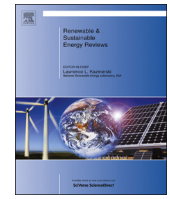
Renewable and Sustainable Energy Reviews 64 (2016) 144–162

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser



A review of micro combined heat and power systems for residential applications

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ARTICLE INFO

Article history:
Received 17 June 2015
Received in revised form
10 January 2016
Accepted 26 April 2016

Keywords:
Micro combined heat and power
Prime movers
Renewable energy sources
Residential applications

ABSTRACT

Cogeneration systems have been employed for many years in various heat and power applications. The micro combined heat and power (mCHP) system is an advanced and miniature version of the cogeneration *system* and is expected to play a major role in curbing CO_2 emissions and increasing the primary energy savings in the near future. The residential sector is a significant consumer of both electrical energy and petroleum based fuels. This paper reviews recent studies related to the research and development of micro combined heat and power (mCHP) systems, which have been proposed and investigated for residential applications. The salient features of each prime mover or energy conversion device used in the systems, in their marketing and potential developments are presented.

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Contents

1. Introduction

Since the industrial revolution began, primary energy sources have been mainly consumed to produce heat and power in many sectors including power, transportation, domestic, agriculture and commerce. As a result, pollutants generated from burning of fossil fuels in heat engines and combustion devices, have increased the greenhouse gases (GHGs). The huge consumption of primary energy sources-particularly fossil fuels has become a deciding factor in the economy of any country [1]. Combined heat and

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http://dx.doi.org/10.1016/j.rser.2016.04.064
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power (CHP) systems have been employed in various applications for over 100 years to provide electric power from 15 kWe to 100 MWe [2]. The miniaturization of cogeneration systems into small and micro units is an important topic of interest today [3].

Small and micro combined heat and power systems offer potential benefits to humanity and the environment; they include reduction of greenhouse gas (GHG) emissions, increased decentralization of energy supply, improved energy security, possible avoidance of investment and energy losses from electricity transmission and distribution networks, and potentially reduced energy cost to consumers [4,5]. In addition to producing heat and power, other benefits such as providing cooling effect or hot water or secondary energy sources are possible through such generation systems. Hence, such small and micro systems can be categorized as dual, tri and poly generation systems. Micro combined heat and power generation is a dual generation system which is capable of producing power and heat simultaneously. A trigeneration system refers to combined heating, cooling and power or energy [6]. A polygeneration system is one in which more than heat and power, hot water, and renewable energy production can be generated in a single plant [7]. It is expected that such systems will be more useful in decentralised systems in the near future. Small-scale CHP refers to combined heat and power generation systems with electrical power less than 100 kW, while the term mCHP refers to an electrical capacity up to 15 kW_{el}. Small and micro systems are suitable for different civil, tertiary and industrial applications, such as residential buildings, hospitals, supermarkets, sporting centres etc., where a significant thermal demand is associated with the user electricity demand **[8]**. During the last three decades small and mCHP systems have been focused on by many researchers. A large market potential for such systems in Europe has been identified in the last fifteen years [9]. It has also a great market potential in USA, Canada, Japan, and Korea [10]. Several research studies have been documented in several aspects of mCHP, tri and polygeneration systems that include introducing new concepts and different energy sources, performance assessment, and economic analysis. This paper reviews the collection of literature available in the area of mCHP applied to residential applications. The general aspects of different prime movers that are optional for micro combined heat and power systems and the market potential and recent research works on the improvement of the system, reducing emissions, its improvement, and modelling and simulation of the mCHP system are discussed. Furthermore, the applications of mCHP systems for residential buildings are discussed with a few examples.

2. Option for different prime movers

Micro CHP(mCHP) systems generally involve a prime mover, such as Sterling engine, reciprocating engines, stream engines, gas turbines and micro turbines, and Organic Rankine cycle, to simultaneously produce power and heat. Examples of these are heating domestic water in a storage tank or storing electricity in a battery and acting as an additional heat source to boilers or district heating. Gas engines, micro turbines and fuel cells are suitable systems for small scale power production, because of their high efficiencies at low power outputs. The small and mCHP systems may be integrated with the renewable energy sources such as biomass, solar, wind, and hydrogen by appropriate methods. Fig. 1 illustrates the possible energy conversion devices and routes of energy conversion through dual, tri and poly generation systems.

2.1. Reciprocating engines

Internal combustion (IC) engines are widely accepted and the most well-established engines for small-and mCHP applications. Both spark ignition (SI) and compression ignition (CI) engines can be used, depending on the energy demand, kind of fuel available for use and space constraints [11]. The arrangement of the ICE based mCHP system is shown in Fig. 2. The characteristics, electrical and thermal efficiency and the targets are listed in Table 1 [11–13]. Although ICE based mCHP have been readily available in the market, some of the issues are yet to be solved; they are; (i) achieving low emissions from the engines (ii) improving power density per kW (iii) introducing renewable fuels for successful operation and (iv) increasing the durability of the engine for longevity when they are used in dwellings or large apartments [13]. A multi fuel mCHP conversion kit to use low boiling point fluids in an SI engine coupled with a small generator was demonstrated [14]. The conversion kit acted as a vapouriser in a dual fuel operation. It used part of the thermal energy produced by the engine during the generation of electricity to evaporate liquid fuels to the gaseous state, and was also capable of recovering part of the residual heat for other thermal uses. The conversion kit was used in a commercial power plant that can be suitable for the power range between 10–30 kW.

A research work was carried out to calibrate and validate a model that was developed for analysing the thermal and electrical performances of a mCHP system. It was suggested that further research is needed to examine the thermal and electrical performances of the AISIN SEIKI cogeneration unit when it would be

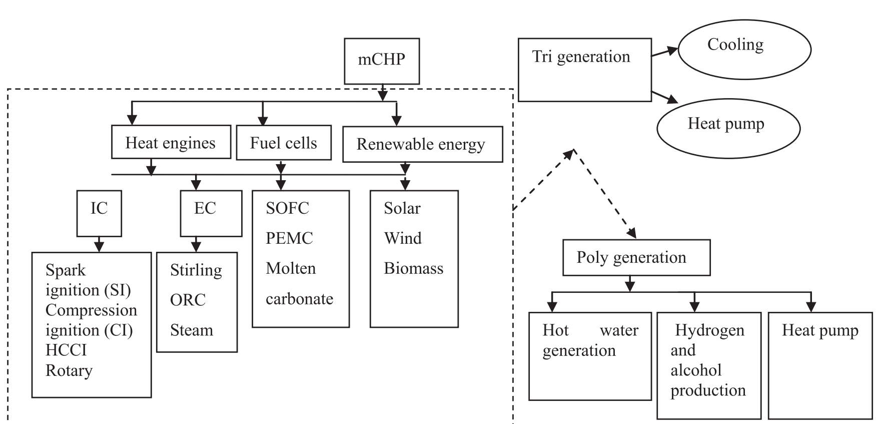

Fig. 1. Dual, tri and polygeneration systems.

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