

## **ThermoElectric Generator (TEG) for recovery of waste heat energy, pre-study**

Extracting electricity from heat by using a so-called thermoelectric generator (TEG) is based on the effect discovered by Thomas Seebeck 1821. Thermoelectric power generation is based on the same physical principle as thermocouples. By exposing the appropriate materials for a warm and a cold side, an electric current is generated. The efficiency of this process has historically been at the level of up to 5%. Since the mid-1990s, much progress has been made in materials research and the conversion rate has increased fourfold. There is now potential to reach up to 20% efficiency and maybe even more.

Most of the energy in the fuel fed into an internal combustion engine is wasted as heat losses (cooling, exhaust and friction losses). If some of the lost heat energy can be recovered, the total efficiency is increased. A method of heat recovery is to extract electricity directly from waste heat with a TEG. It is considered still being far away from implementation in vehicles in serial applications, but material development is moving fast forward and the automotive industry needs to investigate the potential to weigh its merits and competitiveness against other means to recover waste heat energy, such as Turbo-Compounding (exhaust gas turbine) and Rankine cycle (steam expander/turbine).

The pre-study has investigated various waste heat sources potential for energy recovery, such as exhaust gases and cooling water, to investigate the thermoelectric generator design, system complexity and the various heat sources potential to generate electricity under varying driving conditions with the TEG-materials that are commercially available today. The potential and maturity of the new materials have also been investigated.

Depending on that the voltage level output from the thermoelectric modules varies depending on the availability of waste heat energy flow and its temperature and the cooling capacity available, the voltage converter configuration has been studied in order to see how the efficiency and robustness can be kept as high as possible.

The pre-study has resulted in an cooperation between industry and academia and a good knowledge base and tool kit for further work in a possible follow-up project.

### **Objective**

The pre-study aimed to explore the basis for a project that closely examines the recovery potential of converting waste heat, from heavy trucks and buses, to electricity with thermoelectric generator (TEG) using Seebeck effect and understand the systems complexity, robustness and cost levels.

The study has also identified various TEG-materials efficiency, long-term characteristics, maturity and level of costs, for understanding what assessments a project needs to perform to more deeply examine the TEG-materials that are appropriate in this type of applications and what conversion rate can be achieved.

To assess the overall complexity of generating and distributing electricity from a thermal electric generator, the voltage conversion equipment was analyzed. The result of this is the foundation to be able to specify the a follow-up project.

### **Results and deliverables**

- Concept proposals for different waste heat sources in combination with various thermoelectric generator concepts are developed.
- Test prototype, both a Thermoelectric generator and a DC/DC-converter, for the recovery of waste heat energy has been designed and build.

VINNOVA Dnr: 2009-01428  
Project manager: Jan Dellrud

- Detailed literature study on TEG material properties has been done.
- Based on literature study, mathematical equations used for simulation and optimization have been put together. And simulation and optimization method has been established.
- For most commonly used TEG materials, simulations have been done in terms of output power/current and efficiency vs. temperature and available heat power density. This is very useful for choosing right TEG material under given application condition and scenario.
- For a given material under given temperature, temperature difference, and heat density, there is always an optimized TEG material thickness for maximizing output power/current and efficiency. The result and optimization method will be very important for TEG design.
- It is found that for most applications segmenting (thermally and electrically connecting) or stacking (thermally connecting and electrically isolating) multiple TEG materials into TEG legs are always greatly improving TEG conversion efficiency.
- DC/DC conversion network concept has been proposed.
- DC/DC conversion network design method and design flow has been partly established.
- It is noticeable that to have good impedance matching network at lowest level of DC/DC network is essential. How many TEG elements should be series and paralleling at each network level is very much dependent on the application scenario, i.e., where and how to catch out heat energy.

## **Project realization**

The project was performed from April 2009 to February 2011 as a collaboration between Scania CV AB and Royal Institute of Technology in Stockholm, for the benefit of each party's specific skills.

One of the goals of the execution of the pre-study was to reach as good exchange of knowledge and information as possible. This was accomplished through regular project meetings and guided visits at both Scania R&D and at KTH in Kista.

## **Project outcomes**

The pre-study has resulted in skills development and knowledge dissemination, within the industry and academia and between industry and academia.

The newly acquired knowledge of research and development has enabled the planning of a continuation project, which is expected to start within a year.

The results of vehicle model and the DC/DC-converter model can now be used for continued research and development within the partners organizations. Further studies in the form of master thesis projects are also planned after the pre-study ended.

## **Participating parties and Contact person**

Scania CV AB  
Jan Dellrud, project leader  
[jan.dellrud@scania.com](mailto:jan.dellrud@scania.com)  
08-553 50882

The Royal Technical Institute (KTH)  
Ph.D. Qiang Chen  
[qiangch@kth.se](mailto:qiangch@kth.se)  
08-790 417208

VINNOVA Dnr: 2009-01428  
Project manager: Jan Dellrud

## **Publications and dissemination of results**

### **Master thesis report 1:**

The Thermoelectric Generator; an analysis of seebeck-based waste heat recovery in a Scania R-series truck.

Henrik Schauman,  
Fordonodynamik, Kungliga Tekniska Högskolan.  
TRITA-AVE 2009:97  
ISSN 1651-7660

### **Master thesis report 2:**

Optimization of the electric properties of thermoelectric generators

Adham Shawwaf,  
Master's Thesis ISRN LUTFD2/TFRT--5873--SE, Department of  
Automatic Control, Lund University, Sweden, December 2010.

### **Master thesis report 3:**

Thermoelectric-Generator-Based DC-DC Conversion Networks for Automotive Applications.

Molan Li,  
Skolan för informations- och kommunikationsteknik, Kungliga Tekniska Högskolan i Stockholm.  
Publication is planned to be performed during March 2011.