SCALE MODEL OF MODULAR MULTILEVEL CONVERTER

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MMC topology

- Halfbridge or fullbridge cells
- Many low voltage cells: (~300 per arm)
- Energy for several periods in cell capacitors
- Good AC voltage control. Small voltage steps.
- Redundancy
Why lab scale models?

- Many components, complex control.
  - Need for experience building.
- Testing on full scale systems not really feasible.
  - Potentially large consequences. Don't get access.
- Simulation models depends on model
  - Gives the answers you expect. Can miss unexpected aspects.
  - Assumptions and simplifications. May omit something important.
- Real converters contains most aspects.
  - Some adaptations and simplifications here too.

HVDC transmission link between France and Spain: HVDC Plus IGBT converter modules for 1000 MW. www.siemens.com/press".

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Choice of scale. Power level:

• Full scale: 1000 MW
  • Essentially unmanageable.

• Low power model:
  • Safe. Low cost. Ease of operation.
  • Can behave quite different from full scale reference
  • High series resistances and auxiliary losses give deviations from reference case.

• High power model:
  • Low scaling ratios. Moderate scaling effects, properties close to full-scale reference.
  • Expensive to build. Expensive to run. Difficult and expensive to reconfigure.
  • Safety issues. Large damage potential. Careful planning required.

• Tradeoff: 60 kVA
  • Fits existing laboratory infrastructure.
Scale: Voltage level, etc.

- Depends on power level.

- Three main ranges:
  - < 50V: Considered to be safe. Used for low power models, <1 kW.
  - < 1000V: Governed by low voltage safety regulations
  - > 1000V. Governed by high voltage safety regulations Used for high power models, > 1MW

- Standard supply voltages preferred. 230V AC, 400V AC, 690V AC.
  - 400V AC chosen. Nominal grid voltage in lab.

- Most other parameters determined by power and voltage scaling.
  - Base impedance, Inductance, Capacitance, Transformer ratio.

- Some remaining parameters:
  - Cell number, control system topology.
Series resistance

- Difficult to scale. ESR tend to increase at low power.
- Gives additional damping of oscillations.

Noratet 3LT series transformers
## Converter specifications

<table>
<thead>
<tr>
<th></th>
<th>Reference</th>
<th>18 Halfbridge</th>
<th>12 Fullbridge</th>
<th>6 Halfbridge</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Rated power</strong></td>
<td>1059 MVA</td>
<td>60 kVA</td>
<td>60 kVA</td>
<td>60 kVA</td>
</tr>
<tr>
<td><strong>Rated DC voltage</strong></td>
<td>640 kV DC</td>
<td>700V</td>
<td>700V</td>
<td>700V</td>
</tr>
<tr>
<td><strong>Rated AC voltage</strong></td>
<td>333 kV</td>
<td>400V</td>
<td>400V</td>
<td>400V</td>
</tr>
<tr>
<td><strong>Rated AC current</strong></td>
<td>1836 A</td>
<td>85 A</td>
<td>85 A</td>
<td>85 A</td>
</tr>
<tr>
<td><strong>Cells per arm</strong></td>
<td>400</td>
<td>18 Halfbridge</td>
<td>12 Fullbridge</td>
<td>6 Halfbridge</td>
</tr>
<tr>
<td><strong>Nominal cell voltage</strong></td>
<td>2 kV</td>
<td>50V</td>
<td>80V</td>
<td>160V</td>
</tr>
<tr>
<td><strong>Arm inductance</strong></td>
<td>50 mH</td>
<td>1.5 mH</td>
<td>1.5 mH</td>
<td>1.5 mH</td>
</tr>
<tr>
<td><strong>Cell capacitance</strong></td>
<td>10 mF</td>
<td>20 mF</td>
<td>15 mF</td>
<td>7.5 mF</td>
</tr>
<tr>
<td><strong>Number of halfbridges</strong></td>
<td>2400</td>
<td>108</td>
<td>144</td>
<td>36</td>
</tr>
</tbody>
</table>
Power cell board

- Common PCB for all variants
  - 50V, 80V 160V, variants
  - Two independent halfbridges,
  - Copper rails for half or fullbridge configuration.

- Low ESR design
  - Thick copper planes in board.
  - Multiple small, low ESR electrolytic capacitors.

- Power circuit domain functions.
  - Transistor drivers, protection and interlock circuits.
  - Generic control signal interface.
  - Voltage and temperature measurements
Power transistors

- Scaled cell voltage drop: 100mV
  - MOSFETS, not IGBTs
- 5x parallel MOSFETs
  - 50 and 80V variant: 150V, 5 mOhm => ESR: 1 mOhm
  - 160V variant: 250V, 15 mOhm => ESR 3 mOhm
  - MOSFETs types with enhanced body diodes required.
- Switching is fast:
  - Diode reverse recovery snapoff: 20 ns.
  - Little margin for overvoltage transients.
  - Board layout extremely critical.
- Short circuit protection
  - Monitors forward conduction voltage. Trips at 0.8V => 700A

Diode turn off. 5 mm unsymmetry. Ch1, Ch3: uds, Ch4, R1: Id
Control tasks

• Internal
  • Synchronisation of nodes.
  • Protection and state monitoring. Converter fault handling.
  • Cell voltage balancing (within an arm)
  • Arm voltage control (energy balance)
  • Circulating current control

• External
  • Phase current control
  • Active power control/DC voltage control.
  • Reactive power control/ AC voltage control
  • AC phase lock/ Frequency control/ Virtual inertia
  • Harmonic suppression, damping.
  • Grid fault handling, current limiting.
System structure

- Hierarchy:
  - Power cell board
  - Group control board
  - Converter control board
  - Central control unit

- Optical fiber link
  - 3.75 Gbit/s
  - Chain topology

- Operation modes
  - Normal operation.
  - Development mode. Low level control signals
    - Control algorithms on external unit: OPAL-RT
    - Programming in Matlab/Simulink
Control electronics

• **Group control board.**
  • Based on Xilinx Artix FPGA
  • Governs 3-4 power cell boards
  • Gathers measurements.
  • Distributes 24V supply to drivers.
  • Generates, distributes driver signals.

• **Converter control board.**
  • Designed as general purpose converter control board
  • Based on PicoZed7030 module.
  • Xilinx Zynq 7030 FPGA with ARM A9 processor.
  • 8x 40 MSPS AD converter allows oversampling.
  • Handles converter control and protection functions.
Power cell group module

- 19" subrack 6U height
  - Group control board
  - 3-4 power cell boards: 6 or 8 halfbridges, 4 fullbridges
- All connections at front.
- Power cell modules in front and back of cabinets
- Vertical boards: Convective airflow
  - No fans. Fans may be required in 6 level converter.
19" cabinet

- 18 level halfbridge converter.
- Half filled cabinet: One phase
  - Two phases back to back.
  - Three modules per arm,
  - Two arms per phase.
- Large amount of capacitors.
  - 648 capacitor cans for 18 cell converter.
Complete 12 level fullbridge converter

- Cabinet 1:
  - Switchgear,
  - Arm inductors,
  - Control electronics,
  - Power cells phase A,B

- Cabinet 2:
  - 2: Power cells phase A,B.

- Equal layout for 18 cell halfbridge converter

- Single cabinet for 6 cell fullbridge converter
Single phase test

- Test of 18 level halfbridge converter
  - Open loop, no current control
  - Cell voltage sorting selects to be on or off
  - 100% modulation
  - Single phase RL load
  - Center tap DC capacitor bank

- Waveforms equal to simulations
  - Distorted arm current due to capacitor charging/discharging.

Ch1: Arm current, Ch2, Ch3: Arm voltages, Ch4: Phase current.
It works!
Teknologi for et bedre samfunn