# INTEGRATION OF COMBINED HEAT AND POWER MICRO UNITS INTO THE LOW VOLTAGE NETWORK BY USING A GRID ORIENTED OPERATION MODE[1]

Magnus PIELKE
TU Braunschweig – Germany
m.pielke@tu-bs.de

Michael KURRAT
TU Braunschweig – Germany
m.kurrat@tu-bs.de

## ABSTRACT

*Decentralized CHP micro units gain in importance for energy supply of residential buildings because of their high efficiency. The application occurs heat lead while the electrical power-production happens not conform to the demand. By uncoupling operating times and thermal demand with a thermal storage system a gird oriented operation mode is possible to homogenize the grid load. This operation reduces the grid losses and provides electrical power in times of high demands.*

## INTRODUCTION

In Germany the power supply is faced with major challenges due to changes in the power generation sector. Up to now energy generation occurs in centralized large-scale power plants. This energy was transported top down in the low voltage networks. Since a few years a bottom-up-feeding by distributed generations gains dramatically in importance. The number of distributed generators (photovoltaic systems, combined heat and power (CHP) micro units and wind mills) increases rapidly. In comparison with large-scale power plants distributed generators dispose of nearness to the end-consumer which avoids high transportation and transformation losses over several voltage levels. So that distributed generation can discharge 400 kV transportation networks. Photovoltaic systems as well as CHP micro units and wind mills generate energy non-conform to the electrical demand. Photovoltaic energy production depends on the solar radiation which is stochastically fluctuating. That applies also to windmills. Energy production is down to wind conditions. CHP micro units which are placed in multifamily residences operate in a different way. Primary the operation times depend on thermal demands of the residence that hearken back to weather conditions and personal needs.

With these constraints in energy production an offset between energy supply and demand comes along which lead to scenarios in which the distributed energy supply can not be used in the low voltage district and has to be transformed in higher voltage levels where higher demands exist. In this case many advantages of distributed generation drops away. In future an increasing proportion of distributed generators has to be expected. For 2020 a 20 % share of the energy supply provided by CHP micro units will be realistic. In this case a dispatching of distributed generators is necesarrily to avoid load flow reversals and voltage fluctuations.

In the following the grid oriented operation mode for CHP micro units will be presented as an effective instrument of generation management which respects the thermal needs of the building in which the CHP units are installed. The effects of this operation mode on the electrical load profile of the network district will be shown exemplaryly.

## OPERATION MODES OF CHP UNITS

CHP micro units are never installed as stand-alone systems in residences. The installation always occurs with a warm water boiler which is installed in parallel. This kind of installation based on the idea to use the CHP unit for primary thermal supply. A thermal demand greater than the basic demand is supplied by the warm water boiler. The electrical house connection remains just to obtain the lack between electrical power demand and production (Fig. 1).

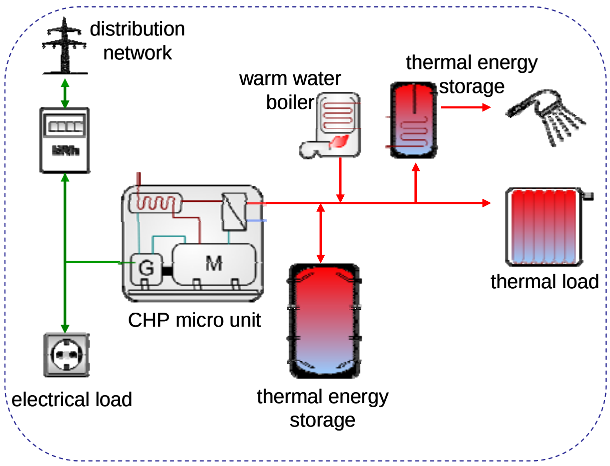


**Fig. 1: Integration of a CHP unit in a residence**

1 The presented idea is developed in the institute for high voltage technology and electrical power systems and in the moment focussed in the Energy Research Alliance of Lower Saxony which is initialised by the federal state Lower Saxony in 2006.

## Conventional operation modes of CHP units

Applications of CHP micro units in residences typically can go on in two different ways: with an heat lead operation mode or an power lead operation mode.

**Heat lead operation mode**

The heat lead operation mode tries to supply the thermal energy demand of the residence. Therefore production times are oriented on thermal demand curves. In times of large thermal demands the difference between the CHP power and the demand will be supplied by the warm water boiler. The generated electrical power is not produced conform to the electrical power demand. A compensation can be arranged with the connection to the distribution network. With this operation mode the whole grade of efficiency of the CHP unit can be guaranteed because of the complete thermal energy consumption.

**Electrical power lead operation mode**

The electrical power lead operation mode orients the production times not on the thermal but on the electrical power demand of the residence. With this operation mode an electrical feeding in the distribution network is avoided. Only in times of a electrical undersupply there occurs an electrical energy consumption from the network. The combined thermal energy production happens non-compliant to the thermal demand. Energy overhangs can be stored first in a thermal storage and be consumed in times of demand-overhang. If the thermal storage is filled up completely a thermal overproduction can not be stored or used and will be lost. In this case the efficiency of the CHP unit decreases. Due to this fact most CHP micro units in residences are installed with a heat lead operation mode.

# OPERATION TIMES OF CHP UNITS IN RESIDENCES

CHP units generate thermal and electrical energy in a fixed ratio. This ratio is called CHP coefficient and describes the ratio of electrical power and thermal power of the CHP unit. For CHP micro units the CHP coefficient amounts to 0.4. This ratio varies in a small range by changing the operation point. Basically the CHP coefficient is fixed. That means the proportion of generated electrical and thermal energy is in every case the same. To supply the electrical and thermal demand of residences by CHP units perfectly the demands have to be always in the same ratio.

## Load profiles in residential buildings

The load profiles of residences depend on several boundary conditions. The thermal demand primarily hearken back to wheather conditions and personal preferences of room temperatures as well as the personal daily routine. Typically the thermal demand rises in winter times and decreases in the summer. During the course of the day the main thermal need exists in the morning hours from 5:00 to 7:00 AM to heat up the rooms, to get warm water for showering and washing. In the following hours thermal demand decreases rapidly – especially in single- or couple-households, where all residents are employed. In this case the thermal demand rises up to finishing times.

The electrical demand rises with the breakfast time. The highest demand occurs to lunch time due to cocking and in the evening for dinner time, leasure time and in times of electrical lighting. The magnitude of the electrical demand depends strongly on the electrical equipment of the residence.

Fig. 2 shows standardised load profiles for electrical and thermal demand in a multi-family house during a cloudy autum weekday exemplary.

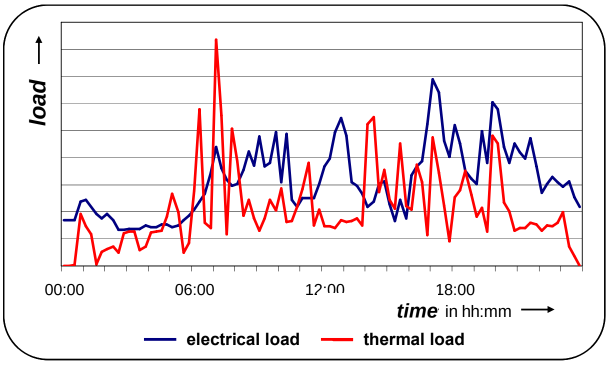


**Fig. 2: Load profile of a multi-family house**

The loadprofiles show that there exists just a small correlation between electrical and thermal demand during the course of the day. Thus the energy generation always arises just for one energy form demand-acutated independantly of the operation mode.

## Operation times of a heat lead operation mode

The operation times of CHP micro units in residences which operate in the heat lead operation mode are geared to the thermal demand of the residence. Due to this fact operation times are primarily in the morning hours and in the finishing time. Not compulsory these time slots represent times of a high electrical load in the network district. Especially the operation times in the morning are often times of light load in the distribution network.

Due to this fact the fluctuation of the electrical load profile of the network district may rise by an increase of distributed generation with CHP units (Fig. 3).

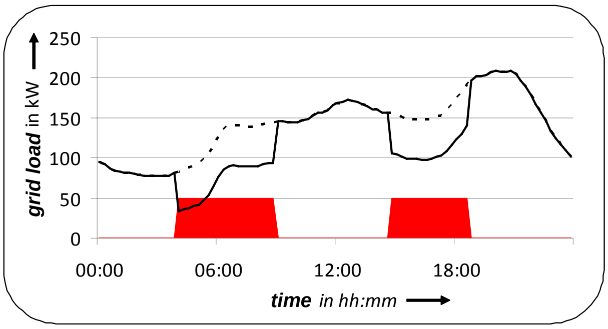


**Fig. 3: Operation times of a heat lead operation mode**

## GRID ORIENTED OPERATION MODE OF CHP UNITS IN RESIDENCES

### Idea of the grid oriented operation mode

Concerning the electrical grid load a consideration of operation modes of CHP micro units in residential might enhance the worth of distributed generation.
In cases of high shares of distributed generators in networks a non-conformal feeding rises the spread of the electrical grid load profile. This situation leads to a higher load of the network assets on the one hand and on the other hand to high losses in the network by a fluctuating voltage level. Furthermore bilateral load flows can be obtained because of an uprising stochastic fluctuation of the electrical feeding. An operation mode which considers the energy demand of the residential as well as the electrical grid load fluctuations can be confined. This operation mode prefers operation times during the peak load periods in the electrical grid and ensures the thermal energy supply of the residence. By managing the operation times of several CHP units by a host system the feeding becomes more planable. This kind of operation mode uses the thermal storage system of each CHP unit to decouple the operation times from the thermal demand. In the following this operation mode will be called *grid oriented*.

### Operation times of a grid oriented operation mode

Conventional operation modes of CHP units do not cover the electrical load of the distribution network. The grid orientied operation modes focusses to smooth even this by using the thermal energy storage system of the CHP system. The thermal demand of the residence will be provided furthermore. Fig. 4 shows an ideal type of operation times of grid oriented CHP units. The operation times are shifted in times of high electrical loads in the distribution network.

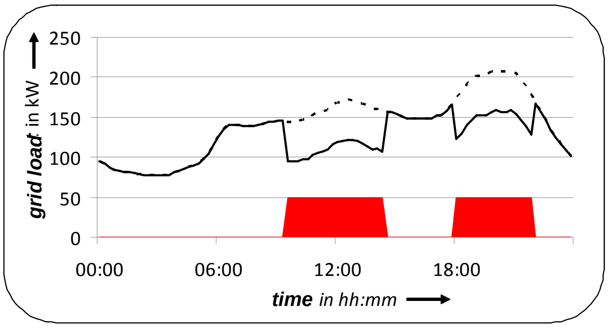


**Fig. 4: Operation times of the grid oriented operation mode**

## EFFECTS OF THE DISTRIBUTED GENERATION ON THE GRID LOAD PROFILE

### Assumptions for a network calcultion

For an estimation of the effectiveness of the grid oriented operation mode a distribution network district was measured over a whole year. The measured data consist of the electrical and thermal load flow of the district. This development area includes of 134 buildings with 288 accommodation units. The electrical supply occurs by two 630-kVA-transformers which transform the voltage from 20 kV to 0.4 kV. The thermal energy supply occurs in all buildings with gas heatings so that the measured gas load flow is a very good approximation of the thermal demand.
For a simulation of the grid oriented operation mode different shares of CHP micro units are defined. As reference scenario the network without any distributed generation is assumed. Further scenarios assume an energy supply of 10 %, 20 % and 40 % respectively of the whole electrical energy demand by CHP micro units. For these cases several multi-family-houses are equipped with one or two CHP micro units. The houses are simulated separately by using their specific energy demand. The development of houses with CHP units occurs by decreasing thermal energy demand. That leads to the effect that houses with the highest thermal energy demand are developed with a CHP unit first. This procedure regards the plausibility of real development scenarios. The dimensioning consider that CHP units shall supply around 10 % to 30 % of the peak load of the thermal energy demand of the building. Furthermore CHP units shall run more than 4 000 hours a year. Thereby 60 % to 80 % of the thermal energy demand shall be supplied by the CHP unit.
The considered CHP unit are endued with an electric power of 4.7 kW and thermal power of 12.5 kW. The thermal storage system is dimensioned with 1 000 liter which stores up to 34 kWh thermal energy.

### Load profile analysis in a distribution network

To estimate the effectiveness of the grid oriented operation mode the load flow calculation of this distribution network is done for an energy supply without distirbuted generators, with heat lead operating CHP units as well as grid oriented operation CHP units.
To evaluate the effectiveness the reduction of the spread of the network load profile and the reduction of the peak load is measured. These two characteristics describe in a very good manner the benefits in the mains operation.
The following table shows the results of the calculation of the load flow profile of the distributed network.

Table 1 describes the effects of the distributed generation in comparison to energy supply without any CHP units exemplaryly for the CHP share of 20 %. The table shows that the peak load will be reduced in both operation modes of CHP units. In case of grid oriented mode the reduction is higher and the spread of the load flow can be reduced in comparison to the load flow without any CHP units. This does not appear with heat lead operation mode.

**Table 1: Comparison of distributed feeding with different operation modes**

| operation mode | heat lead | grid oriented | difference |
|---|---|---|---|
| share of CHP units | 20% | 20% | |
| Δ-peak-load | 8,26% | 14,47% | 6,21 b.p. |
| Δ-load flow spread | -5,61% | 1,82% | 7,43 b.p. |

All in all the distributed feeding with CHP units helps reducing the grid load. The peak load can be cut off in every case. But the reduction of the spread of the load flow of the distribution network is not reached in every case. Only the grid oriented operation mode enables reducing the spread. Table 2 describes the differences of the effects in the network of the two operation modes. The differences are obviously: In every case the new operation mode leads to better results.

**Table 2: Comparison of the grid oriented operation mode with the heat lead operation mode**

| share of CHP units | 10% | 20% | 40% |
|---|---|---|---|
| Δ-peak-load | 0,42 b.p. | 6,21 b.p. | 6,98 b.p. |
| Δ-load flow spread | 0,32 b.p. | 7,43 b.p. | 7,25 b.p. |
| number of CHP units | 4 | 10 | 18 |

b.p. = basis points

## TECHNICAL REALISATION

### Schedule management with a linked system

The control of operation times of several CHP micro units in a low voltage district offers with a host system a homogenization of the grid load profile and a reduction of the peak load. The evaluation of the several single operation schedules of each CHP unit is controllable by a host system which needs for this task several information from the distributed units. Information about the specification of the CHP unit and its auxiliary systems are needed as well as the forecasted energy demands for the following day and the charge level of the thermal storage system. By means of these information it is possible to create with forecast models the load profile of the network of single schedules for the operation times of each CHP unit. These schedules consider the thermal demand of the residences as a primary constraint. Additional the operation times take place in peak load periods of the grid load by using the thermal storage system in an intelligent way.
For exchanging the information a linked system is needed (Fig. 5). As a basis of the information exchange a common communication standard is important. This can be deduced from the international standard of the station automation IEC 61850. Therefore extension are essential which are in process in the moment. The extensions, IEC 61850-7-420, provide a common protocol code for a web based bus. For this communication a web server is needed as well as a FPGA (Field Programmable Gate Array) which describes the bus between CHP unit and standard communication [2].

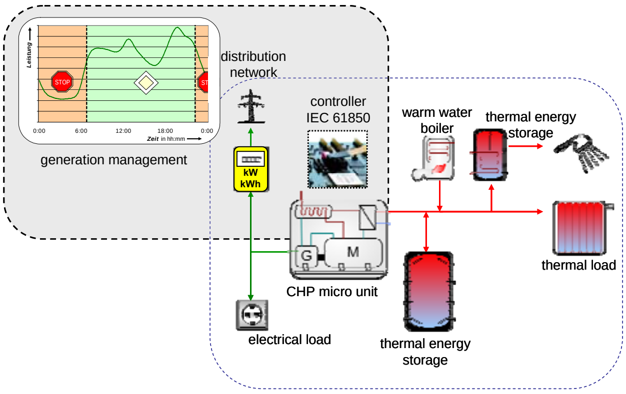


**Fig. 5: Extesion of the distributed system with a linked information system**

### Outlook

To establish this operation mode it is necessary to develop benefits of the operation mode for the plant operators. Up to now there exists no added value to change the operation mode. Up to now the benefits are only given for network operators and power authorities which are not able to act as power plant operators because of the given unbundling regulations.

## REFERENCES

[1] C. Schulz, 2007, "*Systembetrachtung zur Integration von Mini-Blockheizkraftwerken in das elektrische Versorgungsnetz*", Ph. D. dissertation, Dept. El. Energieanlagen. Ger., Techn. Univ. Braunschweig

[2] M. Korte, 2007, "Modellbasierter Entwurf und Simulation von Energiesteuersystemen", *1st status seminar of the Energy Research Alliance of Lower Saxony*, pp. 111-120.

[3] W. Suttor, 2005, „*Blockheizkraftwerke – Ein Leitfaden für den Anwender*", vol. 6, TÜV-Verlag, Germany.

[4] W. Suttor, 2007, „*Blockheizkraftwerk, Eine Heizung, die Ihr Geld verdient*", vol. 3, C.F. Müller Verlag, Heidelberg, Germany.

[5] VDI e.V., 2007, „*VDI 4655: Referenzlastprofile für Ein- und Mehrfamilienhäusern für den Einsatz von KWK-Anlagen*", Beuth-Verlag, Düsseldorf, Germany.

[7] VDI e.V., 2000, „*VDI 3985: Von den Grundsätzen für Planung, Ausführung und Abnahme von KWK-Anlagen mit Verbrennungskraftmaschinen*", Beuth-Verlag, Düsseldorf, Germany.