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Active Filtering of harmonic voltages or currents utilizing a MMC STATCOM-Design Aspects and Performance Experience

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SUMMARY

This paper describes the necessary design aspects which have to be considered for the active filter function. First, this includes the adaptions that have to be made to correctly and accurately measure the harmonic voltages in the relevant frequency range. Conventional transducers cannot be used for this task because a correct measurement is only achieved for nominal frequency. As additional point, the design aspects for the power transformer will be evaluated. Besides the nominal frequency current, actively controlled harmonic currents also have to transmitted across the transformer. These currents lead to additional heating of the windings and must also be considered in the design as well as an increased requirement for the saturation characteristic of the iron core. The design aspects for the converter can be divided into two parts. At first the hardware has to be evaluated for the additional filter function. The performance of the power electronic switches and connected DC capacitors as well as the connected cooling system must withstand the additional stresses through the extra task. In addition, the control functions must be adapted to the active filtering. This includes the selection of the harmonic voltages or currents which have to be filtered as well as the automatic adjustments to changed network conditions.
The second part of the paper presents the results of an existing project. A short introduction to the project shows the necessity of the active filter function of the installed VSCs. Finally, the results of the commissioning are presented.

KEYWORDS

STATCOM, Harmonics, Active Filtering, Modular Multi-Level Converter, Power electronics, Power quality, Power system stability, Static VAr compensators, Field Experience

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1. Nomenclature

MMC: Modular Multilevel Converter
FACTS: Flexible AC Transmission Systems
SVC: Static VAr Compensator
SVC PLUS: Siemens STATCOM solution
PCC: Point of common coupling
CIP: Control interface point

2. Introduction

The Multi Modular Converter (MMC) STATCOM was introduced into the market more than 10 years ago. Since that time more and more new installations of parallel reactive power compensation were erected based on Voltage Source Converter (VSC) technology. The advantages of these devices are, among others, a superior harmonic performance behavior as well as very low losses at 0 Mvar while maintaining the advantages of the Thyristor based Static Var Compensator like very fast response time. The principle of the MMC technology provides additional flexibility which can be used to implement additional features and is not limited to only reactive power generation. One possibility is the active damping of existing harmonic voltage or current distortions in the network which is presented in this paper.
With the global trend in the power generation, changing from fossil power to a higher percentage of regenerative sources, the transmission grid has to be adapted as well. This can include new cable sections (as an example the connection of offshore wind farms) which produce new resonances with the existing transmission grid and in that way be the cause of the amplification of harmonic distortions. The limitation of these phenomena is sometimes not feasible with classical passive solutions like C - type filters. This solution provides only fixed tuning frequencies and is not flexible to react to changing conditions.
A MMC STATCOM provides an optimal solution for limiting harmonic distortions in case of changes in the transmission grid, which are difficult to predict.

3. Description of STATCOM technology

The MMC technology was described in [1] and its realisation was outlined in [2]. Here the basic operation principles used for active filtering will be presented as well as the design aspects which have to be considered for this task.

In Figure 1 the simplified single line of the Hornsea STATCOM as well as the single line of a full bride module is shown. The project Hornsea is introduced in detail in [3].
A typical MMC STATCOM station consists out of a step-down transformer, phase reactors and one or more converters. The converter is built up out of three phase arms which themselves consist of series connected full bride modules. These consist of a DC-capacitor, IGBTs and diodes, as shown in Figure 1 on the right side, and are able to provide positive, negative or zero voltage at their output.

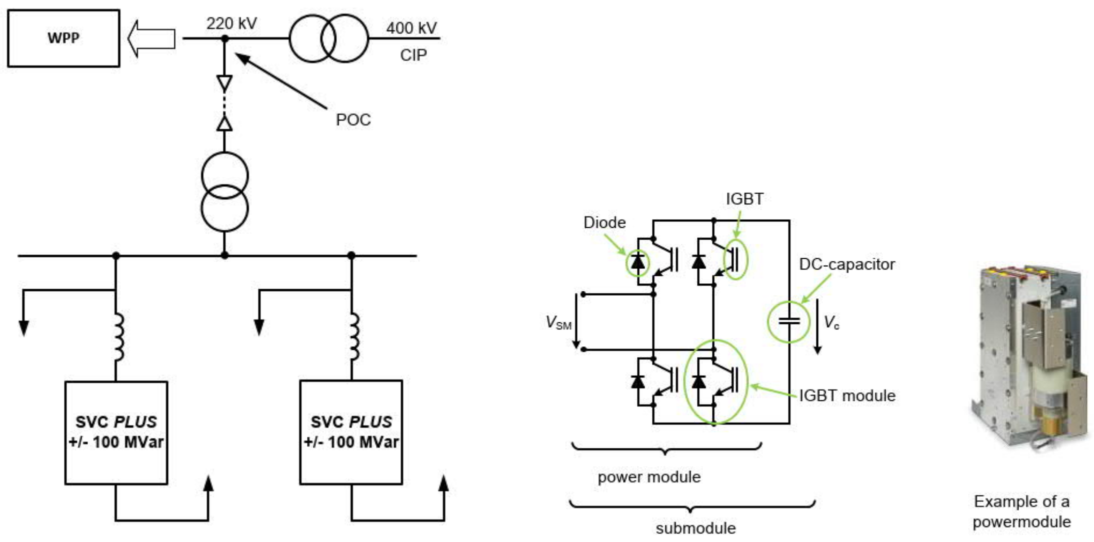

Figure 1: Simplified single line of Hornsea STATCOM; full-bridge submodule [3]

With a series connection of multiple submodules, it is possible to generate output voltages in different waveforms. This enables the STATCOM to generate defined harmonic currents and therefore to act as active filter. [4,5]

4. Principle of the Active Filter Function

In order to generate a harmonic current, the converter must generate the corresponding harmonic voltage. Figure 2 describes the principle of the active filter function. The schematic shows an SVC PLUS between two grids. Grid A has a harmonic source which leads to a voltage with a high harmonic content. The load or grid B has no harmonic source.

Before operation the control gets adjusted to the harmonic impedance. A test signal is generated to evaluate the response of the network to the harmonic signal. This is called Autotuning. The purpose of the autotuning is to adjust the initial response of the active filter to the grid. After that the harmonic controller goes into operation and will compensate the harmonic content of the network.

The active filter has to measure the voltage at the PCC. This voltage is analyzed via a fast fourier transformation to find the harmonic content in the network. With the knowledge of the harmonic voltage content in the network, a harmonic current is generated which will damp or compensate the harmonic voltage at the PCC, dependent of the strength of the harmonic source.

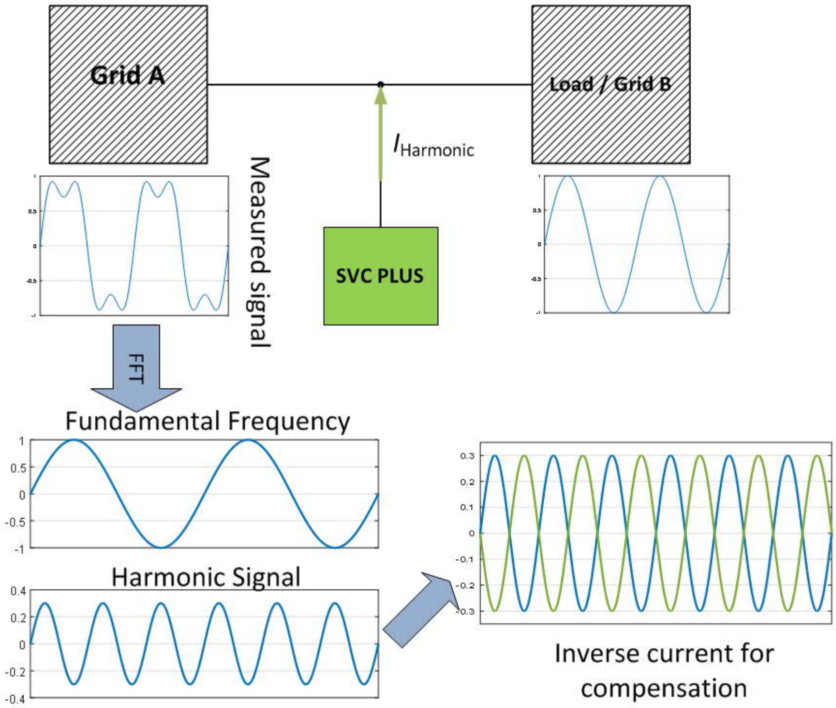

Figure 2: Principle of active harmonic filtering

The harmonic current can have an influence on nearby equipment like filters in the HV grid. For that reason, the active filter should be installed near the harmonic source to limit the effects of the harmonic currents to the HV equipment.

Nevertheless, the harmonic currents will have an impact on the STATCOM components. This includes the STATCOM transformer, the phase reactors, the auxiliary equipment as well as the measurement of the voltage. The main impact of the harmonics is to add to the total thermal rating of the components.

The harmonic voltage has to measured with minimal magnitude and phase error. This can not be accomplished by the usually used inductive voltage dividers. In Figure 3 the accuracy over the frequency is shown for different kinds of voltage transformers. As can be seen resistive capacitive voltage divider is best suited for the measurement of harmonics in a wide frequency range [6].

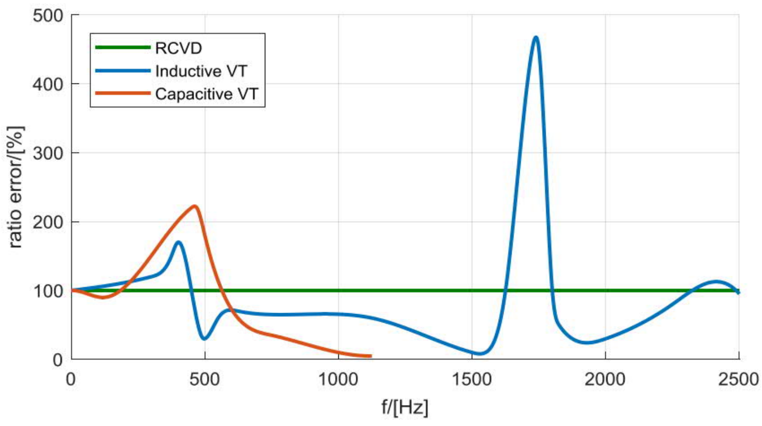

Figure 3: Accuracy vs frequency of voltage dividers

The exact measurement is crucial for the active filter as wrong measurement could lead to even higher harmonic distortion in the grid. Using RCVDs, the exact harmonic content can be measured.

For transformers and reactors, the harmonic currents lead to an impact on the thermal rating. In Figure 4 the possible harmonic reactor currents over the fundamental current are shown in case of the compensation of a single harmonic. Different frequencies have an impact on the current subdivision in the different windings.

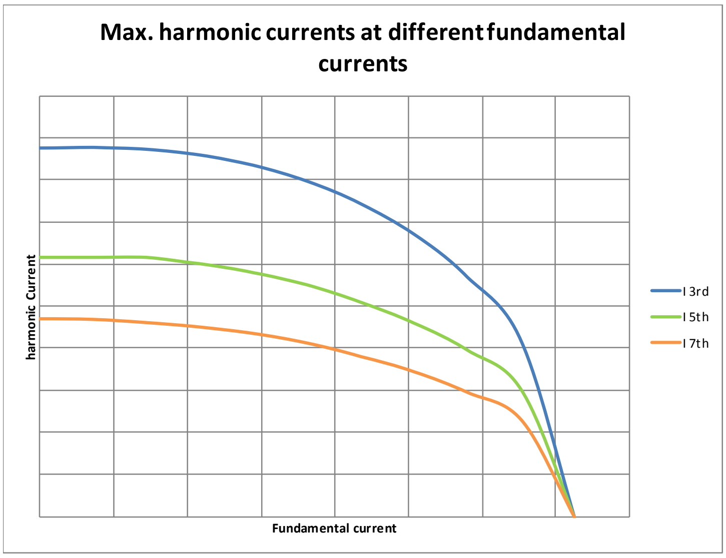

Figure 4: Reactor currents

This leads to certain areas reaching their thermal limit before the whole reactor would reach its theoretical thermal limit. The eddy losses are proportional to the square of the current's frequency. Therefore, the maximum allowed harmonic current is lower with higher harmonic number. The same principle applies for the STATCOM transformer.

For the auxiliary equipment the harmonic content of the voltage is important. Through the transformer impedance the harmonic distortion on the MV busbar of the SVC can be very high. If the auxiliary is supplied from the MV side the auxiliary equipment has to be designed to withstand these harmonic distortions.

For the IGBTs and DC capacitors the thermal impact is also the main issue. For the semiconductors the junction temperature may not exceed its continuous design values. For the DC capacitor the effective current in continuous operation has to be kept.

5. Results of commissioning

In 2019 the Hornsea STATCOM including the active filter function was commissioned. The project comprises three SVC PLUS with active filter function.

The commissioning of the active filter showed a 3rd and 7th harmonic content in the HV grid.

Figure 5 shows the simulated and expected results out of [3]. Here a harmonic voltage source is implemented in the network. At the first timestep the active filter is activated. After that a change in the harmonic content is initiated to show the behaviour of the active filter controller.

The commissioning results confirmed the effectiveness of the active filter function.

The harmonic voltage content in the HV grid, during comissioning, for the 3rd is about 0.001pu based on 400 kV. After the automatic gain adjustment was finsihed the active filter operation starts and the harmonic voltage content in the HV grid is reduced down to close to zero. This is achieved by injection of the corresponding harmonic current of around 50 Amps into the grid.

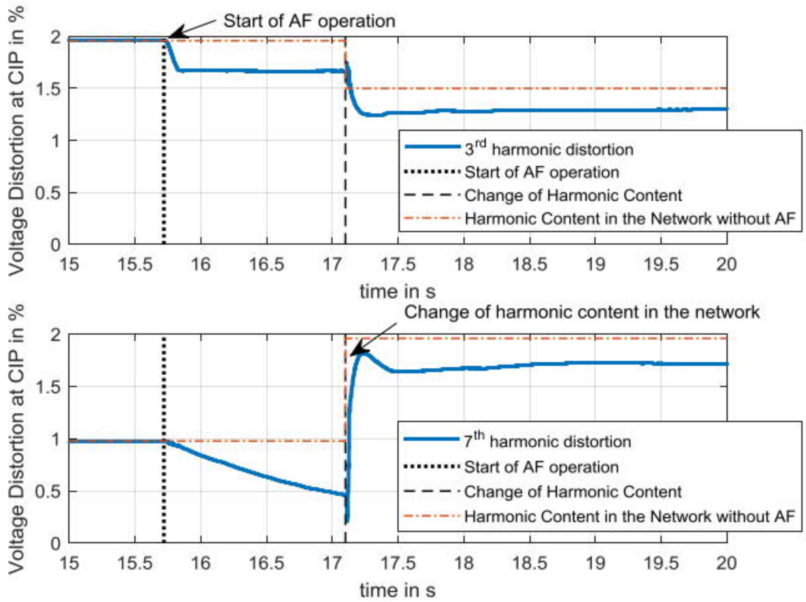

Figure 5: 3rd and 7th harmonic content change and AF reaction

For the 7th harmonic there is a slightly higher harmonic content in the grid of circa 0.0015pu. After autotuning of the 7th harmonic filter, whilst the 3rd harmonic filter is still active, the harmonic content is reduced down to around 0.0002 pu. This is achieved by injecting circa 45 Amps into the grid.

6. Summary

STATCOMs can act as highly dynamic active filters. The impact on the STATCOM design was shown. Measured distortions at the SVC PLUS Hornsea station showed the effectiveness and functionality of the active filter.

BIBLIOGRAPHY

[1] R. Marquardt, A. Lesnicar "New Concept for High Voltage-Modular Multilevel Converter" PESC 2004 Conference, Aachen

[2] M. Pereira, D. Retzmann, G. Pilz, K. Habashi, P. Ernst "SVC PLUS: An MMC STATCOM for Network and Grid Access Applications" 2012 Cigre Canada Conference

[3] M. Lehmann, Dr. M. Pieschel, M. Juamparez, K. Kabel, Dr. Ł. H. Kocewiak, S. Sahukari "Active Filtering in a Large-Scale STATCOM for the Integration of Offshore Wind Power", 2018

[4] M. Pieschel, "DEVICE FOR COMPENSATING HARMONICS OCCURRING IN CURRENT FLOWS IN A HIGH-VOLTAGE NETWORK". Europe Patent EP 2 460 244 B1, 13 07 2010.

[5] M. Pieschel, "DEVICE FOR COMPENSATING HARMONICS". Europe Patent EP 2 436 092 B1, 12 05 2010.

[6] Trench Equipment Brochure, Resistive Capacitive Voltage Dividers for Gas Insulated Switchgear, Linz-Leonding: Trench Austria GmbH, 2017