New Journal For Science Vulgarization

Vol 1, N0 2 (2021) 54–62

Autonomous solar cooker with photovoltaic energy

Mohammed Rhiat [a] , Noureddine El Moussaoui [a], Khalil Kassmi [a,c*], Rachid Malek [a],

Olivier Deblecker [b], Najib Bachiri[c]

[a] Mohamed First University, Faculty of Science, Department of Physics, Laboratory of Electromagnetic, Signal Processing & Renewable Energy LESPRE, Team Electronic Materials & Renewable Energy EMRE, Oujda, Morocco
[b] University of Mons, Polytech. Mons - Electrical Power Engineering Unit, Mons, Belgium
[c]Association Humain and Environnement of Berkane (AHEB), Berkane, Morocco.

Abstract

In this paper, we propose the design and operation of solar cookers (hot plates and box ovens) using photovoltaic energy. The electrical energy to feed the thermal resistances of these cookers is provided by the photovoltaic (PV) panels, via a DC/DC power converter of Boost type equipped with a specific electronic control. The typical experimental results, during the heating of one liter of water, show, for a photovoltaic power of 600 Wp, a frequency of the DC/DC converters of 30 kHz, an illumination and an ambient temperature of the order of 998 W/m^2 and 22°C, very satisfactory performances: powers at the input and there at the output of the converter respectively of the order of 476. 8 W and 465.1 W (i.e. an efficiency of 97 %), temperature of the thermal resistances of 660°C after 20 seconds, rise of the water heating temperature from 24°C to 49°C after 5 minutes and boiling temperature of 98°C after 18 minutes of heating.

All these results show the feasibility of operation of the proposed cooker and thus its use inside or outside the homes for heating and daily cooking (water, meals,…).

Keywords: Cooker, hot Plate, Box Oven, DC/DC Boost converter, photovoltaic panels, solar energy, Electronic Bloc, Digital Circuit

*Corresponding author. Tel: +212678075214
E-mail address: khkassmi@yahoo.fr k.kassmi@ump.ac.ma

1. Introduction

Energy needs for cooking and heating are increasing globally; while conventional energy resources are not only in limited supply but also the most polluting [1-10]. A survey revealed that half of the world's population burns wood from forests to cook food and provide thermal comfort. Thus, fifty percent of the world's population is exposed to indoor air pollution from burning wood for cooking and heating [1]. The use of conventional energy sources therefore has adverse effects on the environment and global warming. Currently, a lot of research on renewable energy sources (solar,)) and the replacement of fossil fuels by these sources [4,5]. In addition, the use of solar energy has become an urgent need for the clean and sustainable development of the energy sector, globally [11]. Solar energy is freely and abundantly available all year round and can be efficiently used to supply electrical or thermal energy to different types of domestic and industrial applications [12-16]; solar cookers, desalination of subterranean and sea water, solar drying,

In the case of household cooking, energy consumption has become increasingly important and costly. This requires the development of alternative, appropriate and affordable cooking methods with competitive costs, especially in developing countries [17]. The integration of solar energy is therefore a practical, competitive, sustainable method of cooking that reduces greenhouse gas emissions. Currently, a lot of research is being carried out on solar cookers in order to propose equipment that can be adapted to the needs of the users [4-9]. The main works concern box ovens [18-20] or concentration cookers [4,5] which are used outside the home. The performance of these ovens is limited (temperature rise, efficiency) and their use requires the intervention of users to orientate these cookers in relation to the sun. However, there is an absence of autonomous solar cookers running on photovoltaic solar energy [8]. In this context, we propose within the framework of national and international projects the development of solar cookers with photovoltaic solar energy, adaptable to the needs of users outside and inside homes in Africa and Europe.

In this work, we propose the design and testing of solar cookers (hot plate and box Oven) operating on photovoltaic energy, with a power of 600 Wp. Particular attention is paid, during the heating of a liter of water, to the electrical quantities (voltage, current and power) of the proposed DC/DC converter, according to the duty cycles of the PWM controls of the power switches, to the transfers of the power supplied by the photovoltaic panels to the thermal resistor, and to the heating temperatures of these resistors and proposed ovens.

2. Structure and functioning of the system

Figure 1 shows the block diagram of the proposed panel-fed cooker system. This system is designed to provide power and heat resistances at high temperature (1000°C). The different blocks of this system are :

- PV panels with a total power of 600 Wp to produce PV energy and power the power block.
- A PV panel of 50 Wp to supply the power board.
- Power box, control and command acquisition formed by :

- ✓ Control, supervision and display board for the operation of the whole system. This board is equipped with a continuous power supply circuit for all the active components of the box.
- ✓ Power block sized according to the power of use. It is formed by a DC/DC converter, whose power switches are controlled by an electrical circuit that provides PWM signals of frequency f and duty cycle α. These PWM signals regulate the electrical power supplied by the PV panels and therefore the temperature of the cookers, playing on the duty cycle α.
- ✓ Electronic relay for system start/stop, controlled by the control board.
- ✓ ON/OFF button to start/stop the system operation. This button connects/disconnects the PV panels.
- ✓ LCD display that shows, by acting on the rotary encoder, the operating mode, electrical values of the DC/DC converter (voltages, currents, powers, yields, α duty cycle).
- ✓ Inputs intended for the connections of the two types of PV panels (2*300Wp, 1*50Wp).
- ✓ Cookers :
  - Hot plate: Heated by a thermal resistor of value 15 Ω by operating a switch, dimensions (length 50 cm, width 32 cm),
  - Box Oven heated by two resistors housed inside the oven: one at the bottom and one at the top. During the operation we activate either the bottom one or the top one.

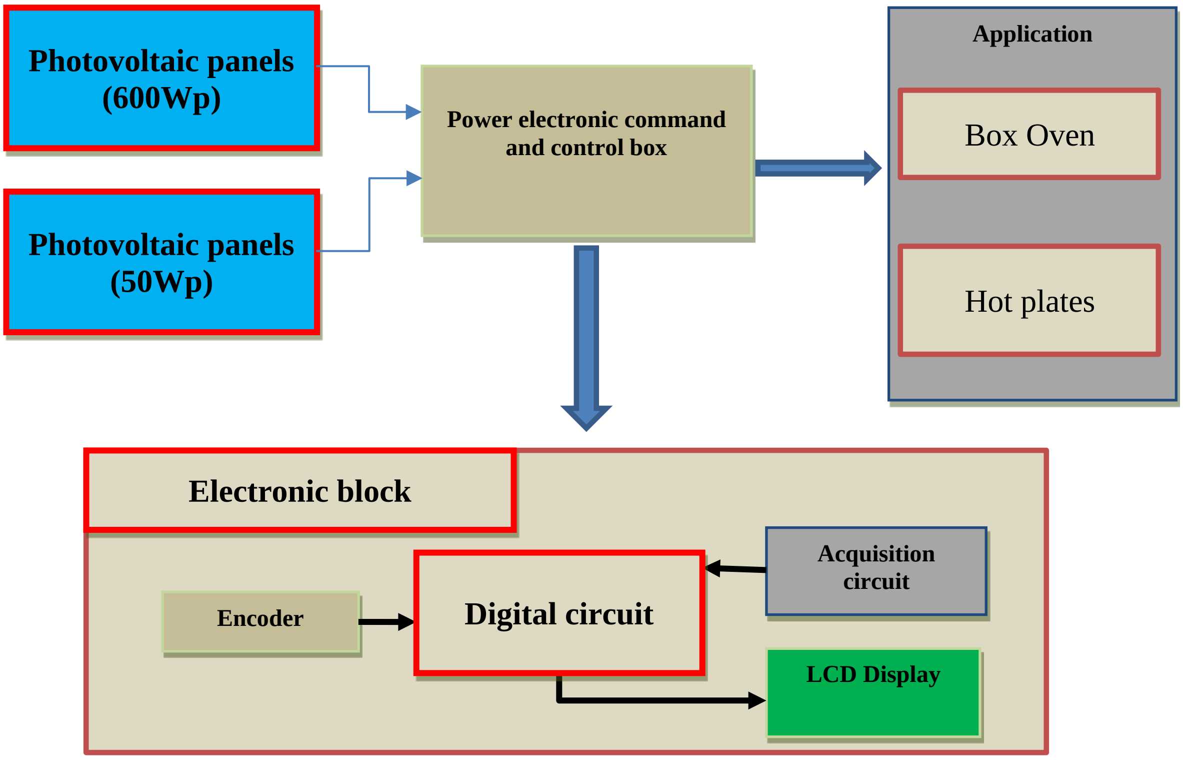


Fig. 1. synoptic diagram of the cooker (hot plate and box oven), powered by photovoltaic panels.

3. Results and discussions

3.1. *Description of the experimental procedure and measurement equipment*

The complete system for powering the cookers through the photovoltaic (PV) panels is shown in Figure 2. This system has the following specifications:

- Heating of the cookers (Hot Plate and Box Oven) by photovoltaic panels energy,
- Power block is formed by a synchronous DC/DC converter of BOOST type, operating at a frequency of 30 kHz and a power of 500-600 W.
- Electronic control block is formed by a Microcontroller, to perform the tasks:
    - ✓ Generation of PWM signal according to the operating mode (Automatic),
    - ✓ Automatic variation of Duty cylcle α,
    - ✓ Acquisition of electrical quantities (Duty cycles, voltages, currents, powers and yields) and display on LCD and computer screen.
- Hot Plate and Box Oven heated by two thermal resistances supporting a temperature of 1000°C, a power of 800 W. A resistance is a metal wire, 90 cm long, curled and mounted on a circular ceramic plate.
- The meteorological quantities (Illumination and ambient temperature) are taken by the meteorological station set up in the laboratory,

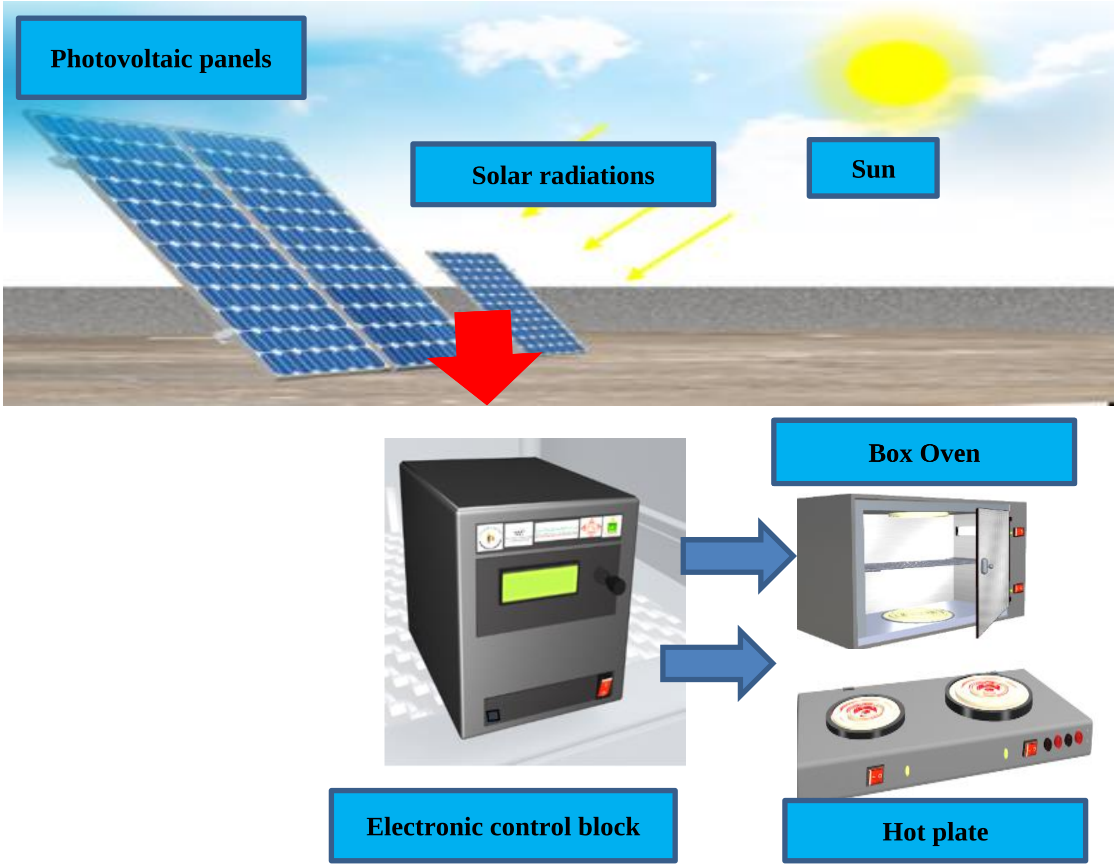


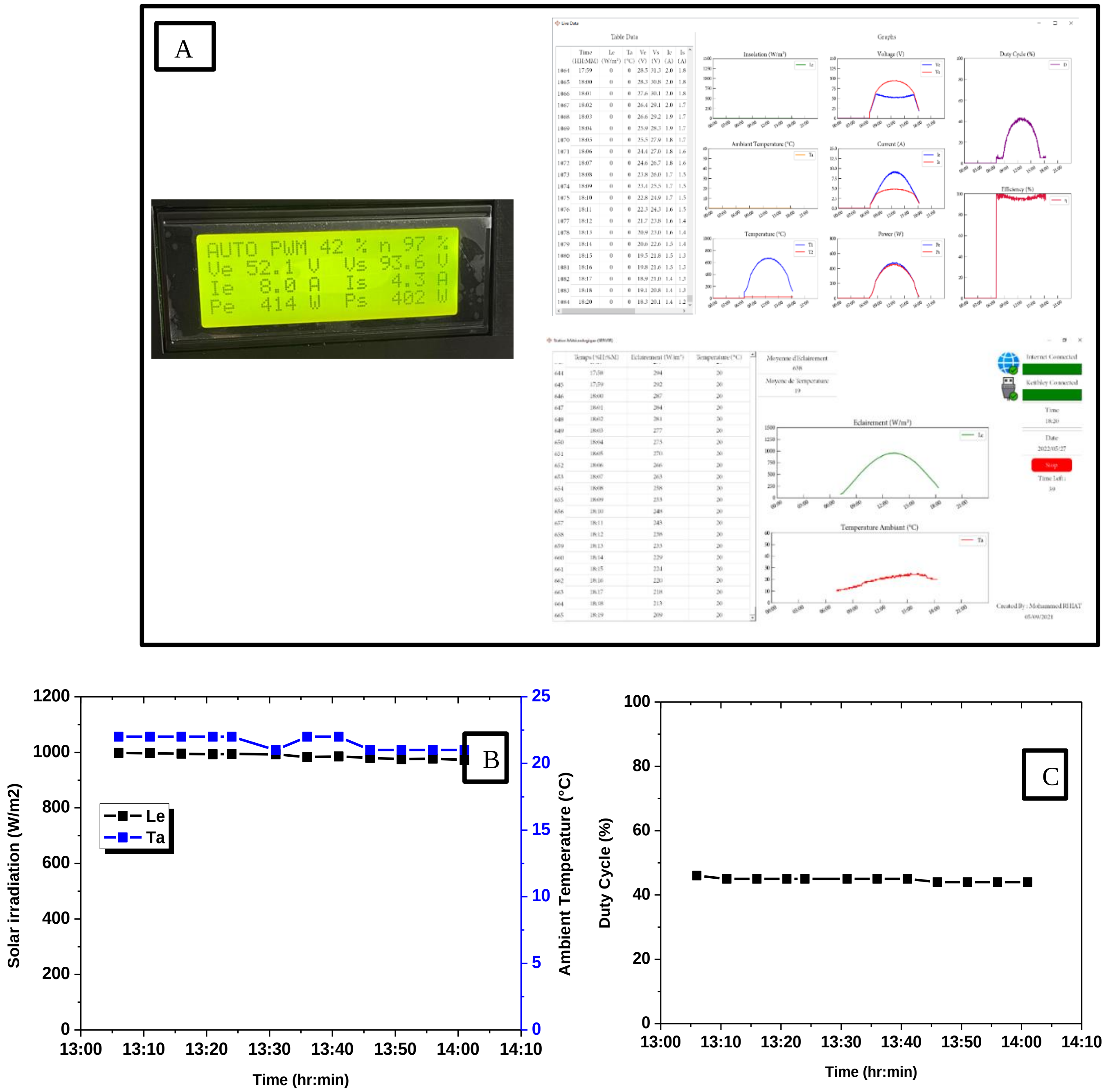
Fig. 2 : Synoptic diagram of the proposed cooker (Hot plate and box oven).

3.2. *Experimental results*

We experimented the system proposed in figure 2 for the heating of one liter of water. For each 5 minutes, we measured the electrical values at the inlet and outlet of the system. The typical results obtained, during a sunny day represented in figure 3, show:

- The illuminance and the ambient temperature reach respectively the maximum values of the order of 998W/m^2 and 22°C.
- The voltages and currents at the input of the converter are respectively of the order of 52.4 V and 9.1 A, and at the output of the order 96.9 V and 4.8 A.
- The powers at the input and there at the output of the converter are respectively of the order of 476.8 W and 465.1 W, i.e. an efficiency of 97%.
- The temperature of the thermal resistor reaches the value of 300°C after 5 seconds of heating (i.e. 60°C/s) and the maximum value reached of 660°C after 20 seconds.

- During 5 minutes of heating, the water temperature varies from 24°C to 49°C, i.e. 3.8°C/min. In this case, the thermal efficiency is about 75%.
- After 18 minutes of heating, the water reaches the maximum boiling temperature, which is 98°C.



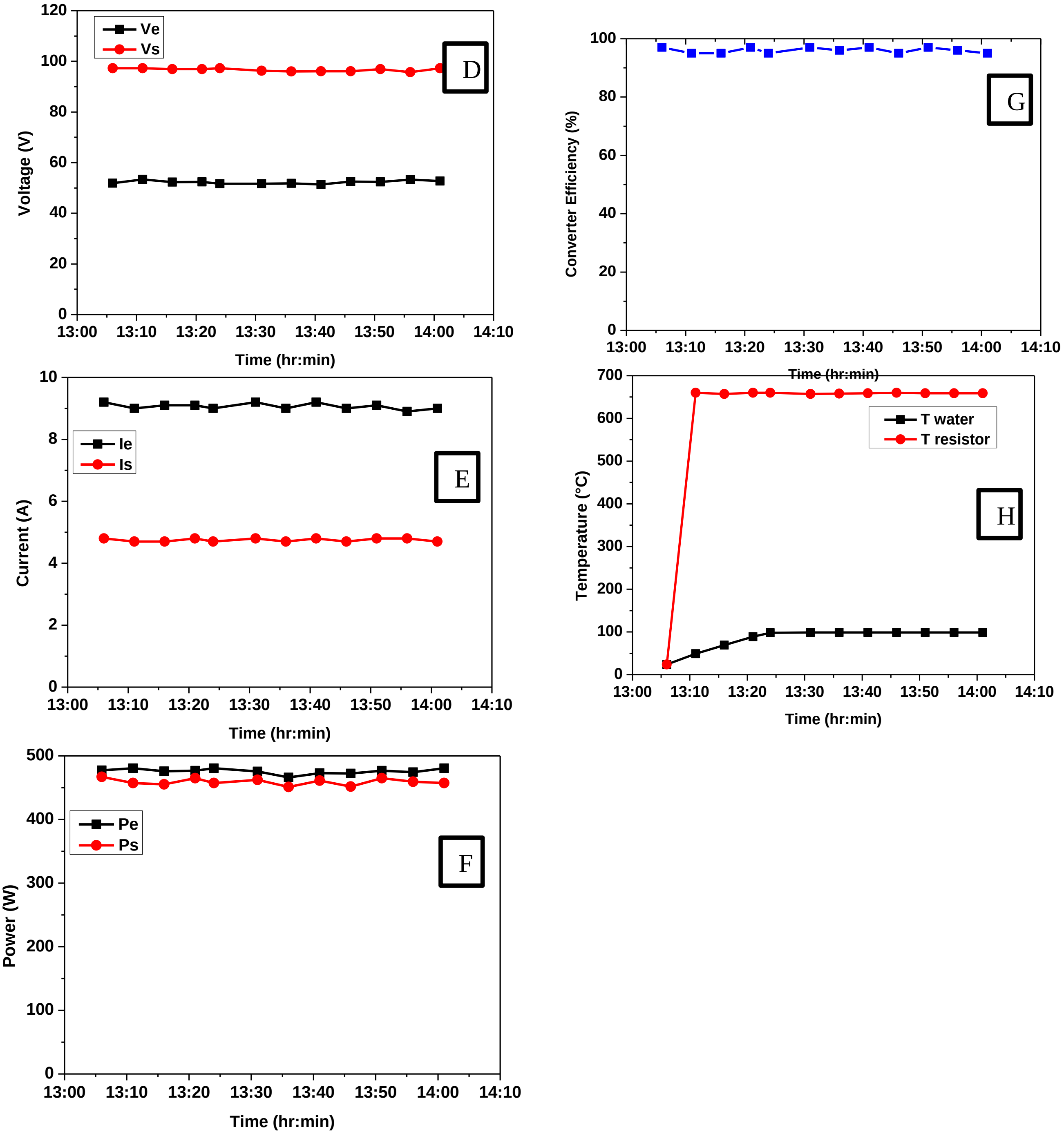


Fig.3 : Experimentation of the cooker (hot plate) (**Figure 2**) while heating one liter of water.

A : Display of the acquired quantities on LCD and computer screen.
B : Illumination and external temperature,
C : Duty cycle of the DC/DC converter,
D : Input and output voltage of the DC/DC converter
E : Input and output current of the DC/DC converter
F: Power of the photovoltaic generator and the heating resistor
G: Efficiency of the DC/DC converter
H: Temperature of the heating resistor and water

4. Conclusion

In this paper, we have presented the design and experimental results of a new technique of powering hot plates and solar ovens with photovoltaic panels, with a power of 600 Wp, through a DC/DC BOOST converter, equipped with a digital PWM control. The experimentation of the proposed cooker by heating one liter of water shows its feasibility and thus its use inside or outside homes: converter efficiency of 97 %, heating temperature rise time of 3.8°C/min, boiling temperature (98°C) after 18 min of heating and thermal efficiency of 75%.

In perspective this work is continued, within the framework of the projects engaged by the team, in order to propose solar cookers functioning at a power of the photovoltaic panels of 1.2 kWp.

5. Acknowledgment

This research is supported within the framework of the projects:

- Morocco-Wallonie Brussels Cooperation Program (2018– 2022), Wallonie-Bruxelles-International (WBI) (Belgium), project 4, n°2,
- Solar Indoor Cooking Systems of the Next Generation SoCoNexGen project (2022-2025) is part of the Long-term Europe Africa Partnership on Renewable Energy LEAP-RE programme. LEAP-RE has received funding from the European Union's Horizon 2020 Research and Innovation Program under Grant Agreement 963530.
- National Initiative for Human Development INDH, Berkane Province, Morocco, project 2017//29.

6. References

[1] SENTHIL, Ramalingam. Enhancement of productivity of parabolic dish solar cooker using integrated phase change material. Materials Today: Proceedings, 2021, vol. 34, p. 386-388.

[2] AL-NEHARI, Hamoud A., MOHAMMED, Mahmoud A., ODHAH, Abdulkarem A., et al. Experimental and numerical analysis of tiltable box-type solar cooker with tracking mechanism. Renewable Energy, 2021, vol. 180, p. 954-965.

[3] ABD-ELHADY, M. S., ABD-ELKERIM, A. N. A., AHMED, Seif A., et al. Study the thermal performance of solar cookers by using metallic wires and nanographene. Renewable Energy, 2020, vol. 153, p. 108-116.

[4] EL MOUSSAOUI, Noureddine, TALBI, Sofian, KASSMI, Khalil, et al. Parabolic Trough Solar Thermal Cooker (PSTC). In : 2020 1st International Conference on Innovative Research in Applied Science, Engineering and Technology (IRASET). IEEE, 2020. p. 1-6.

[5] EL MOUSSAOUI, Noureddine, TALBI, Sofian, ATMANE, Ilyas, et al. Feasibility of a new design of a Parabolic Trough Solar Thermal Cooker (PSTC). Solar Energy, 2020, vol. 201, p. 866-871.

[6] KHALLAF, A. M., TAWFIK, M. A., EL-SEBAII, A. A., et al. Mathematical modeling and experimental validation of the thermal performance of a novel design solar cooker. Solar Energy, 2020, vol. 207, p. 40-50.

[7] VERMA, Sunirmit, BANERJEE, Sanjib, et DAS, Ranjan. A fully analytical model of a box solar cooker with sensible thermal storage. Solar Energy, 2022, vol. 233, p. 531-542.

[8] ATMANE, Ilias, EL MOUSSAOUI, Noureddine, KASSMI, Khalil, et al. Alternating multi-stage maximum power point tracking controlled parallelled photovoltaic systems for "solar cooker". International Journal of Circuit Theory and Applications, 2021, vol. 49, no 11, p. 3908-3921.

[9] HEREZ, Amal, RAMADAN, Mohamad, et KHALED, Mahmoud. Review on solar cooker systems: Economic and environmental study for different Lebanese scenarios. Renewable and Sustainable Energy Reviews, 2018, vol. 81, p. 421-432.

[10] KHATRI, Rahul, GOYAL, Rahul, et SHARMA, Ravi Kumar. Advances in the developments of solar cooker for sustainable development: a comprehensive review. Renewable and Sustainable Energy Reviews, 2021, vol. 145, p. 111166.

[11] HOSSEINZADEH, Mohammad, FAEZIAN, Ali, MIRZABABAEE, Seyyed Mahdi, et al. Parametric analysis and optimization of a portable evacuated tube solar cooker. Energy, 2020, vol. 194, p. 116816.

[12] KHATRI, Rahul, GOYAL, Rahul, et SHARMA, Ravi Kumar. Advances in the developments of solar cooker for sustainable development: a comprehensive review. Renewable and Sustainable Energy Reviews, 2021, vol. 145, p. 111166.

[13] SANSANIWAL, Sunil Kumar, SHARMA, Vashimant, et MATHUR, Jyotirmay. Energy and exergy analyses of various typical solar energy applications: A comprehensive review. Renewable and Sustainable Energy Reviews, 2018, vol. 82, p. 1576-1601.

[14] APAOLAZA-PAGOAGA, Xabier, CARRILLO-ANDRÉS, Antonio, et RUIVO, Celestino Rodrigues. Experimental thermal performance evaluation of different configurations of Copenhagen solar cooker. Renewable Energy, 2022, vol. 184, p. 604-618.

[15] KEITH, Angad, BROWN, Nick John, et ZHOU, John L. The feasibility of a collapsible parabolic solar cooker incorporating phase change materials. Renewable Energy Focus, 2019, vol. 30, p. 58-70.

[16] EL MOUSSAOUI, Noureddine, LAMKADDEM, Ali, RHIAT, Mohammed, et al. Power system of DC/DC applications: Case of cooking. Materials Today: Proceedings, 2022.In press.

[17] THIRUGNANAM, C., KARTHIKEYAN, S., et KALAIMURUGAN, K. Study of phase change materials and its application in solar cooker. Materials Today: Proceedings, 2020, vol. 33, p. 2890-2896.

[18] TALBI, Sofian, KASSMI, Khalil, et MALEK, Rachid. Modeling and simulation of a solar oven box-type with thermal storage. In : 2016 International Renewable and Sustainable Energy Conference (IRSEC). IEEE, 2016. p. 348-352.

[19] YUSUF, S. O., GARBA, M. M., MOMOH, M., et al. Performance evaluation of a box-type solar oven with reflector. International Journal of Engineering and Science (IJES), 2014, vol. 3, no 9, p. 20-25.

[20] NETO, Raimundo Vicente Pereira, DE SOUZA, Luiz Guilherme Meira, DE LIMA, Jaciel Cardoso, et al. Theoretical-experimental study of a box-type solar oven made from disused recyclable elements. Solar Energy, 2021, vol. 230, p. 732-746.