Project Justification

At the current time, electricity generation using concentrated solar radiation (known as CSP) is evolving towards lower electricity costs through more efficient conversion systems and cheaper components with longer life. Over 90% of the currently installed CSP plants are large scale (multi-megawatt) systems using steam turbines energy converters. However, there is a large potential for power generation from Stirling-engines based CSP plants, where the solar collector consists of parabolic dish units in combination with high temperature solar receivers. These plants demonstrate high efficiencies, are easily scalable and can be rapidly expanded as power demand increases. They can therefore also be used in combined heat and power configurations to produce electricity and hot water for applications such as hospitals in remote rural areas without access to the power grid. Furthermore, compared with renewable electricity from wind turbines and solar photovoltaics (PV), CSP plants have the advantage of being able to integrate thermal energy storage or hybridization in order to supply electricity around the clock, regardless of variations in solar radiation.

A critical element for developing competitive CSP plants are efficient and durable solar collectors. In the case of a solar Stirling-engine unit, the collector system consists of a circular parabolic mirror (the solar dish) that concentrates the Sun's rays to a receiver placed at the focal point; this receiver converts the solar energy into heat at high temperatures. The mirror and the receiver system must be finely-tuned in order to ensure a sufficiently high efficiency. Additionally, the receiver needs to be able to withstand high temperatures and high fluxes, whilst meeting industrial life requirements. This project aims to develop and verify the properties of an efficient, durable and cost-competitive solar collector for a 13kW Stirling-engine based CSP system.

The novelty lies in our unique combination of technical goals, with a targeted collector efficiency (mirror + receiver) of over 87% , a component life of at least 15,000 equivalent operational hours and a competitive product cost. These goals will be achieved through aerodynamic design of the mirror to minimize impact of aerodynamic loading and innovative optical design and thermal solutions for the receiver, developed using multi-dimensional optimization and well-validated component modeling (including coupled fluid dynamics, heat transfer and finite element modeling). New prototypes of the solar collector system will then be developed and tested in our unique high-intensity solar laboratories

The project will be implemented as a cooperation between KTH and the Swedish industrial company Cleanergy, a leading player in Stirling -based power generation. The targeted solar collector output of 55kW is designed for direct integration and testing with existing Cleanergy Stirling-engine units.

This project directly contributes to the realization of the European energy plan SET, which has a target of 3% of electricity generated from CSP by 2020. The overall goal is a reduction in greenhouse gas emissions of 20% by 2020, using a 20% share of renewable electricity in the energy mix in the EU. IEA studies predict that CSP-based electricity generation will grow on a global scale to reach around 1000-1500 TWh/year by 2050. Highly efficiency Stirling-engine based CSP plants will have access to a strong niche market for local, scalable and grid-independent power generation. Stirling based CSP plant are also capable of establishing a strong market share in large-scale (multi-megawatt) power, especially in certain climates where access to water is limited.

During the last 5 years, the Department of Heat and Power Technology at KTH has built a strong group within the CSP area, with focus on the development and testing of innovative CSP components, research in CSP system behavior and market roles, as well as thermal optimization of turbomachinery for converting solar heat to electrical power. The group participates in both national and international research projects such as the Swedish's TURBO POWER research programme, KIC InnoEnergy's TESCONSOL project and the European Union's OMSOP FP7 Project. A unique high intensity solar simulator is under construction at the laboratory in order to perform research and testing under concentrated solar flux conditions (see reference 1, 2).

Cleanergy was founded in 2008 with the goal of becoming the world 's leading provider of Stirling based climate-friendly energy solutions. Cleanergy manufactures and sells Stirling engines, initially targeted at the gas-power power with the C9G model. Since 2011, Cleanergy has been involved in the production of engines for CSP system, with the C11S model. These engines are in commercial use today, with dozens of companies having purchased units; large-scale installations can reach up to 25 units in a single CSP facility.

With the successful completion of the proposed project, the Swedish research and industry will be positioned as key players in the field of Stirling-engine based CSP, with the possibility to take a significant share of the growing market of solar-based energy generation.

Goals

The overall objective of the project is to develop and validate innovative, efficient, durable and sustainable solar collector systems for Stirling-engine based solar electricity. The new collector system will enable the 13 kW plant considered to reach an electricity cost of below 50 öre/kWh given that significant production volumes are reached. The solar-electric conversion efficiency shall reach 25 % and operate for 15,000 hours without maintenance.

In detail, this will mean achieving the following specific objectives:

- Design, model and test a parabolic mirror at full scale with an optical efficiency of 95%.

- Develop a solar receiver with a thermal conversion efficiency (solar energy to heat) of 5% units above today's level whilst operating at temperatures of at least 850°C.

- Simulate and verify the solar receiver operation under relevant flux conditions in the solar lab facility.

- Demonstrate that the solar collector system can achieve an overall efficiency of a least 87 % using a combination of simulations and experimental tests, at both lab- and full-scale.

- Verify that the thermo-mechanical lifetime of the solar receiver is at least 15,000 hours, using a combination of simulations and validation measurements.

- Demonstrate a product cost for solar collector system (mirror and receiver) of below 7500 kr/kW for the mirror (concentrator) and 390 kr/kW for the receiver. For Cleanergy's engine at 13 kW this means 75 000kr and 5000 kr in absolute numbers, respectively.

References

[1] Strand T., Spelling J., Laumert B., Fransson T. (2011) "On the Significance of Concentrated Solar Power R&D in Sweden" World Renewable Energy Congress 2011, Linköping, Sweden

[2] Wang, W., Aichmayer, L., Laumert, B., Fransson, T., (2013) “Design and Validation of a Low-Cost High-Flux Solar Simulator using Fresnel Lens Concentrators” Proceedings of International SolarPaces Conference 2013, Las Vegas, USA

[3] Aichmayer, L., Spelling J., Wang W., Laumert B.,(2012) “Design and Analysis of a Solar Receiver for Micro Gas Turbine based Solar Dish Systems” Proceedings of International SolarPaces Conference 2012, Marrakesh, Marocco