Open-source software for HVDC control and protection

-- enabling interoperability and reducing technical risks

Presentation at the workshop “Horizon 2050 power system and the role of HVDC technologies in a highly decentralised RES generation” at Directorate-General for Energy, Brussels
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AC vs DC

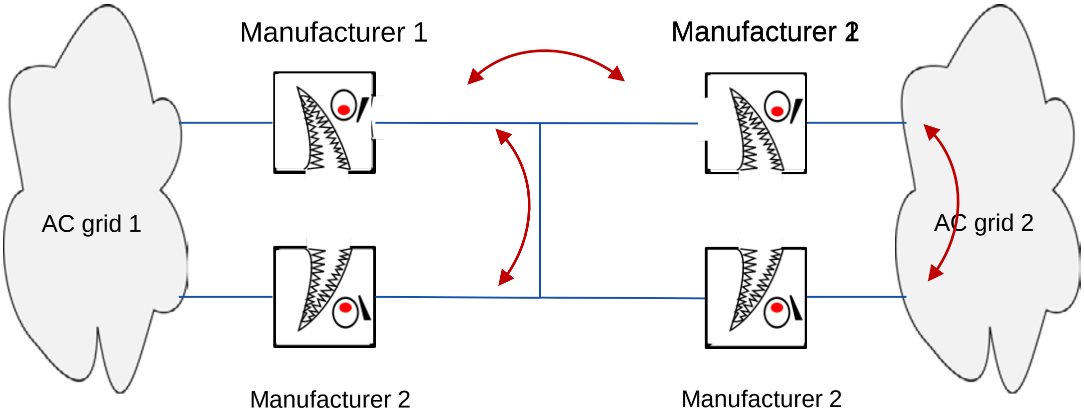
AC grid key component – Transformer

- Copper and steel
- Predictable, easy to model
- Grid expansion made by TSO

HVDC key component – Converter

- Behavior is **software-defined**
- Software is proprietary and closed
- System verification relies on detailed computer simulations

The HVDC software dilemma



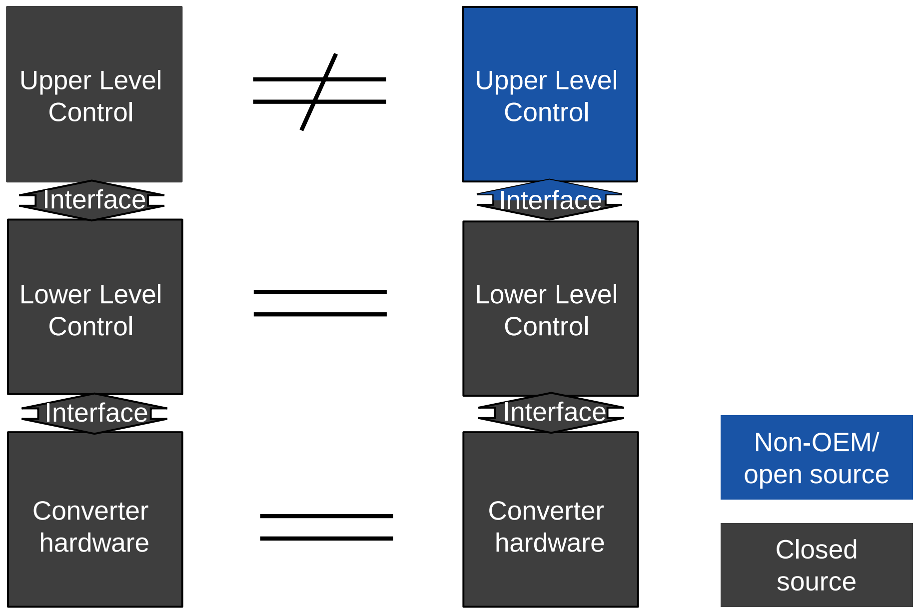
HVDC control and protection with partly open-source software

Existing paradigm | **Added** paradigm

DC voltage / active power
AC voltage / reactive power
AC current , PLL,
external protection

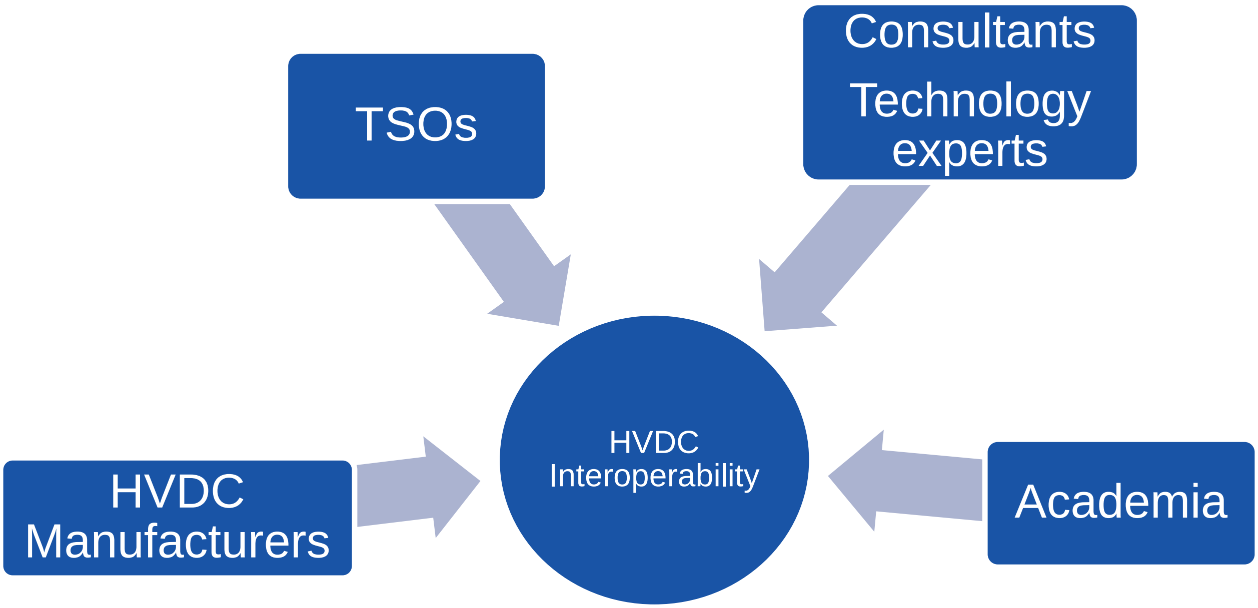
Circulating current,
arm energies
modulation,
capacitor balancing,
internal protection

Valve controllers
MMC cells, sensors



See also CIGRE TB 604: Guide for the Development of Models for HVDC Converters in a HVDC Grid

Why open-source HVDC Control and Protection?



Widen the ecosystem – reduce technical risks

Open issues…

- **Interfaces** between open and closed software parts
- Choice of open-source **software licenses**
- **System verification** in an open-source context
- **Responsibility** for system performance
- **Guarantees**

Ongoing activities this far

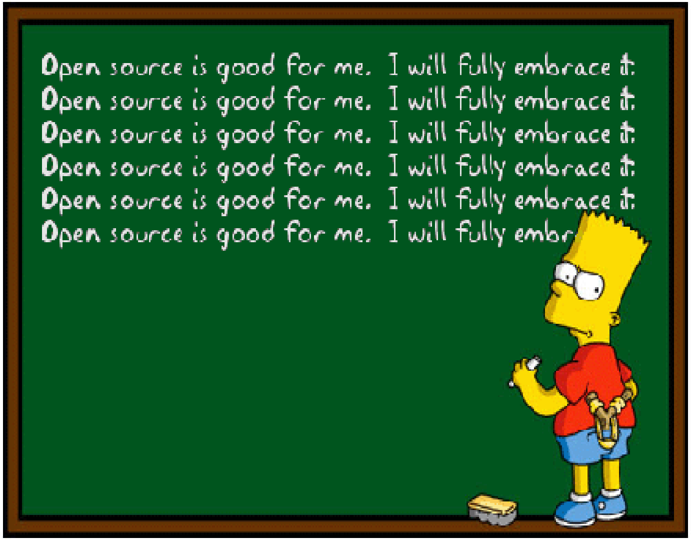
- Cigre Workgroup – B4.85 (Interoperability in HVDC systems based on partially open-source software)
- Research project to be started at KTH with support from Svk and RTE
- Paper at ISGT 2019, Paper at CIGRE session 2020 to be presented

I. Jahn et al., "A Proposal for Open-Source HVDC Control," 2019 IEEE PES Innovative Smart Grid Technologies Europe (ISGT-Europe), 2019

Your participation is welcome!

- Cigre WG B4.85 – contact your Cigre B4 regular member
- Open-source C&P codebase for HVDC
- Contact me:

norrga@kth.se



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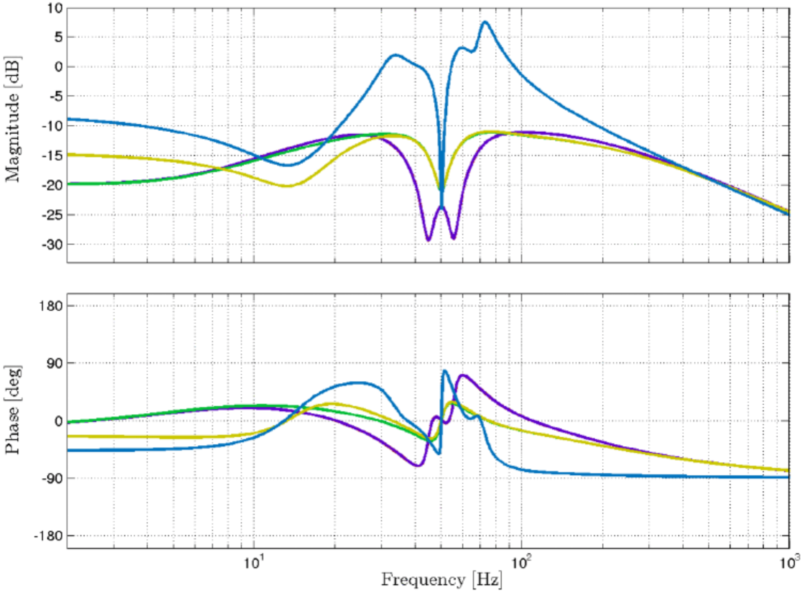
BACKUP

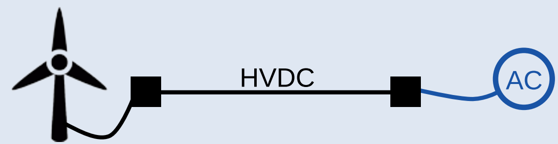
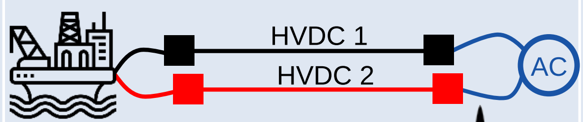
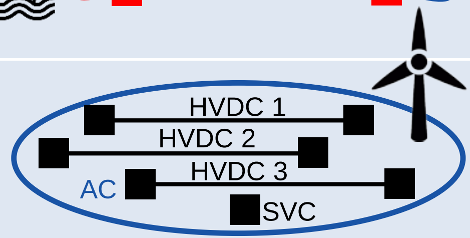
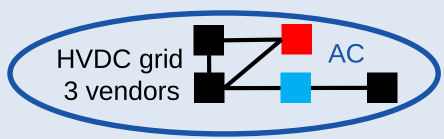
Impact of control on converter behavior

MMC AC-side admittance at different current control elements employed



- fixed references
- ac-side current proportional controller
- circulating current controller
- ac-side current resonant controller
- ac-side voltage feedforward

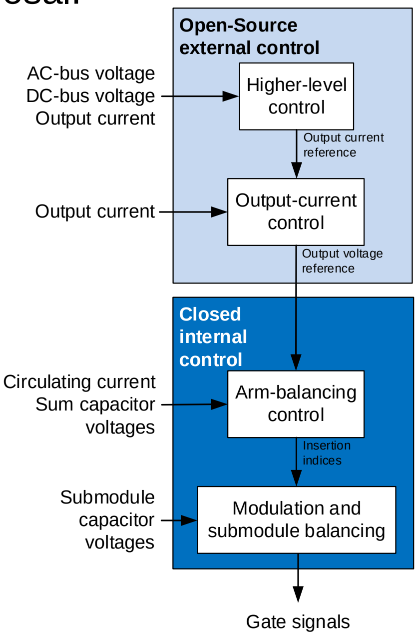
Blackbox Control Problems

<table>
<tr><th>Problem</th><th>Setup</th><th>Party</th></tr>
<tr><td>Switching in AC grid
→ Resonant current
→ Converter trip</td><td>
</td><td>TenneT
(from field)</td></tr>
<tr><td>Generic model HVDC 1
→ Study power sharing
→ Relevance of results?</td><td>
</td><td>Equinor
(simulation)</td></tr>
<tr><td>Blackbox (existing projects), generic (future projects)
→ Assess risk of interactions
→ Solution?</td><td>
</td><td>RTE
(simulation)</td></tr>
<tr><td>Blackbox, multivendor HVDC
→ 15% interoperability problems</td><td>
</td><td>BestPaths
(simulation)</td></tr>
</table>

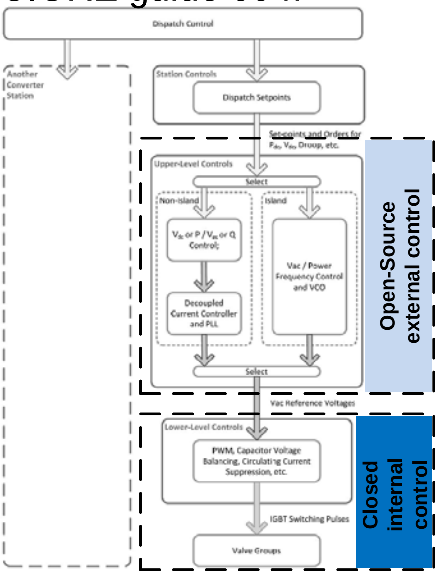
Proposal for Open-Source Control Design

- For specific control scheme:
  circulating current (control) does not impact MMC ac-side admittance

- Proposal:



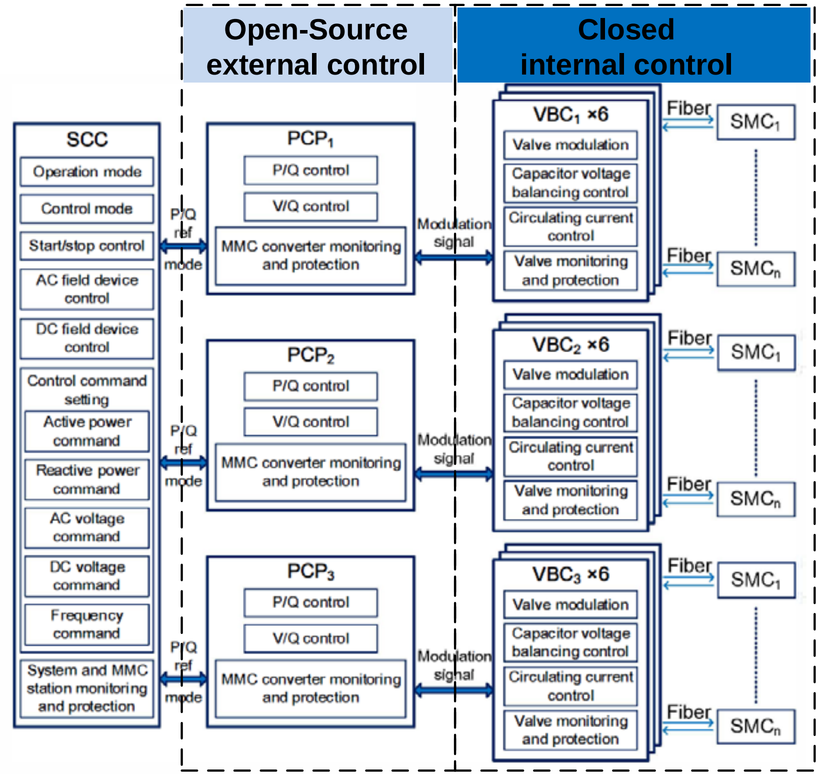
- CIGRE guide 604:



- Similar in IEEE 1676-2100

Existing Control with Proposal

- Chinese multiterminal HVDC system Nan'ao
  - **Several higher-level layers**
  - **Vendor-specific valve and submodule control**



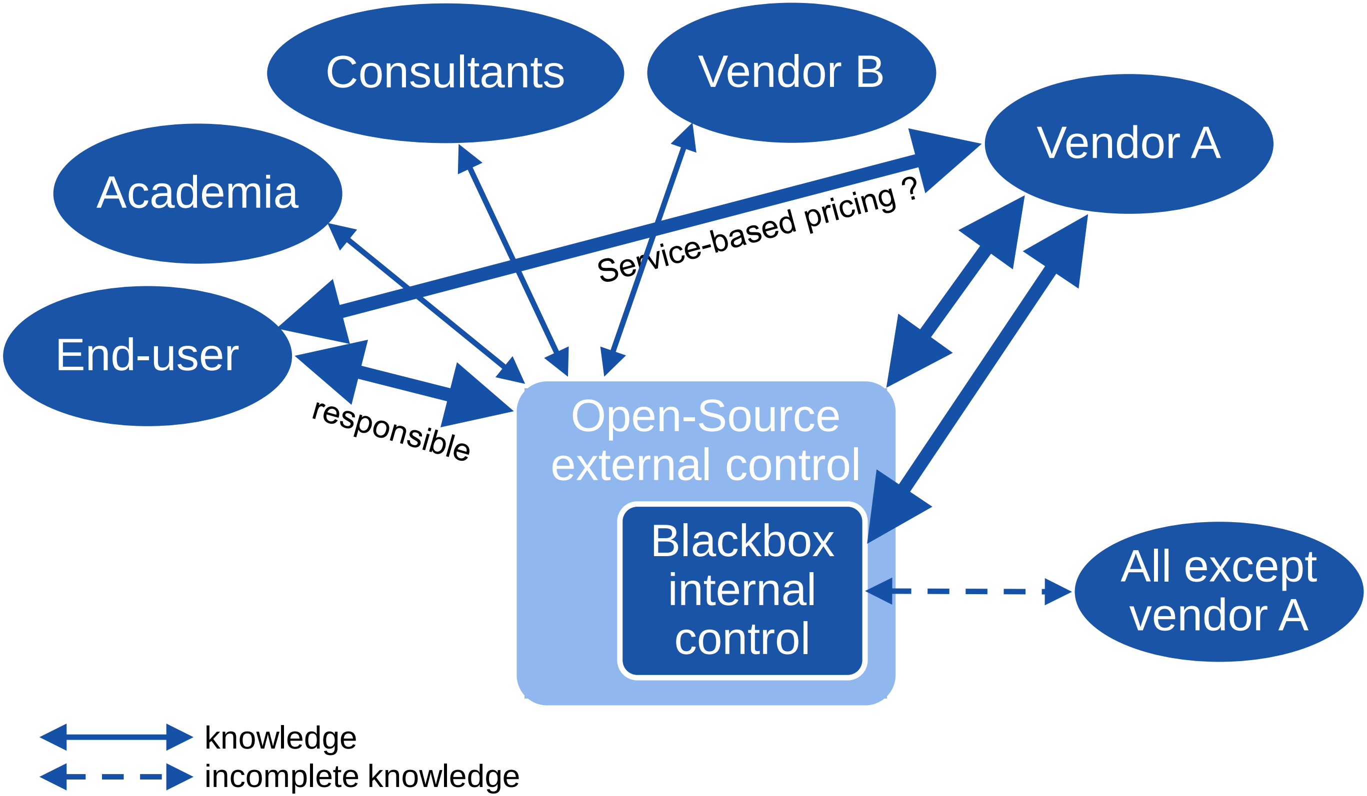
Licensing, Patents, Business models

<table>
<tr><th>License</th><th>Type</th><th>Free Distribution</th><th>Derivative Works (new ext. control)</th><th>Patenting</th></tr>
<tr><td>MIT, BSD</td><td rowspan="2">All permissive</td><td rowspan="5">Yes</td><td>No restrictions</td><td>Not stated ☹</td></tr>
<tr><td>Apache 2.0</td><td>Apache name cannot be used for marketing</td><td rowspan="3">Patent grant required</td></tr>
<tr><td>MPL v2</td><td rowspan="2">Restrictive</td><td>GPL or MPL</td></tr>
<tr><td>LGPL</td><td>GPL or LGPL</td></tr>
<tr><td>GPL</td><td>Restrictive and viral ☹</td><td>GPL</td><td>😐?</td></tr>
<tr><td>Commercial</td><td>All restrictive ☹</td><td>No</td><td>Not allowed</td><td>Okay</td></tr>
</table>

Conclusion:

- Less restrictive licenses
- Patent grant seems to be a requirement
- Option: tailor HVDC-specific license

Parties in HVDC



Implementation and Expected Impact

1) Separation: black-boxed internal - open external controls

- 1 physical unit vs.
  2 physical units
- Communication delay, might be acceptable
- Interface (software / hardware)

2) Requirement: defined interface

Expected impact

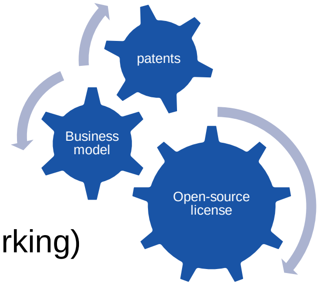
- Easier implementation of external input, (e.g. research results)
- Better studies with actual external controller
- Standard development
- Interoperability
- Multivendor development

3) Accelerate multivendor framework

- End-user responsible for system stability
- Less requirements on vendors to solve system-related problems
- Easier to solve problems touching on other vendors' equipment

(with certain conditions)

Licensing, patents, business models



- Restrictive licenses:
  - Require that alterations published back into the community
  - Risk that this is not done
  - Risk that material is used in closed IP for competitive product (forking)
  - Difficult to re-use in other platforms (e.g. RTDS, PSCAD etc.)
  - Discourage vendors from joining the open-source community and should be avoided

- Permissive licenses:
  - Distribution for derivative work is permitted, but not obligatory
  - Dynamic open-source community has strong incentive to contribute back
  - Better for maintenance in the long term

- Derivative work:
  - Work that has sufficient changes compared to the original work so that the derivative work becomes independent, e.g. a new external control method.

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