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Biography of the presenter

Xin Gao was born in Shandong Province, China. He got his Bachelor degree in Thermal Energy and Power Engineering, Nanjing University of Science and Technology, Nanjing, China, in 2000. He received the Master degree in Power Machinery and Engineering from School of Automotive Studies, Tongji University, Shanghai, China, in 2009. Currently, he is working as a PhD student in the Institute of Energy Technology, Aalborg University, Aalborg, Denmark. His research interests include fuel cells, thermoelectric devices, power generation system design and optimization, and fluid dynamics.

Biography of the corresponding author

Min Chen was born in Beijing, China. He received the Ph.D. degree in energy engineering from the Institute of Energy Technology, Aalborg University, Aalborg, Denmark, in 2009, where he is currently working as a postdoc. His research interests include modeling, monitoring, and control of thermoelectric devices for power/energy systems, thermoelectric energy harvesting, development and design of application-based prototypes, as well as testing and measurement techniques. He is a member of IEEE and IAS.

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Realistic optimal design of thermoelectric battery bank under partial lukewarming

IEEE Industry Applications Society 2012 Industrial & Commercial Power Systems Technical Conference, Louisville, KY

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May 22nd. 2012

Outline

- Introduction of Thermoelectric Generators (TEGs) and application background
- Unique Characteristics of TEG
- TEG System Hierarchical Modeling in SPICE & Prototype Experiments
- Applications of the Model in the Optimal Design of Large Energy Systems

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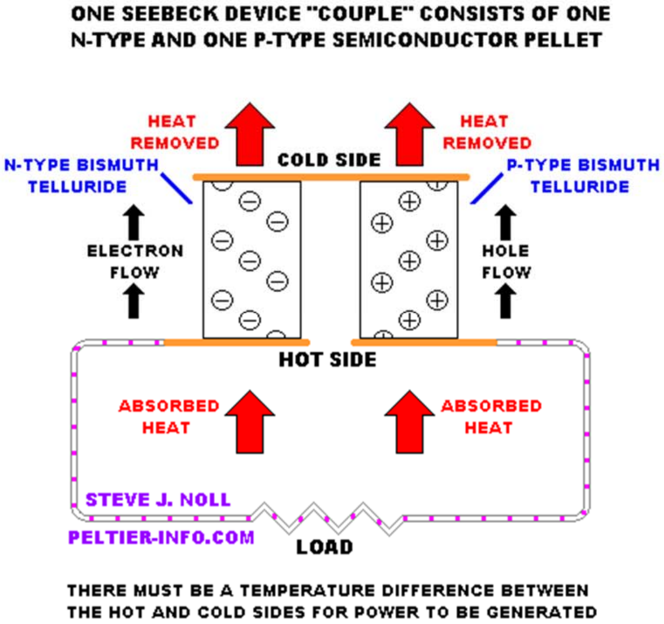
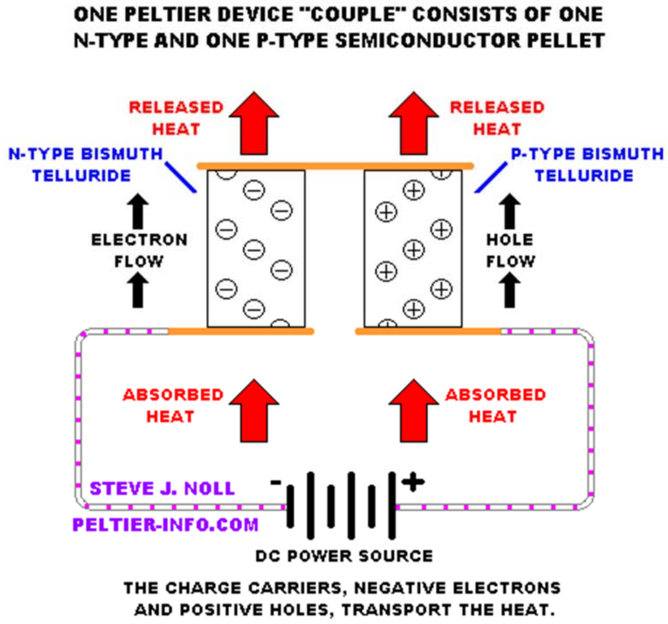
The first principle -- Seebeck and Peltier effects

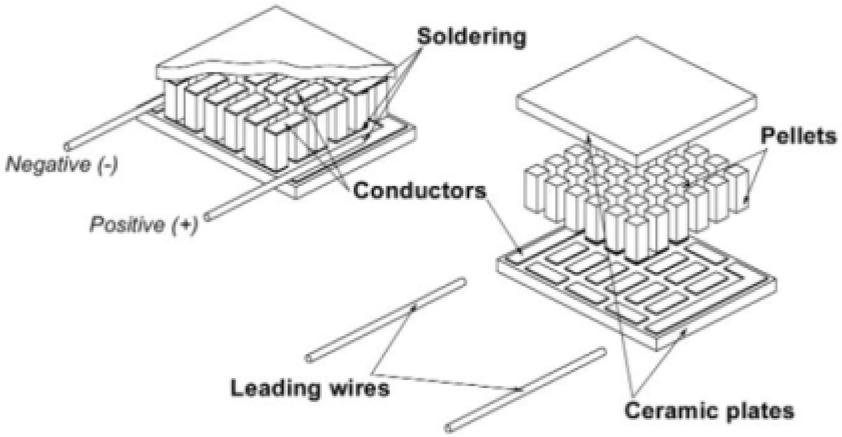


TEG, Seebeck effect



TEC, Peltier effect

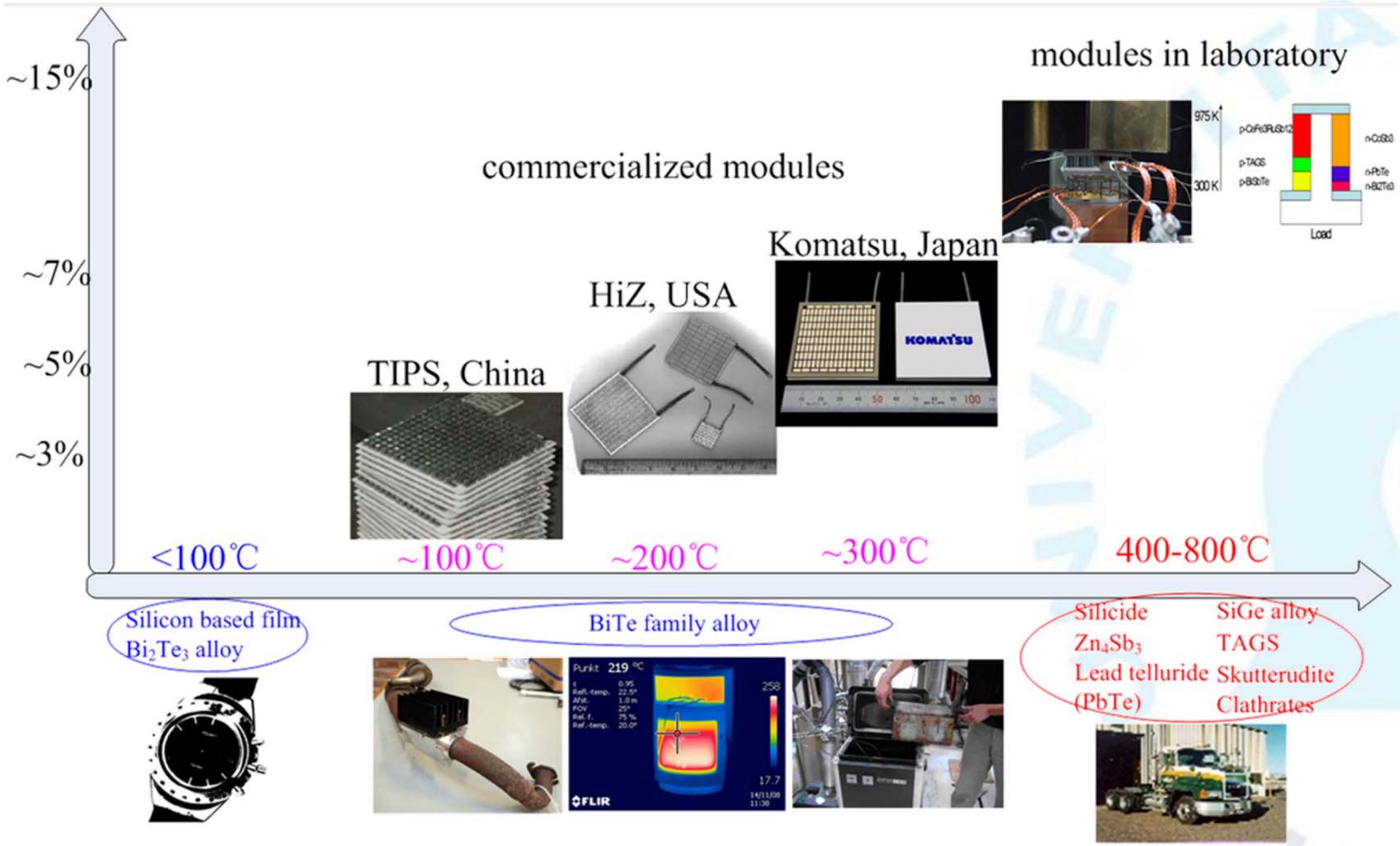
Current commercially available TE modules



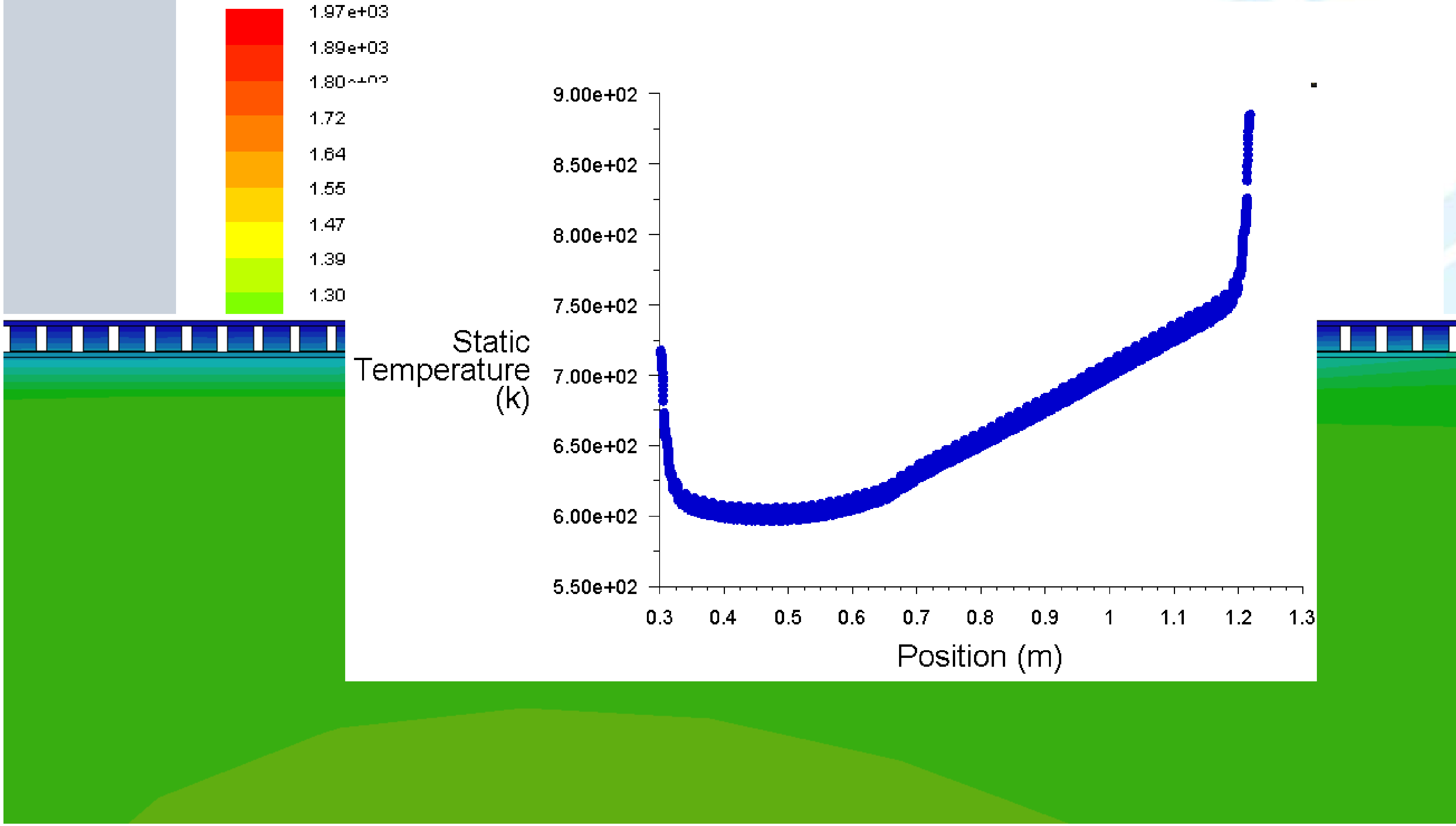
size: from 4*4*3 to 50*50*5 mm3
Lifetime: in the range of 100,000 to 200,000 hours

Advantages: no moving part, totally silent, no any gas/liquid used and can be applied under a wide range of temperatures.

Application contexts of TEG



TEG in Large Thermal Systems: An Example of Lukewarm Condition



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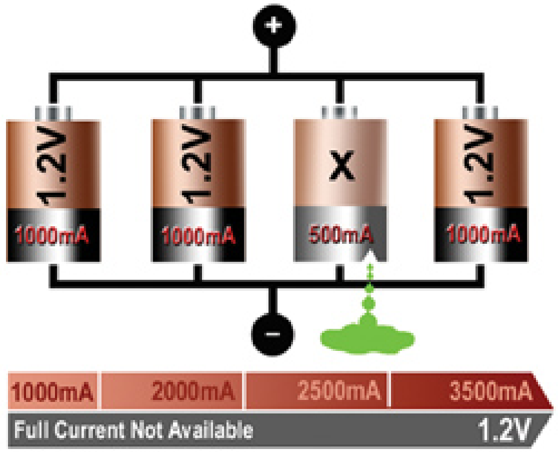
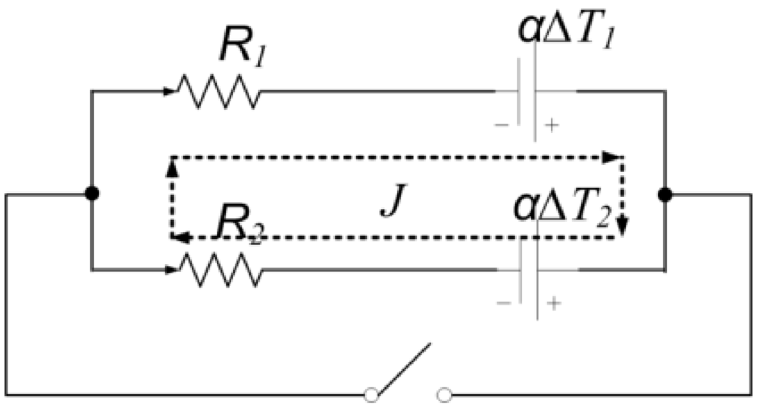
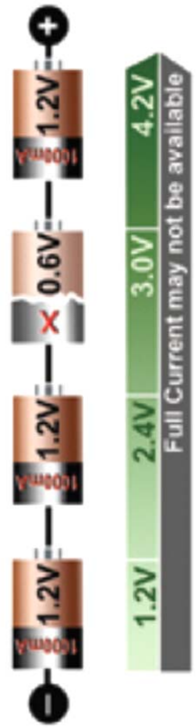
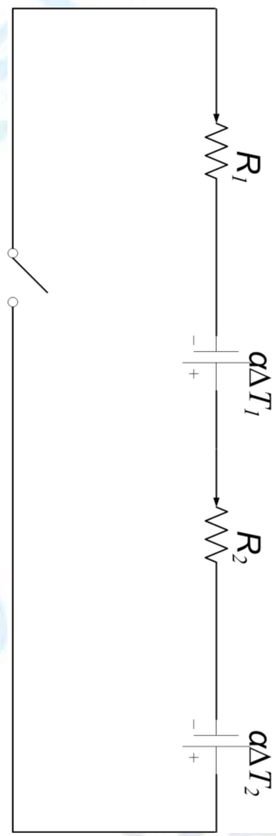
When $\Delta T_1 \neq \Delta T_2$

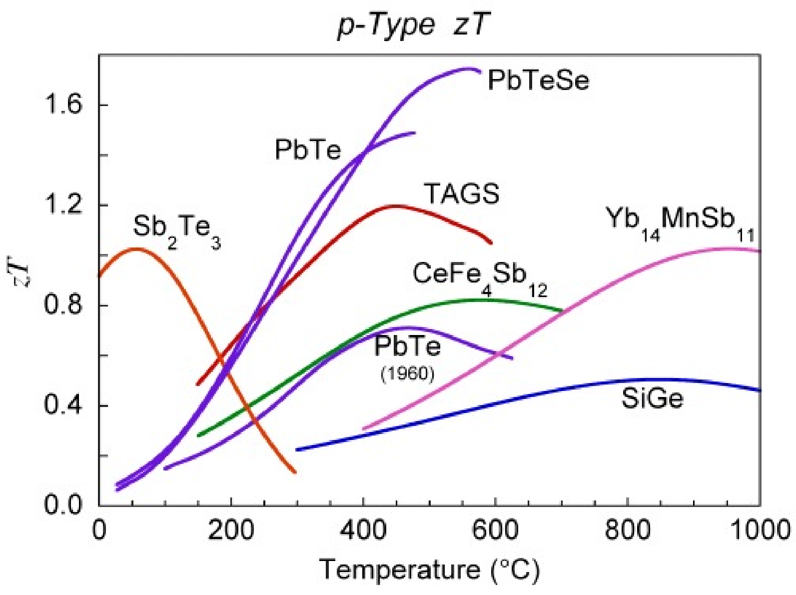


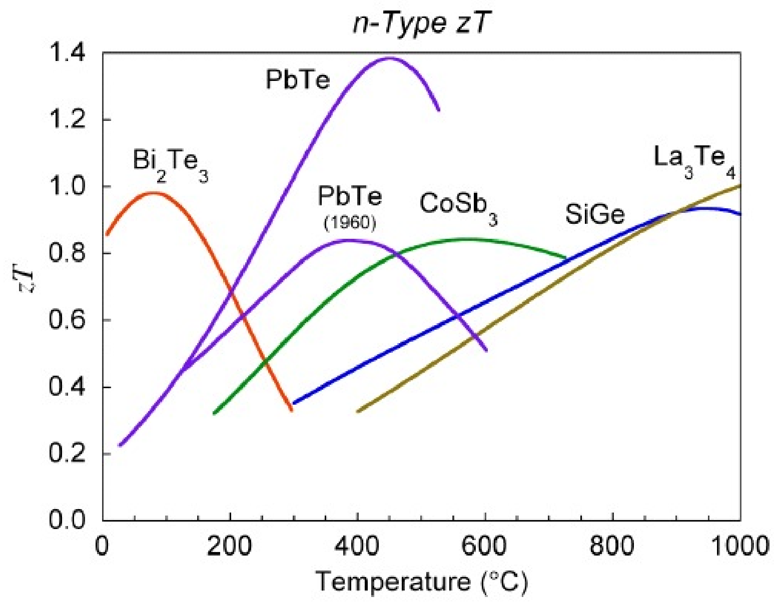






Temperature Dependent Characteristics of Practical TEGs

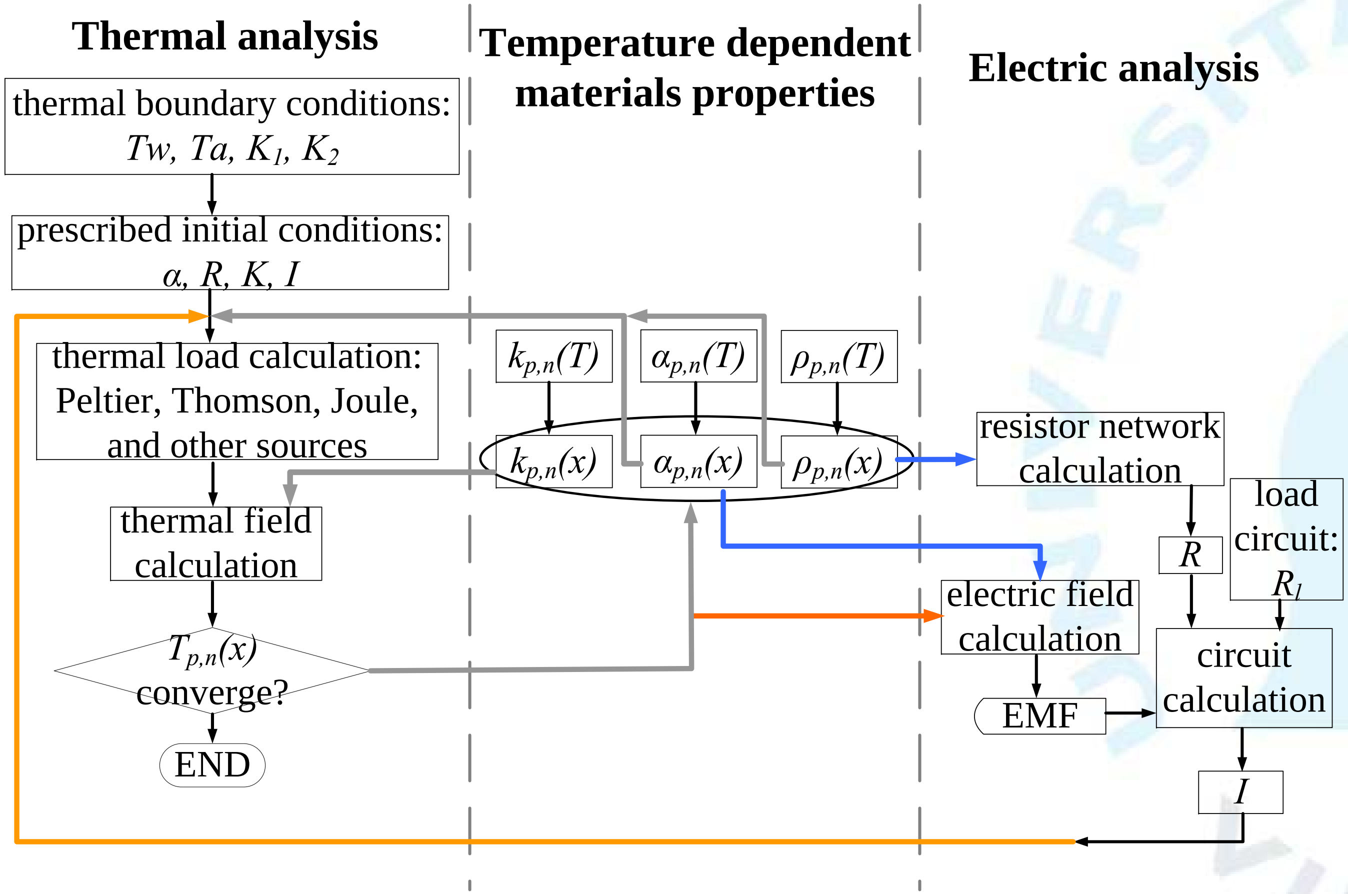




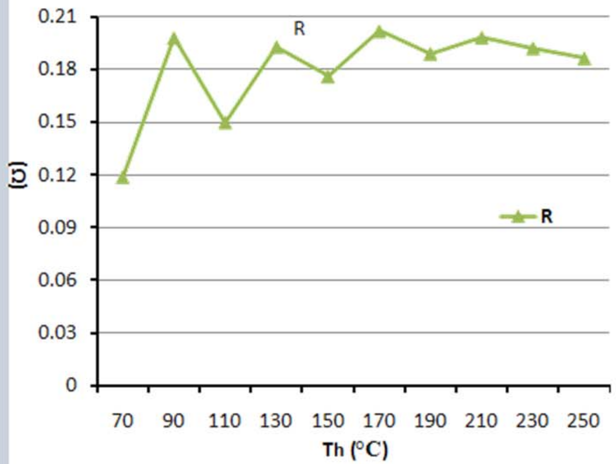
$$V = \int_{T_c}^{T_h} \alpha_{\mathrm{p}}(T_{\mathrm{p}}(x))dT_{\mathrm{p}}(x) - \int_{T_c}^{T_h} \alpha_{\mathrm{n}}(T_{\mathrm{n}}(x))dT_{\mathrm{n}}(x)$$

$$R = \int_0^L \frac{\rho_{\mathrm{p}}(T_{\mathrm{p}}(x))}{S_{\mathrm{p}}}dx + \int_0^L \frac{\rho_{\mathrm{n}}(T_{\mathrm{n}}(x))}{S_{\mathrm{n}}}dx$$

Thermal/Electric Coupled Characteristics of Practical TEGs



Temperature Dependent Contact of Practical TEGs



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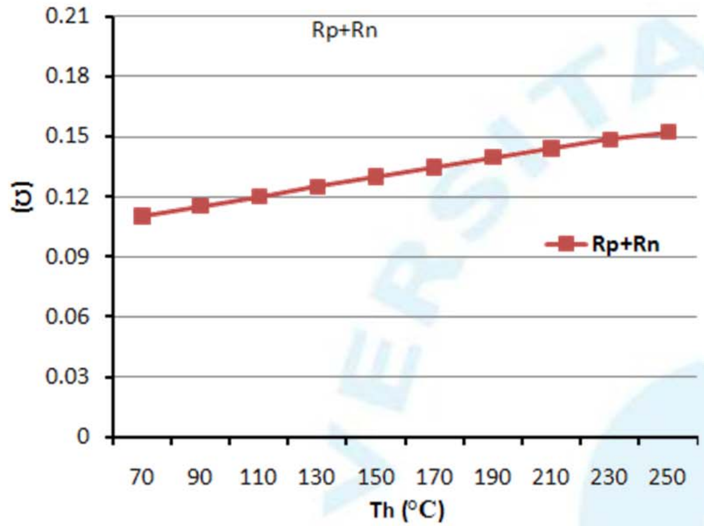

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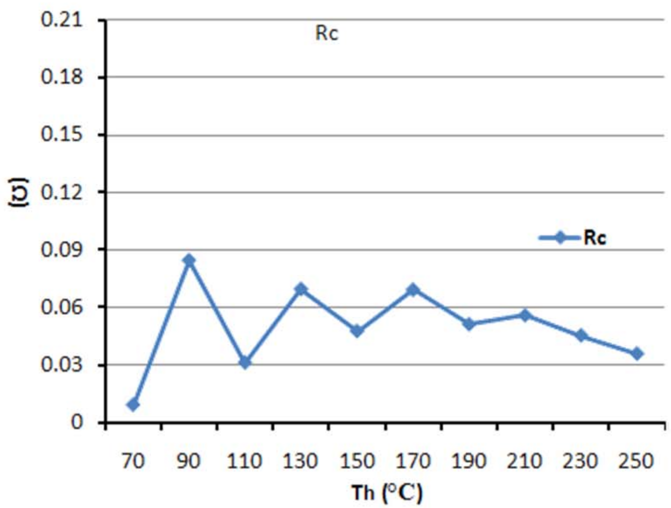

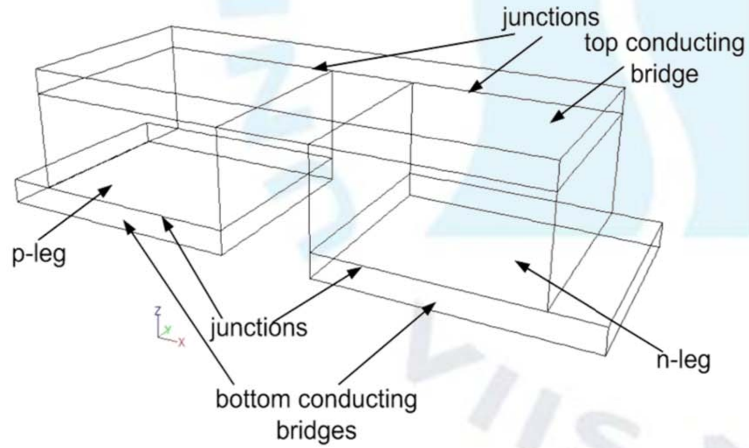

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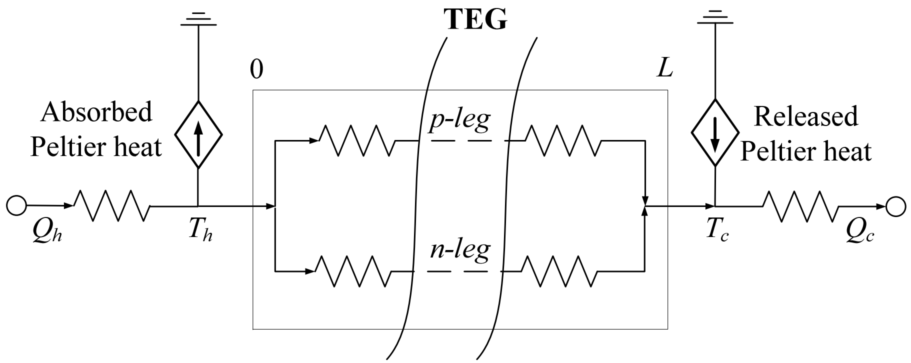
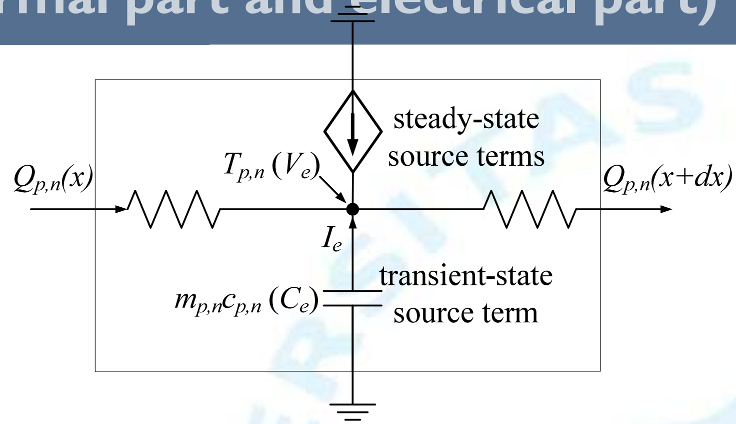
SPICE-based Equivalent Circuit Methodology to study the effects of partial lukewarming

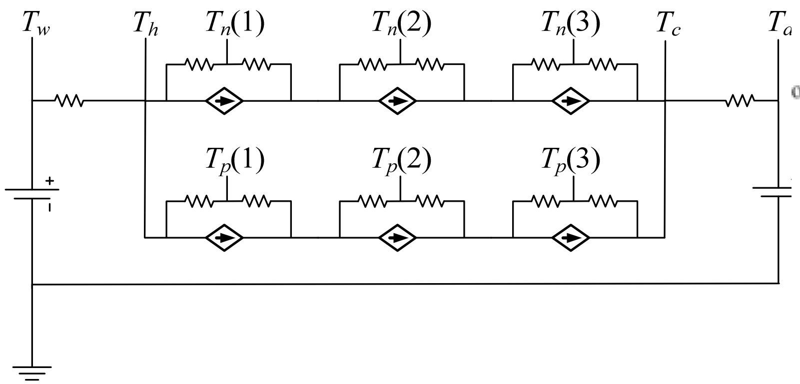
Heat flow (W)	Current flow (A)
Temperature (K)	Voltage (V)
Thermal conductivity (W/mK)	Electrical conductivity (Ω/m)
Thermal mass (J/K)	Electrical capacity (F)

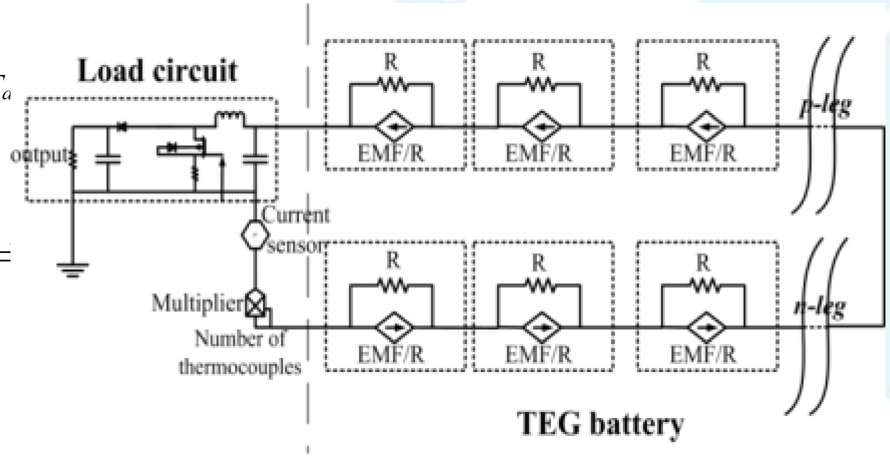
- Accurately predict the TE characteristics (including temperature dependent, coupled, and interfacial) and output power under partially lukewarming conditions.
- Design aid for users who want to build actual TEG systems, study the stability and interfacing aspects (e.g., MPPT applications) without going into the intricate details (e.g., semiconductor physics).
- A tool to study the effect of TEG array configuration on the output power for a likely/known temperature pattern.
- A planning tool that can help in the installation/modification of efficient and optimum TEG arrays in a given thermal surrounding.

Device-level SPICE model (Thermal part and electrical part)

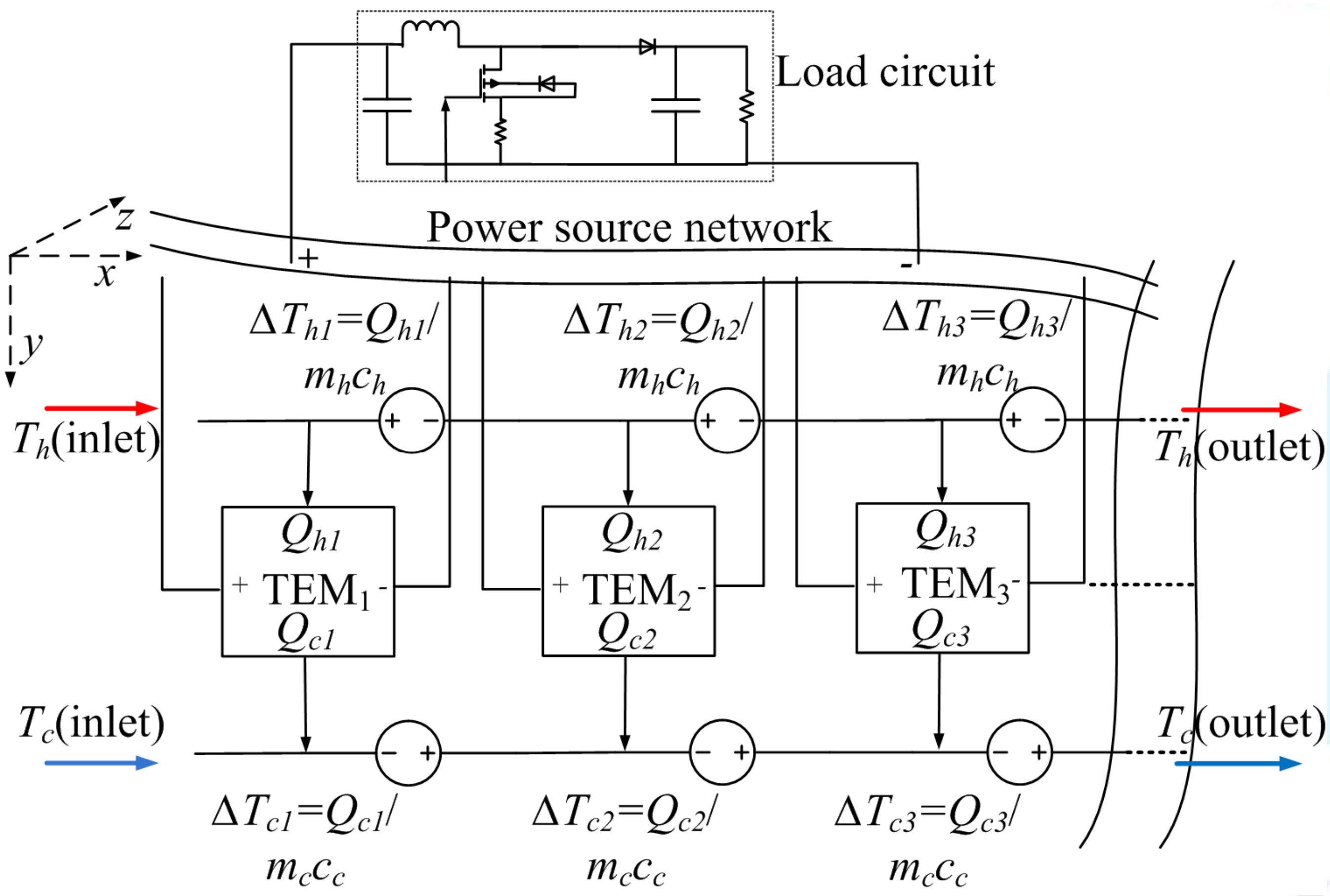




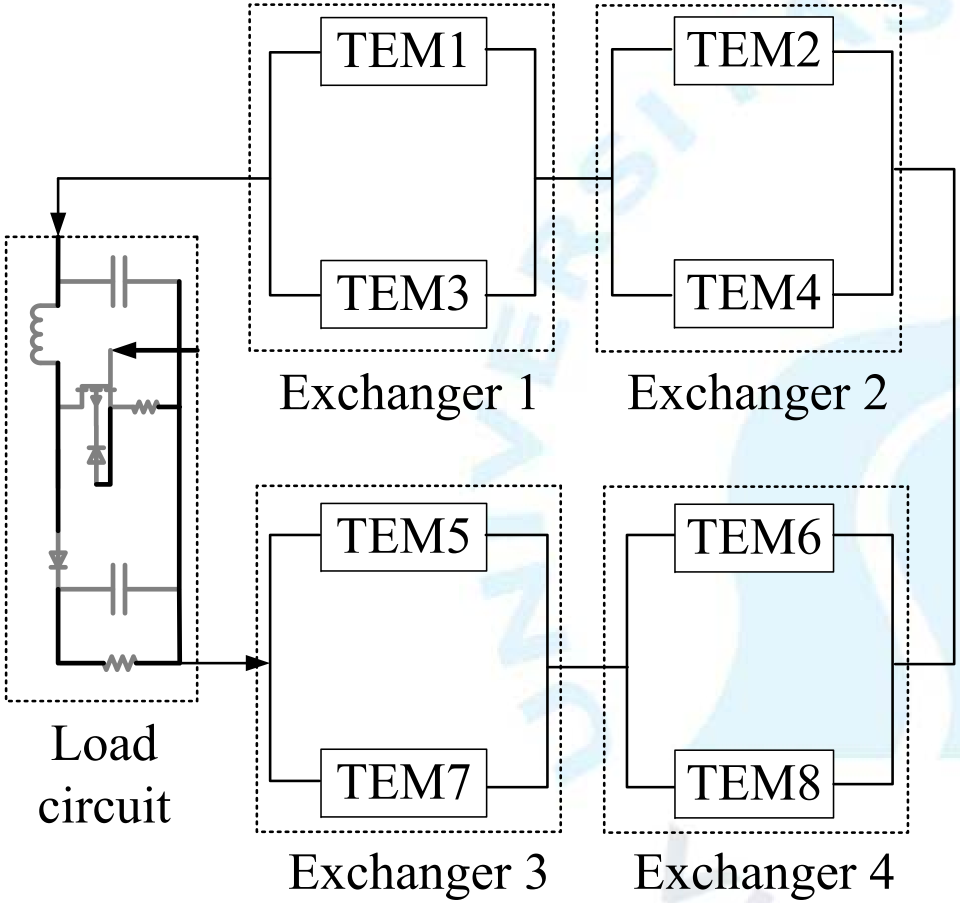




Quasi-1D Hierarchical Modeling: TEG module object oriented



System-level pilot test rig



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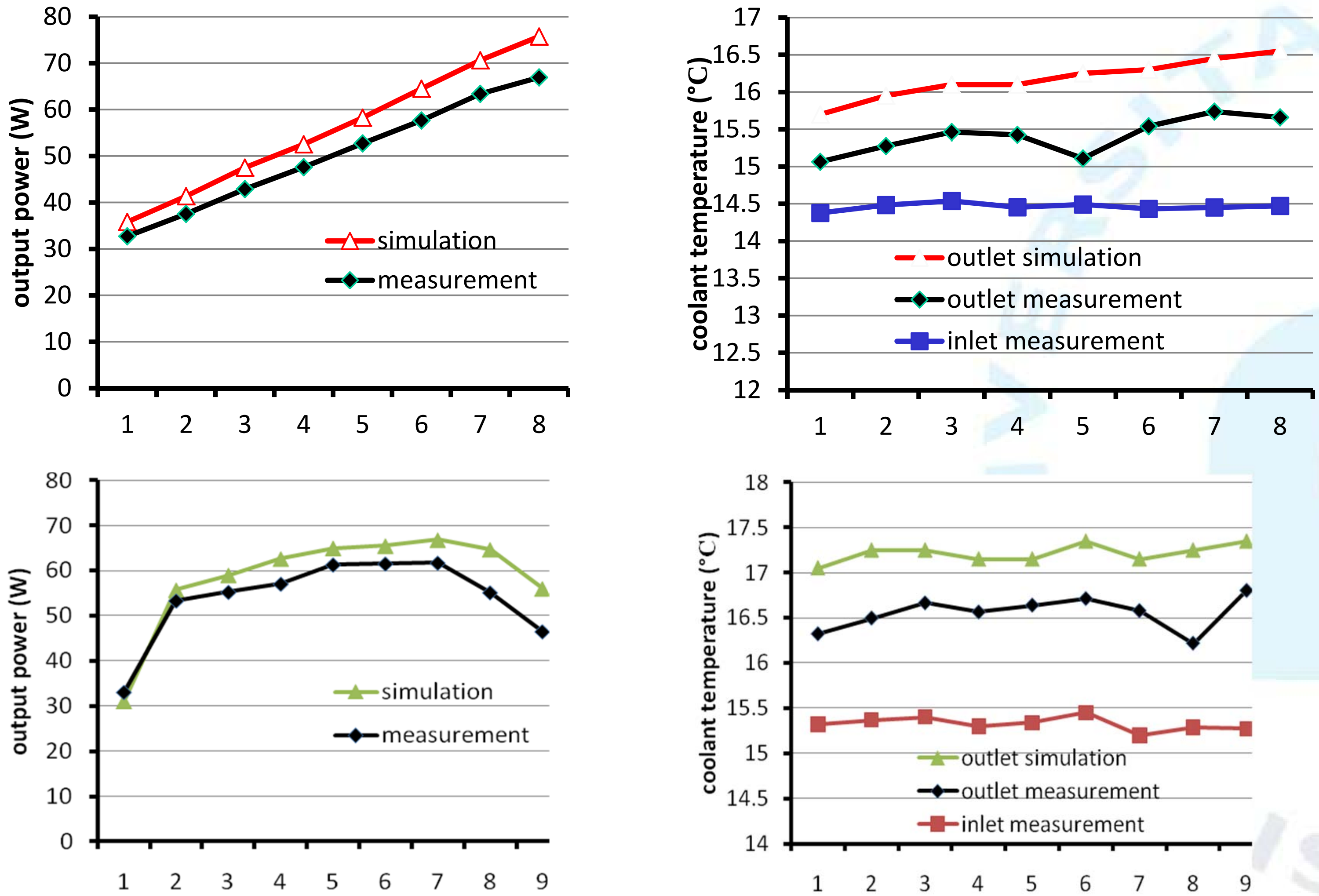
Simulation result

Comparison with experiment results from the test rig



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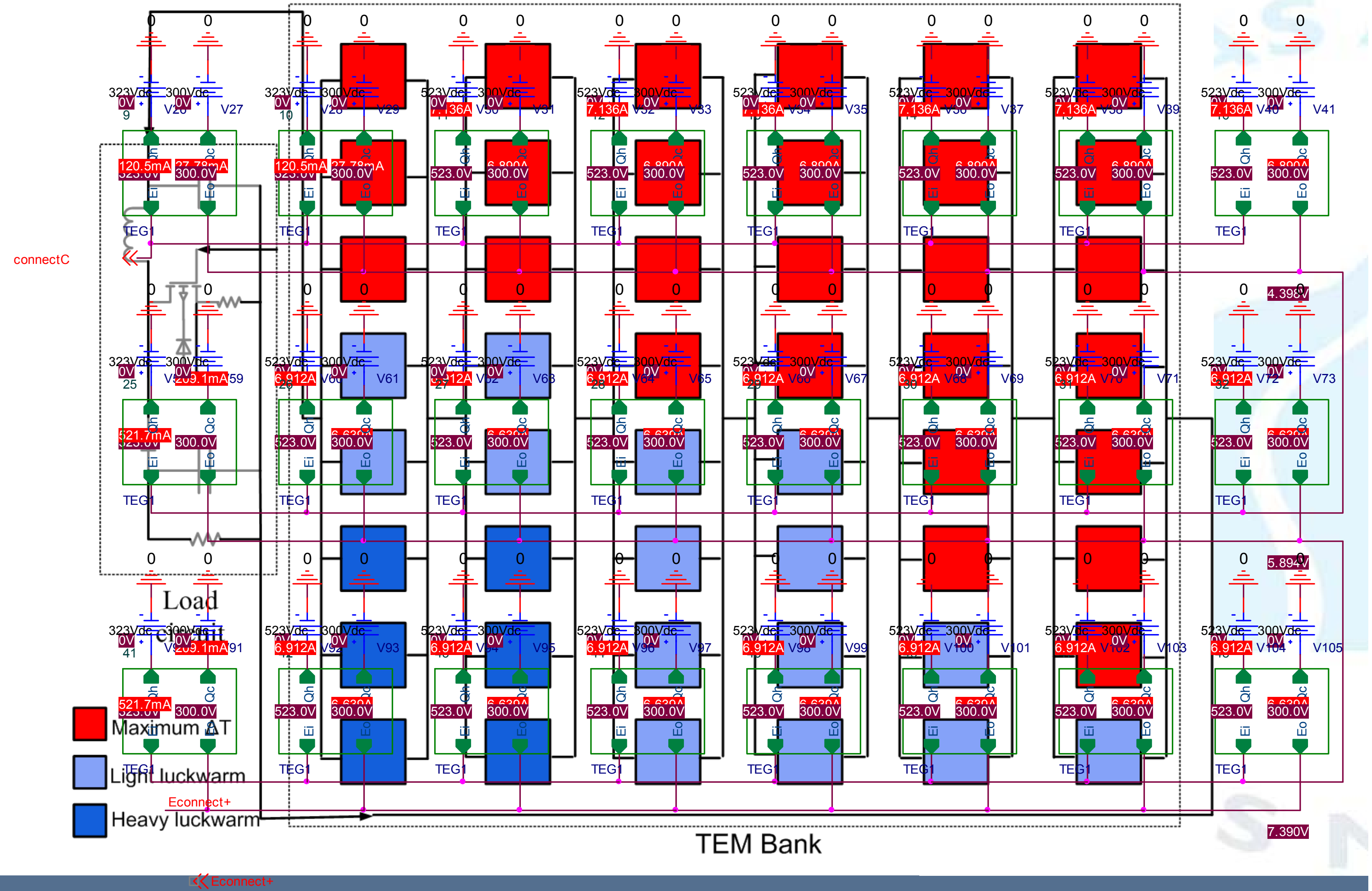
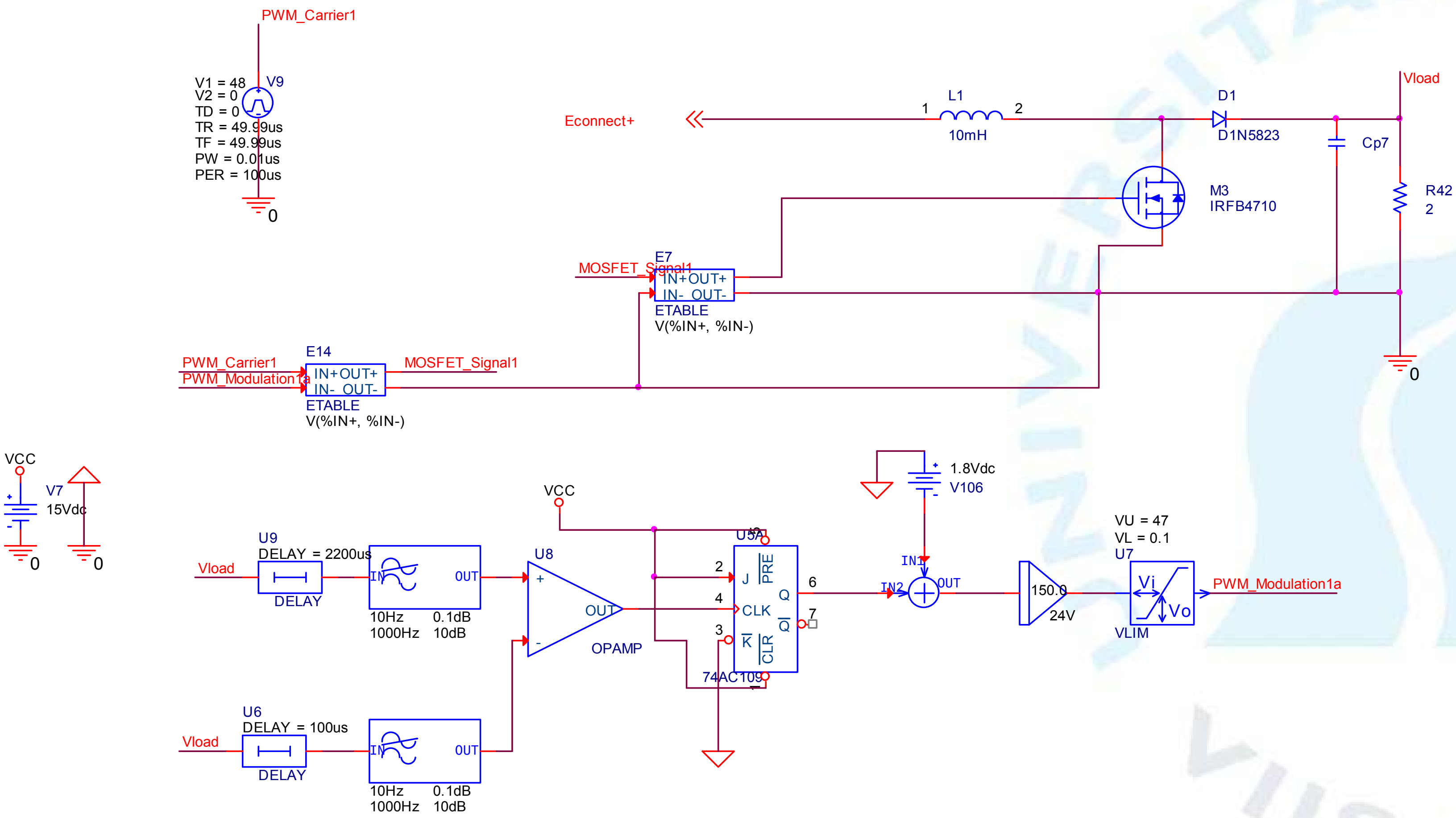
Practical Schematic in SPICE



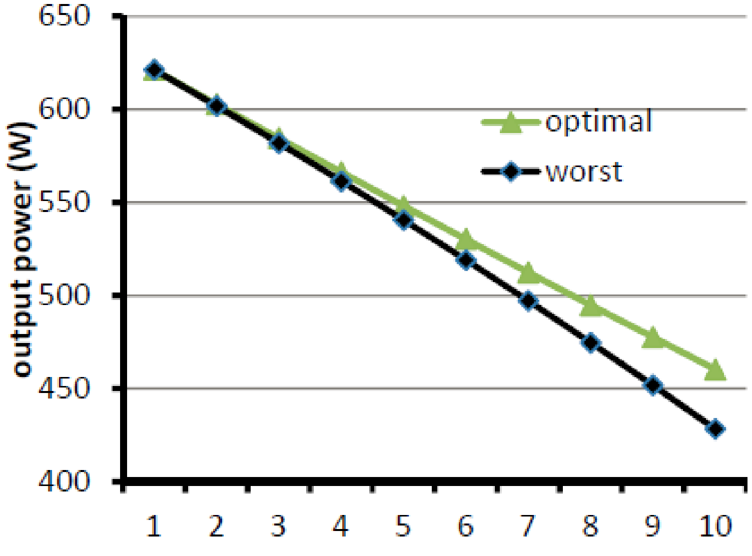
MPPT & Power Electronics Stage Integration and Co-simulation



{16×3} SFPS TEM Array

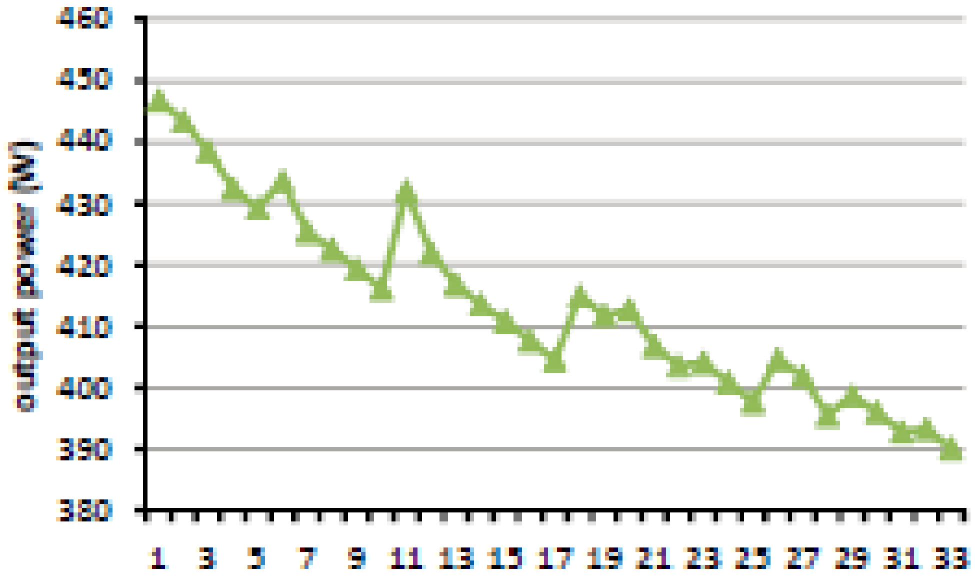
Lukewarm Distribution	P_{max} (W)
[6:0:0]	519.1
[5:1:0]	524
[4:2:0]	526.9
[4:1:1]	527.7
[3:3:0]	527.9
[3:2:1]	529.6
[2:2:2]	530.5

Lukewarm Number	Optimal Distribution	P_{max} (W)	Worst Distribution	P_{max} (W)
1	[1:0:0]	621.4	[1:0:0]	621.4
2	[1:1:0]	602.8	[2:0:0]	601.9
3	[1:1:1]	584.7	[3:0:0]	581.9
4	[2:1:1]	566.2	[4:0:0]	561.5
5	[2:2:1]	548.1	[5:0:0]	540.6
6	[2:2:2]	530.5	[6:0:0]	519.1
7	[3:2:2]	512.4	[7:0:0]	497.2
8	[3:3:2]	494.8	[8:0:0]	474.6
9	[3:3:3]	477.7	[9:0:0]	451.8
10	[4:3:3]	460.3	[10:0:0]	428.3



{8×6} PFSS TEM Array

no.	Lukewarm Distribution	P_{max} (W)
1	[8:2:0:0:0:0]	446.9
2	[8:1:1:0:0:0]	443.5
3	[7:3:0:0:0:0]	438.5
4	[7:2:1:0:0:0]	432.5
5	[7:1:1:1:0:0]	429.2
6	[6:4:0:0:0:0]	433.7
7	[6:3:1:0:0:0]	425.4
8	[6:2:2:0:0:0]	422.6
9	[6:2:1:1:0:0]	419.4
10	[6:1:1:1:1:0]	416.1
11	[5:5:0:0:0:0]	432.1
12	[5:4:1:0:0:0]	421.9
13	[5:3:2:0:0:0]	416.9
14	[5:3:1:1:0:0]	413.6
15	[5:2:2:1:0:0]	410.9
16	[5:2:1:1:1:0]	407.7
17	[5:1:1:1:1:1]	404.5
18	[4:4:2:0:0:0]	415
19	[4:4:1:1:0:0]	411.8
20	[4:3:3:0:0:0]	412.8
21	[4:3:2:1:0:0]	406.8
22	[4:3:1:1:1:0]	403.6
23	[4:2:2:2:0:0]	404.1
24	[4:2:2:1:1:0]	400.9
25	[4:2:1:1:1:1]	397.7
26	[3:3:3:1:0:0]	404.6
27	[3:3:2:2:0:0]	401.9
28	[3:3:1:1:1:1]	395.5
29	[3:2:3:1:1:0]	398.7
30	[3:2:2:2:1:0]	396
31	[3:2:2:1:1:1]	392.8
32	[2:2:2:2:2:0]	393.3
33	[2:2:2:2:1:1]	390.1



Thank you!

Biography of the presenter

Min Chen was born in Beijing, China. He received the Ph.D. degree in energy engineering from the Institute of Energy Technology, Aalborg University, Aalborg, Denmark, in 2009, where he is currently working as a postdoc. His research interests include modeling, monitoring, and control of thermoelectric devices for power/energy systems, thermoelectric energy harvesting, development and design of application-based prototypes, as well as testing and measurement techniques. He is a member of IEEE and IAS.