УДК 620.91 Мехатроніка і робототехніка

# TECHNOLOGICAL INTEGRATION OF STIRLING ENGINES IN FUEL BOILERS AS THE BASIS FOR HIGH PERFORMING MICRO-CHP WITH LOW EMISSIONS

[1] Nikitin Ye., [1]Pavlenko V., [2]Volianyk O.
[1]*National University of Life and Environmental Sciences of Ukraine*
[2]*Kyiv National University of Technologies and Design*

Modern energy systems face many challenges that demand creative, sustainable solutions. We know the need to shift to renewable energy sources, better use our resources, and protect the environment for future generations. One of the most exciting developments in this field is the rise of local micro-CHP (combined heat and power) systems. These systems are designed to generate heat and electricity simultaneously, offering an innovative solution to our energy needs while reducing dependence on large, centralised power grids and fossil fuels.

At the heart of these micro-CHP systems is the innovative use of granular pellets as fuel. These pellets, made from renewable biomass, offer a twofold advantage: they help cut carbon dioxide emissions and boost the energy independence of local installations – whether that is a private home, a remote cottage, or a small industrial facility. Imagine a small community or even an individual household that no longer worries about unreliable power or high energy costs because it uses a system that turns locally sourced, renewable fuel into heat and electricity. It is essential in rural or isolated areas where traditional energy infrastructures might be lacking or outdated [1].

The story gets even more interesting when we look at European energy trends. In countries like Germany and Italy, there has been a significant move towards decentralised energy production. Individuals and local farmers now generate more than half of the renewable energy in these regions. This trend speaks volumes about the growing importance of community-based energy solutions. [2] When local energy systems like micro-CHP become more efficient and widespread, they do not just reduce the reliance on fossil fuels – they empower communities, offering them a stake in the future of energy.

A particularly groundbreaking aspect of these micro-CHP systems is integrating a Stirling engine into a conventional fuel boiler. Unlike more common internal combustion engines, the Stirling engine operates on an external combustion process. This means that it uses heat from an external source to expand and compress a working gas, efficiently turning that thermal energy into mechanical work. The Stirling engine is celebrated for its high efficiency, quiet operation, and low emissions. Its design, with fewer moving parts and the ability to work with various fuels, makes it an excellent match for renewable energy applications.

Engineers have introduced a state-of-the-art heat exchanger that uses microchannel technology to make this system even more effective. The heat exchanger has a network of very small channels that allow heat to be transferred rapidly and evenly, reducing any energy loss. What is clever about the design is that part of the Stirling engine is located inside the combustion chamber of the fuel boiler. This compact design helps reduce the system's physical footprint and production costs – a win-win for anyone looking to implement such a solution in a home or small business.

The automated pellet feeding mechanism is another innovation that makes these systems stand out. By automating the fuel supply, the system ensures that there is always a steady stream of pellets available, which is crucial for maintaining a constant and efficient combustion process. The system also carefully regulates the amount of primary and secondary air entering the combustion chamber. This control ensures that the fuel burns at the optimal rate, maximising efficiency and minimising emissions. Combining these features makes it possible to get a micro-CHP system that is technically impressive, environmentally friendly, and economically viable [3].

Electricity generation in these systems is optimised using a permanent magnet generator. This type of generator is known for its excellent efficiency, turning mechanical energy from the Stirling engine into electrical energy with very little loss. An advanced control system ensures that the power output is steady and reliable. This system carefully monitors and adjusts the engine speed and output current, making the electricity produced stable and high quality. Thanks to these technological advances, the system's overall thermal efficiency reaches about 90%. Although the current electrical efficiency is around 10%, there is real potential to push this up to 15% with further improvements – especially by using helium as the working gas, which can boost the heat transfer within the engine.

The practical benefits of this technology are impressive. The integrated micro-CHP system can deliver around 1 kW of electrical and 5 kW of thermal energy. This balanced output makes it an attractive option for many applications, from powering a small home to providing energy for remote communities. The economic advantages are correspondingly transparent: biomass pellets are relatively inexpensive, and the automation of the fuel supply system drives down operating costs. Plus, the system is flexible enough to work independently or be connected to existing power networks. It means that it can serve as a standalone solution in off-grid areas or enhance the reliability of energy supply in urban environments.

Environmental benefits also play an important role in the appeal of micro-CHP systems with integrated Stirling engines. These systems significantly reduce harmful emissions and the overall carbon footprint by optimising the combustion process and using renewable biomass pellets. Cleaner air, lower greenhouse gas emissions, and a reduced environmental impact are all outcomes of this efficient energy conversion process. This technology offers a promising path forward for communities striving to meet strict environmental standards and combat climate change.

Hybrid systems are another exciting prospect. Combining micro-CHP with other renewable energy sources like solar panels or geothermal systems makes it possible to create integrated energy solutions that can adapt to varying energy demands. Imagine a small community that uses a blend of solar, geothermal, and micro-CHP energy with battery storage systems to manage peak load times. This setup would be extremely resilient and provide a steady, reliable power supply regardless of external conditions.

Battery storage is particularly crucial when considering the fluctuating nature of renewable energy. By storing excess energy generated during periods of low demand, batteries can help ensure that there is always enough power available during peak times. This feature is especially beneficial in remote or off-grid areas, where access to centralised power is either limited or nonexistent. With reliable energy storage, these micro-CHP systems can operate seamlessly, ensuring that homes and businesses remain powered even when traditional grids fail.

Integrating micro-CHP systems with Stirling engines marks a significant leap forward in local energy technology. It is not just about efficiency and cost-effectiveness; it is also about creating energy solutions that are sustainable, resilient, and adaptable to the needs of modern society. As this technology continues to evolve, it promises to play a critical role in transitioning toward a cleaner, more decentralised energy landscape. With each new advancement, we move closer to a future where communities are energy-independent and active contributors to the global effort against climate change.

In conclusion, developing a micro-CHP system that incorporates a fuel boiler with an integrated Stirling engine represents a significant breakthrough in energy technology. This innovative system combines the efficient use of renewable biomass pellets with the advanced mechanics of the Stirling engine, resulting in a powerful and environmentally friendly solution. With a thermal efficiency of around 90% and promising improvements in electrical efficiency, the technology offers a balanced and cost-effective approach to local energy generation. Whether used in rural settings, urban homes, or even industrial applications, these systems are poised to revolutionise how we think about and use energy. As we continue to refine the technology and bring down production costs, the potential for widespread adoption grows ever larger, promising a future where sustainable energy is available to all, regardless of location or circumstance.

**References**

1. Just Transition and Renewable Energy: A Business Brief | UN Global Compact. (2023). https://unglobalcompact.org/library/6143

2. Shunming Zhu, Guoyao Yu, K. Liang, W. Dai, & E. Luo. (2021). A review of Stirling-engine-based combined heat and power technology. Applied Energy. https://doi.org/10.1016/J.APENERGY.2021.116965

3. G. P. Hammond & Adam A. Titley. (2022). Small-Scale Combined Heat and Power Systems: The Prospects for a Distributed Micro-Generator in the 'Net-Zero' Transition within the UK. Energies. https://doi.org/10.3390/en15166049