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Biomass based microturbine system for electricity generation for isolated communities in amazon region

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ABSTRACT

This paper presents the development stages of a micro-scale system for electricity generation from biomass with 500 W of power. The proposed system is based on an open steam power cycle, whose conception was aimed at seeking solutions to meet the needs for energy supply in isolated communities in the Amazon region. In addition the great biomass potential in the region is an opportunity for the application of biomass energy to increase the economic activity and develop new technologies. The tests performed demonstrate that the steam turbine is the critical component to the commercial-scale feasibility of the presented technology, particularly when it's proposed manufacturing of the system by small regional industries.

1. Introduction

In many sites of the Brazilian territory the connection of small communities to the conventional electric energy distribution grid becomes restrictive due to factors of financial and geographical order. Those aspects are especially true when it comes to the Amazon Region, where the long distances and the difficulties to access such areas, among other factors forbid the extension of the conventional grid. The high costs associated with the construction and maintenance of transmission and distribution grids for isolated communities with low population density, which in most of the cases have a small load to be supplied, jeopardize its feasibility.

The Amazon Region corresponds to approximately 45% of the Brazilian national territory, and although it corresponds to almost half of the country, is estimate that only 3% of the national population live in it [1]. Despite the low percentage, there is a great deal of people without access to electricity and its benefits in the Amazon Region. The main problem is that most of those small communities are spread over a very large area with great difficulties regarding accessibility.

The main option for the supply of such areas are fossil fuel driven thermal systems, which shows high costs related to the operation and maintenance and also to the fuel distribution logistics. These difficulties enhance the attractiveness of generation systems running on renewable resources found on site. As the distance from major cities increases, so increases the competitiveness of renewable energy based systems.

Systems of this kind present themselves as an option for the universalization of electricity in the country, and since they use the natural resources available on site for the obtainment of its primary energy, their operation implies in less impact to the environment.

Among all resources available for the use of renewable energy, biomass is, on most sites, abundant and prominent. Solar and wind based technologies for electricity generation are limited due to their intermittent nature. Such ways of producing electricity have a more appropriate use on hybrid systems as a complementary generation, where the main form of energy supply comes from other sources like fossil fuel or energy storage systems like battery sets designed to meet the need for electricity when solar and/or wind energy are not available.

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Regarding environmental issues, biomass based systems have zero balance in carbon emissions and also these kinds of systems can be a solution regarding vegetal residues which are on most occasions abandoned or burned. As for the economic issues, biomass plants can be integrated in local economy, generating direct and indirect jobs that require less qualification and can be filled by the local population.

However, on small communities (up to 5 houses) or isolated homes, the current state of electricity generation technologies points toward the use of small systems based on diesel, photovoltaic, wind or a combination of the later (hybrid systems), which still demand high costs for its implementation as well as for operation and maintenance. As an alternative on such cases, an innovative micro-scale biomass based electricity generation plant was develop on this work. The plant provide up to 500 W, enough to fulfill the demands for electricity with possible smaller costs than the referred alternatives.

Finally, the innovation, and challenge, of this work is because micro-scale biomass based electricity generation plant available in very few references to literature works depict the steam power cycles in the range of 1 kW [2–5]. Much literature is available for Organic Rankine Cycle (OCR) and micro gas turbine, but the steam turbine in the literature is deficient. So in this paper aims to explore a field of research with potential for major breakthroughs. In addition, this type of turbine is not available in the Brazilian market so as well as being an innovation, it is of great help in energy supply communities located in the Amazon region (which is an area of great complexity and challenges).

2. Biomass conversion technologies for small and micro scale applications

The concept used the most for small-scale thermal systems consists in the combination of heat and electricity generation up to 100 kW. Micro-scale is also frequently used to characterize systems that combine heat and electricity up to 15 kW. Most of those are associated with gasification systems [5]. Small and micro-scale systems combining heat and electricity generation are currently developing quickly and consist on an emerging market, holding promising expectations for a near future [3,5–7].

[8] also studied a co-generation system used to supply an absorption chiller with heat and the electrical loads of a laboratory space. The results lead to an electrical efficiency of 21%, while the COP of the refrigeration subsystem remained in the range of 0.5 and 0.58. The total electrical capacity of the evaluated system is 24 kW while the overall efficiency between 40% and 49%.

[9] developed a microturbine prototype as small as 28 W of mechanical power with efficiency of 18%. The high speed of rotation, up to 160,000 rpm, allows the achievement of this relatively high efficiency, which is a good value for the very small scale of power, with a rotor diameter of 10 mm micro co-generation system. The study concluded that while the benefits for the environment and energy economy were unquestionable, technological issues would continue to be an obstacle to large-scale dissemination, since a desirable low cost micro-co-generation system of easy usage for residential personnel was still under design by the time of the study. Therefore, the use of micro-co-generation systems for domestic purpose subjected to factors such as the available technology, the matching between electric and heat loads and the electricity and gas rates.

An evaluation carried out on five co-generation micro-systems (with an output below 5 kW) used for residential applications showed that although primary energy was saved and CO_2 emissions were reduced, such systems for the referred application were considered to be unfeasible due to its high cost and long payback time [10]. Nevertheless, according to some researches [5,6,10,11], the development of a micro-scale co-generation system with low cost requirements is of great importance to change this scenario.

Technologies developed for energy conversion from biomass in heat and electricity basically include, in most of the cases, a primary conversion stage, in which the biomass is converted to hot water, steam, and gas or liquefied product, and a secondary conversion stage that transforms the products in heat and electricity.

Among the main technologies available for energy conversion from biomass, the combination of combustion technology, for the primary stage, with steam turbine, for the secondary stage, is one of the most commonly used strategy. The combination of combustion and Organic Rankine Cycle (ORC) has received great attention on the development of small-scale biomass conversion systems [5]. Instead of using water, ORC use an organic substance, as working fluids, with favorable thermodynamic properties. The organic working fluids need less heat quantity to evaporate than water, so they can operate at lower temperature and pressure than the conventional steam processes.

Working as an advanced electricity generation technology suited for low temperature heat sources applied to systems ranging from fractions of kWe up to 1 MWe, ORC based systems are in many aspects robust and advantageous. At low temperatures, organic working fluids lead to greater cycle efficiency when compared to systems based on water. On small and micro scale the former is preferable, since it provides high turbine efficiency whether working on partial or full load. Another advantage of ORC based systems when compared to conventional systems is the safety. It is known that water shows good performance at high pressures, which, as a consequence, require more rigorous safety measures and therefore are not economic viable for small and micro scale applications. Despite the mentioned advantages, an ORC based systems have two main obstacles: the specific investment is high and its limited electric efficiency [5,12,13]. Even so, the literature reports some experimental studies on microturbine performance in Rankine cycles working with organic fluid, while there are not almost any data provided for steam as working fluid in microscale systems [14]. developed a microturbine with 32.7 kW of maximum power. He carried out experiments on its performance in an ORC (with R245fa as working fluid). The corresponding maximum average overall efficiency and the turbine efficiency was 5.22% and 78.7% respectively. The results were consistent with the design expectations of 30 kW and 75% of turbine power efficiency [15]. also reported similar results on ORC working with R245fa, but in a smaller scale, which is 1 kW power and also using a scroll expander instead of microturbine. They obtained a maximum of 77.74% of isentropic efficiency and 5.75% thermal efficiency.

Based on economic reasons, some researchers argue that biomass applications in small and micro scale should be simplified compared to applications in medium and large, as the number of operating hours is less, and a good portion of those hours operates on partial load conditions.

Although the systems based on Organic Rankine Cycle (ORC) are being implemented in small generating units (applied to a fraction of kW), experimental data to biomass microsystems are not available in literature, both to ORC as other technology. This is mainly due to limited interest in micro scale applications and also the lack of consolidated research. In some situations, available operational technical data are limited because of business secrets. Therefore, this is the great motivation of this work.

3. System assembly and description

The electricity generation micro-system was conceived in a simple manner so it could be easily reproduced on large scale by