OPERATIONAL ASPECTS OF MODULAR MULTILEVEL CONVERTER (MMC) BASED TOPOLOGIES FOR MVDC/HVDC

SUKRASHIS SARKAR

DEPARTMENT OF ELECTRICAL ENGINEERING
INDIAN INSTITUTE OF TECHNOLOGY DELHI
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by

SUKRASHIS SARKAR
Department of Electrical Engineering

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Dedication

Dedicated to my family, who have kept me on track countless times, and whose constant encouragement and support have made completing this journey a reality.

Thesis Certificate

This is to certify that the thesis entitled **"OPERATIONAL ASPECTS OF MODULAR MULTILEVEL CONVERTER (MMC) BASED TOPOLOGIES FOR MVDC/ HVDC"**, submitted by **Mr. Sukrashis Sarkar** to the Indian Institute of Technology Delhi, to the Department of Electrical Engineering, Indian Institute of Technology Delhi, for the award of the degree of **Doctor of Philosophy**, is a record of the bonafide research work carried out by him under my guidance and supervision.

Mr. Sukrashis Sarkar has fulfilled the requirements for the submission of this thesis, which to my knowledge has reached the required standard. The results obtained herein have not been submitted in part or in full to any other University or Institute for the award of any degree.

Prof. Anandarup Das
Dept. of Electrical Engineering,
Indian Institute of Technology Delhi,
New Delhi, India, 110016.

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Sukrashis Sarkar

Abstract

Modular multilevel converters are getting attention in industry and academia as the preferred choice of electronic power conversion for high-power applications. They have a wide application area in a variety of industries involving transmission of power, grid interconnection, renewable integration, rail transportation, and fast electric vehicle charging.

The half-bridge-based modular multilevel converter (HB-MMC) is preferred over all other MMC topologies because of its highest efficiency. However, a key challenge of the half-bridge-based modular multilevel converter (HB-MMC) is the protection of the converter during fault conditions like DC faults and AC faults (mainly valve side SPG fault).

This thesis contributes two major sections: (i) Protection of conventional HB-MMC using passive filter from DC and AC short circuit faults without compromise in efficiency and (ii) A new reduced arms HB-MMC topologies using passive filters for different MVDC applications.

This thesis developed a new class of half bridge sub-module (HB-SMs) based modular multilevel converter (MMC) topologies using passive filters which is derived from conventional HB-MMC. This topology can be used for DC-DC MVDC applications and also for DC-AC applications. It has various possible advantages compared to conventional HB-MMC like Fault current limiting/ blocking features, pre-charging features, reduced arms and switch counts.

The other contribution of the thesis where the main focus is to ptotect the conventional HB-MMC from DC and AC faults. This work introduces a new protection methodology in which a circuit is connected across the arm inductor during fault conditions that has the fault current-limiting capability of HB-MMC-based HVDC along with pre-charging capability.

This thesis also focuses on applications such as HVDC and MVDC applications (both DC-DC and DC-AC). MVDC applications can be fast and multiple EV charging, MVDC rail traction, MVDC/MVAC grid interconnection, and 25kV single phase 50Hz traction power supply.

Using MMC in high power direct current applications requires proper understanding of the converter topology, its working, and protection w.r.t. the required application in terms of power electronics and power systems. This thesis provides the depth

of understanding required in power electronics and power systems for HVDC/MVDC technologies, including their architectures, operation, control, and various topologies. The system level work is performed in the EMTP-RV/ Matlab-simulink platform to validate the working of proposed techniques. A scaled-down laboratory prototype is built to validate the effectiveness of the proposed topology.

सारांश

मॉड्यूलर मल्टीलेवल कन्वर्टर्स (MMC) उद्योग और अकादमिक जगत में उच्च-शक्ति अनुप्रयोगों के लिए इलेक्ट्रॉनिक पावर कन्वर्ज़न के पसंदीदा विकल्प के रूप में तेजी से ध्यान आकर्षित कर रहे हैं। इनका उपयोग विद्युत शक्ति के संचरण, ग्रिड इंटरकनेक्शन, नवीकरणीय ऊर्जा एकीकरण, रेल परिवहन और तेज़ विद्युत वाहन चार्जिंग जैसी विभिन्न उद्योगों में व्यापक रूप से किया जाता है।

हाफ-ब्रिज आधारित मॉड्यूलर मल्टीलेवल कन्वर्टर (HB-MMC) को इसकी उच्चतम दक्षता के कारण अन्य सभी MMC टोपोलॉजी की तुलना में प्राथमिकता दी जाती है। हालांकि, HB-MMC की एक प्रमुख चुनौती डीसी और एसी फॉल्ट्स (विशेषकर वाल्व साइड SPG फॉल्ट) जैसी दोष स्थितियों के दौरान कन्वर्टर की सुरक्षा है।

यह शोध प्रबंध दो मुख्य भागों में योगदान करता है: (i) पारंपरिक HB-MMC की डीसी और एसी शॉर्ट सर्किट फॉल्ट्स से दक्षता से समझौता किए बिना पैसिव फ़िल्टर द्वारा सुरक्षा, और (ii) विभिन्न MVDC अनुप्रयोगों के लिए पैसिव फ़िल्टर्स का उपयोग करते हुए एक नई घटित आर्म्स वाली HB-MMC टोपोलॉजी।

इस शोध में पारंपरिक HB-MMC से व्युत्पन्न पैसिव फ़िल्टर का उपयोग करने वाले हाफ-ब्रिज सब-मॉड्यूल (HB-SMs) आधारित MMC टोपोलॉजी का एक नया वर्ग विकसित किया गया है। यह टोपोलॉजी DC-DC MVDC अनुप्रयोगों और DC-AC अनुप्रयोगों दोनों में इस्तेमाल की जा सकती है। इसके पारंपरिक HB-MMC की तुलना में कई संभावित फायदे हैं, जैसे फॉल्ट करंट लिमिटिंग/ब्लॉकिंग, प्री-चार्जिंग सुविधा, घटित आर्म्स और स्विच की संख्या।

शोध का दूसरा योगदान पारंपरिक HB-MMC को DC और AC फॉल्ट्स से सुरक्षित करने पर केंद्रित है। इसमें एक नई सुरक्षा पद्धति प्रस्तुत की गई है, जिसमें फॉल्ट की स्थिति में आर्म इंडक्टर के पार एक सर्किट जोड़ा जाता है, जो HB-MMC आधारित HVDC की फॉल्ट करंट लिमिटिंग क्षमता और प्री-चार्जिंग क्षमता प्रदान करता है।

यह शोध HVDC और MVDC अनुप्रयोगों (DC-DC और DC-AC दोनों) जैसे तेज़ और मल्टीपल EV चार्जिंग, MVDC रेल ट्रैक्शन, MVDC/MVAC ग्रिड इंटरकनेक्शन और 25kV सिंगल फेज़ 50Hz ट्रैक्शन पावर सप्लाई पर भी केंद्रित है।

उच्च शक्ति प्रत्यक्ष धारा अनुप्रयोगों में MMC का उपयोग करने के लिए आवश्यक है कि कन्वर्टर टोपोलॉजी, उसके कार्य और आवश्यक अनुप्रयोग के अनुसार उसकी सुरक्षा की गहन समझ हो। यह शोध HVDC/MVDC प्रौद्योगिकियों के लिए आवश्यक पावर इलेक्ट्रॉनिक्स और पावर सिस्टम्स की गहन समझ प्रदान करता है, जिसमें उनकी संरचनाएं, संचालन, नियंत्रण और विभिन्न टोपोलॉजी शामिल हैं। प्रस्तावित तकनीकों के कार्य को सत्यापित करने के लिए सिस्टम स्तर का कार्य EMTP-RV/Matlab-simulink प्लेटफ़ॉर्म पर किया गया है। प्रस्तावित टोपोलॉजी की प्रभावशीलता को सत्यापित करने के लिए एक स्केल-डाउन प्रयोगशाला प्रोटोटाइप भी तैयार किया गया है।

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