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MOSAIC GRID SOLUTIONS

TRANSNET BW

Study Committee B4

DC SYSTEMS & POWER ELECTRONICS

Paper ID_11085

A transparent process to ensure appropriate and compliant grid-forming behavior for HVDC systems and FACTS – A TSO perspective

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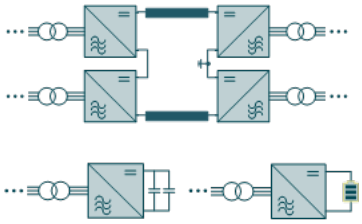
1. Motivation

- Grid-Forming converters are foreseen to play a major role in the future European power system
- German TSOs see a compelling necessity to equip all new converters that are directly connected to the transmission system (e.g. HVDC and STATCOM) with grid-forming controls
- Paper aims to describe the lessons learned from the specification phase of different assets with grid-forming requirements
- Focus lays on the verification procedure and conformity testing methods of grid-forming behavior

2. Future Assets with Grid-Forming Capability

- Three different groups of PEIDs[1] with grid-forming capability are planned to be integrated into the grid: *embedded HVDC*, *STATCOM-GFC* and *Grid-Booster*
- Grid-forming behavior will be required for all of the aforementioned assets
- However, requirements on individual grid-forming design aspects differ due to different physical constraints (e.g. available energy reserves)

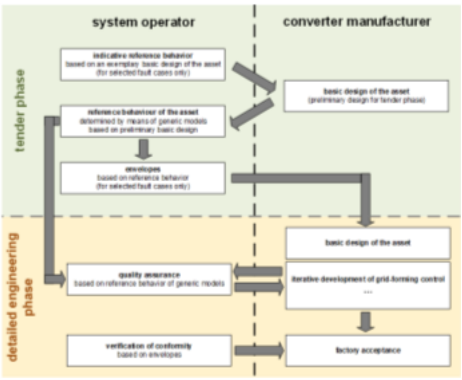
Embedded HVDC, STATCOM-GFC and Grid-Booster



3. German FNN Guideline: Fundamentales & Application

- German FNN guideline provides guidance terms of specification and conformity testing methods for grid-forming assets
- Grid-forming behavior of the asset shall be verified by means of EMT-simulations
- Benchmark system comprising test network and typical test cases (e.g. phase angle or voltage magnitude steps, frequency changes, change in network impedance, islanding with current controlled load etc.)
- Basic idea: TSO specifies a reference behavior for each test scenario by means of simplified models and creates “envelope” curves

Sequence diagram of an exemplary application of the FNN guideline



system operator

converter manufacturer

tender phase

indicative reference behavior
based on an exemplary basic design of the asset
(for selected fault cases only)

basic design of the asset
(preliminary design for tender phase)

reference behaviour of the asset
determined by means of generic models
based on preliminary basic design

envelopes
based on reference behavior
(for selected fault cases only)

detailed engineering phase

basic design of the asset

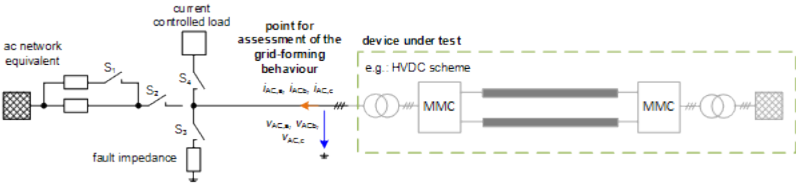
quality assurance
based on reference behavior of generic models

iterative development of grid-forming control
...

verification of conformity
based on envelopes

factory acceptance

Test network for assessment of the grid-forming behavior of a device under test



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[1] Power electronic interfaced devices (PEIDs)

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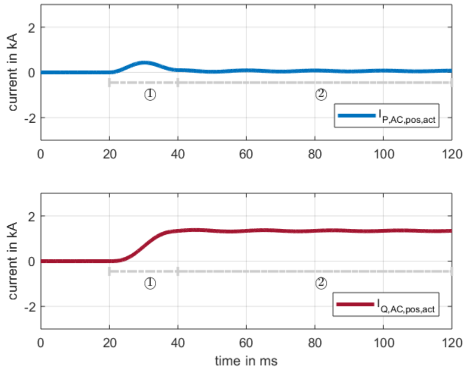
4. Dynamic Performance of GFCs: Exemplary System Behavior

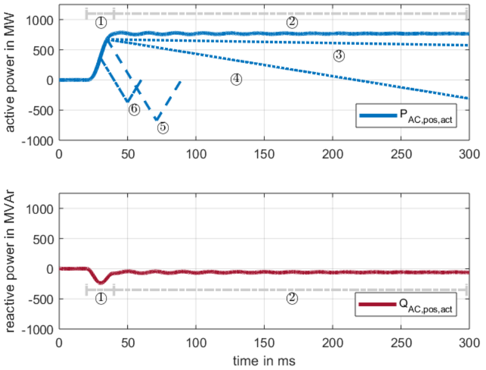
- The system behavior during a **3-phase-to-ground fault** can be divided into different time periods:
- ① Instantaneous response of DUT:
    - Immediate increase of reactive current contribution at the PCC
    - Instantaneous characteristic of the DUT
    - Fast current limitation schemes needed to protect power electronic components
    - Duration: up to two grid cycles
- ② Steady state fault current contribution:
    - Quasi-stationary operating point is reached within approx. one grid cycle
    - DUT provides a constant but parameterizable reactive current

Exemplary reference behavior of the DUT during a three-phase-to-ground fault at t = 20 ms (residual voltage 80 %)



- The system behavior during a **phase angle step (-10°)** can explained as follows:
- ① Instantaneous response of DUT:
    - Immediate increase of active power at the PCC
    - Instantaneous characteristic of the DUT
    - Fast current limitation schemes needed to protect power electronic components
    - Required for all three groups of assets mentioned in Section 2
- ② Transition behavior:
    - Return to a steady state power set point
    - ③-⑥ additional design-related degree of freedom (asset specific, depending on available energy reserves)
    - ③ slow decaying response might be achieved with additional battery storages (e.g. grid-booster)
    - ④ medium decaying response might be achieved for assets equipped with additional supercapacitors (e.g. STATCOM-GFC)
    - ⑤-⑥ fast return of the active power component required due to very limited energy reserves (e.g. embedded HVDC)

Exemplary reference behavior of the DUT during a phase angle step in network voltage at t = 20 ms (-10°)



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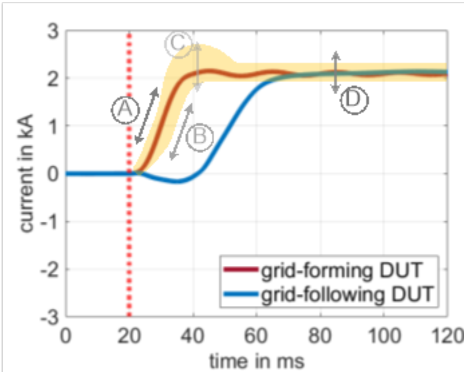
5. Exemplary Determination of Envelopes

- Basic idea: keep the system behavior of the asset close to the specified reference behavior, but allowing room for manufacturer dependent control implementations or basic design differences
- Exemplary procedure to determine an appropriate envelope curve is described for a symmetrical fault:
    - Relevant quantity: reactive current component of the positive sequence $I_{QAC,pos,act}$
- A) Upper boundary of envelope curve:
    - Instantaneous reaction of DUT
    - Rate-of-rise depends on quantity determination (e.g. filtering of IEC calculation method)
    - Rate-of-rise is limited by impedances between converter and PCC (e.g. transformer leakage reactance)
- B) Lower boundary of envelope curve:
    - Instantaneous reaction of DUT
    - Relevant to distinguish between grid-following and grid-forming DUTs
    - Signal acquisition and filtering stages typically lead to delayed system responses in grid-following converters compared to grid-forming DUTs
- C) Overshoot:
    - Overshoot permissible due to grid-supporting effect
- D) Quasi-stationary accuracy:
    - Steady state fault current contribution
    - Similar behavior between grid-forming and grid-following converters possible
    - Reactive current component of the DUT is proportional to the voltage deviation at PCC and quasi-stationary impedances or proportional factors (e.g. definition of *k*-factor in grid-following HVDC converters)

Exemplary determination of an envelope curve for $I_{Q,AC,pos,act}$ (yellow area) – system behavior during a three-phase-to-ground fault for a grid-forming DUT and a grid-following DUT



6. Conclusion

- In line with the system needs related to power electronic-dominated grids, a proper and straightforward specification process of grid-forming behavior is required in order to mitigate the risks for all involved parties in a project
- Paper provides insights into the specification process of grid-forming behavior from the point of view of a German TSO
- Obtained results are relevant for other TSOs, converter manufacturers as well as academia and provide a structured process to benchmark the functional requirements regarding control implementations in case of assets with grid-forming controls