Overview and comparison of renewable microgeneration with Combined Heat Power systems

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Abstract – **This paper presents a study on micro combined heat and power (CHP) system for domestic use. It provides a comparison between existing systems, discussing advantages and disadvantages. The paper suggests an innovative solution in micro CHP system design offering improvements in the overall system topology, as well as in the power electronics converters used in the system. The purposed design has simplified structure, smaller weight and size, reduced price and increased efficiency compared to the current micro CHP (μCHP) systems for domestic heating.**

Keywords – **Combined heat and power, microgeneration, renewable energy**

I. Introduction

Microgeneration is a relatively new term describing a variety of generation systems for thermal or electrical power, where the thermal output is below $45kW_t$ and the electrical output is below $50kW_e$. [1,3] Thus microgeneration units are commercial products intended for onsite installation in single or multiple households. The term however is applied only to systems running on renewable energy or for low carbon emission systems. This creates a great assortment of concepts that can be included under the specification microgeneration, the most popular being wind, hydro, PV, solar thermal, heat pumps, heat generation from biomass, est.. The main advantage of microgeneration systems is the decentralization of power generation, due to the onsite installation of the microgeneration units. This brings benefits such as: (1) Installation of new renewable power without the need of improvements on the distribution network; (2) Reduction of transmission losses; (3) Reducing fuel poverty. Main disadvantages of microgeneration systems are due to the fact that they are relatively new concept, and most systems are in a research state, which makes them pricy and working bellow their maximum efficiency. Microgeneration systems are highly promoted and some of them are even subsidized, but there are still many obstructions in the form of administrative regulations that makes the installation of such units difficult.

μCHP systems are a quite new concept for a microgeneration system that creates thermal and electrical energy at the same time. Conventional CHP on the other hand is a well known idea, dating 100 years back, incorporated in most distributed generation systems. Its basic abstract is that thermal energy dissipated from electrical generators is picked-up and used for heating, thus losses are mostly recovered and system efficiency is increased. μCHP systems are quite the opposite. Their main purpose is heat generation, and electricity comes as a byproduct of the system. In these type of systems roughly 80% of the generated energy is heat and 20% is electricity (fig.1) [2]. Since a great amount of the energy demand in domestic use is thermal, for heating and hot water, a system that can satisfy it and additionally generate low cost electric power will be more efficient than conventional central heating units. This means that μCHP systems can be effectively applied whether in newly build households or as a replacement for a central heating unit that have expired their lifespan.

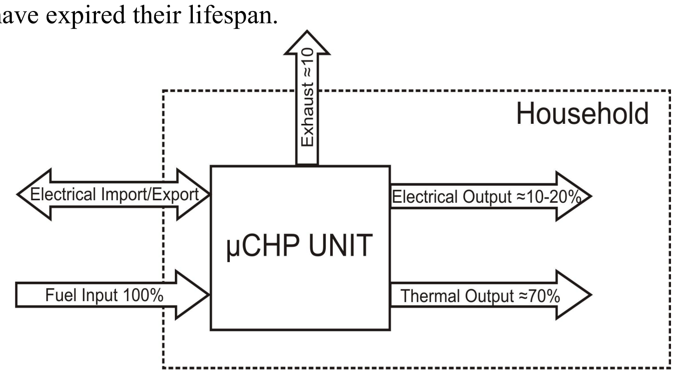

Fig. 1. μCHP in household applications

μCHP systems have all the advantages and disadvantages of a microgeneration units, while still having their own benefits and drawbacks. A major prefer of μCHP is that they can replace central heating units, and by that take the place of a well known and customer popular technology. Great advantage μCHP is also that they can run on different types of fuel – from nature gas to biomass fuel, making them flexible solutions. A drawback of μCHP is that by generating thermal energy first, and electrical second, they become dependent on season change, which limits their use on year basis. Still another disadvantage is that in well insulated households where heat demand is significantly reduced μCHP cannot reach their full potential, because of the reduced electrical generation, increasing their payoff time. It can be said that μCHP are still having significant drawbacks but have the potential to influence the modern energy landscape.

II. Overview on the current micro CHP systems

The concept of μCHP is still in its early stage where it is not still clear which technology is the most efficient for its realization. Many different abstracts are being considered, some of them are still in their research state, while others

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are already being utilized in commercial products. Amongst all there are three main concepts that are most popular – external combustion engines, internal combustion engines and fuel cells.[1,4]

1. µCHP with external combustion engines

External combustion engines are machines that have separate combustion process. They have relatively low level of noise and vibration operation, their size, weight and price are acceptable. Furthermore they are emissions free, and the separation of the burning process makes them usable with a variety of fuels including biomass. Those advantages make the external combustion engine preferable for µCHP applications. Most of the µCHP systems on the current market are based on external combustion engines. This technology allows indoor use of µCHP for single domestic consumer as well as for a block of several households. µCHP systems based on external combustion engines however also have their drawbacks. The control of those systems is very inert and it takes significant amount of time to change the output power by varying the fuel feed, since the stored energy in the burner has to be passed in the heat distribution system. This leads to two major hindrances: First the temperature adjustment will be delayed and inert; second the system will have poor reaction when dealing with emergency situations, especially on the electrical site in the situation where the grid (load) is disconnected, this means that there is need of additional protections. Another disadvantage of µCHP based on external combustion engines is that they generate less heat compared to conventional central heating systems based on gas boilers.

There are two main types of external combustion engines: stirling and rankine. Both are commercially utilized in µCHP, where the stirling is more popular amongst manufacturers.

2. µCHP with internal combustion engines

The internal combustion engine is well known and developed concept that provides power flexibility and allows fine control of the output power by varying the fuel rate. This makes it somewhat suitable for µCHP applications, and it is a part of several marketable products. However this technology has some significant drawbacks. The processes taking place in the engine are noisy, low emissions are hard to be achieve, the system needs constant servicing in the form of lubrication, it has large size and weight. In finished products some of those flaws are corrected by acoustic attenuators, catalytic converters and oil reservoirs, which results in substantial increase in price. Most µCHP systems based on internal combustion engine are not suitable for indoor applications or for single households. Existing products target mainly blocks of several households, bigger buildings or off-grid (stand alone) applications.

3. µCHP with fuel cells

Fuel cells are generation units that convert fuel directly into electrical energy, emitting heat as a byproduct of the electrochemical process and with water as a waste. They are promoted to be efficient, low noised, emissions free and with long lifespan due to the lack of moving parts. This however is not the case when they are applied in µCHP systems due to several specifics. First the natural gas which is the primary fuel source needs to be converted into hydrogen, which requires additional components and parasitic power consumption. Second to be emissions free the exhaust gas needs to be treated to remove CO. The output of the fuel cell is DC which means that additional power electronics will be needed to convert to AC. In overall, fuel cells are still far from reaching their optimum efficiency in µCHP applications, still needing further development.

4. Other µCHP systems

There are various technologies with the potential to be used in µCHP. The most popular of those concepts are microturbines, thermo-ionic generators and thermo-photovoltaic generators. Those however are still in their early development stage and won't be discussed in the current paper.

III. Suggested µCHP System

The suggested µCHP system is represented on figure 2. It is loosely based on an external combustion engine with organic rankine cycle. The topology consists of:

1. Burner

The burner is the place where the combustion is taking part. It is the main energy input for the system. Depending on the type that is selected it can be fed with different types of fuel, in the current application the selected fuel, is biomass pellets. Biomass fuel brings some significant advantages: (1) the systems is classified as renewable energy; (2) low carbon emissions; (3) biomass compared to natural gas is not an imported goods it can be produced in most EU countries either from energy crops or agricultural waste. Since the burner is not integrated part of a working engine, existing stock burners can be used which simplifies the manufacturing process.

2. Heat circle for central heating

The suggested system has two separate heat circles that draw thermal energy from the combustion unit. One of the heat circles diverts energy for central heating and the other for generation of electrical energy. The ratio of which energy is divided amongst the two circles determines the proportion of thermal energy generated against electrical energy. Since heat is the main concern of the system and electricity is a byproduct a major part of the generated energy of the burner will be diverted towards the central heating unit. Having two separate heat circles allows independency between generated thermal and electrical energy. This has the benefit of

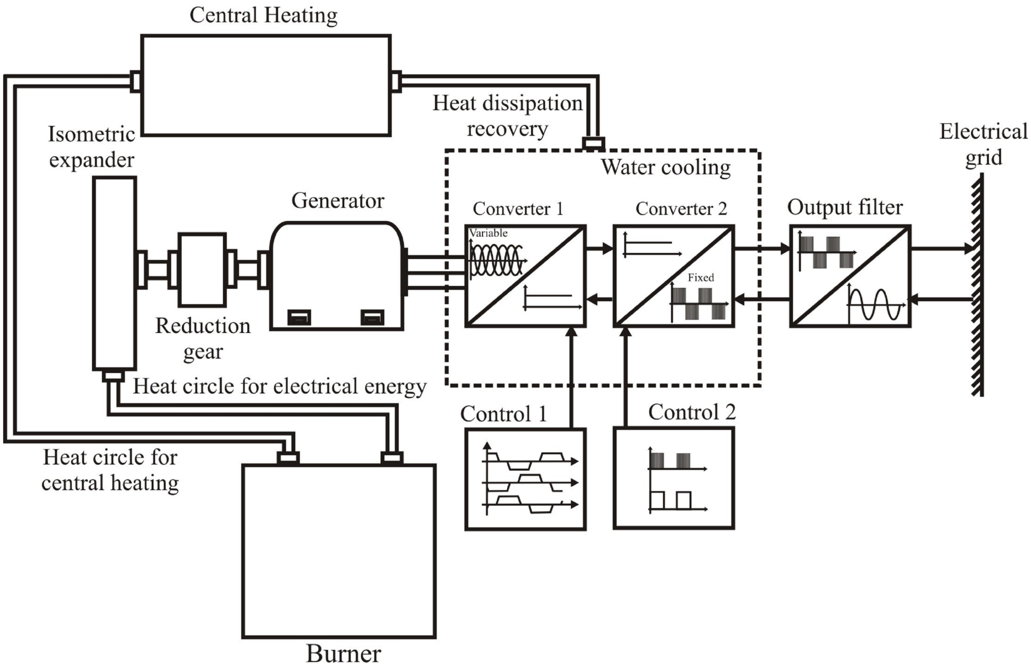

Fig. 2. Suggested µCHP topology

adjustable ratio of the generated energy depending on how much thermal and how much electrical energy is needed for the specific application.

3. Heat circle for electrical energy

The heat circle for electrical generation transfers energy from the combustion unit to the isometric expander which converts the thermal energy into mechanical. The mechanical energy is then transferred via gear reduction box to the generator. The generator utilizes variable speed generation and converts the mechanical energy from the isometric expander into electrical energy, thus completing the conversion of thermal energy into electrical energy.

4. Variable speed generation

The suggested system uses variable speed generation which is uncommon for most of the currently produced µCHP. In this type of generation the mechanical input of generator is not controlled and the generator runs at variable speeds. The electrical output is conditioned to the desired grid properties by power electronics converters. This type of operation gives the freedom and versatility of generation systems. In the case of µCHP the electrical output of the systems becomes directly proportional to the thermal output. Electricity can be produced for a wide range depending on the heat demand. Further more variable speed generation allows the utilization of great variety of generators.

The suggested system uses Brushless Direct Current (BLDC) motor/generator. BLDC machines have great efficiency and superior size and weight to output power ratio. BLDCs however are only usable with specialized control since they require electronic commutation; this makes them available only in variable speed control.

The suggested system is not self starting which means that there is need of parasitic electric consumption when the system is started. This however is not a significant drawback because initial soft-starting from the electrical grid will eliminate high starting currents of the generator.

The power electronic stage of the suggested µCHP system consists of two two-way converters that work as a converter-inverter in the generation stage and as inverter rectifier in the start-up stage. There are variable techniques used to reduce the losses in the power electronics stage. To further improve, the losses from the power electronic unit, which are dissipated heat, are recovered by transferring them via water cooling to the central heating unit. The result is highly efficient conversion of the mechanical energy on the generator into grid suitable electric energy.

4. Overall topology

The suggested µCHP system considered as whole unit provides significant improvements over current designs. It has smaller size and weight compared to output power, which makes it suitable for single or multiple households. Low noise and vibration levels allow indoor use. Specialized generator and system setting increase overall efficiency.

Rugged price estimation of the complete system, in the case that it fits all regulations for safety and power quality, goes to about 15000EU, including parts, production costs and profit. The price was estimated for average power of 3.5kWe (electrical) and 20kWt (thermal).

IV. Conclusion

The paper presents an overview on microgeneration with μCHP and possible solutions for realizing such systems, both in research and commercially available. It summarizes advantages and disadvantages of the different types of μCHP technologies. An innovative solution based on organic rankine cycle is introduced. The suggested topology utilizes variable speed generation control realized with power electronic converters. The proposed system has significant advantages such as reduced weight and size and improved efficiency. It is fueled by biomass which makes it low emission renewable microgenerating unit.

Acknowledgement

This paper is prepared in the frames of projects:
№21 Human development program: BG051PO001/07/3.3-02/21, Ministry of Education and Science, Bulgaria.
Development of specialized scientific infrastructure for investigation of wind and solar energy potential', № Д 002-48/10.12.2008, Ministry of Education, Fund 'Scientific Research'

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