Real-time Multi-rate Co-Simulation for Power System Studies

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Taken from] [1]

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Project Aims

- The intention is to design and configure an optimal testing environment for networks with high penetration on converter controlled and connected devices
- The simulation process will be extended by simulating an increasing number of converters and control schemes taking the simulation to the next level by exploring the limits and scalability of such a scheme.
- Capitalizing on the knowledge and data collected from the creation, evaluation and improvement of this simulation approach:

    - Constraints of computational time and power and mathematical model complexity can be surpassed.
    - Interactions of power systems with control and protection schemes can be tested and evaluated
    - Real-time Controller and Power Hardware-In-the-Loop testing boundaries can be pushed further.
    - Novel concepts safely explored (More electric aircrafts and ships, HVDC multiple interconnected converters, hybrid electric vehicles, future power grids)

Introduction

University of Strathclyde Engineering

CAUSES

- Increased complexity of power networks
- Large scale integration of intermittent energy resources
- Proliferation of power electronics
- Converter connected devices
- Behaviour dependent on the mix, topology and resulting system dynamics

EFFECTS

- Accurate design, analysis, simulation an extremely complex procedure
- High demands of computational time and power

SOLUTION

- Real-time simulation
- Multi-rate, co-simulation approach
- RT Digital Simulators paired with RCP units

Overview of Simulation Techniques

Simulation Analysis

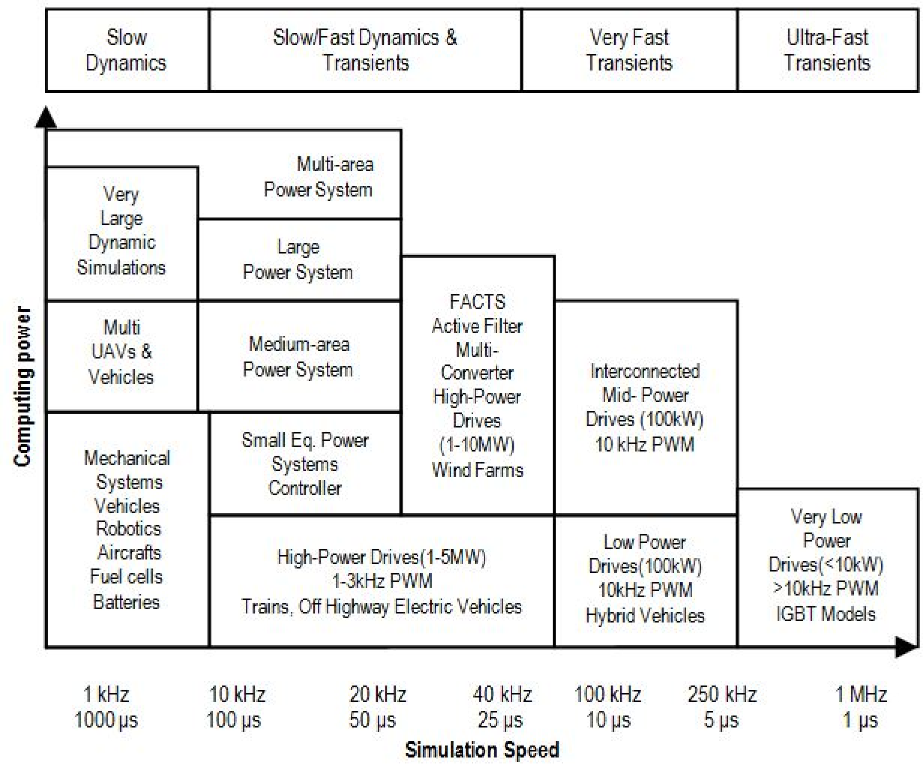
Simulation is a crucial element in the design and development of power generation and transmission systems. Simulation analysis is conducted to verify the system’s stability and response over time under different scenarios.

Offline Simulation

- Computing time shorter than fixed time step
- Computing time longer than fixed time-step
- Idle time used for calculations of next time-step

Online Simulation

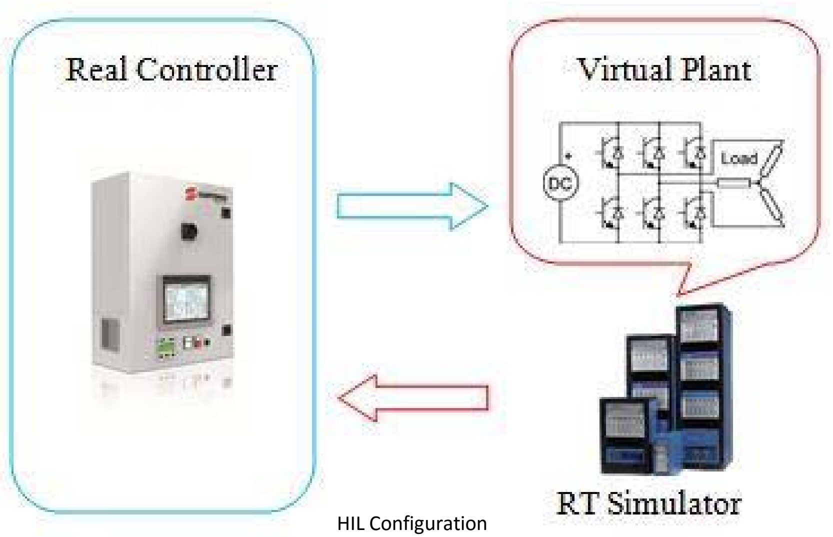
- Computing time in sync with a fixed time-step
- Faster to include I/O to external devices



Computing Power and Simulation Speed requirements. Taken from] [2]

Overview of Simulation Techniques (1)

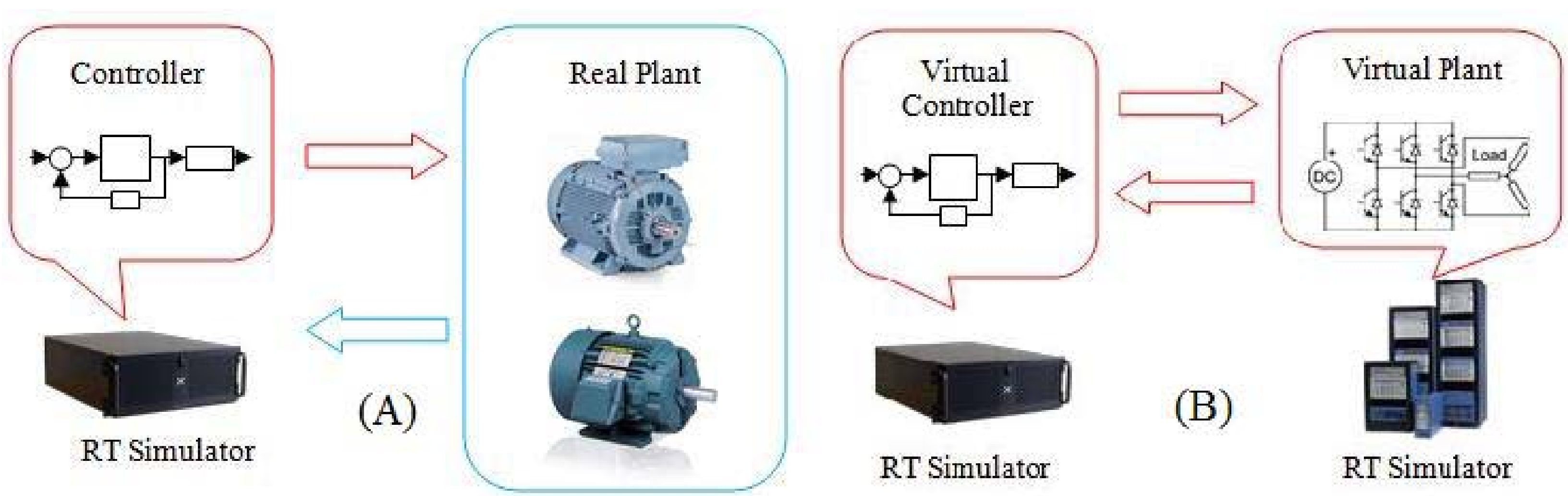
Hardware-In-the-Loop testing (HIL): In this type of simulation a physical controller is connected with a real-time simulator where the model of a virtual plant is implemented. This configuration allows for early testing of controllers when an actual physical hardware is not available. As such not only is a more cost effective procedure than connecting to a physical system it is also a more stable environment that favours repeatability of results and testing under extreme conditions mostly unavailable on a real system.



HIL Configuration

Overview of Simulation Techniques (2)

Rapid Control Prototyping (RCP): The controller of the system is modelled on a real time simulator connected to an actual power plant. This configuration offers the advantage of very flexible development of the controller. It is faster and easier to implement and modify same as to debug. RCP can be used in conjunction with HIL testing, effectively taking the actual hardware out of the equation

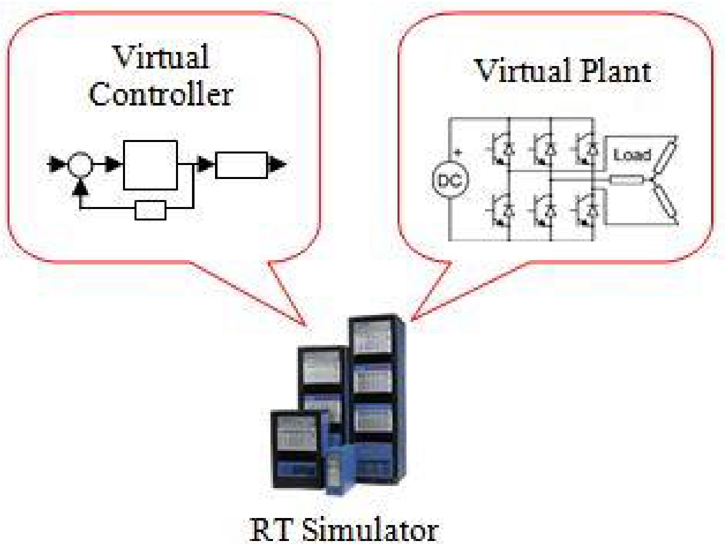


RCP Configuration

RCP - HIL Configuration

Overview of Simulation Techniques (3)

Software-In-the-Loop testing (SIL): In this configuration both the power plant and the controller are realised on a very powerful real-time simulator. The advantage of this technique is that the signals do not need to be communicated through inputs and outputs thus preserving the validity and integrity of the data. Finally SIL can be used for simulations faster or slower than real-time, enabling statistical testing and typically faster simulation time than in conventional computers



SIL Configuration

Relevant Work

Preserving the accuracy in multi-rate

[22] Partition of the system according to different time responses based on the behaviour of Eigen values.

The accuracy of the simulation is maintained by an error prediction algorithm and by approximating the slower solution components.

[23] Pre-calculation technique of all the possible states of converter switches in a HVDC system.

The corresponding state of every time-step is then solved in conjunction with the rest of the system.

[24] Three different interpolation algorithms for synchronization.

Two using fixed time-step and one with variable time-step.

None can correct the error in the time-step it is happening.

Ensures that next time-step will not start with the wrong previous values.

[25] Compares the performance of solving algorithms for real-time simulation

Variable step solver and an interpolation technique results in extreme computational burden

Proposes double-Step interpolation for more accurate results

Relevant Work

Hardware & Communication

[26] Two identical Digital Super-Computer Simulators make use of TCP/IP signals for Communication protocol introduces data delays and losses. Cannot be implemented without a data loss estimation algorithm that pushes the boundaries of computation burden for the selected architecture.

[30] Modelling All-Electric Ship claims internet communication is not an efficient medium. Proposes a digital interface between two Digital Super-Computer simulators through FPGAs creating a high-speed, low-latency digital interface.

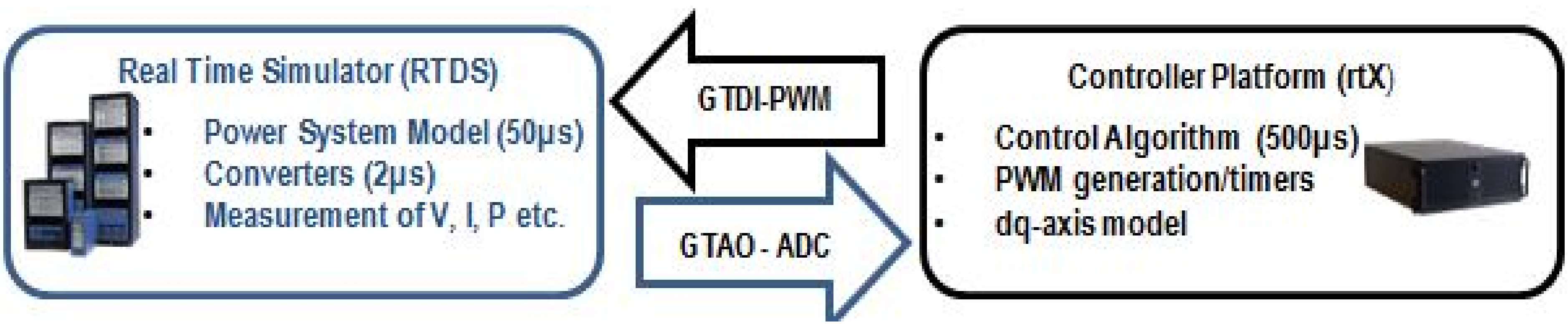
[33] A Digital Super-Computer is used in conjunction with a DSP card. They communicate through ADC and DAC I/O ports. Works really well for moderately complex power system models. Testing is still needed for more complex systems incorporating a large number of converters.

[29] Geographically remote coupling of a Digital Super-Computer and a RCP unit for thermo-electric simulation. The communication is managed through TCP/IP and UDP as well as digital I/O ports. The latency introduced is mitigated through a custom communication interface.

Real-time Multi-rate Co-simulation

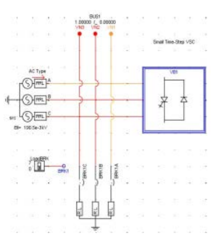
The importance of numerically accurate solutions is made apparent by taking into account the various shortcomings and considering them in context with the very high precision demands of the power electronic converter simulations

The small time-step, high fidelity representation of the converter devices and the large time-step model of the grid, is carried out on RTDS Technologies, RTDS. The controller prototyping, including the converter switching strategy is implemented on ADI's rtX.

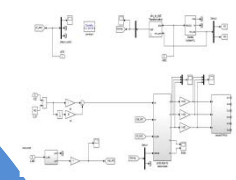


High Level Configuration of connection

Simulation Architecture

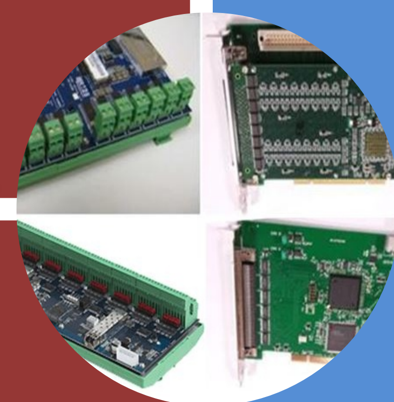


Measurements of Voltage (V), Current (I), Power (P) gathered in real-time, transmitted to the rtX by the GT Analogue Output (GTAO) card

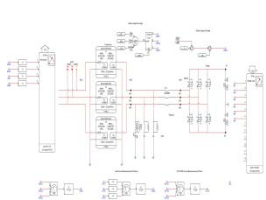


Signals received by the Analogue to Digital Converter (ADC) input card of the rtX. dq and PWM algorithms decide appropriately based on id, iq and udc loops

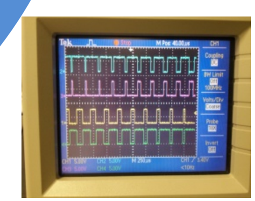
RTDS
The mechanical and electrical part of the system simulated at 50μs and 2.5μs time-step respectfully.



rtX
The control part of the system simulated at 500μs time-step.



Received by the GT Digital Input (GTDI) card of the RTDS, effectively closing the control loop of the simulation.

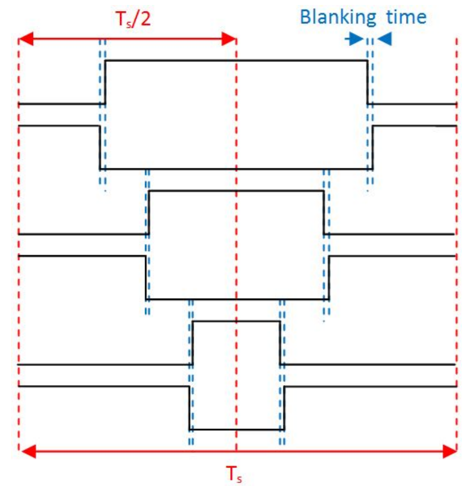


Converter gate drive pulses will be transmitted from the Digital Pulse Generation Analysis (DPGA) output card of the rtX.

Challenges – Signal Conditioning

Blanking time and pulses synchronisation

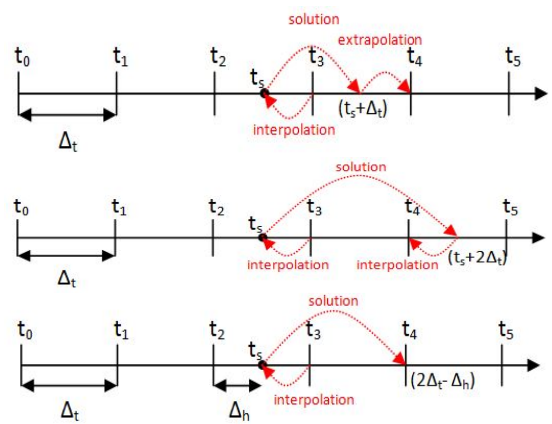
Essential for the accurate driving of the signals through the hardware input and outputs. It should be around 2% of the total 100% of the time of one time-step, distributed before and after the rising and falling edge of the pulse respectively



Pulse blank time and synchronisation

Interpolation & Extrapolation

If the option of reducing the time-step of the simulation to account for inter-time-step events is not available, these corrective measures are essential for the accurate, synchronised operation of the proposed real-time test-bed architecture



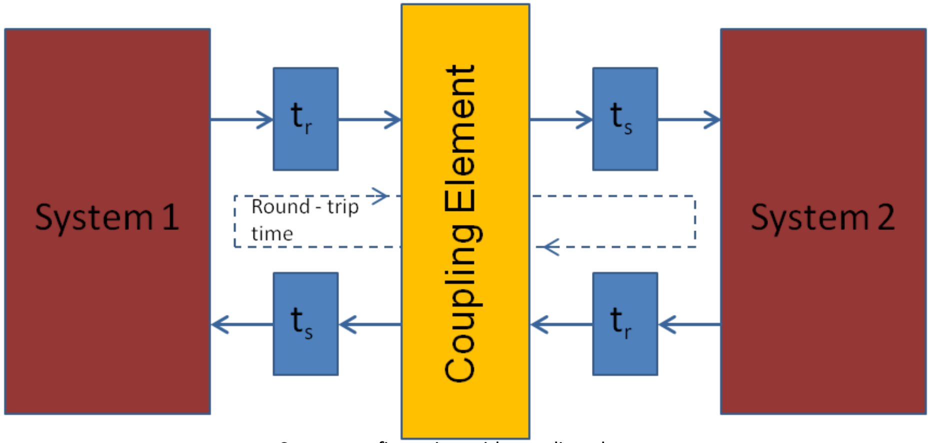
Interpolation & Extrapolation Algorithms

Challenges – Synchronisation

Different operating conditions of the different components prevent the precise determination of chronological order. Additionally some non-transparent components make the prediction of when a condition will occur difficult and only by I/O observation can a resolution be reached.

A synchronisation via the exchange of data is imperative to establish the interactions of the subsystems. Additionally the subsystems should also be synchronised to global clock time.

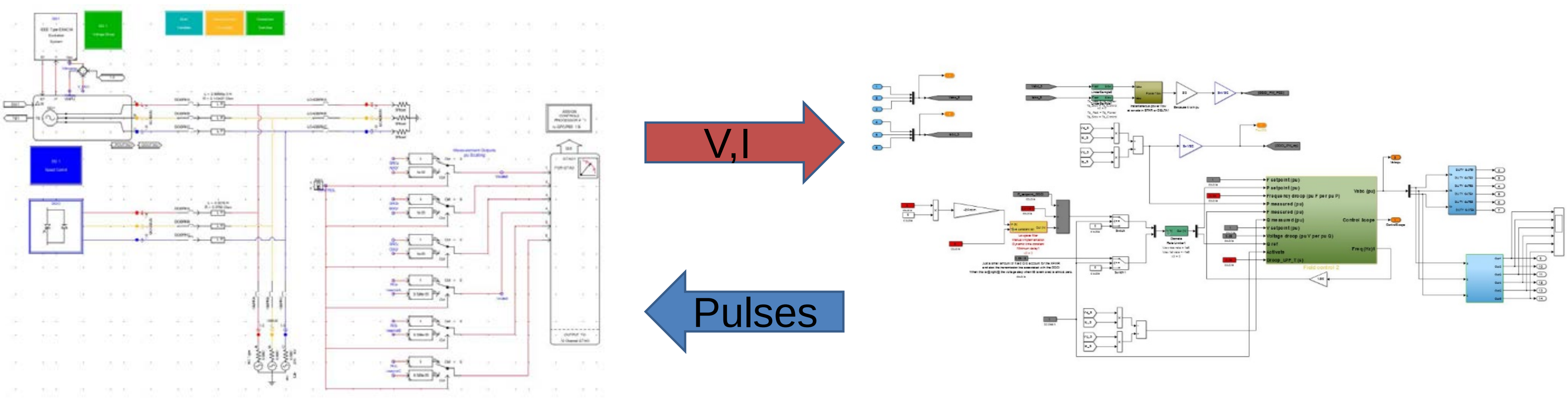
This is achieved via a coupling element that can handle the time delays as well as dead-times



System configuration with coupling element

Current - Future Work

Aggregated simplified model of the National Grid developed in Matlab Simulink, looks into inertia-less virtual synchronous machines for stabilisation of networks with large converter penetration [11].



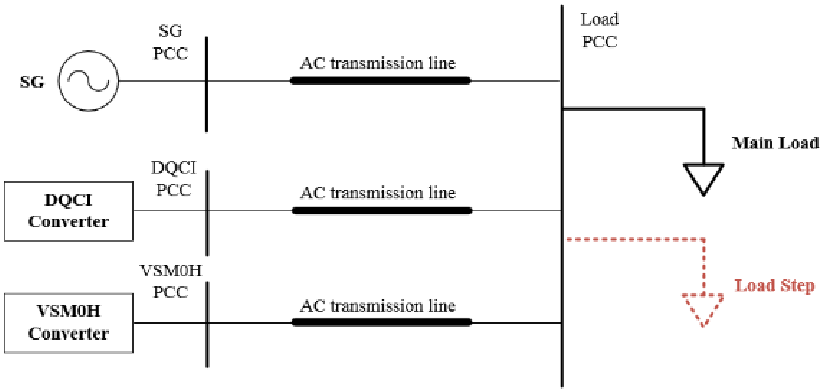
Reduced overall system inertia is considered to be one of the main issues that could compromise system stability under high penetration levels of converter-interfaced generation and HVDC links

Future Work challenges

The previously discussed challenges are still relevant and will become more apparent in this co-simulation because of the high level of complexity of the system and its respective control.

Signal Conditioning & Synchronisation:

- Pulse synchronisation for additional converters
- Computationally heavy model will demand recalculation of time-step requirements and interpolation algorithms



Power Network Configuration. Taken from [9]

Added challenge:

A point of interest is how to start the simulation in real-time as it would effectively look like a system black-start. The order of the generation going on line and the different penetration levels of converters will have to be taken into account.

Questions - References

Q&A Session

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