Economic Analysis of Domestic Combined Heat and Power System in the UK

Thamo Sutharssan, Diogo Montalvao, Yong Chen, Wen-Chung Wang, Claudia Pisac

***Abstract*—A combined heat and power (CHP) system is an efficient and clean way to generate power (electricity). Heat produced by the CHP system can be used for water and space heating. The CHP system which uses hydrogen as fuel produces zero carbon emission. Its' efficiency can reach more than 80% whereas that of a traditional power station can only reach up to 50% because much of the thermal energy is wasted. The other advantages of CHP systems include that they can decentralize energy generation, improve energy security and sustainability, and significantly reduce the energy cost to the users.

This paper presents the economic benefits of using a CHP system in the domestic environment. For this analysis, natural gas is considered as potential fuel as the hydrogen fuel cell based CHP systems are rarely used. UK government incentives for CHP systems are also considered as the added benefit. Results show that CHP requires a significant initial investment in returns it can reduce the annual energy bill significantly. Results show that an investment may be paid back in 7 years. After the back period, CHP can run for about 3 years as most of the CHP manufacturers provide 10 year warranty.

***Keywords*—**Combined Heat and Power, Clean Energy, Hydrogen Fuel Cell, Economic Analysis of CHP, Zero Emission.

I. Introduction

A COMBINED HEAT and POWER (CHP) system is a simultaneous generation of power and heat. Although CHP is in use for a long time, an introduction of fuel cell technologies into the CHP system makes it very attractive because of very low emission of greenhouse gases and higher efficiency of power generation compared the traditional power plants.

A fuel cell is a simple electro-chemical device which converts chemical energy of hydrogen fuel or hydrogen-rich fuel into electrical energy. Fuel cells consist of three main components which are anode, cathode, and electrolyte. Based on the materials used for electrolyte, anode, and cathode, fuel cells can be classified into many different categories. Depending on the materials electro-chemical reaction, operating temperature and catalyst required for the fuel cell are different from each other [1]. The main types of fuel cells can be listed as:

1) Proton exchange membrane fuel cell (PEMFC)
2) Solid oxide fuel cell (SOFC)
3) Alkaline fuel cell (AFC)
4) Direct methanol fuel cell (DMFC)
5) Phosphoric acid fuel cell (PAFC)
6) Molten carbonate fuel cell (MCFC)

In the case of PEMFC, an individual fuel cell produces small voltage which is about 0.7V and high current which is about 0.6A/cm^2. Hence fuel cells need to be stacked together to generate required power and voltage. Therefore, fuel cells come in many different shapes and sizes. Because of this flexibility, fuel cells can be used as from a small portable power unit to a megawatts power plant. Although fuel cells were invented in 1839 by British scientist Sri William Grove, fuel cells were rarely used in commercial application [2]. After many decades of invention, NASA started to use fuel cells for space applications [2]. Nowadays fuel cells are used in many residential, commercial, and industrial buildings, automobiles and also as backup power supplies. One of the main applications of fuel cells is a combined heat and power system (CHP) system. Depending on the generated power, a CHP system sometimes referred as micro CHP (mCHP) system if the power rating of the CHP system is below 50 kW [3]. Micro CHP systems are used to power houses, block of apartments, small commercial buildings etc. Heat generated from such a system is recovered and used for space and water heating. This is the main advantage of the CHP system. In a centralized power plant, this will not be possible as it is very difficult to transport the heat without a loss.

Most CHP systems use natural gas as their primary fuel. Reformer or fuel processor is used to convert the natural gas into hydrogen-rich fuel. Hydrogen-rich gas stream then is fed into the CHP system. Heat dissipated in the chemical reaction is recovered by water cooling system. This water is used to heat the internal space. Electricity is used to power the home electrical appliance and surplus power is exported to the grid. Gird connection may also be used to import power if the power generated by the CHP is less than the demand.

World energy demand is growing but the use of fossil fuel will eventually decrease. Climate change and global warming force the world to reduce emission. This has been reflected in the latest United Nations conference on climate change in Paris. For the first time all countries in the United Nations have agreed to reduce the emission and decarbonize the planet earth. This will be assessed every five years from 2018 [4]. Therefore, counties will have to promote either low or zero emission techniques for power generation. CHP can play a vital role in reducing the emissions. Particularly hydrogen fuel cell CHP system, which does not emit any greenhouse gases or any other byproducts that pollute the environment, can be the ideal solution for decentralized power generation. Main

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problems with the hydrogen fuel cell CHPs are availability of hydrogen and hydrogen infrastructure, hydrogen storage, and safety issues related to hydrogen.

Fig. 1 shows a typical CHP system in operation in a domestic environment. The CHP system needs to be integrated with gird so that electricity could be exported when CHP generates more electricity than the demand in the house and electricity could be imported when electricity demand higher than the electricity generated by the CHP. Heat produced by the CHP can be used for space heating and water heating. Emerging technologies such as Big Data and Internet of Things (IoT) can play a vital role in optimizing CHP operation based on the grid electricity demand, health of CHP systems, and other parameters which are important for the optimization of CHP operation.

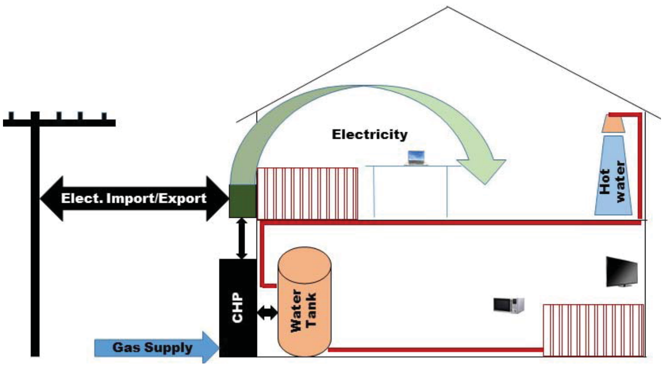

Fig. 1 CHP System in operation

This paper investigates the economic benefits of CHP system in the domestic environment. In this analysis, three different CHP systems that are available in the UK are investigated. This investigation is based on typical household annual electricity demand, heat demand, UK government support, and environmental benefits. A typical UK household has an unadjusted annual electricity demand of 4001 kWh and temperature corrected annual electricity demand of 4115 kWh as of 2014 [5]. For example, a 1.5 kW CHP with availability of 95% can generate 12483 kWh of electricity which is almost three time of the annual demand of an average UK household.

Heat generated by the CHP should be used within the household, as it cannot be transported to another place where heat is needed. So it is vital to choose a CHP system that can match the base demand of heat. If more heat is required, for example in the winter, a top-up heater can be used to supply the excess heat requirement of the house. This will maximize the efficiency of the CHP system. Electric power of the CHP system should be below 2 kW to qualify for the government incentives in the UK.

II. UK Government Policy

Since a micro CHP system produces electricity locally, transmission and distribution losses can be significantly avoided. On top of that, heat generated from the electro-chemical reaction is recovered and used for space and water heating. UK government identified micro CHP as a good quality power generation. Micro CHP systems are eligible for Feed-in-Tariffs for a ten years period in the UK. Maximum rated power of the CHP system should be 2 kW. 485 domestic CHP systems were recorded in 2014. Total capacity of 485 systems is reported as 496 kW [6]. These systems receive 13.45 p/kWh for generation of good electricity and extra 4.85 p/kWh if the electricity is exported to the grid. For example, a 1.5 kW CHP system with 95% availability is eligible for a payment of £1679.00/annum for generation of good electricity and £405.00/annum for exporting the surplus electricity to gird, i.e. total return will be £2084.00/annum.

UK government provides a range of support to increase a number of good quality CHP projects. Some of the support measures are given [6]:

1) Exemption from the Climate Change Levy (CCL) on all fuels that are used for CHP
2) Exemption from Carbon Price Support (CPS) on fuel to CHP consumed for the generation of heat and electricity which is consumed on site
3) Business rate exemption
4) Eligibility for Enhance Capital Allowance for a good quality CHP system
5) Reduction of VAT from 20% to 5% on domestic micro CHP systems

III. Environmental Impact

Fuel cell CHP is a promising technology for energy security, decentralize energy generation, low emission of greenhouse gases and efficient energy generation. Since the energy efficiency of the CHP system reaches more than 80%, fuel consumption is reduced compared with the traditional power generation technologies. Greenhouse gas emissions can be reduced up to 30% from the CHP systems which use natural gas as fuel. If the hydrogen is used as the fuel, greenhouse gas emissions will be brought down to zero. This can be achieved by creating hydrogen infrastructure and using pure hydrogen as fuel. Hence CHP systems can help to reduce the greenhouse gas emission to the environment. But CHP system and hydrogen infrastructure need improvement and further development. Hydrogen needs to be generated from renewable energy such as solar energy, wind energy, etc. and supplied to the CHP system.

IV. Economic Viability

Economic viability is very important from the user or customer prospective. Customers want a good value for money and good return on their investment. Customers are also contentious about the climate change and global warming. Hence, customers need to be informed about the climate change and global warming, environmental and economic benefit by choosing a good CHP system for the power and heat requirements. This paper aims to provide economic assessment of three different systems for a typical UK household with an annual electricity demand of 4115 kWh and base load of 0.3 kW. Typical UK household gas consumption is 14263 kWh [5].

In this analysis, there different CHP systems were considered for a typical household with annual electricity demand of 4115 kWh and heat demand of 14263 kWh. Following CHP system are considered for the analysis:

1) BlueGen 1.5 kW
2) Vitovalor 300-P 0.75 kW
3) Elcore 2400 0.3 kW

BlueGen 1.5 kW is a SOFC based CHP system which is shown in Fig. 2. It operates at very high temperature. BlueGen 1.5 kW was installed in a small office building belong to Chartered Institute of Building Service Engineers (CIBSE) and reported by [7]. Electrical efficiency was reported as 62% initially and thereafter stabilized at 57% at 1.5 kW operating condition. Maximum of 1 kW heat was recovered at the return temperature of 15°C and 0.3 kW was recovered at 45°C. Hence the combined efficiency was reported as about 85% [7]. To operate at 57% efficiency, BlueGen requires 2.62 kW of gas input. At this operating condition, an average 0.73 kW of heat could be recovered if the BlueGens' overall efficiency could be kept at 85%. To operate at 95% availability, BlueGen requires 21803 kWh of gas supply, it can generate 12483 kWh of electricity, and 6075 kWh of heat could be recovered. Heat recovered from the CHP is more than the base heat demand but needs to be topped up by an external heater boiler to meet the peak demand.

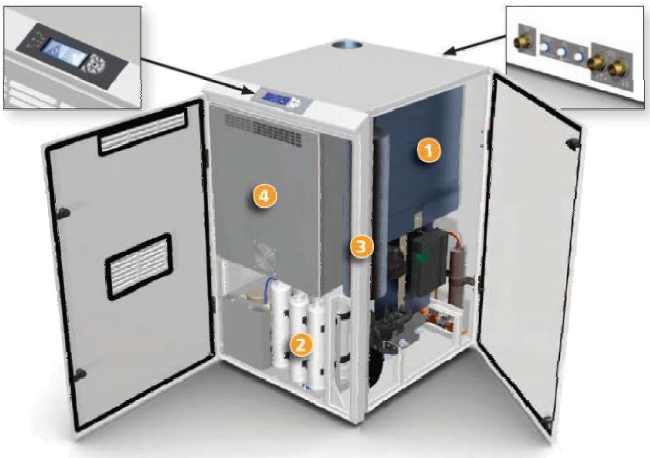

Fig. 2 BlueGen 1.5 kW CHP System

Total investment needed for BlueGen 1.5 kW is £17000 in the UK and it might go down in the near future. Annual return of £2084 could be achieved for generating good electricity and exporting surplus electricity to the grid. From the current standard tariff gas is 3.9p/kWh and electricity is 16.3p/kWh. Before the installation of BlueGen a typical household bill for gas and electricity is £1226 i.e. for 4115 kWh electricity and 14263 kWh gas. After the BlueGen is installed, an energy bill is £1110 including the gas required to supply the extra heat demand. Hence annual energy bill is going down by £116. Therefore total return will be £2200/annum.

Vitovalor 300-P is 0.75 kW PEMFC based fuel cell CHP system which is integrated with integral gas condensing boiler for peak load as shown in Fig. 3. Cost of installation of this system is reported as £22000. Average expected return on this investment is £1000/annum [8]. Electrical efficiency of the fuel cell module is reported as 37% and overall efficiency is 90%. It delivers a maximum of 19 kW of heat output and produces 15 kWh of daily electricity. Internal boiler will start automatically when the heat demand goes above the heat produced by the fuel cell i.e. in the peak time. Vitovalor 300-P also comes with an App (mobile application) to remotely control the CHP operations including to change room temperature, control program timers, start and stop, etc. [8]

Fig. 3 Vitovalor 300-P is 0.75 kW CHP System

Elcore 2400 is 0.3 kW CHP system which is shown in Fig. 4, specially designed for German market but as Elcore 2400 is a part of ene.field project [9]. Elcore is based on high temperature PEMFC technology. It is designed to meet the base load energy demand of an average household. It produces 300 W of electricity and 600 W of heat. It needs to be integrated with existing power and heat infrastructures to meet the peak demand. This system costs around £6750 (9000 Euros) in the UK. At 95% availability of the system, Elcore 2400 will produce 2400 kWh of electricity which may bring and return of £322/annum from the Feed-in-Tariff. As it produces only the base load energy, it will not possible to export electricity into the grid. For an average household, energy bill will go down by £180/annum. Therefore, the total return will be £502/annum.

Fig. 4 Elcore 2400 0.3 kW CHP System

V. Conclusion

The results show that Vitovalor 300-P requires 22 years, Elcore 2400 requires about 13 years and BlueGen requires about 7 years to reach the break-even point. All three products come with 10 years warrantee and BlueGen reach its break-even point within the warrantee period which means only BlueGen is economically viable based on this analysis. Further detail analysis is required to assess the environmental benefit.

Fuel cell based CHP systems are just entering the market and require time to catch the market. Then only mass production can take place which can bring down the manufacturing cost of the system. At an early stage of its product life cycle, financial benefits of CHP system already look promising.

As the CHP is in its early stage of the product life cycle, it is very difficult to collect data such as actual investment required for the complete system installment, maintenance, efficiency near to their end-of-life etc. It is important that researchers, manufacturers, system designers and users share the information related to CHP performance, maintenance, and initial investment.

Government needs to create more attractive policies towards low carbon technologies to encourage, convince and attract more customers to choose CHP system to reduce the carbon emission.

VI. Future Work

Further analysis is required on other CHP systems. Financial performance indicators such as debit to equity ratio, depreciation, return on investment, etc. need to be estimated and compared between the different CHP systems.

Acknowledgment

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