presence of Mg and Ca is typically easier to remove via acid leaching or flotation, but their concentrations here remain non-negligible (Khalifa *et al.*, 2025).

Conclusion. The ICP characterization of Gweru's silica sand demonstrates promising yet imperfect purity for high-value applications. With 92.38 % SiO_2, the silica sand exhibits potential as a feedstock for silicon production but remains below the required purity for electronic-grade use. The elevated FeO (0.312 %) and Al_2O_3 (0.49 %) contents are the principal limiting factors, as these impurities degrade semiconductor performance and optical clarity. However, studies indicate that sequential acid leaching, magnetic separation, and flotation can effectively reduce Fe and Al impurities to acceptable limits (Liu et al., 2023; Long et al., 2024; Pachaly et al., 2022). Therefore, with targeted beneficiation and purification technologies, Zimbabwe's silica sand could transition from a low-value construction material to a strategic mineral resource underpinning local semiconductor and photovoltaic industries.

References

1. Asmaa, Z. Extraction of silica from natural deposits for the production of silicon in photovoltaic applications / Z. Asmaa, H. Saad // Open Journal of Bacteriology. – 2023. – Vol. 7, № 1. – P. 011–015.

2. A review of high-purity quartz for silicon production in Australia / A. Jennings [et al.] // Australian Journal of Earth Sciences. – 2024. – Vol. 71, № 8. – P. 1085–1097.

3. Magniothermal Methods of Silicon Extraction from Quartz Sands of "Jerdanak" Mine / S. I. Jiyanova [et al.] // International Journal of Engineering Trends and Technology. – 2024. – Vol. 72, № 10. – P. 316–322.

4. High-Purity Silica Produced from Sand Using a Novel Method Combining Acid Leaching and Thermal Processing / M. Khalifa [et al.] // Arabian Journal for Science and Engineering. – 2025. – Vol. 50, № 6. – P. 4129–4135.

5. Advanced Processing Techniques and Impurity Management for High-Purity Quartz in Diverse Industrial Applications / H. Long [et al.] // Minerals. – 2024. – № 6. – Art. 571.

6. Innovative process for the extraction of 99.99% high-purity quartz from high-silicon iron ore tailings / H. Long [et al.] // Journal of Materials Research and Technology. – 2024. – P. 2094–2102.

7. Mudimbo, D. Hydrogeology of Zimbabwe / D. Mudimbo. – Harare: Geological Survey of Zimbabwe, 2018. – 245 p.

8. Extraction of Silicon from Silica Sand by Carbothermic Reduction in Mini DC-EAF / D. Tandersen, L. Müller, P. Schmidt [et al.] // E3S Web of Conferences. – 2024. – Vol. 543. – Art. 02006.

9. Research Status and Challenges of High-Purity Quartz Processing Technology from a Mineralogical Perspective in China / R. Zhang, W. Li, X. Chen [et al.] // Minerals. – 2023. – Vol. 13, № 12. – Art. 1505.

UDC 681

EFFECTS OF DEAD-TIME IN DUAL ACTIVE BRIDGE

Machongwe T , Musiiwa P. B., Mutamba C. T., Makusha D. T., Kapuya E. T. , Musademba D.

Harare Institute of Technology, Harare, Zimbabwe

Abstract. The article explores the effect of dead-time in the operation of a Dual Active Bridge (DAB). DABs consist of high-speed switching devices (usually MOSFETS) as the main architecture component. The switches turn off and on at frequencies greater than 50 MHz. During this switching period, switches change from their low state to high state. If the fall time is greater than the time between switching changes, a short circuit is created leading to the damage of the switching devices. Therefore, it is very important to critically analyze the effect of dead-time during the design of the dual active bridge topology.

Keywords: dual active bridge, dead-time, bidirectional converters.

Address for correspondence: Peter B. Musiiwa, BE277 Belvedere Harare Zimbabwe
e-mail: pbmusiiwa@hit.ac.zw

Introduction. A dual active bridge is a commonly used topology in the development of dc-dc converters. It comprises two PWM controlled active primary and secondary full H-bridges, connected through a high-frequency transformer.

The primary function of the DAB is to facilitate controlled, bidirectional power flow between two DC sources or loads, such as a battery and a DC bus, while providing galvanic isolation. This makes it exceptionally suitable for applications like electric vehicle charging, renewable energy integration, solid-state transformers, and aerospace power systems. As can be observed from Figure 1, there are four power switches on each side of the high-frequency transformer, and the transformer provides isolation between the primary and secondary sides. Controlling the magnitude and direction of the phase shift between the four bridge arms, energy flows between the two DC power sources.

Dead time effect. The dead time effect is a phenomenon during the switching transition; this event is deliberately included during the switching phases in which both switches in a half bridge are commanded to be in the OFF state. The fundamental and most critical reason for implementing dead time is to prevent a condition known as shoot-through or cross-conduction. Another important reason for implementing the dead time phenomenon is its ability to create a safety margin. Hence it accounts for the non-ideal characteristics of real-world components. Shoot-through is a fault that occurs when both the high side and low side switches in a leg are turned ON simultaneously, even for a very short time [1, 2].This creates a low-impedance path directly from the DC supply rail to ground, resulting in a very high, destructive surge of current that can permanently damage the semiconductor switches. Effects of increasing deadtime Power Transfer Reduction: As dead time increases from 50 ns to 400 ns, the power output drops from 605 W to 586 W, a reduction of over 20 %. This confirms that the distorted voltage waveform reduces the effective voltage-time product available for power transfer [3]. The relationship can be approximated by the following equation, which modifies the ideal power transfer equation to account for dead time [4].

$$Pout = \frac{Vin \cdot Vout}{\omega Llk}\delta\left(1 - \frac{2Td}{Tsw/2}\right), \qquad (1)$$

where T_{sw} is the switching period, Llk is the leakage inductance.

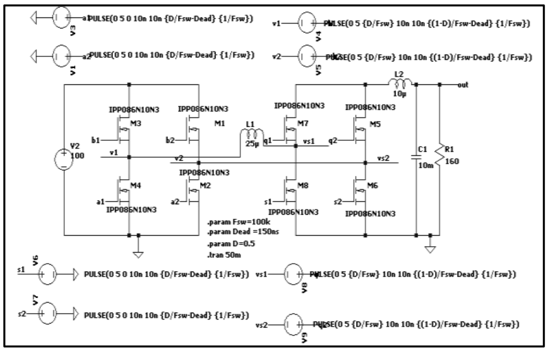

Figure 1 – Basic structure of a DAB topology

Efficiency Degradation: Efficiency follows a similar declining trend, falling from 96.2 % to 88.5 %. This is a direct consequence of several factors such as, increased conduction losses due to extended body diode conduction, the loss of ZVS at higher dead times, and higher RMS currents (evident from the rising peak current) leading to increased conduction losses [5].

Loss of Zero-Voltage Switching (ZVS): The data shows a critical point between 200 ns and 300 ns where ZVS is lost for the leading bridge leg. As dead time is extended beyond the point where the inductor current has fully commutated to the body diode and begun to decay, the conditions for ZVS are destroyed. This transition to hard switching is a primary contributor to the sharp decline in efficiency observed at higher dead times [6].

Increased Current Stress: The peak current in the switches increases with dead time. To compensate for the reduced power transfer per phase shift angle, the control system would typically increase the phase shift command (δ) to maintain a constant power level. This larger phase shift inherently results in higher circulating currents and increased current stress on the semiconductor devices [7].

Table 1 – Performance Metrics vs. Dead Time

Dead Time, Td (ns)	Output Power, Pout (W)	Efficiency, E (%)
50	605	96.2
100	598	95.8
200	592	94.0
300	588	91.2
400	586	88.5

References

1. Mohan, N. Power Electronics: Converters, Applications, and Design / N. Mohan, T. M. Undeland, W. P. Robbins. – New York: John Wiley & Sons, 2003. – 802 p.
2. Erickson, R. W. Fundamentals of Power Electronics / R. W. Erickson, D. Maksimović. – New York: Springer Science & Business Media, 2001. – 883 p.
3. Performance Characterization of a High-Power Dual Active Bridge DC-to-DC Converter / M. H. Kheraluwala [et al.] // IEEE Transactions on Industry Applications. – 1992. – Vol. 28, № 6. – P. 1294–1301.
4. Dead-Time Effect Compensation for a Dual Active Bridge DC-DC Converter / G. G. Oggier [et al.] // 2018 IEEE ICIT. – 2018. – P. 1831–1836.
5. Krismer, F. Closed Form Solution for Minimum Conduction Loss Modulation of DAB Converters / F. Krismer, J. W. Kolar // IEEE Transactions on Power Electronics. – 2012. – Vol. 27, № 1. – P. 174–188.
6. Inoue, S. A Bidirectional DC-DC Converter for an Energy Storage System with Galvanic Isolation / S. Inoue, H. Akagi // IEEE Transactions on Power Electronics. – 2007. – Vol. 22, № 6. – P. 2299–2306.
7. Overview of Dual-Active-Bridge Isolated Bidirectional DC-DC Converter for High-Frequency-Link Power-Conversion System / B. Zhao, [et al.] // IEEE Transactions on Power Electronics. – 2014. – № 8. – P. 4091–4106.

UDC 681

EFFECTS OF PHASE SHIFTING IN DUAL ACTIVE BRIDGE (DAB) CONVERTERS

Mutamba C. T., Musiiwa P. B., Machongwe T.,
Chimonyo K. B, Kapuya E. T. , Musademba D.

Harare Institute of Technology, Harare, Zimbabwe

Abstract. This paper analyses the effects of phase shifting in Dual Active Bridge (DAB) converters, which are widely applied in electric vehicle chargers, renewable integration, and solid-state transformers. Its symmetrical topology, comprising two full-bridge converters linked by a high-frequency transformer and controlled through phase-shift modulation, enables seamless power flow in both directions with galvanic isolation. The direction of power flow and magnitude is determined by which bridge that leads or lags. This study outlines the effects of phase shifting between the two bridges to provide the comparison on the output voltage and current at different phase angle.

Keywords: dual active bridge, phase shift, bidirectional converters, output current, power transfer.

Address for correspondence: Peter B. Musiiwa, BE277 Belvedere Harare Zimbabwe
e-mail: pbmusiiwa@hit.ac.zw