Composite Testing of HVDC-connected offshore wind farms

The National HVDC Centre

Purpose

This document is a summary of the questions, answers and discussions from the webcast co-hosted with RTE International on Thursday 11th March 2021.

Reference Document:

Presentation slides and full technical report used by the presenters are available at:
https://www.hvdccentre.com/composite/

Video recording is available at: http://www.hvdccentre.com/composite/composite-webcast

If you have any further questions, please email us at info@hvdccentre.com

Questions and Answers

Q1: Refer to S1: What is the typical speed of OWPP response (via an HVDC link) to the frequency change in the grid? Is it sufficient to meet the Grid Code requirements?

A1: Two approaches have been considered-
The first method communicates to the HVDC directly and the effect of the HVDC increase or decrease in active power demand offshore (LF or HF response) drives a consequential response from the windfarm. This approach whilst fast, has the disadvantage of providing a large disturbance offshore which can lead to oscillation and interaction across the frequency response without suitable damping being defined within the offshore convertor to compensate. In this first method the frequency offshore presented to the OWPP differs significantly from that measured onshore and as a result the overall response to the onshore system may be different to what was expected, requiring careful tuning, as does post response regulation and damping. This approach is inherently flexible to a multi-terminal environment given specific responses linked to a specific point of measurement can be different within an overall design with more than one connection to the onshore system- you have the choice to take into account different onshore frequency and other measurements and other priorities to inform how and where the frequency response may be delivered onshore.

The second method requires the onshore frequency to be communicated offshore to instruct the OWPP to respond, and the HVDC to then complement that increase or decrease in power. This method has the advantage of presenting the offshore system with the same event that the onshore system, and the OWPP with a frequency event it may have been specifically tested to deliver, with a speed and outcome of response which is clearly defined. This approach would require controller tuning to manage any delays in communication and response given the multiple control interfaces involved in responding to the onshore event. Whilst the initial offshore effect from the windfarm response is lesser than the first method, interaction and oscillation offshore can still result from these conditions, requiring specific damping to address.

Both methods have their pros and cons and can meet existing frequency response needs see report for more detail on the HF simulations illustrating these methods; other faster service needs which are successively faster such as dynamic containment and inertial in nature have not been specifically considered and would be expected to impose further limitation; however this in turn could be overcome by the implementation of storage within the solution. Considerations for coordinated design of the frequency control solution would be required across different points on the onshore system for multi-terminal HVDC arrangements, without limiting the response of the HVDC terminals to ensure he full scale of frequency response available from these arrangements can be delivered.

Q2: **How will the COMPSOITE project recommendations inform compliance of HVDC offshore windfarms with Grid Code or identify potential modifications to the current Grid Code requirements?**

A2: This report uses the current grid code as the basis for its demonstrations of how different devices complement each other with such designs to deliver an overall compliant performance. In addition, we note the need when combining projects which could have different types/ vendors of OWF and owners within them the importance of clear offshore codes clarifying the expected environment (for example frequency and voltage regulation) and the roles of the offshore components to this.

Q3: ***Do you recommend the full wind farm model or aggregated model for off shore network suffices.?***

A3: This is a classic "it depends" answer to a question. The model used needs to be relevant- for example for interactions of a harmonic or inter harmonic character, the array components can be critical in their identification either via small signal filtering or specific dynamic analysis. However, for other forms of analysis, for example onshore fault behaviours, this performance can be less important. A key consideration is the scale and complexity/ variety of operating conditions within the array- it is recognised that specific tuning solutions of WTGs within an array may be different and as such it's not just a question of frequency dependent array topology alone. Damping solutions to address given array interactions should be demonstrated on a detailed model of the array, even if the initial issue was identified via an aggregated model alone, to ensure the intended solution is not itself the source of risk of further interactions not originally considered.

Q4: ***Slide 22: Is this signal transmission delay measured in an actual setup or what is the assumption used for the simulation?***

A4: The following telecommunication delays are considered in the model: (i) for HVDC interstation telecommunications: 15ms (Frequency control #2); and (ii) for onshore to offshore WTG telecom is equal to 200ms (frequency control #1).

Q5: ***Did the study consider communication-less frequency control approaches?***

A5: Communication-less frequency is not considered in this generic study. However, similar performance is expected as for the Frequency control #2.

Q6: ***From supply system perspective, what's the difference between studies needed to be done for a wind farm HVDC connected system and an HVDC interconnector system?***

A6: Within a HVDC system its control functions are described unique to that system alone with reference to interfacing TSO requirements which are in turn respected and delivered. For a HVDC connected OWF, not only do the TSO requirements and its own require respecting, but also those of interfacing OWG project(s), an offshore AC system frequency, voltage and associated dynamic compatible between OWF(s) and HVDC(s) offshore it (and dominated by the HVDC control strategies. Whenever services are provided, and responses to events on or offshore occur, the OWFs and HVDC need to complement one-another within a network environment defined by those complementary behaviours. This has in practice defined additional layers of damping control, additional supervisory controls and additional control modes and transitions for HVDC controls that need to be defined and managed across its delivery. See our report for further detail

Q7: ***How easy is it for you to get dynamic data for the wind turbines and HVDC system? Were OEM willing to release their dynamic data or did you assume parameters?***

A7: See slides and report- vendor specific models, suitably anonymised are included. We also note in our presentation that hosted environments whether the real time environment, potentially utilising hardware or an offline environment, being enhanced with "software in the loop" hybrid simulation developments can support management of confidentiality and the volume of implied simulations required within an EMT domain. We also note RTEI's experience in facilitating such management with HVDC models within the Johan Sverdrup project.

Q8: ***How can the 3.4Hz oscillation be avoided or controlled?***
A8: The important aspect is to detect such issue by performing such studies. Once it is detected, HVDC and/or WTG control systems may be tuned to damp such oscillation.

Q9: ***In page 23, in which case new HVDC interconnection derives the worst TOV ?***
A9: This is due to the inherent behaviour after voltage recovery of the VSC technology and control tuning. For more details you can read the following paper:
Saad, H. and Dennetière, S., 2019, June. Study on TOV after fault recovery in VSC based HVDC systems. In 2019 IEEE Milan PowerTech (pp. 1-6). IEEE.

Q10: ***On Chapter 6: If the AC grid 1 and 2 are interconnected, what is the impact?***
A10: The interaction issue will be more critical since the impact on one side will have an impact the other side. Therefore, we expect higher interaction phenomena in such case.

Q11: **Slide 23: How do you evaluate the system boundary conditions with regards to SCL, saturation effects and filter tripping schemes of the nearby LCC HVDC system?**
A11: The LCC-HVDC model is the manufacturer black-box model validated against the replicas available in RTE's lab. Therefore, it includes the saturation effect and control filter process as per onsite.

Q12: ***For temporary over voltage studies, would RMS simulation is suitable? What is the time step considered? What is your experience on differences RMS and EMT??***
A12: For temporary overvoltage, because the fast dynamic (such as inner current control) is impacted, such test should be performed in EMT tools. Also, transformer saturation will have an impact therefore, RMS tool will not be sufficiently accurate for such TOV study. If RMS should be used, model validation (against EMT) should be performed in order to identify the RMS model limitation before performing TOV study.

Q13: ***AC studies use fault levels to represent system strength. On DC system the fault level contribution is driven by IGBT rating. Does this (fault level metric) adequately represent system strength for studies?***
A13: no. There is much work currently underway to re-define system strength within a convertor environment, which needs to be defined on a frequency domain basis if it is to be relevant to convertor stability considerations Further discussions of this and other considerations will be included within the Cigre. A convertors delivery of fault current is not a constant, and may be limited by more than IGBT rating alone- for example the consequences of post fault TOV may be taken into account. Additionally, initial contributions of fault current may be variable in angle of injection- and can even reduce an effective fault level- we will discuss the effect convertor fault contribution has on protection in a subsequent webinar later this year.

Q14: ***How was coordination ensured between ABB and SIEMENS for offshore parallel operation of two HVDC connected offshore projects?***
A14: Coordination and parallel simulation tools has been used to de-risk the project. The detailed response to this question is explained in the report section 7.6.

Q15: ***There may arrive a scenario when an HVDC-links will be shared by two or more OWF what changes or updates do you anticipate in composite testing?***
A15: If multiple OWF are installed offshore, higher risk of interaction may occur because different control and protection system are design by different OEM. However, the methodology explained in the report (modelling, studies during phase projects, etc.) is still valid and does not really change.

Q16: ***Page 33: which project again was it please that demonstrated the inertia behaviour? Is this in line with the latest GB Grid code development GC0137?***
A16: The Dersalloch windfarm was referenced here which demonstrated both black start and inertial response to frequency response. GC0137 is an active Grid code modification seeking to define a minimum specification relevant to such future control approaches- this modification is currently under

discussion within that workgroup. Further information on the Scottish Power Renewables demonstration of the Virtual Synchronous Machine approach may be found here.
Reference:
https://www.scottishpowerrenewables.com/news/pages/global_first_for_scottishpower_as_cop_countdown_starts.aspx

Q17: ***Did the study include impact on protection/power electronics? What's the view on system need to do study protection impacts & lines of responsibility for study before commissioning; Connectees, OEM, TO or ESO?***

A17: The models discussed within our report include where relevant and computationally feasible appropriate elements of protection as well as control, and we highlight the relevance of replica control where complete control and protection verification is required of a HVDC system. The work does not discuss specific lines of responsibility across the various entities involved in the commissioning process, however it does identify what analysis tasks should be performed; and illustrates real life experiences of doing so.

Q18: ***Page 34, some general questions, so would the conclusion say that generic models are not feasible for the system such like multi-DC or multi-offshore wind projects?***

A18: Generic models are sufficient within the early stages of a project to outline the necessary functions that need to be achieved and how across those devices what options and issues present themselves in delivering such functions and the need or otherwise for supervisory controls. Generic models are however a starting point and do not include the detail of specific control structure for a given vendor solution, optimised to a given set of functions. For EMT analysis there are so many different types of analysis that a generic model can be generated for that there is a danger that a generic model becomes an approximated one which either does not contain the detail to inform a useful hybrid study environment, or is conservative in its function to the extent it provides little insight. In general, it is recommended that where it is possible a project-specific example of the technology in question is used/ adapted in favour- but this is not always available and risks limiting the range of solutions that can be subsequently delivered. The National HVDC centre has continued to make available HVDC open models which provide detailed structure allowing a starting point for the analysis areas discussed, further work is underway within the CIGRE working group C4.60 in order to provide recommendations in this area, which becomes increasingly important as more and more projects coincidently are developed within a convertor dominated environment and require co-ordinated examination.

Q19: ***What is missing today from the regulation to ensure that accurate EMT models will be there? Do really vendors provide accurate models??***

A19: **S**pecification is one part of the solution to provide an accurate model. If the provided requirements are clear and describes the validation methodology that should be used, the model requirement that should be provided is also clear, this will help to validate each process of the model. On the other hand, replicas is an additional solution to ensure accurate model. The replicas is an exact copy of the offsite C&P cubicles, so accuracy is much higher than the offline EMT model. Also, approaches for translating suitable representation of C&P algorithms used within replicas/factory testing into offline modelling tools could be beneficial for improving accuracy

Q20: ***Currently there is no framework for constant improvement of modelling data during operation. How would customers be incentivised to provide this information?***

A20: Yes, this is the main challenge for offline EMT and RMS models. When replicas are available, such issue is not relevant, because it is updated each time there is an onsite update It will also allows validating the offline models.

Q21: ***Shouldn't it depend on type of your investigation if EMT model is sufficient or replica is required? Could you please provide example where you see limitations?***

A21: Yes, practical examples are provided in chapter 7 of the report.

Q22: ***Suggestions regarding studies to make investment decision and specify functional requirements for tendering, when the vendor specific models aren't available?***

A22: The list of studies during specification and tender phase are provided in the report (see chapter 5).

Interactive Discussions with Audience

1. **What is meant by COMPOSITE testing?**

   Composite testing refers to the overall performance functions of electricity connections that cannot be fulfilled by one device alone. It is not new for AC connected OWF will operate in conjunction with FACTs to an extent and the relevance goes beyond just the HVDC-OWF example being used. The challenge composite testing addresses is that at each stage of project development and delivery is to provide assurance that the overall solution combined across individual device performance is robust and test-able. to achieve that it needs to be possible to bring offline and progressively real-time demonstration (for example the FAT being a well-known case) into a common space. This increases the confidence that not only the device performs the task expected of it but also that when they are brought together- there is nothing missing.

2. ***Also, very important points raised for TOs/Developers/Vendors situation and very interesting developments from system studies perspectives. Well said Ben, CIGRE C4.60: "Generic EMT-Type Modelling of Inverter-Based Resources for Long Term Planning Studies" with great interest from the UK will produce important findings in this direction?***

A. Thanks for the comment- we reference C4.60 above and we agree it will be interesting to see its conclusions over the next year.

3. ***I guess there is probably still some work to be done in some areas, the issues of possible risks in real life on bigger systems, interoperability, and about the complex controls and different technologies interaction?***

A. We agree that as systems become more complex, the extent of analysis similarly increases; it is a complexity of interactions and overall functions that drive this rather than necessarily the technologies themselves, which as we discussed in the presentation, we have experience of integrating and both RTEi and ourselves have experience managing within hosted environments. What composite provides is the foundations across the project lifecycle, of how to combine models and hardware in relevant areas of analysis to de-risk overall performance. Going forward, given the scale of GB and wider European net zero transition, the challenge will be to ensure clarity in describing the "ask" of developers and vendors, and ensuring that a collaborative dialogue as discussed accompanies the exchanges of data, models and analysis we undertake- and that we focus on effective ways of delivering the hosted environments and streamlined testing surrounding them that allows both continuation of de-risking and an increase in the pace of it.

4. ***Thank you! Good example of embedded VSC HVDC (FR-SP) participation in damping inter-area oscillation. However, if I am not mistaken this HVDC was not in POD mode, it was in AC line mimic mode?***

A. Yes, it was in AC line emulation mode. Remember that this was not the issue but rather a solution that was used and improved to add further damping on the network.

5. **The report highlighted the type of tools required (RMS/EMT) for different type of studies. I have some general queries on RMS analysis with HVDC and wind farm models.**

   In order to carry out RMs simulation for a system with HVDC as well as wind farm, what is the time step (1ms or 10ms) used in this project? Is there any recommendation on the time step?

A. The studies performed in the Composite testing report, chapter 6, are all done in EMT tools with a time step in the range of 40-50 µs. Such tests are important to be performed in EMT tools rather than RMS tool, because RMS tool will not provide accurate results for such fast transients. The analysis conducted here has focussed on EMT analysis areas, however RMS analysis must where possible follow the time steps against which models have been validated; and any overall simulation reflect the lower timestep provided in that environment each of the models individually or in combination remain stably interfaced to the network. If within the overall simulation a particular behaviour emerges that is dominated by a given contribution (e.g. a particular WTG operating a time step within that overall simulation for which it was not recommended it would run at) there may be value in re-running the simulation at a different timestep for which that dominant models behaviour has been most closely verified against an EMT study. In general RMS simulations operating at lower timesteps such as 1ms whilst potentially not presenting “accurate” within cycle behaviours will nevertheless provide indication of areas where further analysis in EMT would be relevant.

6. Whether HVDC models provided by HVDC manufacturers recommend any particular time step (integration time step of 1ms or 10ms)? Whether HVDC manufacturers can provide RMS model that can work for different time steps?

A. A good approach is to clearly specify the desired time step that should be used for the study. Usually the model should be valid for different time steps, but it is project- and manufacturer specific, unless it is clearly specified in the functional requirements. The exact timestep for which RMS models would be best verified against EMT would tend to vary across manufacturers. Whilst models may be provided at differing timesteps to those e.g. to a standard 10ms timestep, in doing so accuracy of behaviours relevant both to RMS and EMT simulation could occur; for example alignment with fault ride-through behaviour demonstrated in EMT. As with all things studied in RMS for a hybrid study there is a compromise between simulation extent, time to simulate and accuracy which needs to be managed. If a standard time step of e.g. 10ms does not align with the most accurate translation of a vendor model into RMS, it is important to understand what compromises are being made by its adoption, and there may be value in a further model being provided in addition to that at a timeframe for which the vendor is more comfortable of the RMS models' accuracy, which can then be substituted with the lower timestep model for relevant analysis.

7. If HVDC manufacturers are recommending 1ms time step for simulation, whether wind farm model also works for 1ms? If the wind farm model provided by supplier has 10ms as time step, can we use this along with HVDC model that requires 1ms time step?

There is no guaranty that a manufacturer model provided for a specific time step will also be valid for another time step (even though the time step is lower and multiple). The user should perform validation process and/or ask the relevant manufacturer if the model is still valid. See answer to question 5 above for a discussion of this point. If the slower RMS timestep model cannot run at the lower timestep, one option is to request a different timestep model for the study in question and/ or compare between the RMS model provided at that slow timestep and a library model- align the library model behaviour in a 10ms simulation and substitute it to focus in on the HVDC performance within a slower timestep study.

8. Is there any learning from these projects on the different manufacturers model with different time step recommendations?

A. This has not been a focus of the project. The time step topic is not covered in the report because such topic is more related to model implementation rather than system dynamic performance issue. However, the time step issue is very important for interaction study and should be specified at early stage of the project. Also, we would note that in EMT analysis, within a real time simulation environment, Substep/Superstep interfaces are common allowing different models with different stepwise behaviour (at that level often provided at the microsecond - 100microsecond scale), and similarly can be (within hybrid simulation shells) hybrid between offline models of differing integration steps). In principle, these techniques whilst not common to RMS analysis platforms could be developed also.

9. Slides Page 34 – This slide shows the power output from MMC2 before, during and after the fault clearance. My query is on the power output from wind turbines immediately after the fault clearance. Why the power flow is in the opposite direction for a very short period of time? Is it limitation of the model? In reality, power will not change its direction. Isn't it?
As noted, the wind turbine models illustrated include vendor confidential models which mean we cannot discuss specific aspects of behaviour in huge detail. However to make general observations, for fully converted wind farms, their tracking in relation to voltage angle will be disturbed briefly during the phase jumps occurring across fault clearance, the extent of this disturbance and the duration of the response to it being a function of Phase lock loop and associated current loops within the convertors structure which will be different for different vendors. It should be noted that the approaches for tuning wind farm models combined with HVDC connected offshore environment should be carefully considered where concepts such as SCR become increasingly less meaningful for their tuning. In such low SCR environments we have observed from separate research (click here) below SCR 1.5 tuning of conventional current loops becomes non-viable across all operating points. So, there is a challenge that immediately following faults and voltage steps offshore, non-tuneable behaviour occurs, which the offshore HVDC convertor must assume a dominant role in subsequently damping and stabilising to support the OWF.
Reference: https://www.hvdccentre.com/2020/03/hvdc-centre-and-cardiff-university-host-webcast-on-hvdc-grid-code-challenges/

10. Slide Page 23 – This slide shows the plot of RMS value of voltage and analysed the AC temporary voltage. Could you please clarify whether RMS study has been used to analyse the temporary overvoltage issues? I believe you recommended EMT study for TOV studies.

A. Yes- that's correct- EMT should be used to understand the full extent of any TOV magnitude, duration and consequences. Although RMS studies may be capable of highlighting TOV, where this occurs it should be followed up with further EMT investigation. The study was performed with EMT tool (EMTP-rv software) and not RMS tool to account for the non-linear and accurate behaviour. Such study should be performed in EMT tool. If RMS tool is needed, than validation should be performed before using RMS tool for such fast dynamics.