Dynamic Thermoelectric Generator (TEG) model

Documentation and instructions

Version Information

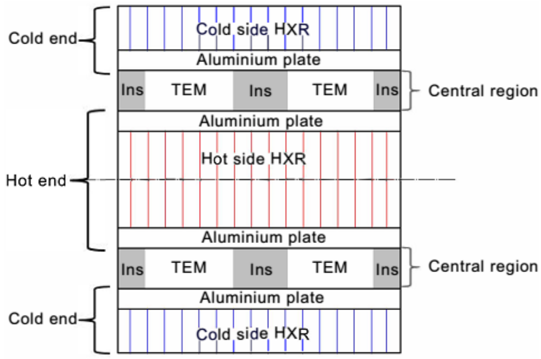
Date	Version	Author	Comment
17-07-2017	0.1	Song Lan (s.lan@lboro.ac.uk)	First draft of instructions

Content

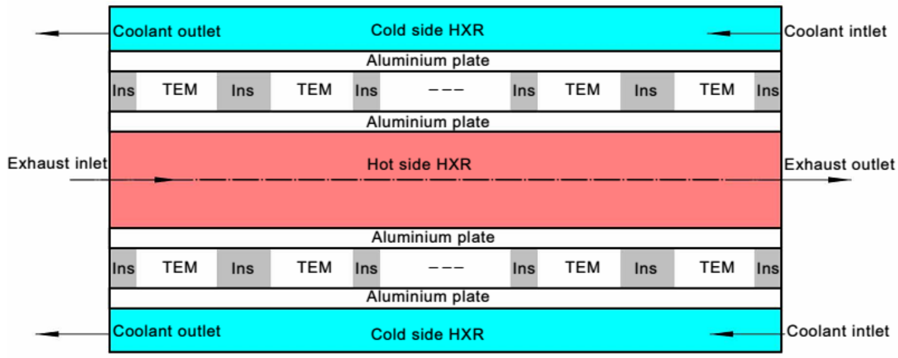
1. Introduction

This model of a thermoelectric generator (TEG) has been developed, validated and tested during an EPSRC funded project, reference, EP/K026658/1, Identifying Cost Effective Routes To Optimised Energy Recovery For The Fuel Economy Of Vehicles.
The intention behind the model has been to predict generator output under the kind of varying (transient) conditions that occur during the driving of a passenger car under normal driving conditions typified by WLTP and real world driving cycles.

This particular version of the model has been designed with the aim of modelling the dynamic performance of a module-based TEG systems with counter-flow heat exchangers (Figure 1). The characteristic of temperature-dependence of thermoelectric modules (TEMs), flow temperature variation along the counter-flow heat exchanger and the dynamics of the system can all be captured by the model.



(a) Front view of a TEG system.



(b) Side view of a TEG system.

Figure 1 a module-based TEG systems with counter-flow heat exchangers

2. Overview of **TEG model**

The TEG model is made up three sub-models, which are two TEM models (**A_TEM_Simple** and **TEMs_CV**) and a heat exchanger model (**HXR_CV**). The sub-models in the library are shown in Figure 2. The **A_TEM_Simple** and **TEMs_CV** models are quasi-stationary models. They are both not suitable for the capture of dynamic phenomena. The **HXR_CV** model is a dynamic model, which takes the thermal inertia of the heat exchanger into account.

The model of **A_TEM_Simple** is only used to model an individual TEM. A complete TEG model is built up by using both the **TEMs_CV** models and **HXR_CV** models. The basic principles of connecting these two sub-models is based on a control volume (CV) approach [1]. A complete TEG system is divided into a couple of CVs and each CV is made up by both a **TEMs_CV** model and a **HXR_CV** model (Figure 5 and Figure 7).

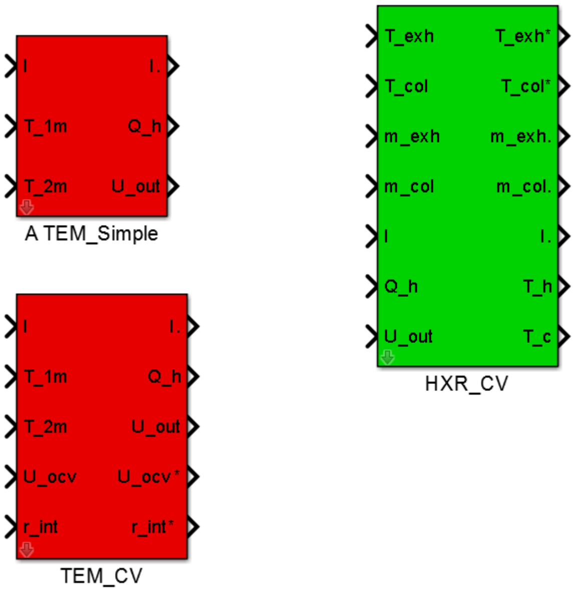


Figure 2. Top view of TEG model in the library

3. The sub-models

3.1 A_TEM_Simple model

Model function

The **A_TEM_Simple** model is built by using both thermoelectric materials properties and geometrical parameters. Two different materials properties (Seebeck coefficient, thermal conductivity and electrical resistance) changing with temperatures are already saved in the folder "\Data\ETL_Bi2Te3 (Reading_Sku)". Therefore, the user may choose to work with the desired thermoelectric materials. The geometrical parameters of the TEM are needed to be input by the user (Figure 3). The **A_TEM_Simple** model is based on solving a thermal and an electrical network simultaneously [2]. The **A_TEM_Simple** model can be tuned by using TEM test results.

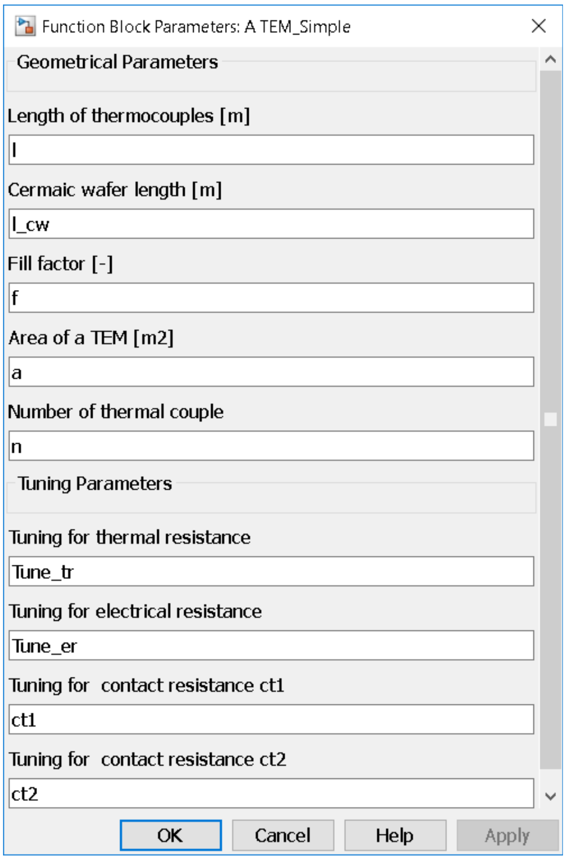


Figure 3 The user interface (mask) of the **A_TEM_Simple** model

Model parameters

The input and output parameters of the **A_TEM_Simple** model are presented as follows:

Inputs:

I	current	A
T_1m	hot side temperature of the TEM	K
T_2m	cold side temperature of the TEM	K

Outputs:

I	current	A
Q_h	energy rate goes into a CV	W
U_out	output voltage	V

As can be seen that the **A_TEM_Simple** model uses current as the input instead of load resistance. Thus, the model can run a relatively faster simulation due to the avoid of iteration for the calculation of current.

Due to the fabrication and connection method, the tested properties of a TEM in the application can be different from a direct calculation from the materials and geometrical parameters. Thus, a few tuning constants are used to tune the **A_TEM_Simple** model and are presented as follows:

Tuning constants:

$Tune_{tr}$	Thermal resistance of the thermocouples R_{tc}	$R_{tc}^{¿} = Tune_{tr} * R_{tc}$
$Tune_{er}$	Electrical resistance $\int ¿$ $r_{¿}$	$\int ¿$ $\int ¿^{¿} = Tune_{er} * r_{¿}$ $r_{¿}$
$ct\,1$	Thermal contact conductance $K_{ct}^{¿}$	$K_{ct}^{¿} = ct\,1 * T + ct\,2$
$ct\,2$	Thermal contact conductance $K_{ct}^{¿}$	$K_{ct}^{¿} = ct\,1 * T + ct\,2$

The thermal contact conductance $K_{ct}^{¿}$ is expressed as a linear function of temperature. Both thermal resistance of the thermocouples and electrical resistance are tuned by multiplying tuning factors.

3.2 TEMs_CV model

Model function

A few changes have been made for the **TEMs_CV** model based on the **A_TEM_Simple** model. The two main changes are summarized as follows:

- By assuming that all M TEMs connected in series in a CV having the same performance, all the TEMs in a CV are modelled.
- Instead of only using current as input, an electrical resistance input (r_int) is added and a system-level iteration process is needed.

The number of the TEMs in a CV and the geometrical parameters of the TEM need to be input by the user in the user interface of the **TEMs_CV** model.

Model parameters

The input and output parameters of the **TEMs_CV** model are presented as follows:

Inputs:

I	current	A
T_1m	hot side temperature of the TEMs	K
T_2m	cold side temperature of the TEMs	K
U_ocv	overall open circuit voltage of the previous CVs	V
r_int	overall electrical resistance of the previous CVs	Ω

Outputs:

I	current	A
Q_h	energy rate goes into a TEM	W
U_out	output voltage of the CV	V
U_ocv*	overall open circuit voltage of all the CVs	V
r_int*	overall electrical resistance of all the CVs	Ω

The tuning parameters for the **TEMs_CV** model is the same as the **A_TEM_Simple** model.

3.3 HXR_CV model

Model function

HXR_CV model is based on counter-flow heat exchangers. Based on the energy conservation in a CV, the temperatures for the gas-out (T_exh*), coolant-out (T_col*), hot end (T_ht) and cold end (T_ct) of a CV are all calculated in this sub-model. Solving all these temperature, **HXR_CV** model needs to be connected to a **TEMs_CV** model, which gives the energy transfer rate in the TEMs of a CV. Since the hot end and cold end of the TEG are closely attached to TEMs in a CV, the hot and cold end temperature (T_ht and T_ct) are respectively equal to the hot and cold side temperatures of the TEMs (T_1m and T_2m). Thus, the outputs of **HXR_CV** model (T_ht and T_ct) are connected to the inputs (T_1m and T_2m) in the **TEMs_CV** model. The connection for **TEMs_CV** model and **HXR_CV** model are presented in Figure 5.

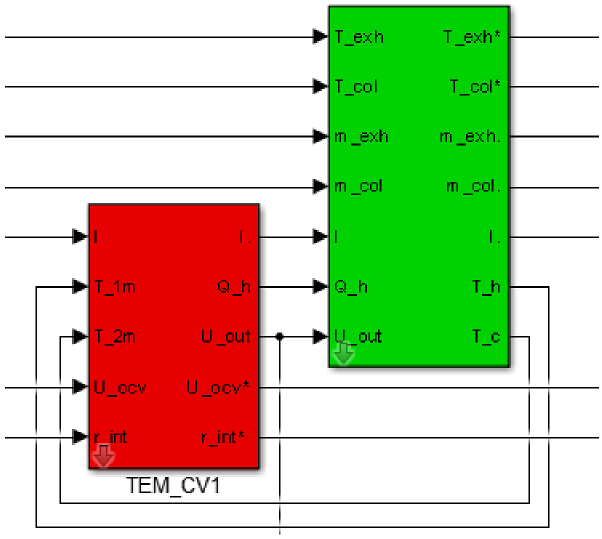


Figure 5. a **TEMs_CV** and **a HXR_CV** model made up of a CV

Model parameters

The input and output parameters of the **HXR_CV** model are presented as follows:

Inputs:

T_exh	exhaust gas-in temperature	K
T_col	coolant-in temperature	K
m_exh	exhaust gas-in temperature	kg/s
m_col	coolant-in temperature	kg/s
I	current	A
Q_h	energy rate goes into all the TEMs in a CV	W
U_out	output voltage of the CV	V

Outputs:

T_exh*	exhaust gas-in temperature	K
T_col*	coolant-in temperature	K
m_exh	exhaust gas-in temperature	kg/s
m_col	coolant-in temperature	kg/s
I	current	A

T_h	hot end temperature of a CV	K
T_c	cold end temperature of a CV	K

The tuning parameters for the **HXR_CV** model are the heat transfer coefficients for both hot and cold side heat exchangers (h_{hxr} and h_{hxr}). The heat transfer coefficients can be expressed as Nusselt-Reynolds-Prandtl relations. The tuning parameters are presented as follows:

Tuning parameters

ca	Heat transfer coefficient of hot side heat exchanger	$h_{hxr}=\frac{Nu}{D_h}k_{exh}=\frac{ca1\Re^{ca2}Pr^{ca3}}{D_h}k_{exh}$
ca		
ca		
cb	Heat transfer coefficient of cold side heat exchanger	$h_{cxr}=\frac{Nu}{D_c}k_{col}=\frac{cb1\Re^{cb2}Pr^{cb3}}{D_c}k_{col}$
cb		
cb		

4. Examples

4.1 Tuning a TEM model

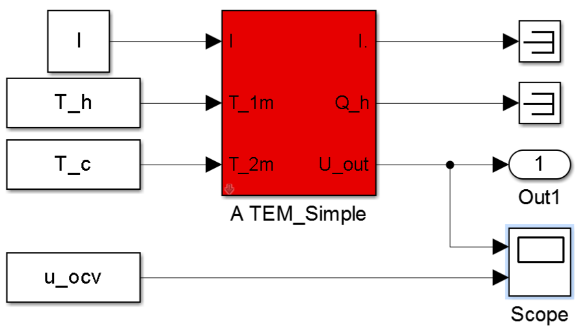


Figure 6 Top view of the tuning TEM model.

4.2 a Three CVs TEG model

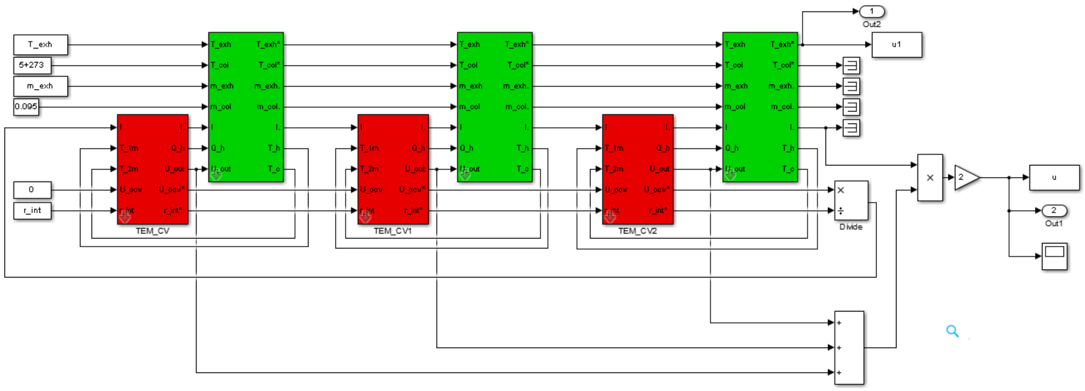


Figure 7 Top view of the three CVs TEG model

5. Reference

[1] S. Kumar, S. D. Heister, X. Xu, J. R. Salvador, G. P. Meisner, Thermo electric generators for automotive waste heat recovery systems part ii: parametric evaluation and top ological studies, Journal of electronic materials 42 (6) (2013) 944.

[2] Lan, Song, et al. The Influence of Thermoelectric Materials and Operation Conditions on the Performance of Thermoelectric Generators for Automotive. No. 2016-01-0219. SAE Technical Paper, 2016.