INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Y. El Alami et al., Vol.14, No.2, June, 2024

Design and Realization of a Descretized PV System with an Improved MPPT Control for a Better Exploitation of the PV Energy

Yassine El Alami*, Ali Lamkaddem**, Houssam Amiry*, Rachid Bendaoud***, Fatima Chanaa****, Said Bounouar*****, Said Dlimi******, Khalil Kassmi**, Elhadi Baghaz*‡, Rachid Malek**, Said Yadir *******, Mohammadi Benhmida*

*Laboratory of Electronics, Instrumentation and Energy, Faculty of Science, Chouaib Doukkali University, El Jadida, Morocco.

**Department of Physics, Faculty of Science, Laboratory of Electromagnetic Mohamed First University, Signal Processing & Renewable Energy LESPRE, Team Electronic Materials & Renewable Energy EMRE, Oujda, Morocco.

***Interdisciplinary Laboratory for Research in Science, Education, and Training, Higher School of Education and Training-Berrechid, Hassan First University, Berrechid, Morocco.

****Systems Control, Pilotage and Supervision Team, Engineering Sciences and Professions Laboratory, ENSAM, Moulay Ismaïl University, Meknes, Morocco.

*****Departement of Electrical Engineering, National Higher School of Arts and Crafts, Hassan II University, casablanca, Morocco.

******Departement of Physics, Laboratory of Sciences and Technologies of Information and Communication, Faculty of Science, Chouaïb Doukkali University, El Jadida, Morocco.

*******Laboratory of Materials, Processes, Environment and Quality, National School of Applied Sciences, Cadi Ayyad University, Safi, Morocco.

(yassineelalami97@gmail.com, ali.lamkaddem@gmail.com, baghaz.e@ucd.ac.ma, houssam.amiry@gmail.com, rbendaoud27@gmail.com, fatima.chanaa.ing@gmail.com, bounouar.said@gmail.com, dlimi1975@gmail.com, kassmiikha@gmail.com, rachidmaleke@gmail.com, yadir1976@yahoo.fr, Bemihda@gmail.com)

‡ Corresponding Author; Elhadi Baghaz, Laboratory of Electronics, Instrumentation and Energy, Faculty of Science, Chouaib Doukkali University, El Jadida, Morocco, baghaz.e@ucd.ac.ma

Received: 18.06.2023 Accepted:23.07.2023

Abstract-This work examines the performance enhancement of the studied PV system, composed of a lower stage and an upper stage connected in series. Both stages are outfitted with a photovoltaic generator, a Boost DC/DC converter commanded by improved MPPT control is provided with a specific power control (SPC). The comparative study shows a better compatibility between the measured electrical quantities corresponding of the studied PV system and the obtained simulation results. Comparing the outcomes with a standard photovoltaic system operating in a single stage reveals a 3% increase in inverter efficiency and a 20% increase in photovoltaic power generation. The findings state that the developed discretized photovoltaic system could improve the reliability of photovoltaic systems in case of possible malfunctions which contributes to reducing their cost.

Keywords*:* Photovoltaic (PV) system, efficiency, illumination, acquisition, discredited PV system, PV Panels, PV energy, specific power control (SPC).

Nomenclature

Ipv1(Ipv2)	PV panel current of the low (High) stage	Is1(Is2)	Output DC/DC converter current of the low (high) stage
Vpv1(Vpv2)	PV panel voltage of the low (high) stage	Vs1(Vs2)	Output DC/DC converter voltage of the low(high) stage
Ppv1(Ppv2)	PV panel power of the low (high) stage	Ps1(Ps2)	Output DC/DC converter power of the low(high) stage
Istotal (Vstotal, Pstotal)	Total output current (voltage, power) of the global PV system	Global efficiency	Global efficiency of the PV system
Efficiency 1	Efficiency of the low stage	Efficiency 2	Efficiency of the high stage
α1(α2)	Duty cycle of the low (high) stage of the PV system	L	Inductor (H)
ΔiL	Variation of the inductor current (A)	G	Solar irradiance (W/m2)

1. Introduction

Authors solar photovoltaic (PV) energy is currently undergoing rapid development worldwide, with the aim of becoming an economical and competitive alternative to fossil fuels [1], [2]. However, the use of PV systems poses many challenges in terms of reliability and cost [3–7]. In conventional solar PV systems, which use solar panels with a single matching stage [8–18], the operation of the solar panels in optimal conditions is uncertain, especially under irregular light conditions. Conventional MPPT controls cannot have a trade-off between speed and accuracy. Moreover, any failure at this stage results in the loss of all the energy produced by the photovoltaic generators [17]. To solve this problem, it is necessary to implement a new photovoltaic panel topology, called discretized PV topology, which involves energy production through several adaptation steps. Each photovoltaic panel, or group of panels, has its own adaptation steps, allowing producing energy independently of anomalies on the cells or at a particular stage of the PV system. There are not many extensive studies and results on discretized PV systems in the literature [19–26]. The main problem is the control of the upper stages of the system, which requires a good understanding of the operation of the matching stages in the presence of other stages [17]. In the case of PV systems with series-connected DC/DC Boost converters, the source of the high stage Mosfet transistor is connected to the low stage voltage (Vs1). Therefore, the use of Half-Bridge Driver [27], [28] to achieve the adaptation between the control part (Digital control) and the power part (MOSFET transistor) is not possible, because quite simply the voltage Vs1 of the low stage is greater than the maximum voltage (20V) of the power supply for this circuit. In the literature, no work has dealt in detail with this problem of controlling transistors with floating sources and no circuit has been made for this purpose. Doron Shmilovitz and all have treated by simulation a multi-stage discretized PV system, but no study has been presented on the transistor control problem [18]. Then, Ho-sung Kim and all studied the same PV system, he presented results that concern all the electrical quantities (Voltage, current and efficiency). On the other hand, they did not deal with the control technique of the switches of different stages of the PV system studied [20].

To remedy this, we propose a structure for a discretized PV system as well as a control strategy for each stage in order to maximize the power generated by each PV panel as well as the efficiency of overall stages (DC/CD converters, etc.).

In this work, we designed and realized a discretized, two-stage (low and high), series-connected PV system. The control of the power transistors of each stage is ensured by an automatic MPPT control improved by our research team. The improvement of this command concerns the precision and the speed of its search for the maximum power point PPM [18]. This command generates a PWM signal of insufficient amplitude to ensure the control of a Mosfet transistor, constituting the DC/DC Boost converter. To remedy this problem, a specific power control (SPC) was carried out. The daily experimental results obtained show that the SPC block, developed during this work, improves the shape of the PWM signals of the improved MPPT commands and takes into account the floating voltages of the outputs of each stage. Also, these same results show that the technique of discretization of PV panels is essential to improve the power conversion. And consequently, improves the overall efficiency of the system (93%).

2. PV System Description

The diagram presented in Fig. 1 illustrates a two-stage photovoltaic system. Each stage consists of:

- Monocrystalline photovoltaic panel produce approximately 54 W of power, 12.8 V of voltage, and 4.4 A of current under standard conditions [12], [17].
- A load, such as a solar battery or a variable resistor, can be used in this proposed system,
- Boost DC/DC converters were chosen for our application (fig.2), which requires a voltage higher than that of the PV panel. The converter operates under a frequency of 10 KHz at a maximum power of 200W.The electrical characteristics of the input and output of each Boost DC/DC converter are dependent on the duty cycles of the lower and high stages, represented by α1 and α2, respectively, as per equations [12], [17].

$$Vs1 = \frac{Vpv1}{(1-\alpha 1)},\quad Vs2 = \frac{Vpv2}{(1-\alpha 2)} \tag{1}$$

$$Is = Is1 = Is2 = (1-\alpha 1) \bullet Ipv1 = (1-\alpha 2) \bullet Ipv2 \tag{2}$$

$$\Delta iL = \frac{Vpv1 \bullet \alpha 1}{L \bullet f} = \frac{Vpv2 \bullet \alpha 2}{L \bullet f} \tag{3}$$

- The MPPT command applied in this work is of enhanced Hill Climbing type (Fig .3). The idea of our contribution was deduced by studying the influence of the optimal voltage of the PV panel according to the illumination and the temperature. This daily study clearly shows that the optimal operation of the PV panel studied is within an optimal voltage range (Vmin and Vmax) [18] (Fig .4). Knowing this optimal voltage range of the PV panel allows us to set a fairly large increment step when the measured voltage does not belong to this voltage range. On the other hand, when the measured voltage belongs to the latter, a small incrementation step is fixed, which makes it possible to operate the studied PV system around its true maximum power point MPP. To conclude, the strong point of this command is the variable increment step, it depends on whether you are close or far from the MPP. This improved control addresses the problems of classic commands (P&O, HILL CLIMBING, IC, ...). These MPPT controls cannot have a compromise between speed and accuracy, as they adopt a fixed increment or decrement step [29–33].

- A specific power control (SPC) is positioned between the MPPT control and the Boost DC/DC converter. The objective of the SPC is to produce a

  PWM signal, tailored to the PV installation requirements, to regulate the power switches of each stage. It consists of two power circuit blocks (Fig. 5).

The lower stage, requires a Driver type IR2111 [27], [28], which provides the PWM signal, the output Ho is the sum of the voltage of the source of the transistor, which is connected in this case to the ground and the supply voltage Vcc=12V:

$$HO = Vcc + VS = 12V \tag{4}$$

The upper stage requires another reasoning, in this case the source of the transistor is not connected to the ground, it is connected directly to the voltage at the output of the converter of the lower stage (Vs1=30V). So, to ensure the closing and opening of this transistor it is necessary to drive its gate by a voltage (Vg), which is the sum of the source voltageVs≈30V and the threshold voltage of the transistor (≈7V):

$$Vg \approx Vsource + Vseuil \approx 30V + 7V \approx 37V \tag{5}$$

To have this amplitude, we thought of combining two identical drivers as shown in Fig.5. The first Driver is used to generate a PWM1 signal, by applying a power supply (VCC1) of 20V and VS1 connected to ground (VS1≈0):

$$HO1 = VCC1 + VS1 = 20V + 0V = 20V \tag{6}$$

The HO1 signal of driver 1 is connected to the VS2 output of the second driver, which allows it to generate a PWM2 signal of amplitude:

$$HO2 = VCC2 + HO1 = 20V + 20V = 40V \tag{7}$$

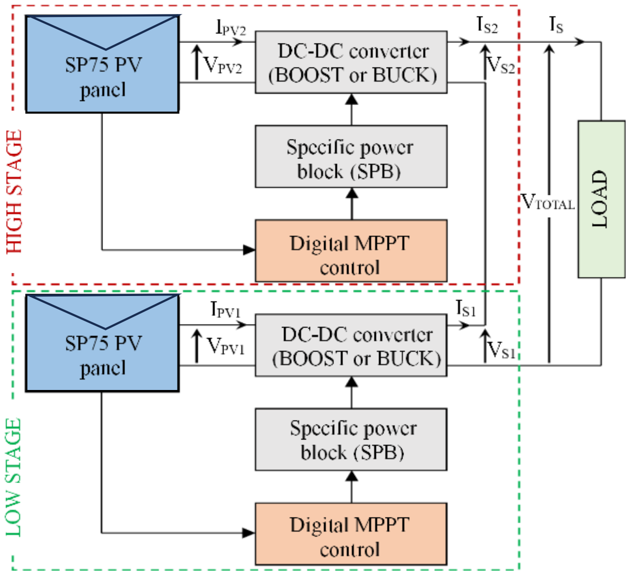


Fig. 1. A global system synoptic diagram.

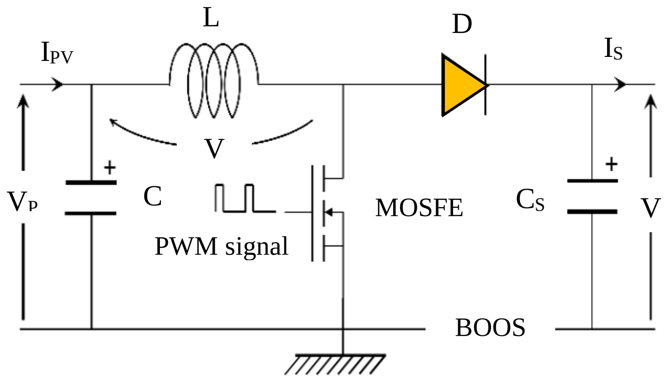


Fig. 2. DC/DC power converter used in this word.

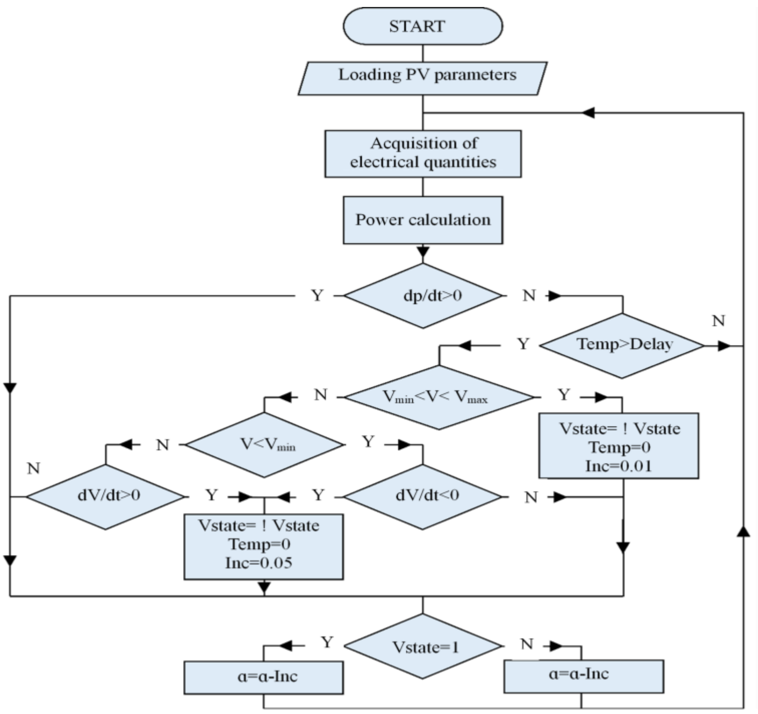


Fig. 3. Improved MPPT control.

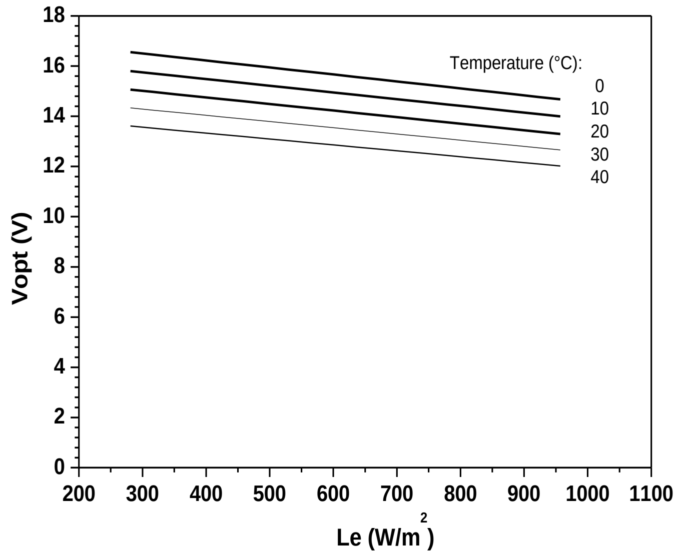


Fig. 4. Simulated voltage of the studied PV panel according to the temperature and illumination.

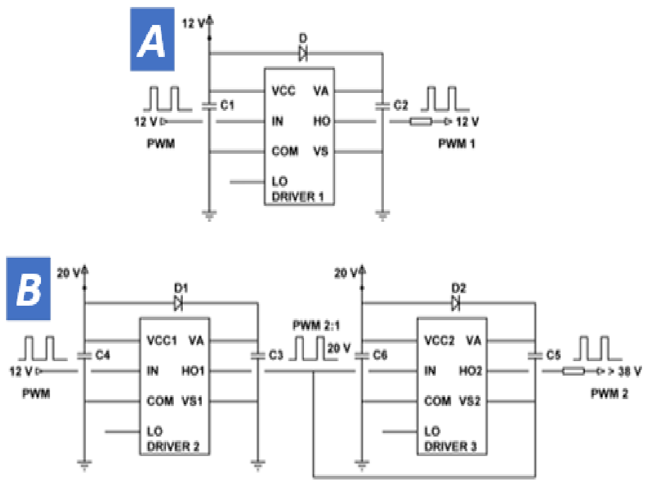


Fig. 5. specific power control (SPC)

3. Experimental Validation

3.1 Experimental Procedure

Fig.6 illustrates the measurement bench utilized in this study, comprising the essential equipment for conducting experiments on the discretized PV system presented in Fig.1:

- Panel field formed by 4 PV modules;
- CMP6 pyranometer to measure irradiance intensity and temperature;
- Two stage discretized system (DC/DC converters, resistive load);
- The digital MPPT control, consisting of:
  - ✓ The purpose of a PIC microcontroller is to execute a program with the following algorithm:
    - The acquisition of the reference voltage by Port A;
    - The conversion of the electrical voltage value into a digital value by the CAN module of the microcontroller;
    - The generation of a PWM signal, whose duty cycle varies according to the power supplied by the PV panels;
  - ✓ An amplifier stage that amplifies the PWM signal generated at the output of the microcontroller;
  - ✓ A specific power control (SPC) that improves shape and amplifies the amplitude of the PWM signal from the MPPT control to the desired value. The latter depends on the application (50 V in our case).

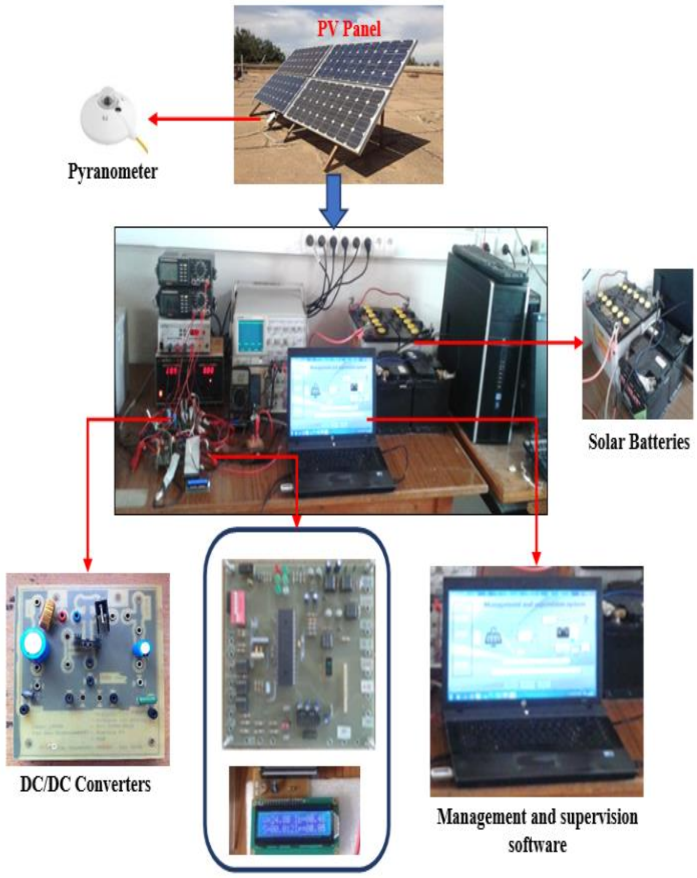


Fig. 6. PV system and measuring bench used in our experimental procedures

- Acquisition card (Fig. 7), developed in the team, in order to carry out electrical measurements (in an interval of 50 ms) of the PV systems during their functioning: Irradiance, Duty cycle, Voltage, Current, Power, Batteries charge rate. As shown in Fig.8, the software is based on a computer application developed in C++ language under Visual studio. We also use the MySQL language to manage the database containing the different electrical quantities of the system (Fig. 8A). We have adapted the software to our application so that it measures, stores and visualizes the electrical quantities in real time (Fig. 8B).

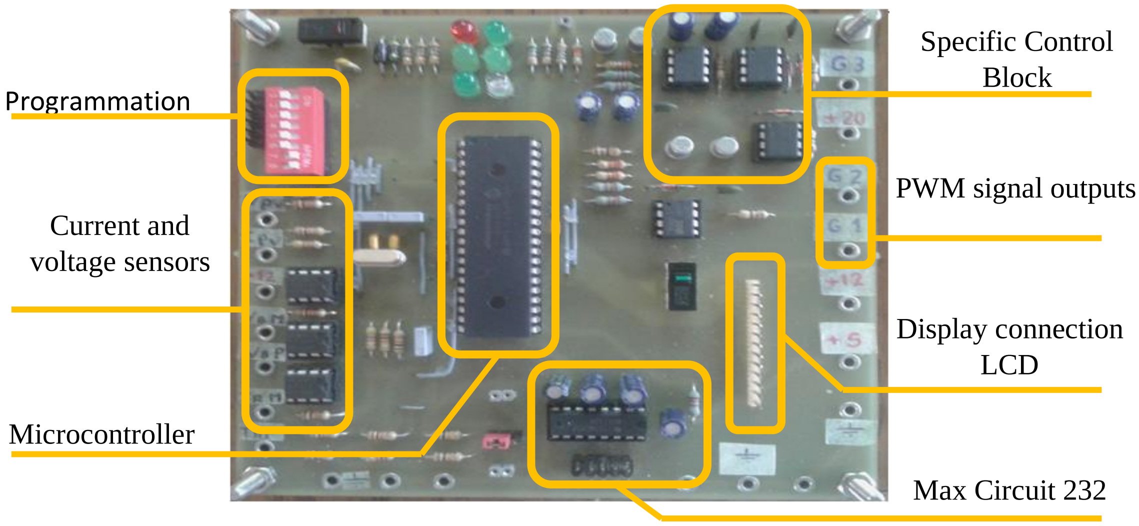


Fig. 7. Acquisition and control card

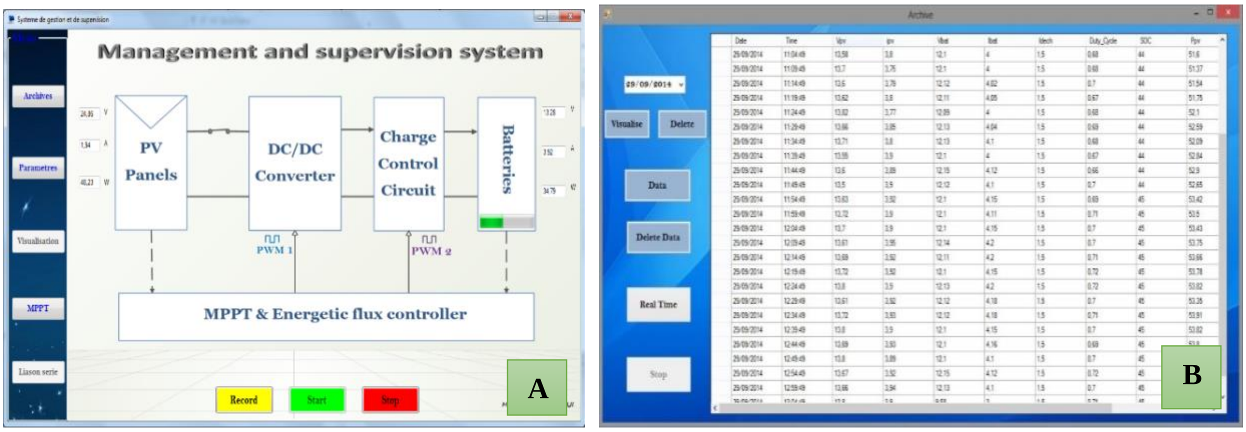


Fig. 8. Acquisition and supervision software developed by the team: A: Main window; B: Database of different electrical quantities of the PV system.

3.2 Functioning Principle of DC/DC Converters

During a very sunny day where the irradiance and temperature were respectively about 900 W/m² and 18°C, we studied the functioning of each block of the studied PV system. We analyzed the typical results obtained during two periods of DC/DC converter, as illustrated in Fig.9 and summarized in Table 1:

- **Low Stage: is** equipped with an improved MPPT control, which allows the PV panel to operate around its maximum power point, generating a PWM signal, with a duty cycle of 0.6 and amplitude of 12 V, as shown in Fig.9F1. The shape of this signal allows for controlling the opening and closing of the switch (Fig.9F2) and charging/discharging the inductance under optimal conditions is represented in the fig.8F3. In order to show the proper operation of the studied system, we theoretically calculated the average value of the inductance current $<i_L> \approx Ipv_1 = 3.65A$, as well as its undulation $\Delta i_L = 1.995A$. These theoretical values are in very good agreement with those obtained experimentally ($<I_{L1}> = Ipv_1 = 3.62A$, $\Delta i_L = 2A$). The output voltage and current of this stage (Fig.11. F1) are stable and correspond well to those obtained by simulations (Table 1). These results, as well as the efficiency (93%) of the DC/DC converter, demonstrate that the lower stage operates correctly under optimal conditions.

- **High stage:** As represented on fig.10.F1, the MPPT control of this stage produces a signal with the same characteristics (frequency, duty cycle, amplitude) as the lower stage. However, due to the fixed reference voltage (30V) of the low stage, the 15V amplitude of the PWM signal cannot control the switch of this stage. To address this issue, a specific power control (SPC) was designed to enhance the shape and amplitude of the PWM signal for the high stage. The SPC generates a signal with amplitude of 40V, which is sufficient to control the high stage switch (as demonstrated in Fig.10.F1). This PWM signal ensures the correct Transistor functioning of this stage (Fig.10.F2). The inductor current, output voltage, and efficiency (as presented in Fig.10.F3 and Table 1) are practically identical for both stages under optimal conditions, indicating that they operate similarly.

- **Complete system:** The sum of the voltages and power outputs of each stage is the voltage and power output of the overall PV system (as shown in Fig.11 and Table 1). The overall efficiency of the system and each stage is about 93%, and almost all the power produced by the PV panels is transmitted to the load. By comparing the efficiency of our discredited PV system to that of single-stage PV systems where efficiency does not exceed 90%, we can conclude that our system has improved the efficiency of the DC/DC converter by 3%. This improvement is attributed to two factors: the utilization of a better MPPT control [18], as well as a technique that considers the state of the PV system (illumination, load, and number of stages) when controlling power switches.
- **Complete system:** From Fig.11, it is clear that the PV system studied ensures optimal functioning of the PV panels, this is justified by the satisfactory experimental yield obtained, which is of the order of 93%. Then, we represented on the same figure, the voltage at the output of each stage and the total voltage of the PV system studied. The results obtained show that total voltage (60V) is the sum of the voltages of each stage (30V).

The results obtained demonstrate that the designed and implemented PV system operates effectively. The specific power control (SPC) played a vital role in controlling the high stage switch and achieving significant efficiency (93%). This system studied during this work is intended for applications requiring high voltages.

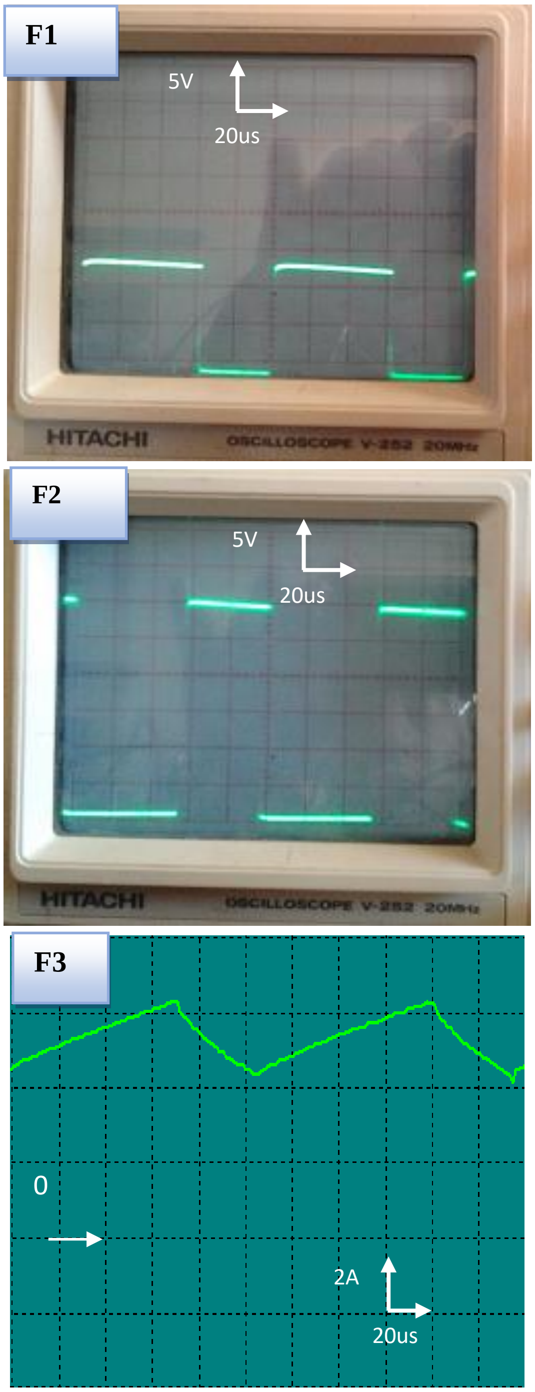


Fig. 9. Low stage signals: MPPT control signal (F1); Transistor drain-source voltage (F2); Inductor current (F3).

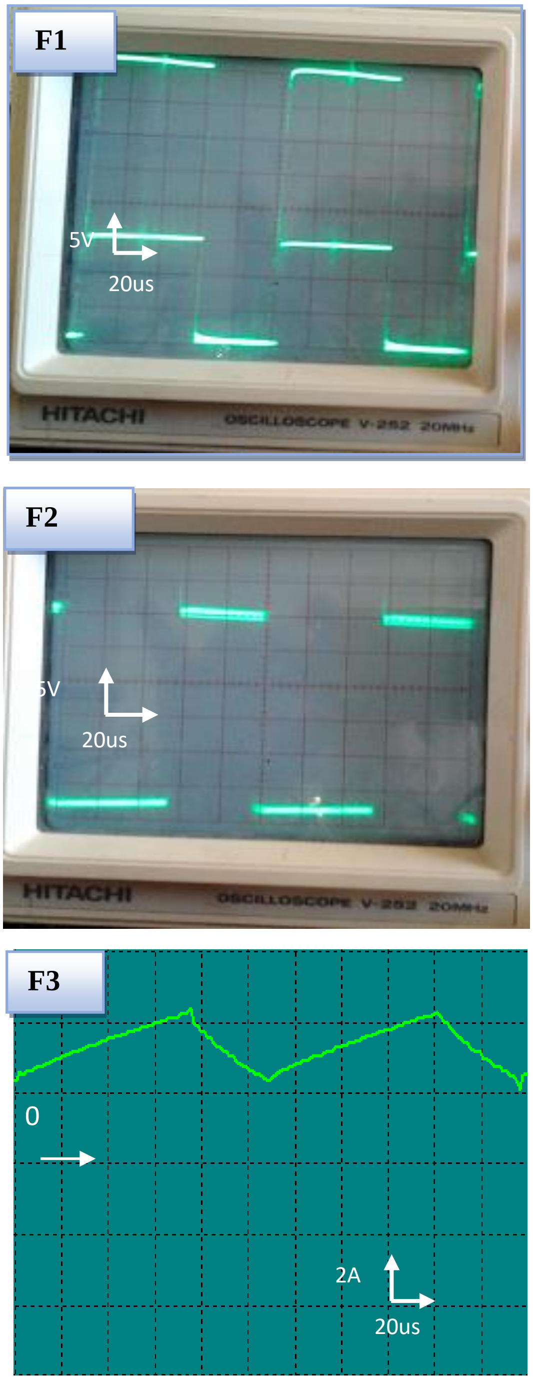


Fig. 10. High stage signals**:** MPPT control signal and SPC circuit (F1); Transistor drain-source voltage (F2); and Inductor current (F3).

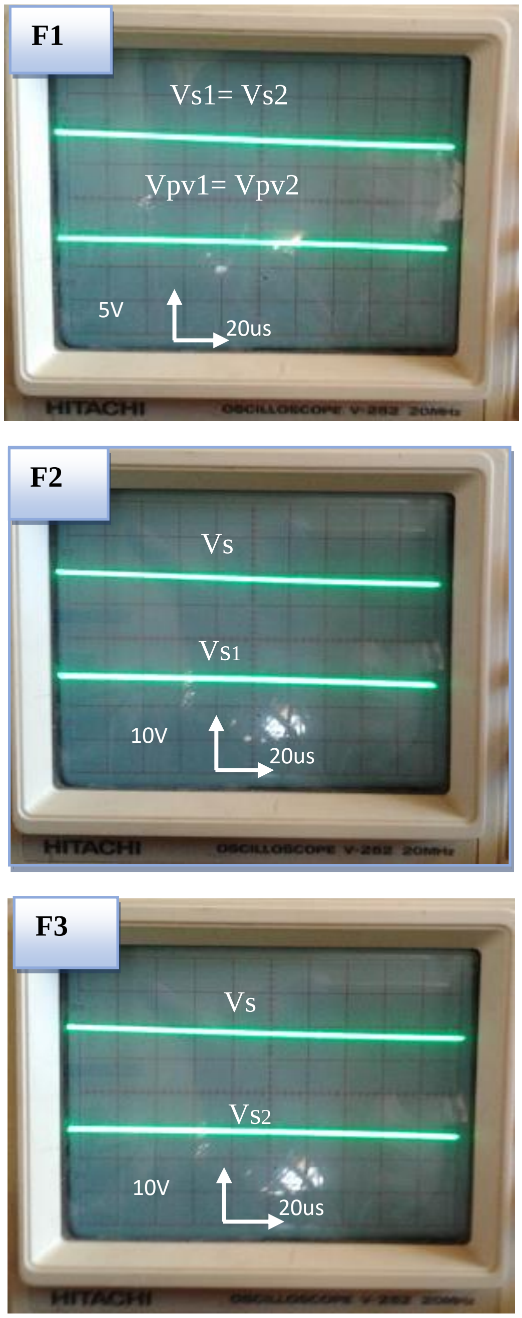


Fig. 11. **F1**: Input (Vpv_1= Vpv_2=13.3 V) and output voltage (Vs_1= Vs_2=29.7 V) of the DC/DC Boost converter; **F2:** Output voltage of the low stage ($Vs_1 \approx$ 29.7 V) and the overall system voltage ($Vs \approx$59.7V) ; **F3**: Output voltage of the high stage ($Vs_2 \approx$ 29,7V) and the overall system voltage ($Vs \approx$59.7V).

Table 1. Recapitulation table that translates the signals in Fig.10 into numbers

	Electrical quantities of the low stage		Electrical quantities of the high stage		Electrical quantities of the lo global system	
	Experience	Simulation	Experience	Simulation	Experience	Simulation
Duty cycle α	0.6	0.586	0.6	0.586		
Input voltage (V)	13.3	13.49	13.4	13.49		
Output voltage (V)	29.7	30	30	30.5	59.7	60
Input current (A)	3.62	3.65	3.63	3.65		
Output current (A)	1.5	1.6	1.5	1.6	1.5	1.6
Input power (W)	48.146	49.23	48.642	49.23	96.78	98.47
Output power (W)	44.55	47.41	45	47.41	89.55	96
Efficiency (%)	92.53	96.3	92.5	96.3	92.52	97.4

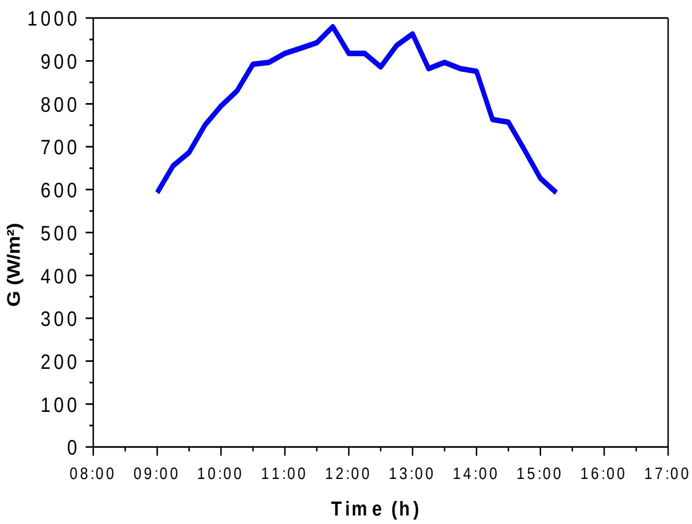
3.3 Experimental and Theoretical Validation of the Studied PV System

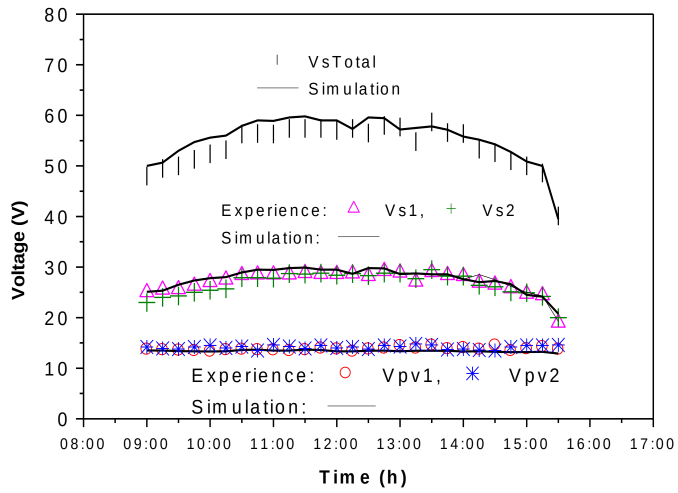
During a full day of operation, we performed the validation of the design and operation of the PV systems by implementing and characterizing the PV systems. This system (Fig.1) consists of two stages matched by a DC/DC boost converter, which is regulated by a digital maximum power point tracking (MPPT) control equipped with a Specific control Bloc.

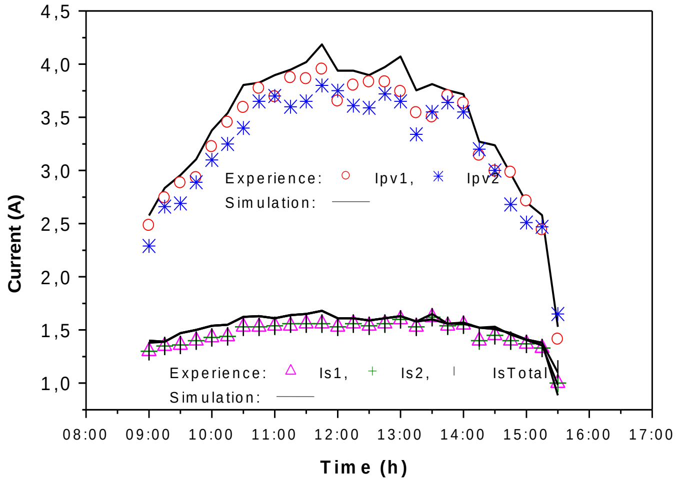
Fig.12 depicts the lighting, duty cycle, and various electrical input parameters (Vpv_1, Ipv_1, Vpv_2, Ipv_2, Ppv_1, Ppv_2,) of each DC-DC converter, as well as the overall system output (Vs_1, Is_1, Vs_2, Is_2) (Itotal, Vstotal, Ptotal). In the same figure, we represented the results of the simulations (Optimum) obtained (currents, voltages, powers, efficiency …). The overall findings are as follows:

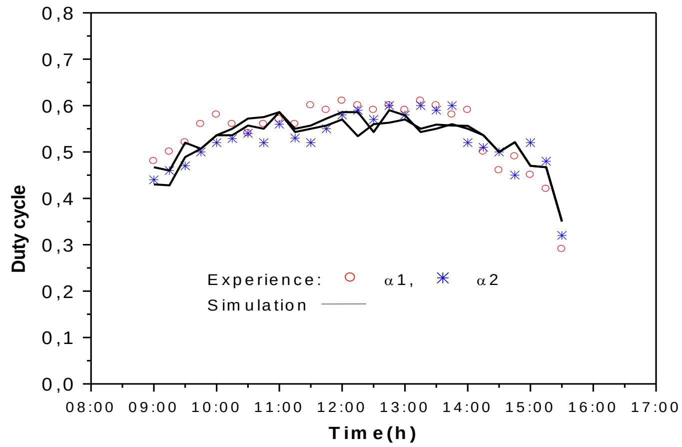
- During an entire day of operation, the temperature and illumination experience successive variations ranging from 12°C to 25°C and from 300W/m² to 970 W/m².
- The output voltage and total power equal to the sum of those of each DC / DC converter.
- The total output current is that at the output of each DC / DC converter.
- The experimental results showed a strong correlation with the simulation, the negligible discrepancy can be attributed to the gradual aging of the PV panels.
- The energy produced by the low (high) stage is 242.13Wh (248.43Wh). The comparison between these energies produced and that produced in the case of a single-stage system [12] (196.5Wh) shows, on the one hand, that the stages produce practically the same energy, and on the other hand, an improvement of 51.93Wh (or 26.42%) compared to single-stage systems. This improvement is therefore attributed by the discredited structure, the operation of which is ensured by the BCS circuit.

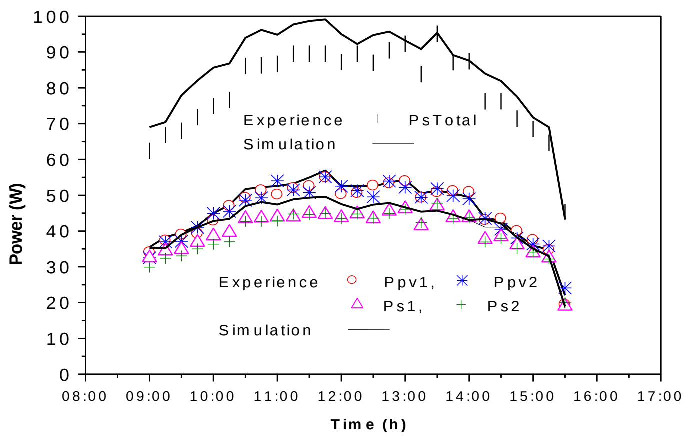
The proper operation of the studied PV system equipped with the SPC circuit, which is necessary for controlling the DC/DC Boost Converters stages, were demonstrated by the positive results obtained over the course of an entire day.











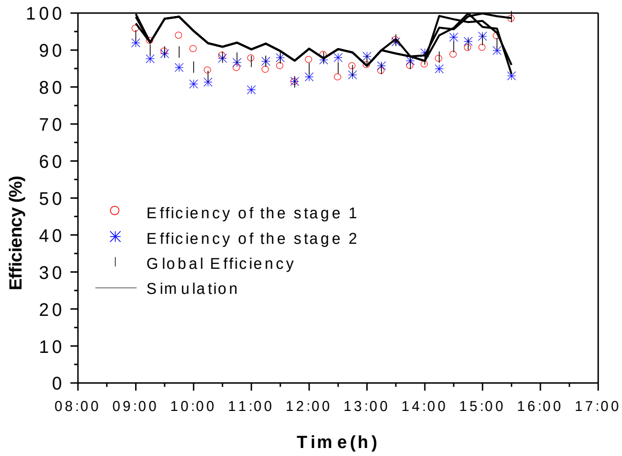


Fig. 12. During an entire day of operation, the electrical quantities (such as currents, voltages, powers, and efficiencies) of each stage and as well as the overall PV studied system, were both experimentally measured and simulated in Pspice.

3.4 PV System Operation During MPPT Control or PV Array Failures

We analyzed the operation of the studied PV system, according to the situation encountered in PV installations: failure panels, DC / DC converters, MPPT control, ... In the context of our experimentation, we limited it to the following phases:

- **Phase 1,3 and 5:** Normal operation of the PV system,
- **Phase 2:** Failure of PV panels of the high stage (or the lower stage),
- **Phase 4:** Failure of the MPPT control of high stage (or the lower stage). In our case, the output of the MPPT control blocks to 1 (or to 0).

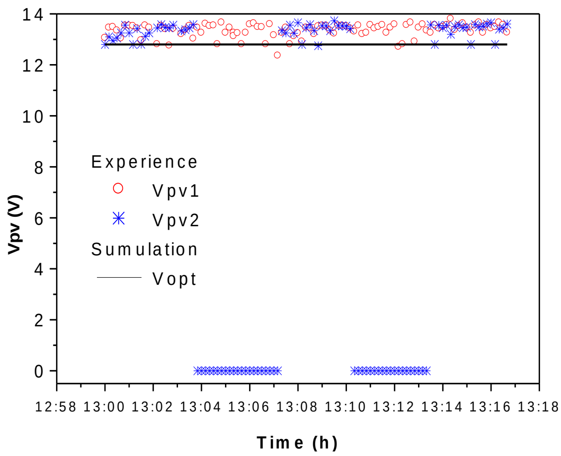
On fig.13, we have represented, for an irradiance and temperature of 900 W/m² and 30 °C, the typical evolution in function of time, of the duty cycles of MPPT control and electrical quantities of each stage and the overall system. On the same plots, we have represented the results of optimal simulations. These results clearly show a behavior that depends on the situations of the PV system:

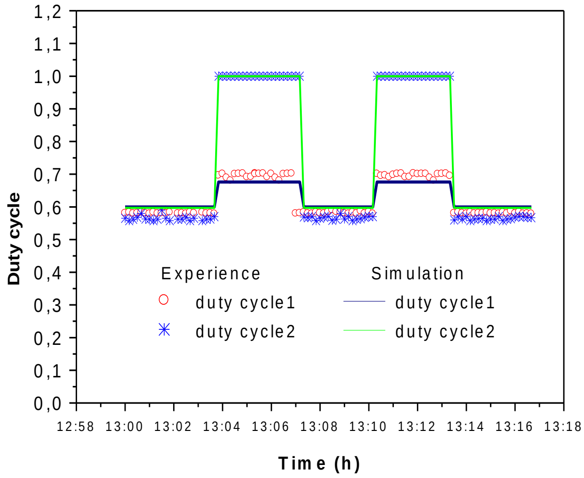
- During phases 1, 3 and 5, the studied system operates normally. For a duty cycle of 0.6, the results obtained show that the total voltage (58 V) of the system studied is equal to that at the output of each stage (29 V) and the same reasoning for the power. Then, the efficiency presented by this PV system is around 93%. From Fig.13, we clearly notice that there is a very good agreement between the experimental results and those of simulation.
- During the failure of PV panels of the high stage (Phase 2): All electrical quantities at the input and the output of the DC / DC converter of the high stage are down to

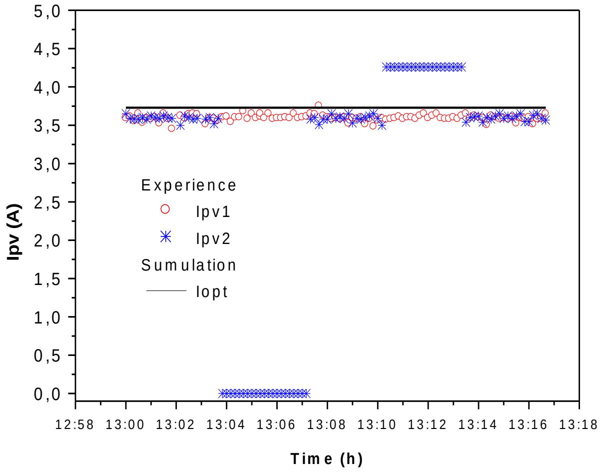
zero. In this situation no regulation of MPPT control, of this stage is made. The MPPT control of the lower stage regulates the operation of this stage following the new situation of the system (duty cycle of the order of 0.7, Vs = Vs_1 = 42 V, Is = Is_1 = 1A and Ps = Ps_1 = 44 W, efficiency>90%). The output power of the PV system (44 W) is practically that provided by the lower stage has a higher than 90% efficiency. Since all the experimental results are practically identical with those simulated (Optimum), we can deduce the optimal functioning of the lower stage, despite the shutdown of the upper stage, with a very satisfactory efficiency.

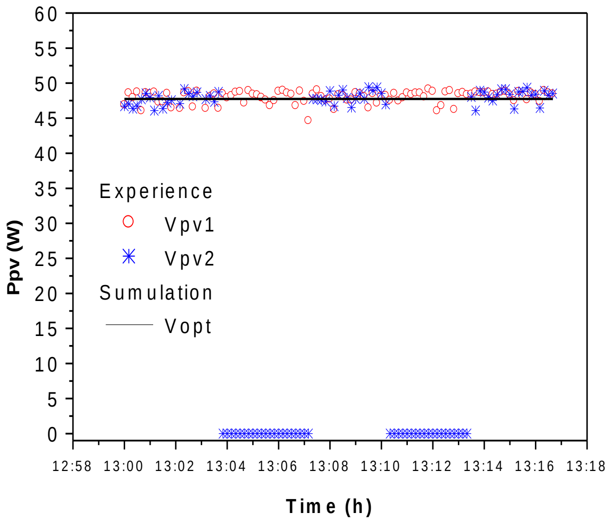
- During the failure of the MPPT control high stage (Phase 4) the operating point of the PV panel of this stage is that which corresponds to the situation of the short-circuit (Vpv_2 = 0 V, Ipv_2 = Icc = 4.4 A, Ppv_2 = 0 W). The MPPT control of the low stage regulates the operation of the system following the new situation (Vs1 = Vs = 42 V, Is = Is_1 = 1A and Ps = Ps_1 = 44 W, efficiency>90%). The output power of the PV system is one of the lower stages. As before, since all the experimental results are virtually identical to those simulated (Optimum), we can deduce the optimal functioning of the lower stage, despite the shutdown of high stage, with a very satisfactory efficiency.

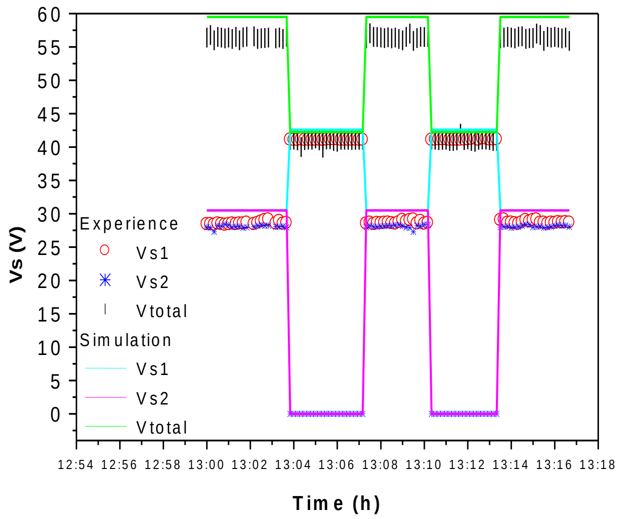
Finally, it appears clearly that despite the failures that affect one of the stages (Panels, or MPPT control), the studied PV system continues to operate without interruption. At the output of the PV system, it provides an optimal electric power stemming from the not failing stage. This shows the importance of the discretized systems in a PV installation to assure the production of electrical energy independently of failures that can take place at the level of panels and PV installations blocks.

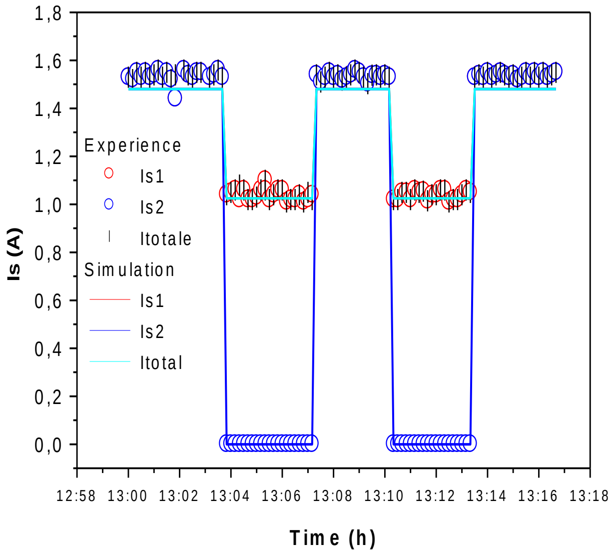


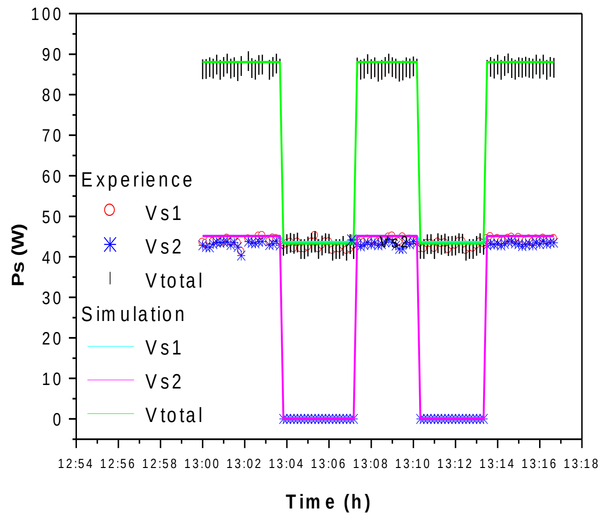












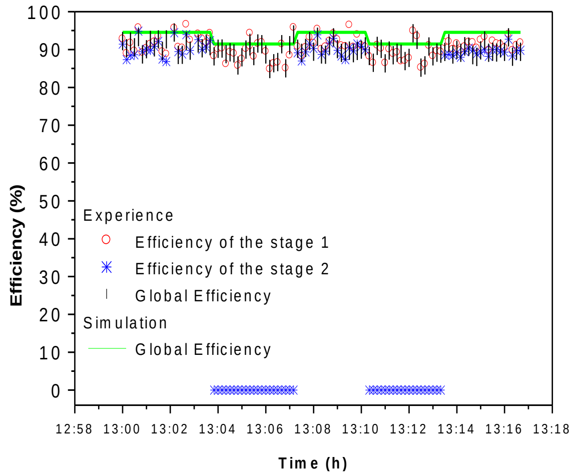


Fig. 13. Reaction of the discretized PV system in a possible failure.

4. Conclusion

The research work concerns the design, realization and optimization of a discretized PV system with two adaptation stages, equipped with power circuits (DC/DC converters) and an MPPT control improved by our team of research. Particular attention is attached to the specific blocks that control the stage power switches (SPC), which allows on the one hand to realize the adaptation between the control part and that of the DC / DC converter, and on the other hand to increase the PWM signal, generated by the MPPT command, to the desired value. It should be noted that in our case the amplitude of the PWM signal can reach 40V. From the experimentation of PV systems, carried out in the presence of DC/DC converters of the Boost type, we showed:

- Good compatibility between the results obtained by simulation and the experimental ones corresponding to the electrical parameters of each PV system block,
- The proposed system ensured proper functioning of each adaptation step and improved the overall performance of the PV system,
- A specific power control (SPC) ensures proper control of MOSFET transistors,
- The DC/DC converters integrated into the proposed system have increased efficiency by 3% compared to single-stage photovoltaic systems,
- In the event of a failure in the PV panel or in the MPPT control of one of the stages of the PV system studied, the proposed PV system makes it possible to generate electrical energy by the other non-failing stages.

The proposed discretized PV architecture has the potential to provide very interesting efficiencies and overcome the drawbacks of single-stage systems.

References

[1] S. Kanwal, M. T. Mehran, M. Hassan, M. Anwar, S. R. Naqvi, A. H. Khoja, "An integrated future approach for the energy security of Pakistan: Replacement of fossil fuels with syngas for better environment and socio-economic development", *Renewable and Sustainable Energy Reviews*, vol. 156, p. 111978, mars 2022.

[2] K. R. Abbasi, M. Shahbaz, J. Zhang, M. Irfan,R. Alvarado, "Analyze the environmental sustainability factors of China: The role of fossil fuel energy and renewable energy", *Renewable Energy*, vol. 187, p. 390-402, mars 2022.

[3] V. Kosorić, S.-K. Lau, A. Tablada, M. Bieri,A. M. Nobre, "A Holistic Strategy for Successful Photovoltaic (PV) Implementation into Singapore's Built Environment", *Sustainability*, vol. 13, nº 11, p. 6452, juin 2021.

[4] D. E. Attoye, Kheira Anissa Tabet Aoul, A. Hassan, "A Review on Building Integrated Photovoltaic Façade Customization Potentials », *Sustainability*, vol. 9, nº 12, p. 2287, déc. 2017.

[5] T. D. Atmaja, "Façade and Rooftop PV Installation Strategy for Building Integrated Photo Voltaic Application", *Energy Procedia*, vol. 32, p. 105-114, 2013.

[6] J. K. Kaldellis, M. Kapsali, K. A. Kavadias, "Temperature and wind speed impact on the efficiency of PV installations. Experience obtained from outdoor measurements in Greece", *Renewable Energy*, vol. 66, p. 612-624, juin 2014.

[7] M. Al-Tamimi , F. E. Alfaris, "Impact of Grid Impedance Characteristics on the Design Consideration of Utility-Scale PV Systems", in *2023 11th International Conference on Smart Grid (icSmartGrid)*, Paris, France: IEEE, juin 2023, p. 1-7.

[8] R. Rajesh, M. Carolin Mabel, "A comprehensive review of photovoltaic systems », *Renewable and Sustainable Energy Reviews*, vol. 51, p. 231-248, nov. 2015.

[9] MZ. Malik, V. Tirth, A. Ali, A. Farooq, A. Algahtani, R. Verma, S. Islam, K. Irshad, A.N. Abdalla. "Efficient Topology for DC-DC Boost Converter Based on Charge Pump Capacitor for Renewable Energy System". International Journal of Photoenergy 2021;2021:6675720. https://doi.org/10.1155/2021/6675720.

[10] E. Baghaz, M. Melhaoui, F. Yaden, K. Hirech, K. Kassmi, "Design, Realization and Optimization of the Photovoltaic Systems Equipped with Analog and Digital MPPT Commands", *Energy Procedia*, vol. 42, p. 270-279, 2013.

[11] M. Villegas-Ruvalcaba, K. Gurubel-Tun, A. Coronado-Mendoza, "Robust Inverse Optimal Control for a Boost Converter", *Energies*, vol. 14, nº 9, p. 2507, avr. 2021.

[12] M. Yaden, M. Melhaoui, R. Gaamouche, K. Hirech, E. Baghaz, K. Kassmi, "Photovoltaic System Equipped with Digital Command Control and Acquisition", *Electronics*, vol. 2, nº 4, p. 192-211, juill. 2013.

[13] J. Kim, I. Kwon, « Design of a High-Efficiency DC-DC Boost Converter for RF Energy Harvesting IoT Sensors", *Sensors*, vol. 22, nº 24, p. 10007, déc. 2022.

[14] A. Raj, R. P. Praveen, "Highly efficient DC-DC boost converter implemented with improved MPPT algorithm for utility level photovoltaic applications", *Ain Shams Engineering Journal*, vol. 13, nº 3, p. 101617, mai 2022.

[15] A. M. Eltamaly, M. S. Al-Saud, A. G. Abo-Khalil, "Performance Improvement of PV Systems' Maximum Power Point Tracker Based on a Scanning PSO Particle Strategy", *Sustainability*, vol. 12, nº 3, p. 1185, févr. 2020.

[16] A. M. Eltamaly, M. S. Al-Saud, A. G. Abokhalil, H. M. Farh, "Photovoltaic maximum power point tracking under dynamic partial shading changes by novel adaptive particle swarm optimization strategy", *Transactions of the Institute of Measurement and Control*, vol. 42, nº 1, p. 104-115, janv. 2020.

[17] M. Melhaoui, E. Baghaz, K. Hirech, K. Kassmi, "International Journal of Emerging Technologies in Computational and Applied Sciences (IJETCAS) www.iasir.net", 2013.

[18] M. Melhaoui, E. Baghaz, K. Hirech, F. Yaden, K. Kassmi, "Contribution to the Improvement of the MPPT Control Functioning of Photovoltaic Systems", *International Review of Electrical Engineering (IREE)*, vol. 9, nº 2, Art. nº 2, avr. 2014.

[19] D. Shmilovitz, Y. Levron, "Distributed Maximum Power Point Tracking in Photovoltaic Systems—Emerging Architectures and Control Methods", *Automatika*, vol. 53, nº 2, p. 142-155, janv. 2012.

[20] Y. Du, D. D.-C. Lu, "Battery-integrated boost converter utilizing distributed MPPT configuration for photovoltaic systems", *Solar Energy*, vol. 85, nº 9, p. 1992-2002, sept. 2011.

[21] A. A. A. Hafez, "Multi-level cascaded DC/DC converters for PV applications", *Alexandria Engineering Journal*, vol. 54, nº 4, p. 1135-1146, déc. 2015.

[22] N. Femia, G. Lisi, G. Petrone, G. Spagnuolo, M. Vitelli, "Distributed maximum power point tracking of photovoltaic arrays: Novel approach and system analysis", *IEEE Trans. Ind. Electron.*, vol. 55, nº 7, p. 2610-2621, juill. 2008.

[23] H. Kim, J.-H. Kim, B.-D. Min, D.-W. Yoo, H.-J. Kim, "A highly efficient PV system using a series connection of DC–DC converter output with a photovoltaic panel", *Renewable Energy*, vol. 34, nº 11, p. 2432-2436, nov. 2009.

[24] Z. Liu, J. Du, B. Yu, "Design Method of Double-Boost DC/DC Converter with High Voltage Gain for Electric Vehicles", *WEVJ*, vol. 11, nº 4, p. 64, oct. 2020.

[25] G. Petrone, G. Spagnuolo, M. Vitelli, “Distributed Maximum Power Point Tracking: Challenges and Commercial Solutions”, *Automatika*, vol. 53, nº 2, p. 128-141, janv. 2012.

[26] H.-S. Lee, J.-J. Yun, “Advanced MPPT Algorithm for Distributed Photovoltaic Systems”, *Energies*, vol. 12, nº 18, p. 3576, sept. 2019.

[27] C. Brañas, J. C. Viera, F. J. Azcondo, R. Casanueva, M. Gonzalez, F. J. Díaz, “Battery Charger Based on a Resonant Converter for High-Power LiFePO4 Batteries”, *Electronics*, vol. 10, nº 3, p. 266, janv. 2021.

[28] K. Górecki, K. Detka, K. Kaczerski, “The Influence of the Transformer Core Material on the Characteristics of a Full-Bridge DC-DC Converter”, *Energies*, vol. 15, nº 17, p. 6160, août 2022.

[29] C. B. Nzoundja Fapi, H. Tchakounté, M. A. Hamida, P. Wira, M. Kamta, “Experimental Implementation of Improved P&O MPPT Algorithm based on Fuzzy Logic for Solar Photovoltaic Applications”, in *2023 11th International Conference on Smart Grid (icSmartGrid)*, Paris, France: IEEE, juin 2023, p. 01-06.

[30] F. Debbabi, F. Mehazzem, T. Soubdhan, “Implementation of Genetic Algorithm-Based MPPT for PV System in Tropical Climate: Study and Comparison with Conventional Method”, in *2023 11th International Conference on Smart Grid (icSmartGrid)*, Paris, France: IEEE, juin 2023, p. 1-6.

[31] O. A. Ba, A. Ndiaye, A. Ba, E. H. M. Ndiaye, M. A. Tankari, “Optimization of the P&O-MPPT controller by the adaptive method (Ad-P&O) for stand-alone PV systems”, in *2023 11th International Conference on Smart Grid (icSmartGrid)*, Paris, France: IEEE, juin 2023, p. 1-8.

[32] R. Z. Caglayan, K. Kayisli, M. Roscia, A. Harrouz, R. Bayindir, I. Colak, “PV&TEG Hybrid System controlled with Fuzzy based MPPT”, in *2023 11th International Conference on Smart Grid (icSmartGrid)*, Paris, France: IEEE, juin 2023, p. 01-06.

[33] F. Tahiri, A. Harrouz, I. Colak, M. A. Hartani, F. Bekraoui, I. Boussaid, “Comparative study of the MPPT methods applied to the PV system; Perturbation & Observation technique, sliding mode control and fuzzy logic control”, in *2023 11th International Conference on Smart Grid (icSmartGrid)*, Paris, France: IEEE, juin 2023, p. 1-6.