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Micro-trigeneration for energy sustainability: Technologies, tools and trends

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HIGHLIGHTS

- Review of micro-trigeneration systems and technologies is presented.
- Attractive option to use waste heat for cooling and heating.
- Very efficient on total energy performance, fuel savings and CO_2 reduction.
- Alternative fuels, like bio-fuels, hydrogen, and wooden-gas can also be used.
- Potential sustainable energy systems for residential and small applications.

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ABSTRACT

The path towards energy sustainability is the incremental adoption of available technologies, practices and policies that help to decrease environmental impact of energy sector, with adequate standards of energy services.

Trigeneration systems use waste heat from prime movers to generate heating and cooling along with power. They are more efficient, less polluting & more economic than conventional systems. Small scale trigeneration power plants, typically, below 15 kW_e, are called micro-trigeneration plants. In such systems, over 80% of fuel energy is converted to useable energy.

Over-exploitation of fossil resources has led to increase in pollutants and CO_2 levels in atmosphere, causing severe health hazards. Low carbon society is less dependent on fuels with high carbon content. Also, Kyoto protocol set reduction targets for the nations. Alternative fuels promise sustainable development, energy conservation, efficiency and environmental preservation. Various alternate fuels & micro-trigeneration technologies can be combined, leading to sharp decrease in almost all the emissions.

This paper presents a brief review of micro-trigeneration systems. They are projected as strategic means to achieve energy security and efficiency, with positive impact on economy, simultaneously reducing environmental threats, leading to sustainable development.

1. Introduction

1.1. Sustainable development

Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. It integrates economic, social and environmental aspects [1].

Energy is the fundamental driver of sustainable development.

Sustainable access to energy with modern fuels is strongly related to the millennium development goals of UNO [2,3].

1.2. Trigeneration technologies

Integrated Energy Systems (IES), as comprehensive integrated approach, combine on-site power or distributed generation technologies with thermally activated technologies to provide cooling, heating, humidity control, energy storage and/or other process functions. IES produce electricity and use by product thermal energy onsite, with the potential of converting 80 percent or more of the fuel into use-able energy. Integrated Energy Systems (IES), offer key solution to global warming and energy security through high overall energy efficiency and better fuel use [4,5].

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Cogeneration or Combined Heating and Power (CHP) is simultaneous production of power and heat. Tri-generation or Combined Cooling Heating and Power (CCHP) is simultaneous production of power, heating and cooling. CHP or CCHP uses only one source of primary energy, represented by fossil fuels or by some appropriate renewable energy sources (biomass, biogas, solar energy, etc) [6].

Thus, CHP and CCHP systems are units of IES that use recovered waste thermal energy from the prime mover to produce heating and cooling. Integrated CCHP system solutions can address all of the following requirements at once: increase in overall thermal efficiency, conservation of scarce energy resources, moderation of pollutant release into our environment, and assured comfort for home-owners [6–8].

Also, in the Energy Performance of Buildings Directive of the European Union, CCHP is seen as a technology to fulfil the energy requirements of buildings [9,10].

1.3. Micro-trigeneration systems and applications

Small scale poly-generation power plants, typically below 15 kW_e, are called micro-CHP (m-CHP) or micro-CCHP (m-CCHP) plants. Micro-CCHPs are especially interesting due to their technical and performance features like, high overall energy conversion efficiency and low emissions [9,11]. They are emerging in various applications like, residential buildings, hotels, hospitals, university campuses, automobiles, etc [11,12].

A typical m-CCHP system consists of five basic elements: prime mover; electricity generator; waste heat recovery exchanger/boiler; thermally activated equipment and the management and control system [6,12].

The line diagram of a typical micro-trigeneration system using internal combustion diesel engine as prime mover coupled to an absorption chiller and a heat exchanger is shown in Fig. 1 [11].

Performance and emission experiments were conducted in a laboratory on a small internal combustion diesel engine (3.7 kW) based micro-trigeneration system. Useful energy output was found to be much higher than in single generation. The thermal efficiency of trigeneration was 155.49% higher than that of single generation at full load, as shown in Fig. 2 [11].

Energy management and optimization was found to be better in small scale CCHP systems based on natural gas and liquefied petroleum gas (LPG) driven engine. Primary Energy Saving (PES) was found to be more for m-CCHP system than m-CHP system [13].

Two different m-trigeneration configurations using micro-turbine (m-turbine) and Internal Combustion Engine (ICE) were configured, tested and found viable [14]. Also, two typical

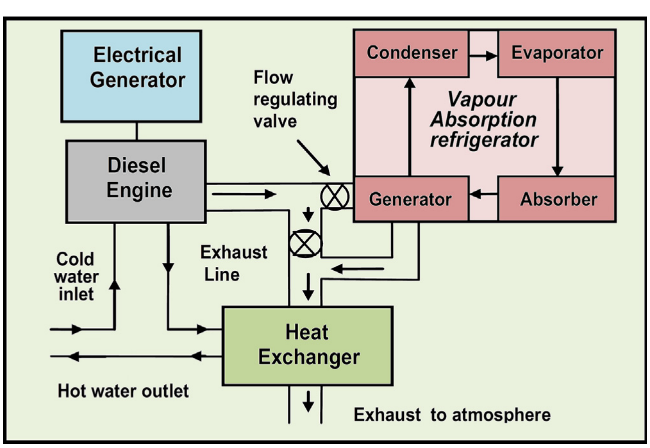

Fig. 1. Experimental set-up for a typical micro-trigeneration unit [11].

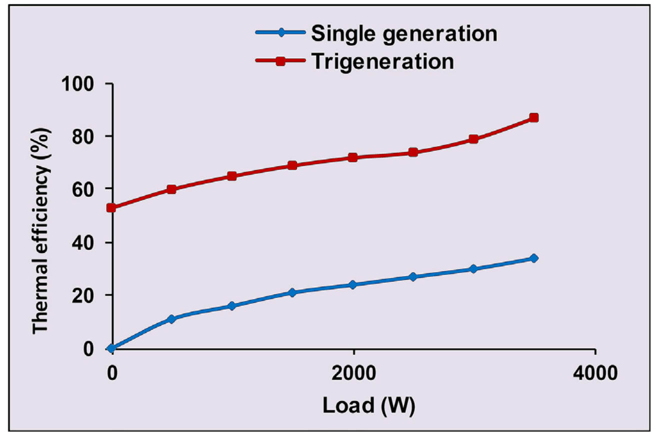

Fig. 2. Variation of thermal efficiency with load [11].

residential m-CHP alternatives, namely gas engines and fuel cell were found to be good alternatives from environmental and economical points of view [15]. District heating/cooling networks have also been developed with trigeneration plant sizing for business building application [16]. Even a truck cabin air-conditioning system, driven by low grade waste heat (80–90 °C) from engine coolant loop has been tested successfully [17].

2. Methods and technologies

2.1. Prime movers

A prime mover in a m-CCHP system generates electricity and the waste heat is recovered downstream. Main prime movers include reciprocating engines, micro steam and gas turbines, stirling engines and fuel cell systems.

2.1.1. Reciprocating engines

The conventional reciprocating internal combustion engines are coupled with generator and heat exchangers to recover the heat of the exhaust gases, coolant and oil.

Reciprocating ICE technology is mature, and has flexibility in design for different fuels. Its efficiency is higher than other prime movers and it has a short start-up time. Some limitations of ICE are frequent maintenance, vibration, noise and emission issues [12,18–20].

2.1.2. Micro turbines

Micro turbines are small gas turbines belonging to the group of turbo machines. They offer a number of advantages like, fast response, compact size, low weight and lower noise with minimum maintenance requirements. Their limitations are high cost and relatively short life.

Though their efficiency is low, but it is enough for residential m-CCHP because of the high thermal/electric load ratio. Micro turbines can use different fuels, including natural gas, hydrogen, propane or diesel and other bio-based liquid and gaseous fuels.

For trigeneration applications, an overall efficiency of 80% and above can be achieved. The electric capacity of current m-turbines, usually 25 kW or above is too high to be used in a residential m-CCHP unit. Research is ongoing for systems with capacities less than 25 kW, e.g. 1 kW and 10 kW, which will be suitable for single family residential buildings. However, in lower power ranges, reciprocating ICE has higher efficiency. Rankine cycle for micro-CHP is less expensive than most other prime mover technologies and is likely to be a competitive prime mover technology [6,10,12,20–23].

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