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DEMONSTRATION OF CAPSTONE MICROTURBINES INCLUDING HIGH EFFICIENCY HEAT EXCHANGER, GAS SAFEGUARD MODULE AND NATURAL GAS COMPRESSOR, DEVELOPED BY GASUNIE ENGINEERING & TECHNOLOGY

Main author

J.J.M. Lemmens
N.V. Nederlandse Gasunie
Gasunie Engineering & Technology
Groningen, The Netherlands
www.getgasunie.nl

Co-authors

J.J. Overdiep
Gasunie Trade & Supply B.V.
Groningen, The Netherlands

K.H. Bos, P.M.G. Bartholomeus
N.V. Nederlandse Gasunie
Gasunie Engineering & Technology
Groningen, The Netherlands

ABSTRACT

Introduction
Microturbines can be used as efficient decentralized power generators in combination with heat supplies, thus realizing significant energy savings and emission reduction. The benefits of microturbines are high power density (output power vs. dimensions), high reliability, long lifetime, low emissions, low maintenance and fuel diversity.

Aim
The aim of this project is to solve some problems in the field of fitting microturbines into applications. This has led to the development of peripherals, suitable in microturbine areas, by Gasunie Engineering & Technology (GET), on the commission of Gasunie Trade & Supply, Dutch Ministry of Housing, Spatial Planning and the Environment and some manufacturers. The equipment developed will expand the utilisation of microturbines in certain areas.

High Efficiency Small Scale Heat Exchanger
For cases in which hot liquid media are needed (e.g. water) and limited line-up space is available, a small scale heat exchanger has been developed. Gasunie Engineering & Technology has developed a cheap highly efficient small scale heat exchanger for existing Capstone microturbines, suitable for redesign for other types of microturbines. With Capstone microturbines, an overall efficiency of at least 83% (based on 70/90 ℃ water system) can be achieve d.

Capstone Gas Safeguard Module
In Europe, Capstone microturbines have to deal with additional standards regarding gas safety issues. In cooperation with the safety department of N.V. Nederlandse Gasunie and a manufacturer, Gasunie Engineering & Technology has developed a Gas Safeguard Module meeting these additional standards on European gas safety. This Gas Safeguard Module can also be adjusted to other types of microturbines.

High Efficiency Natural Gas Compressor (Ex)
Commercially available natural gas compressors for microturbines (< 100 kWe) for inlet pressures of 25 mbar are not efficient enough (electrical power consumption > 3 kWe at full load gas flow of Capstone 30 kWe microturbine) or oversized (e.g. Compare V04G) or too expensive. The Capstone 30 kWe NG LP with internal foil bearing rotating flow compressor (FB RFC) was tested by Gasunie Engineering & Technology on Groningen-gas (G-gas) of 25 mbar, but only delivered approx. 24 kWe of electrical power to the grid.
In cooperation with a compressor manufacturer, Gasunie Engineering & Technology has developed a reliable high efficiency natural gas compressor (Ex) for Capstone microturbines on Groningen-gas (or similar).

Conclusion
Some peripheral equipment has been developed and demonstrated to function properly in the field of microturbine applications based on Capstone microturbines. These peripherals are a high efficiency small-scale heat exchanger, a safeguard module and a high efficiency natural gas compressor (Ex). Gasunie Engineering & Technology and some manufacturers are currently discussing the development of commercially available applications.

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1. INTRODUCTION

Small gas turbines started being developed approximately 15 years ago, especially in the USA. These microturbines can be used as efficient decentralized power generators in combination with heat supply by using advanced techniques such as a recuperator, modern high voltage and control electronics.

The present generation of microturbines combines the advantage of low maintenance costs with high efficiency and low emissions. Flue gases can be used in heat-demanding processes with and without the use of extra heat exchanging equipment. Thus, significant energy savings and emission reduction can be realized.

Other benefits of microturbines are high power density (output power vs. dimensions), high reliability, long lifetime and fuel diversity. Because microturbines have a high air demand, the use of flue gases as “semi combustion air” is possible in combustion processes.

In the USA, Capstone Turbine Corporation has made an important contribution to the development of microturbines utilizing air bearings and air cooling. With respect to machines utilizing e.g. oil bearings, Capstone machines require less maintenance, such as change of oil or oil filters.

Capstone microturbines are currently available in three different scales with respect to electrical power: 65 kWe, 60 kWe and 30 kWe microturbines, all with an electrical efficiency of approx. 28%. They are available in several fuel consumption designs, such as natural gas and biogas, and there is a choice between a grid connected or a stand alone model.

Other microturbine manufacturers are Bowman Power, Elliot Power Systems and Ingersoll Rand. In the past, Turbec also built microturbines.

2. AIM

The aim of the project is to solve the problems regarding fitting microturbines into applications. This has led to the development of peripherals, suitable in microturbine areas, by Gasunie Engineering & Technology on the commission of Gasunie Trade & Supply, Dutch Ministry of Housing, Spatial Planning and the Environment and some manufacturers. The equipment developed will expand the utilization of microturbines in certain areas.

3. DEVELOPMENT OF PERIPHERALS

The peripherals are developed and demonstrated to function properly according to the results in several projects. Discussions with manufacturers are taking place to achieve commercially available hardware.

High Efficiency Small Scale Heat Exchanger

For cases in which hot liquid media are needed (e.g. water) and limited line-up space is available, a small scale heat exchanger was developed. For Capstone microturbines, there are several heat exchangers (e.g. Unifin) available, but they need much set-up space. Moreover, the thermal efficiency of existing heat exchangers is low. With these two facts in mind, Gasunie Engineering & Technology developed a cheap highly efficient small scale heat exchanger for existing Capstone microturbines, adaptable to other types of microturbines.

A specification sheet was set up for the heat exchanger, suitable for a Capstone 60 kWe microturbine, with the following requirements:

- Minimum heat exchange based on 70/90 ℃ water system and temperature difference of max. 5 ℃ between the water input temperature and the flue gas output temperature of heat exchanger (approach temperature of max. 5 ℃)
- Small footprint
- Compact design
- Simple casing
- High life span (due to the material used with respect to corrosion by e.g. sulphur containing components in flue gases of the microturbine)
- Durable material

First an intensive scan of the market was performed on compact high efficiency heat exchangers and their manufacturers in the Netherlands.

A particular group of heat exchanger manufacturers were invited to make a quotation including a design based on these demands. On the basis of the proposed compactness of the designs received and the price quality ratio, two manufacturers were commissioned to produce their prototypes. These prototypes were tested by Gasunie Engineering & Technology. For these tests, a special test facility was built to exchange the heat from the flue gases to a local water circuit, which can release the heat absorbed to a cooling system (see Figure 1).

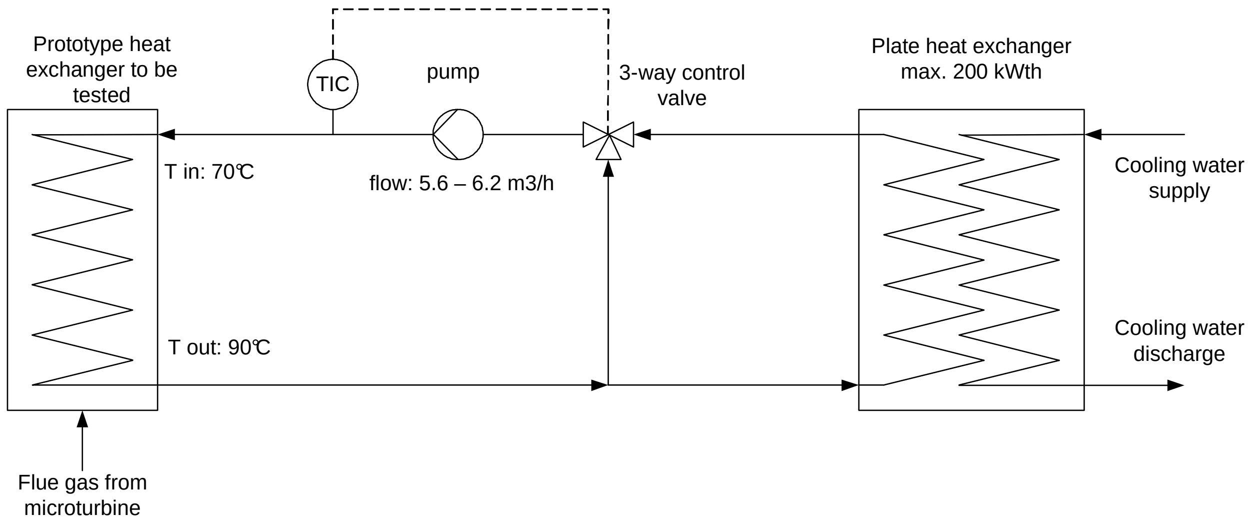

Figure 1 Test rig for prototype heat exchangers

A water circuit including a pump, a three-way control valve and a plate heat exchanger (to withdraw the heat transferred out of the flue gases to the water) was constructed to define the flow and temperature of the incoming water to the prototype.

By fixing the position of the three-way valve and the water flow through the pump, the inlet and outlet water temperature are defined when testing the heat exchanger.

Important figures during these tests were:

- Heat exchange based on a 70/90 °C water system
- Back pressure on the Capstone microturbine

In view of the performance and the compactness of the heat exchanger prototype, one prototype of the compact heat exchanger with extendable heat exchanging area was made of high grade material in view of the demand of a high life span. Based on prototype 1, a design was made for a second prototype. To improve the heat exchange area, flue gas and water flow, a second prototype was built (see Figure 2).

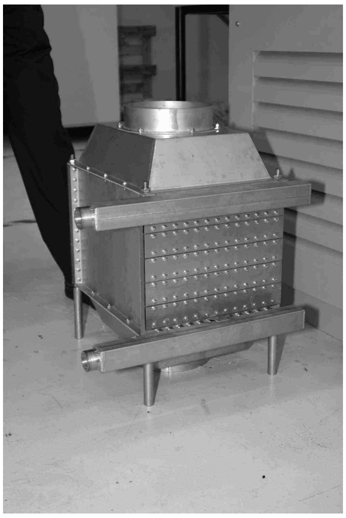

Figure 2 Prototype 2 of compact heat exchanger

Test results for this prototype 2 on a Capstone 60 kWe microturbine are:

- Heat exchange to water phase: 118 kWth (based on 70/90 °C water system)
- Approach temperature of 5 or 7 °C, depending on in coming flue gas temperature (317 and 341 °C respectively)
- Maximum flue gas backpressure of 14.5 mbar.

Finally, the improvement of the second prototype led to a commercial version of the heat exchanger with the following properties:

- Cheap and simple design
- High grade stainless steel with respect to corrosion by e.g. sulphur containing components in flue gases of the microturbine
- Mounted on the exhaust of the microturbine
- Small footprint, dimensions: H * W * D = 24.5 * 17.7 * 14.2” (63 * 45 * 36 cm)
- Proven technology
- Approach temperature of max. 5 °C, based on 70/90 °C water system:
    - Proven thermal capacity on top of a C60 microturbine at full load: > 118 kWth (overall efficiency: > 83%)

    - Proven thermal capacity on top of a C30 microturbine at full load: > 60 kWth (overall efficiency: > 84%)
- Flue gas backpressure of max. 15 mbar

Capstone Gas Safeguard Module

In Europe, all microturbines have to deal with additional standards regarding gas safety issues. Gas safety demands for cogeneration equipment are non-transparent. This equipment originally did not correspond to equipment based on Gas Appliance Directives but was not explicitly excluded either. As a result, cogeneration equipment fell into an undefined area.

Therefore, Gasunie Engineering & Technology, in cooperation with the safety department of N.V. Nederlandse Gasunie and a manufacturer, developed a Gas Safeguard Module for microturbines meeting these additional standards on European gas safety, especially the gas regulations for gas turbines [1]. This Gas Safeguard Module can also be adjusted for other types of microturbines.

After listing the additional gas safety standards and the resulting safety issues and parameters that had to be controlled, a manufacturer involved in the project designed the gas safeguard module on the basis of commercially available components.

The Gas Safeguard Module is based on an extra line of defense (diversity) parallel to the existing control and is based on PLC technology. It can be placed over Capstone I/O signals, flows and measured parameters and acts as a redundancy of the Capstone hardware on gas safety. For example, one extra component is a shut down valve outside the Capstone microturbine. Both the Gas Safeguard Module and the Capstone hardware on gas safety can shut down this valve.

An external bleed valve is also introduced to prevent any released natural gas in the combustion chamber and/or inside the microturbine casing. For meeting ATEX regulations, these two valves are mounted outside the microturbine casing.

This redundant control substantially improves safety by minimizing the chance of common cause failures. Diversity is accomplished by separately monitoring the gas turbine process within the following measurements:

- Mass flow of combustion air as a parameter for purge flow and indication for rotational speed
- Natural gas flow as a parameter for starting load and maximum load
- Temperature measurement due to flame detection and flame loss and overload. Originally this was a lambda probe situated in the flue gases of the microturbine. Because of repeatable malfunction of this lambda probe in a demonstration project, it is replaced by a temperature signal (TET: turbine exit temperature).

An additional flow measurement has been installed in the ventilation channel of the Capstone casing, also to meet ATEX regulations [2]. Some status signals of the controls of the microturbine have been passed to the Gas Safeguard Module.

The Gas Safeguard Module controls the following microturbine processes:

- Starting (including starting load monitoring and control) and stopping conditions
- Purging conditions
- Ignition conditions

- Operation mode (flame detection and monitoring, overspeed and overload monitoring and control, air flow monitoring and control)

An emergency shut down procedure can also be carried out.

In case of interference of the Gas Safeguard Module, the procedure is to wait for a new starting request. It is then locked in this mode till an external reset signal is received.
When meeting at starting conditions, the Capstone microturbine will be starting and fulfilling its own routing program. At ignition, the gas supply must be released by giving the safety valve a command from the Capstone controls and giving the external safety valve a release command from the Gas Safeguard Module.

The whole microturbine process will be controlled by the Gas Safeguard Module (see Figure 3). If the successive conditions conflict, an emergency shut down procedure will be carried out.

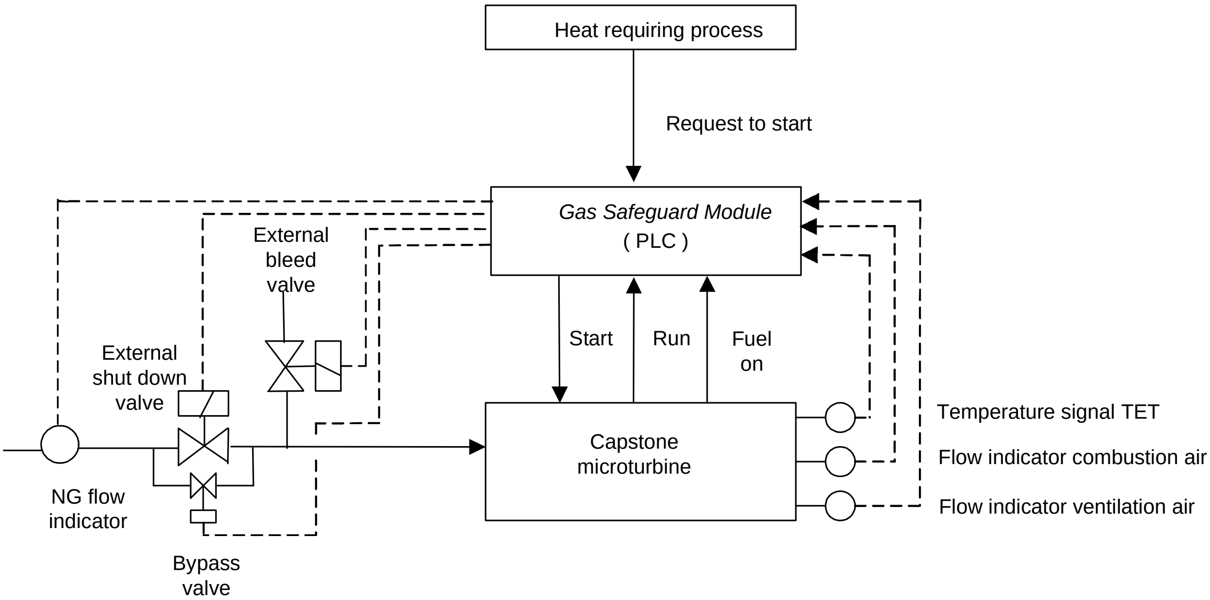

Figure 3 Principle Gas Safeguard Module

The design has been reviewed by the safety department of N.V. Nederlandse Gasunie, which is also responsible for the gas safety standard contents. A definite design of the Gas Safeguard Module has been made for both Capstone 30 and 60 kWe microturbines, using different software parameters.

High Efficiency Natural Gas Compressor (Ex)

Commercially available natural gas compressors for microturbines (< 100 kWe) for inlet pressures of 25 mbar are not efficient enough (electrical power consumption > 3 kWe at full load gas flow of Capstone 30 kWe microturbine) or oversized (e.g. Compare V04G) or too expensive.
The Capstone 30 kWe NG LP with internal foil bearing rotating flow compressor (FB RFC) was tested by Gasunie Engineering & Technology using Groningen-gas (G-gas) of 25 mbar, and delivered approx. 24 kWe of electrical power to the grid. The reason for this is the limited maximum capacity of relative low calorific Groningen-gas of this internal FB RFC.

A high efficiency natural gas compressor, suitable for the Capstone 60 kWe NG HP machine and relatively low calorific Groningen-gas, does not even exist.

In cooperation with a compressor manufacturer, Gasunie Engineering & Technology has developed a reliable high efficiency natural gas compressor (Ex) for Capstone microturbines on Groningen-gas (or similar gases).

A comprehensive study has been made of commercially available high efficient natural gas compressors for microturbines on Groningen-gas (or similar) up to 100 kWe. None of the existing compressors met the requirements formulated by Gasunie Engineering & Technology. These requirements are:

- Comply with regulations for natural gas usage, especially ATEX
- Low energy usage
- Cheap maintenance
- Good price/quality ratio
- No piston compressor (expensive in maintenance)

Taking these requirements into account, a manufacturer subsequently designed some compressors. After reviewing these designs, two natural gas vane compressors were manufactured and demonstrated. Properties of these models are:

- Supplying natural gas (Groningen-gas) for Capstone microturbines from 25 mbar to inlet pressure conditions for the 30 kWe microturbine (4 barg; see Figure 4) and the 60 kWe microturbine (5,2 barg) at full load. The expectation is that the natural gas vane compressor, made for the 60 kWe microturbine, can supply the new Capstone 65 kWe microturbine;
- Power consumption: for 30 kWe microturbine at full load: approx. 1.5 kWe; for 60 kWe microturbine at full load: approx. 3 kWe;
- Electrical power needed is supplied by a frequency converter.

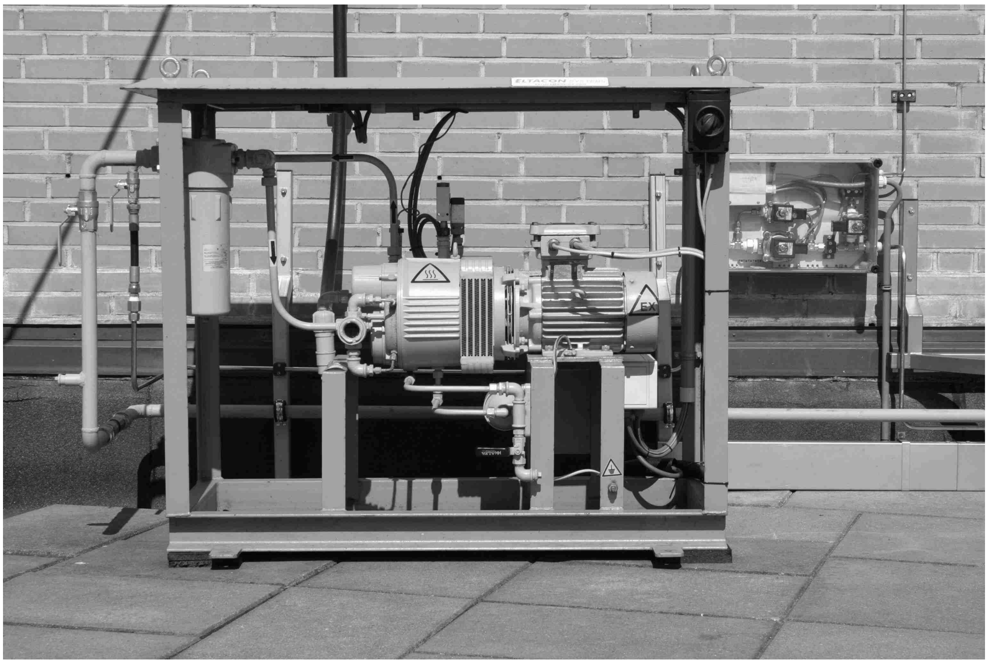

Figure 4 High Efficiency Natural Gas Compressor (Ex) for a Capstone 30 kWe microturbine

Testing of the 30 kWe microturbine with corresponding natural gas vane compressor led to a replacement of the original frequency converter due to a very tight selection based on electrical capacity needed. It was tested at various capacities during 2,000 running hours.

4. DEMONSTRATION PROJECTS

Currently, a demonstration project of a Capstone microturbine in combination with a spray dryer is running. Another demo of a Capstone microturbine as a CHP-unit in a boiler house is planned to run. In both demonstrations commercial versions of equipment are used, based on the developed peripherals described in this paper.

Capstone 60 kWe microturbine in combination with a spray dryer

The flue gases of the microturbine are led into the burner of a spray dryer. The microturbine is equipped with the Gas Safeguard Module and the High Efficient Natural Gas Compressor (Ex).
The demonstration started at the end of January, 2004. During the period January – September 2004, several start-up malfunctionings occurred concerning:

The microturbine:

- Cooling fan failure: has been replaced
- SPV-valve failure: has been replaced
- Ignitor (due to normal wear): has been replaced

The Gas Safeguard Module:

- Out of range of combustion air flow indicator and cooling air flow indicator: range has been adjusted
- Combustion air flow indicator failure: has been replaced

The High Efficient Natural Gas Compressor (Ex):

- Frequency converter failure: has been replaced
- Pressure indicator converter failure: has been replaced
- Electrical relay failure: has been replaced

From October 2004 to 9 December 2005 no serious malfunctioning occurred. In this period, 963 starts and 6,798 running hours were made.

From the beginning of this project on 29 January 2004 to 9 December 2005, a period of 680 days, 1,317 starts occurred and 8,149 running hours were made. A total consumption of 198,135 m^3 of Groningen-gas was realised and 460,559 kWh of net electricity was produced.
Some characteristics (based on the figures above) are:
- Mean amount of starts: 1.9 starts/day
- Mean amount of running hours: 12 hrs/day and 6.2 hrs/run
- Mean natural gas consumption (Groningen-gas): 24.3 m^3/hr
- Mean net electricity production: 56.5 kWh/hr
- Mean net electrical efficiency: 26.5%

- Mean overall efficiency: 92.0%

The number of starts is related to product exchange on the spray dryer. Every time there is a product exchange, the Capstone microturbine is turned off while keeping the spray dryer at temperature by means of limited gas supply to the burner.

The number of starts of the microturbine can be decreased by changing the controls. Instead of the burner, the microturbine can be used to keep the spray dryer at temperature during product exchange. In that case the number of running hours of the microturbine will increase which is favourable for economical reasons.

Because of the electricity consumption of 3 kWe of the natural gas compressor, a net electricity production of 57 kWe can be delivered to the grid at full load of the microturbine. It can be concluded that when the microturbine is running, it is almost running at full load.

Capstone 30 kWe microturbine as a CHP-unit in a boiler house

The microturbine is equipped with the High Efficient Natural Gas Compressor (Ex) and the High Efficiency Heat Exchanger (see Figure 5). The heat exchanger is the big square part on top of the microturbine behind the dark tube (for supply of combustion and ventilation air).

Figure 5 Capstone 30 kWe fitted with commercial version of high efficiency small-scale heat exchanger, developed by GET

The heat exchanger releases the heat of the flue gases into the space heating system.

This demonstration project is currently beginning.

5. CONCLUSION

Equipment to incorporate a Capstone microturbine for a number of combined heat & power applications has been developed and demonstrated to work properly by Gasunie Engineering & Technology (GET). A robust high efficiency small scale heat exchanger has been developed and tested. The test results have met the specifications stated for Capstone microturbines (30 kWe and 60 kWe types), i.e. total efficiency > 83% based on 70/90 °C water systems and backpressure lower than 15 mbar. A demonstration project in which a Capstone 30 kWe is equipped with a commercial model of the heat exchanger is currently being started up.

A Capstone Gas Safeguard Module, adaptable for other types of microturbines, has been developed and demonstrated. It meets the current Gas Appliance Directive, gas regulations for gas turbines and ATEX regulations (e.g. ATEX 137). This Safeguard is based on an extra "line of defence" parallel to the existing control and is based on PLC technology. The standard flame detection has been replaced by a temperature signal (TET: turbine exit temperature). A commercially ripe design has been made for both Capstone 30 and 60 kWe microturbines, using different software parameters.

A high efficiency natural gas vane compressor (explosion safe) has been developed, suitable for use in Capstone 30 kWe and 60 kWe microturbine with relatively low calorific (Groningen) natural gas. Current natural gas compressors are not efficient enough, oversized or too expensive. Power consumption of these vane compressors are: 1.5 kWe for the 30 kWe Capstone microturbine and 3 kWe for the 60 kWe Capstone microturbine at full load (inlet pressure of the compressor: 25 mbar).

In a demonstration project, the Capstone Gas Safeguard Module and the High Efficiency Natural Gas Vane Compressor in combination with a Capstone 60 kWe have been tested. The flue gases of the microturbine are fed into a spray dryer. From October 2004 to December 2005 no serious malfunctions have occurred. In this period, 963 starts and 6,798 running hours were made.

These systems are at present commercially ripe and we are open to other parties for market introduction.

Contact information:
Gasunie Engineering & Technology
P.O. Box 19
9700 MA Groningen
The Netherlands
get@gasunie.nl
www.getgasunie.nl

6. REFERENCES

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7. LIST OF FIGURES