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Small-scale power generation using stationary gas turbine with renewable energy

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Abstract. This article mainly discusses one of the most important applications of stationary gas turbines—the small-scale power generation. Micro/Small-scale gas turbines have immense hidden potential due to fuel flexibility, low emissions and maintenance. In recent years, the substantial pressure to address environmental issues has led people to focus more on green technologies, so most of the related applications of micro gas turbines use renewable energy like wind energy or biomass. Small-scale power generation can be applied in commercial and residential areas and areas with worse living conditions, such as rural or remote ones. And it is usually designed to exploit more waste heat for cooling/heating purposes. Anyway, there are still drawbacks exist. These turbines require high angular velocity and advanced electronics that can convert high-frequency electricity. The author surveyed distributed energy generation, biomass power plants and mini/micro gas turbines, some typical examples of small-scale power generation that are also stationary and have combustion processes. This application of stationary gas turbines is relatively more innovative and updated than others, so there are not many reliable researches posted online in recent years. This paper will reference all the researchers who want to work in this field.

Keywords: stationary gas turbine, small-scale power generation, micro gas turbine, power plant, renewable energy.

1. Introduction

A gas turbine is an internal combustion engine that operates with rotation motion rather than reciprocating motion, which leads to high speeds and a continuously operating process. The micro/small-scale gas turbine is a gas turbine, but the power output and volume define the name “micro”. It also can be called “nano”. It usually has a larger amount of power with a smaller weight and size. Small-scale power generation is one of the technology choices for power generation and efficient supply to the grid and rural areas, with smaller volumes and fewer emissions.

Decentralized power is characterized by power generation close to demand centers, mainly focused on meeting regional energy needs. A decentralized power system can function either in the presence of grid, where it can feed the surplus power generated to the grid, or as an independent/stand-alone isolated system exclusively meeting the local demands of remote locations [1].

Because of the damage caused by rapid climate change and foreseeable global warming, access to sustainable energy has become key to sustainable development of a global society. Meanwhile, as the

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internal combustion engine has been widely used in various fields of the national economy, with its large output and quantity, environmental pollution is becoming more and more serious. This circumstance makes renewable energy more widely used in gas turbines. According to the International Energy Agency (IEA), coal is the most used resource globally, and renewable resources such as hydro and wind still need to be more widely utilized [2]. Figure 1 demonstrates the proportion of different renewable resource utilization. Biomass contributes 50% of all of them.

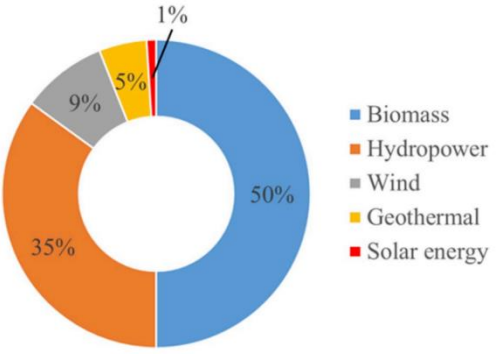

Figure 1. Percentage of power generation resources utilized globally [3].

Gas turbines possess certain merits such as low maintenance expense, low vibration level and short delivery time compared with diesel engine. Its smaller weight and size can bring more convenience for construction and popularization and higher efficiency. Meanwhile, most small-scale power generation started to use renewable energy with more significant public attention to environmental issues. These turbines would help improve the power.

2. Distributed energy generation (DEG)

Distributed generation, also referred to distributed energy, is the electrical production and storage of a variety of small, grid-connected or distribution system-connected devices known as distributed energy resources (DER) [4]. Generally speaking, DEG system comprises many small-scale power plants in different places. DEG is a new trend in the power industry and the market. It mainly depends upon installing and driving a small-scale, compact and clean generator set under electrical or near-load conditions [5].

2.1. Advantages

Replacing centralized energy plants with DEG systems has significant advantages.

a) A DEG system can efficiently reduce substantial carbon dioxide because renewable sources like solar power and wind can replace fossil fuels.

b) The location of DEG plants is usually near industrial, commercial and residential users, which means it can reduce energy losses due to inefficient power lines.

c) Distributed systems provide various types of energy resources and fuel choices taking advantages of different technologies. Thus, there will be no more demand for one certain type of fuel than others.

d) The combined heat and power system allows DEG to harness energy. The short distance between generation and consumption provides access to small heat sources/sinks, and an opportunity to utilize waste heat for cooling/heating purposes which is barely possible in practical centralized power generation.

e) Apart from the economic benefits, DEGs technically favor the operation of the system. These companies can provide enough electricity to meet demand and reduce unnecessary electricity flows within the transmission network, thereby reducing electricity losses on the grid.

2.2. Types and technologies

Figure 2 shows a summarization of different DEG technologies in the mix.

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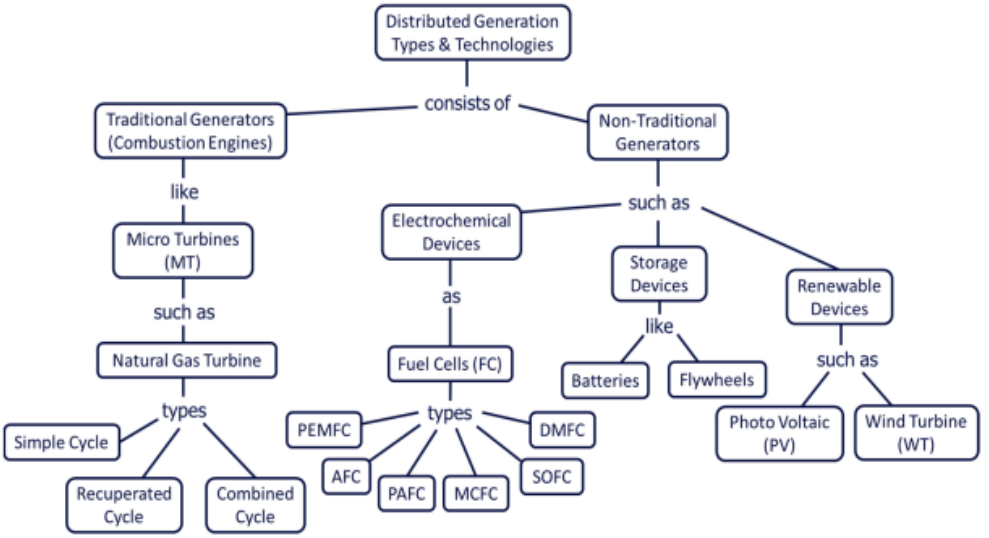

Figure 2. Different types and technologies of distributed energy generation [4].

2.3. Development of DEGs

DEGs are becoming increasingly common worldwide. They are more widely available, efficient with lower prices than a decade ago. Figure 3 demonstrates the share of DEG in global generating capacity in 2000 and 2020. The proportion of distributed power generation increased and almost caught up with the centralized power generation in this two decades.

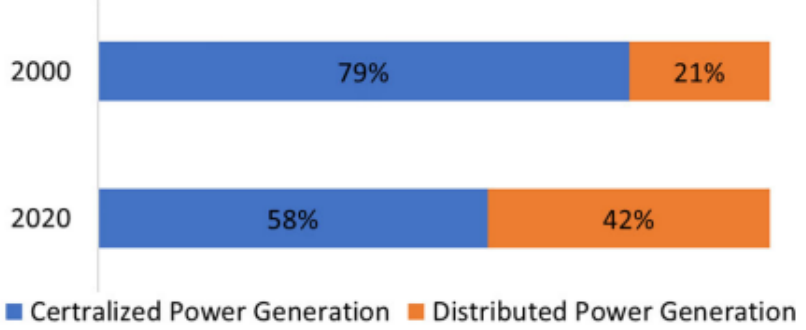

Figure 3. Share of DEG in global generating capacity [4].

There are some researches that showed a positive relationship between increased use of electricity and improvements in income, education and health. In particular, developing countries with low per capita income, such as China, India, and Brazil, are the countries with the highest demand for distributed power currently [6].

3. Small-scale biomass power plants

Biomass power, or biofuel, is a promising renewable energy resource specially produced from botany biomass, vegetable oils, or treated industrial wastes. Biomass is non-pyrogenic and biodegradable organic materials derived from natural creatures, so this kind of renewable energy has a significant amount of availability, which makes biomass considered one of the main energy sources and the primary substitute to conventional fuels that is enough to meet the sustainability of future fuel supplies. As old as human civilization, energy based on biomass is one of the most critical environmental-friendly energy resources to meet daily energy requirements. A new type of small power plant capable of generating electricity and heat from solid and gaseous biomass has been proposed for rural electrification projects [7]. As shown in Figure 4, waste, such as industrial waste, produce more biomass than other factors.

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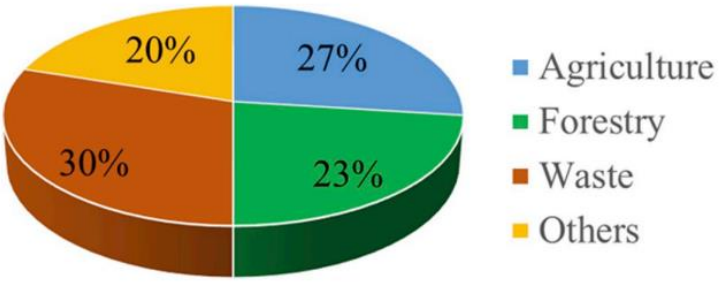

Figure 4. Percentage of biomass resources [3].

3.1. Micro gas turbine combustion process

Micro gas turbine technology can be integrated with direct biomass combustion systems. The operation process is given in Figure 5.

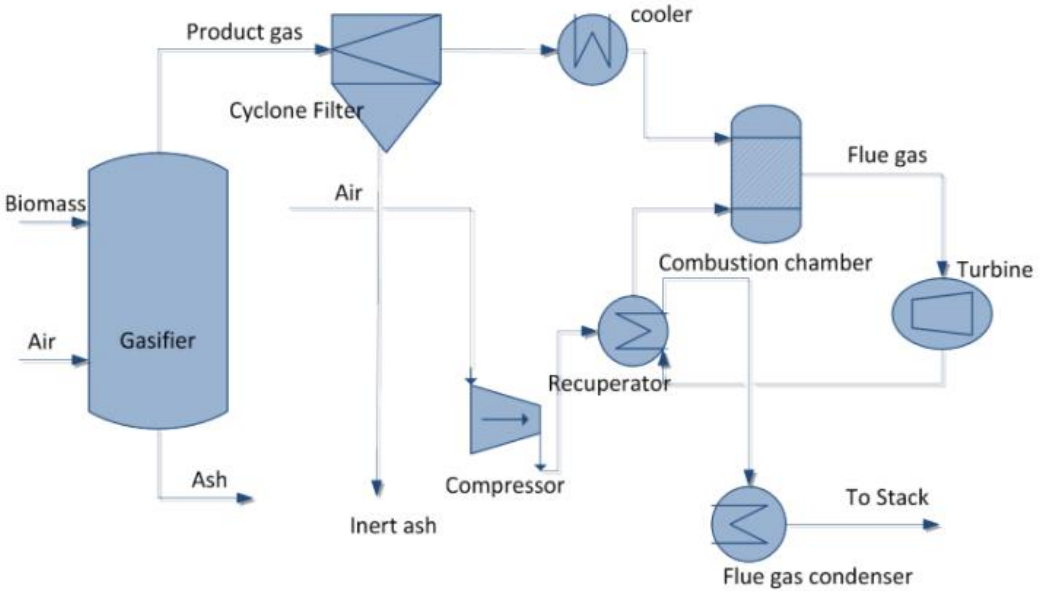

Figure 5. Schematic flow sheet of a recuperated micro gas turbine plant operation [8].

The operating principle of micro gas turbines is in the same way as the conventional gas turbine, the Brayton cycle. Here, Figure 6 clearly shows the two typical diagrams of the Brayton cycle.

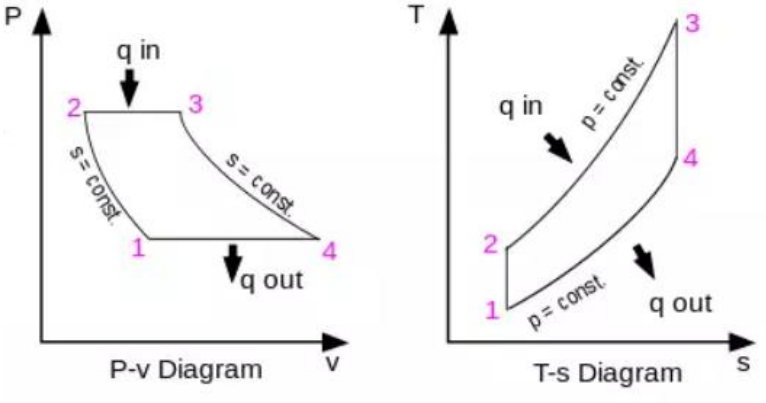

Figure 6. Pressure and volume diagram, temperature and entropy diagram of Brayton cycle.

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3.2. Examples

3.2.1. An experimental prototype. The scheme associated with this experimental prototype is as follows, a Steam Rankine Cycle (SRC) bottoming cycle shown in Figure 7. Figure 8 shows an experimental prototype that Politecnico di Bari is currently working on.

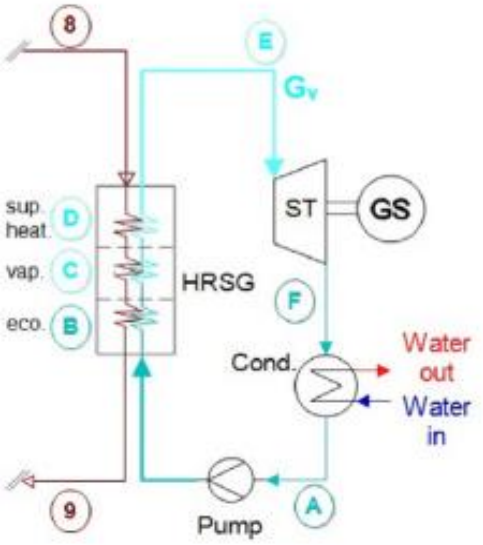

Figure 7. Functioning scheme of the experimental prototype [7].

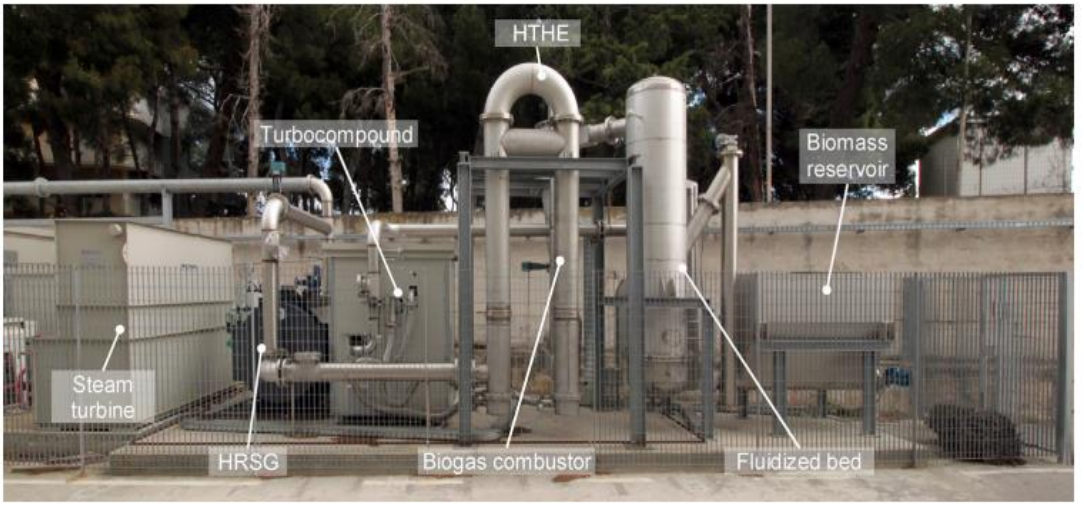

Figure 8. The experimental prototype at the laboratory Lab ZERO [7].

3.2.2. Small-scale biomass gasification power generation. Gasification of biomass to provide gaseous fuel for power generation is currently recognized as one of the primary alternatives to fossil fuels, despite the high cost of capturing large amounts of biomass. A variety of small-scale biomass gasification systems are being developed and deployed in Europe, North America and Asia. Countries in Africa and Latin America should be areas of growth and potential for the practical application of this technology, especially in developing countries [3]. The two main types are bubbling fluidized bed gasifiers (BFBG) and circulating fluidized bed gasifiers (CFBG). Figure 9 shows the whole schematic of both BFBG and CFBG designs.

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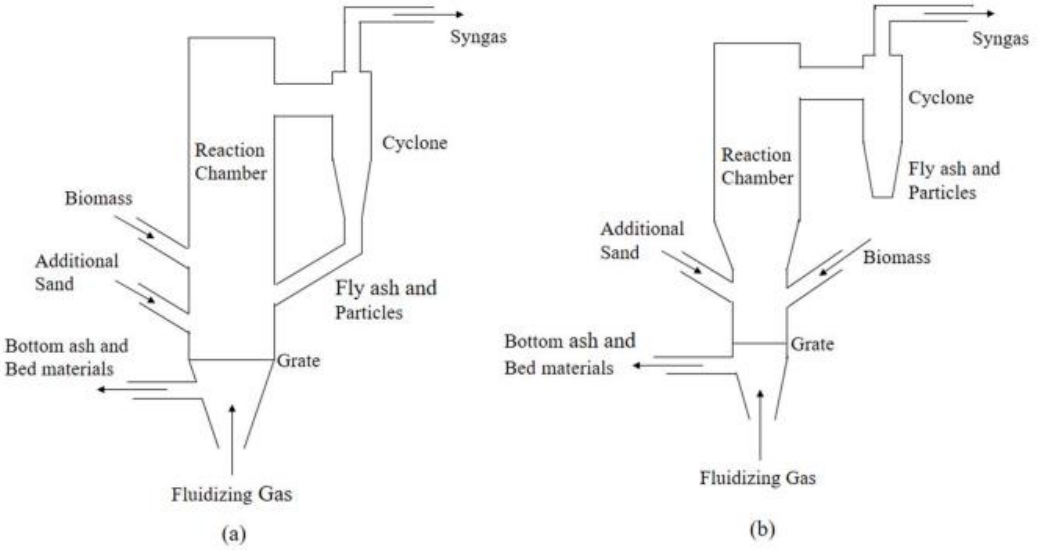

Figure 9. Schematic of (a) BFBG (b) CFBG [9].

4. Mini/Micro gas turbine

Mini-/micro turbines are portable and easy to install; with their supercharging system of small integrated energy supply equipment, their power is generally less than 500 kW.

4.1. Advantages

Small and microturbines offer several potential advantages over other small-scale power generation technologies, especially distributed generation, though there are a number of technical and non-technical barriers to the implementation of this technology [10]. The most remarkable advantages are compact size and low-weight per unit power.

4.2. Market

Micro turbines have substantial potential for power generation in the industrial, commercial and residential markets. But the biggest utilization of micro turbines may be in combined heat and power systems. Gas turbines have high exhaust heat quality, i.e., high temperature, which can generate the heat needed for industrial engineering or space heating. In order to achieve higher efficiency, the micro-turbine can pass the exhaust through the recovery period to improve the power efficiency, so the final available thermal grade quality is lower (temperature) [10]. Their market potential is uncertain, but they have great value in all varieties of areas especially industrial and commercial sectors.

5. Drawbacks and challenges

The scope of this emerging technology still has many non-ignorable drawbacks, but scientists have been working hard to find the most effective solution. For example, a population-based search algorithm called ant lion optimizer has been proposed for non-convex economic load dispatch problems [11]. An investigation of a new LNG cold-utilized power generation and cryogenic CO_2 capture system according to the energetic and thermos-economic approaches determined the workable operating conditions for practical engineering applications. The calculation result shows that the gas turbine and the compressor rank first and second respectively when summing up damage and component costs [12]. Moreover, there are several obstacles in technical and economic aspects for renewable energy to enter the mainstream energy supply chain. Speaking of the institutional aspect, government policy also influences success. For instance, the Ministry of Energy, Green Technology and Water in Malaysia established Special Committee on Renewable Energy (SCORE) [13].

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6. Conclusion

In this paper, the author presented two typical examples of small-scale power generation from stationary gas turbines, explaining their advantages and significant global utilization. The author now has more acknowledgment and a better understanding of stationary micro gas turbines and different types of power plants. This kind of small-scale power generation popularization has become increasingly important because of its fuel flexibility, higher thermodynamic efficiency and more advantages. Anyway, some limitations of this updated technology still need to be solved.

For all varieties of small-scale power generation using gas turbines, there is always a need to improve the systems further to achieve higher efficiency. The mounting height, the system's diameter, the materials used, and other parameters may be considered for further system exploration.

References

[1] Kaundinya D, Balachandra P and Ravindranath N 2009 *Renewable and Sustainable Energy Reviews* 13 2041.
[2] IEA. 2017 *Key world energy statistics.* International Energy Agency.
[3] Situmorang Y, Zhao Z, Yoshida A, Abudula A and Guan G 2020 *Renewable and Sustainable Energy Reviews* 117 109486.
[4] Reyhaneh B and Mohsen A 2022 *Energies* 15 8084.
[5] El-Khattam W and Salama M 2004 *Electr. Power Syst. Res.* 71 119.
[6] Owens B 2014 *The Rise of Distributed Power* https://www.windpowerengineering.com/rise-distributed-power/
[7] Amirantea R, Brunob S, Distasoa E, Scalab M and Tamburrano P 2020 *Renewable Energy Focus* 34 57.
[8] Megwai G 2014 *University of Borås, School of Engineering.*
[9] Sansaniwal S, Pal K, Rosen M and Tyagi S 2017 *Renew Sustain Energy Rev* 72 363.
[10] Pilavachi P 2002 *Applied Thermal Engineering* 22 2003.
[11] Vikram K, Ashutosh B and Bath S 2017 *Neural Comput & Applic* 28 2181.
[12] Baris K, Xiang L, Dubey S, Choo F and Duan F 2019 *Energy Conversion and Management* 181 507.
[13] Nor F, Ahmed N and Mat S 2017 *Renewable and Sustainable Energy Reviews* 72 228.