Study and Simulation of a Thermoelectric Generator for the Intelligent Agricultural System

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STUDY AND SIMULATION OF A THERMOELECTRIC GENERATOR FOR THE INTELLIGENT AGRICULTURAL SYSTEM

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Abstract

Smart farming has become one of the priorities that has emerged recently and will be in the future in the agricultural field, due to the availability of programmed electronic devices, which are used to measure and track the necessary indicators in this domain. In this context, we try, through this scientific work, to study and deal with the problems of power supply of local electronic devices placed in agricultural fields, which detect, measure and follow the growth of plants by measuring indicators related to development and growth of plants. These devices, which are implanted in each tree or locally in each plant, of course need continuous and permanent electrical energy to supply the electrical sensors.

It should be noted that the power supply of these devices is considered one of the technical challenges for the following reasons:

- Multiple electrical wiring when using the conventional electrical power source.
- The use of photovoltaic energy for each measuring device/sensor/transmitter is also costly and impractical because it requires the use of photovoltaic cells and a storage battery for each of these devices.
- Using a dry battery is a reliable solution, but it remains financially costly and requires intervention to replace and control these batteries.

In this scientific work, we propose a new way of producing electricity to power devices from the thermal energy present in the ground and according to the temperature difference between those of the ground and those measured in the environment. exterior, using semiconductors based on the Seebeck effect. In this work, we use special software such as "ANSYS" and "TeGDS" to simulate and design an ideal miniature electric generator of "16cm x 16cm x16cm" geometry, capable of producing electric power to power the electronic devices used. The results found show the importance of this work in the field of smart agriculture.

Keywords: Renewable energy, Smart agriculture, Thermoelectric, Seebeck effect.

I. Introduction

As the world's population grows, global food needs will continue to grow, so we need to develop agriculture. There are intelligent applications in agriculture, based on the best techniques to follow for good agricultural production. This can be achieved, for example, by introducing new technologies, such as monitoring greenhouses with electronic sensors and measuring and sending data to a computing center. Implementation of these technologies in the field requires continuous and permanent electrical energy to operate the electronic devices used. In the normal case, they can be powered by ONE electrical network, solar photovoltaics, or dry batteries. The technical challenges and issues of these power supply modes are for the following reasons: When using a traditional power source, multiple and lengthy power wiring is required.Also, the use of photovoltaic energy for each measuring device, sensor, and transmitter is also costly and inconvenient since it requires the use of photovoltaic cells and a storage battery for each of these devices. In addition, the use of a dry battery is a reliable solution, but it remains financially expensive and requires intervention to replace and control these batteries. In this scientific work, we propose a new innovative way to produce electricity to power devices from the thermal energy present in the ground and according to the temperature difference between those of the ground and those measured in the soil. the external environment using semiconductors based on the Seebeck effect.

II. Data and methods

1. Smart agricol system

The intelligent agricultural measurement and monitoring system consists of three phases (Fig. 1):

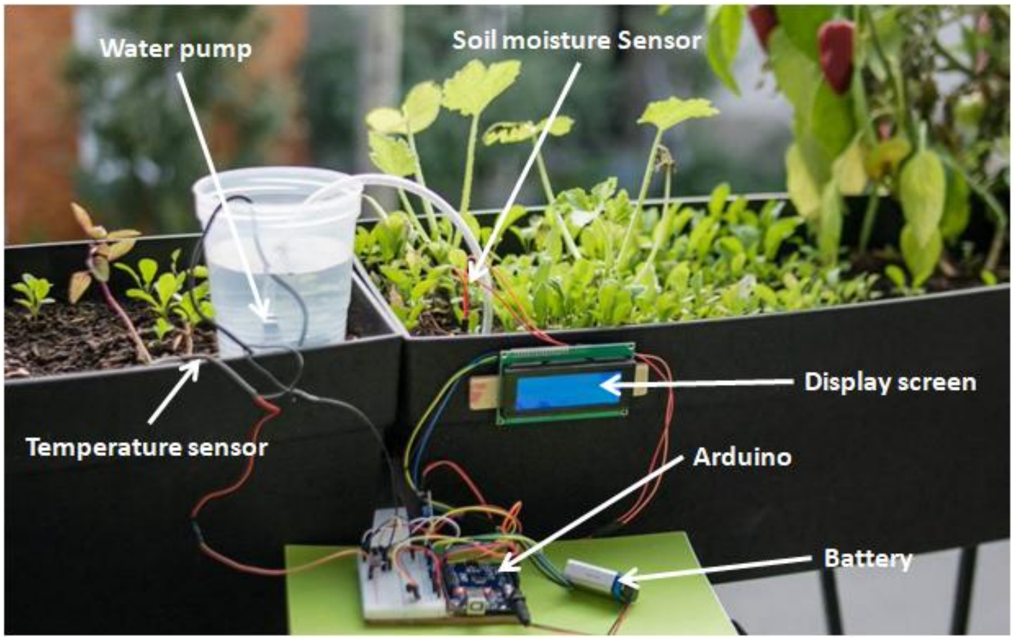

Figure 1. Intelligent agricultural system

- The first consists of a programmable electronic device whose purpose is to measure the physico-electronic quantities of the soil and the plant, namely the temperature, the humidity, the rate of minerals in the soil, etc., using sensors.
- The second is the electronics responsible for sending measured data to a computing center remotely via wifi or GSM technology.

- The third is responsible for the production of the electrical energy necessary for the operation of these electronic devices, even during the night.

In this work, we propose a new technique to ensure a source of electrical energy based on a thermoelectric generator.

2. Thermoelectric effects

The principle of thermoelectricity is based on thermal and electrical phenomena (heat transport and electric current circulation), Thermoelectric effects describe the interaction between heat and electric current in solids. Based on these effects, thermoelectric devices have been developed and used for power generation or refrigeration. Thermoelectric effects that occur in a MMT include: the Seebeck effect, the Peltier effect, and the Thomson effect. These three effects are linked by Kelvin's relationships. They represent the fundamentals of thermoelectricity [1], [2]. The Joule effect and the thermal conduction are added to this [3].

This is the generation of an electrical voltage V at the terminals of two junctions of two deferent materials a and b, when they are exposed to a temperature gradient DT=Tc-Tf, where Tc and Tf denote the temperatures of the hot and cold sides, respectively [2], [4]. The generated open circuit voltage is given by the relation [5]:

$$V_{OC} = \alpha \, \Delta T$$

the heat quantities on the cold side and on the hot side are [6]:

$$Q_f = \alpha \, T_f \, I + 0.5 \, R \, I^2 - \theta \, \Delta T$$

$$Q_C = \alpha \, T_C \, I + 0.5 \, R \, I^2 - \theta \, \Delta T$$

The electrical power generated per module is [6]:

$$P = Q_C - Q_f = \alpha \, \Delta T \, I - R \, I$$

The voltage across the module is [6] :

$$V = \alpha \, \Delta T - R \, I$$

3. Thermoelectric Module

The thermoelectric module is an association of several thermoelectric couples, each pair consisting of two P and N type semiconductor materials. The thermoelectric couples are connected so as to be electrically in series and thermally in parallel (FIG. 2).

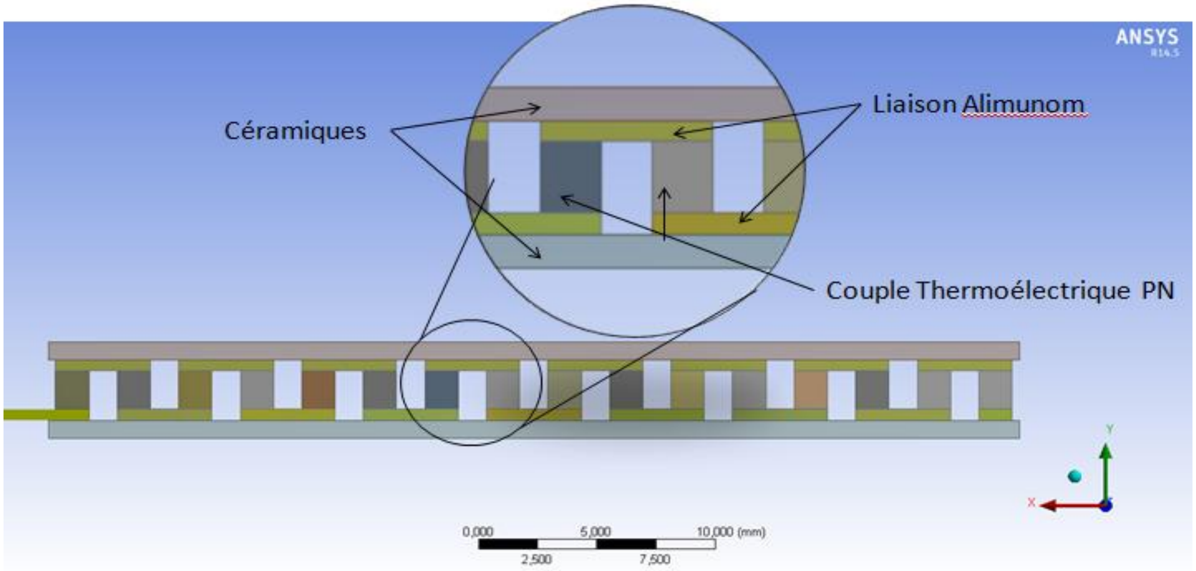

Figure 2. Thermoelectric module diagram on ANSYS

Table (1) shows the dimensions of the modules used in the simulation.

Tableau 1. Dimensions of modules used in simulation

Ceramic	Al_2O_3
solder	BiSn (melting point at 138°C)
Module Dimensions	40x40x3.9mm
Semiconductor dimensions	(1,4 x 1,4 x 1,7mm)

For Thermoelectric module materials, the detailed properties are given in Table 1, where the equivalent Seebeck coefficient, thermal conductivity and electrical resistivity of the P-type and N-type branches are measured experimentally by the method described [7].

Tabeau 2. Thermoelectric generator system material properties [7]

Thermal conductivity of ceramic plates	22	$W.m^{-1}.K^{-1}$
Thermal conductivity of copper electrodes	165,64	$W.m^{-1}.K^{-1}$

Electrical resistivity of copper electrodes	$1,75 \times 10^{-8}$	$\Omega.m$
P-type semiconductor thermal conductivity	$\lambda_p(T) = -3.05948 \times 10^{-9}\ T^4 + 4.56781 \times 10^{-6}\ T^3 - 2.51621 \times 10^{-3}\ T^2 + 0.61074\ T - 53.98632$	$W.m^{-1}.K^{-1}$
Seebeck Coefficient of P-type Semiconductor	$\alpha_P(T) = -\ 1.80268 \times 10^{-7}\ T^4 + 3.23632 \times 10^{-4}\ T^3 - 0,21537\ T^2 + 62.97444\ T - 6616.56781$	$\mu V.K^{-1}$
P-type semiconductor electrical resistivity	$\sigma_P(T) = = -\ 3.08802 \times 10^{-9}\ T^4 + 4.56531 \times 10^{-6}\ T^3 - 2.58541 \times 10^{-3}\ T^2 + 0,65579\ T - 60.58804$	$10^{-5}\Omega.m$
N-type semiconductor thermal conductivity	$\lambda_n(T) = -\ 3.05948 \times 10^{-9}\ T^4 + 4.56781 \times 10^{-6}\ T^3 - 2.51621 \times 10^{-3}\ T^2 + 0,61074\ T - 53.98632$	$W.m^{-1}.K^{-1}$
Seebeck Coefficient of N-type Semiconductor	$\alpha_n(T) = 1.80268 \times 10^{-7}\ T^4 - 3.23632 \times 10^{-4}\ T^3 + 0,21537\ T^2 - 62.97444\ T + 6616.56781$	$\mu V.K^{-1}$
N-type semiconductor electrical resistivity	$\sigma_n(T) = -3.08802 \times 10^{-9}\ T^4 + 4.56531 \times 10^{-6} T^3 - 2.58541 \times 10^{-3}\ T^2 + 0,65579\ T - 60.58804$	$10^{-5}\Omega.m$

A total of 20 Bi2Te3-based TEMs are uniformly distributed over the five dimensions of the geometer, four modules per surface, and a heat exchanger is installed on two sides of the modules, one towards the hearth and the other towards the waist (Figure 3 and 4).

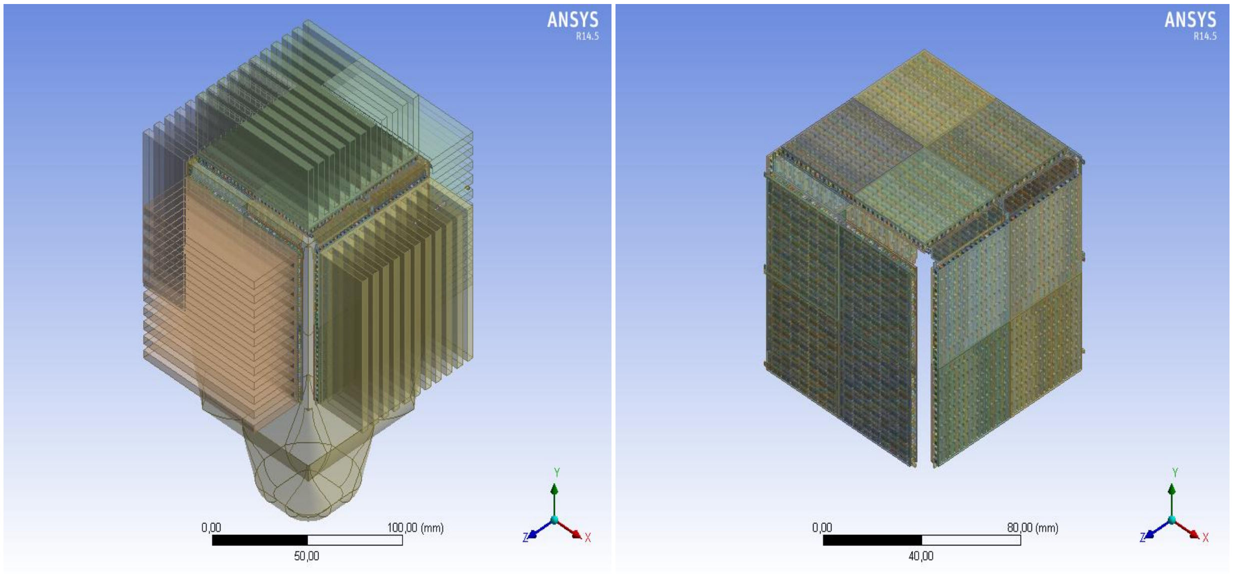

Figure 3. Architecture diagram of the thermoelectric generator system on ANSYS

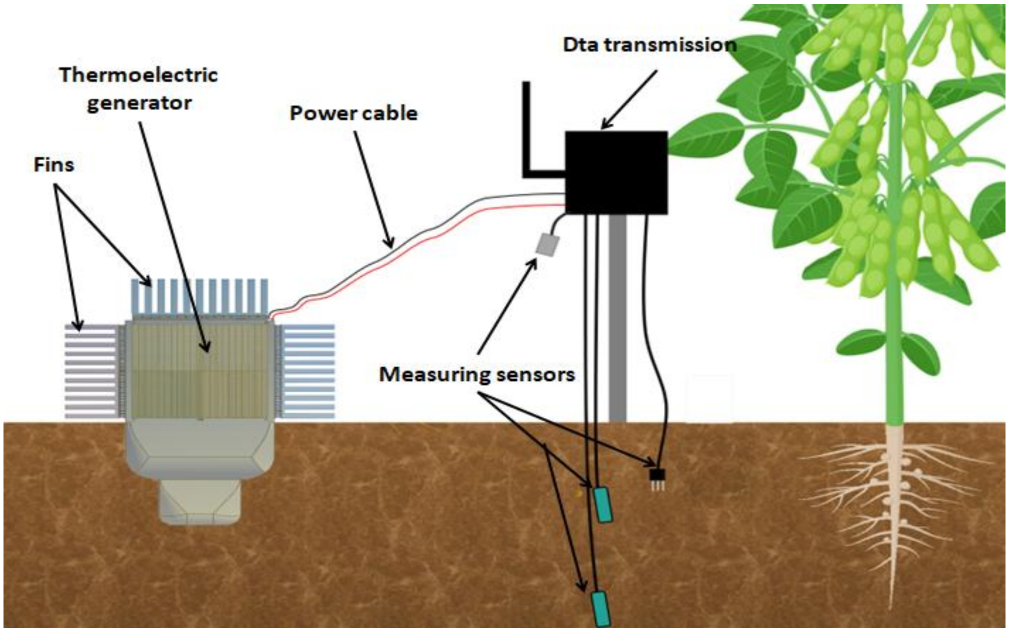

Figure 4. Field thermal generator system for feeding measurement sensors

III. Results and Discussion

1. Thermoelectric module simulation by TeGDS

The TeGDS program makes it easy to simulate and analyze the performance of a Thermoelectric generator as a function of temperature, and also by describing the properties of temperature-dependent materials, geometry and other interface materials. The program is based on an iterative algorithm, that from the outside temperatures, it evaluates the temperature error in the passive elements and it makes it possible to correct the actual temperatures on the thermoelectric elements.

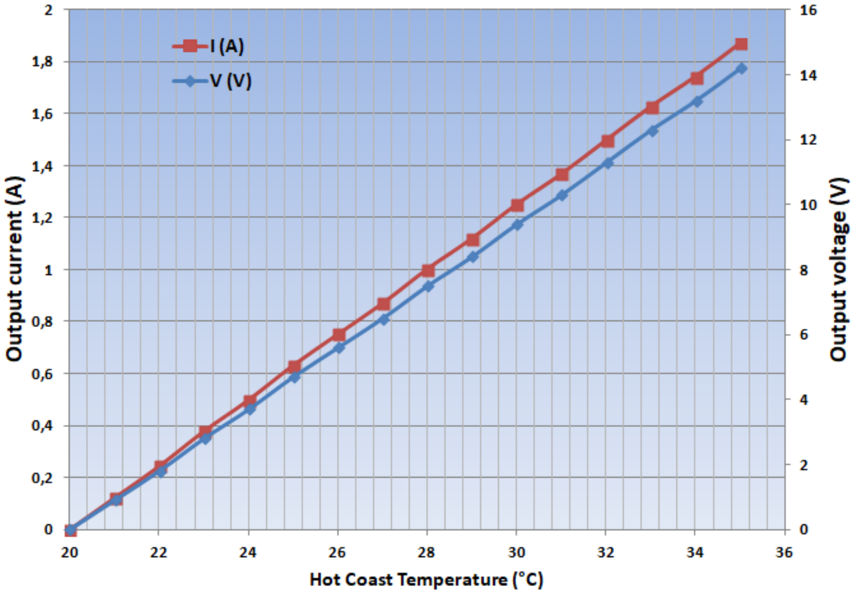

FIGURE 5. Open circuit voltage and current at maximum power of the TEG module as a function of T with *$\Delta T=15°C$*

FIG. 5 shows the voltage Voc and the current IPmax at the maximum power, as a function of the temperature of the hot side, the maximum value of the electric voltage Voc=14,2 V and of the current IPmax=1,8 A.

FIG. 6 shows the variation of the electric power, it increases there as a square function with a maximum value equal to Pmax=2.65 W.

The simulation by TeGDS of 20 thermoelectric modules, with a temperature difference DT=15° C. and a size of the semiconductor elements (1.4 mm×1.4 mm×1.7 mm), makes it possible to obtain a maximum power of P=2.65 W, an electric current at the maximum power I=1.8 A, a maximum voltage Vco=14.2 V.

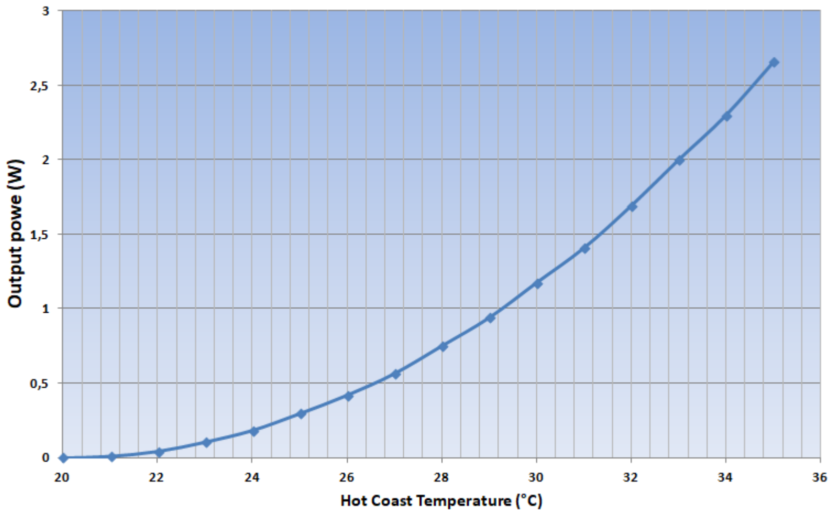

Figure 6. Electrical power of the TEG module as a function of T with *ΔT=15°C*

1. Thermoelectric module simulation by ANSYS

Simulation calculations were performed with an Intel Core i5(R) Core(TM) i5-4210U processor at 1.70 GHz 2.40 GHz, RAM: 4.00 GB. The resolution time depends on the geometer mesh and the power of the machine, several meshes have been tested in order to obtain a compromise between these parameters. Indeed, we have worked with a mesh of the size of the elements of order 5.10^{-4} m. The thermoelectric module simulation on TeGDS was done with boundary conditions namely: the temperature on the hot side Tc=35° C., the temperature on the cold side Tf=20° C. On "ANSYS" the condition of the reference electrical voltage placed on the input surface of the module which is equal to 0 V shall be added.

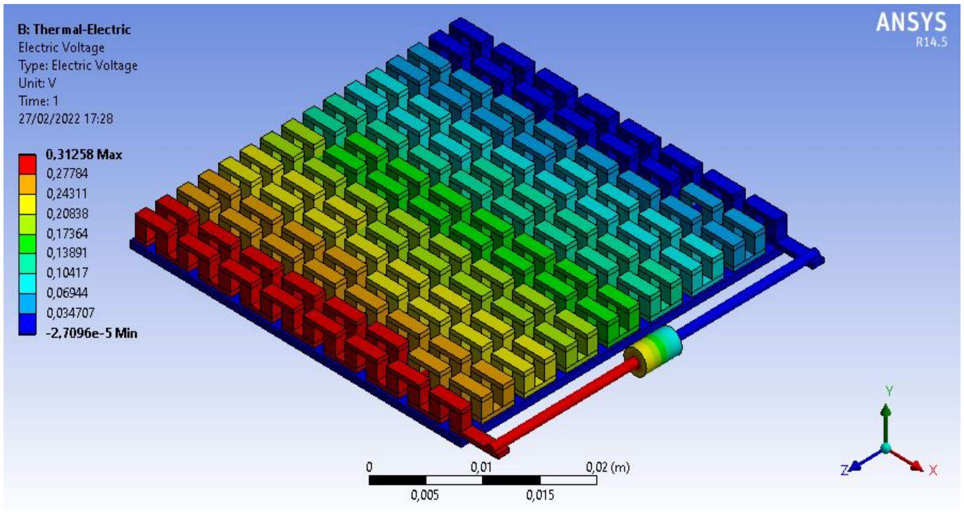

Figure 7. Electrical voltage of thermoelectric generator with ANSYS with *ΔT=15°C*

FIG. 7 shows the voltage gradient in all thermoelectric module pairs in the geometer. Regarding colors, red indicates the maximum voltage and dark blue indicates the ground.

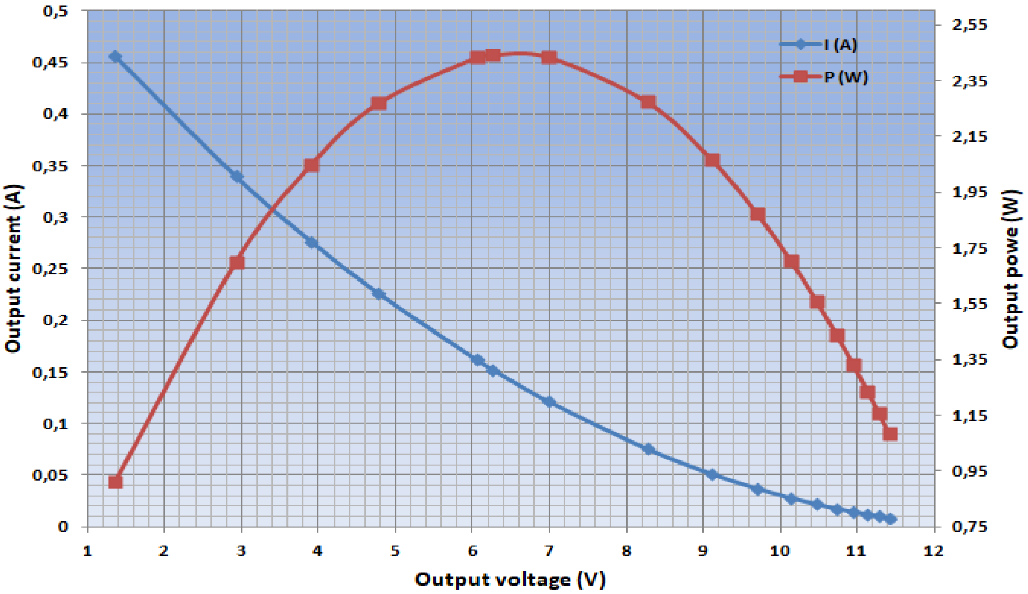

Figure 8. Thermoelectric generator performance (20 TEG) with *ΔT=15°C*

Simulation by "ANSYS" for 20 thermoelectric modules TEC1-12706, at a temperature difference DT=15° C., makes it possible to obtain the maximum voltage Vco=12 V, a current 0.45 A and a power P=2.4 W (FIG. 8).

IV. Conclusion

In this work, we used special software such as "ANSYS" and "TeGDS" to simulate and design an ideal miniature electric generator of geometry "16cm x 16cm x 16cm", by "ANSYS" allows to obtain an electric power of 2.4 W and by "TeGDS" P=2.65 W. This technique of producing energy allows to power electronic devices used in intelligent agriculture.

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