A Novel GaN-Based Solid-State Circuit Breaker With Voltage Overshoot Suppression

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***Abstract*—This article proposes a novel ultra-fast self-powered bidirectional solid-state circuit breaker (SSCB) with voltage overshoot suppression that uses gallium nitride switches with very low conduction losses. This SSCB can be used in low and medium ac/dc networks for both short-circuit protection and overcurrent protection. An exhaustive methodology for RCD snubber design applied to SSCBs is provided. A comprehensive review of the technical literature is presented exhibiting that the proposed SSCB reduces conduction losses and detection time in comparison with other similar SSCBs. The performance features of the proposed SSCB are verified through the functional tests that are carried out employing a hardware-implemented prototype. Experimental results confirm that our proposal is able to detect and process the short-circuit failure in 282 ns; the authors have not found any faster results in the literature.**

***Index Terms*—Gallium nitride (GaN) FETs, overcurrent protection, short-circuit protection, snubber circuit, solid-state circuit breaker (SSCB), voltage overshoot suppression.**

I. Introduction

WITH the development of distributed generation [1]–[3], smart grid [4], microgrid technologies [5], and the significant increase in sensitive digital loads [6], it is imperative to incorporate fast and reliable protection elements to the electrical systems [7]. The interconnections of electrical networks and massive renewable energy penetration may lead to increase the short-circuit levels in power systems [8]. Likewise, the installation of new generation units can cause higher fault currents [9]–[11]. Since the safety and reliability of buses, transformers, and other electrical equipment are directly affected by high levels of fault currents, the protecting system needs to guarantee an acceptable safety level [12], [13]. In this context, an appropriate isolation of the fault source is a significant challenge due to the quick and dynamic changes in the demand, as well as the changes in the configuration of modern electrical networks [14]–[16].

Mechanical circuit breakers are the traditional solution to deal with the fault source isolation, since these devices are characterized by low conduction losses and a high load capacity. However, their limitations, such as: slow response time, mechanical aging of moving parts, low lifespan due to the difficulty in extinguishing the arc, low reliability and high electromagnetic interference, make them unsuitable for modern electrical networks [8], [12], [17], [18].

Conversely, solid-state circuit breakers (SSCBs) emerge as a solution to tackle the mechanical circuit breaker's problems. Which are very attractive due to their excellent performance, ultra-fast current interruption (high reaction speed), arc-free operation, current limiting capacity, lower weight, and lower volume. Nevertheless, its main drawback is the conduction losses caused by the resistance of the semiconductor during normal operation (R_{ON}) [17], [19]. This means that the use of power switches with low R_{ON} and fast switching is a priority in this application [7], [20], [21].

A SiC JFET-based SSCB is experimentally tested in [8] by embedding its logical system into a microcontroller and reaching a total system response time about 10 μs. In [14], a microgrid enabled self-powered SSCB is introduced, where the short circuit fault detection is performed by sensing voltage between two power terminals of the switch, which compromises its precision; since this voltage depends on the R_{ON}, and in turn, it relies on the operating temperature of the switch. Another fast 380 V SSCB is developed using a simple circuit and discrete components [17], whose experimental results show an ultra-fast response time of 0.57 μs; however, its main power switch operates in the active or Ohmic region, when the inrush current protection is implemented. Besides, this switch operates out of the safe operation area when the circuit responds to short circuit faults. In consequence, the power dissipation is high, and it puts the device

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