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Development of a scale model of a Modular Multilevel Converters

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Abstract

Modular Multilevel Converters are now being introduced in the power grid. Control systems for these converters are complex with many degrees of freedom. Simulation models are useful for exploring control algorithms, but there is still a need for acquiring experience from real converters. As extensive experiments on full-scale converters are not always feasible due to the cost and potential consequences, reduced-scale models that correctly reproduce the salient characteristics of the original converters are necessary. This paper describes the development of 60 kVA scaled models of modular multilevel converters with 6 halfbridge, 12 fullbridge and 18 halfbridge cells per arm, respectively. Most parameters scale naturally, but the equivalent series resistance and therefore the per-unit losses due to load current tend to increase, giving more damping of oscillation than in the full-scale reference.

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Keywords: Modular Multilevel Converter; HVDC; scale model; laboratory model

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1. Introduction

A large-scale transition to renewable energy has a significant impact on the electrical power grid. This can be seen in northern Europe where many new large wind farms located in the North Sea are going to be connected to the grid via subsea HVDC cables. This and the use of HVDC transmission lines to the consumers in central Europe, leads to a significant number of HVDC converters in the grid. The large total power rating of the HVDC converters has a significant impact on the power system as converter dominated grids have different properties than traditional grids where most of the power was provided by rotating machines. Individual HVDC links may also be merged to form HVDC grids in order to handle the demands for large-scale power transmission.

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Modular Multilevel Converters (MMC) are quickly becoming the preferred choice for new HVDC implementations [1]. They are able to generate smooth AC voltages without requiring large filter components, and have an inherent energy storage capability that can be utilized to reduce propagation of power transients through the converters. As these converters are new and quite complex, it is necessary to gain insight and experience on their interaction with other components in the grid, especially in strained operating conditions and during faults.

Simulations give extensive insight, but there is still a need for experience building from the use of real converters. Full-scale MMC converters can give experience about close to normal operating conditions, but they cannot be used to perform fault condition experiments due to the potential consequences and the safety issues caused by the high power level. Such experiments can instead be done on a scaled-down laboratory grid with line equivalents and converters. This paper describes the development of a set of low power (60 kVA) scale models of MMC converters. These converters are designed for laboratory use as testbeds for converter control algorithms, and for system studies where interaction between grid components in abnormal operating conditions are investigated.

2. MMC converter topology

A Modular Multilevel Converter consists of a large number of series connected converter cells, each with its individual DC link capacitor (Fig 1a). The circuitry inside the cells is not exposed to the full converter voltage, so they can be made using low voltage (1- 10kV) components. The voltage across a string of cells, an arm, is determined by the number of cell capacitors that are engaged at any time, so the output voltage can be can be changed in small steps approaching a sinusoidal voltage without large voltage switching transients.

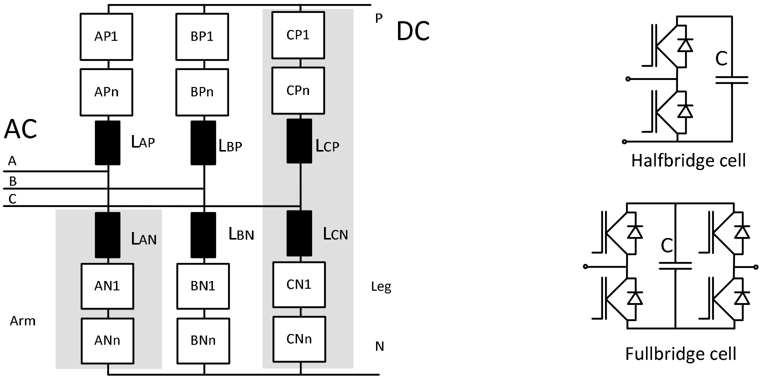

Fig. 1 (a) MMC converter topology; (b) MMC cell topologies.

A halfbridge cell can switch its capacitor either in or out of the string, while a full bridge can insert it into the string in either positive or negative direction. A converter with halfbridge cells has unipolar arm voltage while a fullbridge converter has bipolar arm voltage (Fig 1b). This means that the DC voltage of a fullbridge converter can drop below the peak AC voltage, or even be reversed, giving the fullbridge converter an inherent ability to handle faults on the DC side without requiring a separate DC breaker. For DC grid systems, this ability may outweigh the higher losses in a fullbridge converter in some cases.

The control system is complex with a large number of switches and measurement signals. There are many degrees of freedom, giving many choices for control methods and tradeoffs between losses (number of switching actions), waveform quality, energy storage requirements, and component stress. For each arm, the sum of the cell capacitor voltages must be maintained, and the distribution of the voltages between the individual cells in an arm must be managed with a reasonable number of cell switching events. The arm currents consist of two components: one contributing to the phase output current and the other, the so-called circulating current, flowing between the different converter phases. Each of the six arm currents are controlled individually.