operation of certain devices, especially larger electro-thermal loads with a significant power demand – for instance a washing machine.

So far, commercial CHP plants do not include sophisticated control structures for flexible and automatic adaptation of their operation to individual customer behavior, given tariffs and local infrastructure; innovative control approaches (e.g., fuzzy based [2]) are presently under investigation. *Heat demand follow* is currently the most favored operation strategy for small CHP systems (e.g., [3]); but in consequence of

- the interdependence of electrical and thermal output,
- very weakly coinciding electrical and thermal load curves and
- no interrelation of these parameters with the actual electrical grid exchange power tariffs, an economic benefit of CHP operation can essentially be achieved by consistent consumption of the *electricity* generated by the CHP unit in order to minimize electricity demand from the grid, and by maximizing electricity delivery to the grid at high tariff periods. In contrast, heat demand follow operation – despite the advantage of procuring high overall efficiency – proves economically only moderately beneficial; this is confirmed by the results shown below.

Since the potential of installed CHP plants with such conventional operation strategies cannot completely be exploited, in the frame of a recent research project [4] – accompanied by manufacturers of CHP plants, network operators and natural gas service providers – a powerful energy and load management of a micro CHP based energy supply for detached homes has been developed and was verified by an extensive simulation of the complete CHP system. Besides evaluating the operational requirements and

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boundaries of the plant components involved, *energy management* is designed to fulfill comfort demands by flexible adaptation to user habits (evaluation of past consumption and consequential prognosis of future consumption) as well as taking into account local tariffs and infrastructure, and therefore provides economic generation of electricity and heat under inclusion of environmental compatibility. The *load management* optionally controls the operation release time of certain (mainly larger electro-thermal) devices based on evaluation of past user behavior – considering both comfort demands and economic aspects. The management functionalities were elaborated and verified on a detailed operational simulation of the complete CHP system under consideration. Both flexibility and user adaptability of this system greatly result from the internal employment of various techniques of computational intelligence (CI).

The objective of this paper is to sketch the structure and functionality of the developed system, and to demonstrate its performance with examples taken from the verification studies made.

2. CHP system management

The principal structure of a micro CHP system for domestic supply including electricity (el) and thermal (th) flows is shown in Fig. 1. The CHP unit supplies the electrical and thermal circuits of the building. Significant variations of the thermal load are smoothed out by both the thermal storage and the peak boiler, whilst the public electric power system acts as an (expensive) electricity buffer, limited only by the maximal exchange power (in-/output) as contracted with the grid utility.

Anticipatory and cost-optimal ad hoc determination of components commitment and time dependent CHP power set-points is a demanding task taking into account the following diversified constraints:

- current system state (e.g. electrical and thermal load, storage filling level);
- operating point dependent component characteristics (e.g., electrical vs. thermal output of the CHP unit);
- operational constraints (e.g., minimal operation times or intervals between activation of components);
- interdependencies in components' co-operation;
- varying tariffs for both electrical power exchange with the public grid and CHP fuel (e.g., natural gas from public supply);
- forecasted electrical and thermal loads;
- potential commercial contracts.

Flexible and cost-optimal system operation under these conditions, as well as continuous adaptation to the local infrastructure, given tariffs and the individual customer behavior were achieved by development of the three computational intelligence (CI) based modules of (*a*) energy management, (*b*) load forecast and (*c*) load management; CI techniques applied and their performance are described in particular in [5]. Coupling these management modules with a Matlab/Simulink® based simulation of the complete CHP system in high temporal resolution and simulation fidelity (60 s calculation step rate was applied here) allowed for their testing and verification under largely realistic conditions. The simulation package used – also developed for the project regarded here – is described in more detail in [6].

2.1. Energy management

The energy management generates the actual CHP set-points based on past, current and forecasted loads, tariff information as well as current and past operating states, Fig. 2; in particular the constraints as listed above are regarded.

The relevant features are allocated to an adaptive network fuzzy inference system (ANFIS [7]) as inputs; the selection of these features can optionally be supported by correlation methods. The adaptation to local tariffs and changing user habits is done by off-line application of the well-known procedures of optimization and generalization: in a first step *archived* load curves are used to determine the corresponding optimal CHP set-points based on meta-heuristic optimization techniques. In a second step the identified set-points as well as the corresponding input features (according to Fig. 2) are used to extend the ANFIS knowledge base by means of the implemented training algorithm. Periodic appliance of this process results in a continuously improving on-line management of the CHP system. Even though the user is free to select the objective function (e.g. minimization of emissions), overall cost minimization will be most commonly used in practical applications; this is achieved by proper CHP power set-point setting and – if actually applied – load management:

$$\text{cost}_{\text{total}} = \text{cost}_{\text{fuel}} + \text{cost}_{\text{el from grid}} - \text{revenues}_{\text{el to grid}} + \text{cost}_{\text{assets}} \tag{1}$$

$$\min_{P_{\text{CHP set-point}},\,\text{load}_{\text{managed}}} \text{cost}_{\text{total}} = f(P_{\text{CHP set-point}}, \text{tariffs}_{\text{el,fuel}}, \text{load}_{\text{managed}}) \tag{2}$$

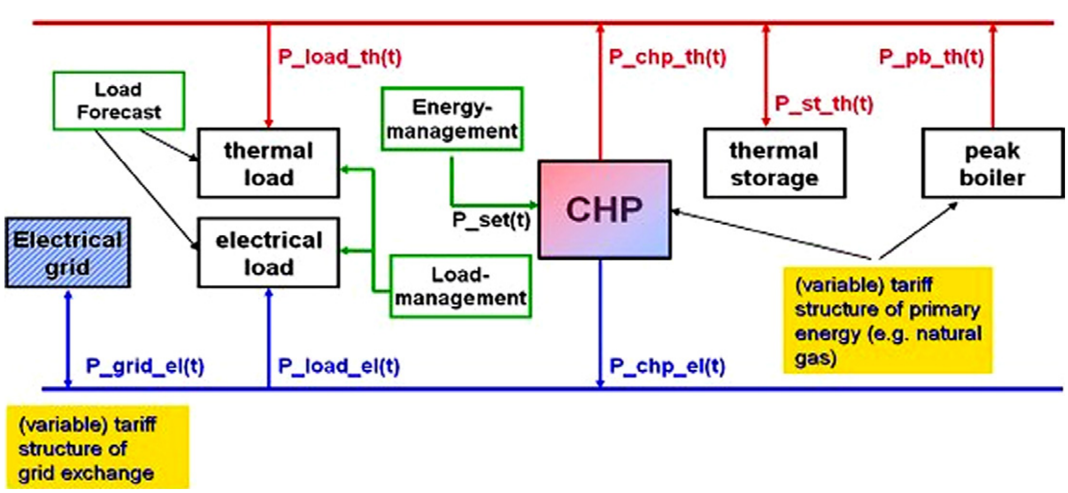

Fig. 1. Micro CHP system structure.