Modelling DC

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While AC power transmission was dominant in 20th century, DC transmission will be prevailing in the 21st.

1. Background

Motivation

1. DC transmission networks are required for large-scale offshore energy evacuation,
2. DC grids will be fundamentally different from AC transmission systems. Technical challenges include:
   - DC voltage stepping
   - DC fault isolation
   - DC grid control and dynamics
3. Typical (mid-size) DC grid shown in Figure 1:
   - How many DC/DC are required and where should they be located?
   - Is it better to use many DC CBs or few DC/DC?
   - Takes 4 hours of simulation on PSCAD for 1s of real time,
   - Not possible to determine eigenvalues,
   - Takes a PhD project to tune controls for stable operation,

Goals of Modelling DC project:

1. Analyse role and topologies for DC/DC in large DC grids.
2. Analyse role and topologies for DC hubs in large DC grids.
3. Develop Models for DC/DC and DC hubs,
4. Understand DC grid Control/stability challenges,

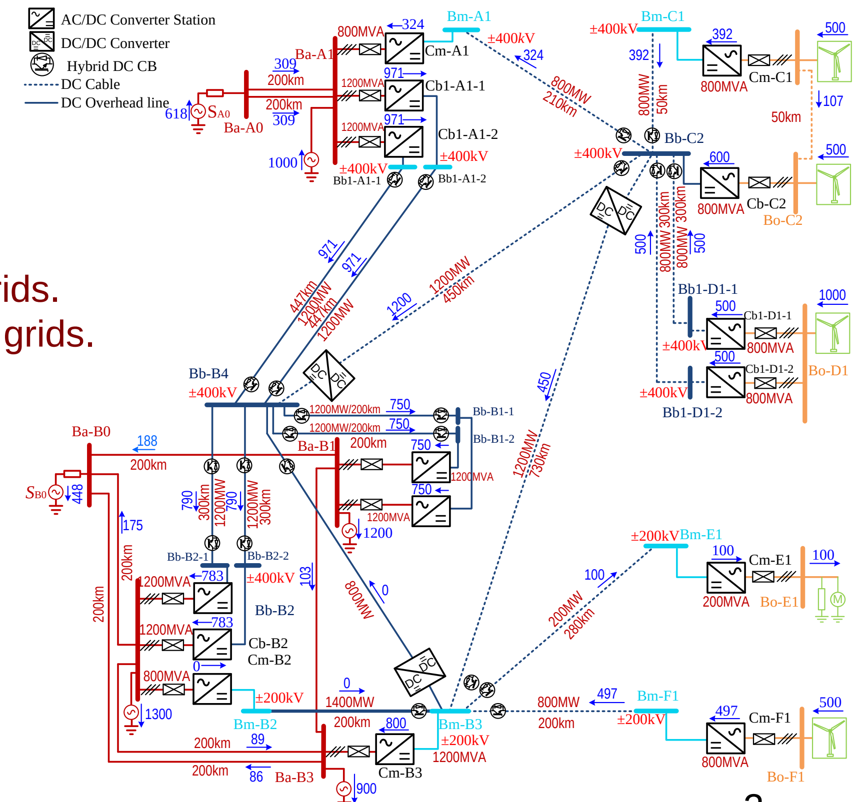


Figure 1. 11 terminal DC grid (based on CIGRE DC grid) with 3 DC/DC converters.

2. DC/DC converters

Using DC/DC converter in DC grids

- Power trading between two DC systems of different voltage levels,
- Improved operating flexibility,
- Two protection zones, DC faults are not transferred across DC/DC,
- Two HVDC of different manufacturers. DC/DC resolves multivendor issues,
- DC/DC becomes:
  - transformer (DC voltage stepping) ,
  - power flow regulator,
  - DC Circuit Breaker.

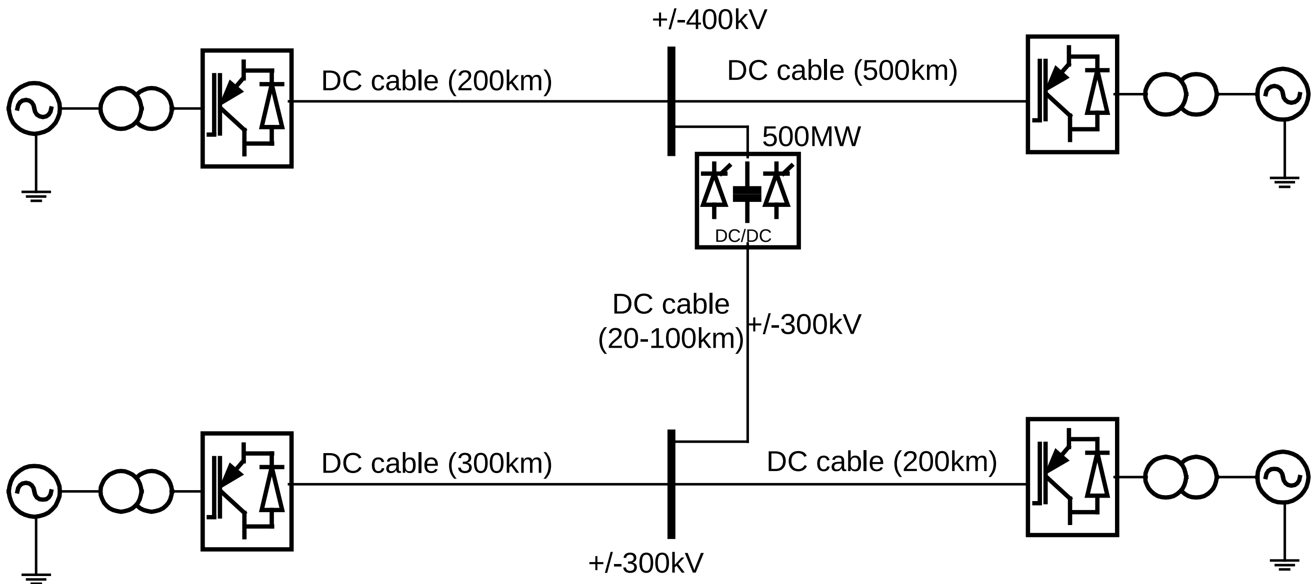
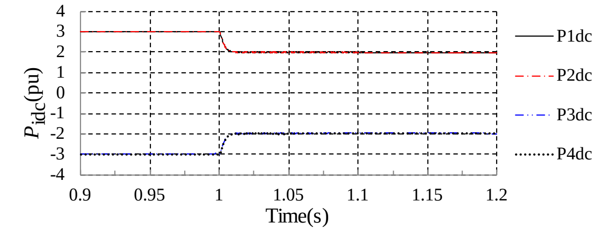
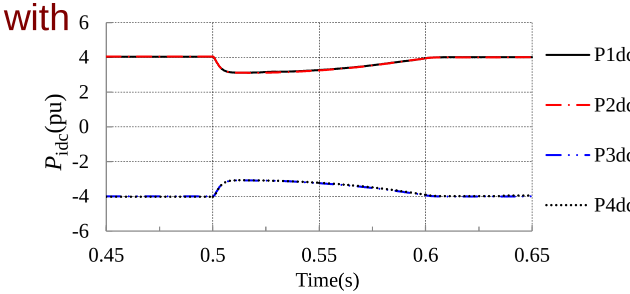


Figure 2. Connecting two existing DC systems using a DC/DC converter.

3. DC Hubs

- Interconnect multiple DC systems of different DC voltages,
- Power flow in possible on each port. Any port is readily disconnected,
- DC faults are not propagated to other ports,
- No need for DC circuit Breakers,
- Any phase is readily disconnected in case of an internal fault, (graceful degradation),
- Use redundant phase to meet N-1 criterion (substitute faulted phase with a stand-by phase),





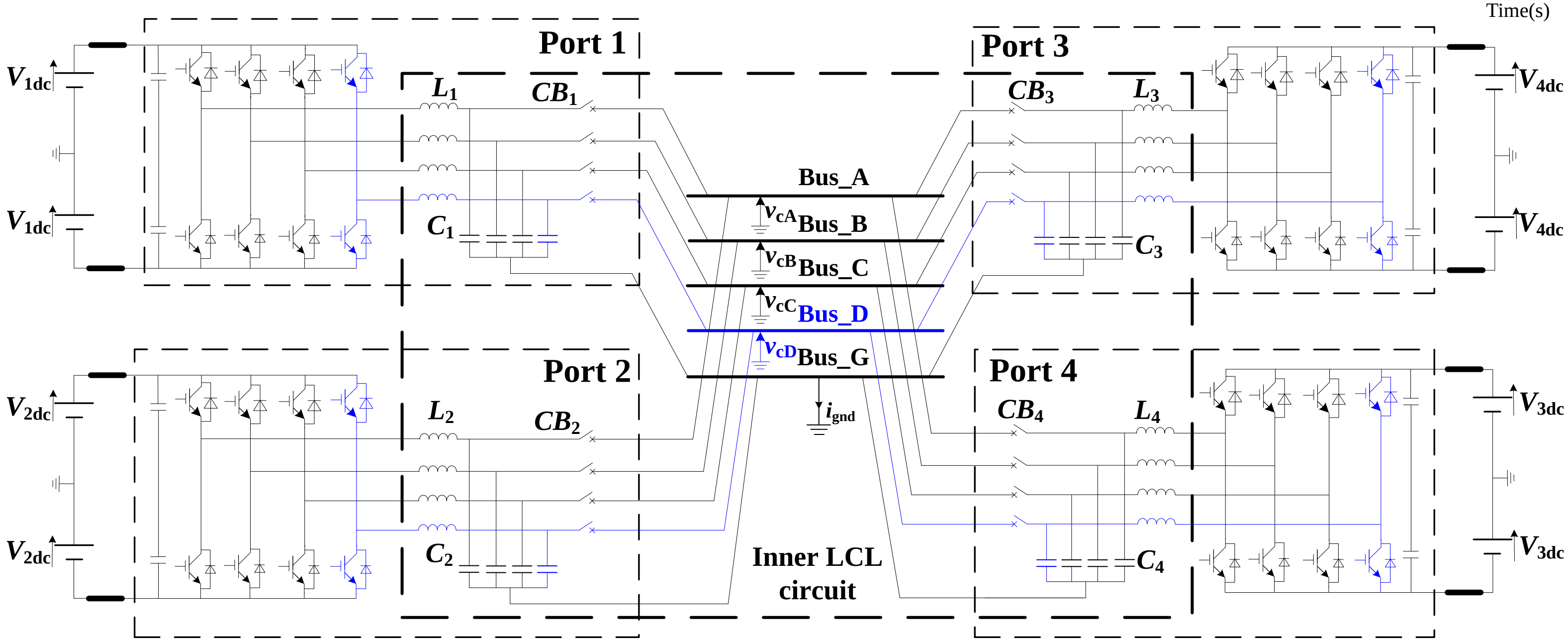


Fig.3. 4-port, 4-phase DC hub. Phase D is in stand by.

3. DC Hubs

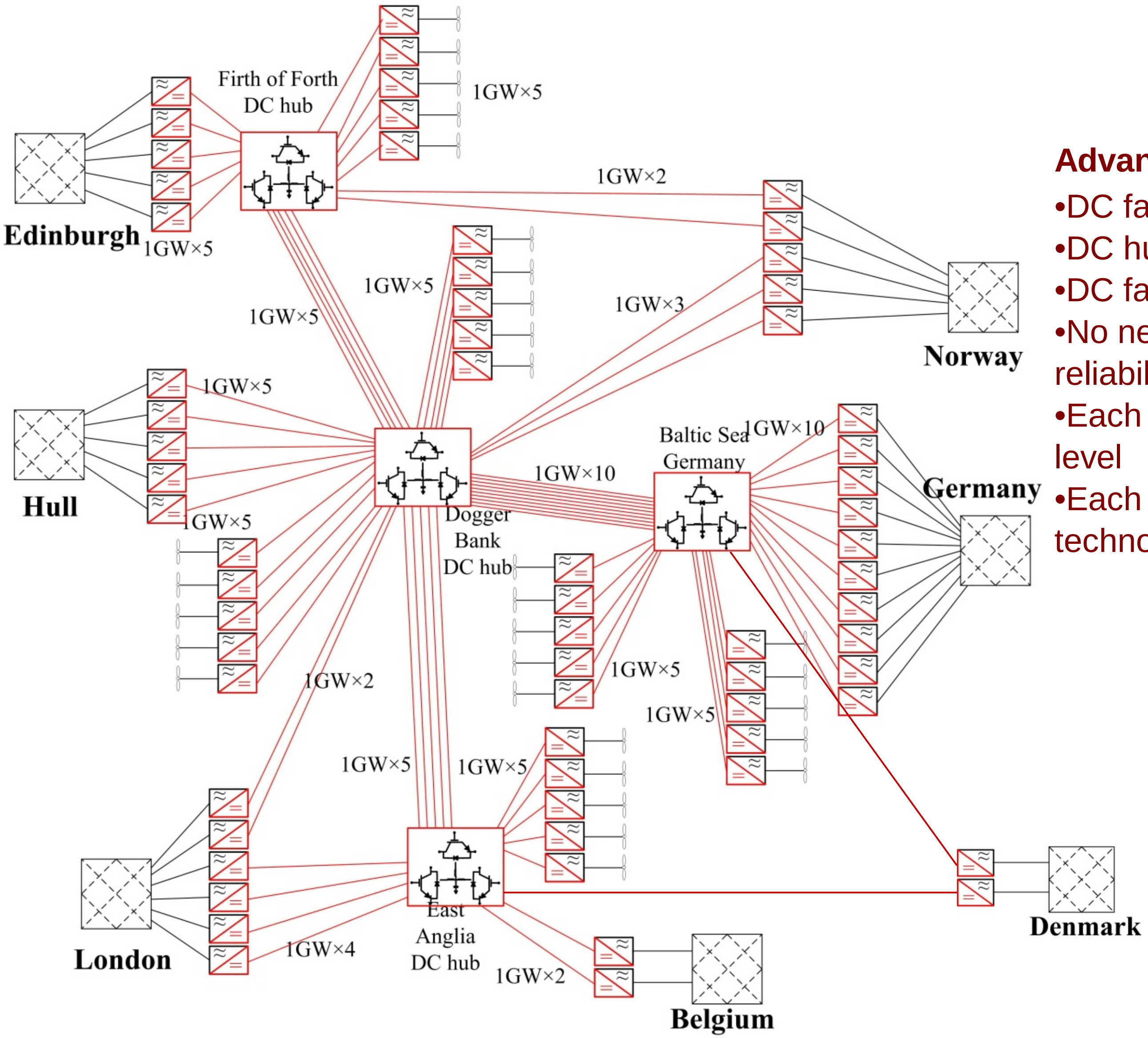


Fig.4. North Sea DC grid with 4 DC hubs

Advantages:

- DC fault is only a local disturbance
- DC hub inherently reduces fault current,
- DC fault is readily isolated
- No need for DC CBs or fast protection, reliability is high
- Each DC line can have different voltage level
- Each DC line can have different HVDC technologies

4. DC Grid demonstrators

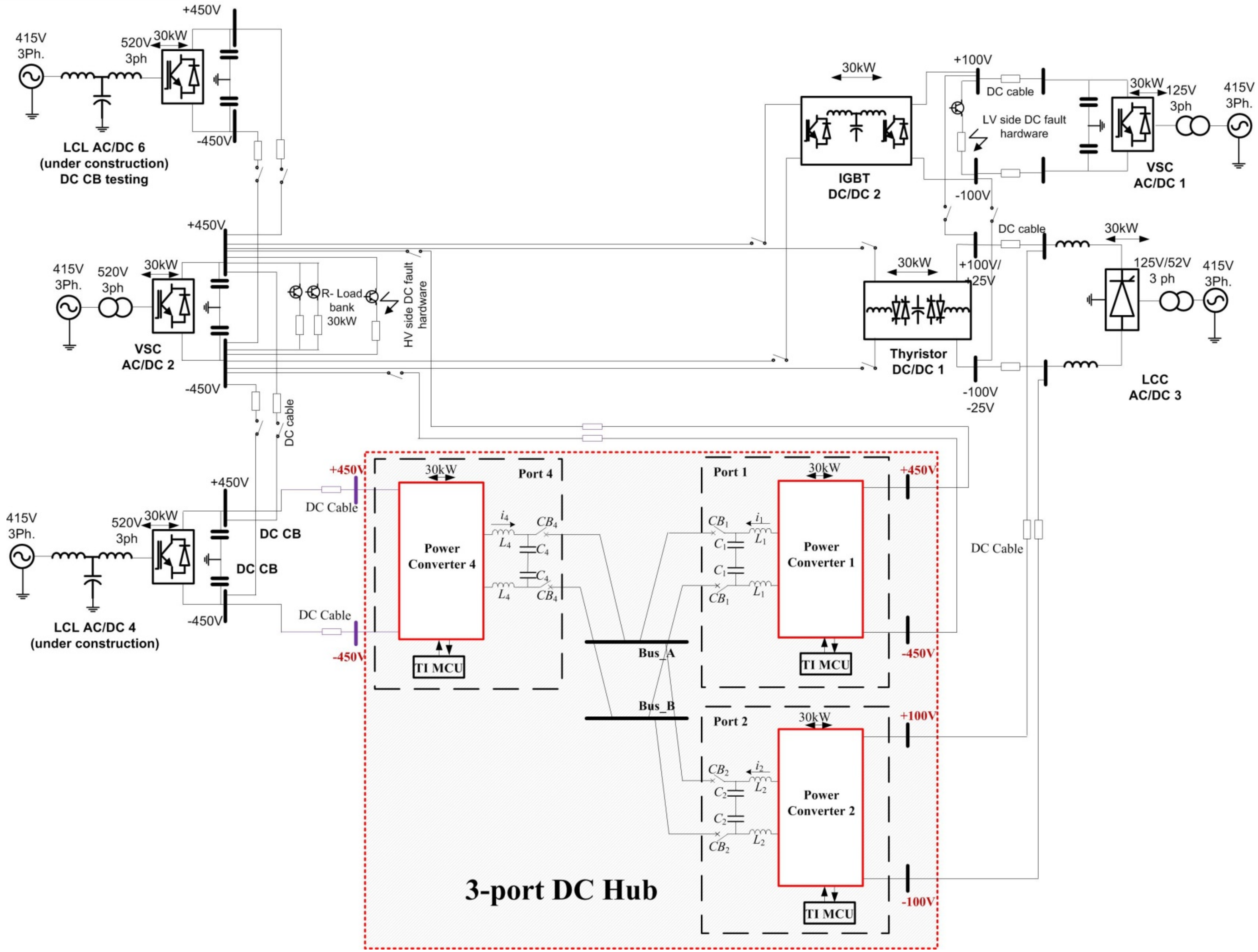


Fig.5. 5-terminal, 900V, DC Grid demonstrator at Aberdeen HVDC research centre

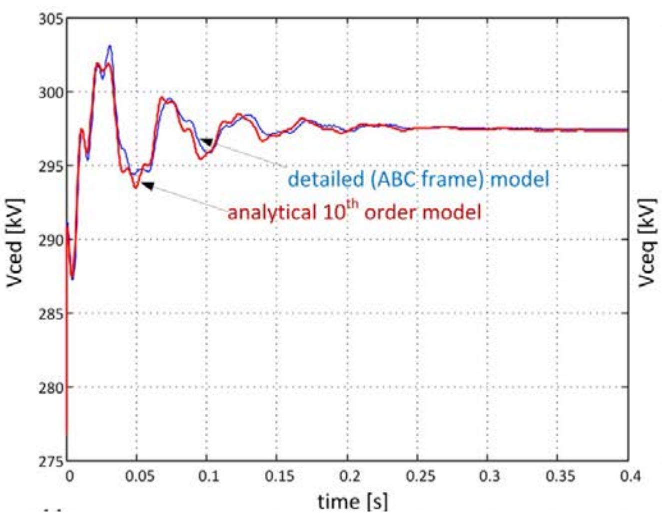
5. DC Grid modelling

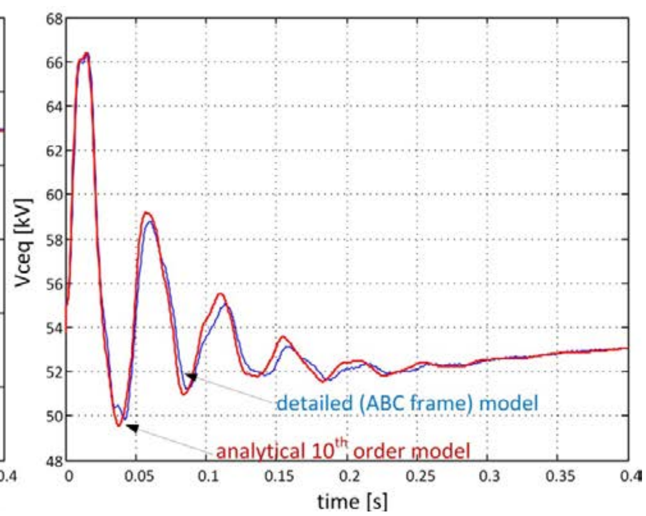
Average value, simulation based, DC Grid modeling:

- Average value (type 5) model for each converter is fastest approach with reasonable accuracy,
- CIGRE 10 terminal DC grid model, 20s of real time takes 4 hours simulation using average model (20µs).
- Standard simulation platforms (PSCAD,EMTP) support only trial and error study in time domain,

Small-signal, linearized, state space, analytical models:

- Multiple DQ frames are required at different frequencies and harmonics,
- Non-linear elements can not be directly transferred to DQ frame,
- Requires manual modeling with elementary equations for each converter,
- Medium frequency (300Hz-1000Hz) circuits in the dc/dc converter complicate modeling,
- Eigenvalue studies or frequency domain studies are possible,
- Parametric studies are fast even for very complex DC grids.





Key eigenvalues original system	-14.56 ± j313.2 -17.82± j129.5
Key eigenvalues with increased PLL gains	-6.98 ± j317 -33.74± j101.3

Fig. 6. MMC 10th order DQ analytical model validation, and eigenvalue study example.

6. DC Grid control

Primary/secondary response is decentralised:

•DC grid dynamics are 2 orders of magnitude faster than AC grid dynamics.
•No inertia. GW powers should be balanced within 1-2ms.
•Each converter contributes to DC voltage control.
•Control interactions within and between converters are a challenge.

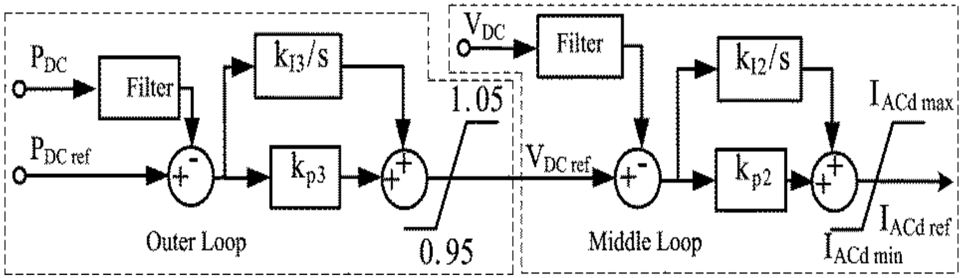


Fig. 7. 3-level controller for DC grid terminals

DC Grid central controller:

•Secondary response ensures power balance (automatic),
•Optimisation of secondary response requires communication and a dispatcher.
•Slow, Average DC voltage regulation is proposed,
•Tertiary response (human intervention),

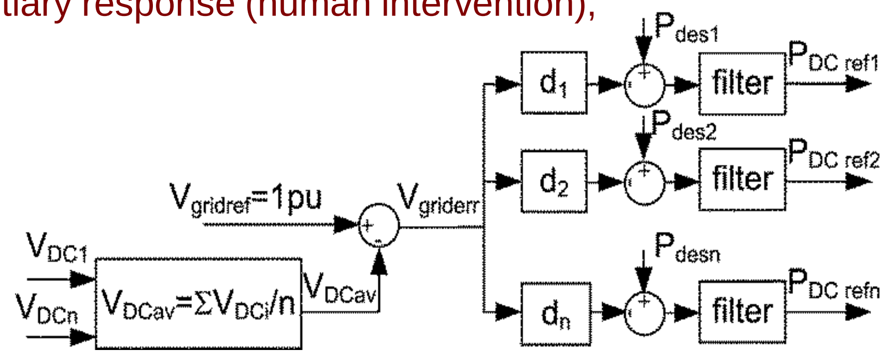


Fig. 8. DC Grid Dispatcher Controller

7. Conclusion – further research

Further research/development work:

1. DC/DC converters as multifunctional DC grid components,
   - Have not been developed for GW powers.
   - DC grid planning with DC/DC (architecture, location, flexibility, security),
   - Complementary/interaction with DC Circuit Breakers,
   - Optimisation of losses, cost, size, reliability, ...
   - Adoption of MMC approach,

2. DC Hubs (electronics DC substations),
   - Have not been developed for GW powers.
   - DC grid planning with DC/DC (architecture, location, flexibility, security),
   - Optimisation of losses, cost, size, reliability ...
   - Control, modelling,

3. Simulation/Modelling of DC grids,
   - Simulation is very slow and model is too complex if number of converters is high (over 10),
   - Eigenvalue and parametric study capability is needed.
   - Faster analytical modeling is required for complex systems.

4. DC grid Control/stability challenges,
   - Generic control framework does not exist.
   - Grid control layers and interactions,
   - Bandwidth segmentation. Temporal and spatial interactions. Distributed fast, and centralized slow control,
   - Robustness, flexibility, interoperability, interaction with AC grids,

5. Hardware (low power) demonstrations,
   - De-risking of new converters and grid topologies,