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Question 2: What are the experiences on harmonic instability associated with IBRs in AC power systems? Can the phenomena be reliably predicted using the existing modelling and analysis methodologies, paying attention to data requirements and possible improvements for the future?

What are the experiences on harmonic instability associated with IBRs in AC power systems?

Low damping is a characteristic of a weak network with high density of inverter-based resources IBRs, due to the presence of a large amount of power electronics and cables, with a low amount of conventional generation and loads. The low damping presents an unfavourable scenario in the occurrence of a harmonic resonance, where the oscillations can get amplified instead of attenuated.

The reason why high density of IBRs is linked with low damping is that the IBR controls can behave harmonically as equivalent negative resistance seen at their connection with the AC power system. This is due to the nature of their control system, and it can vary based on the vendor's design.
If the harmonic impedance of the IBR interacts with the harmonic impedance of the rest of the AC power system in a way that a resonance occurs at certain frequencies, the negative resistance can have the effect of amplifying the resulting oscillations, with possible damage to the equipment and interruption of operation.

Paper no. 10928 [1] highlights that a common problem faced by HVDC transmission systems connected to converter-based networks, as wind and solar power plants, is the occurrence of harmonic currents and voltages or harmonic oscillations caused by system resonances and low damping [2].

Can the phenomena be reliably predicted using the existing modelling and analysis methodologies, paying attention to data requirements and possible improvements for the future?

Paper no. 10928 [1] focuses exactly on the importance of modelling the IBRs as thoroughly as possible, including their control systems and demonstrates the impact that this has on the accuracy of harmonic performance assessment. The paper is focused on the impact from the point of view of HVDC design, but this analysis can be extended to any power system design issue when IBRs are in the picture.
Traditionally, power system elements are modelled by passive circuit conventional elements. For example, loads may be represented by their passive impedance, generators may be characterized by their reactance, transmission lines and cables by a combination of inductive/capacitive reactance and resistance, transformer by their reactance and resistance, etc. Power electronic components in the power system are also represented often by their passive circuit elements like transformers, coupling reactors, passive filter.
However, when it comes to model IBRs, more detailed data representing the harmonic behaviour of their control systems is essential when modelling a weak network with high density of power electronics, but even a strong network in special operating scenarios where the power electronics behaviour become more prominent.

The current literature is very advanced in providing modelling and validation techniques for the most common power electronic converters in the power systems [3]. Big contributions are given by CIGRE WG C4.49 "Multi-frequency stability of converter-based modern power systems" [4] and WG B4.81 "Interaction between nearby VSC-HVDC converters, FACTS devices, HV power electronic devices and conventional AC equipment".

More often now the manufacturers of such equipment are including the controls in their models. Such mathematical tools, combined with accurate in-house dynamic models of these subsystems, allow full description of the control systems in the frequency domain and its validation. Manufacturers are then able to provide the other vendors or the TSOs with impedance-based models which describe their devices with a fair degree of accuracy in the harmonic domain without giving away proprietary information about their control algorithm.

The way forward is a common understanding of the importance of accurate harmonic modelling and a coordinated effort to make such models available to all the parties involved in the engineering of the AC power system. Clear data requirement is key in this respect, and this level of information is expected to become standard practice in the power industry.

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