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SiC Solid-State Power Contactors SSPC`s in Comparison to E-Fuses and Solid-State Circuit Breakers

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Abstract

In this work, the novel approach of a DC protection system based on an all-solid-state semiconductor PCB solution was presented. The switching element, called the "solid-state power contactor - SSPC", is implemented as a circuit board. Modern system integration technologies are used here. The focus is on circuit board technologies that distribute the power losses of the semiconductors in a targeted manner on the circuit board and can very quickly reduce high temperature gradients in the semiconductors in critical operating conditions. There are fundamental differences between the three systems E-Fuse, SSCB and SSPC, depending on their intended use. This is why E-Fuse is primarily considered a fuse replacement system, SSCB as an on/off switching device and the SSPC presented here as a protective device for functional safety must enable "safe disconnection and switching". In addition, the naming E-Fuse, SSCB or SSPC are not absolute.

Keywords: SiC, Solid-State Circuit Breaker (SSCB), DC Circuit Breaker, Solid-State, Thermal Design

1. Introduction

Electrical networks distribute energy, supply consumers and integrate energy sources such as PV, power generators, as well as renewable energy sources, energy storage and electric vehicles. To do this, every circuit must be protected against unforeseen events, but also be able to be switched on and off at any time and according to its operating state. For this purpose, switching devices are required in DC networks that fulfill these tasks as DC protection technologies [1-3].

1.1. Solid-State Power Contactor SSPC

In today's network systems, protection technologies mainly consist of electromechanical switching devices (AC networks and DC networks) or, in current research for DC networks, of hybrid systems. These hybrid systems consist of electromechanical contactors in combination with semiconductor circuits [4]. The use of semiconductor-based DC protection technologies, in a so-called all-solid-state approach, offers opportunities for reducing the size and expanding the area of application [5]. In the “SSPC” (power class 22kW nominal, 30kW permissible overload, bipolar DC network, voltage range +/-380VDC), as presented in this work, the protection system enables the following tasks of classic DC protection systems or classic switchgear combinations:

- Overcurrent protection
- Overvoltage protection
- Thermal protection against overload of the connected loads
- In addition, the following additional functions are also implemented by the “SSPC” (see Figure 1):
- Overcurrent shutdown in the sense of functional safety SIL2
- All-pole separation of the DC network in critical operating situations • Load management tasks in the sense of functional safety SIL 2
- Additional overload capabilities up to 4s or 5fold overload for 5ms

Only these additional functions enable meaningful use in critical system structures of the DC networks. However, these additional functions make the circuit design of the “SSPC” significantly more complex (see Figure 2 and Figure 3).

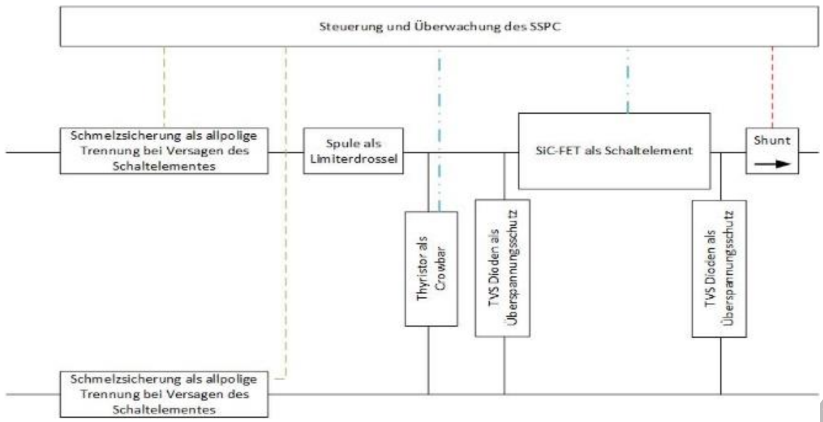

Figure 1: Block Diagram of the SSPC

Figure 2: Top View on SSPC PCB

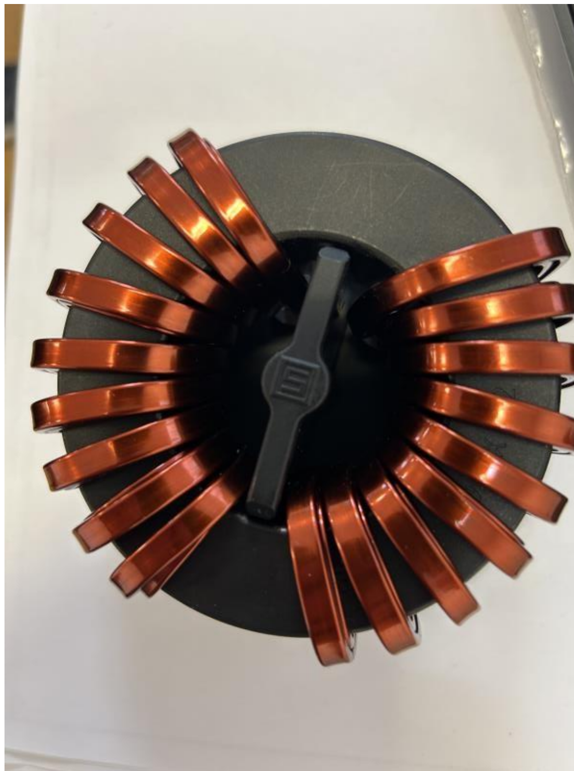

Figure 3: Top View on Predesigned Limiter Choke For SSPC

2. Conceptual Distinction Between EFuse, SSCB and SSPC

Up to now in different scientific papers as well as in product description for solid-state based protection systems and or SiC based protection systems, you can find the naming E-Fuse (or electronic fuse), SSCB (solid-state circuit breaker) as protection devices for dc net systems. The author proposes a third naming as solid-state power contactor or SSPC. But are the differences or the conceptual distinction? This will be described in the next lines.

2.1. E-Fuse or Electronic Fuse

The aim of the E-Fuse is to provide rapid protection against thermal fuses, which protect circuits from overcurrent damage using I^2t tripping characteristics. E-Fuse therefore refers to all solutions that can be used as an electronic fuse equivalent to thermal fuses.

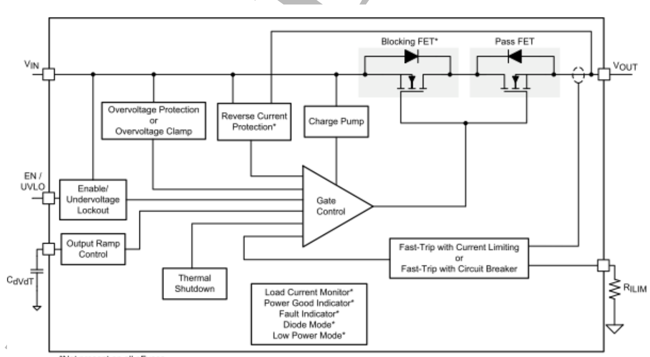

Figure 4: Block Diagram of the E-Fuse from TI [6]

This results in areas of application ranging from HIFI end devices to power supply systems in the server and IT landscapes area, to industrial applications. Additional tasks of current E-Fuse designs include, depending on their intended use (mostly automotive applications), overvoltage monitoring with partially integrated overvoltage protection using TVS diodes, as well as reverse polarity protection solutions. In other additional applications, bidirectional solutions are also known, through the use of additional semiconductor switches.

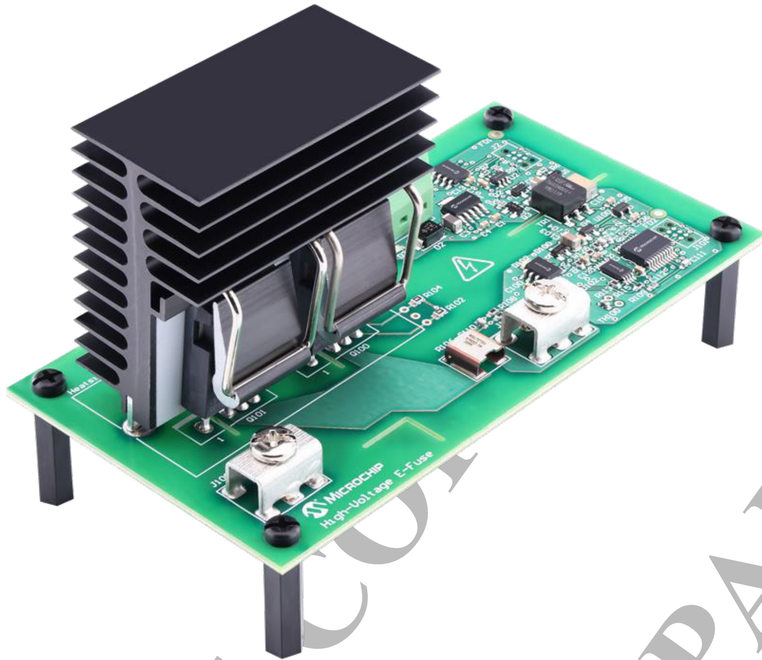

Figure 5: Reverence Design of an E-Fuse from Richardson RFPD and Microchip [7]

2.2. SSCB - Solid-State Cicuit Breaker

Solid-state circuit breakers SSCB (for MVDC nets ABB products are mostly used) primarily have the task of closing the connected load circuit in the event of an overcurrent by means of classic ON/OFF switching, analogous to classic AC circuit breakers or electromechanical main switches [8]. For these products, too, there is not just "one" specific application, but, similar to E-Fuse systems, there are also more complex switching devices, which are referred to as "iBreakers", "Z-Source Solid-State Circuit Breakers" or "T-Type SSCB`s" and include bidirectional applications as well as overvoltage protection elements. Solid-State breakers are also very well known in combination with electromechanical switches as so called "hybrid SSCB`s" [1,2,4,8], mostly in high voltage dc nets or mid voltage dc nets up to 3kV [9-11].

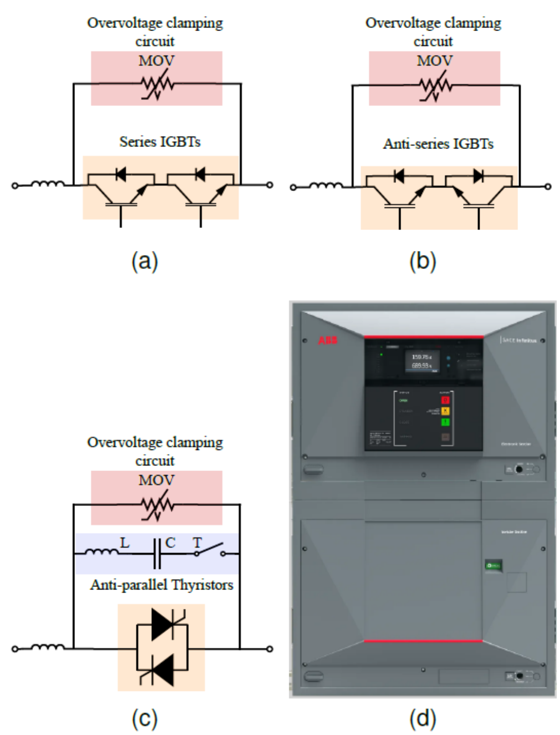

Figure 6: Block Diagram of the SSCB from ABB [12]

In the introduction to this chapter it was stated that there are conceptual distinctions between EFuse, SSCB and SSPC. So it can be defined as there is a big difference between E-Fuses and SSCB`s on one hand and the SSPC on the other hand. Because the main task of the SSPC is to safely switch and disconnect the load from its source with a single SiC solid-state switch, whereby the current direction should not necessarily be unidirectional by reverse polarity protection in most E-Fuses, but use as a bidirectional protective circuit is also expressly desired. The functional safety aspect in the event of failure of the central semiconductor switch is based on the use of a crowbar, which triggers the thermal fuses, for all-pole, electromechanical separation.

2.3. Thermal Design of the SSPC

An all solid-state system based on PCB designs needs additional thermal designs, because thermal resistance form the solid-state switch ends up with thermal losses (R_ds[on] for SSPC). In order to be able to control the thermal situations of the "SSPC", especially the SiC-FET, the heat dissipation of the semiconductor switches was investigated in relation to thermal impedance and transient thermal impedance for the overload capabilities during the development of the circuit boards. In general, the heat dissipation of the current-carrying circuit elements and conductor tracks plays an important role in every circuit board development [13].

For the final circuit board of the “SSPC”, a combination of “Copper-Coin-embedded” design and 2 mm “IMS” base plate made of copper was used [5,14]. This makes the “SSPC” a hybrid solution of “MCPCB - Metal Core Printed Circuit Board” (see Figure 7) and “IMS-PCB - Insulated Metal Substrate Printed Circuit Board” (see Figure 8) [15].

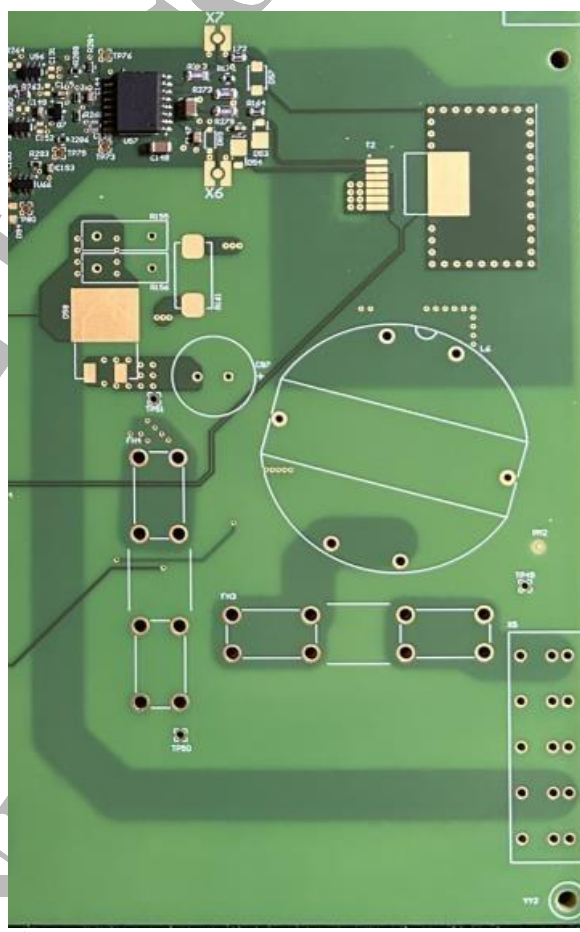

Figure 7: Top View on SSPC with Copper-Coinembedded Thermal Design

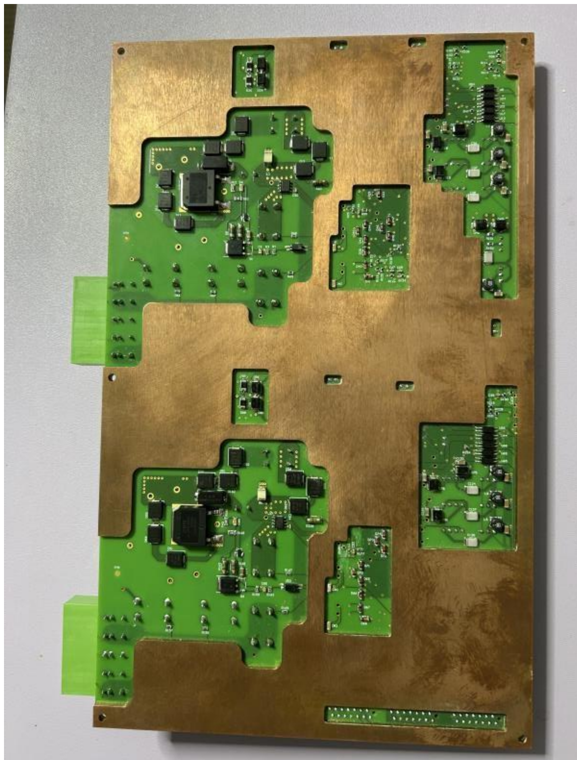

Figure 8: Bottom View on SSPC with Copper Based 2mm IMS-PCB

2.4. Electrical Design of the SSPC

The entire “SSPC” system as an all solid-state system-based circuit board solution must be able to handle load-side and network-side short circuits at all times, in addition to normal operation with load management tasks (load connection and load shedding). So, the electrical design, from functional safety point of view, was realized by analog controls and fast measurement circuits [16,17].

The following short circuit types were therefore defined for the “SSPC”, which will be investigated in the further course of the project:

- Type 1 – “switching on” to a short circuit
- Type 2 – occurrence of a short circuit when the
- “SSPC” is switched on
- Type 3 – critical short circuit when switched on, diode across the switching element is in freewheeling mode
- Type 4 – short circuit when switched off, diode is in freewheeling mode

The digital control of the SSPC is realized by PWM control loops with variant switching PWM frequencies depending on load values [18,19].

3. Conclusion

In this work, the novel approach of a DC protection system based on an all-solid-state semiconductor solution was presented. The switching element, known as the "solid-state power contactor - SSPC", is implemented as a circuit board. Modern system integration technologies are used here. The focus is on circuit board technologies that distribute the power losses of the semiconductors in a targeted manner on the circuit board and can very quickly reduce high temperature gradients in the semiconductors in critical operating conditions.

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This leads to a classification of the system names according to their application sectors. such as: EFuse in the automotive sector, SSCB in energy technology and drive technology and SSPCs as new introduced units in safety-critical systems, like railway or basic research institutes.

In the area of DC protection technologies, semiconductor-based solutions are also becoming increasingly important. Artificial intelligence (AI) methods are opening new fields of application for a variety of new technologies, like SSPC systems. The combination of an weak AI called as "current feeded power fencing" and the SSPC, as part of the "NetFlexum" research project, can be open new fields of application for DC protection method described in a contribution paper [20].

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