

An experimental investigation design of a bidirectional DC-DC buck-boost converter for PV battery charger system

Boualam Benlahbib¹, Abdeldjalil Dahbi^{2,3}, Bennaceur Fares⁴, Abdelkader Lakhdari¹,
Noureddine Bouarroudj¹, Saad Mekhilef⁵, Thameur Abdelkrim¹

¹Unité de Recherche Appliquée en Energies Renouvelables (URAER), Centre de Développement des Energies Renouvelables, Ghardaïa, Algeria

²Unité de Recherche en Energie Renouvelables en Milieu Saharien, Centre de Développement des Energies Renouvelables, Adrar, Algeria

³Département d'Électronique et des Télécommunications, Université Kasdi Merbah Ouargla, Ouargla, Algérie

⁴Laboratory of Sustainable Development and Computing, Department of Electrical Engineering, Adrar University, Adrar, Algeria

⁵School of Science, Computing and Engineering Technologies, Swinburne University of Technology, Melbourne, Australia

Article Info

Article history:

Received Mar 7, 2023

Revised Apr 19, 2023

Accepted May 3, 2023

Keywords:

Bidirectional DC/DC converter

Boost mode

Buck mode

DC link

PV array

Storage battery

ABSTRACT

The aim of this paper is to present a bidirectional DC-DC buck-boost converter design that is specifically intended for use with storage batteries in a PV system. The primary purpose of the batteries is to mitigate the unpredictable and intermittent nature of renewable energy sources. To achieve this, a DC-DC converter is used in buck mode during daylight hours to charge the batteries with power derived from the PV system. If the photovoltaic energy source is unavailable, the batteries can discharge to power the DC load through the converter in boost mode. Therefore, the bi-directional DC/DC converter, which has a high-power capacity, manages the power storage system. To this end, the paper describes the design and implementation of both the power circuit board and drive circuit board of the buck-boost converter, taking into account the rated current, voltage, and power. Finally, the effectiveness and efficiency of the designed converter are verified through experimental tests carried out in both charge and discharge modes, with results demonstrating the validity and efficiency of the converter.

This is an open access article under the [CC BY-SA](#) license.



Corresponding Author:

Boualam Benlahbib

Unité de Recherche Appliquée en Energies Renouvelables (URAER)

Centre de Développement des Energies Renouvelables

CDER, 47133, Ghardaïa, Algeria

Email: bouallam30@gmail.com

1. INTRODUCTION

Among renewable resources, wind and solar energy are the most widely used. According to the 'Renewables Global Status Report (2022) (REN21)', wind energy will be the primary source of new power generation capacity in the United States, Europe, and China in 2023. As of now, 845 GW of wind power capacity has been installed worldwide, as shown in Figure 1. Due to its reliability and advantages, many corporations and private companies are transitioning to this type of power source. Nevertheless, wind potential is limited to specific regions, which is where the photovoltaic system comes in to address this issue [1]. Solar photovoltaic systems have emerged as the primary source of clean energy in markets like Japan, India, China, and the United States. In 2021, the global solar PV capacity increased by about 175 GW, resulting in a total global capacity of 942 GW [1].

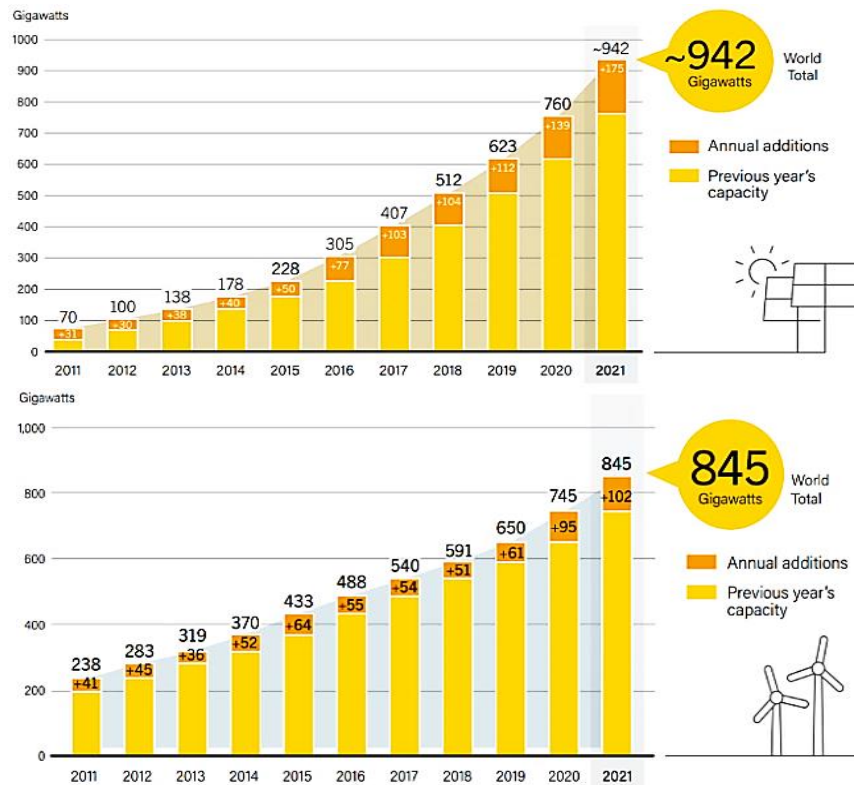


Figure 1. Solar photovoltaics and wind energy annual capacity and globally installed, 2011-2021 [1]

The design of energy production systems has shifted towards a smart and microgrid architecture, which necessitates the integration of renewable energy sources. However, the intermittency issue of renewable energy sources requires the use of a storage system. To facilitate the transfer of energy between the storage system and the main microgrid, a bidirectional DC-DC buck-boost converter must be integrated [2], [3]. These converters are highly suitable for use in a variety of applications, such as DC power supply systems, electric vehicle systems, motor drive systems, aerospace power systems, solar power systems, and wind energy systems [4]–[6].

Numerous buck-boost converter topologies have been proposed in the literature [7], including the four-switch non-inverting converter. This type of converter is based on four switches and has both advantages and disadvantages [8]. Ioinovici [9] explained the potential input voltage range of the design is advantageous for battery applications. This topology enables stable mode switching between boost and buck operations. The word [10] employed a four-switch topology for a power system composed of photovoltaic panels capable of discharging and charging up to 20 kW. They achieved 97% efficiency with their 5 kW prototype and concluded that the structure is suitable for a power system.

The result [11], a different topology was introduced that only requires two switches and a single conductor, as shown in Figure 2. The purpose of this topology was to illustrate how it could be used in a PV system that needs to manage battery charging and discharging through an energy management strategy. The researchers used synchronous switching, which resulted in higher conversion efficiency. Another study [12] demonstrated that the same topology could function as a buck converter with non-synchronous switching, by setting Q2 to be blocking and monitoring Q1 in the same way as a basic buck converter [13]. In this case, Q1 is set to conduct in boost mode, even though Q2 is switched based on the way a boost converter is controlled. By incorporating this bidirectional buck-boost converter into a battery charging circuit, a 96% efficiency was achieved. After evaluating various topologies, the researchers chose the bidirectional buck-boost converter with two switches due to its ease of implementation and design.

The main focus of this paper is to provide a comprehensive account of the development and practical implementation of an inexpensive and uncomplicated DC-DC bidirectional buck-boost converter. This converter is particularly suitable for academic institutions and laboratory settings, as it is tailored to the needs of students and researchers. Additionally, numerous experiments have been conducted to showcase the significance of this converter in hybrid energy production systems.

The paper's organization is as follows: i) In section 2, the studied system is described; ii) Section 3 discusses the various operation modes of DC-DC buck-boost converters; iii) Section 4 provides an in-depth explanation of the power and driver circuits' design, along with the software utilized for designing and printing

the circuit boards (PCB); iv) The experimental findings of the designed circuits are presented in section 5; and v) Lastly, section 6 summarizes the key points and offers conclusions.

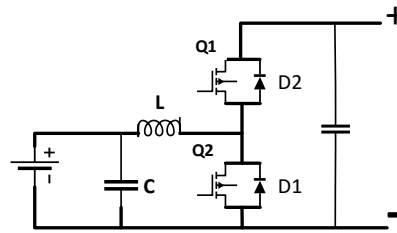


Figure 2. Bidirectional buck-boost converter with two-switch

2. DESCRIPTIONS OF THE STUDIED SYSTEM

Figure 3 illustrates the DC-DC bidirectional converter utilized in the microgrid system under investigation. The system comprises a photovoltaic generator (PVG), which is linked to the DC bus via a DC-DC boost converter Figure 3(a). The converter operates optimally, allowing the GPV to track the maximum power point (MPPT) [13], [14]. Additionally, a storage battery is connected to the DC bus through a bidirectional Buck-Boost converter Figure 3(b). The entire system provides power to a resistive DC load Figure 3(c).

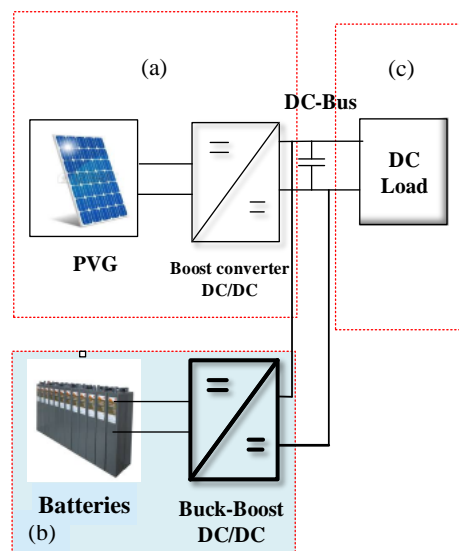


Figure 3. Photovoltaic system with storage batteries, (a) PV-Generator, (b) storage subsystem, and (c) DC-load

3. DC-DC BUCK-BOOST CONVERTER OPERATION MODES

The GPV's converter facilitates the transfer of power in a single direction from sources to the DC bus. However, when it comes to charging and discharging the battery, a reversible converter is required [15], [16]. A bidirectional buck-boost converter, as shown in Figure 4, can achieve power reversibility through its switches which are designed to transfer current efficiently in both directions. This results in two distinct operation modes, as described in references [17], [18].

3.1. Buck mode (charging mode)

While charging the battery, the bidirectional converter functions as a Buck converter. In this mode, switch S1 and diode D1 are turned on, while switch S2 and diode D2 are turned off, as depicted in Figure 4(a). As the cycle progresses, the inductor current diminishes, and the energy stored in inductor L is utilized to charge the battery, as explained in reference [19], [10]. Moreover, whenever there is a surplus of renewable energy production, the bidirectional converter transfers the extra power from the DC bus to the battery.

3.2. Boost (discharging) mode

During battery discharge, the bidirectional converter operates as a boost converter. This means that switch S2 and diode D2 are turned on, while switch S1 and diode D1 are both turned off, as shown in Figure 4(b). The converter's role in this mode is to transfer energy from the battery to the DC bus. However, in situations where the renewable energy production falls short, the bidirectional converter regulates the power flow and maintains the DC bus voltage in both charge and discharge modes [4], [20], [21].

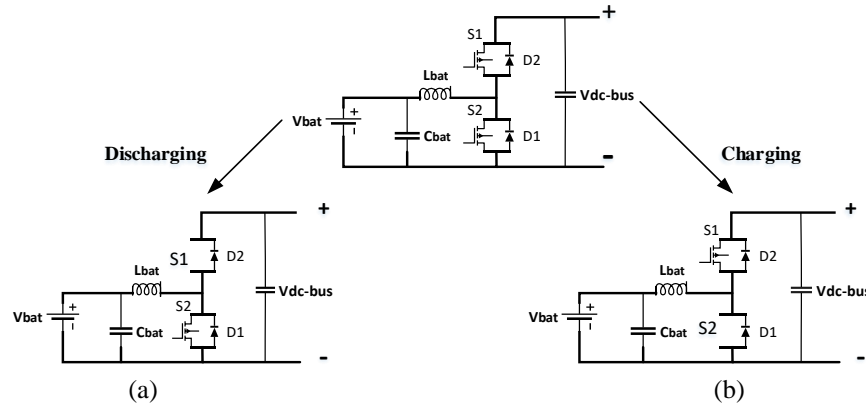


Figure 4. Describes the configuration of a bidirectional DC/DC converter in two modes: (a) discharging mode and (b) charging mode

4. DC-DC BUCK-BOOST CONVERTER CIRCUIT DESIGN

Zed two separate circuit boards, each serving a specific purpose. One circuit board was dedicated to the power circuit, responsible for handling the electrical power conversion and distribution. The power circuit board was designed to efficiently manage the input power, regulate voltage levels, and ensure proper current flow. The second circuit board was specifically designed for the drive circuit. This board focused on controlling the switching operations and managing the overall functionality of the converter. It incorporated components and circuitry to enable precise control of the power flow, timing of switching transitions, and protection mechanisms. Now, let's delve into the specifications of each circuit board to provide a more detailed understanding of their capabilities and features.

4.1. A driver circuit board

The driver circuit board depicted in Figure 5 is designed around the IR211 driver, which receives control signals from the microcontroller's outputs, such as Pic or Arduino. These control signals are analog and have voltage levels ranging from 0 to 5 volts, with sufficient current levels to power the MOSFETs. However, it is important to note that the low voltage of the gate must be isolated from the high voltage applied to the collector, which requires a signal conditioning mechanism [21], [22].

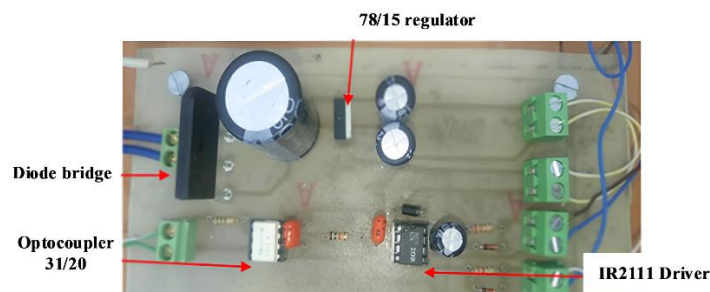


Figure 5. Converter driver card typically, the signal conditioning circuit consists of two stages

4.1.1. HCPL-3120 optocoupler

The initial step towards achieving galvanic isolation between the driver circuit board's two sides (the microcontroller and power circuit board), is illustrated in Figure 6. The HCPL-3120 comprises a GaAsP LED that is optically linked to a power output stage integrated circuit, making it beneficial for motor drive

applications that involve driving MOSFETs and IGBTs. The output stage's broad functional voltage range offers the necessary drive voltages for the gate-controlled devices. With the optocoupler's current and voltage output, IGBTs rated up to 1200 V/100 A can be directly driven. If the IGBTs have higher ratings, the HCPL-3120 can be used to supply a separate power stage that controls the IGBT gate [4], [23].

4.1.2. IR2111 driver

In the second stage, depicted in Figure 7, an IR2111 driver is utilized, which possesses high voltage and high frequency for the power supply, making it suitable for driving power MOSFETs and IGBTs. The reference dependency between the high and low side output channels is taken into account in the half-bridge design. The use of HVIC technology proprietary to the device and a CMOS latch allows for a robust monolithic structure. The logic input operates with standard CMOS outputs, while output drivers employ a high pulse current buffer stage to minimize conductive cross-conduction. Internal dead time is set to prevent output Half-Bridge from switching. The floating channel has the ability to supply power to a high-side configuration N-MOSFET or power IGBT channel that operates up to 600 volts.

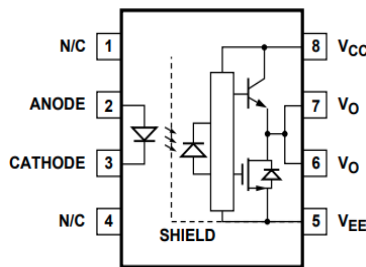


Figure 6. Functional diagram of HCPL 3120 optocoupler

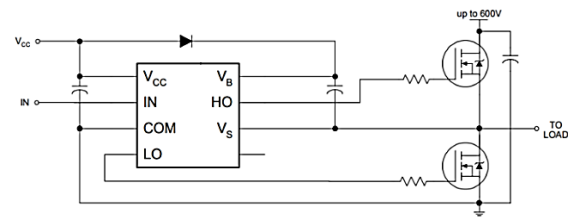


Figure 7. IR2111 driver

4.2. Converter power circuit board design

As shown in Figure 8, the power circuit portion of the Buck-Boost converter has been implemented. The key components are listed: i) a MOSFET transistor, ii) an input and output capacitors, iii) an inductor, iv) a heat sink and v) connection cables. The main components of the power circuit board were selected according to the following procedures.

4.3. Inductance choice

When designing a DC/DC converter, it is crucial to take into account the inductor design because it is often tailored to meet specific requirements based on frequency, voltage, and current [8], [16]. To select an appropriate inductor with a desired inductance L for a back mode converter (1) or boost mode converter (2), the following equations can be utilized.

$$L > \frac{V_{out} \cdot (V_{inmax} - V_{out})}{K_{ind} \cdot F_{sw} \cdot V_{inmax} \cdot I_{out}} \quad (1)$$

$$L > \frac{V_{inmin}^2 \cdot (V_{out} - V_{inmin})}{K_{ind} \cdot F_{sw} \cdot I_{out} \cdot V_{out}^2} \quad (2)$$

Where V_{out} is the voltage at the output, V_{inmax} is the maximum voltage at the input, I_{out} is the rated current at the output, K_{ind} is the maximum current ripple and F_{sw} is the switching frequency. The inductance with the highest value was chosen.

$$L > 0.6944mH$$

4.4. Capacitor output selection

A low equivalent series resistance (ESR) capacitor is the best practice to reduce the output voltage ripple [11]. As a result, the peak-to-peak resistance of the ripple voltage $V_n = 0.05V$ and $(I_2 - I_1) = 0.2A$, so the need for ESR is (13).

$$R_0 = \frac{V_{rr}}{dI} = \frac{V_{rr}}{(I_2 - I_1)} = 0.25\Omega \quad (3)$$

Using the typical ESR capacitor value relationship.

$$R_0 C_0 = 20 * 10^{-6}, \text{ it can be } C_0 = 50 * \frac{10^{-6}}{R_0} = 200\mu F \quad (4)$$

4.5. Power switch selection

The converter's maximum input voltage is 48 V. As a result, The IRFP260N can function as the primary circuit-switching device [24], [25]. The threshold voltage is 200 V, whereas, the threshold current is 50 A. The resistance is 4 mΩ, which is extremely short.

4.6. PCB design

The PCB design was created using EASYEDA software. Figure 9 illustrates the specific segments of the footprints and traces that make up the essential bidirectional DC/DC converter's components. Consequently, the power circuit PCB board and the driver PCB board were created using EASYEDA software, as depicted in Figures 10 and 11 respectively. The illustration presented Figure 12 shows the complete design of the DC-DC bidirectional buck-boost, comprising both the driver and power circuit boards, which are divided into two parts.

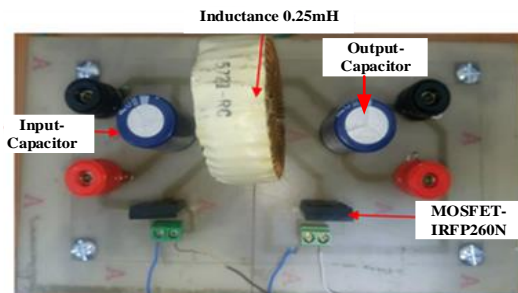


Figure 8. Converter power circuit board

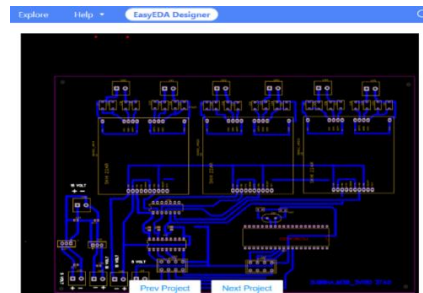


Figure 9. Easy EDA PCB designer software

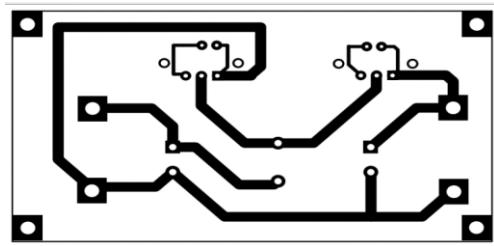


Figure 10. Power circuit board PCB

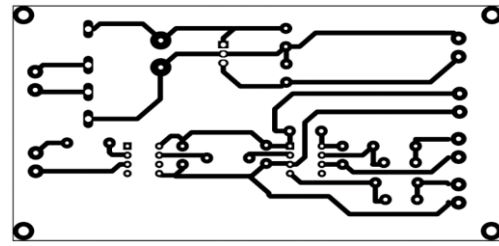


Figure 11. Driver circuit board PCB

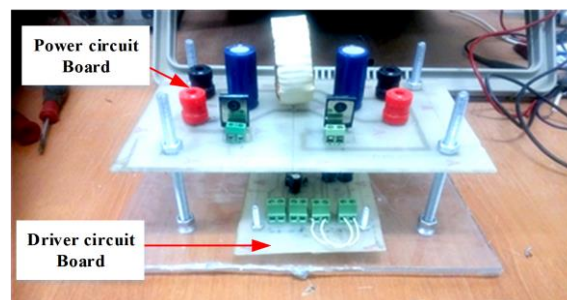


Figure 12. Bidirectional DC-DC buck-boost converter

5. RESULTS AND DISCUSSION

5.1. Experimental test bench exhibition

The photovoltaic conversion chain experimental setup illustrated in Figure 13 was divided into two parts. The first part, a continuous DC current section, includes a DC-DC Boost converter, which efficiently harvests power from the photovoltaic generator. The storage component comprises a bidirectional DC-DC Buck-Boost converter and a gel battery to regulate the DC bus voltage and ensure power balance between the source and load sides. The second part is the alternative current (AC) section, which features a 1.5 KVA

inverter based on IGBT modules controlled by the PWM technique. Real-time regulation loops are implemented using the DSP cards TMS320F28377S and TMS320F28335. This complete conversion chain is suitable for various photovoltaic applications, such as water pumping, charging solar batteries, and supplying electricity to three-phase engines in remote locations, as demonstrated in the experimental test bench of the photovoltaic conversion system shown in Figure 13.

Note: The PV system examined in this study consisted of several components, namely the PV panel, Boost, buck-Boost battery, and DC load.

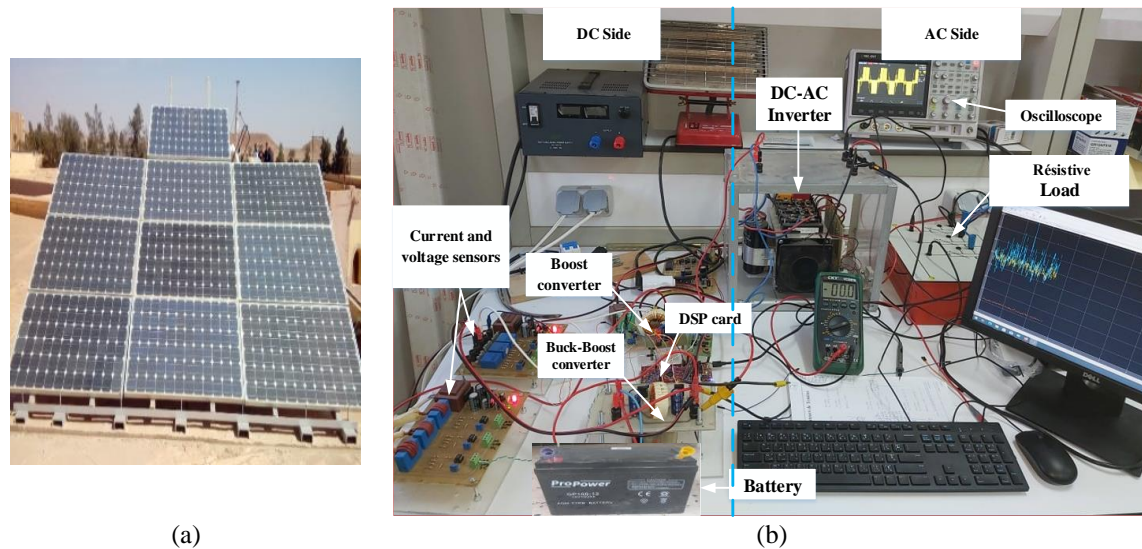


Figure 13. Buck boost converter test bench: (a) PV array-l'URAER-ghardaia and (b) experimental test bench of the photovoltaic conversion system

5.2. Experiment results and discussion

Initially, the bidirectional DC-DC buck-boost converter is tested to verify the regulation of the DC bus voltage. This test involves assessing the performance of the converter at different voltage set points. Subsequently, the converter is employed to administer the storage system, allowing the batteries to be charged or discharged depending on the amount of photovoltaic power available and the load requirements. Figures 14, 15, and 16 display the results that were obtained.

- The waveform of the control signals generated by the control board is presented in Figure 14. The signals generated for both IGBTs are complementary to prevent any potential short circuits.
- In Figure 15, the waveform of the DC bus voltage during the transition phase is illustrated. It is evident that the measured voltage tracks the reference voltage accurately and rapidly when the reference voltage changes. This demonstrates the effectiveness of the regulation system developed and emphasizes the significance of the transformer's buck-boost operation.



Figure 14. The shape of the control signals

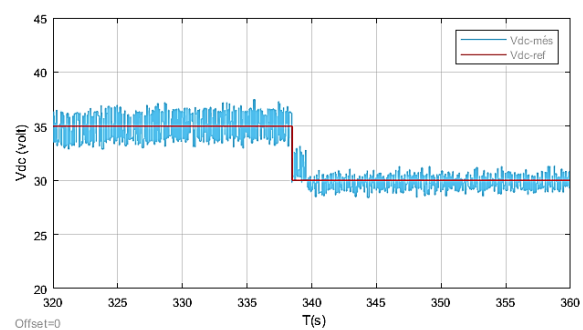


Figure 15. DC bus voltage regulation

Figure 16 illustrates the waveforms of PV's power, current and voltage, DC link voltage and battery current while operating in the charging and discharging modes. The plot demonstrates that the required power exceeds the generated power during the time interval of [19.5-28.7s]. As a result, the battery discharges to compensate for the power deficit, which is made possible by the boost operation mode of the implemented buck-boost converter.

During the time intervals of $t[15-19.5s]$ and $[28.7-33]$, the power produced by the PV generator is greater than the power needed by the load. As a result, the buck-boost converter functions in a buck mode, which enables it to store the excess power in the battery. The successful implementation of the system indicates that the control is valid and efficient. It ensures that the power demand for charging and discharging is met even when there are fluctuations in weather conditions, while also following the battery charging procedure. This demonstrates that the system is able to provide sufficient power and maintain consistency.

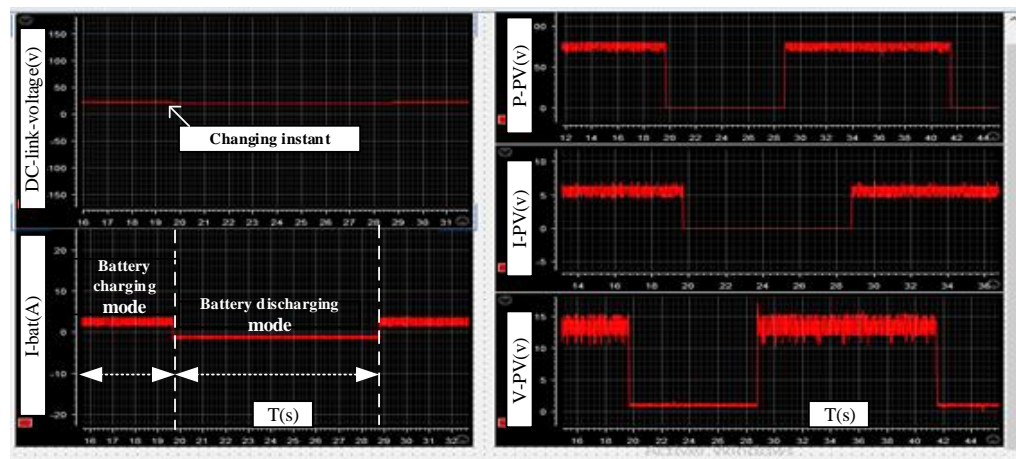


Figure 16. Battery current while charging and discharging

6. CONCLUSION

To address the unpredictable and intermittent nature of renewable energy sources, energy storage technology is crucial. Therefore, a buck-boost bidirectional converter has been designed and implemented in a dual battery application to facilitate the energy storage process. The driver and power converter boards have been designed to handle current and voltage stress on both sides, and the appropriate software has been utilized to create these boards. To evaluate the converter's capabilities in a microgrid, an experimental test was conducted. The buck-boost converter was used to regulate the DC bus voltage and charge/discharge the battery using dual control. The experimental results demonstrate that the converter design is capable of bidirectional energy transfer.

ACKNOWLEDGEMENTS

The authors greatly acknowledge the assistance and support of the Algerian Ministry of Higher Education and Scientific Research.




REFERENCES

- [1] R. Ren, "global status report 2012. Renewable energy policy network for the 21st century," *REN 21 Secretariat*, 2022. <http://www.ren21.net/gsr>.
- [2] W. Abitha Memala, C. Bhuvaneswari, S. M. Shyni, G. Merlin Sheeba, M. S. Mahendra, and V. Jaishree, "DC-DC converter based power management for go green applications," *International Journal of Power Electronics and Drive Systems*, vol. 10, no. 4, pp. 2046–2054, 2019, doi: 10.11591/ijpeds.v10.i4.pp2046-2054.
- [3] H. Liao, Y. T. Chen, L. Chen, and J. F. Chen, "Development of a Bidirectional DC-DC Converter with Rapid Energy Bidirectional Transition Technology," *Energies*, vol. 15, no. 13, 2022, doi: 10.3390/en15134583.
- [4] P. A. Dahono, "Simplified cascade multiphase dc-dc boost power converters for high voltage-gain and low-ripple applications," *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 1, pp. 273–285, 2021, doi: 10.11591/ijpeds.v12.i1.pp273-285.
- [5] Z. Wang, P. Wang, H. Bi, and M. Qiu, "A bidirectional DC/DC converter with wide-voltage gain range and low-voltage stress for hybrid-energy storage systems in electric vehicles," *Journal of Power Electronics*, vol. 20, no. 1, pp. 76–86, 2020, doi: 10.1007/s43236-019-00017-2.
- [6] K. Dadialla and R. S. Hardas, "Development of prototype model of DC-DC bi-directional converter," *IEEE International Conference on Power, Control, Signals and Instrumentation Engineering, ICPCSI 2017*, pp. 1620–1623, 2018, doi: 10.1109/ICPCSI.2017.8391986.




- [7] N. Hou and Y. W. Li, "Family of Hybrid dc-dc Converters for Connecting DC Current Bus and DC Voltage Bus," *ECCE 2020 - IEEE Energy Conversion Congress and Exposition*, pp. 412–417, 2020, doi: 10.1109/ECCE44975.2020.9235473.
- [8] D. C. Zacharek and F. Sundqvist, "Design of Bidirectional DC / DC Battery Management System for Electrical Yacht," pp. 12–37, 2018, [Online]. Available: <https://liu.diva-portal.org/smash/get/diva2:1229999/FULLTEXT01.pdf>
- [9] A. Ioinovici, "Modeling DC-DC Converters," *Power Electronics and Energy Conversion Systems*, pp. 161–368, 2013, doi: 10.1002/9781118443040.ch2.
- [10] T. Ouchi, A. Kanouda, N. Takahashi, and M. Moteki, "Seamless controlled parallel bi-directional DC-DC converter for energy storage system," *2014 16th European Conference on Power Electronics and Applications, EPE-ECCE Europe 2014*, 2014, doi: 10.1109/EPE.2014.6910837.
- [11] X. Xu, C. Zheng, C. Hu, Y. Lu, and Q. Wang, "Design of Bi-directional DC-DC converter," in *2016 IEEE 11th Conference on Industrial Electronics and Applications (ICIEA)*, Jun. 2016, pp. 2283–2287. doi: 10.1109/ICIEA.2016.7603972.
- [12] E. Ates, B. Tekgun, and G. Ablay, "Sliding mode control of a switched reluctance motor drive with four-switch Bi-Directional DC-DC converter for torque ripple minimization," *SEST 2020 - 3rd International Conference on Smart Energy Systems and Technologies*, 2020, doi: 10.1109/SEST48500.2020.9203523.
- [13] L. Mitra and U. K. Rout, "Optimal control of a high gain DC-DC converter," *International Journal of Power Electronics and Drive Systems*, vol. 13, no. 1, pp. 256–266, 2022, doi: 10.11591/ijpeds.v13.i1.pp256-266.
- [14] B. Benlahbib, N. Bouarroudj, F. Bouchafaa, and B. Batoun, "Fractional Order PI Controller for wind farm supervision," *IEEE International Conference on Industrial Engineering and Engineering Management*, vol. 2015-January, pp. 1234–1238, 2014, doi: 10.1109/IEEM.2014.7058835.
- [15] B. N., B. D., B. B., and B. B., "Sliding Mode Control Based on Fractional Order Calculus for Dc-Dc Converters," *International Journal of Mathematical Modelling & Computations*, vol. 5, no. 4, pp. 319–333, 2015.
- [16] D. S. G. Krishna and M. Patra, "Modeling of multi-phase DC-DC converter with a compensator for better voltage regulation in DC micro-grid application," *International Conference on Signal Processing, Communication, Power and Embedded System, SCOPES 2016 - Proceedings*, pp. 989–994, 2017, doi: 10.1109/SCOPES.2016.7955589.
- [17] A. Thameur *et al.*, "New Fuzzy Control of Photovoltaic Conversion Cascade Based Three Levels Inverter for Stand-Alone Applications," *2018 20th International Middle East Power Systems Conference, MEPCON 2018 - Proceedings*, pp. 1009–1013, 2019, doi: 10.1109/MEPCON.2018.8635162.
- [18] B. Benlahbib, F. Bouchafaa, S. Mekhilef, and N. Bouarroudj, "Wind farm management using artificial intelligent techniques," *International Journal of Electrical and Computer Engineering*, vol. 7, no. 3, pp. 1133–1144, 2017, doi: 10.11591/ijece.v7i3.pp1133-1144.
- [19] S. Jadhav, N. Devdas, S. Nisar, and V. Bajpai, "Bidirectional DC-DC converter in Solar PV System for Battery Charging Application," *2018 International Conference on Smart City and Emerging Technology, ICSCET 2018*, 2018, doi: 10.1109/ICSCET.2018.8537391.
- [20] Z. Zhang, S. Xie, Z. Wu, and J. Xu, "Soft-switching and low conduction loss current-fed isolated bidirectional DC-DC converter with PWM plus dual phase-shift control," *Journal of Power Electronics*, vol. 20, no. 3, pp. 664–674, 2020, doi: 10.1007/s43236-020-00074-y.
- [21] B. Benlahbib and F. Bouchafaa, "PSO-PI algorithm for wind farm supervision," *Journal of Electrical Engineering*, vol. 14, no. 3, 2014.
- [22] B. Benlahbib *et al.*, "Experimental investigation of power management and control of a PV/wind/fuel cell/battery hybrid energy system microgrid," *International Journal of Hydrogen Energy*, vol. 45, no. 53, pp. 29110–29122, 2020, doi: 10.1016/j.ijhydene.2020.07.251.
- [23] S. Mekhilef, N. Bouarroudj, B. Benlahbib, and F. Bouchafaa, "Fractional Order PID Controller for DC Link Voltage Regulation in Hybrid System Including Wind Turbine- and Battery Packs- Experimental Validation," *International Journal of Power Electronics*, vol. 11, no. 1, p. 1, 2020, doi: 10.1504/ijpelec.2020.10013305.
- [24] S. Fan, H. He, S. Chen, J. Duan, J. You, and L. Bai, "Zero voltage switching non-isolated bidirectional DC-DC converter with transient current built-up technique," *Journal of Power Electronics*, vol. 22, no. 5, pp. 764–772, 2022, doi: 10.1007/s43236-022-00398-x.
- [25] R. D. N. Aditama, N. Ramadhani, J. Furqani, A. Rizqiawan, and P. A. Dahono, "New bidirectional step-up dc-dc converter derived from buck-boost dc-dc converter," *International Journal of Power Electronics and Drive Systems*, vol. 12, no. 3, pp. 1699–1707, 2021, doi: 10.11591/ijpeds.v12.i3.pp1699-1707.

BIOGRAPHIES OF AUTHORS






Boualam Benlahbib    is a senior research fellow at Algeria's Applied Research Unit on Renewable Energies (URAER). In 2009, he earned a B.Eng. in electromechanical systems from the University of Badji Mokhtar in Annaba, Algeria, and a Magister in electromechanical systems from the Polytechnic Military School, Bordj Elbahri (EMP) in Algiers, Algeria. In 2019, he received a Ph.D. in electronic instrumentation from the University of Science and Technology Houari Boumediene USTHB in Algiers, Algeria. Then, in 2020, the Habilitation (HDR) in Electrical Engineering from the University of Ouargla in Algeria. Renewable energy systems, electric machine controls, microgrids, energy management systems, wind energy, photovoltaic systems, motor drives, smart control systems, and power electronics are among his research interests. He can be contacted at email: bouallam30@gmail.com.






Abdeldjalil Dahbi    is currently a Senior Researcher at the Research Unit in Renewable Energies in the Saharan Medium (URER-MS) in Adrar, Algeria. He received his engineering in Electromechanical engineering from the University of Bourdj Bou Arreidj in 2009. He received another diploma of technical English from Setif university in 2011. He received the Magister degree in Electrical Engineering (Electric controls) from the University of Setif in 2012. He has also another diploma in energetic physics in 2015 from the University of Adrar. He received his doctorate degree in Electric Controls from the University of Batna in 2018; then the Habilitation (HDR) in Electrical Engineering from the University of Adrar in 2020. He taught and supervised a lot of students in different fields. His main research interests are: renewable energy systems, electric machine controls, wind energy conversion systems, photovoltaic systems, smart control systems, remote control, meteorology, and IoT. He has many

national and international patents; furthermore, he realized many prototypes in different domains. He is a head of a research project and the author of several papers which were presented and published in national and international conferences, and books too. He is a reviewer in many international conferences and high-quality journals (IEEE and Elsevier). He can be contacted at email: Dahbi_j@yahoo.fr.






Bennaceur Fares    is currently a Ph.D. student at the electronic and telecommunications department, of Kasdi Merbah Ouargla University. He received a baccalaureate certificate in 2016, then a bachelor's degree in electronics from Ouargla University in 2019. He received a master's degree in embedded systems in 2021. In 2022, he won the doctoral competition in electronics specialization in Ouargla, Algeria. His current research interests include renewable energy systems, electric machine controls, microgrids, energy management systems, wind energy, photovoltaic systems, motor drives, smart control systems, and power electronics. He can be contacted at email: fareschab2017@gmail.com.






Abdelkader Lakhdari    is a fellow researcher at the applied research unit in renewable energy, Algeria. He received the B.Eng. degree in Electronics from University of Mohammed Boudiaf, M'sila, Algeria, in 2009, Magister degree in Electronics from University of Ferhat Abbas-Setif, Algeria, in 2012 and Ph.D. Degrees in Electronics from the same University in 2020. His research interests include renewable energy, power quality and power system reliability. He can be contacted at email: lakhdari_abdelkader@hotmail.com.






Noureddine Bouarroudj    was born in Cheria, Tebessa, Algeria, in 1983. He received his Engineer degree in Automatic control from University of Tebessa, Algeria, in 2008 and his MSc, and Ph.D degrees in Electrical Engineering (automatic control) from Ecole Nationale Polytechnique (ENP), Algeria, respectively in 2011, and 2017. He is currently a Researcher at Unité de Recherche Appliquée en Energies Renouvelables/CDER, Ghardaia, Algeria. His research interests include fractional-order control, sliding mode control, renewable energy systems and their controls and control optimization. He can be contacted at email: autonour@gmail.com.



Saad Mekhilef    received the B.Eng. degree in electrical engineering from the University of Setif, Setif, Algeria, in 1995, and the master's degree in engineering science and the Ph.D. degree in electrical engineering from the University of Malaya, Kuala Lumpur, Malaysia, in 1998 and 2003, respectively. He is currently a Distinguished Professor with the School of Science, Computing and Engineering Technologies, Swinburne University of Technology, Melbourne, VIC, Australia, and an Honorary Professor with the Department of Electrical Engineering, University of Malaya, Kuala Lumpur, Malaysia. He has authored or co-authored more than 500 publications in academic journals and proceedings and 5 books with more than 32 000 citations. His current research interests include power converter topologies, the control of power converters, renewable energy, and energy efficiency. He can be contacted at email: saad@um.edu.my.



Thameur Abdelkrim    was born in 1978 in Algiers, Algeria. He obtained Engineer degree in Electrical Engineering in 2001 from University of Boumerdes in Algeria. He obtained respectively Magister, PhD and the Authorization to Supervise Research (ASR) degrees in Algiers, Algeria from Polytechnic Military School in 2004, Polytechnic National School in 2010 and University of Science and Technology Houari Boumediene in 2012. In 2005, he joined the Applied Research Unit on Renewable Energies in Ghardaïa, Algeria. He is Research Director in Electrical Engineering and research team leader in mini solar power plants division. His research interests are in power electronics, electrical drives and renewable energies. He can be contacted at email: tameur3@gmail.com.