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Modular Matrix Converter Based Solid State Transformer for smart grids

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ABSTRACT

This paper proposes a grid forming Modular Matrix Converter Based Solid State Transformer for smart grids. The Modular Matrix Converter Based Solid State Transformer regulates the voltage amplitude and frequency of the low voltage grid, enabling sag and swell mitigation. Each module includes a three-phase Matrix Converter, connected to a three-phase High Frequency Transformer, whose secondaries are connected to three Single-Phase Matrix Converters. Input and output LC filters are required to guarantee nearly sinusoidal waveforms in the MV connection and in the LV grid.

The three-phase Matrix Converter uses a modified High Frequency Space Vector Modulation, with a novel feature to guarantee the non-saturation of the High Frequency Transformer at 2 kHz operation. To restore the waveform that would result from the original Space Vector Modulation the High Frequency Transformer is connected to three Single-Phase Matrix Converters. Combining the advantages of Matrix Converters with high frequency operation, the volume of the galvanic isolation transformer can be reduced, and using decoupled controllers, the output voltage waveforms are regulated both in amplitude and frequency, to form a low voltage grid.

The proposed Modular Matrix Converter Based Solid State Transformer is simulated and the obtained results show that it is able to regulate the secondary side voltage and frequency, even in a bidirectional power flow operation scenario, allowing power factor correction in the local MV connection, and providing mitigation capability of voltage sags and swells up to 20%, therefore improving power quality in the smart grid.

1. Introduction

Traditionally, electrical power generation and control have been centralized, and the balance between the power production and the consumption guaranteed that the grid frequency was kept at a nearly constant value. However, this balance is becoming more difficult to achieve due to the increase of renewable generation penetration levels, together with their intermittent and low duty-cycle power characteristics. At the distribution voltage level, the bi-directional power flow is now a reality, especially in no-load scenarios with high penetration of distributed power generation, and problems such as sustained overvoltages are introducing new challenges to Distribution System Operators (DSOs).

Smart grids are usually characterized as flexible, integrated, optimized and intelligent [1]. They include new solutions for the grid infrastructure (AC or DC), active Distributed Energy Resources (DER) as Distributed Generation units (DG), Distributed Storage devices (DS), Electrical Vehicles (EV) and controllable loads (large industrial consumers/set of domestic clients). Their aim is to allow interaction with consumers and markets, adaptability and scalability to different operation scenarios, proactivity rather than reactivity, thus predicting events to prevent emergencies, while providing self-healing characteristics, supported by a high level of grid automation, smart metering, telemetering and other ICT solutions [1].

The development of power electronics is fundamental in the context of smart grids [2], as they enable the connection of DERs to the grid, allowing a high level of controllability. Power electronic converters allow frequency and voltage conversion from one level to another and nowadays they are well-known due to their high reliability and robustness in a wide range of applications. In particular, Matrix Converters (MC) have become increasingly attractive

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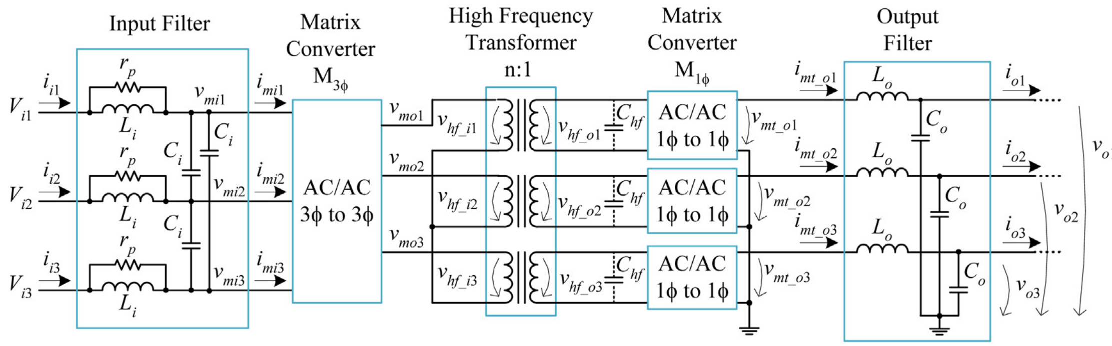

Fig. 1. Module of the MMC-SST.

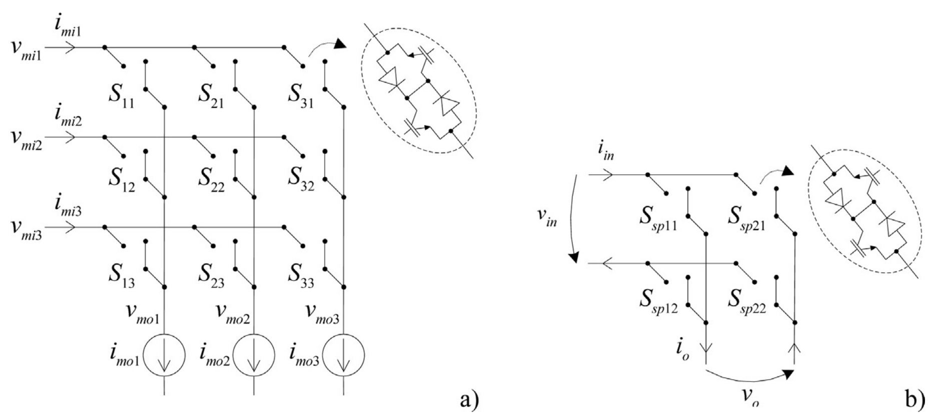

Fig. 2. (a) Three-Phase Matrix Converter (AC/AC: 3ϕ to 3ϕ); (b) Single-Phase Matrix Converter (AC/AC: 1ϕ to 1ϕ).

[3] as they are high frequency switching power electronic converters, able to perform direct AC/AC conversion in a single stage, still allowing the independent control of the three-phase output voltages amplitude and frequency, as well as the input power factor regulation [4]. When compared to the conventional back-to-back AC/DC and DC/AC arrangement using Voltage Source Converters (VSC), MCs present higher power density (at least 1.5 higher than three-phase AC/DC converters with the same rated power [5]) and reduced losses (efficiency may reach 98% [6,7]). MCs do not need DC bulky electrolytic capacitors since there is no intermediate DC-link (the converter protection circuit can be based on metal-oxide varistors [8]) which contribute to limit the VSCs lifespan [9] (the percentage of failure of electrolytic capacitors is considered to be at least two times higher than the semiconductors failure percentage [10]), while increasing electric losses, volume and costs [5]. Furthermore, MCs allow bidirectional power flow while not significantly contributing to the harmonic degradation of the input current. They have been used to control electrical drives [11], in power electronic transformers [12], in power quality applications [13,14], and in the transportation industry from the railway [15] to the aerospace sector [16].

With the development of power electronic converters, High Frequency Transformers (HFT) are becoming increasingly attractive [15,17]. These power electronics assisted transformers, also known as Solid State Transformers (SST), allow both voltage and frequency transformation from one level to the other, providing a medium to high frequency galvanic isolation link, and potentially reducing the volume [18] and weight when compared to the traditional line frequency power transformers [17]. The controllability of the SST voltage and frequency allows enhanced power quality performance [19,20], and nowadays they are considered as one of the fundamental components to empower future smart grids [20,21].

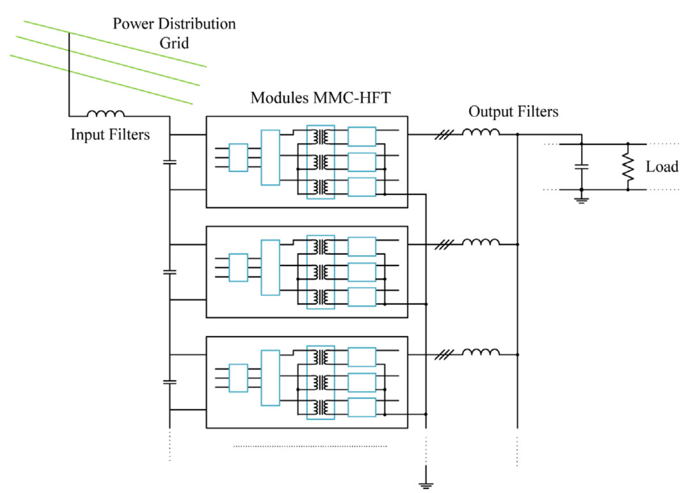

Fig. 3. Simplified scheme of the MMC-SST implementation in smart grids.

The proposed Modular Matrix Converter Based Solid State Transformer (MMC-SST) module is presented in Fig. 1 and includes a three-phase High Frequency Transformer (HFT) using direct AC–AC power electronic converters (Fig. 2; Section 2), thus eliminating DC bus filtering requirements. The input is connected to a three-phase Matrix Converter (Fig. 2(a)) with a novel High Frequency Space Vector Modulation (HF-SVM), which is based on the Space Vector Modulation (SVM) technique. This technique here includes an innovative feature that guarantees the non-saturation of the HFT (Section 2.3). The MMC-SST output consists of three Single-Phase Matrix Converters (Fig. 2(b)) with output filters to restore the original SVM waveforms (Section 2.4). For high power applications, several modules might be used with filters