# PART-LOAD OPERATION OF MINI COGENERATION PLANTS IN MEDIUM VOLTAGE GRIDS

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## *ABSTRACT*

*This paper deals with control strategies for mini cogeneration plants (short: CGP) in medium voltage grids. The aim of the paper is to explain and to minimize the trade-off between highest electrical efficiency in electrical energy production and the needs of energy reserve caused by uncertain load estimation. In general, high energy reserve means low electrical efficiency in electricity production. But fuel cells offer a high electrical efficiency in a relatively wide control range.*

## *1. INTRODUCTION*

Today, Germany’s electricity production system is a historically grown mixture of different technologies (fig. 1). The main part is produced in conventional power plants based on coal firing or nuclear energy, i.e. a totally installed power of 120 GW. The energy output is supplied to the consumers via transmission grids, distribution grids and consumption grids. Due to financial support offered by law, wind power plants, solar power plants and small cogeneration plants have been added to the existing system within the last 10 years. Today, there is an installed wind power of 16.6 GW in Germany. The installed power of solar power plants and small cogeneration plants is less, but continuously growing.

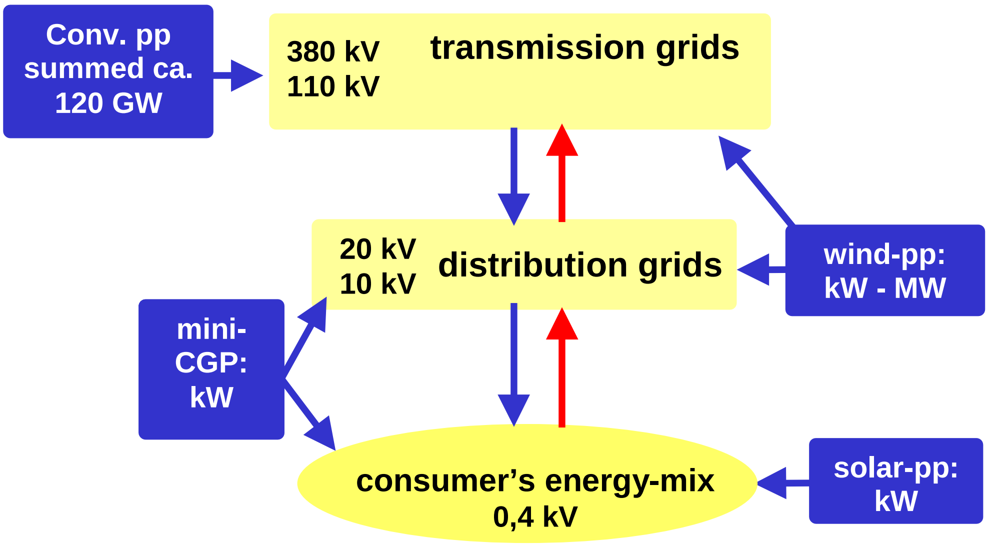


Figure 1: Today’s electricity production in Germany [1].

Indeed, people ask for a final concept for tomorrow’s electrical energy production. A final solution has not been developed yet. A desirable energy supply system has to be economically and ecologically efficient and technically feaseable. Therefore, the final concept will also be a mixture of different production technologies. Mini heat and power cogeneration plants (short form: CGP) are promising elements, because their electricity production is independent from weather and place. Furthermore, electricity production from CGPs is very near to the consumers. Due to this, transmission losses in the grid are minimised. In respect to losses, the optimum is a current controlled plant close to the consumers. But in part-load operation, this would cause a reduced electrical efficiency, a trade-off problem.

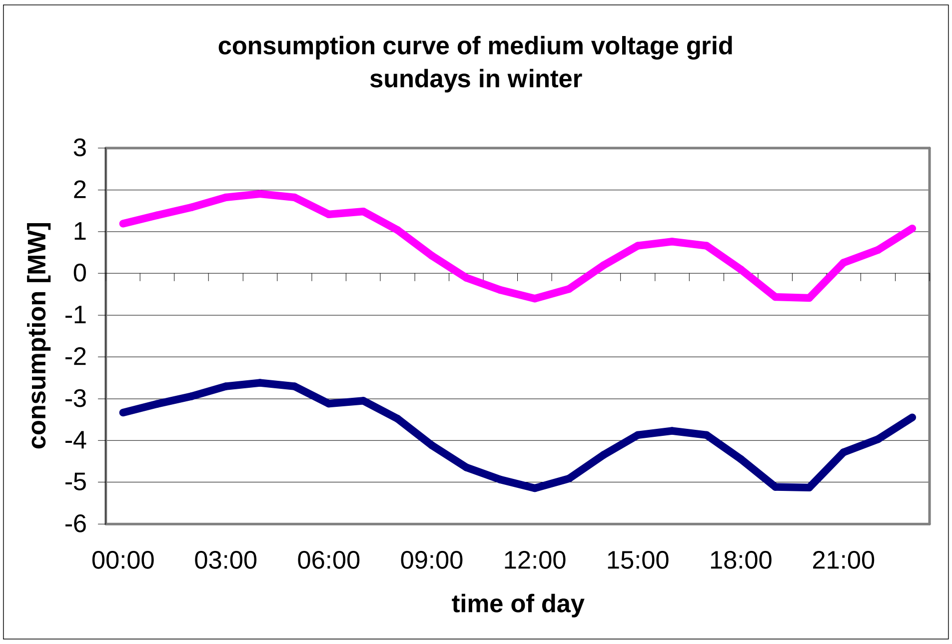
## *2. CALCULATION METHOD FOR OPTIMISING THE TRADE-OFF BETWEEN ELECTRICAL EFFICIENCY AND CONTROL RANGE*

Taking a real distribution grid of a typical city in Germany, the original consumption curve can be impacted due to uncontrolled, constant current producing CGPs (fig. 2). If given CGPs are installed at optimal places, they produce the average consumption of the year for each node of the grid. The black original consumption curve is shifted until the integral over the year is zero. If the value of the red curve is below zero, the electrical energy flow is in the normal direction. If the value of the red curve is higher than zero, electrical energy is fed back into the transmission grid. This electrical energy has to be consumed in other distribution grids or it has to be stored. Energy storage is expensive and technically not efficient yet. Alternatively, small CGPs can also be controlled using the actual current flow.

Figure 2: Consumption curve of a typical distribution grid for the day of minimum consumption in the year considering a scenario without distributed generation (black) and with decentralised production of the average consumption (red) [1].

The market offers several types of mini-cogeneration-plants. CGPs with conventional combustion engine, micro-turbines and fuel cells are the most common ones. All of these three types offer a high electrical efficiency in part-load operation.

The characteristic curve of a combustion-engine-CGP is similar to the characteristic curve of a conventional power plant (fig. 3). It is designed for highest efficiency in constant nominal power operation. Power reduction due to current controlled operation causes a decrease of the electrical efficiency and therefore an increase of gas emissions per kWh produced electricity. Regarding ecological aspects, the electrical efficiency of fossil fuel burning power plants should be as high as possible. Unfortunately, current-controlled operation is unavoidable, because electricity consumption is not constant and electricity storage is even more un-efficient. Therefore, the key question is how much electrical efficiency is lost due to part-load-operation without energy storage.



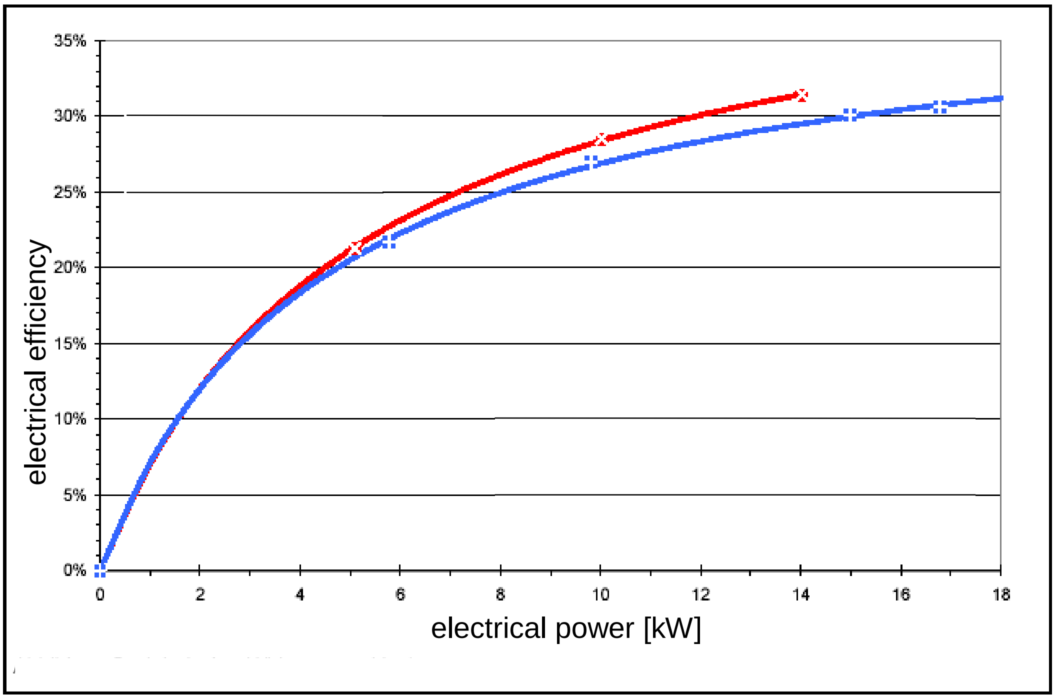


Figure 3: Electrical efficiency of combustion-engine-cogeneration-plants as a function of electrical load [2]

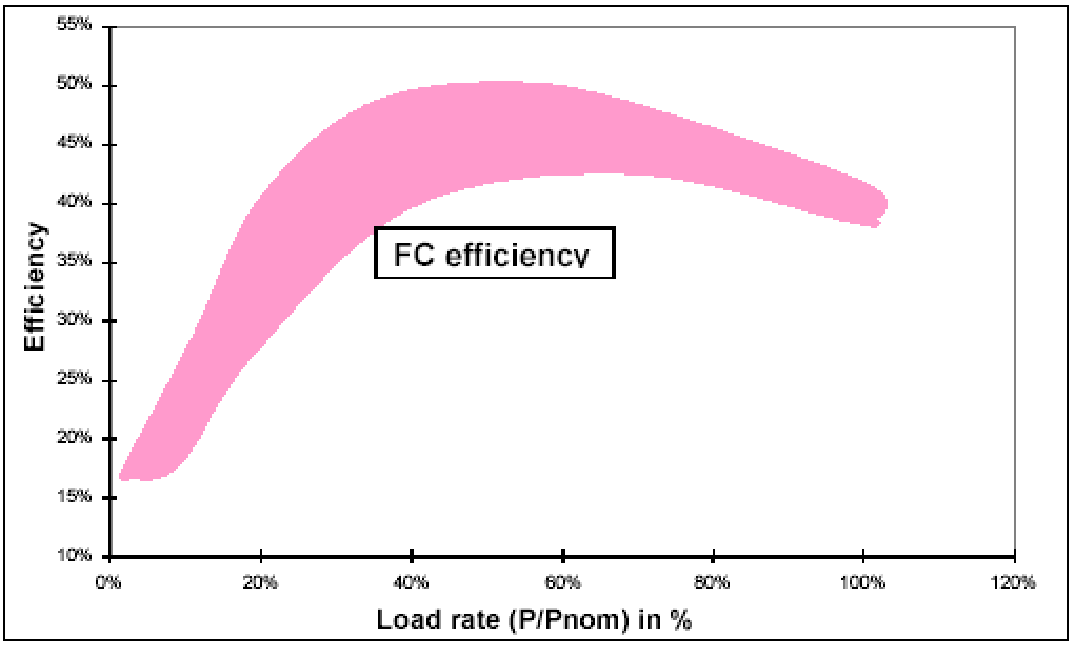


Figure 4: Electrical efficiency of fuel cells as a function of electrical load rate [3]

In contrast to conventional power plants and combustion-engine CGPs, the maximum efficiency of the fuel cell characteristic does not correspond to maximum load. That is why fuel cells seem to be very promising for part-load-applications. In order to test these applications, the CGPs in the optimised scenario produce a small constant basic current and a variable load in a certain range. Starting with range zero, the difference between consumption and production curve is equal to the scenario described before (fig. 2, red line). For the simulated city grid, a storage with a maximum power of 1.905 MW and a maximum capacity of 43.126 MW is necessary. Starting at this scenario, the control range and the installed CGP-power are extended step by step until a storage is not necessary anymore. For each step, the lack of total electrical system efficiency has to be calculated. The total system efficiency $\eta_{el,sys}$ is

$$\eta_{el,sys} = \frac{\sum_{1}^{n} E_{CGPn} \cdot \eta_{el,CPGn}}{\sum_{1}^{n} E_{CPGn}} \cdot \frac{E_{load}}{E_{load} + E_{loss}} . \qquad (1)$$

The electrical efficiency of CGP number n, $\eta_{el,CGPn}$, is a function of the part load rate (fig. 3 and 4). $E_{CGPn}$ is the electrical energy that is produced by the CGP number n within one year. $E_{load}$ is the electrical energy consumed, $E_{loss}$ includes all losses in the grid.

In order to calculate the lack of electrical efficiency, the total system efficiency of the scenario with control range zero is set to 100 %. The lack is the difference between the total system efficiency of the certain scenario and 100 %. If parameters of the CGPs in the grid simulation are considered, storage size and capacity can be extracted from the new calculated consumption characteristic.

Cost per kWh in part-load operation compared to cost in full-load operation directly depends on the electrical efficiency:

$$\text{part-load-price} = \text{full-load-price} \cdot \frac{\eta_{\text{part-load}}}{\eta_{\text{full-load}}} \qquad (2)$$

The ecological impact per kWh produced electricity in part-load operation also depends on the electrical efficiency:

$$\text{part-load-impact} = \text{full-load-impact} \cdot \frac{\eta_{\text{part-load}}}{\eta_{\text{full-load}}} \qquad (3)$$

Therefore, the total electrical system efficiency has to be as high as possible in electricity production.

## 3. CALCULATION RESULTS

For the scenario with decentralised production of the average electricity consumption of a German city within a year the total system efficiency has been calculated (tab. 1 and fig. 5).

| control range x % of $P_{max}$ | storage size in MW | storage capacity in MW | lack of electrical efficiency in % |
|---|---|---|---|
| 100 ... 100 % | 1.905 | 43.126 | 0.00 |
| 76 ... 100 % | 1.363 | 26.201 | 1.11 |
| 58 ... 100 % | 0 | 0 | 2.27 |

Table 1: Storage size and capacity depending on the control range

The electricity production system in this scenario consists of 900 kW installed power generation capacity of fuel cell CGPs, 1.170 kW installed power of micro-turbine-CGPs and 2.450 kW installed power of combustion-engine-CGPs.

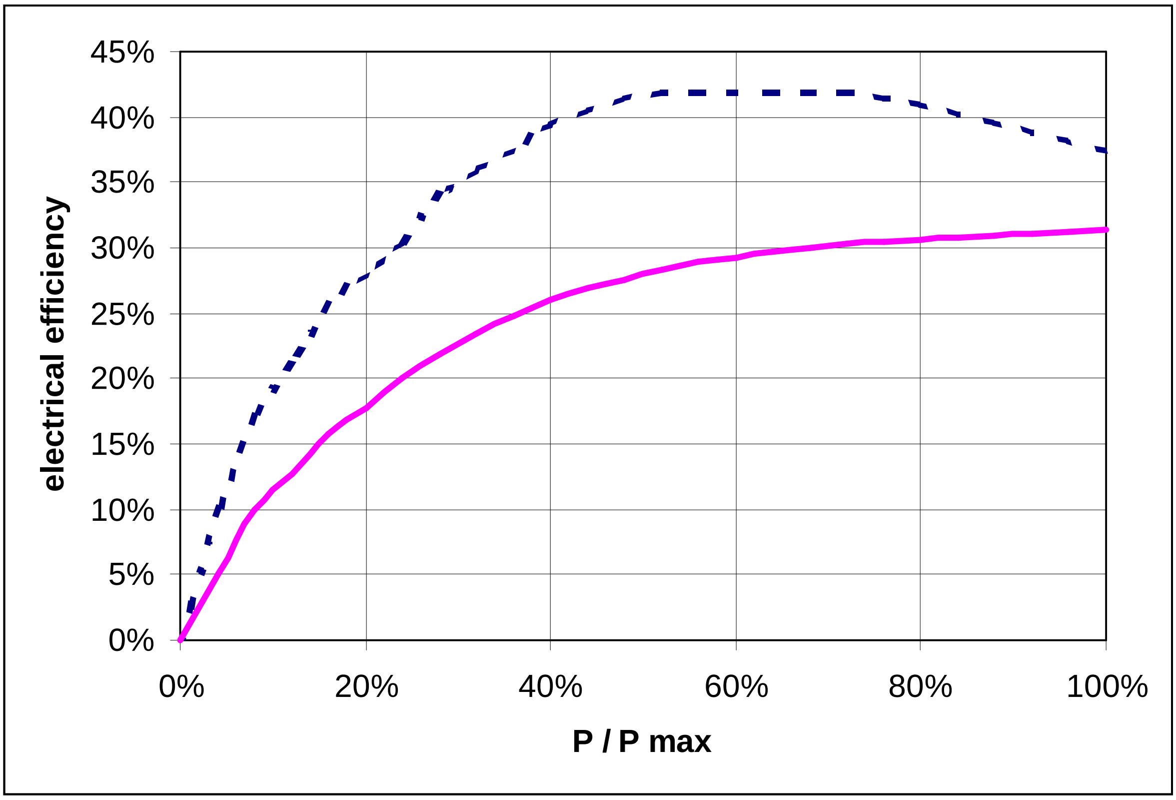


Figure 5: Electrical system efficiencies at constant part-load operation points both for the electricity production system based on different CGP technologies (red line) and for only fuel-cell CGPs (black, dotted line).

## 4. *CONCLUSIONS*

Current-controlled operating CGPs with narrow control range allow storage elimination without remarkable decrease in electrical efficiency. If there were only fuel-cell CGPs, there was no decrease in electrical efficiency. Almost constant electrical efficiency means almost constant cost per kWh produced by a CGP. In normal operation, the production cost of 1 kWh electricity via CGP is between 6 Eurocent in case of combustion engine and 11 Eurocent in case of fuel cell. Due to current-controlled operation, the price for combustion-engine-CGP increases up to 6 Eurocent / 0.9773 = 6.2 Eurocent. The price for fuel-cell-CGPs remains constant at 11 Cent / kWh, because there is no lack in efficiency for fuel cells.

If the efficiency remains constant, the ecological impact of electricity production also remains constant. Therefore current-controlled operation of CGPs and avoiding storages is the optimum solution, especially considering fuel cell applications.

## *5. SUMMARY AND OUTLOOK*

Current-controlled operation with narrow range allows storage elimination without remarkable lack of electrical efficiency and is therefore the most promising way of operation. During actual load change, there is an additional lack of electrical efficiency which has not been considered in the presented calculation. The efficiency decrease during load changes is estimated to be very low, but has not been measured yet. Therefore this basic calculation has to be upgraded in future.

At least, we have to develop the final concept for tomorrow's electrical energy production by arranging many different elements:

We have to make solar- and wind energy technically useable within an efficient electricity production system via intelligent control strategies, either by commonly using part-load operation of other power plants or part-time shut-down of plants or new storage technologies.

In order to evaluate ecological aspects, we have to compare the total system efficiencies of different electricity generation technologies considering part-load operation or operation combined with storages including a detailed analysis of part-load operation options for conventional power plants.

Additionally, we have to consider economical aspects. Due to part-load operation or shut-downs, the time of amortization increases. Especially a part-time shut-down of wind power plants instead of part-load operating CGPs and conventional power plants has to be evaluated.

## *6. REFERENCES*

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