Experimental Study and Simulation of a New Power Supply Method for Intelligent Agricultural Systems by a Thermoelectric System

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Abstract- Agricultural engineering is a multidisciplinary field that integrates technology with agriculture for the design, construction and improvement of agricultural equipment and machinery to achieve more efficient and sustainable agricultural production. The implementation of technologies in the intelligent agricultural field requires a continuous and permanent power supply to operate the IoT systems used. This article presents a new technique for ensuring a thermoelectric generator-based power source for IoT systems used in smart agriculture. The technique presented in this document produces electricity based on the difference in temperature between the ground and the outside environment, using semiconductors based on the Seebeck effect. In this work, «ANSYS» were used as two special software to simulate the architecture of a miniature thermoelectric generator de-vice of dimensions ”6cm x 6cm x10cm”, and the realization of a prototype of a thermoelectric generator, for the production of electricity by converting the thermal energy present in the environment into electricity usable for intelligent agricultural projects.

Keywords Smart agriculture, Power supply, IoT systems, Thermoelectric, Seebeck effect, Renewable energy.

1. Introduction

Currently, digital technology affects all potential sectors of the economy, industry, education, administration and also the farmer. The agricultural sector is becoming and will soon become a direct target of connected objects that enable farm management using recent IoT (Internet of Things) [1] techniques to increase productivity by optimizing time, energy and products [2,3,4]. Indeed, technological innovations have taken place to facilitate the farmer's work while maximizing the resources of our planet [5,6]. Several technologies are used in this field and other technologies are also being developed. The sound of these techniques is based on electrical devices connected to communication networks, namely Wi-Fi, GSM, Internet [7,8]. One of the most important axes for the development of these systems is the optimization of electrical sources by using to power these systems. Indeed, the implementation of IoT techniques in the field of intelligent agriculture requires continuous and permanent power to operate the electronic devices used [9]. In the normal case, IoT systems implemented in smart agriculture can be powered by a conventional power grid, or by photovoltaic sources or both independent electric batteries [10].

These power modes present challenges and technical problems, especially because the traditional energy source requires multiple and long electrical wiring, while the use of photovoltaic energy for each measuring device, Sensor and emission, it is also expensive and impractical, as it requires the use of photovoltaic cells [11] and a storage battery for each of these devices. These solutions are limited by factors such as the proximity of the electricity grid, the location of the measuring sensors and the extent of sun exposure for the photovoltaic solution. In addition, the use of a dry battery is a reliable solution, but it remains costly and requires intervention to replace and control these batteries.

This article presents a new technique that ensures independent and permanent electrical energy based on a TEG (thermoelectric generator) for IoT systems used in intelligent agriculture as well as for IoT-based remote laboratories for students in the field of agricultural engineering. The technique presented in this paper produces electricity based on the temperature difference between the soil and the outside environment, using semiconductors based on the Seebeck effect.

As part of this work, “ANSYS” (ANalysis SYStems) were used as two special software programs to simulate the architecture of a 16 cm x 16 cm ideal geometry mini power generator capable of producing electricity by con version. The aim is to transform the thermal energy present in the environment into electricity suitable for intelligent agricultural projects. The “ANSYS” software is based on the finite element method which uses a simple approximation of unknown variables to transform partial differential equations into algebraic equations [12]. This simulation tool allows the design of a with new hard-ware data and optimizes the geometry by adjusting the parameters. The purpose of the special software simulation was to verify and ensure the realization and implementation of the proposed system for feeding IoT devices in smart agriculture.

The IoT device used in agricultural fields detects, measures and tracks plant growth by measuring indicators related to plant development and growth. These types of devices require continuous and permanent electrical power to power the electrical sensors.

The rest of this document is structured as follows. Section 2 discusses the processes of a thermoelectric generator. Section 3 presents the simulation of a thermoelectric generator. Section 4, the implementation of a prototype used in smart agriculture. Finally, Section 5 presents the results of the simulation and experiment.

2. Process of a Thermoelectric Generator

Thermoelectric effects are based on thermal and electrical phenomena and de-scribe the interaction between heat and electric current in the solar systems [13,14]. In fact, other devices have been developed primarily for energy production or refrigeration. The thermoelectric effects produced in the thermoelectric module include the Seebeck effect, the Peltier effect and the Thomson effect. These three effects represent the fundamentals of thermoelectricity and are linked by Kelvin’s relationships, the Joule effect, and thermal conduction [15,16].

The generation of electrical voltage V at the terminals of two junctions of two different materials, when exposed to a temperature gradient $\Delta T = T_H - T_C$, where T_H and T_C indicate the temperature of the hot and cold sides respectively [16, 17].

The open circuit voltage generated is given by the relation:

$$V_{OC} = \alpha \, \Delta T \tag{1}$$

With α the proportionality coefficient in V.K-1

The heat quantities on the cold side and the hot side are [18]:

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

$$Q_H = \alpha T_H \, I - 0.5 \, R \, I^2 - \Delta T/\theta \tag{3}$$

Where θ is the thermal resistance and R is the electrical resistance of TEG.

The electrical power generated per module is [18]:

$$P = Q_H - Q_C = \alpha \, \Delta T \, I - R \, I^2 \tag{4}$$

And the thermoelectric efficiency [18]:

$$\eta = P/Q_H \tag{5}$$

The efficiency of a thermoelectric generator depends on several factors, such as the temperature of the heating element and the cooling element, the nature of the thermoelectric materials used and the design of the generator. In general, the efficiency of a thermoelectric generator is relatively low. However, it can be improved by using high-performance thermoelectric materials and optimizing the generator design.

Indeed, it is essential to consider these properties for the right choice of a thermoelectric material for energy production or refrigeration by thermoelectric effect [19]. It is no longer easy to identify a suitable thermoelectric material using each separate cleanliness to assess it [20]. Thus, a factor called "merit factor" rated Z or Z_T, such as T is the absolute temperature in K allows to evaluate the quality of a thermoelectric material by combining its three properties, this factor is written [21]:

$$Z = (\alpha^2 \sigma)/\lambda \quad ; \quad Z_T = (\alpha^2 \sigma)/\lambda \, . \, T \tag{6}$$

3. Simulation of the Electrical Perimeters of an TEG

ANSYS is a high-performance simulation software that allows modeling and analysis of various systems and devices, including thermoelectric generators [22,23]. The simulation of a thermoelectric generator in ANSYS generally involves the use of different simulation modules, such as the heat transfer and structural mechanics module [24,25,26]. To simulate a thermoelectric generator in ANSYS, we first need to create a 3D model (Figure 1) of the generator using finite elements. Then we have to define the conditions at the limits of the model, specifying the temperatures of the heating element T_H=40°C and the cooling element T_C=20°C and the condition of the reference electrical voltage placed on the module input surface equal to 0 V must be added.

Figure 1 shows the thermoelectric generator design of our experiment. The purpose of this experiment and to produce electricity belongs to the difference in temperature between the soil and the environment, the use of thermoelectric generators. The proposed structure converts thermal energy into electrical energy and increases the performance of the TEG.

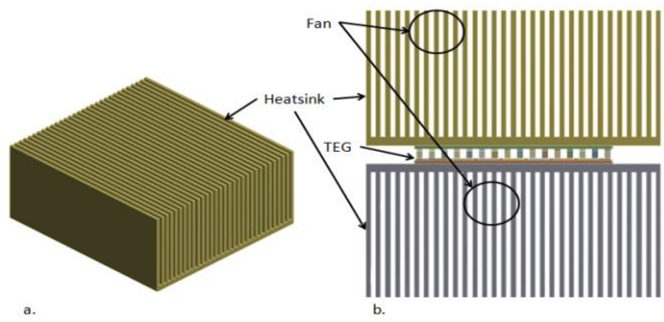


Fig. 1. The measured configurations. a) Heatsink. b) TEG and heatsink. TEG is placed between two heatsink. Heat sinks has the size of 60mm x 60mm x 35mm.

4. Creation of a Prototype Device used in Smart Agriculture

Intelligent agricultural systems are based on parameters or quantities measured by sensors, namely air parameters (Light, temperature, humidity, CO2) and water parameters (pH, temperature, conductivity). Our team worked on the specialized laboratory for the practical work of power electronics for embedded systems [27,29]. The second part represents the electronic systems responsible for sending the measured data to a remote computing center via WI-FI technology. The third party is responsible for producing the electrical energy needed to operate these electronic devices even at night. For this reason, we propose in this work a new technique to ensure an electric power source based on the thermoelectric generator for the IoT systems used in intelligent agriculture as well as for the IoT remote laboratories for the students in the field of agricultural engineering.

The experimental system was designed and built as shown in Figure 2. All components of the thermoelectric generator and data acquisition system are detailed. These are two heat exchangers and a thermoelectric module located between the heat exchangers [29]. Indeed, the data acquisition system contains three temperature sensors (to measure the temperature of the hot side, the temperature of the cold side and the ambient temperature), a microcontroller board EP8266 [30], an LCD display, voltmeter and ammeter to measure voltages and electrical currents. It also contains a MT3608 voltage converter module to control the voltage of the thermoelectric generator at its output.

Figure 3 shows an intelligent agricultural system, with sensors, which feed off the thermoelectric generator

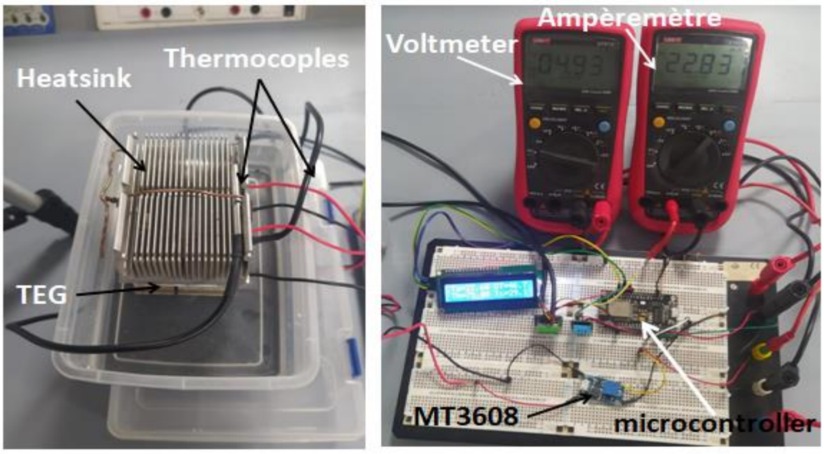


Fig. 2. Intelligent agricultural system

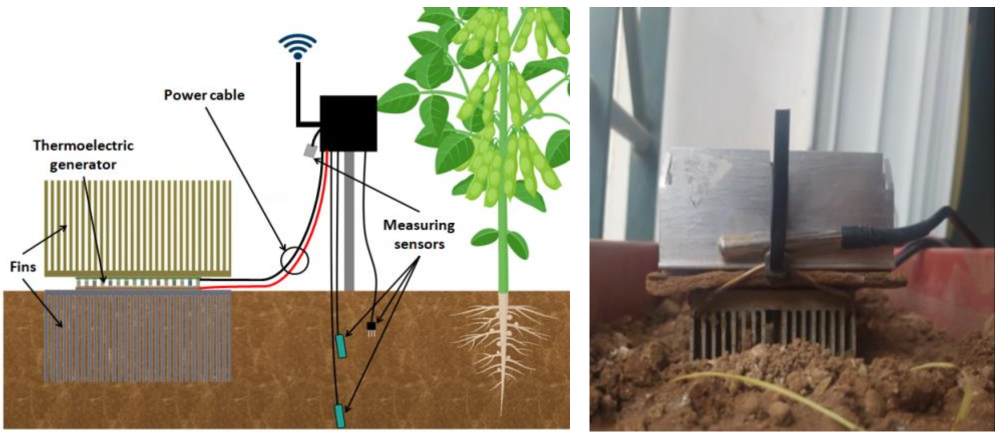
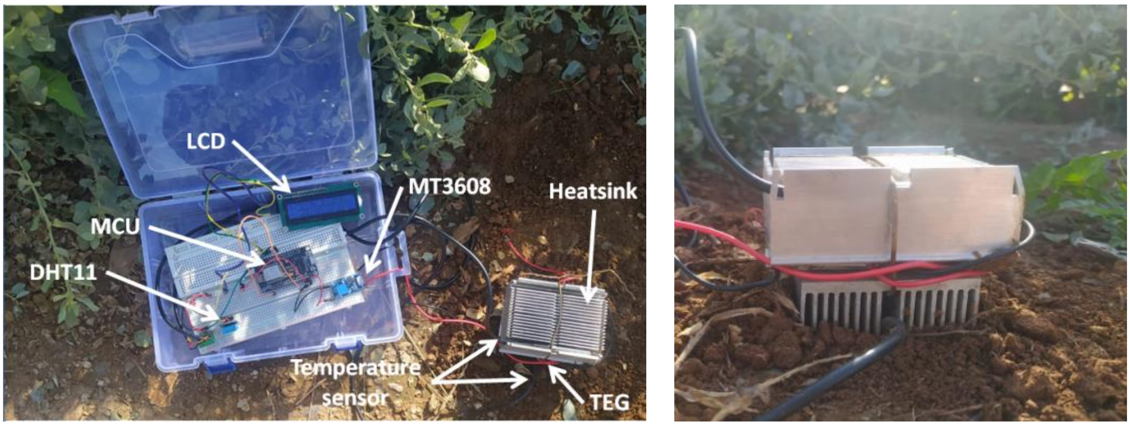


Fig. 3. Architecture diagram of the thermoelectric generator system on ANSYS

Figure 4 shows the data acquisition system installation (Figure 4.a) and TEG (heat sink, Figure 4.b). The TEG module is type SP1848 SA 27145. The heat sinks serve as thermal handsets and are large enough for the temperature sensors to be easily mounted. Two heat sinks can be mounted on both dimensions of the TEG module. A wooden plate is added between the heatsinks to eliminate heat exchanges between them directly. The TEG module is type SP1848 SA 27145; it has dimensions of 40mm x 40mm x 3.9mm.



(a) (b)

Fig. 4. Device realized and electronic circuit developed

To increase heat exchange between heat sinks and TEG can add thermal paste. Thermal and electrical quantities are measured by the MCU ESP8266 electronic board.

The MT3608 is a monolithic boost-type integrated circuit that provides an output voltage higher than the input voltage. It is often used in applications where it is necessary to provide a stable power supply to an electronic or electronic device from a low voltage power source. It is capable of providing up to 2A of output current from a comprise input voltage between 2V and 24V. It has high efficiency (up to 95%) and high switching frequency (up to 1 MHz), making it suitable for use in high-performance circuits. It is also protected against over current and short circuits, and has a function of decreasing the output voltage in case of overheating.

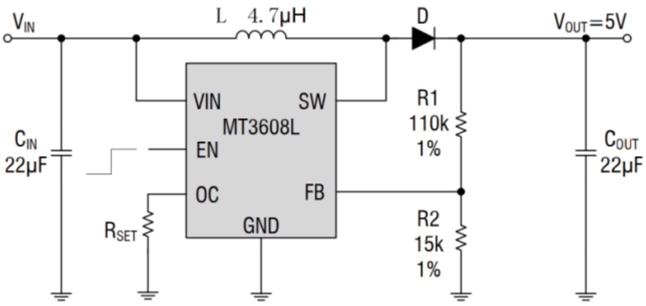


Fig. 5. MT3608 Booster electrical diagram

The MT3608 is small and easy to use, it can be used in a variety of situations, such as to provide a stable power supply to a portable electronic device from a low voltage battery, or to increase the voltage produced by a thermoelectric generator to provide stable power to a microcontroller (MCU). The output voltage (V_{out}) can be calculated according to the internal reference voltage (V_{REF}=0,6V) and resistors R_1 and R_2 by the following relationship:

$$V_{out}=V_{REF}\,(1+R_1/R_2) \quad (7)$$

The maximum output current (Iout) can be calculated as a function of the in-ground voltage (Vint), the under-voltage start voltage (Vstart) and the load resistance (Rload):

$$I_{out}=(V_{int}-V_{start})/R_{load} \quad (8)$$

With Vstart voltage under-voltage is a feature of the MT3608 that defines the minimum voltage at which the voltage booster can operate in a stable manner.

The efficiency equation of the MT3608 is a formula for calculating the efficiency of the voltage booster. It indicates the proportion of electrical energy supplied by the power source (V_{int} I_{int}) that is actually used to power the charge (V_{out} I_{out}).

$$\eta=(V_{out}\ I_{out})/(V_{int}\ I_{int}) \quad (9)$$

5. Results and Discussions

5.1. Results and Simulation of Module TEG par ANSYS

Figure 6 shows the voltage gradient in all pairs of thermo-electric modules of the geometer. For colours, red indicates the maximum voltage and dark blue indicates the mass. The "ANSYS" simulation for a TEG SP1848 SA 27145 thermoelectric module, at a temperature difference ΔT=20°C.

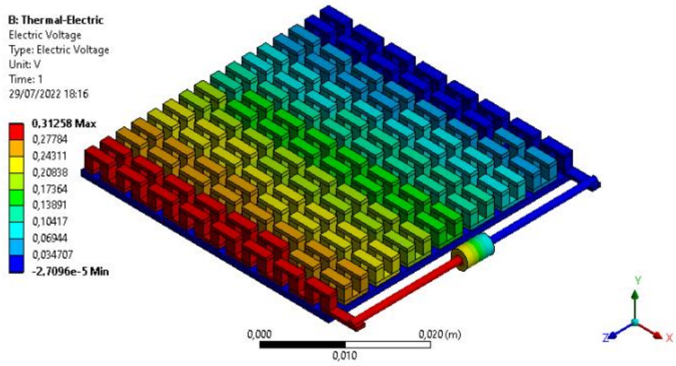


Fig. 6. Open circuit electrical voltage of thermoelectric generator with ANSYS with ΔT=20°C

Figure 7 shows the current-voltage characteristic of the thermoelectric generator, with a maximum voltage V_{CO}=1,9 V, a current I_{max}=53,44mA, and a power P_{max}=44,57mW. The current-voltage characteristic at a function (I = 0,0529

V^2 - 28,116V+ 54,851) which is almost linear, this function is identical to the literature of the thermoelectric module.

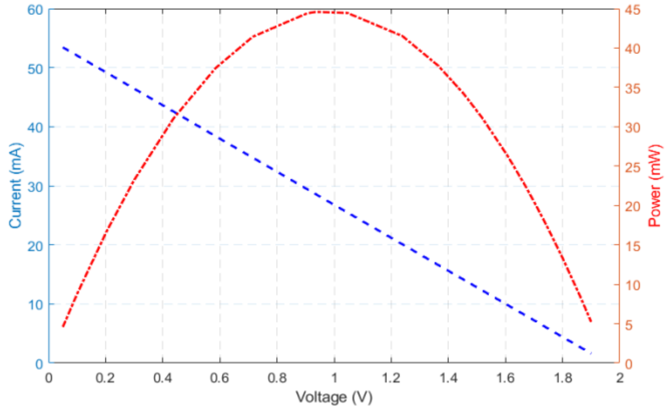


Fig. 7. Thermoelectric generator current-voltage characteristic with ΔT=20°C

The power-voltage characteristic of the thermoelectric generator followed by the function ($P=-46,473V^2+ 90,98V + 0,1279$), the same as the characteristic current voltage this function is identical to the literature of the thermoelectric module.

5.2. Results of Measurements Carried out on the Completed Prototype

The purpose of the experiments we do in this work is to show that it is possible to produce an equal electrical power of the temperature difference between the soil and the environment. This is why the experiments were in real conditions and we see the electricity production at the temperature difference.

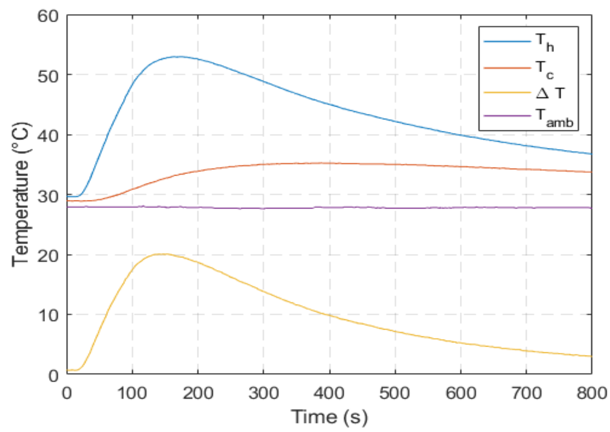
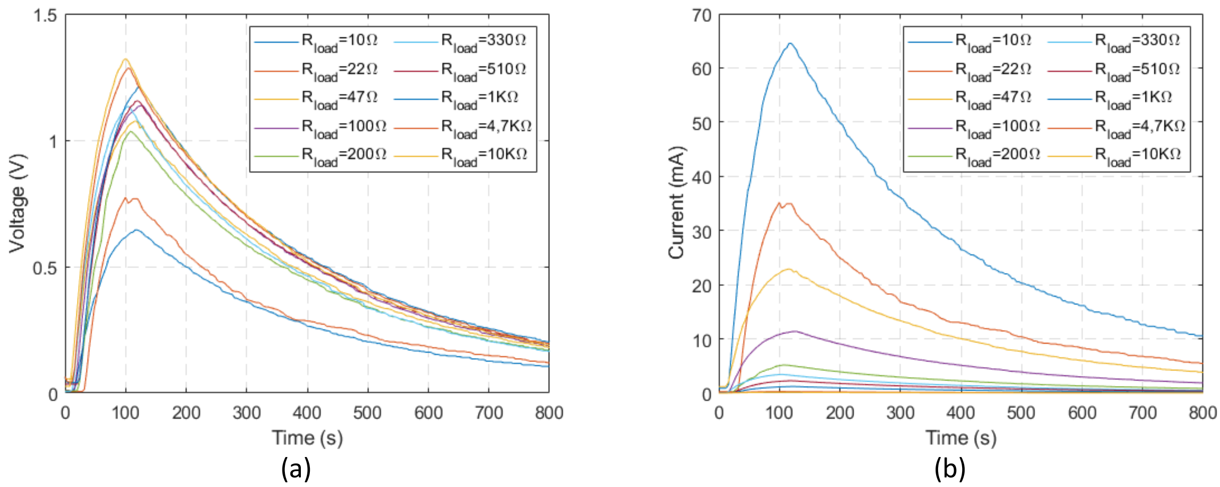
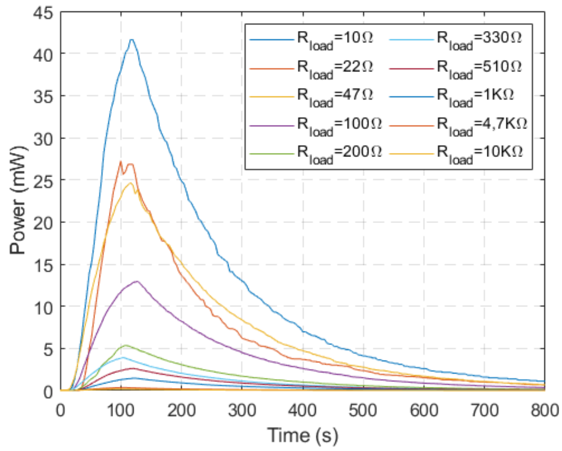


Fig. 8. Temperature variation in heat exchangers and ambient temperature

Figure 8 shows the temperature variations for the two heat exchangers (T_C, T_H), its difference (ΔT) and the ambient temperature (T_{amb}). We rely on the differential temperature variation of the heat exchangers to evaluate the production of TEG. We use this temperature variation to see electrical quantities and their variation, and access the experimental relationship between electrical quantities and temperature.

Figure 9 shows the production of thermoelectric generators, both voltage and current and power. For the voltage figure 9 (a) shows its variation over time with the external electrical resistance values of the rectifiers. The electrical voltage generated by TEG is increased by increasing the external resistance. Figure 9 (d) shows the variation of the generator voltage as a function of the temperature difference between heat exchangers having different TEG external resistance values. The current also increases with temperature; Figure 9 (b) shows its variation with time and load resistance. Electrical power varies over time, such as current and voltage (Figure 9 (c)).





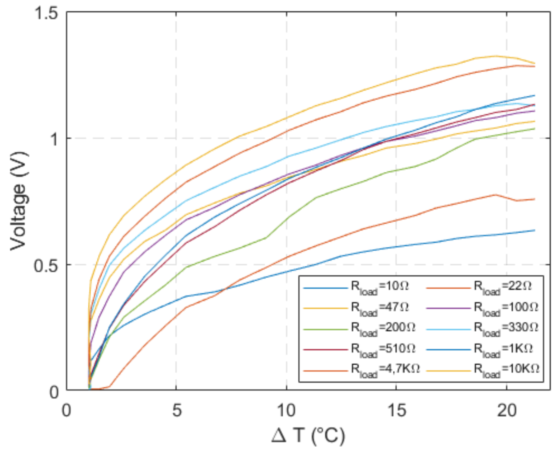


Fig. 9. Voltage, Electrical Current and Electrical Power Generated by the TEG Module

The curves of the experimental study results have a maximum electrical power at ΔT_{max}=20°C, a voltage of V_{max}=1.32V, I_{max}=64.51mA and a power of P_{max}=41.62mW.

We participated in this study on a new technique of electricity production, based on the results of the simulations of the thermoelectric generator, which we made by the software ANSYS. Generators produce enough energy to power intelligent agricultural systems. The experimental study confirmed the simulation results. This system can be developed by increasing the thermoelectric generators used to increase the power produced by the system and can also increase the temperature difference of both ends of the system. To use a thermoelectric generator to power other systems, it is necessary to determine the power of its operation, to determine the number of thermoelectric modules you will need, and the temperature difference to produce the required power. However, there are limitations to this approach, particularly as regards dependence on an external heat source and the need to maintain a sufficiently high temperature difference between conductive materials. We also discuss the implications of these findings for the future use of this system in SAIs and other applications.

6. Conclusion

In this article, we present a new method of power supply for intelligent agricultural systems based on a thermoelectric system. The thermoelectric system is a device that converts thermal energy into electricity thanks to the Seebeck effect. We conducted an experimental study to test different configurations of the thermoelectric system in the laboratory and measured the electrical power produced as a function of the temperature difference between the conductive materials. We also simulated the use of this system to feed an intelligent agricultural system using real climate data. Our results show that the thermoelectric system can be reliably used to power intelligent agricultural systems.

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