University of Nevada, Las Vegas
Electrical and Computer Eng.
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Preliminary Exam

Presented by: Yacouba Moumouni

<u>Committee members</u>:

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Designing, building and testing a solar thermal electric generation, STEG, for energy delivery to remote residential areas in developing regions

Contents

Background of the research

.Contributions
.Summary
.Publications (I)

Future Work
(The remaining work)

.Contributions
.Summary
.Publications (II

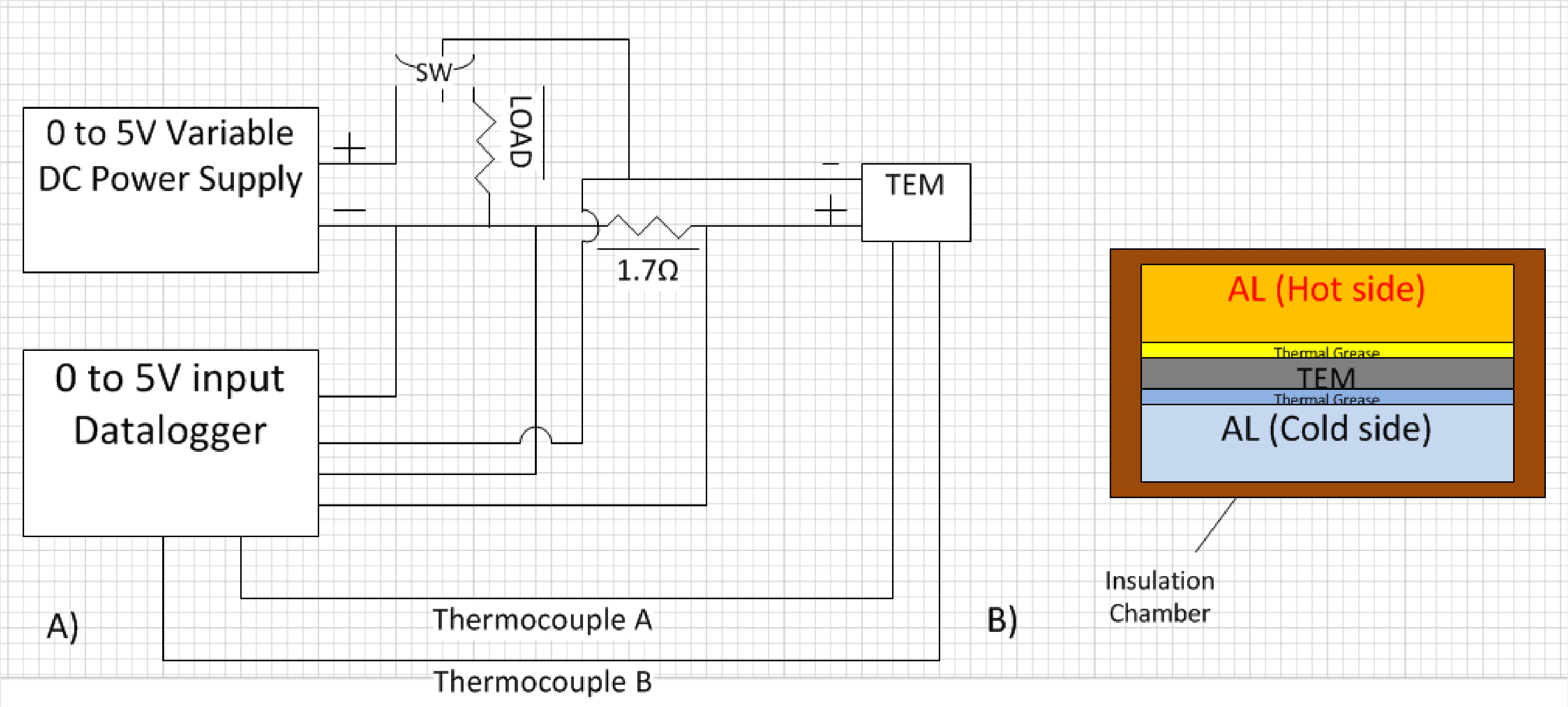
Part I--Background

TEG inside “Insulation Box”

Insulation foam
water boiling

Data logger/Laptop

Block diagram



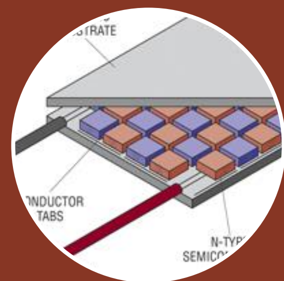
The Seven (7) TEG Modeling Steps

1. Identify the Components
2. Calculate the Biot Number
3. Calculate the thermal R and C
4. Define and draw parasitic elements (R, L, C)
5. Express the Electrical equivalence of thermal parameters
6. Connect the analogy blocks in series-parallel
7. Run the TEG in LTspice

Thermal to Electrical Equivalence

Thermal	Electrical
°C/Watt	Ohm (Resistor)
Joules/°C	Farad (Capacitor)
Watt	Ampere (Current Source)
° C	Volt (Voltage Source)
Ambient Temperature	GND (0V)

Some TEG properties



Bi_2Te_3 *Al_2O_3*

Material	ρ[kg/m^3];	c [J/kg $\cdot$ K];	κ[W/m $\cdot$ K]
Aluminum	2770	875	177
Alumina	3570	837	35.3
Bi_2Te_3	7530	544	1.5

TEG Parameters

Extracted from

Internal parasitic components

Datasheet

Device geometries

Material properties

Inductances and Capacitances

Sample parameter computations

Mass of the ceramic plate

- $m_{cer} = \rho \cdot V\ [kg] = \frac{3570kg}{m^3} \cdot (0.056m)^2 \cdot (0.002m) = 2.239 \cdot 10^{-2}kg$

The mass of the semiconductors

- $m_{Bi2Te3} = m_T - m_{cer}\ [kg] = (4.8 - 2.239) \cdot 10^{-2}kg = 2.561 \cdot 10^{-2}kg$

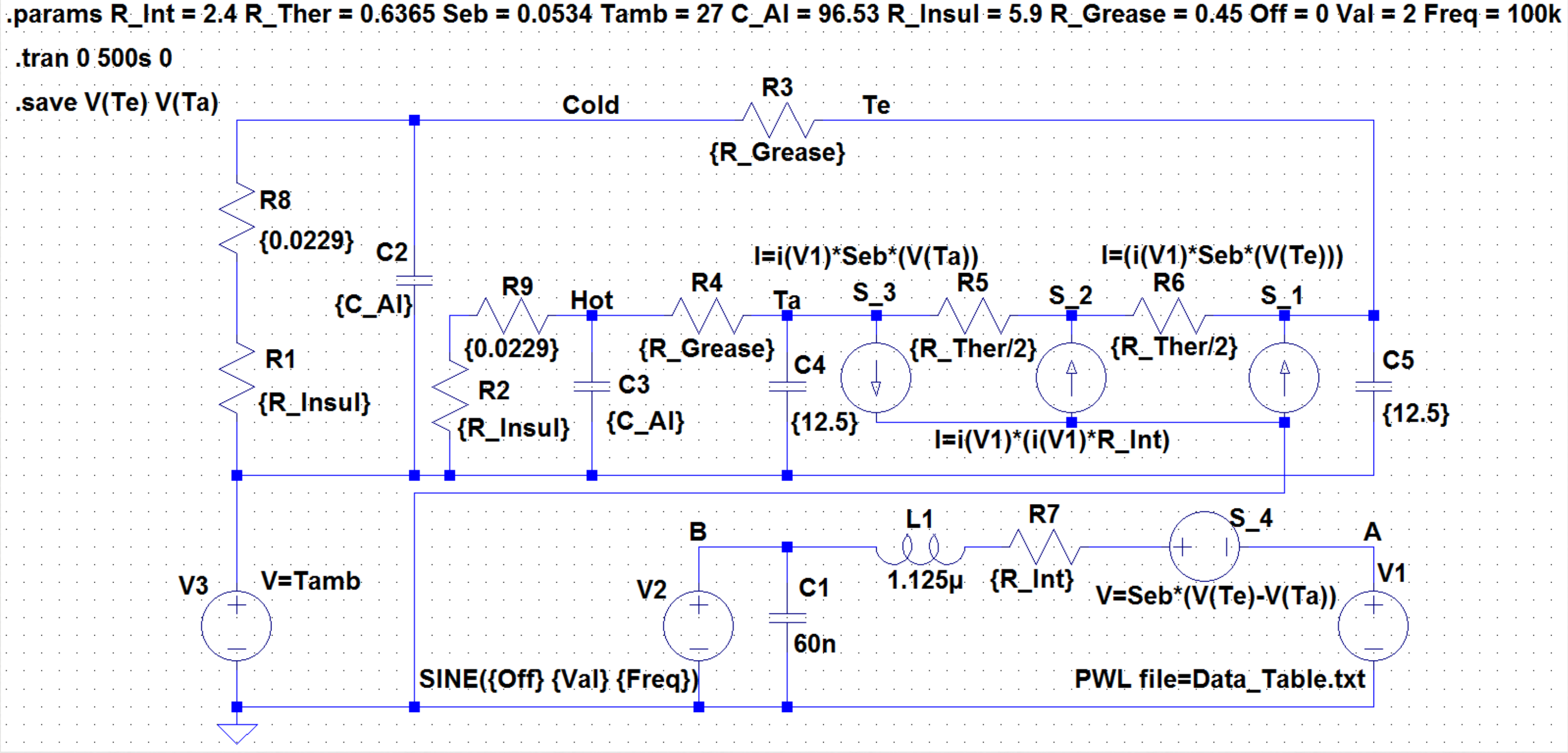
Molar heat capacity of the plate

- $C_{cer} = \rho \cdot Cp \cdot V\ [J/K] = \frac{3570kg \cdot 837W \cdot (6.272) \cdot (10^{-6}m^3)}{m^3 \cdot m \cdot K} = 18.74J/K$

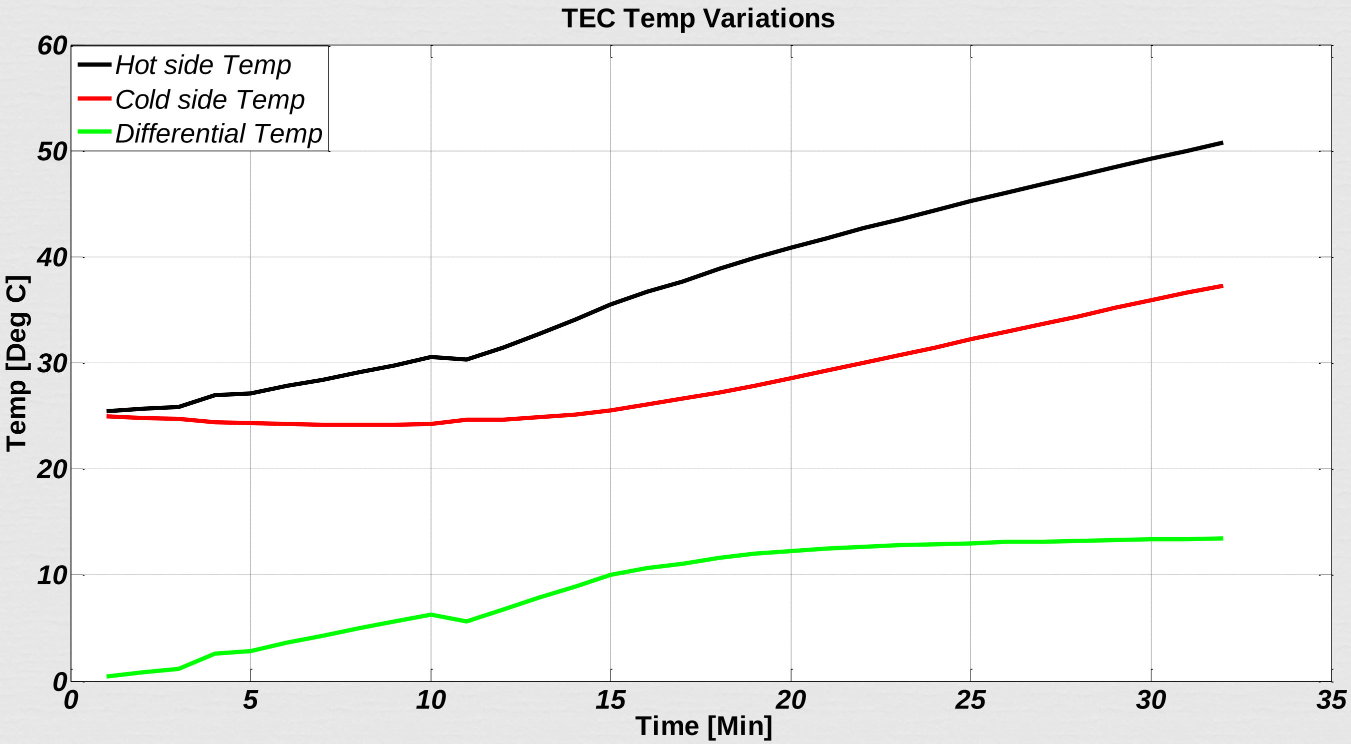
The molar heat capacity

- $C_{Bi2Te3} = \frac{C_{mol}}{M} \cdot m_{Bi2Te3}\ [J/K] = \frac{126.16J \cdot mol}{800.76g \cdot mol \cdot K} \cdot 25.61g = \frac{4.036J}{K}$

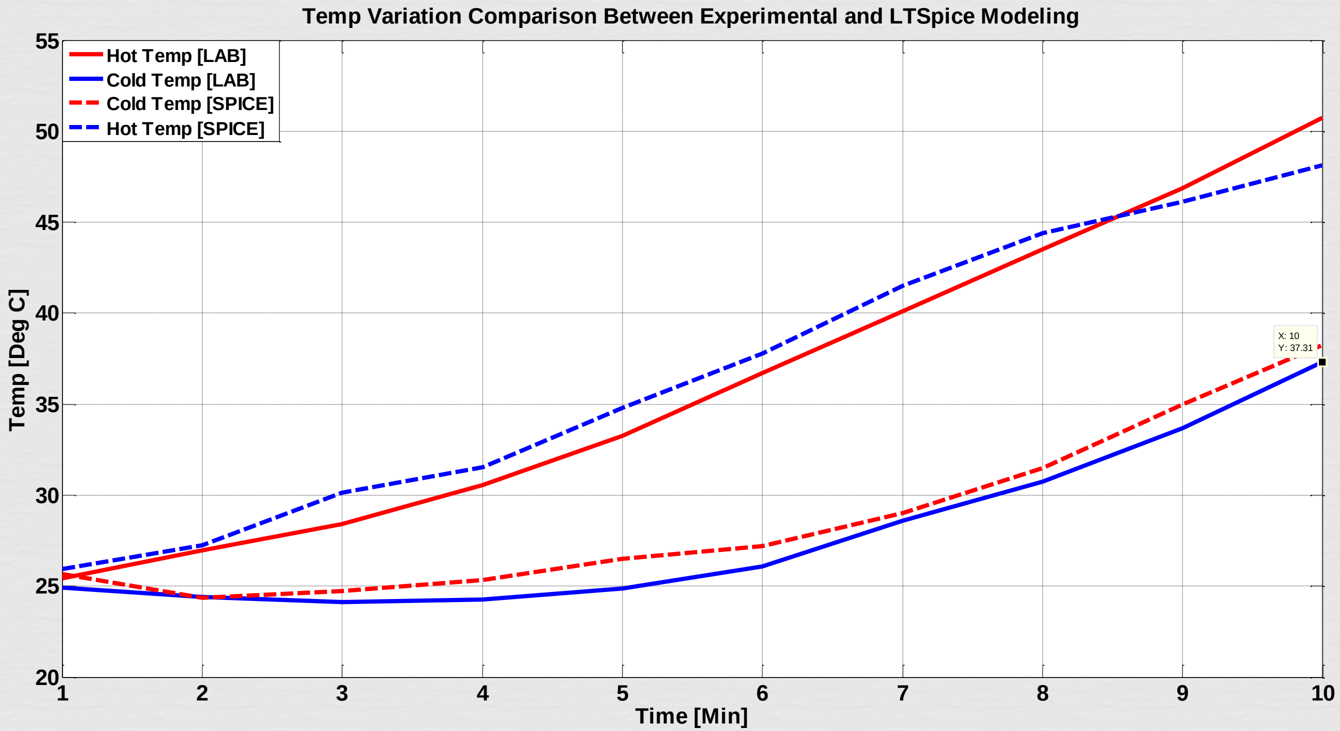
Spice Model of the TEG



Experimental Results



Comparative Results



My Contributions (I)

- Data extraction from the manufacturer datasheet, material properties, and device geometries
- Utilization of the extracted data to compute the thermal capacities and thermal resistances necessary to perform the thermal to electrical conversion required for the simulation
- Through the reverse polarity method, I was able to run the TEG as a TEC (**ΔT = 13.43°C**)
- I was the first to summarize concisely the Thermal to Electrical conversion methods into seven (7) broad steps
- I was able to accurately compute all the parameters and lay out the LTspice model of the TEM
- Successfully model the real behavior of the TEM through LTspice simulator

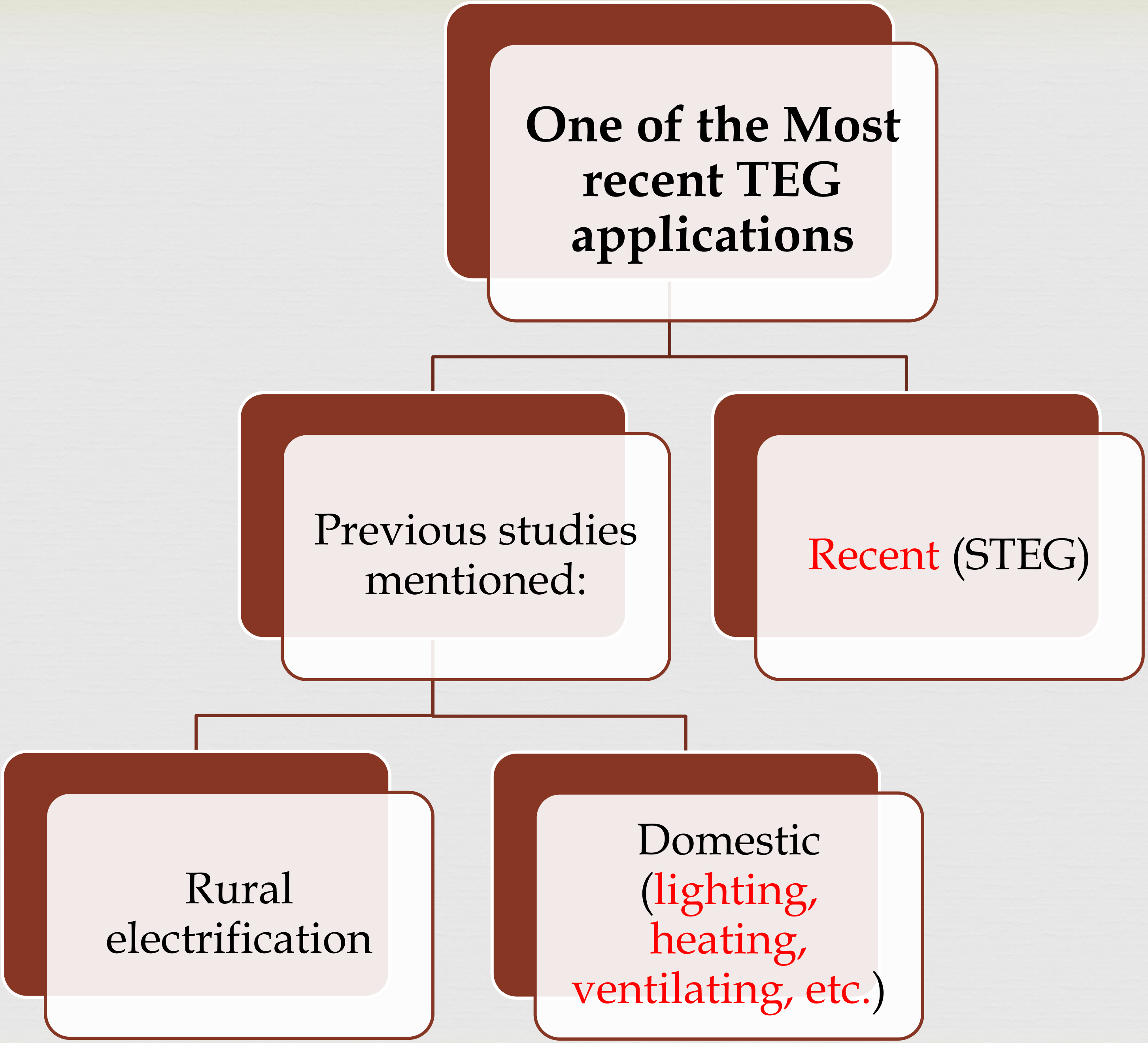
My Publications (I)

Y. Moumouni and R. Jacob Baker, "Concise Thermal to Electrical Parameters Extraction of Thermoelectric Generator for Spice Modeling," accepted for publication in MWSCAS 2015.

Y. Moumouni and R. Jacob Baker, "Improved SPICE Modeling and Analysis of a Thermoelectric Module," accepted for publication in MWSCAS 2015.

State of the art of TEG

- TEGs have been proposed for woodstoves
- Body heat powered watches
- Car seat cooling/heating for passenger comfort (**Toyota, GM, Nissan, Ford, and Range Rover**)
- Industrial waste heat recovery to power ancillary devices
- Vehicular waste heat recovery to enhance fuel economy
- Harvesting micropower for low power applications such as wireless, mobile sensors, and bio-sensors


One of the Most recent TEG applications
Previous studies mentioned:
Recent (STEG)
Rural electrification
Domestic (lighting, heating, ventilating, etc.)

Literature Review (Spice)

References	Study	Limitations
Chen et al. [33]	SPICE model of TEG and stabilization time after load change occurs	Idealized T_h and T_c to be constant
[34]	Demonstrated that Seebeck coefficient is dependent on temperature	
Lineykin et al. [35]	Developed a Spice compatible equivalent circuit of a TEM	No enough precision in the results –R of Al. plates and C of the chamber neglected.
[36]	An improved micro energy harvesting TEG in a Spice.	
Mihail [37] and Gontean et al. [32]	Proposed an energy harvesting system by means of the LTspice	Systems were limited to laboratory experiment

Part II
Complete Energy Harvesting System

U N L V

- Solar Tracker
- 5 TEGs

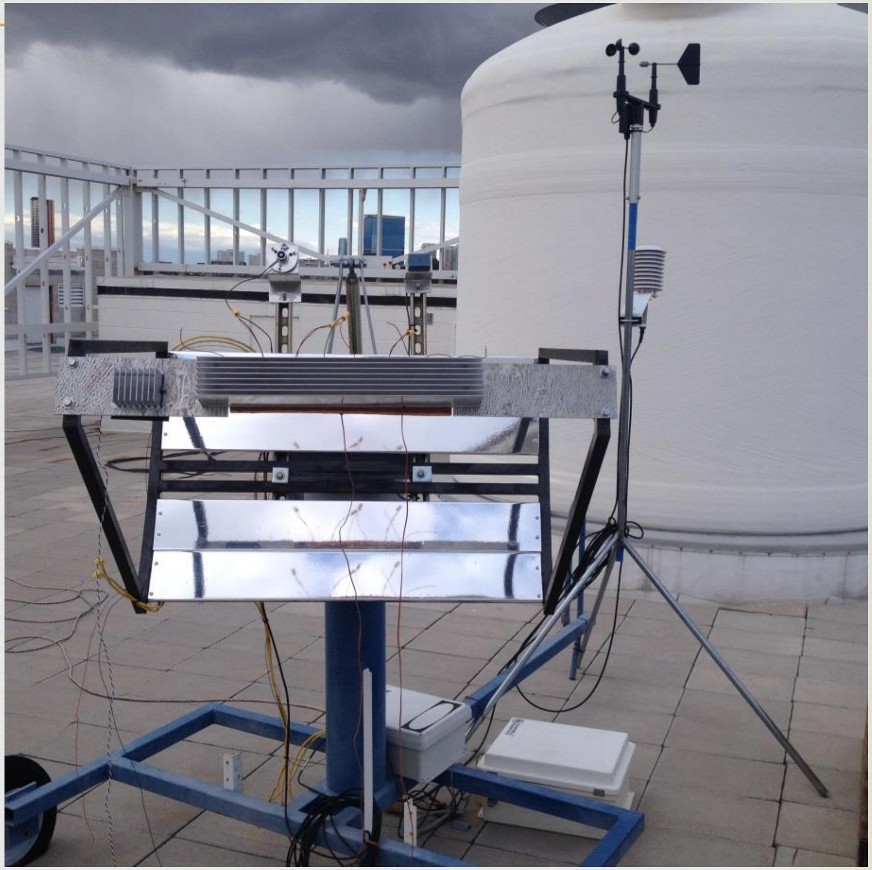
- Pyrheliometer
- Solar flux sensor

- Two Aluminum Heat exchangers
- Two thermocouples (K)

- Data logger
- DC-DC converter

- Battery
- Wind speed sensor

- Wind direction sensor
- Relative humidity sensor



Methods

- Analytical Transient Heat Transfer--**Cumbersome**
- Numerical electrical analogy method is proposed
- LTspice software simulator to be used
- A lookup table of real data (T_H and T_L) created
- Built-in piecewise linear (PWL)
- Simulation speed improved
- Experimental and simulated curves compared
- Efficiency will be computed

Energy harvested

- $Qc - \alpha \cdot T_C \cdot I + \frac{1}{2} I^2 \cdot R_{Int} + \kappa \cdot \Delta T = 0$

- $Qh - \alpha \cdot T_H \cdot I - \frac{1}{2} I^2 \cdot R_{Int} + \kappa \cdot \Delta T = 0$

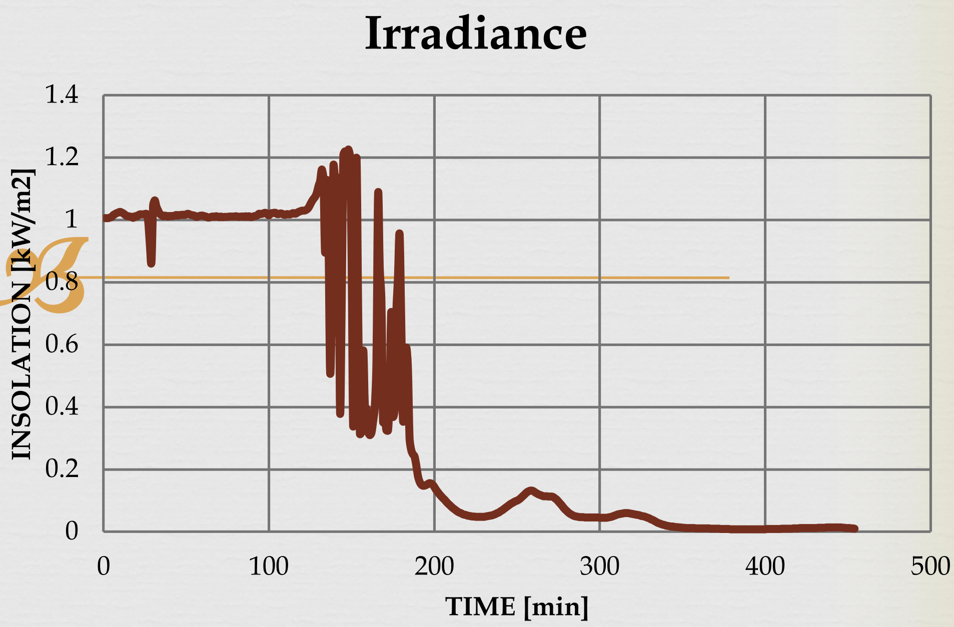
Electrical power generated

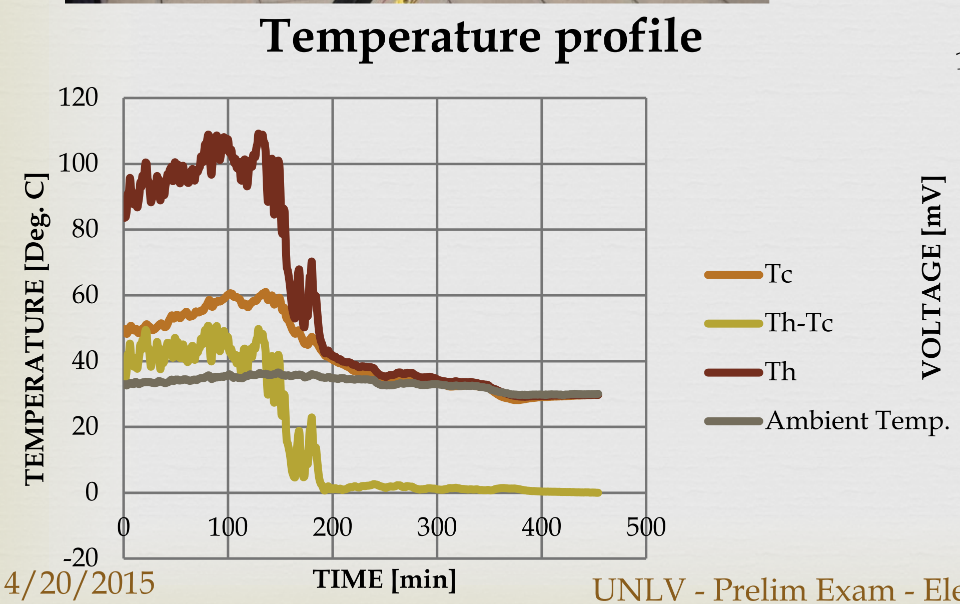
- $P_{Elect} = Qh - Qc = \alpha \cdot \Delta T \cdot I + R_{Int} \cdot I^2$

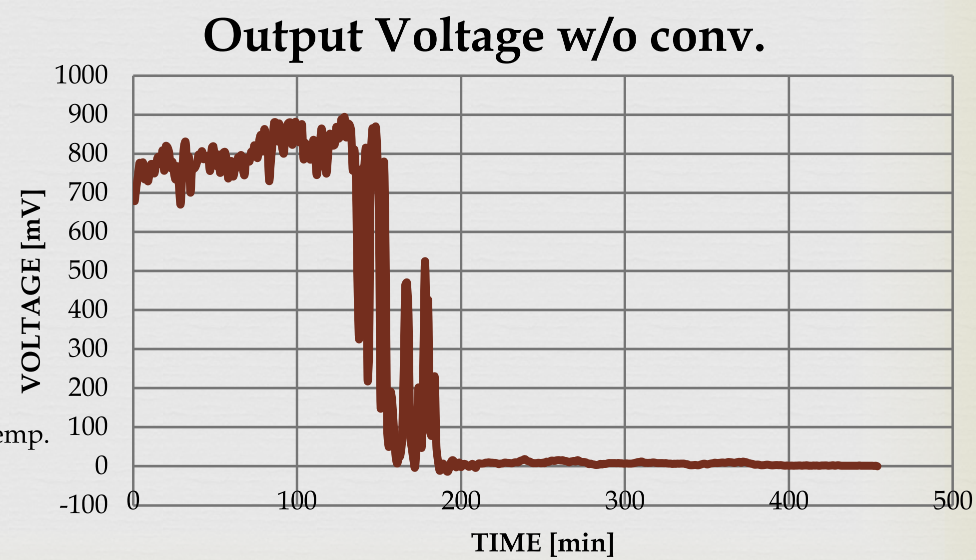
Data

TOA5	PVcell_te:	CR1000	[illegible]0005	CR1000.Std.13	CPU:Yacouba.(	64757	Table1						
TIMESTAMP	RECORD	Batt_Volt_	Slrk[illegible]g	WS_ms_Avg	WindDir	AirTC_Avg	RH	Diff[illegible]_Avg	DiffVol_2_Avg	DiffVol_3_Avg	Temp_C_Avg	Temp_C_2_Avg	
TS	RN	Volts	kW/m[illegible]	meters/secon	Degrees	Deg C	%	mV	mV	mV	Deg C	Deg C	
		Avg	Avg	Avg	Smp	Avg	Smp	Avg	Avg	Avg	Avg	Avg	Th-Tc
7/28/2014 10:46	0	13.3	1.006	0	10.43	33.01	30.04	678.9	0	14.33	83.6	49.75	33.85
7/28/2014 10:47	1	13.3	1.006	2.363	3.945	32.74	30.59	714.4	0	17.06	83.9	48.88	35.02
7/28/2014 10:48	2	13.3	1.006	1.313	63.95	32.63	30.89	745.1	0	19.79	86	48.31	37.69
7/28/2014 10:49	3	13.3	1.008	0.45	63.13	32.91	30.89	777.2	0	21.49	90.9	48.76	42.14
7/28/2014 10:50	4	13.3	1.01	1.012	18.04	33.19	30.59	744.5	0	22.52	91.1	49.35	41.75
7/28/2014 10:51	5	13.3	1.016	0	10.53	33.26	30.48	778.4	0	23.88	95.7	50.34	45.36
7/28/2014 10:52	6	13.33	1.019	1.688	10.19	33.41	30.15	734.9	0	19.79	92.6	50.76	41.84
7/28/2014 10:53	7	13.32	1.022	1.575	11.31	33.11	30.42	760.5	0	20.47	91.4	50.31	41.09
7/28/2014 10:54	8	13.31	1.024	2.125	9.91	33.11	30.76	729.8	0	17.74	88.8	49.96	38.84
7/28/2014 10:55	9	13.31	1.026	1.713	61.66	33.09	30.65	748.6	0	21.84	87.7	49.33	38.37
7/28/2014 10:56	10	13.31	1.024	1	27.55	33.64	31.26	773.8	0	22.69	90.7	49.72	40.98
7/28/2014 10:57	11	13.29	1.021	2.075	13.63	33.67	31.1	764.2	0	21.15	89.8	49.84	39.96
7/28/2014 10:58	12	13.3	1.017	2.788	19.75	33.25	30.79	749.9	0	19.11	86.8	49.11	37.69
7/28/2014 10:59	13	13.3	1.013	1.688	15.63	33.11	30.76	773.8	0	20.47	88.2	48.57	39.63
7/28/2014 11:00	14	13.3	1.012	1.225	18.3	33.06	31.54	790.9	0	22.86	90.5	48.63	41.87
7/28/2014 11:01	15	13.3	1.011	0.65	12.72	33.25	30.55	792.2	0	21.15	94.4	49.3	45.1
7/28/2014 11:02	16	13.31	1.01	1.713	12.44	33.33	29.94	773.6	0	22.52	93	49.5	43.5
7/28/2014 11:03	17	13.31	1.007	0.75	5.684	33.52	29.91	809	0	21.84	96.4	49.92	46.48
7/28/2014 11:04	18	13.31	1.012	1.275	3.616	33.6	29.54	756.7	0	17.74	94	50.13	43.87
7/28/2014 11:05	19	13.3	1.011	0.725	7.502	33.58	29.57	820	0	25.76	97.6	50.25	47.35
7/28/2014 11:06	20	13.31	1.015	0.825	11.02	33.75	29.23	817	0	23.88	100.4	50.91	49.49
7/28/2014 11:07	21	13.31	1.018	0.875	28.47	33.65	29.23	803	0	22.52	100	51.23	48.77
7/28/2014 11:08	22	13.3	1.018	2.1	8.1	33.65	29.94	763.6	0	21.15	94.7	50.98	43.72
7/28/2014 11:09	23	13.31	1.018	1.55	7.153	33.72	29.47	779.9	0	22.35	94.6	50.64	43.96
7/28/2014 11:10	24	13.31	1.019	1.888	7.343	33.64	29.33	749.2	0	19.45	91.9	50.48	41.42
7/28/2014 11:11	25	13.31	1.019	2.538	15.59	33.5	29.6	734.9	0	17.4	88.4	50.05	38.35
7/28/2014 11:12	26	13.31	0.998	1.575	9.9	33.52	29.7	768.3	0	23.2	89.3	49.64	39.66
7/28/2014 11:13	27	13.31	0.925	1.688	26.37	33.4	29.84	716.5	0	20.47	90	49.44	40.56
7/28/2014 11:14	28	13.31	0.864	0.937	19.64	33.41	30.86	670.8	0	19.79	91.8	49.61	42.19
7/28/2014 11:15	29	13.31	1.046	1.463	15.25	33.31	30.42	754	0	21.32	90.6	49.78	40.82
7/28/2014 11:16	30	13.3	1.063	1.363	4.179	33.45	30.01	818	0	25.25	92.9	50.1	42.8
7/28/2014 11:17	31	13.31	1.043	0.7	10.3	33.48	30.59	831	0	25.25	96.3	50.43	45.87
7/28/2014 11:18	32	13.31	1.031	1.15	6.022	33.86	29.67	779.3	0	24.56	94	50.66	43.34
7/28/2014 11:19	33	13.31	1.02	1.175	52.66	33.97	29.16	792.9	0	23.88	95.1	51.1	44
7/28/2014 11:20	34	13.31	1.016	2.338	73.35	33.86	29.54	700.8	0	21.49	89	51.29	37.71

Results before DC-DC converter

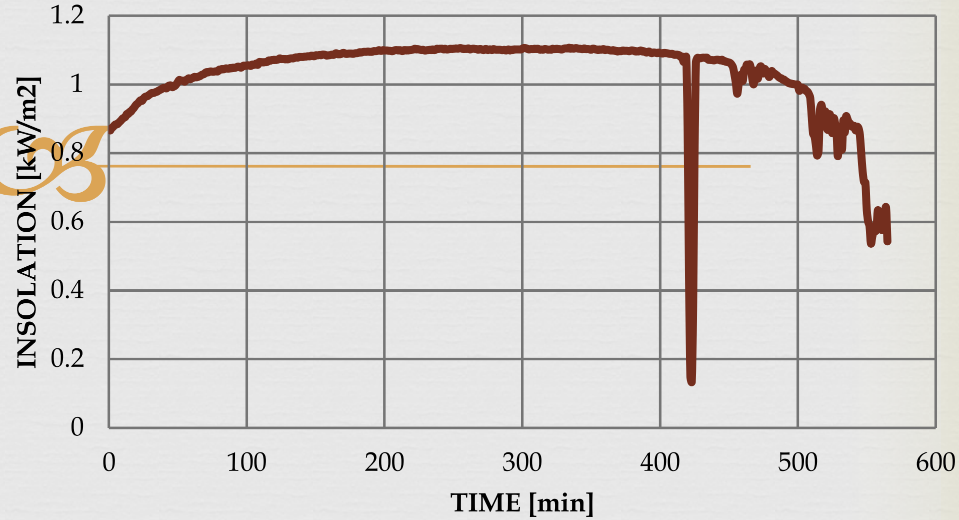




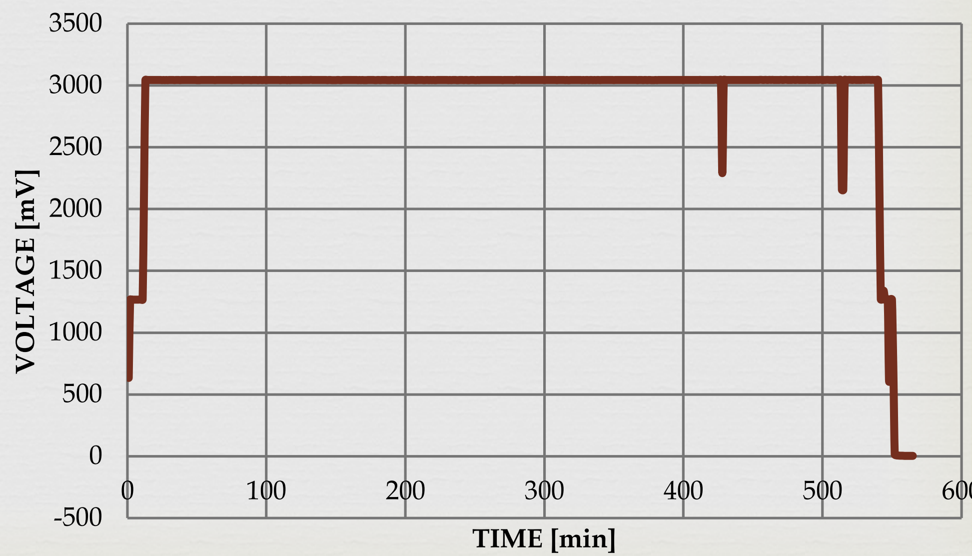


Results (3V)

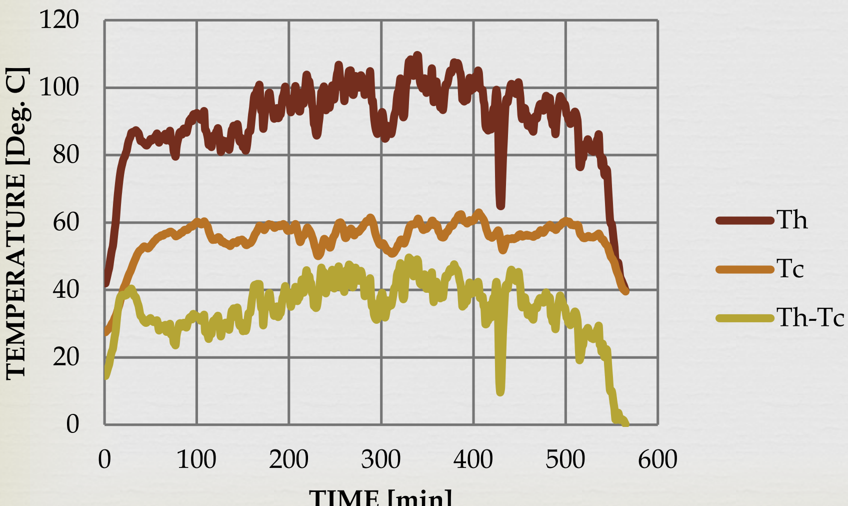
Solar Irradiance



Voltage profile w/ conv.

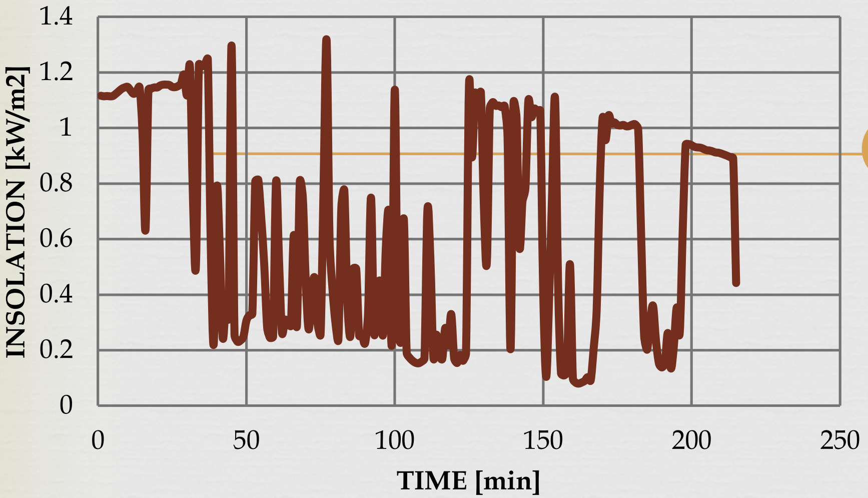


Temperature Variations

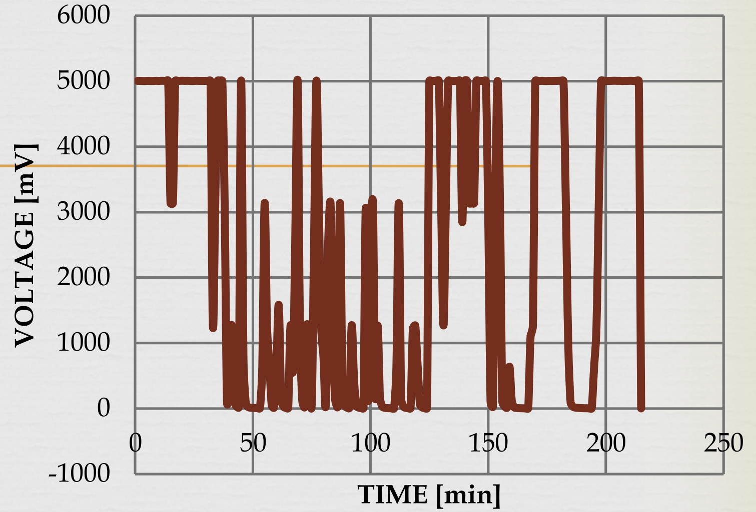


Results (5V)

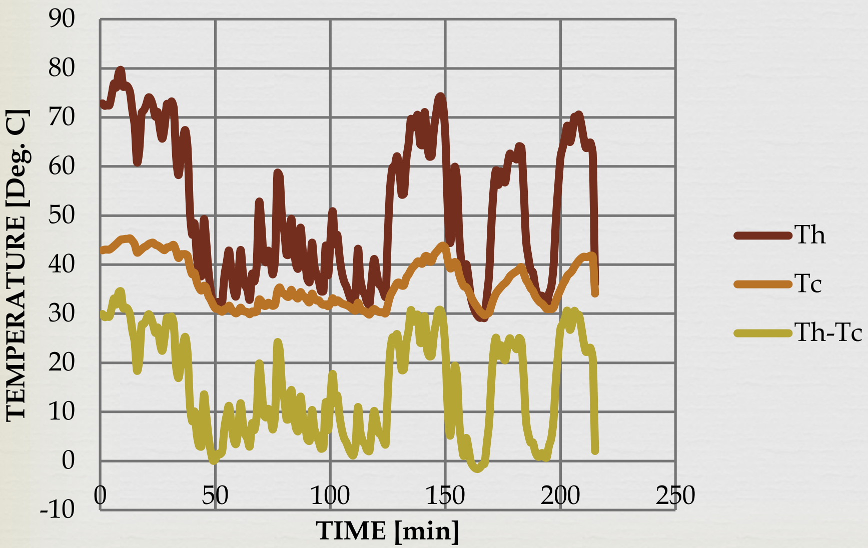
Irradiance



Voltage profile w/ conv.



TEMPERATURE VARIATIONS



Summary of the Work

(Physics and Theory)

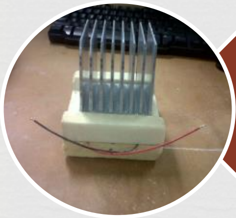
Seebeck effects

Peltier effects

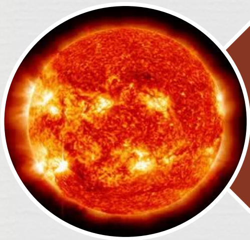
Joule effects

Thomson effects (**Negligible**)

Summary of the Work (cont.)



TEG efficiency increase is challenging



STEG—Energy Harvesting System--accordance with Electrical and Mechanical standards

Thermal to Electrical Analogy (LTspice)

A true 30 degrees increment manual solar tracker is proposed, instead of the real tracker (Seen above)

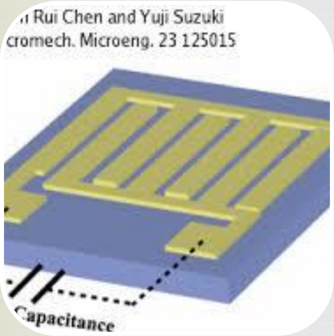
Finally, Economic Analysis be performed

Conjectures

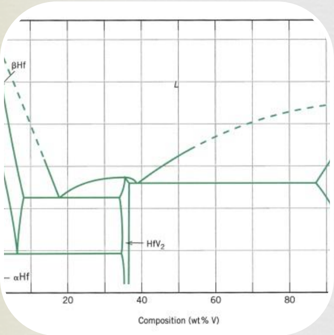
- Design complexity
- Hardware and/or Software failures
- Inner complexity of each individual part
- Minor undetectable errors of imperfect interconnections
- Incompatibilities at a microscopic level
- Heat lost in the system due to material defects
- Complex device geometries, and
- Different material properties of the parts

Conjectures (Cont.)

Any error can be explained by either one or both of the following:



Internal parasitic components' variation



Non-homogeneity of the physical blocks that we may assume to be of pure metals during the thermal to electrical parameters computations.

My Contributions (II)

- Design, construct, and monitor the real performance of a complete TEG system
- Proposed to design a manual solar tracker (**Solid Works**)
- Most of the above steps will be repeated (**Requirement**)
- Modeling the real behavior of the energy harvesting system through LTspice simulator (**Electrical circuit**)
- Proposed a novel method to analyze such a complex energy harvesting system (STEG)
- Publish the results to advance the **"State-of-the-art"**
- Evaluate the "**Economic**" and "**Technical**" feasibility of such a system as compared to PV system

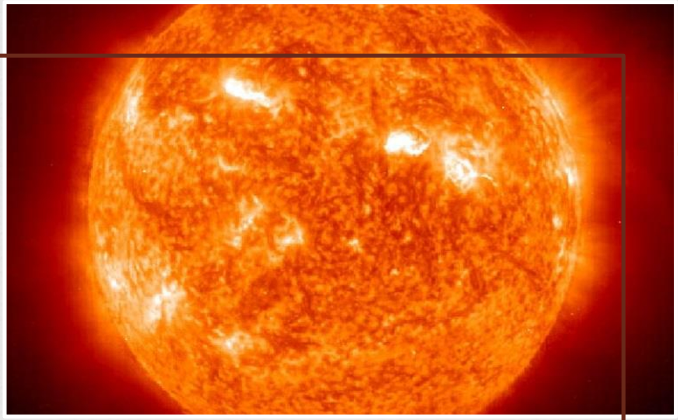
My Publications (II)

- Y. Moumouni and R. Jacob Baker, "Application of Used Electric Vehicle Batteries to Buffer PV Output Transients," accepted for publication in MWSCAS 2015.
- Y. Moumouni and R. Jacob Baker, "CPV Battery Buffer Sizing and Economic Analysis," accepted for publication in MWSCAS 2015.
- Y. Moumouni , Sajjad Ahmad and R. Jacob Baker, A System Dynamics Model for Energy Planning in Niger; *International Journal of Energy and Power Engineering. Vol.3. No.6, 2014, pp.308-322. doi: 10.11648/j.ijepe.20140306.14*
- K. Hurayb, Y. Moumouni, and Y. Baghzouz, "Evaluation of the impact of Partial Shading on the Performance of a Grid-Tied PV system;" *IEEE 5th International Conference on Clean Electrical Power, Italy 2015 (Accepted)*
- Y. Moumouni and Robert F. Boehm, "Utilization of Energy Storage to Buffer PV Output during Cloud Transients;" *International Conference on Renewable Energy Technologies, ICRET, Hong Kong 2014*.
- Y. Moumouni, Y. Baghzouz, and Robert F. Boehm, Power "Smoothing" of a Commercial-Size Photovoltaic System by an Energy Storage System; *IEEE Power & Energy Society, ICHQP, Romania 2014.*

Conclusion

- Major sources of Energy are depleting
- Renewable sources are the future solutions
- Emerging economies demand more and more energy
- PV dominates the renewable supply to date
- Can TEG compete with PV in terms of efficiency and applicability in rural and arid regions?
- Numerical analysis thru' Ltspice simulator is proposed
- Thermal to Electrical analogy will be implemented
- Complete energy harvesting system developed
- Thorough Literature Survey was conducted

Thank you,



Infinite source

5 TEGs

K2