THE ANNALS OF "DUNAREA DE JOS" UNIVERSITY OF GALATI
FASCICLE XIV MECHANICHAL ENGINEERING, ISSN 1224-5615
2009

THERMOELECTRIC GENERATOR -AN ALTERNATIVE ELECTRIC POWER SOURCE

PhD. Assoc. Prof. Ioana DIACONESCU
PhD. Assoc. Prof. Luiza GRIGORESCU
“Dunarea de Jos” University of Galati
Faculty of Engineering from Braila
SIM Department

ABSTRACT

This paper presents the thermoelectric generators which converting directly heat flow into electric energy. Thermoelectric modules (TEM) normally designed for cooling are suited for power generation as well, as they are made of materials of high thermoelectric efficiency when operated with low level heat sources (up to 380 K).

KEYWORDS: thermoelectric generator, power generation, TEM, nanostructure materials

1. INTRODUCTION

The world energy crisis deepened with natural resources depletion and the escalating environmental pollution. Because of that, the electric power generation by means of thermoelectric modules could be an alternative electric power source. The thermoelectric generators (TEG) transform heat fluxes directly into electric power (Seebeck's effect). Many existing heat sources can be used as sources in thermoelectric power generation. These are: solar energy, oceanic and land heat, human body heat, heat evolved as a result of human activity.

Temperature differences exist anywhere on Earth and at any time. With respect to that, thermoelectric generators offer better possibilities for solar photovoltaic converters which operate efficiently only under direct solar irradiation. This imposes energy solutions based on using alternative methods - thermoelectric generators are just one of these alternative methods and this makes them pertinent on national and world-wide level. Three types of thermoelectric phenomena are known: Seebeck's effect, Peltier effect and Thomson's effect. Only the first two are of relevance to the proposed paper topic. Peltier's effect is manifested when electric current flow is a closed loop consisting of heterogeneous pair of metals or semiconductors p- and n-type (a thermo element); depending on the direction of current flow, defined amount of heat is either evolved or absorbed at the contacts. The thermoelectric module (TEM) consists of a certain number of thermo elements connected electrically in series and thermally in parallel clamped between thermally conducting ceramic plates. When charge current flows, one of the plates gets heated and the other cooled. Seebeck's effect is the manifestation of the reverse phenomenon - the origination of electromotive force in a closed loop consisting of heterogeneous metals or semiconductors n- or p-type, if the contacts are being maintained at different temperatures. The thermoelectric modules normally designed for cooling are proper for electric power generation application, as they are made of highly thermoefficient materials permitting operation at temperatures up to 380 K.

2. TEM AS POWER GENERATOR

Thermoelectric generators converting directly heat flow into electric energy have attracted growing interest as alternative sources of energy. Thermoelectric modules (TEM) normally designed for cooling are suited for power generation as well, as they are made of materials of high thermoelectric efficiency when operated with low level heat sources (up to 380 K). Cooling TEMs have maximal cooling power at low temperature differences ΔT, while the generating ones have maximal efficiency at high ΔT. Cooling TEMs are made of Bi2Te3 with Sb and Se dopants. If the modules are being used in reverse mode, i.e. temperature difference applied at both module sides, they are suited for power source operation in the temperature range of 180 - 380 K. Generators applicable for high thermal power conversion are made with different materials and technologies such as PbTe, Si/Ge alloys, etc. and are usable up to the maximal temperature of 500 K. The thermoelectric module used for power generation is similar to the common thermocouple. Figure 1[1,5] presents a single thermocouple with the applied temperature difference $\Delta T = T_h - T_c$.

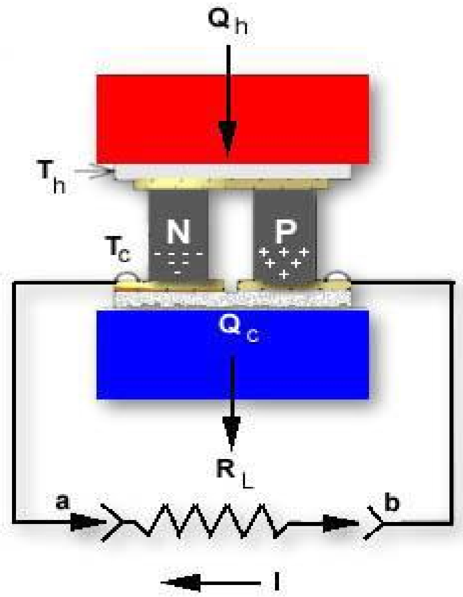

Fig. 1 A single thermocouple; $T_h > T_c$

If no load is connected (R_L disconnected), the open source voltage between **a** and **b** is

$$U = S \cdot \Delta T \quad (1)$$

where: U is the output themocouple voltage and S is the averaged Seebeck coefficient. When some load is connected to the thermocouple, the output voltage drops as a result of the internal generator resistance. The current through the load is:

$$I = (S \cdot \Delta T)/(R_C + R_L) \quad (2)$$

where I is the output current, R_C is the averaged internal resistance of the thermoelectric couple and R_L is the load resistance. The complete heat input into the thermocouple (Q_h) is:

$$Q_h=(S\cdot T_h\cdot I)- (0.5\cdot I^2\cdot Rc) + (k_c\cdot \Delta T) \quad (3)$$

where Q_h is the input heat, k_c is the couple thermal conductance in W/K and T_h is the thermocouple hot side temperature. The generator efficiency is

$$E_g = (U \cdot I)/Q_h \quad (4)$$

3. THE POWER GENERATING SYSTEM

A single thermoelectric couple has been considered so far. The module consists of a high number of such couples and it is necessary to present a real module equation which has the form:

$$U_o = S_M \cdot \Delta T = I \cdot (R_M + R_L) \quad (5)$$

where U_o is the generator output voltage, S_M is the averaged Seebech coefficient and R_M is the averaged module resistance. The output power is:

$$P_o = R_L \cdot (S_M \cdot \Delta T/ R_M+ R_L)^2 \quad (6)$$

It is possible that the exact calculations be based on a particular application of the generator where each module provides the exact power in demand. As a result, most thermoelectric generators (TEG) contain a certain number of individual modules connected either in series or in parallel or in a combination of both. A typical TEG configuration is presented in Figure 2. This generator has a total number of modules NT, NS is the number of modules connected in series and NP is the number of modules connected in parallel. So NT=NS · NP.

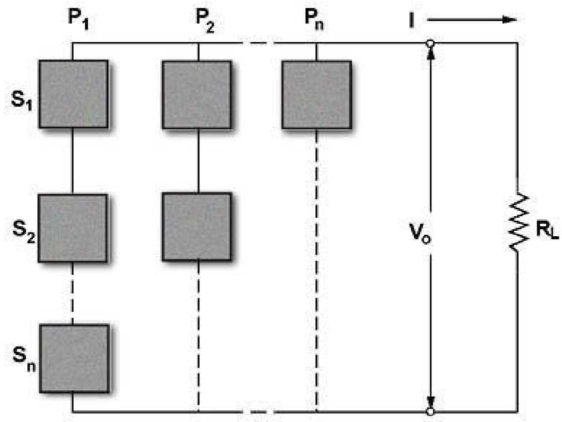

Fig. 2. A typical TEG configuration with series/parallel connected modules.

The current through the load resistance is:

$$I = NS \cdot S_M \cdot \Delta T/ [(NS \cdot R_M)/NP]+ R_L \quad (7)$$

The generator output voltage is:

$$U_o = R_L \cdot I \quad (8)$$

The generator output power is:

$$P_o=U_o \cdot I = [NT\cdot (S_M \cdot \Delta T)^2] / 4R_M \quad (9)$$

The total heat input into the generator is:

$$Q_h=NT\cdot[(S_M\cdot T_h\cdot 1/NP)-0,5\cdot(I/NP)^2\cdot R_M\cdot k_M\cdot\Delta T)] \quad (10)$$

The generator efficiency is:

$$\varepsilon_g = P_o/Q_h \cdot 100 \ [\%] \quad (11)$$

The parameter $ZT = S^2 \cdot \sigma \cdot T / k$, characterizes the material and should be greater than unity, σ is the electric conductivity [4]. Maximal power transfer efficiency is achieved when the generator internal resistance (R_{GEN}) equals the load (R_L) $R_{GEN} = (NS \cdot R_M)/NP$.

For any thermoelectric generator design it is always advantageous to increase the temperature difference in order to decrease the total number of modules in the system. It is clear that a high number of modules are needed when the cold side temperature is high and therefore the temperature difference is low. The basic challenge in thermoelectric materials research is to increase the characteristic factor ZT. ZT is a dimensionless quantity dependent on the fundamental material features. To obtain high TEM output voltage at given temperature gradient, the material used should have high Seebeck coefficient and low thermal conductivity to maintain the temperature difference through the material. The best materials are defined as "phononsglass electron-crystal" (PGEC) which means these materials should exhibit low lattice heat conductivity as in glasses and high electric conductivity as in crystals. The best thermo - electric materials are highly doped semiconductors. Insulators have poor electric conductivity and metals have low Seebeck coefficient. Thermal conductivity in semiconductors is defined by both electrons and phonons, the latter providing the main contribution. Phonon heat conductivity may be decreased without significantly degrading electric conductivity. Alloying is one of the processes that decrease lattice heat conductivity without influencing significantly electric conductivity. Presently used materials for cooling are based on Bi2Te3 - Sb3Te alloys. Each has room temperature ZT value of about 1. Low dimensional materials as quantum wells, super lattices, quantum wires offer new ways to alter electron and phonon properties of a given material. In such structures quantum effects dominate and the electron and phonon energy spectra can be controlled by altering structure sizes which provides new ways to control ZT. Super lattices obtained by thin film deposition are not suitable for mass production and require new assembling technology of TEMs. In contrast, nanocomposites can provide similar thermal conductivity reduction and increase of the ZT characteristic while simultaneously permitting the use of existing assembly technology and TEM applications. The thermoelectric generator contains the following components: TEM, heat sinks (radiators) coupled to the module hot and cold side and a cooling fan. The conversion feature of the cold side heat sink (radiator) is of paramount importance and its thermal resistance should be as low as possible. It should dissipate the large amount of heat evolved by the TEM and stay at constant temperature to keep high ΔT [3]. Both water cooling and thermal pipes can be used besides the fan. In many cases, the heat sink design proves to be crucial for overcoming the engineering challenge.

A basic design of a TEG used in cooling aggregates is shown in F igure 3.

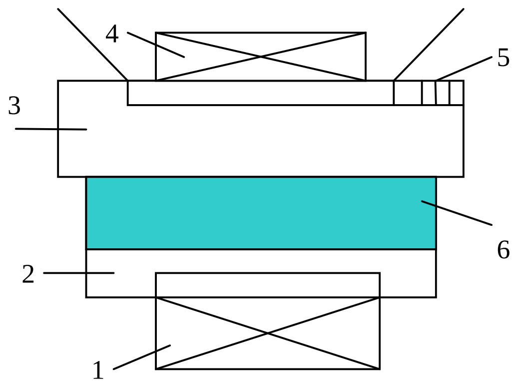

Fig. 3 TEG components: 1, 4 - fans, 2 - cold radiator, 3 - hot radiator, 5 output lead for the generated electric power, 6 - insulation

The generator operation depends both on the TEM type used and on the hot and cold side radiator design to create maximal temperature difference with minimal losses in the total circuit. Calculus of the circuit thermal balance is based on the TEM type and heat input and heat dissipation.

4. THE HYBRID SOLUTION

Theoretical analysis of both presently used materials and designs and the new nanostructure materials and their properties create a new solution. This will concentrate on their thermoelectric properties, the crystallite size and their impact on the electron and phonon scattering and therefore on electric and thermal conductivity. This solution includes thermal calculation for the circuit, choice and calculation of suitable TEMs and a model of a TEG with cooling TEM at maximal temperature of 380 K and a solar collector heat source. Such a TEG where heat is obtained by means of a solar collector can be included in a system from Figure 4 (by Termomax) [2,5]. A thermoelectric generator producing electricity that charges an accumulator is placed in the hot collector circuit path between the collector and the boiler. When solar heat is insufficient (in cloudy and rainy days), an electric heater is switched on to heat the water. It is powered by the charged accumulator and heats the water to the prescribed temperature. The electric power produced thus can be used for other applications.

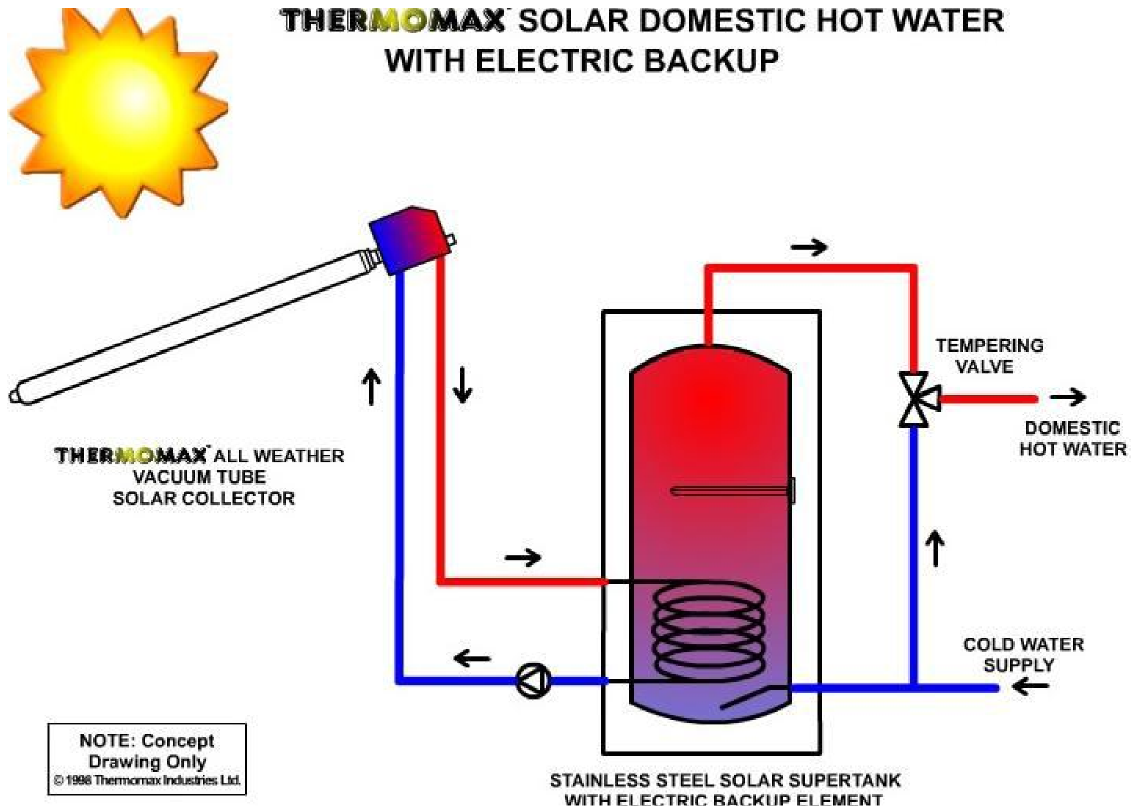

Fig.4 System of TEG and solar collector

This type of generator can increase solution efficiency up to 10 - 12 %.

5. CONCLUSIONS

This paper presents the TEMs application and how to improve its performances. Taking into account the amenability of TEMs for power generation, the following conclusions could be taken:

- A mathematical model of TEG allows the optimization of the heat-to-electricity conversion parameters.

- A study for developing new materials of enhanced thermoelectric parameters and efficiency could make possible a ZT characteristic greater than unity.

- The analysis of these material preparation technologies shows whether their preparation is possible at the II-VI photoresistor production equipment available at CLAP by means of sintering and by MBE for Si-Ge.

- The TEG thermal and electric parameters are measurable and based on these values the relevant thermoelectric modules can be chosen.

-A TEG-K model system incorporates a heated solar collector with a fluid heat carrier as a heat source and the heat source works with direct heating by a solar concentrator (TEG-D).

REFERENCES

[1] **M.Neshev, L.Bedikyan, St.Zachariev, M.Zacharieva**, *Thermoelectric generator modules as an alternative source of electric energy*, Proc. of International Conference NANOHARD 2009, Sozopol, Bulgaria, 24-27 May 2009.

[2] **P. Shindov, R. Kakanakov, L. Bedikyan, S. Kaneva, T. Anastasova**, *Investigation of Pulsed Laser Annealing and Thermal Annealing of CdS Layers Designed for Thin Layer Solar Cells*, Proc. of International Conference NANOHARD 2009, Sozopol, Bulgaria, 24-27 May 2009.

[3] **Diaconescu I.,** *Exergetic Analasys of Recovery Energy Proces,* Romaniana Techincal Science Academy, MOCM-14-Vol.2, ISSN 1224-7480, 2008, pg. 66-71.

[4] **Costinas S., Diaconescu I., Fagarasanu I.**, *Wind Power Plant Condition Monitoring*, in the Book “Energy Problems & and Environmental Engineering”, ISBN 978-960-474-093-2 ISSN 1790-5095, included in ISI/SCI Web of Science and Web of Knowledge, Tenerife, Spain, 2009, pp.71-77.

[5] http://www.thermomax.com/Consulting