Karlsruhe Institute of Technology

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Institute for Data Processing and Electronics

Design and experimental verification of advanced control strategies to provide ancillary services with a bidirectional Vehicle-to-Grid (V2G) inverter

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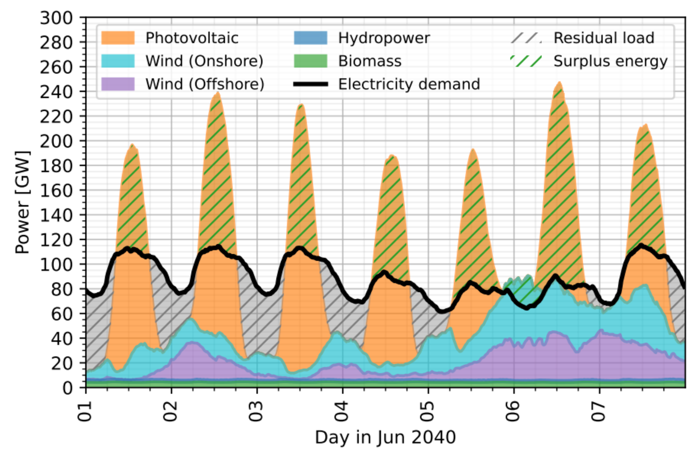
Abstract:

- V2G may significantly contribute to storage capacity and grid stability in renewable energy systems
- As conventional power plants are phased out, V2G inverters could provide ancillary services instead
- We offer detailed insight into a V2G inverter control structure + experimental validation (DDSRF-PLL, virtual inertia, …)

Motivation:

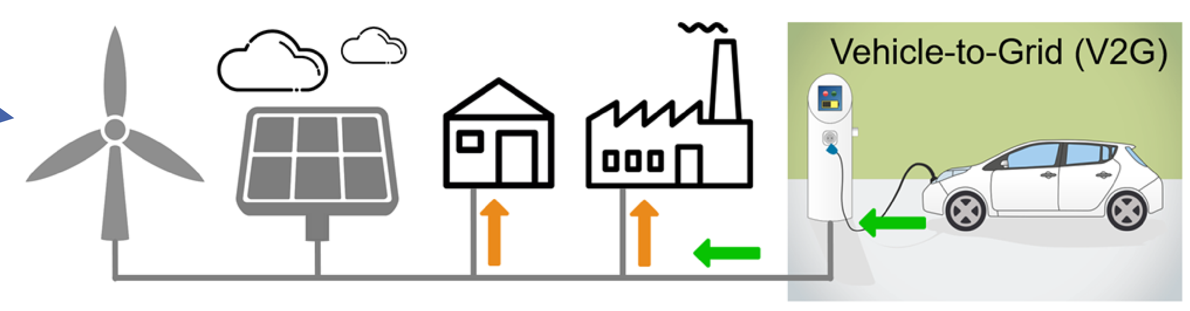
How electricity generation & demand could look like in Germany in 2040:



- **Energy transition:**
  - Increased share of volatile (wind, solar) & decreased share of dispatchable power plants
    - ➔ need for storage capacity (short & long term, e.g., batteries & Power-to-Gas)
    - ➔ storage inverters replace conventional (& sometimes volatile) generators → need to provide ancillary services
      e.g.: virtual inertia, primary / secondary / tertiary frequency control, voltage control, congestion management, black start capability
- **Mobility transition:**
  - In the future, millions of EVs on the road – or actually: on parking lots (private passenger cars park >95% of time!)
  - Only a fraction of EV battery capacity used on a daily basis
    e.g., in Germany: average daily driving distance is 40 km (≈8 kWh) – average BEV capacity: ca. 50 kWh
  - Using EV battery capacity for the gird with V2G has enormous potential, even if just a fraction of BEVs participate
    2023 in Germany: 2.2% of passenger cars were BEVs – combined battery capacity (≈71 GWh) already exceeds pumped hydro cap.

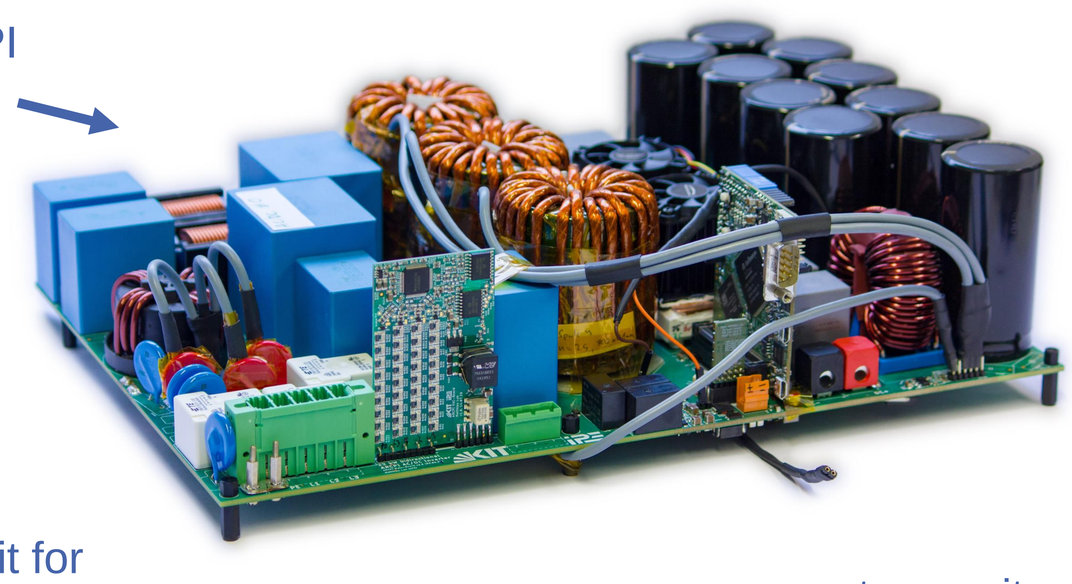
Experimental setup:

V2G: use EV batteries as energy storage for renewable electricity

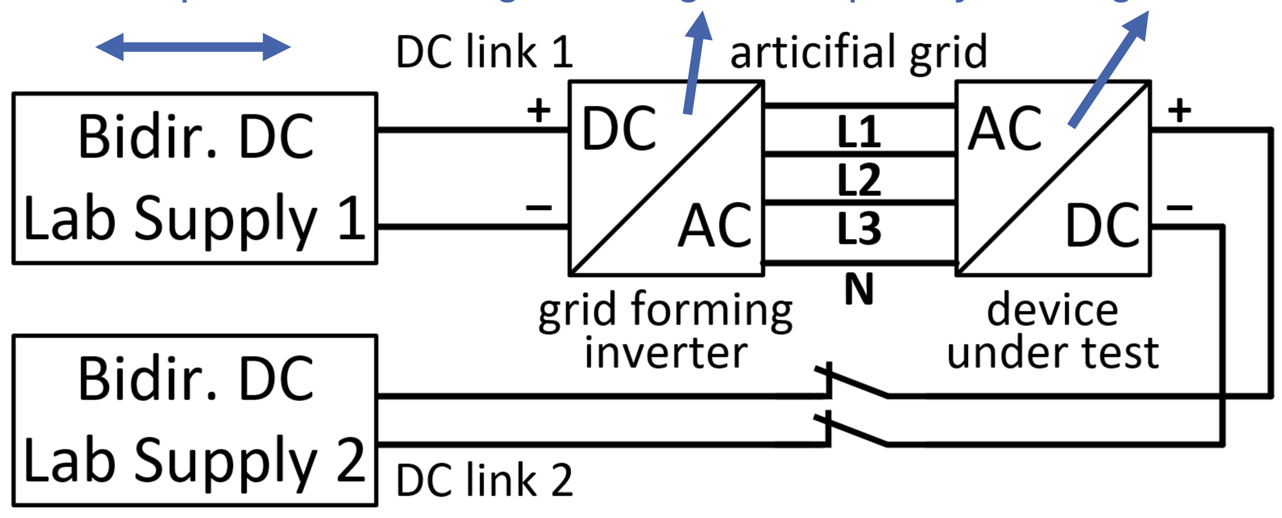


- Bidirectional 22 kW three-phase ARCPI (Auxiliary Resonant Commutated Pole Inverter) [11]
- Here, the ARCPI is a soft-switching active front end / active B6 bridge / three-phase voltage-sourced two-level inverter
  (control structure presented here also works with hard switching topologies)
- Two inverters used: One forms the "artificial grid", the other is the device under test (DUT) that provides ancillary services

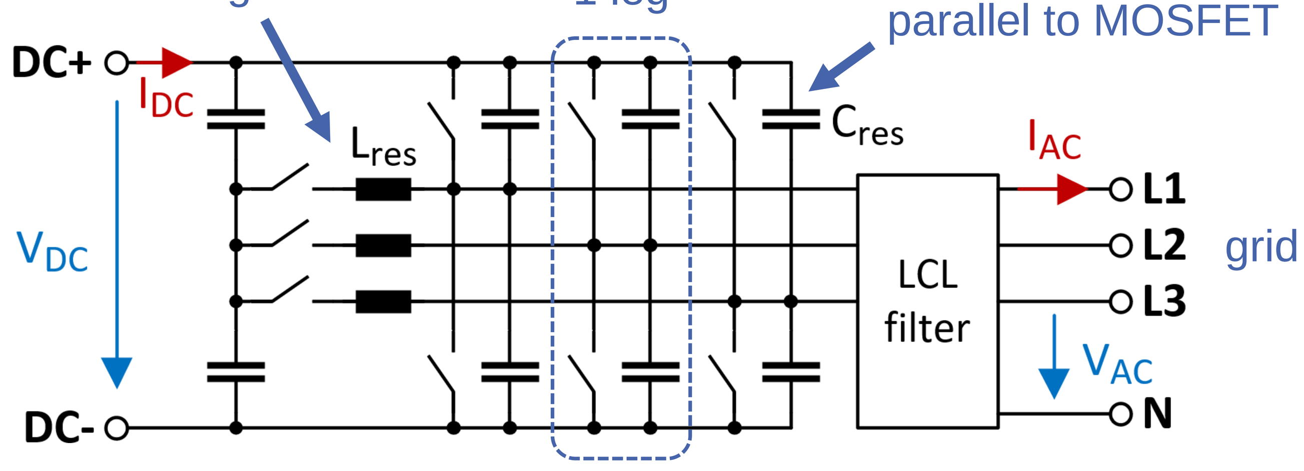
prototype of ARCPI as bidirectional V2G inverter



bidirectional power flow is possible — this inverter forms grid voltage & frequency — the investigated control algorithms run on this inverter



auxiliary circuit for soft-switching — 1 leg — resonant capacity parallel to MOSFET — EV battery (connected with an isolated bidirectional DC/DC converter)



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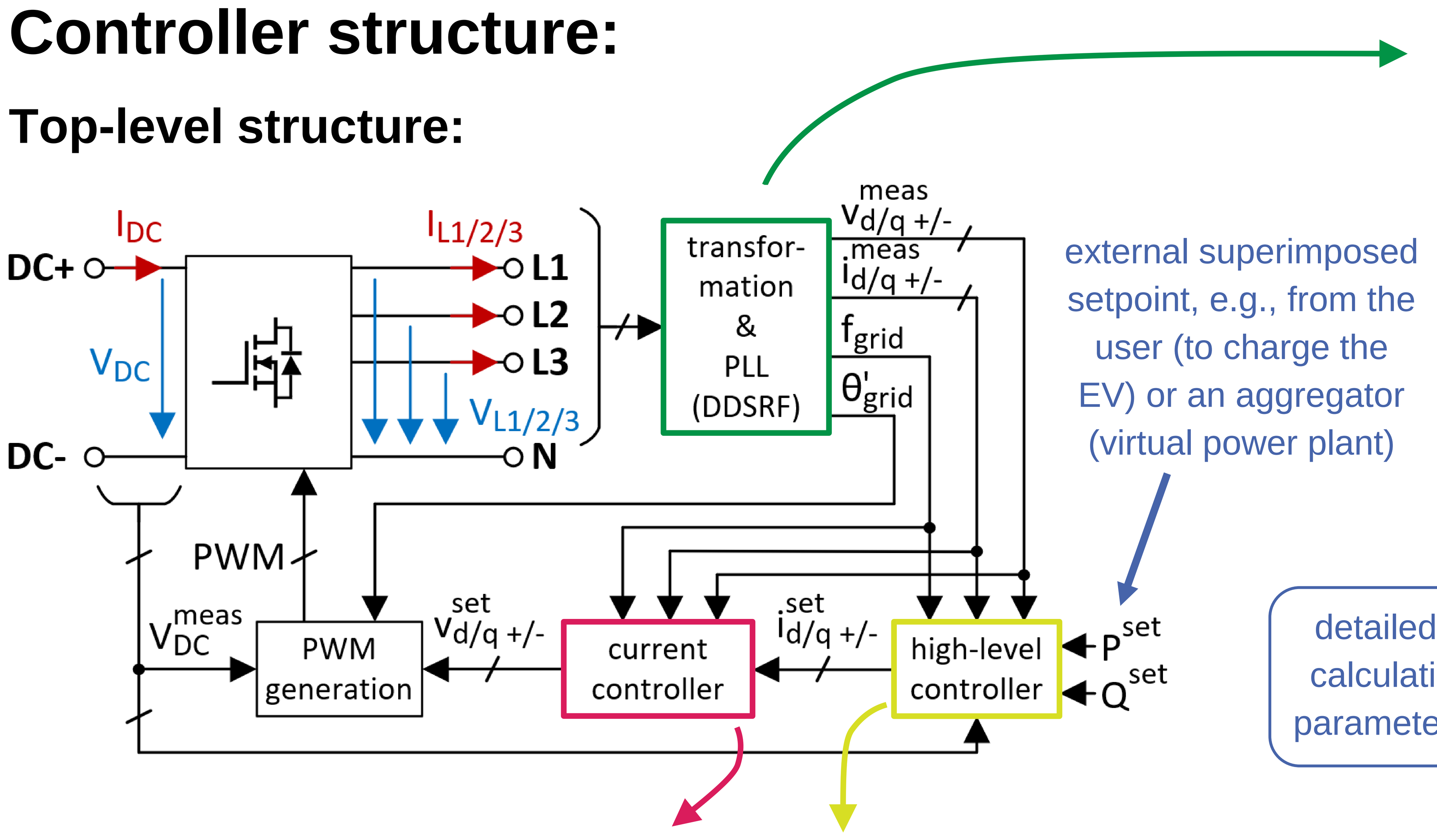
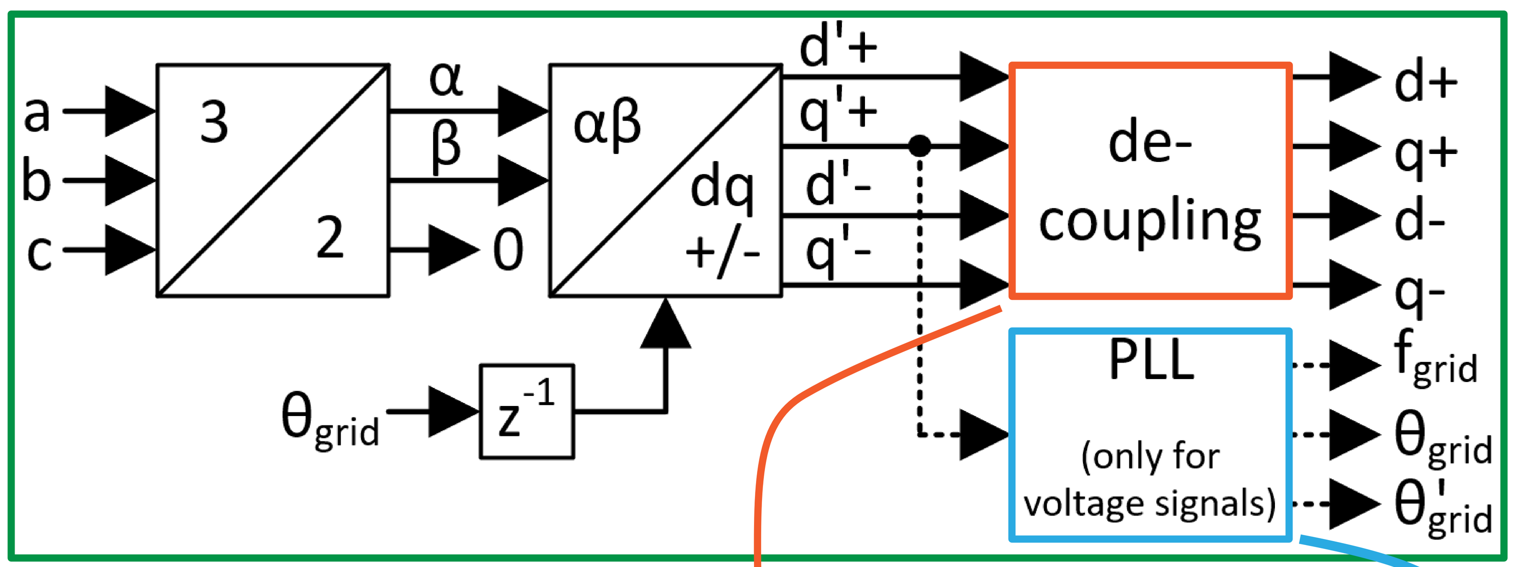
Controller structure:

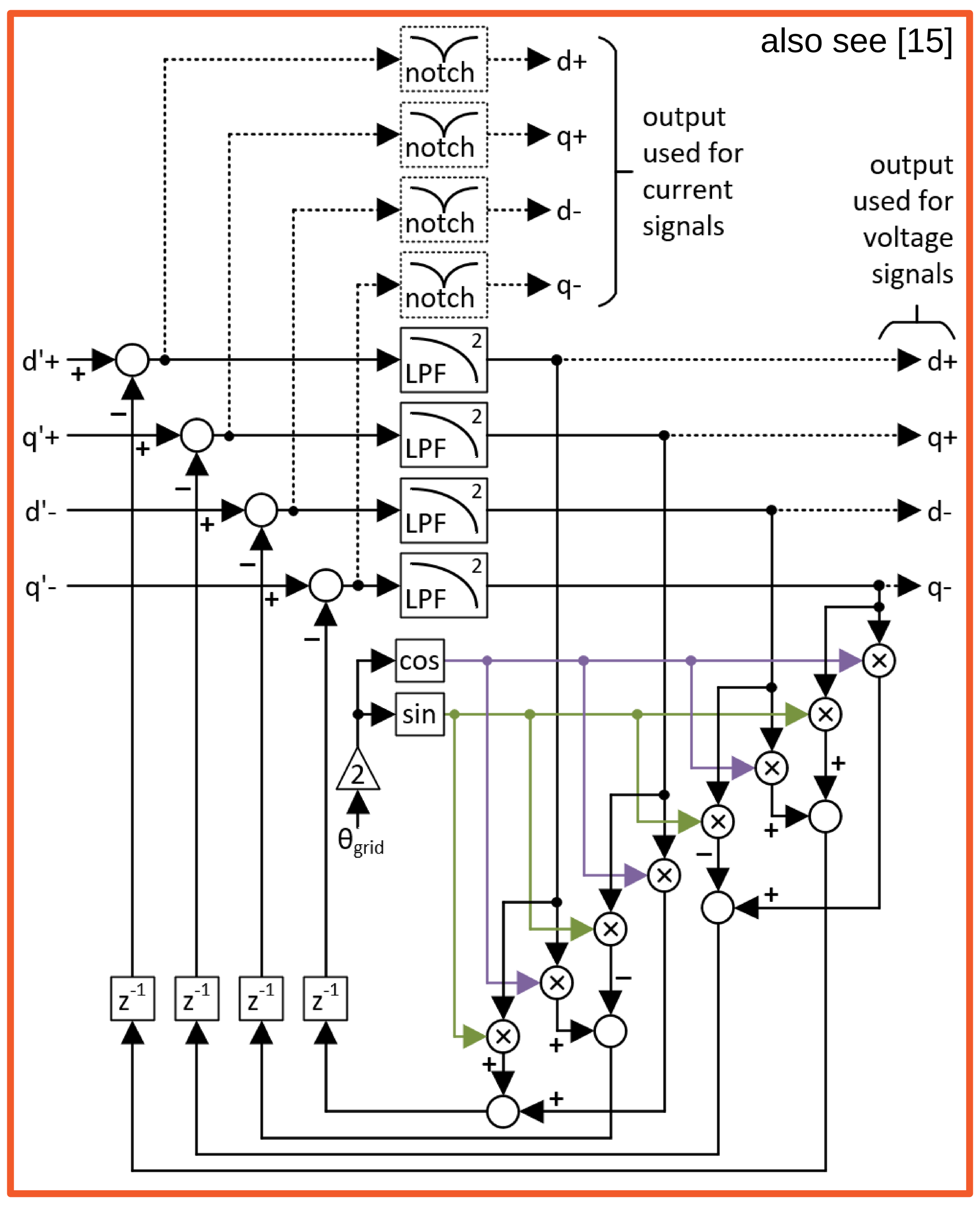
Top-level structure:



Transformation of signals: *a/b/c → d/q+ & d/q-*



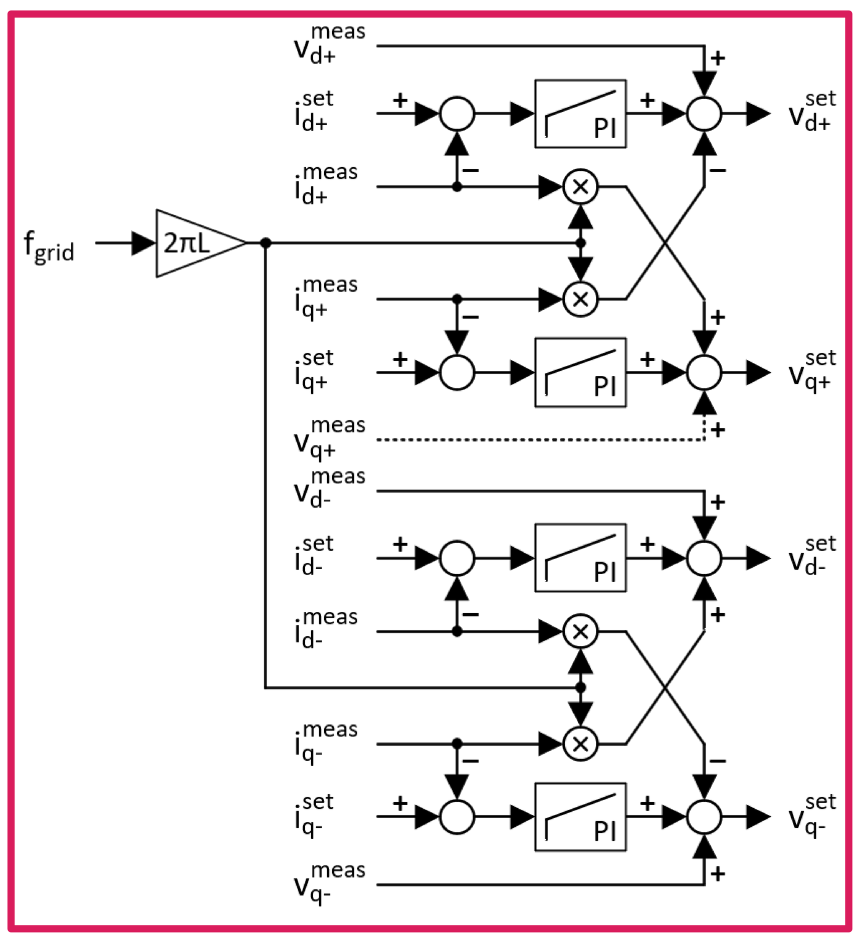
Decoupling: *steady state: const. d/q+/-*



detailed explanation with calculations and example parameters in the full paper

Current controller: [12-15]

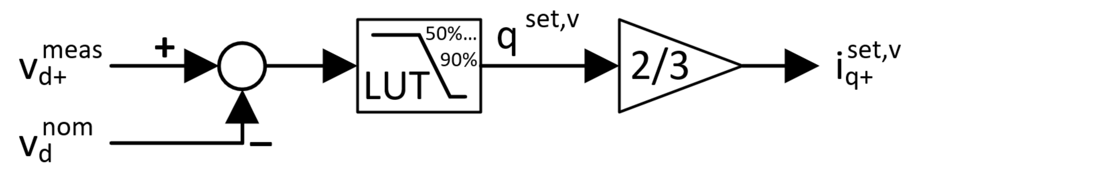
symmetric or asymmetric operation



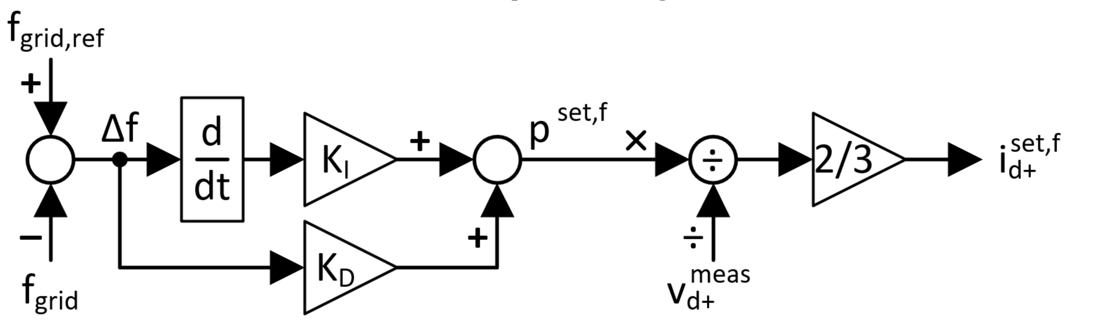
High-level control: e.g., ancillary services

one or multiple of:

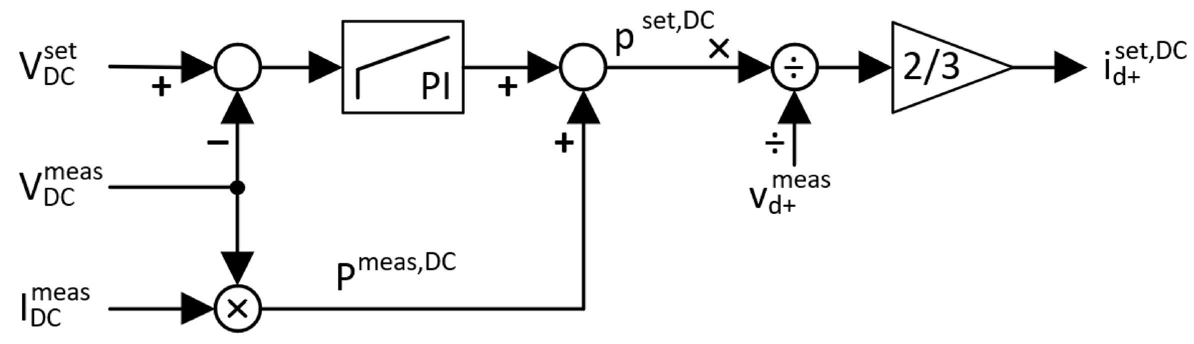
- AC grid voltage control (reactive power):



- virtual inertia & frequency control:

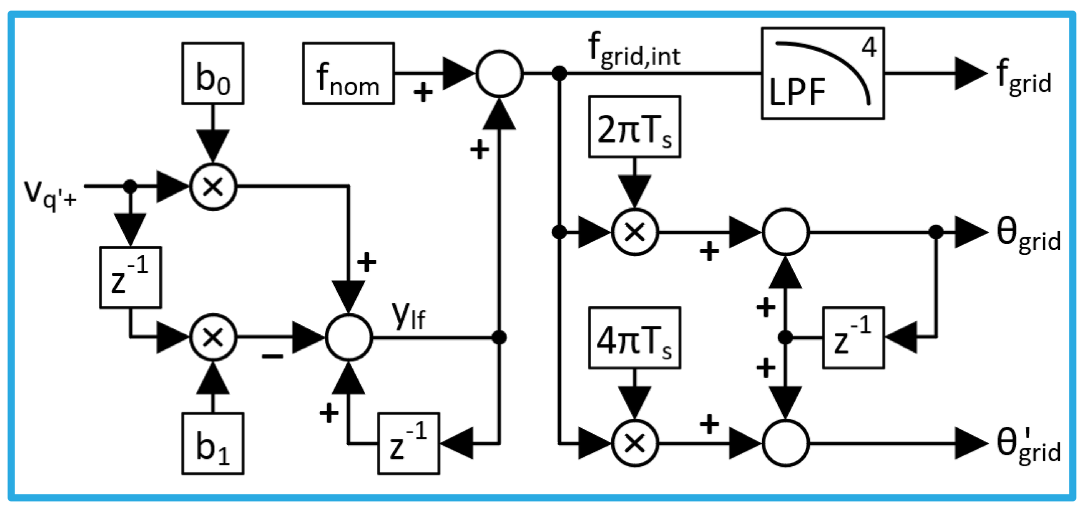


- DC link voltage controller:



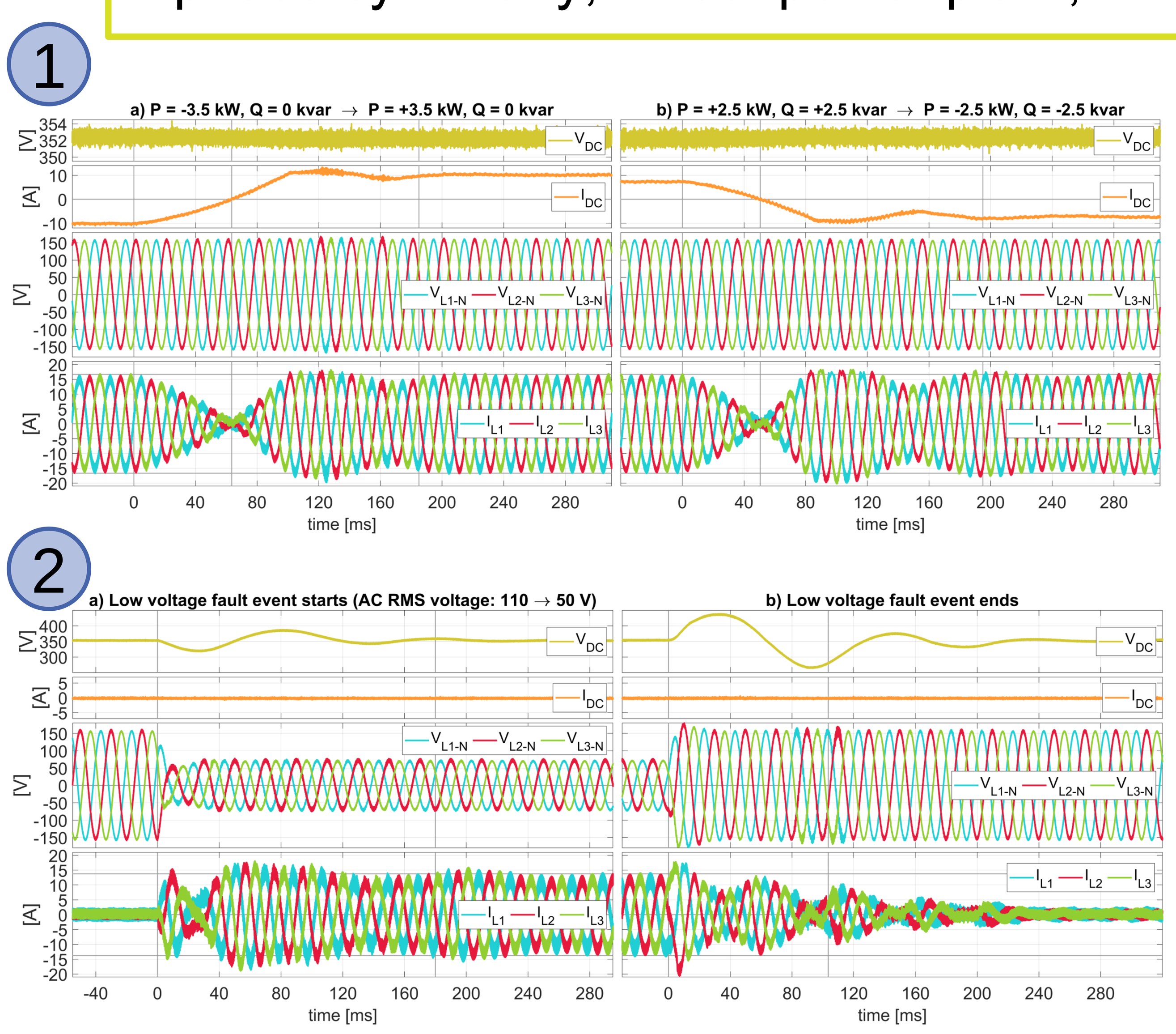
- phase symmetry, virtual power plant, …

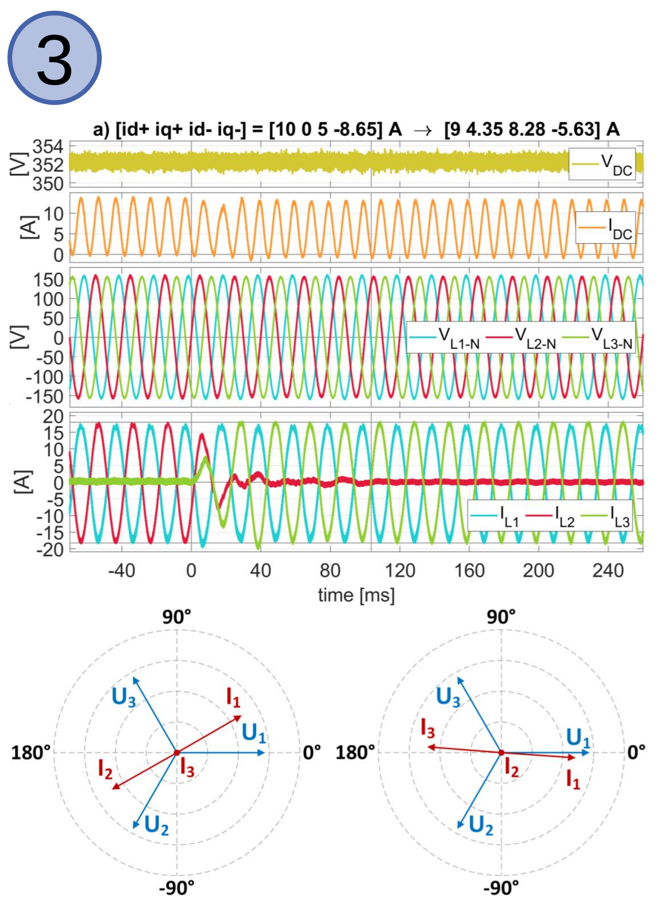
PLL: detect frequency & phase

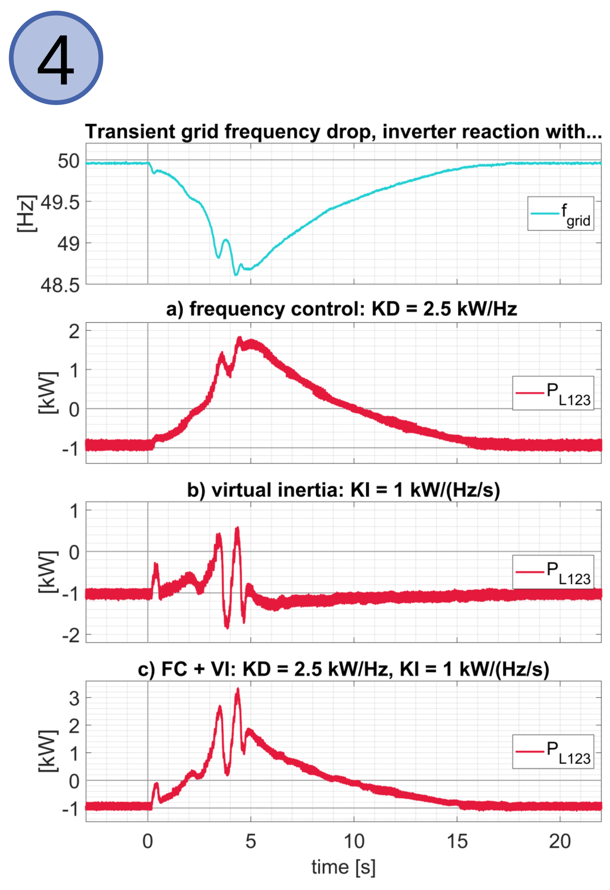


Experimental results:

1) Symmetric power:
   a) step from –3.5 kW load to +3.5 kW gen.
   b) With reactive power: +2.5 kW / +2.5 kvar to –2.5 kW / –2.5 kvar
2) Low-voltage fault ride through with reactive power provision
   (DC link unconnected! → DC charger without EV)
3) Asymmetric power: step from I_{L3} = 0 to I_{L2} = 0
4) Large frequency drop:
   a) frequency control
   b) virtual inertia
   c) both







Conclusion:

- Detailed presentation of controller for three-phase, bidirectional, grid-tie inverter
- Verified with prototype *(virtual inertia, frequency + voltage control, phase balancing)*

References: (same numbering as in the paper)

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