HVDC system and laboratory analysis

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Introduction

• In the late 19th century, Thomas Edison and Nikola Tesla were involved in a "battle" now known as the War of the Currents.

• During the early years of electricity, DC transmission was the standard.

• Today, the transmission is predominantly AC. The main reason is that AC current is easily converted to higher or lower levels.

• However, the transmission of large amounts of energy over long distance is more convenient in DC.
Advantages:

• Overall power losses are lower in DC than AC for long distances.
• Shunt reactive compensation is not needed in HVDC.
• AC/DC converters play an essential role in DC transmission.
• Converters provide full power flow control.
Multiterminal HVDC (MT-HVDC)

• A multi-terminal HVDC (MTDC) system consists of more than two converters connected through a DC network.

• Such a system can facilitate the large-scale integration of **renewable energy** and improve the **power market**.

• MT-HVDC systems have many components and complex control interactions.

• Extensive interoperability testing is essential to ensure safe and reliable operation under the wide range of possible operating conditions.
How to study a MT-HVDC?

• Testing on **full scale** systems is not really feasible.

• **Simulation** models give a full test coverage with a limited test fidelity.

• **Power testbeds** have a good fidelity but limited test coverage. They are a bit expensive and not very flexible

• **Hardware power-in-the-loop (HIL)** simulation offers a good balance between test coverage and fidelity.
Power testbed

A scaled experimental platform was developed in SINTEF Energy Research with the following:

- Four 60 kVA VSCs
- The wind farm is emulated using a 55 kVA induction motor/generator-set.
- The strong grids are represented by the laboratory 400 V supply.
- An independent grid is emulated using a 17 kVA synchronous generator.
- The DC line emulator consists of variable series resistors to vary the length of the emulated cable.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>MTDC system</th>
<th>Lab set up</th>
<th>Scale factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power</td>
<td>1200 MVA</td>
<td>60 kVA</td>
<td>1:20000</td>
</tr>
<tr>
<td>DC voltage</td>
<td>±320 kV</td>
<td>640 V</td>
<td>1:1000</td>
</tr>
<tr>
<td>AC voltage</td>
<td>400 kV</td>
<td>400 V</td>
<td>1:1000</td>
</tr>
</tbody>
</table>
Disconnection of two terminals using a decentralised droop control. System response is stable and with no overshoot against these severe events.
HIL approach

200 kVA High-Bandwidth Grid Emulator

Real time wind farm model

SINTEF Energy Research has three different MMCs

grid emulator 200 kVA

MMC18
60 kVA

MMC12
60 kVA

2L VSC
60 kVA

700 V dc

400 V ac

400 V ac

Real Time Simulator

Main grid

400 V ac

Real Time Simulator

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400 V ac
MMC technology

- MMC is emerging topology for offshore wind substations due to its black start capabilities, low Total Harmonic Distortion (THD) and high efficiency.
- The MMC uses a stack of identical modules.
- Each module creates one level. The multiple voltage steps make the MMC being capable of producing very small harmonic content in the output voltage.
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SINTEF Energy Research has designed and built three different MMCs:

- MMC unit with half bridge cells with 18 cells per arm
- MMC unit with full bridge cells with 12 cells per arm
- MMC unit with half bridge cells with 6 cells per arm
MMC technology

Main components in the MMCs:

The power cell unit

Modules

Arm
MMC technology

MMC Assembling stages

Some facts of the MMCs:

- 42 modules
- 144 power cell boards
- 1764 capacitors
Figure shows a test of 18 level halfbridge converter
• Open loop, no current control
• 100% modulation
• Single phase RL load
Waveforms equal to simulations
Three MMC were commissioned on June 2017

Ch1: Arm current, Ch2, Ch3: Arm voltages, Ch4: Phase current.
Wind Farm Emulator

Power Hardware in the Loop implementation combining the real time simulator and the grid emulator

- Flexibility in the model simulated
- Possibility to reproduce faster dynamics
Final Remarks

- For long-distance bulk-power delivery, **HVDC** transmission is more attractive than HVAC transmission.
- MT-HVDC systems have many components, and complex control interactions. Testing on full scale systems is not really feasible in M-HVDC.
- Simulation models gives a full test coverage with a limited test fidelity.
- Power testbeds have a good fidelity but they are expensive and very little flexible.
- Hardware power-in-the-loop simulation offers a good balance between low testbed cost, good test fidelity, and excellent test coverage.
Thanks

Picture by John Olav Tande

Thanks to all the sponsors