NAME : Omar F Jasim
COUNTRY : UK
REGISTRATION NUMBER : 4852

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Question 1.7: *Harmonic interactions between the active and passive components of HVDC, FACTS and AC grids are of concern. During the past years several major incidents have been reported due to harmonic interactions between the PEs or PEs and the AC grid components.*

• With large integration of PE equipment to the grid will the industry observe more stability issues and in the worst case more blackouts?

Large-scale integration of power-electronic-based power generating units in power system networks with the utilisation of renewable energy sources and High Voltage Direct Current (HVDC) has resulted in the displacement of conventional power generation by lowering system inertia and minimising short circuit capacity in AC power systems. This increases the complexity of the power system infrastructure, allowing for dynamic interactions between Power Electronics (PEs) or PEs and the AC grid components.

The Voltage Sourced Converter (VSC) might exhibit non-passive behaviour at certain frequency ranges due to for example control dynamics as a result of time delay in the control system, or non-linearities such as transformer saturation. The frequency of the interaction phenomena between PEs or PEs and AC grid components can occur across a broad frequency range, ranging from inter-area oscillations to sub-synchronous interaction and even high frequency interaction (between 100Hz and for VSC can reach in kHz).

In general, there are different tools available to address and analyse the interaction issues for VSC HVDC related technologies which are listed as: offline Root Mean Square (RMS) simulation, Electro-Magnetic Transients (EMT) simulation, Small Signal Analysis and Control hardware in the loop with real time simulators.

A variety of factors increase the likelihood of interaction phenomena:

1. Several difficulties involving the inappropriate use of analysis tools and model types
2. A lack of well-defined guidelines on modelling needs, processes, and data exchanges for converters and passive grid components related to a certain power system occurrence.
3. Absence of accepted or agreed tools to be used at specific stages of the project life cycle to conduct the necessary studies

Therefore, there is need for a clear recommendation on analysis, modelling, and mitigation of interactions between VSC-HVDC converters, other converters, and the AC grid components, through the complete lifetime of the project.

Interaction between Line Commutated Converter (LCC)-HVDC and Flexible AC Transmission System (FACTS) devices has been well covered in CIGRE WG 14.29 Brochure TB 149, 1999. One of the most recent CIGRE documents on VSC HVDC harmonic design is CIGRE WG B4.67 Brochure TB754, "AC Side Harmonics and Appropriate Harmonic Limits", which explains the relationships between control design, converter harmonic impedances dependent on control functions, and the potential for harmonic instabilities. The CIGRE WG C4.49 entitled “multi-frequency stability of converter-based modern power systems”. Where the objective is to describe the phenomena, consolidate definitions and explain available methods for analyses with their advantages and disadvantages as well as providing a common understanding on modelling, analysis, evaluation, and mitigation techniques. Guidelines regarding the general approach to such studies and the availability as well as choice of tools are also addressed. Finally, CIGRE WG B4.81 entitled “Interaction between nearby VSC-HVDC converters, FACTS devices, HV power electronic devices and conventional AC equipment.” Which is focusing on types of models and methodologies for different interaction studies, Criteria for selection of the study area, and Risk assessment during project life cycle.

The task forces of these many working groups have made enormous contributions, making it possible to utilise such guidelines and references and thoroughly examine system stability to ensure stable, robust, and reliable operation. Therefore, blackouts caused by harmonic issues will be much less common in the future if such guidelines as those listed above and the contribution of paper [1] are used and taken into consideration for new

VSC HVDC schemes. This is because the industry will have a better understanding of the causes of the issues and more proposed standard solutions will be available such as active damping control.

[1] Jose A. R. Montero, Omar F. Jasim, Elisabetta Lavopa, Hani Saad, Sarath Wijesinghe, “The Harmonic Loci-Based Control Design: Practical Methods in Frequency and Time Domain for a Consistent Design of VSC HVDC Harmonic Active Solutions”, CIGRE Paris Session, August 2022.

Dr Omar Jasim
GE Grid Solutions
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