Thermoelectric Generators for Heavy-Duty Vehicles – A Systemic Approach and Development

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INTRODUCTION

Future trucks are meant to satisfy high requirements in terms of cost-effectiveness, as well as pollutant emissions, whereby the conflict of objectives can no longer be resolved solely by in-engine measures only (Fig. 1). While fuel consumption is the major factor, in form of Total Cost of Ownership (TCO), low pollutant emissions are essential for compliance with legal requirements.

Approximately 2/3 of the fuels chemical energy in modern truck engines dissipates as waste heat roughly in equal shares in the exhaust and coolant system. A Thermoelectric Generator (TEG) as Waste Heat Recovery System (WHRS) provides a high potential to fulfill the future requirements. Even though most of the approaches were scaled up from car applications and the overall systemic assessment has not been investigated. Natural gas-powered trucks appear interesting for TEGs, as focused in the HD-TEG Project.

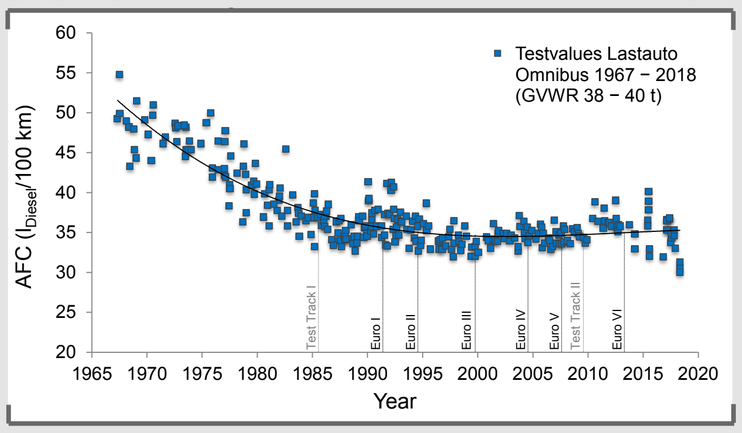

Fig. 1: Development of Average Fuel Consumption (AFC) on the Truck and Bus Omnibus Test Track, R.[1]

STATE OF THE ART

The research is focused on electric peak power $P_{el,max}$ of the TEG (Tab. 1). The consideration of the net power $P_{el,net}$, transient behavior or long term stability of the technology is rare. In addition the essential TCO-evaluation represents a research gap.

Year	TEG System (by company / project name)	max. el. Power	dyn. el. Power	Power	TEG Fuel Saving	System Costs
–	–	$P_{el,max}$	$P_{el,dyn}$	ρ_{TEG}	Δb_{TEG}	$C_{net,TEG}$
(–)	(–)	(W)	(W)	(W/kg, W/l)	(%)	(€/W)
1991–1994, 2000–2004	Hi-Z Technology, Inc.	1000	600	73,5 , 97,1 (TEG core)	n.i.	n.i.
2008, 2013	Magna Powertrain Eng.	2700	179, 862, 1200	n.i.	n.i.	n.i.
2008–2011	RENOTER	1200	n.i.	120, 171,4 (TEG core)	n.i.	n.i.
2012–2015	MAN (M. Bernath)	1200	578	n.i., n.i.	0,3 (~ 0,7)	n.i.
2013–2015	Scania, Eberspächer et al.	411	533, 255 (net)	1,125, n.i.	n.i.	130
2014–2017	GASTone	820	506	n.i., n.i.	n.i.	n.i.

Tab. 1: State of the Art of Thermoelectric Generators for Heavy-Duty Vehicles (GVWR > 12 t), [m. R].

METHOD

The TEG development approach is based on real driving data from conventional diesel and alternative gas-powered long-haul trucks. A TCO model to evaluate the component costs and a holistic system consideration is included (Fig. 2). The focus on the TCO means to concentrate on applicationrelated development. Increasing the efficiency of the TEG in the application by a limited coolant side represent the development goal.

The TCO of a Diesel Truck (DT) is still lower than of a Natural Gas Truck (GT) (Fig. 2b). In case of high yearly mileage a GT can become competitive. In a typical cost structure of a long-haul truck the fuel costs represent min. 25 % of the TCO. A GT is however a promising technology because even with a lower vehicle efficiency (Fig. 2d) the emissions are lower than of a DT. The TEGs major impact is to reduce the fuel consumption which present the easiest variable that can still be optimized in terms of operating costs of a truck. From it, the vehicle data and the transportation task the TEG Target Costs (TC) and the Break-Even-Point can be calculated. For a WHRS a typical requirement is the amortization time T_a, which should be reached within two years. The TEG Cost Estimate (CE), which represent the TEG component costs, should fulfill this requirement.

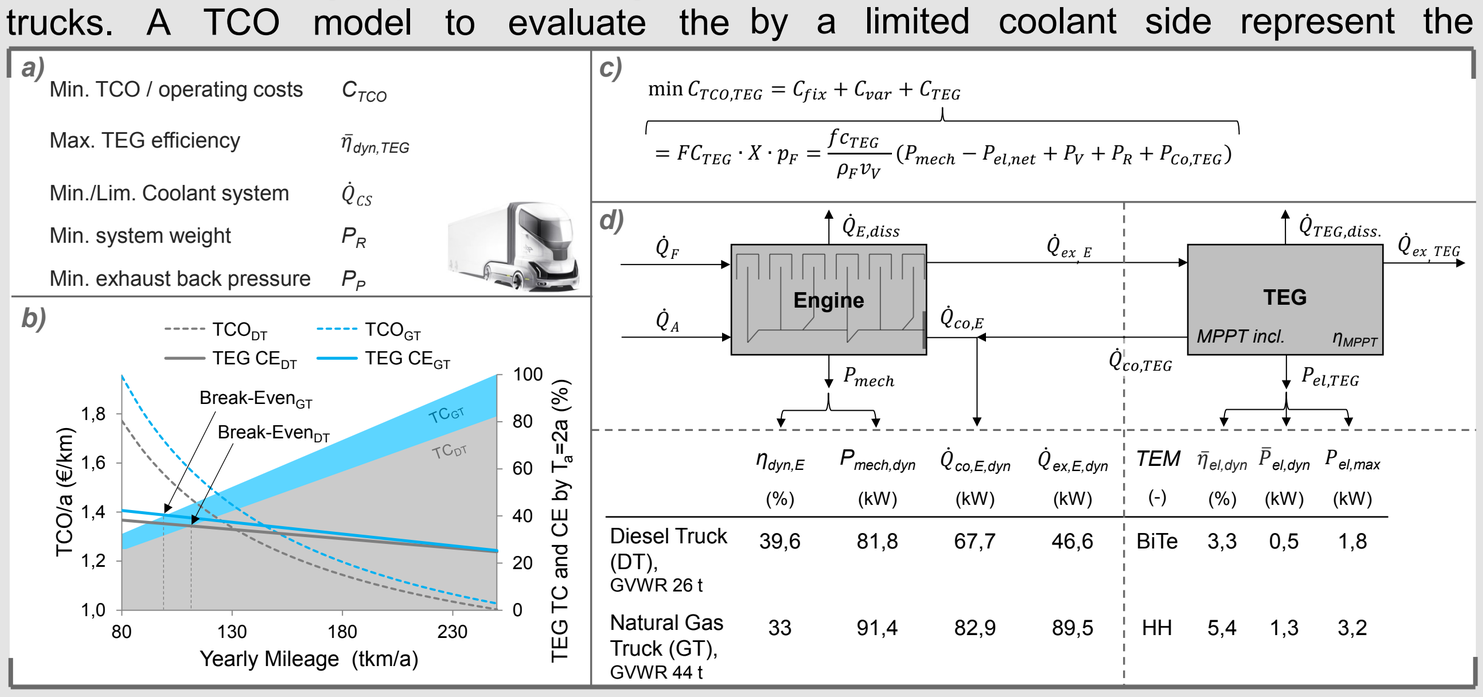

Fig. 2: Systemic approach and development of the TEG, a) Optimization objectives, b) TCO of a long-haul diesel (DT) and a Natural Gas (GT) Truck, the TEG TC and CE, c) Problem formulation, d) Energy balances of the engine (GT data base analyzed from [2]), the TEG, exemplary model inputs and essential TEG results.

SIMULATION

The TEG results based on a dynamic analytical (Fig. 3) and a more precise steady state numerical CFD simulation model (Fig. 4). The interactions of the TEG with the vehicle, e.g. electric power, weight, back pressure, costs are included. Exceptions are the capacities of the coolant and the electric onboard system, which present tasks of future work.

As results the TEG electric energy raise the efficiency of the DT and the GT as well as the coolant impact. The TEG largest negative impact is the weight of the component, P_R. The additional power for the coolant pump $P_{Co,TEG}$ represents very low values. The dynamic results constitute the fuel saving.

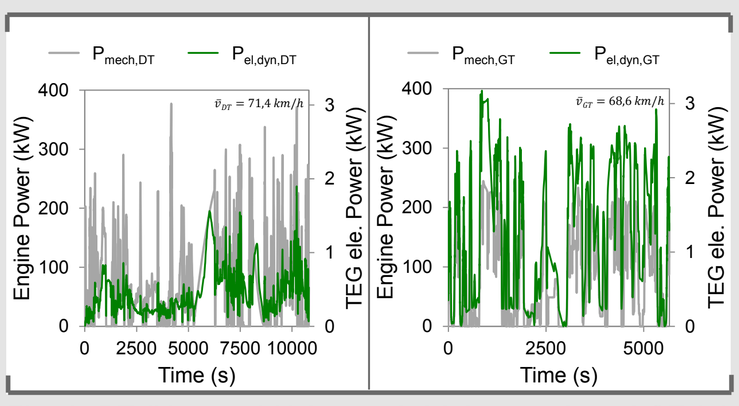

Fig. 3: DT (l.) on a 210 km real driving track and GT (r.) on the ACEA Long Haul Cycle (GT data base analyzed from [2]), presenting the engine power P_{mech} and the simulated ele. power of the TEG $P_{el,dyn}$.

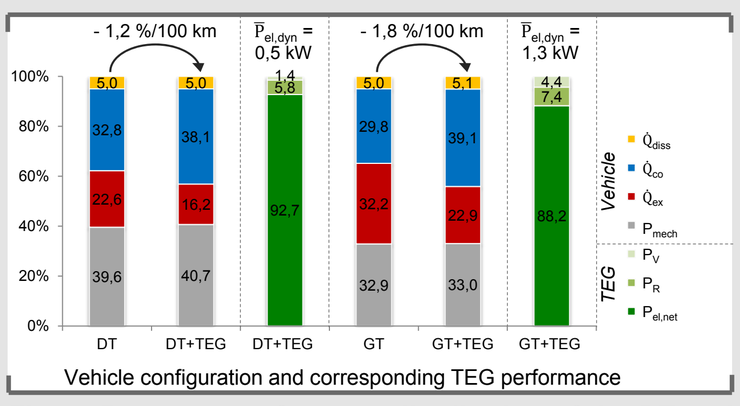

Fig. 4: Percentage of energy distribution of the DT and the GT on the respective test tracks, the vehicle with TEG and its mean dynamic electrical power $\bar{P}_{el,dyn}$ (GT data base analyzed from [2]).

CONCLUSION

TEGs for long-haul trucks can comply the requirements. 1,2 % for the DT and 1,8 % fuel saving for the GT in the targeted amortization time of 2 years could be obtained.

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[2] Hervas-blasco, E., et al. (2017): Potential fuel saving in a powertrain derived from the recovery of the main energy losses for a long haul European mission. In: Energy Convers-ion and Management, Vol. 150, S. 485–499.

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