Modelling and Control of Dish-Stirling Solar/Gas Hybrid System

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March 2021

The world is moving towards more sustainable energy production creating pressure and opportunity for the development of renewable energy sources. One of the reasons for this development is the fact that the non-renewable energy sources that we rely on are starting to deplete. Burning of fossil fuels also contributes to climate change and affects human health. The United Nations General Assembly has set goals as part of "Agenda 2030" to not only increase sustainable energy production but also make energy available to a larger part of the human population. The new energy system is likely to be built around renewable energy sources like wind and solar but also around renewable gasses like hydrogen and bio-methane.

Most renewable energy sources like wind and solar are intermittent, meaning that the energy generation is dependent on weather. The fact that the future energy system is likely to consist of a lot of intermittent energy sources and that environmental gas fuels are going to be part of the energy system drove the company Stirlingversal to start developing a new energy system which is illustrated in figure 1.

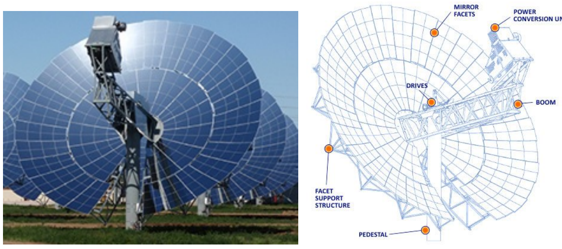

Figure 1: Dish-Striling system with functional parts

The new system is called a Hybrid Dish-Stirling system and is a modular controllable energy generation system that work with solar power as well as gas fuels. The Hybrid Dish-Stirling system consists of a power conversion unit (PCU) and a parabolic mirror dish. Solar radiation is concentrated by the dish onto the receiver of the PCU. The receiver is thereby heated and that thermal energy is extracted by the Stirling engine. The Stirling engine in turn drives a generator that generates electrical energy. The receiver features a gas burner with an innovative combustion technology that maximises the burner efficiency and reduces NOX emissions to near zero. The burner can work with a wide array of fuels that includes: hydrogen, bio-methane and gas from industrial processes. What makes the Stirling system unique is that it uses the resultant heat from the combustion instead of the resultant force from the gas expansion like in an internal gas combustion engine. This makes the engine able to burn the gas in a more controlled and effective way. In addition the combustion occurs outside of the engine, as a result the engine can use gas with lower quality than other systems. Gas from waste treatment plants, pyrolysis or metal forges could be used. Today these gasses are often considered to be waste products and burned emitting CO_2 into the atmosphere for no gain. Technically the engine could work with any heat source but the technology would have to be developed to be able to consume energy from for example solid fuels.

In this thesis a model of the Dish-Stirling system is developed including a model of the Stirling engine and the generator connected to the grid. A fixed speed generator configuration is modeled, compared with a variable speed generator configuration and power quality improvement methods are implemented in both systems. Lastly an electrolyser is modeled and integrated with the system. A comparative study was then carried out between the hybrid system and a photovoltaic and battery system with similar performance and utility. The study was done in two locations: Lund (Sweden) and Johannesburg (South Africa).

The speed of the stirling engine affect the efficiency of the system. Therefore two system configurations were modeled: fixed speed and variable speed. The control algorithm for the variable speed system was developed to maximize the gas pressure inside the stirling engine. In addition power quality improvement methods were developed for both configurations in order to control the power factor of the systems.

The results showed that it is possible to improve the efficiency of the system with a variable speed configuration. The performance was especially improved in the lower power input levels. As the system approaches maximum power input the efficiency of the fixed speed and variable speed configurations became more similar as illustrated in figure 2.

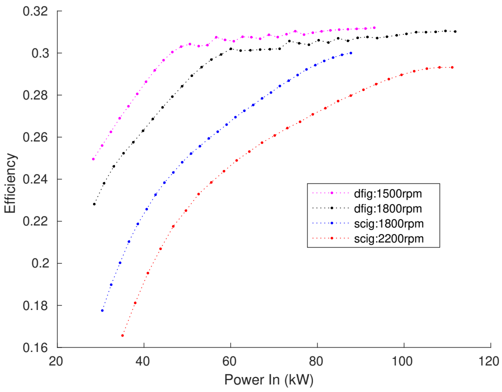

Figure 2: Efficiency over power input range

As a result of this the gas consumption was also similar between the two systems. This was due to the system working at maximum power when the gas burner was on. The variable speed system is thereby deemed superior when the system is operating with variable input or output while the fixed speed system is equal when operating with a fixed input like in hybrid operation mode. When power quality improvement methods were applied the cost difference between the systems were reduced significantly in favor of the variable speed system.

The comparative study between the Dish-Stirling system and the photovoltaic and battery system was done with a specific scenario. The systems were set to produce a given power demand of 950kW at all hours of the day during one year. Monthly average insolation data was used to calculate the amount of gas consumed during the year. The same data was used to calculate the required photovoltaic capacity in order to meet the power demand. The study showed that the Dish-Stirling system require a smaller initial investment than photovoltaic and battery system. However, that the gas cost is critical to making the Dish-Stirling system economically viable. The Dish-Stirling system consumes more gas in a northern country like Sweden which increases the operational costs for the system. The photovoltaic system however, require more installed capacity in order to produce enough energy to meet the demand. In a sunnier country like South Africa the system uses considerably less gas but the photovoltaic system in turn requires less installed capacity. The gas cost that would result in equal system costs at end of life was defined as the break-even gas cost. The break-even gas cost was similar in both locations which means that the system is equally viable in both locations although the Dish-Stirling system had slightly better performance in Sweden. One example of the cost comparison projected over 20 years can be seen if figure 3.

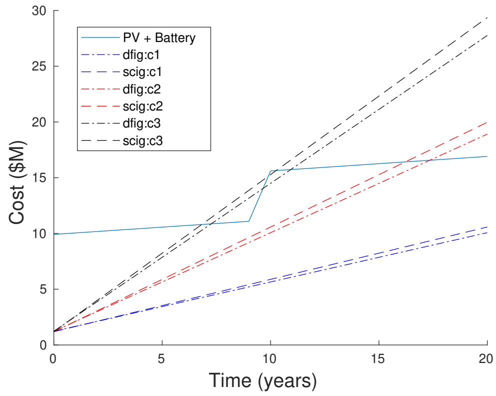

Figure 3: Cost comparison Lund with 33 Dish-Stirling units

The system was shown to be viable compared to competitive technology given a low enough gas cost. It is worth considering that the system has higher utility due to its controllability as well and an additional output product in the form of warm water that was not considered in this comparison. The work showed that there is room for improvement in the system configuration and operation that is worth exploring further. It also showed the importance of efficiency optimization due to the considerable share of the total system costs being the gas cost.