

Modular 100kA Surge Current Source with Programmable Current Shape

The often cited I^2t value describes a power semiconductor's ability to withstand surge current events. However, the dependency on current shape is usually overlooked. This article gives a short introduction to a surge current tester with arbitrary output current waveform and exceptionally low output current ripple, which enables a wide range of surge current tests.

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Introduction

Surge current withstand capability is an important ability for power semiconductors, e.g. in case of a fault event. The overcurrent capability of power semiconductors is quantified by the maximum surge current I_{TSM} and the I^2t -value. Both parameters are defined for a half-sinusoidal current pulse with a pulse duration $T_p = 10$ ms [2]. This definition does not, however, take different current waveforms or multi-pulse surges into account.

To perform experiments for a wide range of applications, a wide range of amplitudes, pulse durations and waveforms is required. Well-known standard solutions using passive components (e.g. resonant or capacitor discharge circuits) do not meet these requirements, as they can only realize fixed current waveforms with frequencies and time constants depending on the passive components used.

Alternatives utilizing active switches do exist, but come with their own drawbacks. An example is presented in [3]: A massive parallelization of MOSFETs used as analog amplifiers enables a programmable current waveform, but causes very high losses, which limits pulse duration and repetition rate.

Design of the surge current source

Requirements for the surge current source presented in this article include a freely programmable current waveform with a maximum amplitude beyond typical thyristor maximum peak currents, which can exceed 90 kA, see e.g. [4]. To potentially realize pulse-trains corresponding to multiple grid-frequency periods, pulse widths of several tens of ms are required. Further requirements include high accuracy and a low device under test (DUT) current ripple.

Table 1 lists key parameters of the surge current source. To meet the requirements a modular approach has been chosen: the current source is comprised of 16 cells, each consisting of two IGBT half-bridges, a dc-link capacitor $C_{DC} = 9$ mF and one output inductor $L_{out} = 50$ μ H per half-bridge. The structure of a cell is depicted in Figure 1, together with its possible output configurations: The cells can be used as two independent half-bridges in high current mode (HCM) or as one full-bridge in dynamic current mode (DCM).

In Figure 2 a photograph of the setup can be seen. Mechanically, the current source is divided in two halves, with 8 cells each. To limit the magnetic forces, the full current is only flowing through the DUT itself. The copper bars connecting eight cells per side to the DUT only carry half the current, reducing the occurring magnetic forces by a factor of four. The copper bars on each side are clamped together with insulating clamps, to withstand the remaining magnetic forces.

Parameter	Range	Notes
maximum DC-link voltage	1200 V	low voltage, (<1500 V DC)
max. IGBT voltage	1700 V	low voltage IGBTs
max. stored energy ΣW_C	104 kJ	-
max. current I_{pk}	100 kA	-
max. current ripple	60 A	equals 0.06 % (at 100 kA)
min. current rise time t_r	380 μ s	controller-limit
maximum di_{DU}/dt	768 A/ μ s	hardware-limit
	263 A/ μ s	resulting from t_r (at 100 kA)
pulse width T_p	≈ 1 ms ... ≈ 100 ms	min/max width, dependent on waveform, peak current and DUT

Table 1: Key parameters of the surge current source

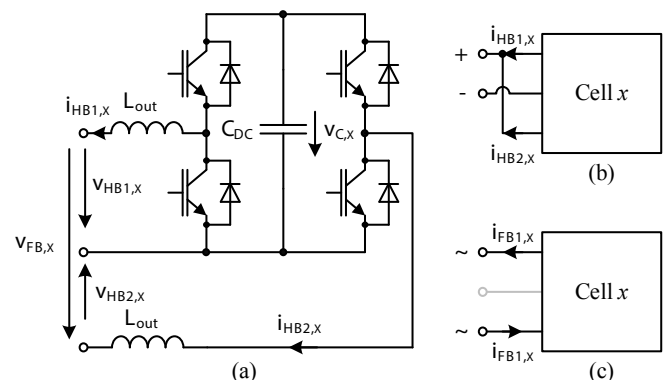


Figure 1: Electrical structure of one of the cells in the surge current tester (a). The cells can be configured in HCM (b) or DCM (c) [1]

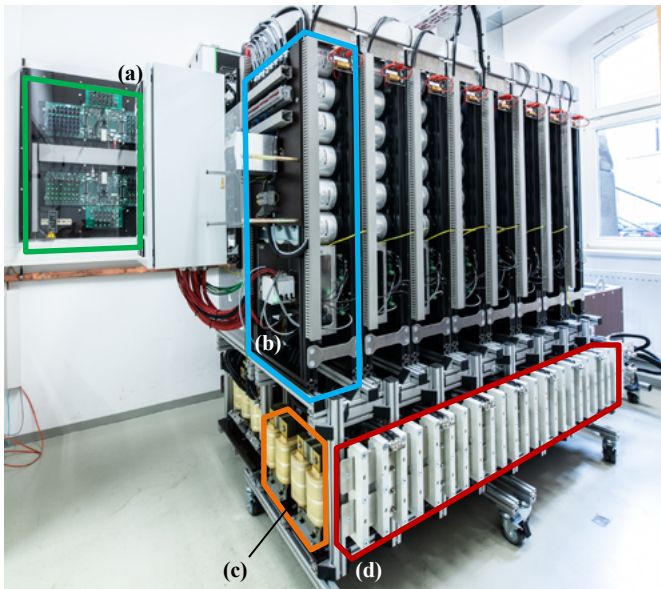


Figure 2: Photograph of the high current source [1]. Highlighted parts are (a) control platform, (b) one of 16 cells, (c) inductors L_{out} and (d) high current bus bars

The control platform, see Figure 2(a), is responsible for communication with the operator’s computer and runs the control algorithms. It handles a multitude of signals. This includes measurements: 32x current and 16x dc-link voltage, control signals: 32x enable, 32x PWM, 32x GDU feedback as well as auxiliary signals: 2x arc detection, 4x discharge relays, 16x delta-sigma clock. The half-bridges are switched interleaved with an effective switching and control cycle frequency of 96 kHz. All signals are transmitted using fiber-optics.

Experimental Test Results

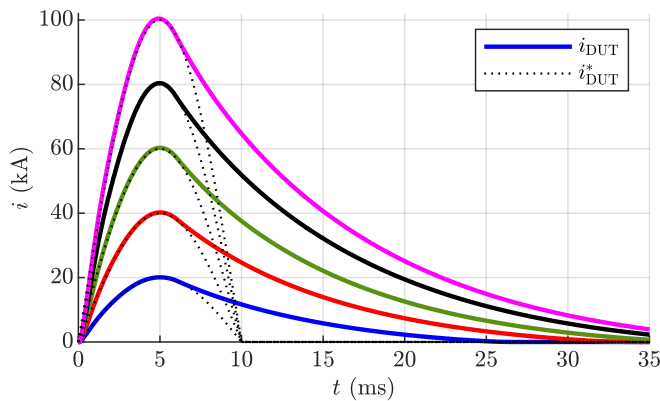


Figure 3: Comparison of current i_{DUT} measured by the control platform and target current trajectory i^*_{DUT} . Short circuit load. HCM

The performance of the surge current tester has been evaluated by a multitude of practical experiments, both in HCM and DCM. Two examples are shown here. In Figure 3 a comparison of half-sine current pulses with different amplitudes can be seen, realized in HCM. Since the cells are configured as half-bridges in HCM, the falling current slope is only determined by the losses in the system. In DCM on the other hand, the cells are configured as full-bridges, which enables negative output voltages and thus a controlled negative di_{DUT}/dt . As an example Figure 4 shows a waveform resembling the outline of the Frauenkirche in Dresden.

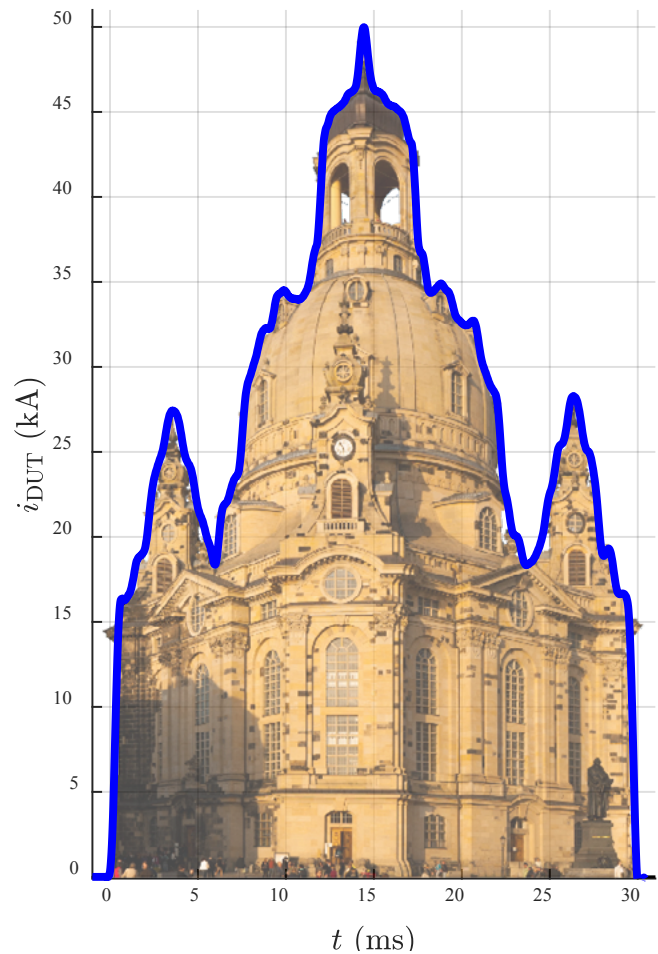


Figure 4: Example of a dynamic current waveform: DUT-current tracing a profile of the Frauenkirche in Dresden [1]. Source of photograph: [5]. Thyristor as load. DCM

Conclusions

This article is a short introduction to the authors’ recently built programmable, modular surge current tester. The basic principles and abilities of the current source are described and shown with experimental test results. For further reading see the open access publication “Topology, Design and Characteristics of a Modular, Dynamic 100 kA Surge Current Source with Adjustable Current Shape” [1]. It describes many aspects of the current source’s design in more detail.

Sources

[1]	S. Wettengel, A. Hoffmann, J. Kienast, L. Lindenmüller and S. Bernet, “Topology, Design and Characteristics of a Modular, Dynamic 100 kA Surge Current Source with Adjustable Current Shape,” IEEE Open Journal of Industry Applications, pp. 29-42, January 2024.
[2]	Dynex Semiconductor Ltd., „Case Non-rupture Current Ratings,” 2014.
[3]	V. Verevkin, D. Ivanov, V. Kostusyak, A. Sytyi, P. Semenov and D. Alymov, “A Next-Generation Surge Current Tester,” Bodo’s Power Systems, pp. 30-34, August 2020.
[4]	ABB Ltd, „Phase Control Thyristor : 5STP 48Y7200,” October 2016.
[5]	J. Wellniak, „Dresden, Frauenkirche, Panorama.jpg,” [Online]. Available: https://commons.wikimedia.org/w/index.php?title=File:Dresden,_Frauenkirche,_Panorama.jpg&oldid=461456248 . [Accessed 15. September 2022].