Design and operation of a local cogeneration plant supplying a multi-family house (9,5 kW electrical / 35 kW thermic power) – a field report

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Abstract

In the paper at hand design and operation of a small co-generation plant that is suitable to maintain a three family house is presented. The plant is capable of delivering 9.5 kW electrical power to the mains and 30 kW thermal power used for heating the domestic hot water and the building respectively. A detailed description of the plant is followed by a description of the measurement setup.
Practical experiences from two years of operation and measurements concerning the electrical as well as the thermal efficiency are presented.

Key words

Energy efficiency, heat generation, cogeneration plant, exhaust gas after-treatment.

1. Introduction

The efficiency of power generation via caloric power plants can be increased by utilizing rejected heat. So in order to utilize the primary energy carrier more efficient, some existing district heating grids are fed from the rejected heat of large and medium scale caloric power plants.
This concept is not suitable for rural (sparsely populated) regions as the heat transport via district heating grids in this case is highly unprofitable. Secondary especially in agrarian regions most farmers are well provided with heating material from their forests (wood) or fields (e.g. straw) and therefore not interested in a comfortable but for them more expensive heating facility.
In order to reduce the costs for heating of a three family house (lived-in by my parents and brother), for the preparation of the domestic hot water and in order to generate electrical power a cogeneration plant named "Turdanitsch 2" has been planed and built up.
Building up as well as operation of the plant proof that the concept of combined heat and power generation is efficient even for small scale units.
At present no plants providing about 10kW electrical and 30kW thermal power are purchasable. Therefore a prototype had to be designed and built up. The concept of powering the plant by utilizing woodgas was chosen as the efficiency obtained with small units is higher than by using steam or ORC processes. The cogeneration plant was planed as an easily to be operated, low maintenance and reliable unit. This could be confirmed during the last two years since beginning of operation.

2. Description of the plant

A. Gas process

Wood chips are used as energy carrier. These are small pieces of wood produced by shredding waste wood from thinning the forest or the sawmill industry. In the presented power plant, the wood chips are transported automatically from the storage room via the drying unit into the woodgas generator. The dimensioning and construction of the gasifier was first taken from [1]. The gas quality of this design was insufficient and the produced tar destroyed the internal combustion engine after few hours. It turned out that reaction temperatures had to be about 1400°C to generate tar-poor gas. The whole gasifier had to be completely redesigned to generate tar-poor gas of sufficient quality. (Theory of Gasification [2]). For this design it is essential for the gas quality to keep the gas flow constant, because the achieved temperatures are dependent on the gas flow. Therefore it is not possible to change the gas flow rate. So the electrical or the thermal output power of this plant can not be adjusted easily.
The emerging woodgas is cleaned from soot particles by using a cyclone and an electrostatic filter system. The gas has to be cooled down to raise the gas density. The emitted heat energy is given to the domestic heating water via a heat exchanger. The conditioned gas is mixed with air (the necessary amount of oxygen is determined via the built in lambda probe). The air gas mixture is then fed to a standard combustion engine which has been dismounted from a motorcar. The combustion engine powers an induction generator which is connected to the three phase power system. The rejected heat of the wood gasifier, the combustion engine's cooling water and the heat of the exhaust gases are fed via heat exchangers to a heating water buffer storage. If required, the heating system as well as the domestic hot water can be fed from this buffer.
For efficient use of the produced thermal energy, the plant has to be operated in a heat led mode. Power modulation is not advisable due to the underlying concept. Therefore the house is heated using the previously heated up buffer storage during standstill of the plant. If the rejected heat cannot be dissipated the plant shuts down.

In this case no electrical power is generated. As there is no electric energy storage system implemented, it is necessary that in this case the electric power company provides the necessary electric energy. If the heating water buffer storage can not provide enough heat, the plant has to be started up again.

B. Exhaust gas treatment

The combustion gas passes the lambda probe and is after-treated in a standard three-way catalytic converter in order to reduce the anyway low CO and HC percentage. A heat exchanging device extracts further useable warmth from the combustion gas and feeds the central heating. After this treatment the utmost temperature of the combustion gas is about 60 degree Celsius. The subsequent muffler reduces the acoustic emission to an scarcely audible measure.

C. Generator

An induction machine has been chosen as a generator. Compared to a synchronous generator, one big advantage of an induction generator is that switching the generator to the mains is much more easily. Neither rotor speed nor polar wheel angle has to be controlled very accurately. A second advantage is that no excitation device has to be provided.
The induction machine used is designed as to be run as a motor and features a nominal voltage of 420V. As the mains voltage is only 400V, the machine's magnetization state and the magnetizing current are not too high. This is essential for low iron and copper losses in generating mode.
In a second stage of expansion a rotor speed measurement unit is designed that allows to measure the speed from the voltage induced into the stator windings by residual magnetism. With this the switching of the generator to the mains can be carried out smoothly.
The excess electric energy produced during operation of the plant is applied to the public mains. Parallel main operation is carried out.
In order to reduce the reactive power that has to be provided by the public mains, capacitors are switched in parallel to the induction machine after connecting the machine to the mains.
Building up of the plant started in January 2005, during summer 2006 the plant was switched to the mains for extensive test runs after considerable tests carried out by the local energy supply company (Kelag).

3. Efficiency analysis

Efficiency analysis has been started recently. For this purpose several additional energy-counters have been installed. The measurements are still in progress. Figure 1 shows efficiency data that has been determined by now.
Experiments show that output power and efficiency could be increased in the future by optimising the gas cleaning and cooling process and the heat exchangers. Modifying the compression rate of the combustion engine or turbo charging are further perspectives [3].

Consumed woodchips per hour	0.06483	loose m³/h
Woodchip moisture after dryer	18.26	%
Overall el. power dissipation	6.48	kW/h
Dissipated useful heat	26.55	kW/h
Electrical efficiency	13,32	%
Thermal efficiency	54,52	%
Overall efficiency	67,84	%

4. Government aid and basic financial conditions

Whereas the building up of commercially available biomass heating systems is funded no government aid is available in case of self-construction prototypes.
The whole project as well as the research and development work carried out (the application of a patent is under examination) are financed privately.
The electric power is payed according to the austrian law concerning green electricity [5]. The fees are 0,12 €/kWh when using saw mill residue as a heating material and 0,16 €/kWh when using wood chips from small trees as a heating material. The fee does not depend on time of day or season. Hence on an average 1400€ are earned per year, the consumption of wood chips is about 90m³.
The energy produced equals the one of 8000 liters heating oil. As wood is carbon neutral, an amount of 23 t of carbon dioxide is saved.

5. Results

During winter 2006-2007 and 2007-2008 the cogeneration plant was under operation without major faults [5]. In December 2008, after 3000 hours of operation, the first bigger breakdown occurred due to a service failure. By now 3500 hours of operation are reached. The amount of maintainance is about 15 minutes per operating period, which lasts about 2-4 days depending on the weather.
It could be shown that the concept of combined heat and power generation is efficient even for small scale units fed from biomass. The high market price for wood chips makes the mere generation of electrival power from biomass unprofitable. The break even point can only be reached when utilizing the rejected heat for heating purposes.

References

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