How thermoelectrics can be integrated successfully into the electrical power grid.

Institute of Vehicle Concepts
DLR

Microinverter for thermoelectric generators for combined feed-in to AC grids and low-voltage battery storage systems

Florian Liebetrau (DLR), Julian Schwab (DLR), Timo Knobelspies (DLR), Martin Kober (DLR), Christian Weber (DLR), Frank Rinderknecht (DLR)

Introduction

Establish a link between energy generation and energy demand.

The use of thermoelectric generators in stationary applications, for example in heating systems such as pellet heaters or industrial systems with a high amount of waste heat, represents an interesting opportunity to increase the overall process efficiency of these systems. [1] [2] However, the utilization of the generated electrical energy poses a challenge, as the thermoelectric generators supply a low DC voltage, but most of the loads are connected to the AC grid. In addition, the available waste heat is not necessarily available at the same time as the electrical demand of the building.

To address this problem, a microinverter is presented that realizes the highly efficient conversion of low DC voltage into AC voltage. The system also has two maximum power point trackers (MPPT) to enable thermoelectric modules to be operated separately and efficiently in different temperature areas. The microinverter also has a module for easy connection to 12V, 24V and 48V battery storage systems. This means that the generation and feed-in of electrical energy can be easily decoupled in terms of time and adapted to the respective demand. The microinverter for thermoelectric generators can be operated in accordance with the corresponding standards applicable for small solar power plants. [3,4] The system can be easily retrofitted anywhere by plugging it into a standard domestic socket. The maximum feed-in power is 600W.

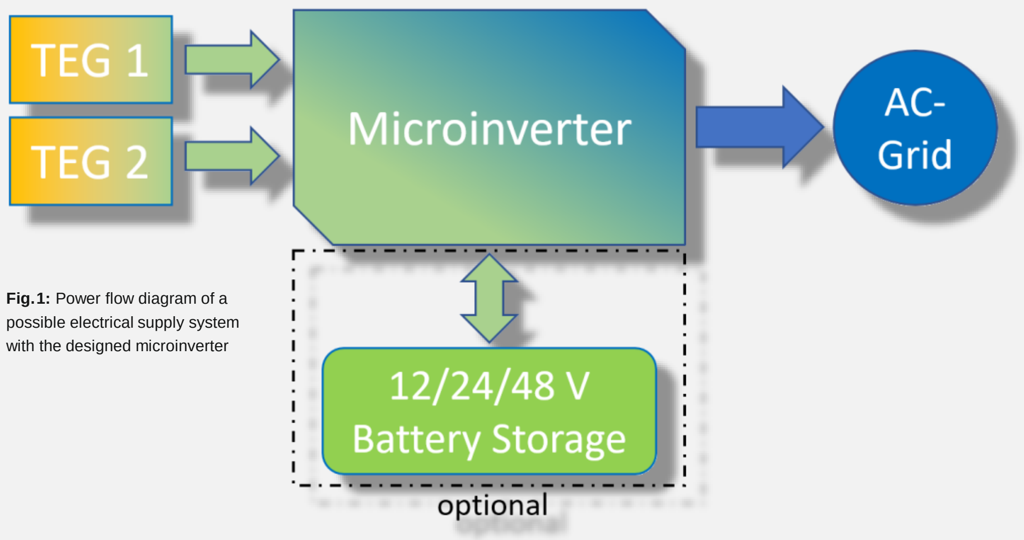


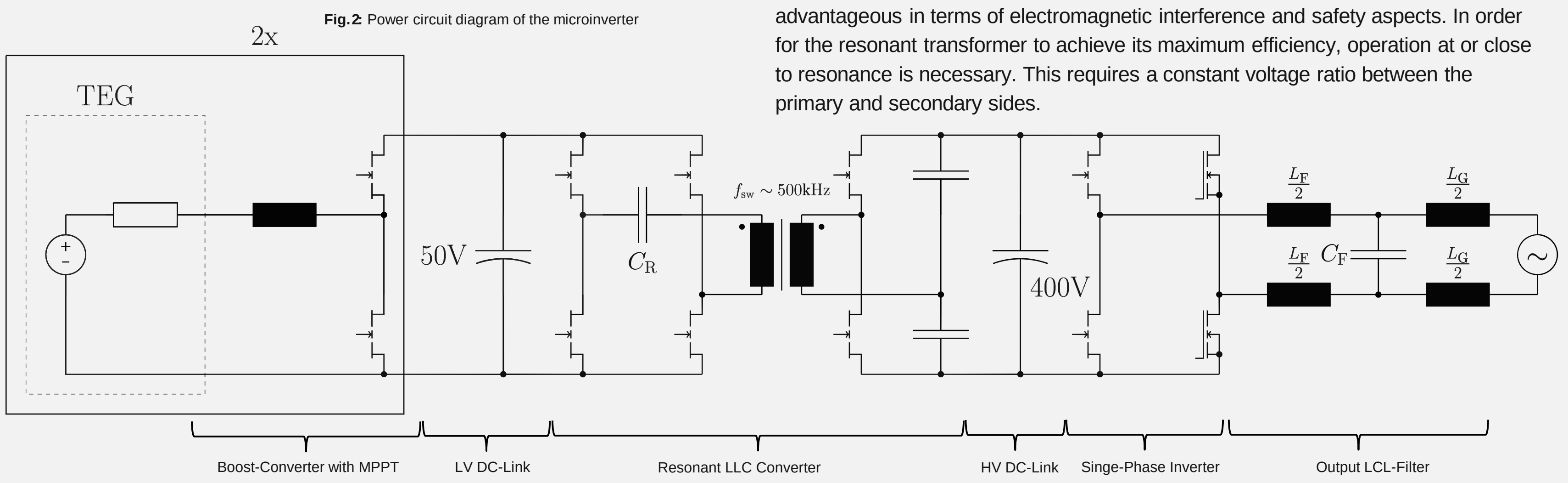
Fig. 1: Power flow diagram of a possible electrical supply system with the designed microinverter

System Design

Design with high energy efficiency by using the latest semiconductor technologies for a flexible supply connection.

A two-stage design is used to convert the low DC voltage of the TEGs to a higher AC voltage. In the first stage, the variable output voltage of the thermoelectric module is converted to a constant DC voltage of 50 V using a boost converter arrangement. This arrangement is present twice in order to be able to control two different thermoelectric modules independently of each other. This part of the circuit also realizes the task of maximum power point tracking.

Fig. 2: Power circuit diagram of the microinverter

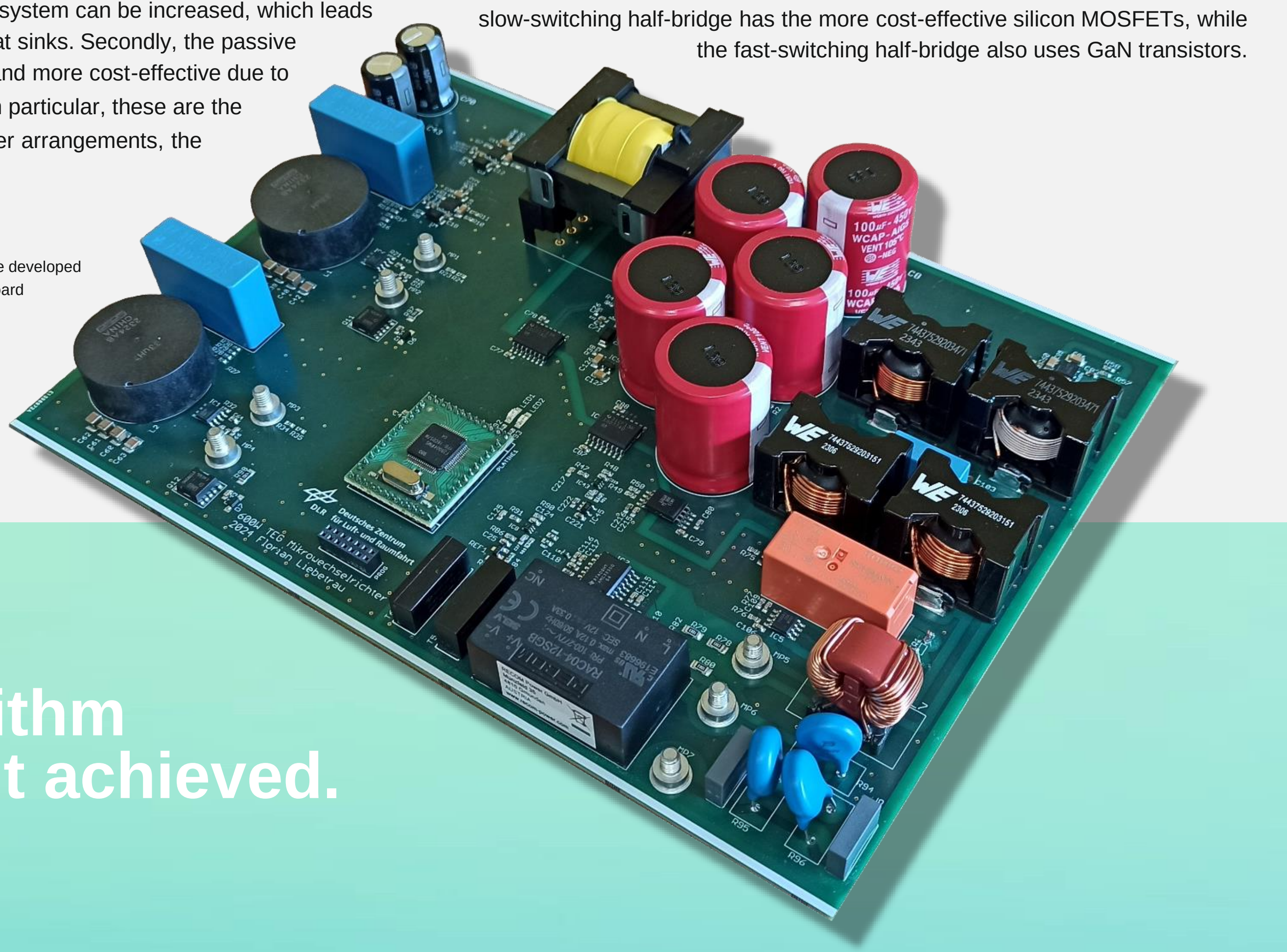


The 50V voltage level at the output of the boost converter arrangement is necessary to achieve a fixed voltage ratio to the high-voltage DC link for the inverter. Typically, the voltage level is in the range of 380 - 400V. The electrical connection of the 50V voltage level to the 400V level is realized by a resonant high-frequency transformer configuration, a so-called LLC transformer. It fulfills two tasks. Firstly, the very efficient energy transfer of voltage levels with a high relative spread (factor 8 in this case). Secondly, it provides galvanic isolation from the AC voltage grid, which is advantageous in terms of electromagnetic interference and safety aspects. In order for the resonant transformer to achieve its maximum efficiency, operation at or close to resonance is necessary. This requires a constant voltage ratio between the primary and secondary sides.

Gallium nitride (GaN) transistors are used in both the boost converter arrangements and the LLC transformer. This modern wide-bandgap semiconductor technology enables very low-loss switching, which has two advantages. Firstly, the efficiency of the system can be increased, which leads to less heating and therefore smaller heat sinks. Secondly, the passive components can also be made smaller and more cost-effective due to a higher possible switching frequency. In particular, these are the storage chokes of the two boost converter arrangements, the HF transformer and the EMC filters.

The inverter section consists of two half-bridges, one switching at high frequency in the kilohertz range and regulating the grid current and the other switching at grid frequency according to the half-waves of the grid voltage. This slow-switching half-bridge has the more cost-effective silicon MOSFETs, while the fast-switching half-bridge also uses GaN transistors.

Fig. 3: Illustration of the developed 600W microinverter board



Results and Discussion

Power injection with 600W and a search algorithm adapted to TEGs for the maximum power point achieved.

The operating behavior of a PV module differs from that of a TE module. Accordingly, the search algorithms and the requirements for the input of the Maximum Power Point Tracker (MPPT) are also different. In the PV module, the MPP voltage is in the range of the open-circuit voltage of the module. In the case of the TE module, the open-circuit voltage is approximately twice as high as the MPP voltage. For this reason, PV micro inverters cannot easily work with TE modules. The search algorithm also differs from PV inverters. While the MPP is searched over a wide range for the PV module, it is easier to determine this for the TE module due to its relatively linear output characteristics. As a result, the MPPT optimized for TE modules operates at the maximum power point for a significantly longer time than a comparable PV MPPT.

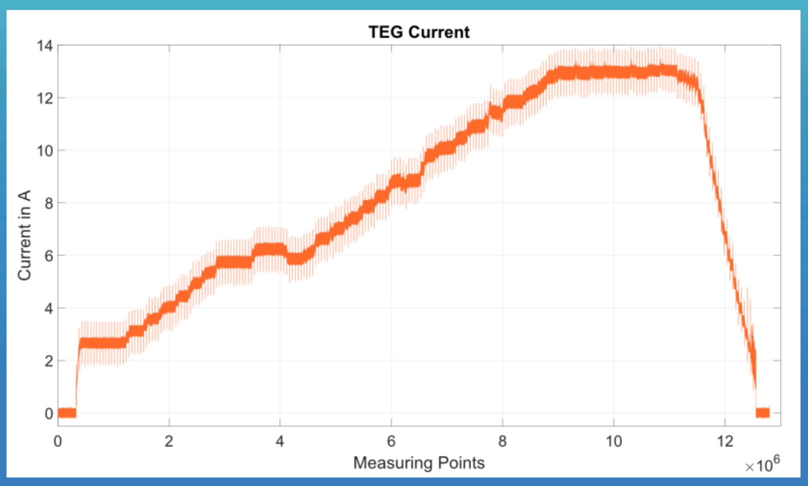


Fig. 4: Exemplary TEG Input Current with MPP Tracking

The Microinverter was able to be operated in initial tests in accordance with the requirements. MPPT operation and grid feed-in were demonstrated at nominal power. Corresponding measured curves are shown in Figures 4 and 5. Table 1 shows the specifications of the microinverter.

Tab. 1: Specifications of the Microinverter

Max. Continuous Output Power	600 VA
Output Power Factor	> 0.98
Nominal Output Voltage	230/240 Vac
Nominal Output Frequency	50/60 Hz
Max. Continuous Input Current	2x 13 A
MPPT Voltage Range	3-40 Vdc
Max. Input Voltage (TEG open circuit)	80 Vdc

Further investigations of the microinverter are ongoing with regard to EMC behavior, operation in the environment as well as dealing with grid disturbances and fluctuations in the grid frequency. Appropriate protective measures and sensors for grid detection are available on the hardware side. The functionality needs to be implemented in software.

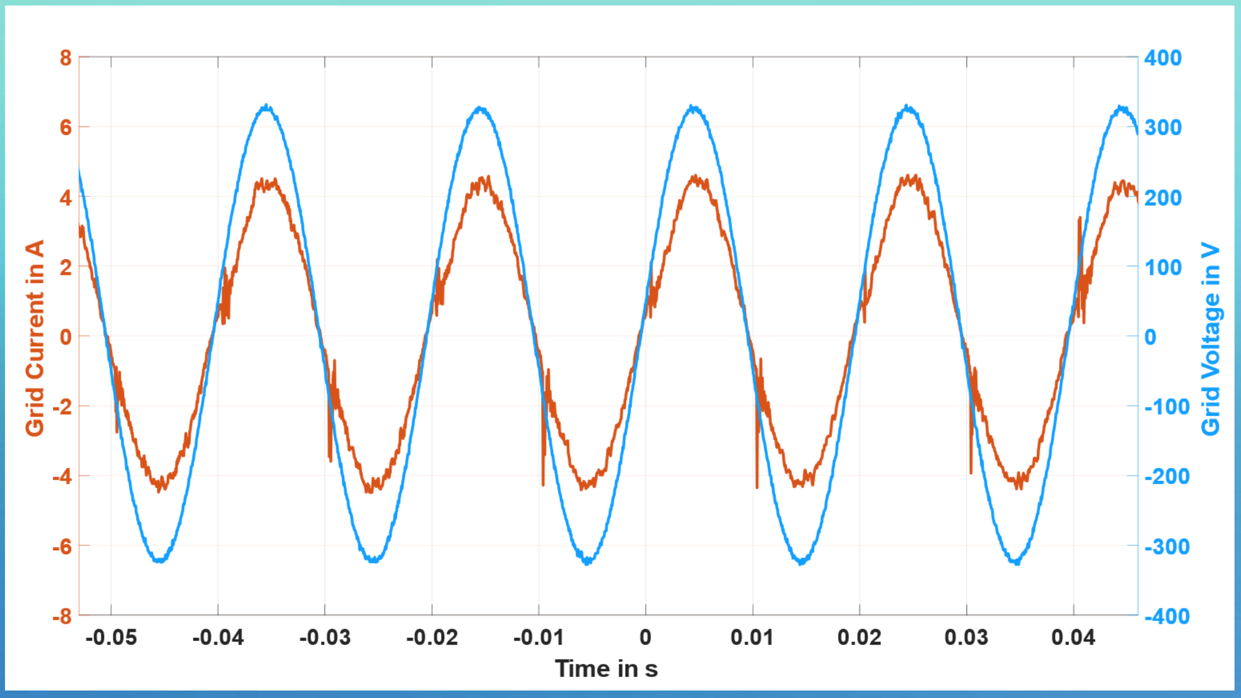


Fig. 5: Grid voltage and grid current curves with 600W feed-in

Contact: florian.liebetrau@dlr.de
Scan this code and
get all the information
on your smartphone.
s.dlr.de/p-teg

1 Schwab, Julian and Knobelspies, Timo and Fritscher, Christopher and Helmich, Matthias and Stumpf, Arne and Fey, Arno and Rink, Nils and Zuckermann, Daniel and Kraft, Moritz and Wendker, Kai and Kober, Martin and Rinderknecht, Frank and Siefkes, Tjark Demonstration of the Economic Viability and Energy Savings Potential of Thermoelectric Generators for Pellet Boilers. 19th European Conference on Thermoelectrics, 17. - 21. Sep. 2023,

2 Kober, Martin and Schwab, Julian and Heber, Lars and Knobelspies, Timo and Fritscher, Christopher and Helmich, Matthias and Zuckermann, Daniel and Rinderknecht, Frank and Siefkes, Tjark Applications of thermoelectric generators: Overview and results in stationary and mobile usage considering the cost-benefit. 39th Annual International Conference on Thermoelectrics, Seattle, USA, (2023)

3 INTERNATIONAL ELECTROTECHNICAL COMMISSION. IEC 62920:2017 Photovoltaic power generating systems - EMC requirements and test methods for power conversion equipment. (2017)

4 VDE Verlag. VDE-AR-N 4105 Anwendungsregel:2018-11 Erzeugungsanlagen am Niederspannungsnetz. (2018)

Federal Ministry
for Economic Affairs
and Climate Action

Supported and funded. Based on a decision of the German Bundestag as part of the project: PellTEG (03EN4019B)

Institute of
DLR Vehicle Concepts

German Aerospace Center, Institute of Vehicle Concepts, Stuttgart, Germany

ICT/ECT
2024
KRAKOW

40th INTERNATIONAL & 20th EUROPEAN CONFERENCE on THERMOELECTRICS
June 30–July 4, 2024, Krakow, POLAND