Limitations of Digital Simulation and Advantages of PHIL Testing for DG providing Ancillary Services

Panos Kotsampopoulos: Smart RUE-National Technical University of Athens
Felix Lehfuss: Austrian Institute of Technology - AIT
Georg Lauss: Austrian Institute of Technology - AIT
Benoit Bletterie: Austrian Institute of Technology - AIT
Nikos Hatziargyriou: Smart RUE-National Technical University of Athens

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Evolution of power system/component analysis, testing and validation

- Full System Hardware Testing
  - Network, Substation
  - Inverter DuT
  - PV arrays

- Component Hardware Testing
  - Grid Simulator
  - Inverter
  - PV array Simulator

- Pure Simulation Methods
  - Full system digital simulation
  - Numeric analysis

- Hardware in the Loop (HIL): System Testing
  - RTS: Network, Substation
  - Power Amplifier
  - Inverter DuT
  - Power Amplifier
  - RTS: PV arrays
PHIL Fault-Ride-Through tests on PV inverters

- Simulated network according to Standards for Fault-Ride-Through
- Fault in the simulated network in the RTDS

The hardware PV inverter is disconnected following the relevant standard
The settings of the hardware-software relays are adapted to the network conditions (e.g. DG on or off)
PHIL testing of ancillary services by inverter-based DG

- Inverter-based DG are particularly difficult to model accurately
- Therefore the “classic” pure digital simulation can face limitations
- PHIL makes use of the real DG and can therefore reveal the actual system behaviour
New scaling and stability-accuracy method

- PHIL allows scaling of the software and hardware. A 2kVA hardware LV PV inverter is used to evaluate the integration of a 15MVA PV park connected to the MV. The grid voltage control algorithm of the full and reduced-scale DGs are exactly the same.

- Shifting part of the software impedance on the hardware side is proposed. Stability can be achieved without compromising accuracy (if necessary a “smaller” feedback filter can be used)

\[ a = \frac{V_{SW}}{V_{HW}} \]

\[ b = \frac{S_{HuT\_full}}{S_{HuT\_red}} \]

\[ Z'_{SW}(s) = \frac{b}{a} Z_{SW}(s) - a \cdot Z_{sh}(s). \]
Accuracy Improvement with the proposed method

Down-scaling of the voltage improves the stability

Up-scaling of the current deteriorates the stability

No need for feedback filter with the shifting impedances → Much higher accuracy

Formula for the minimum shifted impedance to achieve stability was derived

G
LPF
(s)
Z
SW
(s)
1/Z
HW
(s)
Vs
e−steTd
G
filter
(s)
Vz
HW
 Vz
HW
(a)
Z
SW
(s)−a·Z
sh
(s)
GLPF(s)
(b)
DG and OLTC interactions: $\cos \varphi(P)$

- DG operates with $\cos \varphi(P)$ control
- DG active power increases, stays constant and then decreases
- Recurring tap-changes occur
- Good accuracy of the PHIL test due to the proposed method
DG and OLTC interactions: Q(U)

- Active power of the DG increases → **DG voltage increases** → reactive power absorption by the DG increases (Q(U)) → Voltage of the secondary of the transformer decreases → tap-change occurs

- Recurring tap-changes occur

- **Instability of the Q(U) controller (i.e. Oscillations): not visible at the pure digital simulation**

![Graph showing DG and OLTC interactions](image-url)
DG and OLTC interactions: Q(U)

- Additional reactive power flow
- Instability of the Q(U) controller (i.e. Oscillations): not visible at the pure digital simulation
DG and OLTC interactions: Q(U)

- Voltage drop at the HV network
- Similarly, the oscillations are not shown at the pure-digital simulation
Q(U) controller instability

- Closed-loop. Internal delays in the controller (e.g., signal processing, average filtering of the voltage measurement, delay in communication between processors) of the commercial inverter are unknown. Could not be represented in pure simulation.

- PHIL was able to show the true behaviour.
Conclusions

- PHIL is a valuable tool that merges component testing and power system simulation: Power system testing
- New interfacing method was proposed
- PHIL could reveal interactions of OLTC and DG that were not visible in pure-digital simulation
- Potential problems of OLTC and DG were identified
Thank you for your attention

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www.smartrue.gr       www.ait.ac.at
kotsa@power.ece.ntua.gr   georg.lauss@ait.ac.at