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Studies for Interaction of Power Electronics from Multiple Vendors in Power Systems

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T&D Europe aisbl
BluePoint Building
Boulevard A. Reyers 80
1030 Brussels - Belgium
+32 2 206 68 67
secretariat@tdeurope.eu
www.tdeurope.eu
T&D Europe is registered under the European Union 'Transparency Register'
ID number 90453504235-64 **VAT** BE 0898 208 617

1. Introduction

Controllers of power electronic interfaced devices (PEID) and their design give a wide variety of control options to fulfill a desired response. Although all these options are parametrized to be stable by themselves, they can interact with other equipment in the transmission system. Therefore, interactions studies need to be performed to identify the risk of interactions and, if a risk is identified, to redesign the control parameters. To do so, an appropriate representation of involved equipment is needed. Currently, interaction studies involve mainly interactions between converters and passive elements or converters and generators. With the increase of power electronic devices (e.g. HVDC transmission, wind power plants and FACTS) in the transmission system, interaction studies also need to consider interactions between power electronic devices. In case these devices are from different vendors, no common procedure is defined yet.

This document describes general interaction phenomena and the required tools to perform interaction studies. Furthermore, it defines which models are needed and depicts a proven workflow for multivendor interactions studies.

2. Investigation of interaction phenomena

The basic structure of interconnected large scale power systems worldwide has changed quite significantly over the last decades. Until the beginning of the 21st century, power systems were dominated by the characteristics of synchronous generators located at centralized power plants. With the increasing number of renewables, decentralized infeed and controlled energy trading, more and more PEIDs are used. These devices are operated by fast controls, and it has become more likely that they are in close vicinity to each other as the number of devices is still increasing[1]. An increasing number of issues with interactions is being observed, whereby the type or nature of interaction may vary within a huge area of physical phenomena. These phenomena can be categorized in slow and fast controller interactions, fast electro-magnetic phenomena as well as resonances in the sub-synchronous and super-synchronous (harmonic) frequency range.According to the literature (e.g. CIGRE, IEEE) on interaction phenomena with

[1] https://www.wind-energie.de/english/statistics/

PEIDs (such as HVDC, wind power plants or FACTS), three main areas of interaction can be identified:

- Interactions associated with the controls of the involved plants
- Interactions with electromagnetic transient effects
- Interactions with resonance effects.

A brief overview of the observed multi-infeed and interaction phenomena is shown in Figure 2-1.

at least two mainly power electronic controlled devices (HVDC, FACTS, Renewables, etc.)					
Control Interaction		**Electromagnetic Transients Interaction**		**Resonance Interaction**	
Steady-State (slow controls)	**Dynamic (fast controls)**	**AC Fault Recovery Performance**	**Transient Overvoltage**	**Sub-Synchronous Resonance**	**Harmonic Resonance**
• AC Filter Hunting • Voltage Control Conflicts • P/V Stability	• Controller Interaction • Sub-Synchronous Control Interaction • Controller Stability • Voltage Instability	• Commutation Failure Performance • Voltage Distortion • Phase Imbalance	• Load Rejection • Voltage Phase Shift • Filter Trip Scheme	• Sub-Synchronous Torsional Interaction	• Resonance Effects • Harmonic Instability • Core Saturation Instability
• Static Analysis • (extended) RMS Time Domain	• RMS Time Domain • EMT Time Domain • Small-Signal Stability	• EMT Time Domain	• EMT Time Domain	• EMT Time Domain	• Harmonic Analysis • Frequency Domain • EMT Time Domain

Figure 2-1: Overview of multi-infeed and interaction phenomena.

3. Concluding interaction studies

3.1 General

Depending on the nature of the interactions described above, different tools, analysis methods and simulation environments can be used to effectively investigate these. Typical environments are steady-state tools / RMS time domain simulation, EMT time domain simulation and analysis in the frequency domain.

Data, tools and models are described in the following sections.

3.2 Required data

The data required within the interaction study process can be summarized as follows:

- To start a multi-infeed / interaction study the current state of the system is of crucial importance. Therefore, a valid description of all relevant AC grid components and their configuration in the individual system states is needed. The quality and details of the data shall correspond with the specific phenomena to be investigated.
- The corresponding TSO(s) and / or HVDC system owner(s) is / are responsible to provide information which is relevant for the required studies to all parties involved. This includes information for existing equipment as well as the equipment which is going to be installed. Regarding the required data exchange between the involved vendors the TSO(s) and / or HVDC system owner(s) is responsible to arrange this as part of the coordination work.
- The study starts investigating the simulation model behavior without any new equipment included. This fulfills the purpose to benchmark the model against the existing system.
- After the benchmark tests with the existing equipment are completed, the new components are added to the models and the involved parties can study the system interactions with the new equipment.

3.3 Required tools

Depending on the investigated phenomena the tools might be either RMS based simulation software (e.g. PSS®E, NETOMAC, PowerFactory, etc.) or EMT based simulation software (e.g. PSCAD, EMTP RV etc.). Additionally, calculations for harmonic impedance analysis may be needed.

3.4 Required models

Interaction studies assess the behavior of systems from different vendors. To study the phenomena of interest the relevant functionality of the individual systems needs to be identified and represented in corresponding models which may also be executed separately.

It is important that all parties involved agree which parts of the system need to be modeled in detail and where a simplification is possible. As this is currently still under discussion (e.g., in CIGRE WG B4.81) for the time being this definition needs to be done on a project-by-project basis. In any case, the representation of the relevant equipment needs to be appropriate for the studied phenomena. This includes, but is not limited to generators, transformers, cables, overhead lines, converters and filter and is supported by documents like CIGRE TB 766 and TB 604.

4. Possible workflows for interaction studies

While the tools, methods and simulation environments are different, the methodology of how interaction studies are performed is independent from the phenomena under study.

In the following sub-sections different approaches on how to organize the model and information exchange between vendors and TSO(s) and / or HVDC system owners are described in detail.

4.1 Vendors sharing models and data directly via the TSO(s) and / or HVDC system owner

One possible workflow for multi-vendor interaction studies is that vendors are sharing the required information directly via the TSO(s) and / or HVDC system owner. This approach can be split into discrete stages, shown in Figure 4-1. Within this graph it is depicted for two vendors but can be extended accordingly if more vendors are involved. The exchange of information between vendors via the TSO(s) and / or HVDC system owner always requires a signed agreement to be in place, defining that the purpose of the model is for testing and validation of connected equipment for stable operation. In addition, scope, content, format and form (e.g., black-boxed) of information to be exchanged between the individual parties as well as their individual roles in the process shall be defined in this signed agreement. Furthermore, the agreement shall define the time schedule for the exchange of information as well as the process and conditions for meetings to discuss potential issues identified during the study. Preferably, the principles of information exchange should be agreed in a group consisting of several TSOs and vendors, e.g. as outcome of the European Coordination and Support Action project named “READY4DC”.

The Interaction Studies are started in Stage 1 where vendors are exchanging the minimum set of required models based on the above-mentioned agreement. The entire process of model exchange between the vendors is coordinated by the involved TSOs and / or the owner of the HVDC that is /are responsible to provide the required models for all existing equipment. In this stage a benchmark of the model without including any new equipment is performed by each vendor to have identical starting conditions for all vendors as described above.

In Stage 2 each vendor performs studies using its own model in combination with the model(s) provided by the other vendor(s) where their respective equipment is represented. These studies continue independently if no interactions or any other issues with foreign model parts are observed.

In case of interactions or any other observations, either vendor may contact the other involved parties for discussion (shown in Stage 3 within Figure 4-1) under supervision of the involved TSO(s) and / or the owner of the HVDC system. The necessary clarifications are held under the commonly agreed NDA.

This approach will help to maintain clear performance responsibilities, since any changes on control algorithms and parameter of an AC/DC or DC/DC converter station that are required will take place in the sole responsibility of the respective vendor.

In the exceptional case that an issue cannot be solved between the vendors, TSO(s) and / or HVDC system owner in charge (e.g. because a solution is rather complex, time consuming or it is unclear how to solve an observed interaction due to the ambiguity with more than one possible solution), an external mediator may be assigned by the TSO(s) and / or HVDC system owner to coordinate the discussions between the vendors (as shown in Figure 4-2). The only task of this mediator is to find the balance between the expectations of the parties involved.

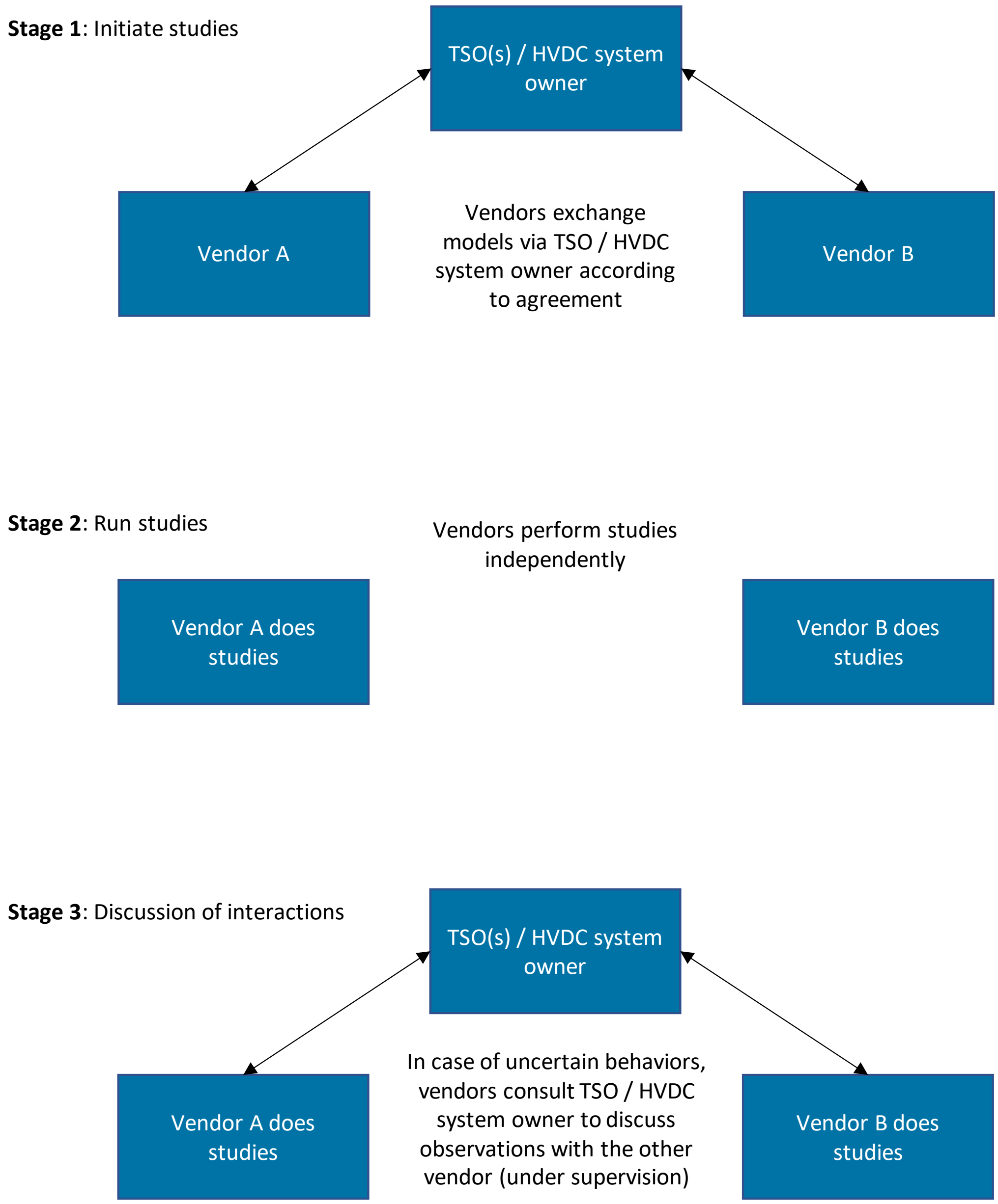

Figure 4-1: Workflow for Multi-Vendor interaction studies if vendors share data and models directly via the TSO(s) and / or HVDC system owner

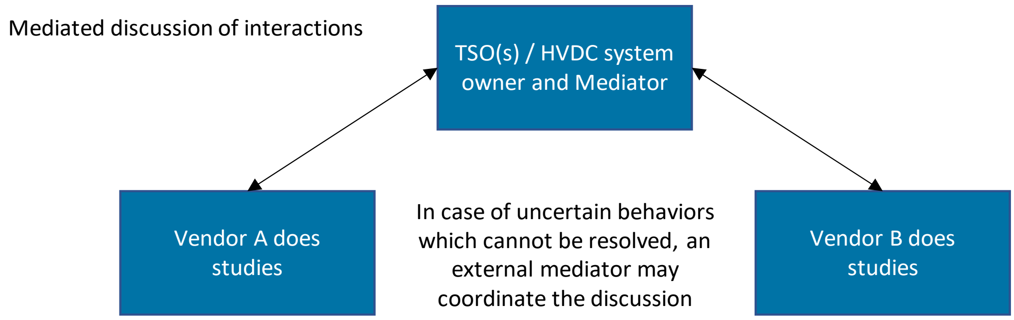

Figure 4-2: Workflow for Multi-Vendor interaction studies if vendors share data and models directly via the TSO(s) and / or HVDC system owner in case of conflicts

4.2 Certified institution collecting proper models as will soon be required by the Grid Code from National Grid

This example of a possible workflow for multi-vendor interaction studies is based on the model exchange procedure requested within the Grid Code from National Grid in the UK. There, the workflow is similar to the workflow which is proposed within the preceding section (section 4.1).

In the UK, any type of electrical plant or utility that requires interconnection with the high voltage AC transmission system needs to fulfil all the relevant requirements given in the Grid Code (GC) from National Grid (NG). The grid code will soon include a proposed modification titled GC0141[2] that contains a set of new conditions relating to RMS and EMT models. The new conditions are part of the Planning Code and stipulate that RMS and EMT models must be provided to NG under a Non-Disclosure Agreement (NDA) as part of the Grid Code Compliance process. Therefore, the permission of interconnecting to the high voltage AC transmission system depends on the submission of these models.

The main purpose of this new grid code requirement is the collection of proper representative models of any electrical plant connected to the power system in the coming years. If a new plant (e.g., HVDC converter, FACTS device, Wind Power Plant) shall be connected, the corresponding interaction studies need to be performed. Therefore, appropriate models will

[2] https://www.nationalgrideso.com/industry-information/codes/grid-code-old/modifications/gc0141-compliance-processes-and-modelling

be provided by NG under an NDA established directly with NG and can then be shared with the executing party connecting the new plant. Consequently, this avoids the need for many multi-lateral NDAs being signed for the exchange of models for each new electrical plant and results in more robust interaction studies based upon reliable models.

4.3 Model and data exchange via third party only

Another approach of a possible workflow for multi-vendor interaction studies is to define a third party, which collects the models from the two HVDC vendors and performs the interaction studies on its own. Therefore, both vendors must provide their models to the third party and communicate to this third party with regards to data exchange, model requirements and the issues detected.

The models from both parties are black-boxed models which require continuous black boxing processes for all involved vendors to be able to deliver model updates - even for small changes such as a parameter change. When an identified issue (inadvertent interaction between the converters) will be presented to a vendor by the third party, this vendor must understand the issue and related influence of the other vendor's C&P without having the chance to directly observe it by himself. The latter point will be very challenging when analyzing interoperability issues and tuning controls accordingly must be done.

5. Proposed workflow

This document describes general interaction phenomena and the required tools to perform interaction studies. Furthermore, it defines which models are needed and how a workflow for interaction studies can look like.

Different examples for possible workflows are described to show benefits or disadvantages of certain contributor setups for system interaction studies.

The comparison of the introduced possible workflows clearly shows the advantage of the direct exchange of models between vendors through the coordinating TSO and / or the HVDC system owner while vendors perform the required studies in-house. Doing so keeps the number of parties to be coordinated as small as possible and allows the vendors to analyze interaction phenomena in the most efficient way. This is because a vendor can then change the controller settings of his system and directly see the system response including the latest controls of the other vendors. Afterwards the results and findings can be discussed in the presence of the TSO(s) and / or HVDC system owners directly, models can be updated accordingly and vendors continue their studies while the TSO(s) and / or HVDC system owner continue(s) to coordinate this whole collaboration. It is important to highlight that this proposed workflow also maintains clear responsibilities for the individual deliveries, since the responsibility of any change of control algorithms or parameters solely stays with the respective vendor.

As a pre-requisite, this method requires vendors committing to provide their detailed, black boxed models to other vendors under defined conditions, e.g., an NDA. Some grid codes already contain corresponding requirements for model sharing.

In case any conflicts occur which really cannot be solved directly between the involved parties, the backup solution to involve a mediator can be chosen at any time.

6. Related Literature

- Guide for the Development of Models for HVDC Converters in a HVDC Grid, CIGRE Working Group B4.57, TB604, December 2014
- Modelling and Simulation Studies to be performed during the lifecycle of HVDC Systems, CIGRE Working Group B4.38, TB563, December 2013
- Grid Integration of Wind Generation, CIGRE Working Group C6.08, TB450, February 2011
- Systems with Multiple DC Infeed, CIGRE Working Group, B4.41, TB364, December 2008
- Impact of Interactions among Power System Controls, CIGRE Working Group TF 38.02.16, TB166, May 2000
- Coordination of Controls of Multiple FACTS / HVDC Links in the same System, CIGRE Working Group 14.29, TB149, December 1999
- GUIDE FOR ELECTROMAGNETIC TRANSIENT STUDIES INVOLVING VSC CONVERTERS, CIGRE WG B4.70, TB832, April 2021
- Network modelling for harmonic Studies, CIGRE JWG C4/B4.38, TB766, April 2019

ABOUT T&D EUROPE

T&D Europe is the European Association of the Electricity Transmission & Distribution Equipment and Services Industry, which members are the European National Associations representing the interests of the electricity transmission and distribution equipment manufacturing and derived solutions. The companies represented by T&D Europe account for a production worth over € 25 billion EUR, and employ over 200,000 people in Europe. Further information on T&D Europe can be found here: http://www.tdeurope.org

CONTACTS

Diederik Peereboom
Secretary General, T&D Europe
secretarygeneral@tdeurope.eu
+32 2 206 68 88

Dimitar Kolichev
Junior Adviser
policyadviser@tdeurope.eu
+32 2 206 68 91