Micro-CHP: Overview of Selected Technologies, Products and Field Test Results

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This paper gives an overview on selected Micro CHP technologies and products with the focus on Stirling and steam machines. Field tests in Germany, the UK and some other EC countries are presented. Test results show the overall positive performance with differences in sectors (domestic vs small business). Some negative experiences have been received, especially from tests with the Stirling engines and the free-piston steam machine. There are still obstacles for market implementation. Further projects and tests of micro-CHP are starting in various countries. When positive results will prevail and deficiencies are eliminated, a way to large scale production and market implementation could be opened.

1. Introduction

Decentralized power generation combined with heat supply (CHP) is an important technology for improving energy efficiency, security of energy supply and reduction of CO_2 emissions. Micro-CHPs are especially interesting for market of single family (SFH) and multifamily (MFH) houses, smaller buildings and small to medium businesses (SME) due to their technical and performance features:

- A high overall energy conversion efficiency (eg in excess of 90% for Stirling engines)
- Low maintenance requirements equivalent to a domestic gas boiler.
- Very low noise and vibration levels for installation at home.
- Very low emissions of NOx, COx, SOx and particulates.

Early adoption of CHP by utilities and manufacturers could lead to sales and service contracts worth over £1.5bn/y (€2.2bn) across Europe by 2010 (Cambridge Consultants, 2007).

2. Methods

The paper benefits in particular from the German experience in Stirling machines and field tests of a special Stirling engine (power range 2 – 9.5 kWel) of a German manufacturer, field tests of a Stirling engine (about 1 kWel) of a manufacturer from New Zealand in France and the Netherlands and UK field tests of a number of CHPs. Market studies (Berger et al. 2006) and the description of experiences with field tests in Germany (Forster, 2006) and UK (The Carbon Trust, 2005) were evaluated to get comprehensive information for this study. They focused on producers and conversion techniques with a high development status. These products are close to market introduction and either undergo CE-certification procedures or are already matured. They are expected to timely enter the market. The classification was: Stirling engine, hot air engine and combustion engine. Fuel cells and micro-gas-turbines were not considered because of their problematic application in the small-scale housing sector.

3. Results

Tests in Germany, UK, France and the Netherlands show various results.

3.1 German market study

In the framework of the market study (Berger, 2006) 15 relevant micro-cogeneration products were identified and analyzed. To study feasibility and application of micro-cogeneration the following objects were chosen:

1. Lion Powerblock (free-piston steam engine)
2. WhisperGen MicroCHP (Stirling engine),
3. Microgen M-CHP (Stirling engine)
4. Ecowill (combustion engine),
5. Dachs (combustion engine),
6. Ecopower Mini-CHP (combustion engine)

The profitability was analysed considering a cost benefit calculation of the product application in single consumption mode different buildings in Germany. The evaluations were in most of the cases negative, a larger number of the case studies was analysed as cost inefficient. The energy costs varied in a range from 38.0 to 9.8 ct/kWh. For Stirling-engines WhisperGen micro-CHP and Microgen micro-CHP savings of 10% of the energy costs can be reached in SFH. Because of the less heat consumption (50%) in new build SFHs the feasibility of micro-cogeneration is much lower than in older buildings. For a newly-build SFH the Stirling is inside the feasibility limit (better: at its feasibility limit). The free-piston-steam-engine Lion Powerblock is the least cost efficient with an energy price of 38 ct/kWh, which derogates the yearly energy costs.

A general statement for the feasibility can’t be made. The feasibility is dependent on the operational mode and engine application according to the demand structure. Single task oriented products have a better feasibility, as modules designed with an additional “back-up” like a boiler or a gas-fired thermae.

3.2 German field tests with Stirling engines (Forster, 2006)

A company in Sindelfingen had started a serial production of a gas-fired Sterling 161 engine in 2004. Over 120 units were sold.

Berlin

One of the Stirling 161 engines was tested by the Berlin gas utility. A first Stirling-cogeneration-unit is used to power a state public institution building - the Kreuzberg fire station in the district Friedrichshain-Kreuzberg of Berlin. Together with a large gas distributor (VNG) the company has been checking the capability and client acceptance in a three years test (since November 2005). The first engines from the serial production run well, yet with some small problems. The electrical output has been underachieved, and a frequent faults lead to higher maintenance costs. Overall the VNG is positive as the Stirling is a very efficient way to convert energy. It is a well-engineered technology on the way of market implementation, in comparison to fuel cells. This Stirling 161 (2-9.5 kWel; 8-26 kWth) was integrated in the existing heating system of this building. It is parallel spliced with the central heating boiler. When it is no requirement for the heat the boiler is not used. The whole Stirling cogeneration unit can be taken offline with an automatic powered shut-off valve. As this fire station has a constant demand of energy and heat it is perfectly suitable for the test run. The Stirling 161 can be operated at a full load about 5,800 h and part-load 7,800 h. The feed temperature 68°C in the heating circulation is judged as less efficient which reduces the electric power. The producer recommends a maximum feed temperature of 65°C. After to serial production in 2004 several problems with material occurred. The company Solo investigates the reason for the defect of the connection rod of the aggregate. Meantime a new method was developed for precise measurement and evaluation of tolerances. There was also a change of a subcontractor and the piston rod is available with the requested quality and has been be refitted.

Fürth

Another test run of Solo production Stirling 161 is proceeding in Fürth. In cooperation with the energy agency EAM and a local district heating provider a station was chosen, which is supplying heating power for a residential area (79 buildings). Because of the combination of the district heating station (max. 4.5 MWh) and the Stirling CHP unit, various modes can be measured, without having an impact on the supply of the client. Solo Stirling achieved a degree of efficiency of over 90% and its optimum in part-load. Because of the high feed temperature from the district heating station the pre-conditions can be considered as suboptimal. The forecasted degree of efficiency could have been complied since the beginning of the test run. EAMs appraisal is positive saying that fundamental problems do not exist but the testing of a larger number of Stirling engines is regarded to be useful.

Otherwise an EAM project manager has some doubts regarding Stirling 161, questioning if the malfunctions like the defect of the connection rod were system systematic or only an outlier. However Solo maintains that the major part of the 120 Stirling hot-air-engines runs without any problems.

Ditzingen-Hirschlanden

An ESCO (part of a large French utility) reports only modest results using the Striling 161. In the Swabian town of Hirschlanden a Stirling CHP unit integrated in a district heating station is supplying 100 SFHs, a home for old people and a nursing home with heat. The Stirling SHP unit is predominantly used to provide the demand of the boiler house.

The correlation between the high feed temperature and the derogation of electric efficiency has occurred also in this test-run. At a feed temperature of 60°C an electric power of 6.5 kWel is measured in Ditzingen-Hirschlanden. The total efficiency amounts up to 79%. Because of the external combustion the interior of the Stirling engine remains free of residues. The pollutant emissions are much lower than the emission of other engines.

The ESCO specified the following disadvantages: the little operation experiences, the lack of a mass production and the still relatively high specific investment costs. The technical potentials are still not taped fully. The service and support could be optimized. But if the positive experiences will proceed, further projects with the Stirling will start.

Others

In 2006 the Berlin gas utility started the second two year test-run in a SFH, where a gas-operated Striling-CHP unit WhisperGen from a New Zealand manufacturer (1 kWel; 7.5 kWth) was installed. The same CHP unit was chosen by another German utility company in Mannheim. Over 20 SFH started with voluntarily participation in the test.

3.3 UK market study

The UK market for micro-CHP is assessed to be about 400,000 households (Carbon Trust, 2005) within ca 1 million households and SMEs which displace boilers per annum (Envocare, 2007) Unlike mini-CHP (which is regarded as a mature technology and have been applied for quite a long time), micro-CHP technology is not yet available commercially and there are rather few data about its performance in UK. Mini systems used in industrial and commercial applications show advantages of their performance for quite a long time. On the other hand, the direct projection of mini-CHP experience to micro-CHP level turns counterproductive due to extra complexity at the micro level and lesser tried technologies (for example fuel cell technology) which still needs to get mature.

Overall CHP are intrinsically more efficient in comparison with other generating facilities and the grid with its 30-40% efficiency (Ecpower, 2007) Potentially micro-CHP can have the competitive edge over condensing boilers, but still considerable work has to be done to implement this into real economic and environmental benefits.

The latest research shows that micro-CHP have to improve their performance to become widely accepted in the market. Since the potential market is quite large in terms of units, there are good incentives for improvements. By 2006, not much progress was made in micro-CHP penetration into the market. There are still very few micro-systems available, the public, architects and civil engineering community en mass are not much familiar with the technology.

Another factor of a rather poor micro-CHP market penetration was a successful campaign to promote energy-saving condensing boilers. The UK government in 2001 stated that CHP was one of important ways to implement the Kyoto commitments. The UK target for installations set for the end of the year 2000 was 5,000 MWe and by 2010 further target of 12,000 to 19,000 MWe (Envocare, 2007)]

3.4 UK Carbon Trust field tests

Carbon Trust launched a trial in 2003 aimed to a comprehensive analysis of the current situation and development of recommendations to overcome the barriers that impede the implementation of this technology. The trial is expected to finish by mid/late -2007 and results will be published. Only preliminary data have been available so far.

The technologies assessed were Stirling Engines, Organic Rankine Cycle Machines, Fuel Cells and Internal Combustion Engines. In total about 40 units (of those 31 micro-CHP, mostly in homes) have been assessed. The performance indicators recorded were: overall thermodynamic efficiency, the amount of electricity generated the carbon intensity of the electricity displaced from the grid. A significant result of this trial is that the first two performance indicators differ very significantly for micro- and small CHPs. The micro-CHP units assessed show very different performance characteristics in different environments. The carbon footprint and savings being important characteristics, the capital costs needed to be evaluated as well. So far the units are not manufactured at the scale sufficient enough to a give a final conclusion on the capital cost. The preliminary results of the Carbon Trust trial indicate that the performance of micro-CHPs was not as impressive as expected. Some of the reasons are:

- Actual efficiencies of was lower than assumed by existing models.
- The amount of electricity generated is much lower than the forecast.

The poorer than expected efficiency is caused by the current stage of the design and operation. The thermal inertia of the micro-CHP units seems to be still too high compared with the conventional boilers for a fluctuating demand for heat in buildings. In many houses the demand is to a large degree irregular and the heat is required only for short periods but many times a day. The repeated warm-ups cause waste of energy which is not re-released in a useful way which reduces the efficiency. This makes a vast scope for improvements focused on reduction of thermal inertia and/or number of cycles. Another problem for micro-CHP performance is the assumption of constant average electricity demand. The trial has proved that for the most of the time demand is much lower than average and also lower than typical micro-CHP output. This is also combined with short periods of very high demand (when some appliances are running, e.g. kettles, electric showers, etc). So far the significance of peaks and troughs has been neglected by the designers. With new design of low voltage networks which could cope with high levels of export, in addition to full load import when the units are not running, the micro-CHP industry needs to design units with the ability to modulate electrical output much more widely than currently. Summarising the preliminary test the Carbon Trust indicates that at the current stage of technology micro-CHP have limited contribution to CO_2 reductions and considerable improvements are required.

3.5 Field tests with Stirling engines in France and the Netherlands

A DGTREN funded project DEO (Priaulx, 2003) compiled a comparative study on innovative technologies of power generation in buildings, analysing pilot-projects in 2001-2003. Partners were several European gas supply companies. The study focused on the application of innovative gas-technologies as micro-cogeneration, gas-heat-pumps; gas fired household appliances and combination-systems e.g. with solar heat.

The DEO project studied SFHs or apartments for the period of a year. To compare the energy saving potential, other objects without the innovative technology were compared. Micro CHP units were installed by leading gas companies in France and the Netherlands. A Whisper-Gen module powered a test-run apartment in France and a SFH in the Netherlands. In the Dutch test the micro-CHP unit was supported by applications of other energy saving technology, as gas heat pumps, gas fired household appliance and electronic thermostatic-valves etc.

The French demonstration run achieved satisfying results. No operational malfunctions appeared. The specific performance of the heat supply met the producer data. The electricity was close to the predicted performance 82% efficiency (75% thermal and 7% electric). During the monitored test 55% of the power demand was satisfied. The average value for the available electrical power was 0.2 kW considered over the year . Savings 13% of primary energy (gas) and 7% of final energy (electricity, heat) were achieved in comparison to a reference building. The Dutch test example was in contrast disappointing. Several problems were observed in operation and with the start/stop mode and noise-emissions. The operation time was limited. Only 278 kWh were generated overall by the micro-CHP - just 6% of the energy demand. By combination of actions savings of 13% primary and 12% end-use energy were achieved.

4. Discussion

For certain consumers micro-CHP is already a comprehensive solution for energy supply by the present market study (Berger at al, 2006). As shown in Berlin study potential customers for micro-CHP units exist and their attitude is in principle positive. The market introduction of micro-CHP has to be supported actively with the help of energy utilities, research institutes, producers and networks. The need of further stimulation is the outcome of tests (Foster, 2006 and Carbon Trust, 2005). The conclusions are - with positive experiences of micro-CHP and the elimination of the deficiencies a mass production and full market implementation would start in the future.

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