Practical Use of Real Time Simulation for HVDC Integration

The National HVDC Centre

Purpose

This document is a summary of the questions, answers and discussions from the webcast co-hosted with RTDS Technologies® on Thursday 16th April 2020 and 24th April 2020.

Reference Document:

Presentation slides and video of presenters are available at:

https://www.hvdccentre.com/rtds-webinar/

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

Questions and Answers

Q1: What defines the capability of simulating in RT? How do you select the capability of your RT platform?

A1: The capability of the real time simulator is determined by several factors.

1. The extend of network elements and nodes which the model is represented with.
2. The number and variety of dynamic components modelled within RSCAD
3. The time step resolution the model is running for a study.
4. The numbers of and specific processing requirements relevant to the hardware that is being used for simulation.

The section of the platform depends on the following but is not limited to them;

1. The number of physical interfaces needed to external equipment.
2. The mode of interface to physical equipment (electrical connection or Communication protocol)
3. The number of nodes you want to simulate.
4. The details of the model that is being represented.
5. Need of FPGA connection for firing pulses to mimic convertor component operation.

As with other tools network reductions can be used to focus on hardware focussed analysis within the limits of the RT platform. However, given the power of current generations of RT platforms it should be possible to provide for scales relevant to your entire grid model where needed. Contact Paul at RTDS for more discussion of your specific network.

It is also important to note that the number of nodes isn't the only factor that should be considered when talking about simulator capability. In order to maintain real time; the type and quantity of models (machines, lines, converters, etc.) in the circuit need to be considered as they all require processing power. Specifying several nodes that can be simulated but having this number dependent on a passive-only network may not be practically meaningful.

Additionally, when we allocate networks to the RTDS Simulator hardware, it is important to consider "embedded" nodes. Breaker nodes on machines, transformers, and transmission lines, for example, can be absorbed into and solved by the component model rather than counted toward the node count of the system. This means that the effective size (in nodes) of a network is reduced when modelling it on the RTDS Simulator.

Q2: What's the smallest time step simulated on the CPU on RTDS simulator?

A2: The smallest Timestep that could be run in a CPU can be smaller than < 1 µs. For example, if we have "small timestep" at 3-4µs, the converter bridge blocks could be simulated at 1/4 or 1/5 of that, and scan for C-HIL gate drive signals every 700-1000ns. It is defined by the requirements of the hardware being modelled or supported and will vary between application. Smaller timesteps (in the 250 ns range) are also possible using the RTDS Simulator's GTFPGA (FPGA-based auxiliary hardware).

Q3: ***Can you elaborate on the current solutions for interoperability of HVDC multiterminal systems?***

A3: RTDS could be used to simulate physical equipment (converter valves and its associated switchgear) from several vendor. These Real time model could be then interfaced with the control and protection system from different vendors and could be studied in conjunction with each other. Slide 29 & 30 of the presentation shows examples of multivendor solution for two parallel links both in VSC and LCC settings. Similar concept could be applied for multiterminal multivendor solution, but more coordination and communication would be needed between vendors for multiterminal than what is needed for parallel links. Multiterminal systems also require control and protection to be over-arching across vendor (or multivendor) solutions and RTDS is able to discretely model and test this.

With multi-terminal systems, the more complex they are, the greater the range of tests to the DC and AC networks which are required- and this is an area where RTDS can support efficient simulation and analysis. As with other areas of developing new designs, de-risking of multi- terminal environments need to combine models or hardware is sufficiently complete in function that all of the interacting controls and protections associated with the design are relevantly reproduced. RTDS-HiL offers the opportunity to use real or representative hardware of convertor control and protections to help define what the important areas of modelling and study are. Finally, a multi-terminal environment is likely to be constructed in a staged manner- and understanding performance at each stage and how you can transition between stages are important factors which lend themselves to real-time study.

There is an upcoming webinar that would discuss about multivendor protection solution for multiterminal HVDC links. If interested please register for it using the below https://www.ssen.co.uk/StakeholderEvent/Registration/?EventId=503

Q4: ***Any experience simulating transients on grid forming converters in black start situations?***

A4: Transient conditions such as energisation inrush, and TOV associated with line energisation can be modelled in real time in the same manner as these would be modelled in other EMT platforms. The flexibility of the platform allows additional detail of the black start provider- for example the protections associated with its operation in those situations to be included in model and hardware form. This is particularly relevant to Grid Forming convertors during a black start, as these forms of black start resource do not have the same overloading capabilities available to conventional synchronous resources and as such the protections which limit transient current and disconnect the convertor protectively across re-energisation transients are especially relevant

Grid forming in this context represents a convertor acting as a stiff voltage source which defines the voltage profile of the re-energised power island across stages of its re-energisation and load pick up. The black start resource can be modelled across a sequence of black start stages in a real time overall simulation. As a stiff voltage source it will seek to define its angle to the system, which will result in interaction with other power electronic devices re-energised to that network seeking to behave in that same manner, or synchronous machines. As a result, there will need to be a transition between the black start grid forming behaviour and normal convertor operation to avoid interaction and inter-area oscillation. This transition- when it is done and how it is done are key questions that can be considered within RTDS simulation. Note this grid forming behaviour should not be confused with a different Virtual Synchronous Machine control philosophy which can be referred to as grid forming.

During a black start process the protection will be responding to a condition of low overall fault current, and low inertias where voltage angles and current monitored by AC protection move very differently during faults than they do during healthy grid conditions. As such the normal settings or forms of protection used in this situation may need to change to support earlier stages of black start and re-energisation, and then be changed once more to reflect the later stages of grid energisation- again this transition is a critical area which can be assessed within an RTDS environment.

We had earlier webinars that explained about ac protection performance while using VSC converters to blackstart the grid. The slide pack and Q&A are available in the link below https://www.hvdccentre.com/wp-content/uploads/2020/02/EPRI-HVDC-Restoration-Project-Final-Webinar_20200213.pdf

Q5: ***What is maximum number of node possible to simulate?***

A5: In standard simulation mode, a network of 600 nodes can be simulated on one NovaCor chassis by using two cores.. This 600-node network solution, though, is tightly coupled (no subsystem splitting required). As mentioned in Q1, not only the quantity of nodes, but also the complexity of the network (i.e. density of non-passive components) is important to consider. Also, the embedded node concept discussed in Q1 should be noted.

Up to 144 NovaCor chassis can be interconnected to achieve simulations of much larger systems.

A simulation environment called Distribution Mode also exists in which up to 1200 nodes can be simulated on a single NovaCor chassis. This is achieved by slightly relaxing the simulation timestep and simulating radial feeders. However, using Distribution Mode, only one tightly coupled network can be simulated – the network cannot be expanded by connecting multiple chassis. More here: https://knowledge.rtds.com/hc/en-us/articles/360034825333-Distribution-Mode

Q6: ***Does any load despatch centre use RTDS?***

A6: For R&D it can and has been done. However, existing implementations have not included a direct link to the grid or real dispatch. These systems can be considered a "digital twin" of the dispatch centre.

On load dispatch an important consideration is the data being used for such control system- via PMU devices normally which have two core specifications - protection and monitoring which govern sample scale accuracy and associated latencies- these are key to modelling these systems- and can be done within the RTDS environment using physical PMUs and/or models. the Centre here has plans to further investigate this.

Q7: ***How are the machine models in library different from PSCAD?***

A7: The machine models are basically the same as PSCAD. We have added some new models that are not yet available in PSCAD though. We have a phase domain machine model that includes true internal faults, access to the field winding, etc.

The RSCAD models have been successfully validated against PSCAD but need not be limited to that granularity. Offline simulation models frequently require flattening to conform with practical simulation time and scale whereas RSCAD can in practice include slower acting protections controls and internal protections that may not form part of a conventional power electronic model

Q8: ***What components can be used to interface systems with different time steps in RSCAD?***

A8: A traveling wave component is used to connect between different timestep areas.

Q9: ***Can you use RTDS to do DLR (Dynamic Line Rating to factor the environment effects to estimate the real usage of an interconnector to maximize it) in an HVDC interconnector? or would you need an extra real time monitoring of the system?***

A9: There would be ways to test the DLR, but we are not modelling the thermal aspects of wind on the line, but you could provide a signal profile for the control to react to. The control may be interfaced as physical hardware (this is something we have plans to do for other WAMPAC projects at the Centre) or modelled. Phenomena such as data loss, latency, noise & error can be introduced into the study to test the robustness of the system.

Q10: ***If you could please explain the significance of Superstep? Slide no. 25***

A10: The Superstep environment is intended to allow the user to relax the simulation timestep (e.g. 150 microseconds) for a portion of the network in order to reduce the simulation hardware required to simulate it but still provide more detail than a network equivalent.

Q11: ***Which algorithm is used for the loadflow in RSCAD software?***

A11: A version of the Newton-Raphson power flow solution is used for RSCAD built-in load flow capability. This is used to initialize the system and is not a real-time function.

Q12: ***Is it possible to run part of the large PSSe network in RTDS and remains large network in PSSe? Co-simulation with PSSe***

A12: First, the reasons for co-simulating with PSSe or any other RMS simulation tool should be considered – is this just for proof-of-concept or is there a solid technical justification for representing a large portion of the network with a phasor solution? We currently have limited evidence that co-simulating in this way has a clear technical benefit. That being said, a tool has been developed for creating a continuous, synchronized co-simulation between the RTDS Simulator and the TSAT software (RMS simulation).
There is a capability to interface to an RMS simulation in order to extract network data and initial network conditions as required. However RMS is a very different entity and co-simulation is neither practical nor desirable For more information please visit the below link - https://www.dsatools.com/tsat-rtds-interface-tri/

Q13: ***Is there any tool or interface between Matlab and RTDS/RSCAD in order to do some programming? or these are totally apart?***

A13: There is a conversion utility to import Matlab control models. The RSCAD platform also includes the Cbuilder interface which can be used to similarly build external control code, for example, using a version of the C programming language. Further data on these tools may be found at: https://knowledge.rtds.com/hc/en-us/articles/360037537653-RSCAD-Modules, https://knowledge.rtds.com/hc/en-us/articles/360034292774-PSS-E-Matlab-Integration

Q14: ***Is it possible to load models from Simulink?***

A14: MATLAB/Simulink control models can be converted for use in RSCAD via the above conversion utility.

Q15: ***Would there be some communication protocol available to RTDS?***

A15: Yes, RTDS support many standard industry Ethernet protocols.
https://knowledge.rtds.com/hc/en-us/articles/360034788593-GTNETx2-The-RTDS-Simulator-s-Network-Interface-Card

Q16: ***I wonder if RTDS offer a remote access to hardware for the researchers?***

A16: As long as you can see the IP address of the rack and associated equipment, you can run it remotely. But you need to make sure the appropriate IO is physically connected first, of course. There also example mentioned about remote testing on of control hardware in loop tests being carried out.
PS: Yes, theoretically you can access RTDS Simulator units remotely via VPN for example if the IT has been worked out. As mentioned earlier, this can be a challenge when there is I/O and you are not physically on site.

Q17: ***Sometimes, AC network connection to HVDC station is changed. Is it standard practice to check operation of existing HVDC control software for modified network in RTDS environment?***

A17: It is usual to do studies with HVDC converter by simulating various load flow scenarios in the AC network for future and existing condition along the HVDC converter during the design stage. But it is a good do further studies if there are significant changes near the HVDC converter in the later stage.

Q18: ***Are RSCAD and PSCAD models same?***

A17: No RSCAD and PSCAD are different simulation software and the models are not the same. But there are tools in RSCAD to convert PSCAD model in to RSCAD model. RSCAD is used for real time simulation using dedicated RTDS Simulator hardware and it has capabilities to perform hardware in loop testing; whereas the PSCAD is intended to run EMT studies on any desktop PC and also does not run real time EMT studies.

Q19: ***Is RTDS capable for testing of PV controller testing. if yes, then please share the experience***

A19: Yes, RTDS is capable of testing PV controller. [RSCAD](#) contains a solar PV array model which allows for insolation and temperature as inputs. Controls can either be simulated or physically connected to the simulated network for testing.

Q20: ***Does RSCAD has plans to implement snapshot functionality that is available in PSCAD?***

A20: Snapshot functionality is mainly to perform multiple test from a saved point in simulation time without repeating the simulation up to the saved point. Example to do multiple fault tests after a study state is achieved in the network. This functionality is mainly used to reduce the time for performing multiple simulation cases.

Snapshot functionality is less relevant in the context of RSCAD, as the simulation runs continuously in real time. However, RSCAD contains a Breakpoint functionality in which the user can pause the simulation and resume it from the same point at a later time. When the simulation is paused in breakpoint mode, it can be set to run freely again by pressing the "resume" button, or the simulation can be run for a specified time or number of timesteps and then automatically suspended again. It should be noted that all analog outputs are set to zero when the simulation is paused.

Q21: ***Will you please give us a brief information about what are the risks with HVDC integration?***

A21: There are several risks that could occur during the integration of HVDC Converters some of them are

1. Small signal interactions
2. Large signal classical interactions
3. PLL tracking issues
4. Control and protection problems like limits, mode changes and toggling
5. Control hunting / polarisation
6. AC side protection problems
7. WAMS system interactions

For further discussion on specific type of interaction please contact: info@hvdccentre.com

Q22: ***How much reliable is PSSE to RSCAD conversion tool? When I use PSSE to RSCAD conversion tool, is it possible to create the subsystems of some random buses of my choice in each subsystem?***

A22: The PSSE to RSCAD conversion is being widely used and have been tested in several projects. But this conversion requires validation as not all the data required for EMT simulation would be available in PSSE.

When running the PSSE to RSCAD conversion, the user can choose the method of hardware allocation based on the type of simulation hardware they have available (e.g. the quantity of licensed NovaCor cores or PB5 processor cards). The program will then create a subsystem split at an eligible location if necessary. The user can also choose only a certain number of buses to be included in the conversion, so multiple subsystems could be created by doing multiple conversions this way.

Q23: ***Are there any options for DigSilent PowerFactory conversion to RSCAD?***

A23: Currently there no functionality/tool to convert DIGISILENT model to RSCAD model. RTDS is currently working on a tool for this conversion that might be available in early 2021.
Also, there is a possibility of three step conversion (i.e.) DIGISILENT to PSSE and then to RSCAD.

Q24: ***Can offline model considers Converter losses and harmonics as well? How it is evaluated?***

A24: Yes, offline tools like PSCAD can be used to model converter loss and harmonic studies. Converter loses are verified against theoretical calculation while harmonics are analysed by using FFT tools.

Q25: ***Please explain more detail in Travelling wave protection or can you mail it***

A25: There are many papers on TW protection. The SEL TW protection paper mentioned in the presentation is in this link - https://selinc.com/featured-stories/pnm/

Q26: Amplifier used for PHIL (Power Hardware in Loop) testing

A26: RTDS has worked with Spitzenberger and Spies (SPS) and Egston to develop digital links to their amplifiers, which can simplify the interface. Also, Triphase is another popular manufacturer. Triphase was used in the example discussed of PHIL analysis at the University of Strathclydes' Power Network Demonstration Centre. The RTDS Simulator is "agnostic" to the device(s) connected as long as they have appropriate I/O capabilities, so theoretically, any four quadrant amplifier could be connected to the Simulator; there is no list of approved manufacturers (of course, creating a meaningful interface is another issue).

Q27: Can HIL be utilised to simulate stresses, especially MTDC, for testing HVDC Cable Systems up to 525 kV DC? The reason I enquire about this is because currently the DC cables meant for MTDC application are tested as per the norms of point-to-point. DC cables testing specification for MTDC does not exist, not even within CIGRE

A27: Yes, in principle it should be possible. Please contact kati@rtds.com and Benjamin.Marshall@sse.com for further information.

Interactive Discussions with Audience

1. ***Is 600 nodes per chassis or per core?***

A. A network of 600 nodes can be simulated on one NovaCor chassis by using two cores, which are each dedicated to a 300 node network solution. This 600 node network solution, though, is tightly coupled (no subsystem splitting required). As mentioned in Q1, not only the quantity of nodes, but also the complexity of the network (i.e. density of non-passive components) is important to consider. Also, the embedded node concept discussed in Q1 should be noted.

2. ***That's a chip with high clock frequency. What kind of chip is used in CPU of RTDS simulator?***

A. The RTDS Simulator's NovaCor uses the IBM P8 processor. We do not use an OS, bare metal, while running real time simulations so it is very efficient.

3. ***Where converter will be modelled in slide 27?***

A. The convertor of C-M is modelled in RTDS simulator that is physically located at the centre- the list on this slide is of other organisations with facility or facilities housing replica control and protection. Practically it's important to have the physical controllers present close to the RTDS environment- signal degradation and latency considerations- just as you would have in the physical facility itself.

4. ***What do you mean by Power Hardware in slide 34?***

A. PHIL is Power hardware in loop that is slightly different in application- you use the RTDS to inform devices such as triphase (four quadrant amplifier) to deliver a voltage/current disturbance, faults etc onto a physical network or equipment (power electronic converters or any test equipment that is under test) as such it is present at PNDC- these applications can also model reference to a wider system but are more hardware oriented approaches.

5. ***Integration of IBGs and other power electronic units like HVDC into power networks has been changing the physics of the system and deploying either EMT or RMS can't solve the corresponding challenges. Grid forming approaches could be deployed instead either under RMS for frequency stability or under EMT for fault analysis. Does it really matter which software is deployed (DIgSILENT Power Factory, or PSCAD)? What do you think? However, in case of online simulations, RTDS would be of help specially to integrate hardware-based power electronic units in the loop of simulation studies?***

A. Yes, the intrusion of power electronics devices has been changing the behaviour of the power grid. It is an engineering judgement on what type of tools must be used for a study. Where a problem is well defined and the models available equally well defined, and the simulation requirements therefore limited, it may be the case that offline simulation tools are sufficient. In other cases, for example control interaction, protection performance and their solutions, you are combining unknowns- IP protected control and protection structure and code within one or many devices, which will drive RTDS-HiL consideration. The advantage of RTDS-HiL is that black-boxed controls need not be "opened up" or simplified; the complete control and protection structure is included within and may be considered across a sufficiently wide envelope of operating conditions rapidly to determine the potential for vulnerability and test solutions to it. Such RTS environments can then inform and validate offline models then used for the screening of these particular risks, and construction of RSCAD models informing wider interactions. RSCAD models in principle may be as detailed and granular as the actual control structure of the actual power electronic device, provided processing capability within the RTS hardware is dedicated to this purpose for the intended simulations.

Offline programs such as DigSilent, Power Factory and PSCAD ATP etc. are only fully effective in de-risking if you know what exactly you are using them *for* and that the models being used in that package are sufficiently complete and accurate for that purpose. This was relatively straightforward and well covered by technical codes in a conventional synchronous generator environment but is less so in a convertor dominated one. Use of offline simulation tools for power system analysis cannot handle the resulting unknowns well, as the models flattened to operate within the simulation environment may now lack the critical aspects of the original device that lead to network vulnerability- or conversely the network may not be set up for the most critical operating condition that affects the unknown control structure within the model. The vendor will not see the detail of the network and the network owner will not see the detail of the control leading to an information gap.

RTDS-HiL by bridging the gap between the two provides a key additional tool to support focussing the off-line modelling environment. It's not a question of either or, but rather how they complement.

EMT simulations are required to have realistic representation of the control dynamics of the power electronic based schemes, especially PLL as Ben has mentioned. Kati listed references at the end of her presentation that speak to the need for EMT simulation over RMS.

To provide the example of digital protection behaviour- here at least two unknowns are present- how the convertors respond to fault conditions, and how the algorithms within a digital protection interpret the fault condition and its clearance to inform a protection relay operation.

During a fault, a convertor will via its PLL based tracking of system voltage and angle seeks to provide fast fault current injection from the power electronic device; fault behaviour varies across phase and scale of fault current injection, the speed of that response, the quality of its tracking of its response to the systems voltage and angle- and may be very different for different retained voltage levels during faults, or for different types of faults. All of these aspects will be defined by proprietary control and internal device protection structures which are black boxed. When the fault is cleared – the convertor's black-boxed control and protection will similarly respond to track the recovering voltage and the jump in system voltage angle based on again unique vendor solutions and project specific tuning- as mentioned in the presentation the fault current injections tend to continue after the fault clearance.

Within a digital protection the protection algorithm is analysing the voltage, current and angles being measured and against programmed filtering techniques, internal protective responses and other criteria are determining relay operation, all of which again are proprietary and black boxed and additional to the settings for example of maximum current and protection zones that are visible and set in liaison with network owners. During a fault these relays are configured to expect certain behaviours in fault current based on what is expected from conventional synchronous dominated environments, rather than the above convertor behaviours which a protection vendor has limited insight into.

As such digital protection relays can potentially respond differently to expectation and intention during the initial behaviour of convertors during a fault or the extent of fault current provided across the fault, or the scale of fault current occurring for faults at different locations or with different fault resistances, or the time and type of fault clearance occurring on the network. The latter effect is defined by protections; when and where a fault is cleared on the network, and as such there is a feedback loop between the protection back-up protection behaviour, the reach of protection zones being specified and the convertor behaviours. To verify a protection, a complete representation of the protection system and the convertor behaviour is needed to do this- so an RTDS-HiL environment is invaluable in achieving this form of verification.

6. ***Would you have some examples for Replica of windfarm?***

A. Most wind turbine manufacturers use a generic process of compliance certification whereby types of turbines are tested in RTDS environment vendors will use replica controls of single turbine, or which are able to replicate an array of turbines to verify overall performance and resilience.

There are a number of RTDS customers doing work with replicas of wind farms. In addition, within the RSCAD library, we have some sample cases for different wind turbine configurations available in RSCAD.

At the HVDC centre we have identified that there is a need to combine these principles with an ability to combine with the other "unknowns" within increasingly complex offshore wind designs (in particular) driving these considerations. For example, a large HVAC design will have wind turbines, FACTs devices, variable operating configurations, filter and reactor selections and overarching control and protection across these devices supporting normal function- with future HVDC connected wind farms having again an operating concept defined by several devices.

The Centre would seek to define the requirements and consider the performance of composite systems at different stages in their project lifecycle; including validating the detailed design concept and a composite system test ahead of commissioning and supporting validation in service behaviour. We believe at the Centre that developing the concept of Reconfigurable Replica hardware where different power electronic device firmware from a vendor may be uploaded into a common hardware foundation across different devices allowing hardware to be pooled and used flexibly across multiple projects. If these concepts are confirmed to be feasible in initial work, the next stage would be to dry run for new project case studies.

7. ***Actually, I would propose we stay in "grid forming" all the time .... but there are still some mode changes ... just not grid-forming to grid-following ... For sure the protection strategy may need to also change radically between blackstart/island and "normal" as well, as you say?***

A. The issue of grid forming mode is that the concept works by defining the frequency and voltage profile of the synchronised island during its initial phase of energisation. When another Grid forming control connect it competes to do the same. All initial black start projects are limited in rating in active power capabilities to support load pick-up and reactive power to regulate the voltage of the network across its energisation and load pick-up. This unavoidably limits a grid forming convertor to that scale. Note we are here describing grid forming convertors controls used today which represent a "stiff" voltage source with no inertia rather than future GB Grid forming "Virtual Synchronous Machine" controls which have additional capabilities to support the islanded network with inertia and overload capability in reactive power support which behave more closely to synchronous generation in these situations. More details on the latter control may be found at the link below:

At the point where the re-energised power island needs to either synchronise with another power island, or combine with synchronous generation or other convertors operating in todays' form of grid forming control, no one generator/ interconnector is capable of defining the frequency and voltage profile in the power island. As each generator/ interconnector tries to do this, it risks being overloaded and tripping, or de-loading itself to support inter-area oscillation that results, or interacting with other fast acting controls- all risking the destabilising and collapse of the power island. It is therefore necessary for initial grid forming control to transition to grid referencing forms of control at these later stages of black start. The transition of mode and criteria for doing so are key areas of study. RTDS is particularly effective in the simulation of such control and protection transitions.

The protection also sees very different fault currents during a re-energisation, even with conventional resources, but especially in the context of an energisation started by a convertor. Again, the RTDS environment is capable of testing the transitions in protection systems. These areas of analysis are ones we are planning to consider in more detail within the distributed re-start project.

8. *In the developer lead environment in the UK, these large HVDC projects cost significant sums of money and in this current competitive environment it is very difficult to justify the cost of a set replica panels, which I am led to believe are not seen by Ofgem as allowable costs under the "cap and floor" projects. How do you see this developing in the future?*

A. A requirement of any new connection upon the transmission system is to remain compliant to the performance requirements of the network across the lifetime of a project. Whilst this has in the past required some limited demonstration in place within an EMT environment, this has not in the past extended beyond RMS modelling to extensive EMT model exchange and model verification in that domain, nor has the tracking of performance during the commissioning and compliance phase extended discretely beyond that.

This position is now subject to change In mid-March this year, National Grid ESO raised a modification proposal GC0141: Compliance and Modelling Processes, and was given the highest priority to proceed by the Grid Code panel, being directly related to Ofgem's recommendations following the 9th August 2019 low frequency event. See link: https://www.nationalgrideso.com/industry-information/codes/grid-code/modifications/gc0141-compliance-processes-and-modelling. From the Centres review of this proposal, This new modifications is founded on some key principles-

- Compliance needs to be supported by industry standard model exchange in the EMT domain, and where relevant other models and or hardware supporting real-time simulation (for example protection verification)
- That all models and other material provided needs to be complete, suitable and verified for the purposes for which they are used *{this is where off-line modelling may be challenged in fully meeting all requirements- and would need to be complimented with other real-time analysis using physical replica or a more complete RSCAD model if that is maintainable by the vendor}*
- Compliance needs to be conducted across the range of operating conditions of the onshore network that might be reasonably foreseen, and across the range of operating conditions of the Users connection assets/ offshore network. *{this is where Real-time platforms excel- platforms such as PSCAD are slower and more resource consuming cumbersome to drive wide ranging simulation running such as this}*
- There needs to be a way of avoiding IP inhibiting complete and open data exchange. Control settings that get changed and their impact need to be visible within those models and kept current across the projects life. {in a replica environment this is not an issue-for off line EMT modelling, the vendors would need to review how they could achieve this, and whether it's cost beneficial to resourcing}
- Compliance process does not stop at point of Final Operational Notification. New requirements for re-demonstrating every 5 years and in-service verification of performance *{as I mentioned on the telecon- if you cannot track changes- you will find yourself in limited operation until you can- that's a big deal}*
- New role of an Independent Engineer who must verify all compliance and modelling information ahead of delivery to the ESO. *{it is expected that an independent engineer will want to see clear and unambiguous proof of the above- and it is harder to get clearer than RTDS-Hi; afterall that's how FAT requirements demonstrating compliance to a more reduced scope happen today}*
- New provisions for legacy generators to provide data- including that supporting SubSynchronous Torsional Interaction (SSTI).

Vendors and developers will of course need to work out between them how best to meet these new requirements but the obvious approach will be in a combination of EMT offline modelling and RTDS-HiL validation work. The exact combinations of the two may vary by vendor and project, but we'd see a role for RTDS in meeting these changes across the majority of projects where control and protection are complex, not easily or completely translated into offline models nor their risks easily summarised into a limited array of operating conditions, nor these control and protection settings and functions easily maintained across iterations of in service tuning and modification.

As this presentation notes, the GB network is not unique in these challenges and increasingly projects are being complemented by the replica control and protection within an RTDS-HiL environment which can maintain a capability to analyse and verify performance. The question is increasingly can you can afford not to have a replica? The cost of a replica may be included within a project as the cost efficient approach to compliance de-risking, and has a range of other benefits beyond its analytical and modelling benefit.

9. ***Regarding RTDS one should not only consider the cost of purchasing the replica's, but also the operating cost of an RT-facility: building, people.***

A. In GB, the National HVDC centre exists as a pooled resource to the TOs and ESO which may support de-risking HVDC and other FACTS devices across GB integration. This approach avoids individual TOs and ESO each having separate facilities with separate associated personnel and hardware, and promotes the whole system integrations necessary. Another key consideration is that convertor and other models and hardware require strict IP protections in place with vendors, and equally network models contain confidential data which cannot be shared outside of network owners and operators via strict arrangements for confidentiality. A central facility is therefore an optimal approach to address such risks.
Key to any RTDS facility or facilities being considered is what do you want them to *do*? The scope of analysis will define the optimal strategies. Some facilities are purely test oriented, others analysis focused. Others like ourselves cover the whole scope of integration (Eg, RTE facilities in Lyon, France)
Please feel free to contact us further if you would like to further understand our experience and the thinking behind it at Info@HVDCcentre.com.

10. ***Just a general comment. To get that "completeness" to manage the risks, you need to apply quite a lot of thought to generating the test cases and running thousands (10s of thousands) of cases exploring all the possible combinations of operating-point transition. So while real-time simulation is FAST, you can still easily end up with 100s of hours of simulations, and at least as much again of post-analysis to try and search the results for what are problems, and what is "acceptable".***

A. Quite true even though the RTDS is FAST it takes 100s of hours to build the model, interface them with the hardware and test 1000s of test cases. This is why we have highlighted in previous webinars techniques that may be used to hone in on the conditions around which vulnerabilities may exist- RTDS analysis would not, we would suggest, be used to scan literally all conceivable conditions (unless this is considered an unavoidable requirement), rather sensitivities across the ranges of operating points where exposure to risk have been identified across small signal and large signal techniques of analysis which may be replicated in RTDS, and to validate real-world performance in that environment.

11. ***Another general comment to real-time simulations taking away all and any doubts regarding modelling accuracy: there are still many differences with the actual power system: inaccuracies in non-linearity and frequency dependency of network components, selected study cases, load behaviour, the model of the HVDC converter hardware, wind turbine etc. and even synchronous generator models (standard IEEE models are not accurate for non-fundamental frequency studies). Absolute accuracy is impossible, there will always be remaining risk, and the reduced risk must be evaluated against the cost.***

A. Of course, the RTDS environment can only be as good as the data that supports it- and where this is not hardware but models the question should naturally include the representative nature of those network and other models included in the simulation. There are however processes for validating such models across all platforms which apply just as much to RTDS as to other platforms; i.e. it must be possible to replicate real world in-service behaviour, and real in-service phenomena when replicating the in-service experience. It must also be able to reflect future conditions and behaviours which relate to physical behaviour rather than any numerical error. We have experience at the centre validating in service behaviour and in the using and construction of such models informed from detailed TO data. Whilst absolute accuracy is never achievable, alignment with real-world behaviour and trend is; and provides the necessary standard required for this work. These are not new considerations- any FAT work requires such verification today.

12. *Have to tried using PSS/E and EMTP together as a co-simulation tool?*

A. We have not co-simulated PSSE and EMTP RV. We have done co-simulation in PSCAD with to different part of network. There are also options to do Co-simulation with RTDS and PSS/E please refer to question 12.

13. *The main benefit of having a Real-time simulation facility is related to use replicas of real controllers for performing of the hardware in the loop (HIL) studies. However, such equipment are very expensive to buy and also them demand some specialized knowledge of the C&P programming framework used by the different suppliers for allowing of customization and parameterization, e.g. So, how the National HVDC Centre is intending to face this challenge for effect of the several HVDC projects that are being planned for the next years? Is the National HVDC Centre evaluating some kind of soft emulation (conceptual models on RTDS environment) for a set of the controllers to be represented? ….Plans to accommodate C and P cubicles..?*

A. Yes, the HVDC Control and protection equipment are expensive and require specialised skills to acquire, maintain and use them. HVDC Centre has plans to expand along with the expanding portfolio of HVDC projects to support in GB. The HVDC Centre has applied planning permission to increase its hosting capability. The HVDC centre is a partnership across all the Transmission owners in GB to de-risk the integration of HVDC projects in GB. It is funded by OFGEM through National innovation competition funding. This model allows simulation expertise and infrastructure to be concentrated, minimising the costs of these activities. Further active engagement with vendors surrounding the development of the concept of reconfigurable replicas to allow hardware to be pooled across projects, together with the advice the Centre provides to allow an appropriate class of replica hardware to support a projects needs all act to minimise the overall costs of delivering the de-risking activities of the centre within RTDS-HiL.

As we note RSCAD models have the capability also to exceed the levels of detail typically made available in PSCAD. The National HVDC centre has already funded a project to develop a generic representation of VSC HVDC converter (in RSCAD) that could be modified and tuned to represent a specific VSC HVDC converter depending on the study requirement. Also, it is possible to acquire exact representation of converter models in RSCAD from manufacture for specific project when required.

PS: This is an area where much work is being done. Such models can already be created for the RTDS Simulator as you know, but there is ongoing effort to have the manufacturers provide representative models as part of the project. In China for example the owners of HVDC schemes have had manufacturers provide detailed control models for the RTDS Simulator

14. *In fact one of the main challenge in my opinion is to keep the reliability of C&P replicas during the years.*

A. Maintaining Control and Protection cubicles are challenging. This maintenance challenge of the replica can be handled by aligning the replica maintenance with site control and protection cubicle. Also, it is expected that the issues in replica cubicle would be same as that in site so this would be beneficial to pass the experience to site or vice versa.

15. ***(ONS - Brazil) On the ONS simulation facility, we have to face with a proper representation for a large transmission/generation network system. It is a hard task since we have to consider several dispatch scenarios, dynamic loads and the different network configurations. We would like to hear from the National HVDC Centre about the reducing do you impose to network representation so as not to overload the RTS hardware demand and on the other hand without compromising the proper simulated system response. In other words, what type of electrical/dynamic equivalents do the National HVDC Centre normally adopts: Frequency Dependent Network (FDNE), Modal analysis dynamic aggregation, Coherency based dynamic aggregation, e.g.? What off-line tools do the National HVDC Centre uses for supporting of such a synthesis? What about the automation do you use for changing of network configuration during analysis?***

    At the HVDC centre we have a detailed model of north of Scotland. This model has a frequency dependent model for transmission lines, the generators are modelled with dynamic data were ever available and the equivalent are represented as voltage sources. The offline tools used at HVDC Centre to develop RSCAD models include PSSE, DIGSILENT and PSCAD. We mostly use RSCAD scripting facility toto automate the tests, capture data and simulate various scenarios in the network. Also, we use python scripts to automate simulation in PSSE. For PSCAD we use multi run tool for running multiple cases.

16. ***(ONS - Brazil) Currently some Real-time simulation facilities in Europe and North America are developing an integrated data communication infrastructure to manage simulations by using hardware resources (RTS equipment and C&P replicas) geographically distributed. Such a cooperative way for doing analysis intends not only to reduce the costs related to the expansion of individual labs and sharing of expertise but also it can allow precise evaluation of C&P logic without compromising data covered by intellectual property clauses imposed by the suppliers. Currently, one of our activities is to evaluate which compromises are imposed by the data communication latency and impairments for effect of co-simulation our resources with others simulation facilities here in Rio de Janeiro. So, is the National HVDC Centre involved in some way on such European initiative? What is the National HVDC Centre opinion about that?***

A. The National HVDC Centre is not currently involved with any European initiative for co-simulation. RTE however is one of the major RTS facility that that we are in close collaboration. The HVDC Centre would be interested in how within a distributed RTDS environment cyber security, model confidentiality, signal degradation and signal latency challenges are addressed.

   PS: There are some research work done for co-simulation with geographically simulated in different location. There would be expected problems of signal latency and data synchronisation.

17. ***I am modelling a quite large-scale converter-based system in RTDS with LCC-HVDCs, VSC-HVDCs, DFIG and PMSG –based wind farm. During the system operates at low inertia conditions, there is some oscillation found out in the frequency response (0.8-1.5 Hz). However, we cannot find out which component exactly caused that oscillation in this EMT simulation of RTDS unlike small signal stability. Do you have any comment or suggestion to deal with this issue?***

A. Please contact RTDS support.

18. ***Is there any availability of inertia control model through battery storages in Offshore and onshore wind farm to support ancillary services.***

    RSCAD does not contain a pre-built control model or sample case for this, but you could absolutely simulate inertial control for a battery (or other power electronics-based resources) by developing your own controller using the controls components library or importing a control model from MATLAB/Simulink, for example. I believe some real-time simulation was done in this vein as part of the MIGRATE project out of the EU'S Horizon 2020 programme (information available here: https://www.h2020-migrate.eu/downloads.html).

19. ***What has been your experience with obtaining manufacturer models of wind and solar PV generation for use in RTDS simulations? Are the manufacturers generally willing to provide such a model in black-box format? We have many such models in PSCAD but it limits the accuracy using generic representations.***

A. We have used generic detailed wind farm models for our projects. We are in the process of obtaining manufacture specific wind farm model for our upcoming projects. We have not yet had any model for PV generation till now. But we have used generic PV models for research and innovation project that we have engaged till date.