STUDY AND DESIGN OF A DIGITAL PULSE WIDTH MODULATION SIGNAL GENERATOR FOR DC-DC CONVERTERS

MOHAMED KAOUANE[1, 2], NIDHAL CHERRAT[2], MANAR DEROUECHE[2], AKKILA BOUKHELIFA[3]

This paper presents the design and implementation of a novel digital pulse-width modulation (PWM) signal generator for controlling DC-DC power converters. The proposed digital approach enables precise control of both the switching frequency and duty cycle of the PWM signals via a computationally efficient algorithm. This technique is versatile and can be integrated into various DC-DC converter configurations, thereby facilitating the development and experimental testing of new power-circuit designs. Experimental results demonstrate that the method offers significant advantages over traditional analog and digital techniques, including enhanced accuracy and improved signal quality. The performance of the proposed generator is validated through testing with a single-ended primary-inductance DC-DC converter (SEPIC). Additionally, the control board is suitable for both research and educational applications.

1. INTRODUCTION

Electronic power converters are widely used in electrical applications to convert and deliver energy from generators to loads. In many power-electronic systems, such as renewable energy conversion, it is required to convert generated voltage levels into different electrical potentials [1,2]. DC-DC converters can be used as switching-mode regulators to convert an unregulated DC voltage to a regulated output voltage. A DC-DC converter can be a step-down converter (Buck function), a step-up converter (boost function), or it can be a step-down/step-up converter (Buck-boost function) [3,4].

There are various techniques to regulate the DC source voltage. The most efficient regulation method is to incorporate pulse-width modulation (PWM) control within the converter at a specified frequency and duty cycle. The controlled switching device is typically a BJT, MOSFET, or IGBT. Commonly used techniques include single-PWM, multiple-PWM, and sinusoidal-PWM [5,6].

PWM generators are increasingly used in a range of new electrical applications that require superior performance. Recent advances in power electronics and semiconductor technology have improved power electronic systems. Hence, various techniques and circuit configurations for PWM control of DC-DC converters have become popular and have attracted considerable interest from researchers. Various PWM signal generation techniques can be employed to achieve suitable conversions of electrical parameters, such as voltage and current [7].

PWM signals can be generated using either analog or digital circuits. The conventional method is an analog technique that compares a reference control voltage with a sawtooth signal, yielding the PWM output as the result of that comparison. However, this technique exhibits low efficiency, and the parameters of the PWM signal cannot be adjusted effectively [5]. In contrast to the analog method, a digital technique for generating PWM signals is more optimal and suitable, but a programmable integrated circuit is required to achieve better results; however, frequency and duty-cycle control are not always accurate [7].

This paper proposes a new digital PWM signal generator, which has been studied, designed, and tested with a DC-DC converter. The electronic board operates under a program uploaded to a microcontroller that implements the studied algorithm, enabling precise control of the PWM signal's frequency and duty cycle.

The paper is organized as follows: The first section introduces the principles of PWM techniques. The second section details the algorithm and digital circuit design of the new signal generator. The third section presents and discusses the experimental results, and the paper concludes with a summary of the findings.

2. PULSE WIDTH MODULATION TECHNIQUES

Due to advances in solid-state power devices and microprocessors, switching power converters are widely used in industrial applications to convert and deliver the required energy to the load. In many electronic applications, it is necessary to control the output and input voltages of power converters. PWM control is the most effective and widely used method for output-voltage regulation in DC-DC converters. When a PWM signal is applied to the gate of a power switch, it determines the switch's "turn on" and "turn off" intervals, producing a range of output voltage levels depending on the duration of conduction.

The types of PWM techniques are single-pulse width modulation (SPWM), multiple-pulse width modulation, and sinusoidal pulse width modulation (carrier-based pulse width modulation). The first technique is the most convenient for DC-DC converters; the other two techniques are intended for other circuits, such as DC-AC inverters [8,9].

In SPWM control, there is only one pulse per half-cycle, and the pulse width varies to control the output voltage.

However, the SPWM generating circuits may be classified as follows:
- Analog pulse-width modulation generators;
- Digital pulse-width modulation generators.

2.1. ANALOG GENERATORS

The basic method for building a pulse-width modulator is to use a comparator that compares an input reference voltage with a triangular or sawtooth signal, yielding a linear relationship between the amplitude of the input reference voltage and the pulse width. Whenever the sawtooth signal deviates from the reference voltage V_{ref}, the comparator output voltage abruptly changes state. If the reference voltage exceeds the sawtooth signal level, the PWM signal will be High. On the other hand, if the reference voltage is

---

[1] National Higher School of Autonomous Systems Technology, NHSAST, Algiers, Algeria.
[2] Faculty of Technology, University M'hamed Bougara of Boumerdes, Boumerdes, Algeria.
[3] Faculty of Electrical Engineering, University of Sciences and Technology Houari Boumediene, USTHB, Algiers, Algeria.
 E-mails: mohamed.kaouane@enstsa.edu.dz, n.cherrat@univ-boumerdes.dz, m.deroueche@univ-boumerdes.dz, aboukhelifa@usthb.dz

less than the sawtooth signal level, the PWM signal is set to Low. By varying the reference voltage, the PWM signal's duty cycle can be adjusted.

The basic analog PWM generator and its waveforms are shown in Figs. 1 and 2. The duty cycle (D) can be stated as:

$$D = \frac{t_{on}}{T}, \quad (1)$$

where t_{on} and T are, respectively, the pulse width (sec) and the period of the pulse (sec) [5].

Fig. 1 – Classic Analog PWM generator.

Fig. 2 – Analog PWM generator waveforms.

Analog PWM generators can also be built using multivibrator circuits based on transistors, operational amplifiers, or NE555 Timers [10].

2.2. DIGITAL GENERATORS

Most analog circuits used to generate PWM signals are unstable with respect to voltage and do not permit precise adjustments. To address these limitations, a digital circuit is required that allows the amplitude, frequency, and duty cycle to be adjusted via programming to meet the requirements of the power circuit. The digital circuit may be based on a microcontroller, a DSP, an FPGA, or other programmable digital devices that have sufficient memory, an analog-to-digital converter, and a PWM output [10]. The input signal to the digital modulator is often pulse code modulated (PCM), meaning the samples arrive uniformly and represent the magnitude of the original signal with a binary word. This modulation is often referred to as PCM-to-PWM conversion [11].

Note that even when using a digital circuit, we cannot have an ideal signal. Each pulse of the PWM signal is characterized by several parameters, such as its rise and fall times. A common digital technique uses the increase/decrease principle with buttons to vary the frequency and duty cycle (Fig. 3), but variations in one parameter can affect the other.

Fig. 3 – Conventional digital PWM generator (example board).

3. PROPOSED PWM GENERATOR

Figure 4 shows the block diagram of the digital PWM signal generator under study. The circuit comprises a microcontroller, a transistor-based switching-mode amplification block, and a power driver that generates two complementary PWM signals with the desired parameters.

The microcontroller PIC18F4550 is used in this application. It has an analog-to-digital converter (ADC) that allows selection of frequency and duty cycle values, which are set using two potentiometers. This microcontroller enables the generation of PWM outputs, which is the most important function for building the studied circuit. The code is written in a specific software (MikroBasic) and transferred to the microcontroller; it is based on the flowchart of the proposed digital technique shown in Fig. 5.

Using potentiometers and an Analog-to-Digital Converter improves parameter control and enables the acquisition of a wide range of values.

Fig. 4 – Block diagram of the proposed digital technique.

Fig. 5 – Basic flowchart of the proposed PWM signals generator.

Fig. 6 – Schematic diagram of the proposed circuit.

An amplification circuit based on a transistor in switching mode is essential to bring the PWM signal to an amplitude able to operate with the driver. This latter is chosen as an IR2111, a high-voltage, high-speed power MOSFET and IGBT driver; it generates two complementary, regulated

PWM signals, enabling control of the converters' power switches. Figures 6 and 7 show, respectively, the schematic diagram and the PCB of the digital PWM signals generator.

Fig. 7 – PCB of the proposed circuit.

4. EXPERIMENTAL RESULTS

The experimental tests are carried out in two parts: First, the PWM generator is tested independently, and then with a SEPIC DC-DC converter.

For the first test, the PWM switching frequency is fixed at 30 kHz, and the duty cycle of the high output (HO) is 42.5%. The results are visualized using a digital oscilloscope (Fig. 8) equipped with a USB port, which allows saving the obtained curves from the circuit.

Fig. 8 – Digital Oscilloscope (Instek GDS-1062)

Figure 9 shows the PWM signal generated by the microcontroller. The signal is then amplified using a transistor operating in switching mode. The obtained signal is shown in Fig. 10.

This signal is zoomed to highlight its rise and fall times, as shown in Fig. 11 and 12.

The obtained signal is applied to the driver, which regulates its form and generates two complementary signals, shown in Fig. 13 and 14. Zoomed views of the high-side output (HO) signal are presented in Fig. 15 and 16.
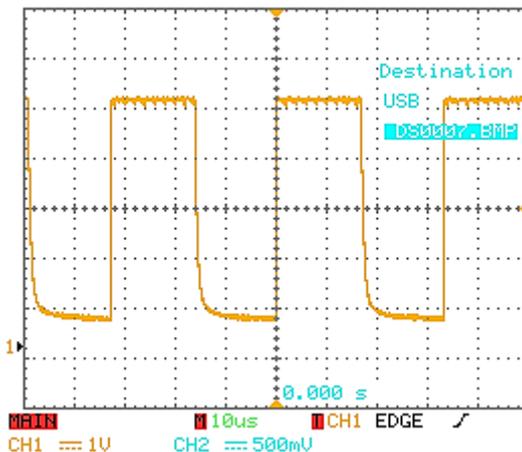
Fig. 9 – PWM waveform generated by the microcontroller.
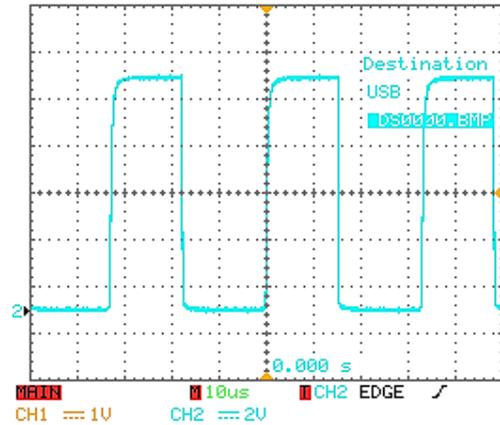
Fig. 10 – Amplified PWM waveform at the transistor emitter.
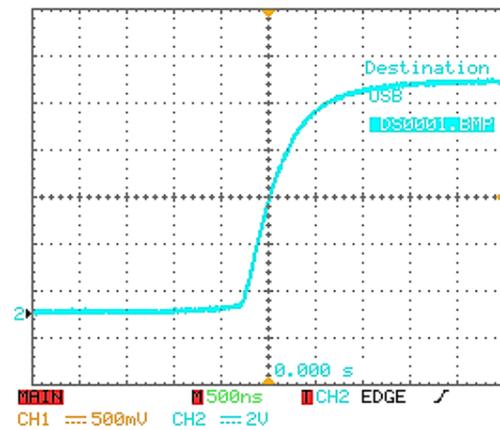
Fig. 11 – Zoomed view of the amplified PWM waveform -Rise time.
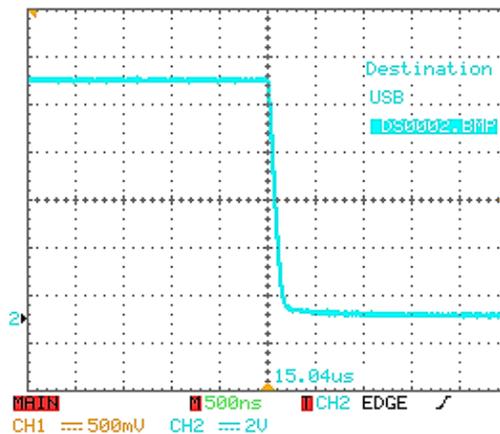
Fig. 12 – Zoomed view of the amplified PWM waveform -Fall time.
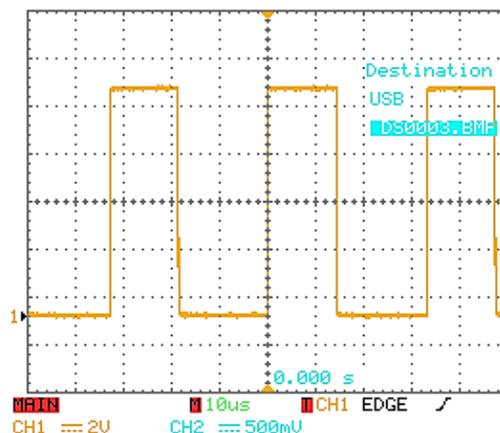
Fig. 13 – High-side (HO) PWM waveform generated by driver.
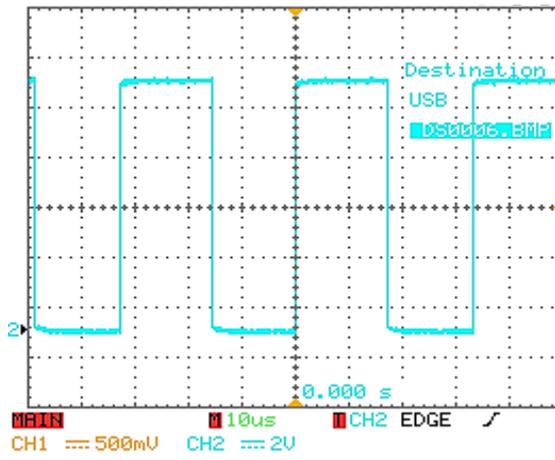
Fig. 14 – Low-side (LO) PWM waveform generated by driver
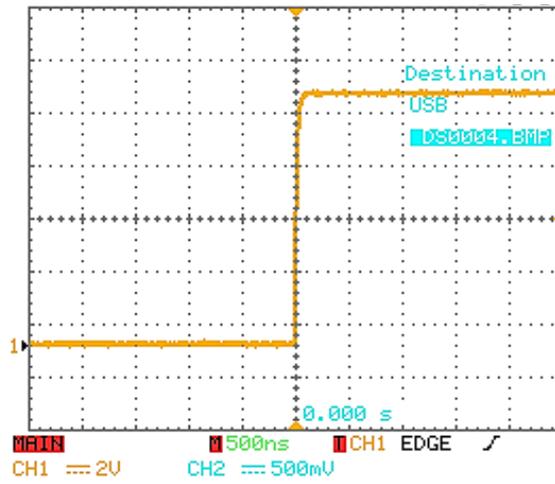

Fig. 15 – Zoomed view of HO waveform showing the rise time.
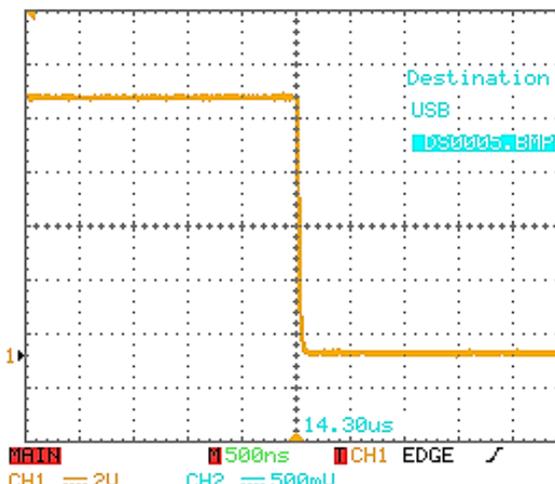

Fig. 16 – Zoomed view of HO waveform showing the fall time.

A test with a single-ended primary-inductance DC-DC converter (SEPIC) using the proposed PWM generator is conducted to provide further evidence about the performance of the presented technique.

Figure 17 illustrates the electrical scheme of the SEPIC converter. It comprises two coupled inductors, $L1$ and $L2$, both equal 150 µH, an input capacitor, $C_{in} = 330$ µF, an AC coupling capacitor, $Cc = 330$ µF, an output capacitor, $C_{out} = 2200$ µF, a Schottky diode (1N5819 or equivalent), and a power switch, which is an N-Channel Power MOSFET IRFP150. The PCB of the converter is illustrated in Fig. 18 [12,13].

The SEPIC output voltage follows the next expression:

$$V_{out} = \eta V_{in} \frac{D}{1-D}, \tag{2}$$

where η is the efficiency of the converter (%).

The converter input voltage is fixed at 13.72 V. The SEPIC output-voltage curve and its zoom are shown in Figs. 19 and 20. These are obtained at a switching frequency of 30 kHz and a duty cycle of 42.5%.

The proposed circuit generates high-quality, low-dead-time PWM signals, resulting in a significantly improved SEPIC response compared with operation with the transistor output directly [14].
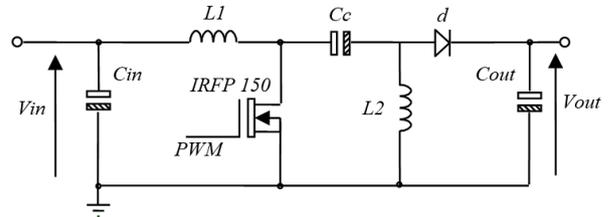

Fig. 17 – Schematic diagram of the SEPIC converter.
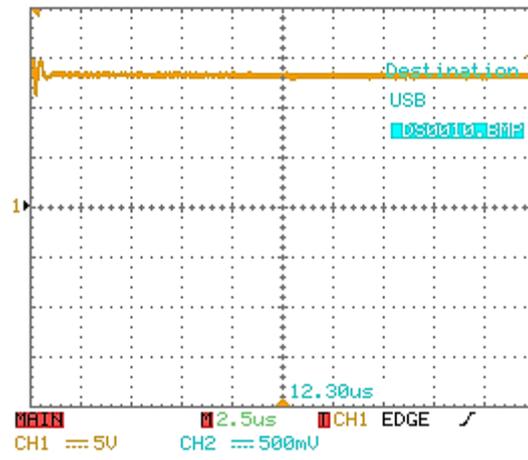

Fig. 18 – PCB of the SEPIC Converter.

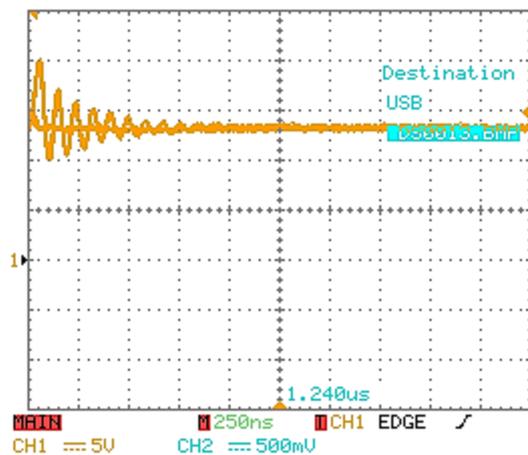Fig. 19 – Output voltage waveform of the SEPIC converter.

Fig. 20 – Zoomed output voltage waveform of the SEPIC converter.

The DC-DC converter has been tested at a constant input voltage, V_{in} = 13.72 V, with two PWM signals at 30 kHz and 50 kHz, and a variable duty cycle, D, from 20% to 60% in steps of 5%. These tests are conducted to observe the DC-DC converter's response. Table 1 presents the output voltages V_{out} obtained for different duty cycles D.

The results validate the operation of the PWM generator and show that power converters can be controlled and tested effectively by applying the proposed technique.

Table 1

Obtained output voltages.

D (%)	F = 30 kHz Vout (v)	F = 50 kHz Vout (v)
20	05.3	04.1
25	06.8	05.0
30	08.6	06.6
35	10.1	07.5
40	11.9	08.9
45	13.6	10.9
50	15.5	13.4
55	17.3	16.9
60	20.3	20.9

A comparative analysis between the proposed digital PWM generator and existing analog and digital PWM techniques is presented in Table 2. Unlike conventional analog PWM generators, the proposed solution eliminates sensitivity to component tolerances and thermal drift. Compared to traditional microcontroller-based PWM techniques that rely on timer increment/decrement methods, the proposed approach provides independent, continuous control of both frequency and duty cycle via ADC-controlled inputs.

While DSP- and FPGA-based solutions provide high precision, they are often costly and complex [15]. The proposed generator achieves comparable signal quality with lower cost and reduced implementation complexity, making it particularly suitable for research and educational DC-DC converter platforms.

Table 2

Comparison of PWM techniques.

Criterion	Analog PWM	Conventional Digital PWM (MCU Timer)	Proposed Digital PWM Generator
Execution principle	Comparator-based	Timer interrupt / polling	Optimized MCU algorithm with ADC
Execution time	Continuous (analog)	Interrupt dependent, variable	Low and deterministic
CPU cycle usage	N/A	Moderate to high (timer + updates)	Low (few cycles per update)
Frequency control	Limited, component-dependent	Discrete steps, coupled with duty cycle	Very precise
Duty cycle control	Sensitive to noise and drift	Discrete steps, affects frequency	Very precise
Signal stability	Low	Moderate	High
Dead-time control	No	No	Yes
Cost & complexity	Very low	Low	Low to moderate

5. CONCLUSION

This paper presents a new digital PWM signal generator designed to control DC-DC converters in power-electronic applications. The circuit is based on an efficient algorithm that enables accurate control of the frequency and duty cycle, a level of control that is difficult to achieve using conventional analog techniques and limited by standard digital implementations.

The proposed algorithm is implemented as code edited in a specific software environment and uploaded to a microcontroller, the core of the circuit. The experimental results show that this method has several advantages over existing techniques; it exhibits lower losses, lower pulse noise, and greater signal stability. Testing with a SEPIC DC-DC converter validates the performance of the proposed digital technique.

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Mohamed Kaouane: Conceived the research idea, developed the experimental methodology, and provided oversight during the implementation of the digital PWM signal generator. Performed experiments, collected data, and analyzed results. Contributed to the technical writing of the methods and experimental sections.

Nidhal Cherrat: Assisted with data interpretation and the refinement of experimental results. Contributed to the discussion section and reviewed the manuscript.

Manar Deroueche: Contributed to writing the introduction, results, and conclusion sections. Assisted with editing and formatting of the final manuscript.

Akkila Boukhelifa: Assisted with the experimental setup, calibration, and troubleshooting of the system. Analyzed the performance data and helped refine the experimental platform.

REFERENCES

1. R. Thankakan, E. Nadar, *Novel power converter fed by photovoltaic source employing improved incremental conductance algorithm under partial shadow conditions*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **67**, *2*, pp. 145–150 (2022).
2. E. Mamarelis, G. Petrone, G. Spagnuolo, *Design of a sliding-mode-controlled SEPIC for PV MPPT applications*, IEEE Transactions on Industrial Electronics, **61**, *7*, pp. 3387–3398 (2014).
3. M.A. Ilie, D. Floricău, *Grid-connected photovoltaic systems with multilevel converters – modeling and analysis*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **68**, *1*, pp. 77–83 (2023).
4. L. Devarajan, S. Chellathurai, *Aquila optimized nonlinear control for DC-DC boost converter with constant power load*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, *4*, pp. 419–424 (2024).
5. Y. Chen, B. Zhang, D. Qiu, F. Xie, *A unified frequency-domain model of analog and digital PWM DC–DC converter considering PWM delay*, IEEE Transactions on Power Electronics, **38**, *12*, pp. 15390–15405 (2023).
6. L. Mo, Y. Wang, C. Jiang, X. Wang, B. Zhang, *A novel topology derivation method revealed from classical Cuk, SEPIC, and Zeta converters*, IEEE Transactions on Power Electronics, **39**, *7*, pp. 7828–7833 (2024).
7. A. Sarkar, N. Deshmukh, S. Anand, *Modified PWM scheme to reduce reverse conduction loss in GaN-based independently controlled multiple output flyback converter*, IEEE Transactions on Power Electronics, **37**, *11*, pp. 12968–12972 (2022).
8. A.S. Joseph, S. Ramalingam, *Enhancement of power factor correction in an AC-DC converter with an integrated boost-flyback circuit*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **69**, *2*, pp. 213–218 (2024).
9. M. Burlacu, V. Năvrăpescu, A.I. Chirilă, I.D. Deaconu, *Optimal reactive power management for microgrids based on photovoltaic inverters using sine-cosine algorithm*, Rev. Roum. Sci. Techn. – Électrotechn. et Énerg., **67**, *2*, pp. 117–122 (2022).
10. R. Cvetanovic, I.Z. Petric, P. Mattavelli, S. Buso, *Small-signal modeling of phase-shifted digital PWM in interleaved and multilevel converters*, IEEE Transactions on Power Electronics, **38**, *3*, pp. 3057–3068 (2023).
11. L. Xing, Q. Wei, Y. Li, Y.-F. Liu, *Phase-shifting SPWM-based modulation for single-source five-level current source inverter*, IEEE Transactions on Power Electronics, **40**, *8*, pp. 10343–10348

(2025).

12. E. Paul, M. Sannasy, S.V. Naik, *Design and evaluation of a noncoupled inductor enhanced gain dual switch SEPIC converter for PV application*, IEEE Transactions on Industry Applications, **61**, *2*, pp. 3187–3199 (2025).

13. M. Kaouane, A. Boukhelifa, A. Cheriti, *Design of a synchronous SEPIC DC-DC converter for a stand-alone photovoltaic system*, 2015 IEEE 28th Canadian Conference on Electrical and Computer Engineering (CCECE), Halifax, NS, Canada, pp. 870–874 (2015).

14. F.I. Kravetz, R. Gules, *Soft-switching high static gain modified SEPIC converter*, IEEE Journal of Emerging and Selected Topics in Power Electronics, **9**, *6*, pp. 6739–6747 (2021).

15. S.R. Geninatti, M. Ortiz-López, F.J. Quiles-Latorre, T. Morales-Leal, A. Gersnoviez, A. Moreno-Muñoz, *Fast FPGA prototyping to explore and compare new SPWM strategies*, IEEE Transactions on Circuits and Systems I: Regular Papers, **71**, *3*, pp. 1208–1221 (2024).