VIRTUAL POWER PLANTS AS REAL CHP-CLUSTERS: A NEW APPROACH TO COORDINATE THE FEEDING IN THE LOW VOLTAGE GRID

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ABSTRACT

A virtual power plant (VPP) is the concept of pooling distributed electricity generating (DEG) units. In addition to the grid-connection, they are attached to a telecommunication network.

The following paper presents a method that works without extra communication channels. The grid itself and the observation of the product flow parameters are used by DEG units to coordinate their activities.

1 MOTIVATION

Increasing sales of Senertec' Dachs in Germany, as well the Honda Ecowill in Japan, are showing that µCHP systems are eager to jump out of their niche market. Considering the fact that the British utility Powergen plans the large scale installation of Whispergen units until the end of this decade, the question is whether these tiny electricity generators should operate on their own, or whether synergy effects of a concerted action are worth the extra effort. The smart grid concept [10] shows a vision of a framework in which distributed generation is largely supported.

2 MICRO COGENERATION

The combined production of heat and power (CHP) promises an increase in fuel efficiency. Small units also known as 'magic boilers' serve as electricity generating heating units in buildings. MicroCHP benefits from the edificial integration as no district heating grid is needed. Nevertheless, the higher capital expenditures compared to usual heating systems constrain the widespread installation.

2.1 Combined Heat and Power Technologies

Small CHP modules are typically integrated in a heating installation along with extra sections. First, an auxiliary burner assists in meeting the heat peak demand during winter. Then, a heat storage – usually a hot water tank – minimises the thermal cycling of the µCHP unit and temporally decouples the supply of heat and electricity. The power balance is settled via the link to the low voltage (LV) grid, as displayed in Figure 1.

Several conversion technologies [9] have been developed to provide electricity and heat from fossil fuels. They are powered with heating oil, or more commonly with natural gas and propane. Recent developments incorporate the use of biofuels.

The classic design is an **internal combustion engine** propelling an alternator. Heat is recovered from the closed circuit cooling, the generator, and the exhaust gas. Another type is the **Stirling engine** where an external flame heats a sealed amount of working gas. The gas drives a power piston and is cooled down by the cold return flow of the hydronic heating. The **steam engine** works similarly: water is evaporated by external combustion, and the steam generates power in an expander. Thermal energy is transferred to the heating system in the condenser where the vapour liquefies and is then pumped back into the steam generator. **Micro turbines** derive from exhaust turbo-superchargers. Furthermore, progress in materials science has allowed the development of high speed generators. The temperature level of the exhaust gas satisfies process heat applications and combines well with absorption chillers. The last three CHP configurations show low emissions due to the continuous combustion and minor maintenance costs because of oil free lubrication.

Fuel cells promise high efficiency, as well as marginal emissions at low maintenance efforts. They are regarded as the power system of the future, but still need research to reduce manufacturing costs and to increase durability. The fuel is burned indirectly in an electrochemical cell, thus generating an direct current. Power electronics convert it to alternating current.

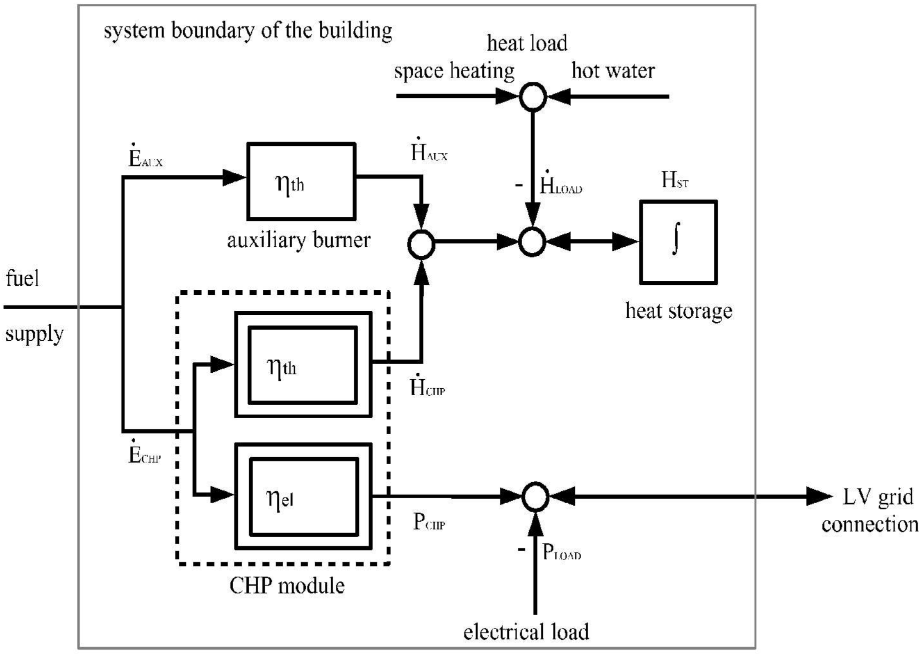

Figure 1: *Energy flow diagram of a microCHP installation*

Inverter based designs [7] of distributed energy resources (DER) are used not only in future cogeneration concepts with fuel cells but also in present µCHP units with thermal engines. As an electronic gear, they support power modulation without relevant efficiency losses by varying the engine's RPM. Furthermore, modules for observing the grid are integrated in order to detect any grid failures.

2.2 Operating Modes

In addition to the production levels **OFF** and **ON** (=full throttle), power modulation enables the operator to fulfil specific production schemes within the CHP-module's individual capacity limits $P_{MIN,i}$ and $P_{MAX,i}$.

2.2.1 Heat driven

In heat driven mode, unit **i** follows the local demand for heat $\mathbf{H'_{LOAD,i}}$. Therefore, with $\mathbf{s = \eta_{el} / \eta_{th}}$ as CHP coefficient, the power output is:

$$P_{CHP,i} = s_i \cdot H'_{LOAD,i} \tag{1}$$

2.2.2 *Power driven*

In power driven mode, the unit of feed-in node **i** follows the local demand for power $\mathbf{P_{LOAD,i}}$ – thus the power output is:

$$P_{CHP,i} = P_{LOAD,i} \tag{2}$$

Usually, a power driven and heat capped approach is chosen in cogeneration practise, so that no excess heat is wasted.

$$P_{CHP,i} = \mathit{Min}\ (P_{LOAD,i}\ ;\ s_i \cdot H'_{LOAD,i}) \tag{3}$$

2.2.3 *Grid driven*

The idea of the grid driven mode is that the local LV-grid segment detects its load condition and accordingly sets the production levels of attached energy resources. Consequently, the grid driven mode is a special occurrence of the power driven mode, where the unit **i** follows the aggregate demand for power $\Sigma\ P_{LOAD,i}$.

$$P_{CHP,i} = f\ (\Sigma\ P_{LOAD,i}) \tag{4}$$

2.2.4 *Mode switching*

The heat buffer is used to switch between the operating modes. Depending on the heat storage level, the local control may switch between the modes full load, heat driven, power driven, grid driven, and off.

The operating modes are arranged by return on consumed fuel (see Figure 2). The thermal credit is added to the power credit and related to the cost of the fuel input. As the feed-in tariff for electricity is usually lower than the yield from avoided grid supply, the power driven mode is preferred to the heat driven. Where to put the grid driven mode is strongly dependant on the operator's view, i.e. as an owner, contractor, or utility affiliated power producer, and the compensation for grid friendly feed-in behaviour.

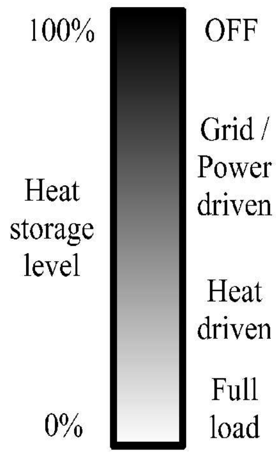

Figure 2: *Heat storage as a switch*

Nevertheless, the CHP unit is the building's basic heat source. Thus, it is obvious that in periods of high heat demand such as cold winter days, the energy level of the thermal storage is low and the power block runs at full load, assisted by the auxiliary burner. During summer, when the heat demand is rather low and determined by the domestic hot water consumption, the heat storage is often full and the power block switches off. The range between these extremities can be utilised for grid controlled power production.

3 COORDINATION BY COMMUNICATION

The common idea of a virtual power plant is a cluster of distributed energy resources, which are connected to a control and communication system. The central control station optimises the operation of the whole system by yielding surplus value e.g. by reducing maximum load and generating valuable peak time power. Virtual power plants promise a more efficient utilisation in the domain of distributed generation. The first pilot projects have already been implemented by e.g. Stadtwerke Unna and a consortium headed by Vaillant.

Since the installation and operation of the data network is costly, major utilities do not believe that the extra earnings of a VPP will justify the extra expenditure [13]. Particularly the small-sized units, connected to the LV-grid, offer only a minor benefit compared to the overhead of the data link-up. In the following, a method will be proposed that does not require a communication network. Instead, the parameters of the product flow on the low voltage lines determine the power dispatch.

Visions of automated power trading have already been presented [8]. Small consumers and distributed generators balance supply and demand. The grid operator acts as a central counterparty and broadcasts price signals. In [6] a similar idea is drafted, where the system is controlled locally. The pricing is determined by the local working voltage plus a frequency component on the synchronous area level.

Table 1 shows typical parameters for high, medium, and low voltage lines. As can be seen, low voltage lines are dominated by ohmic resistance. Therefore, in LV-segments of the grid, a voltage drop indicates high local loads. This sign can be used for the power dispatch of the CHP module when running in grid driven mode. Compared to power quality management procedures published in [12], the proposal how to manage a VPP on the low voltage grid works similarly. However, the objective is another: the main issue is the economic dispatch of the CHP cluster whereas the voltage impact is a side effect.

Table 1: Typical Line Parameters [4]

Type of line	*specific resistance* R' *[Ω/km]*	*specific reactance* X' *[Ω/km]*	*impedance phase angle φ (power factor cos φ)*	*nominal current* I_N *[A]*
low voltage	0.642	0.083	7.37° (0.992)	142
medium voltage	0.161	0.190	49.73° (0.646)	396
high voltage	0.060	0.191	72.57° (0.300)	580

To each feed-in node **i** a voltage value $U_{0,i}$ is assigned according to the topology of the LV-grid segment, the distance to the distribution transformer, and the general energy flow state. When operating in grid-driven mode, the DG **i** increases the feed-in power $P_{CHP,i}$ if the voltage drops below $U_{0,i}$ and vice versa. The droop factor p_i has to be adjusted according to the same determinants as well as the switching on threshold of the voltage. The setting can be done during the installation of the unit and has to be updated after major changes in the LV grid, e. g. increasing DG capacity or new consumers with significant loads, as well as retrofitting the infrastructure. An autonomous methodology could be implemented by memorising daily voltage courses locally and calculating U_0 and p as a function of U_{MIN}, U_{MAX}, the heat storage and the estimated thermal demand.

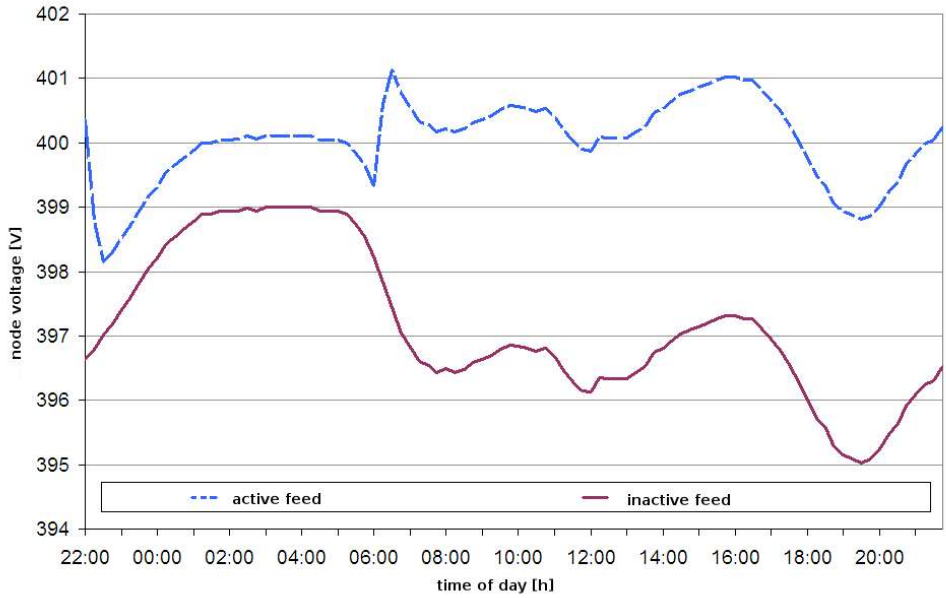

Figure 3: *Voltage developing at a LV-line end node during a winter workday with and without DG feed-in [1]*

Figure 3 shows the results of a simulation made for a new housing estate in the supply area of Lechwerke AG [1]. The voltage curve with DG resembles the typical load curve for households, just inverted. When the feeding of the µCHP-blocks along the power line kicks in, the voltage rises according to the power output. Clearly visible is the lower production level during the night, as the night temperature setback reduces the thermal load.

The voltage variation during the day is a signal for the segment's load state. It serves as an input value for the economic dispatch, in the sense of a tertiary power control [11]. Fluctuations of the voltage level are not to be compensated completely, but factored into a feedforward control. Stability concerns regarding the failure of the central control or data links are rendered void. Thus, the voltage driven mode for LV-grid connected feed-in nodes is an implementation of a self-organising virtual power plant.

4 FUTURE PROSPECTS

Large scale virtual power plants at the low voltage level could result from the heating technology's innovation cycle. Compared with the life cycle of low temperature heating systems and condensing boilers, the µCHP-block stands a chance to be the dominating domestic heat source in two decades [3]. Figure 4 illustrates the aggregate electric load of 80 homes in 10 apartment buildings, each with a 5 kW_{el} cogeneration miniplant. A static, but daytime variable price profile has also been implemented. During times of high heat demand, the CHP-modules run at full load and the curve is dominated by the stochastic power demand. The flat areas of the matrix show the grid driven mode, where the preset power flow of 10 kW is delivered by the distribution transformer.

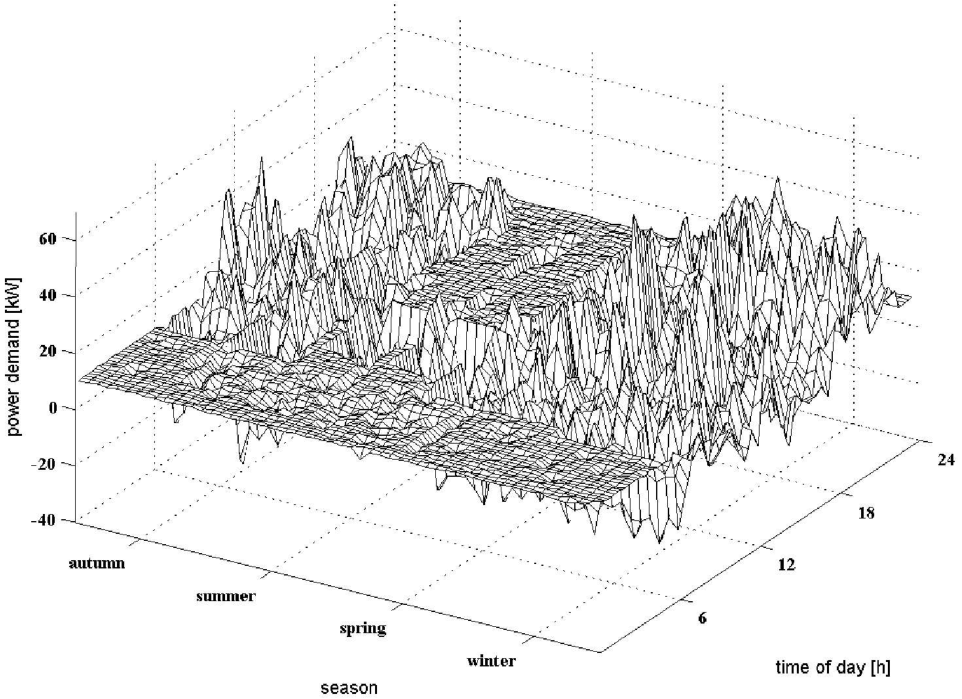

Figure 4: *Power demand of a CHP equipped settlement (80 households) in grid driven mode combined with a feed-in tariff profile*

The residential area substitutes (e.g. coal based) medium load power by natural gas, as the feed-in primarily occurs during the day. Primary energy consumption is reduced by 10-15%, with a modern coal fired power plant ($\eta_{el} = 45\%$) as a reference. In Germany, the market for domestic space heating and hot water is about 2400 PJ [2]. Combined with cogeneration at available efficiencies $\eta_{el} = 15\%$ this could generate 100 TWh.

Thus, fostering µCHP is a twofold mechanism of a CO_2 reduction strategy: efficiency improvement plus fuel shift. Fixed feed-in tariffs have shown effectiveness in the stimulation of the renewable energy market [5]. This instrument has the potential to accelerate the technology specific innovation system and to generate a mass market for magic boilers as well.

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