Fachhochschule Südwestfalen
University of Applied Sciences
Elektrische Energietechnik - Energieversorgung

APEC

# Smart Integration of Renewable Energy into Electrical Supply Systems

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# Agenda

- Status of the Renewable Energy in Germany
- Problems and Strategies for Grid Integration
- System Architecture and Control Methodology of Smart Inverter
- Implementation and Verification of Smart Inverter
- Conclusion

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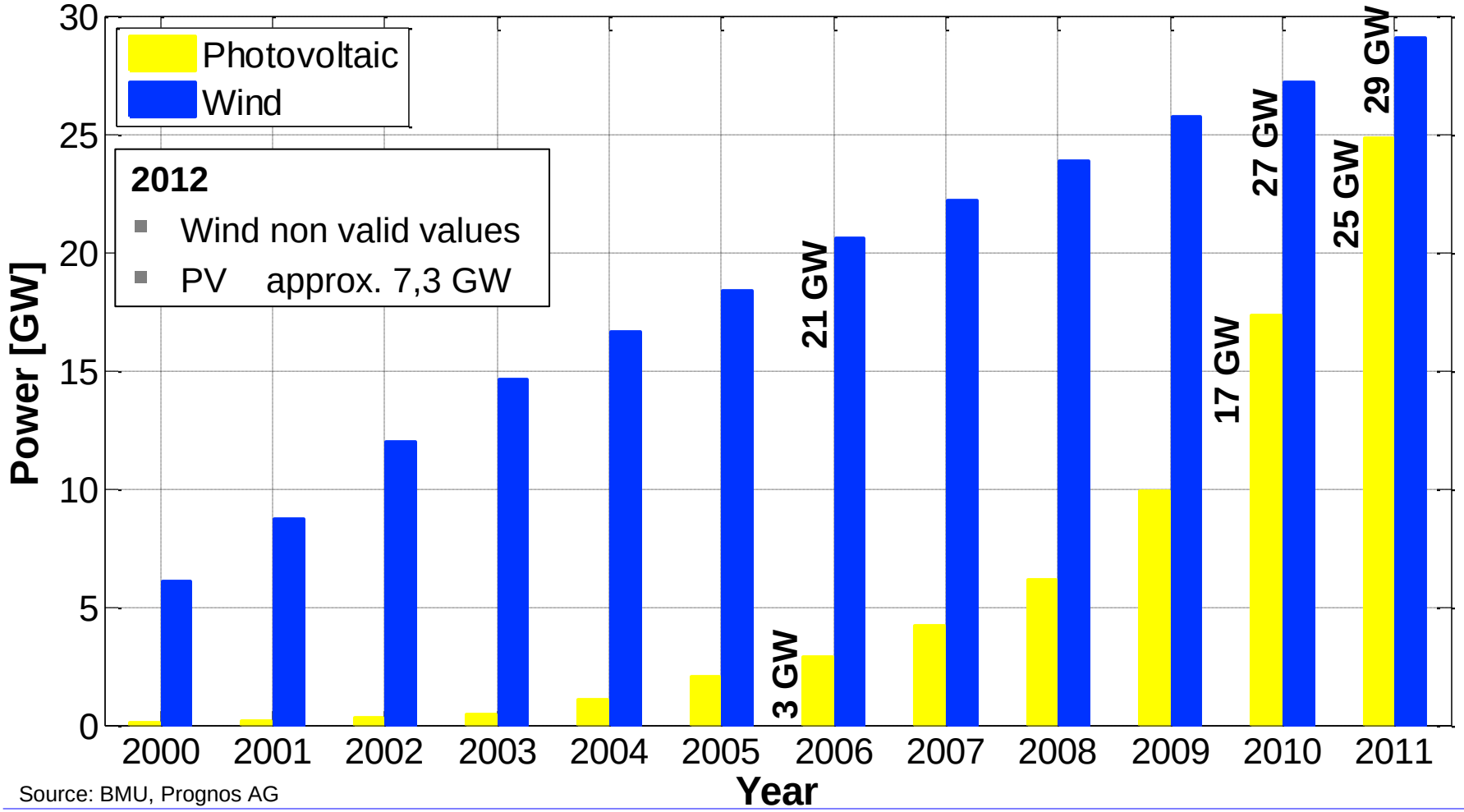
# Status of the Renewable Energy in Germany

- German Government's Renewable Energy Target
  - 18 % Renewable energy share in total primary energy consumption of Germany up to 2020
  - Renewable energy share in the electricity supply system of Germany:
    - 35.0 % up to 2020,
    - 50.0 % up to 2030,
    - 65.0 % up to 2040,
    - 80.0 % up to 2050.

Source: Research of Renewable Energy: http://www.fvee.de, Richtlinie 2009/28/EG Erneuerbare Energien

# Status of the Renewable Energy in Germany

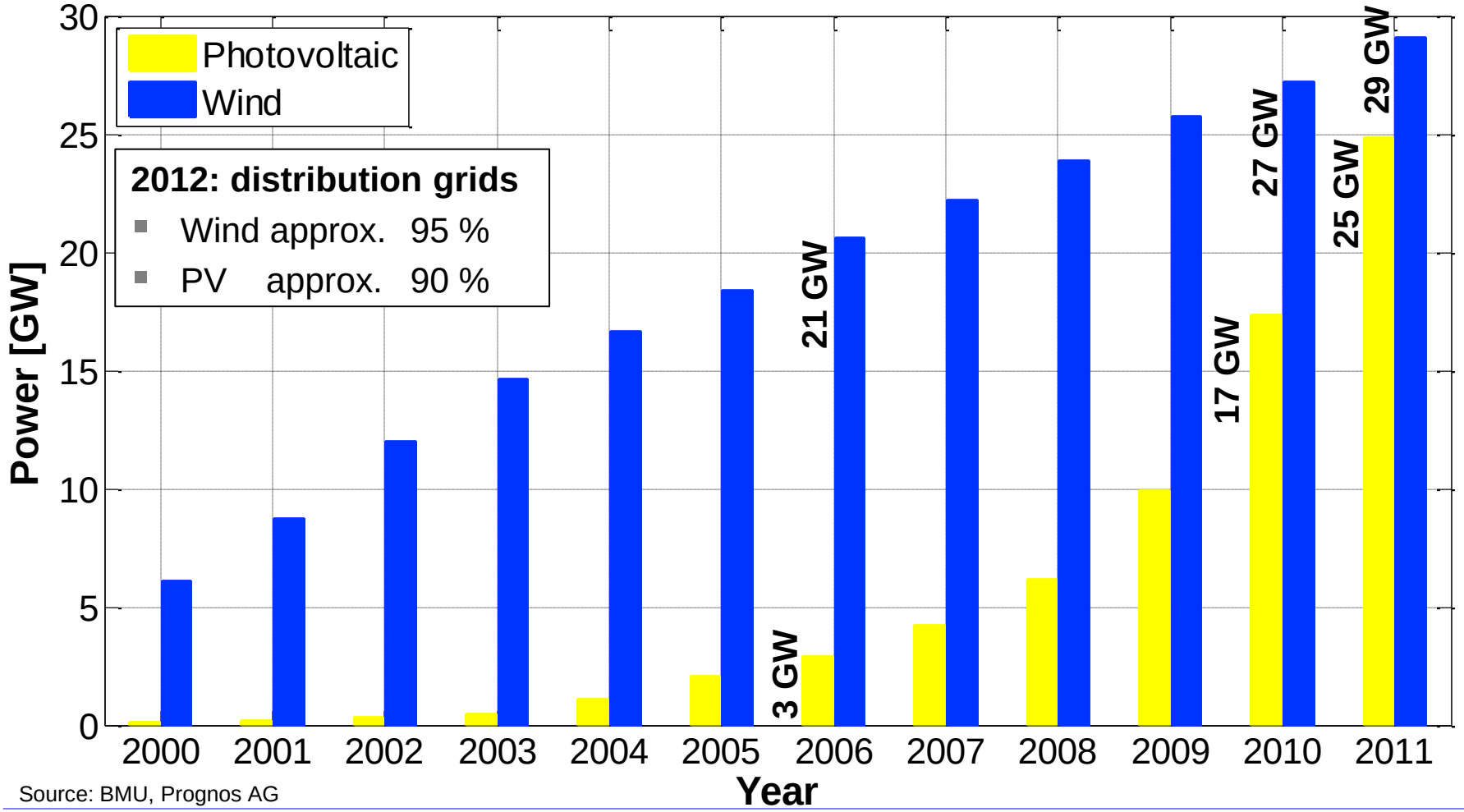
- Installed capacity of grid tied PV systems and wind turbines




Source: BMU, Prognos AG

# Status of the Renewable Energy in Germany

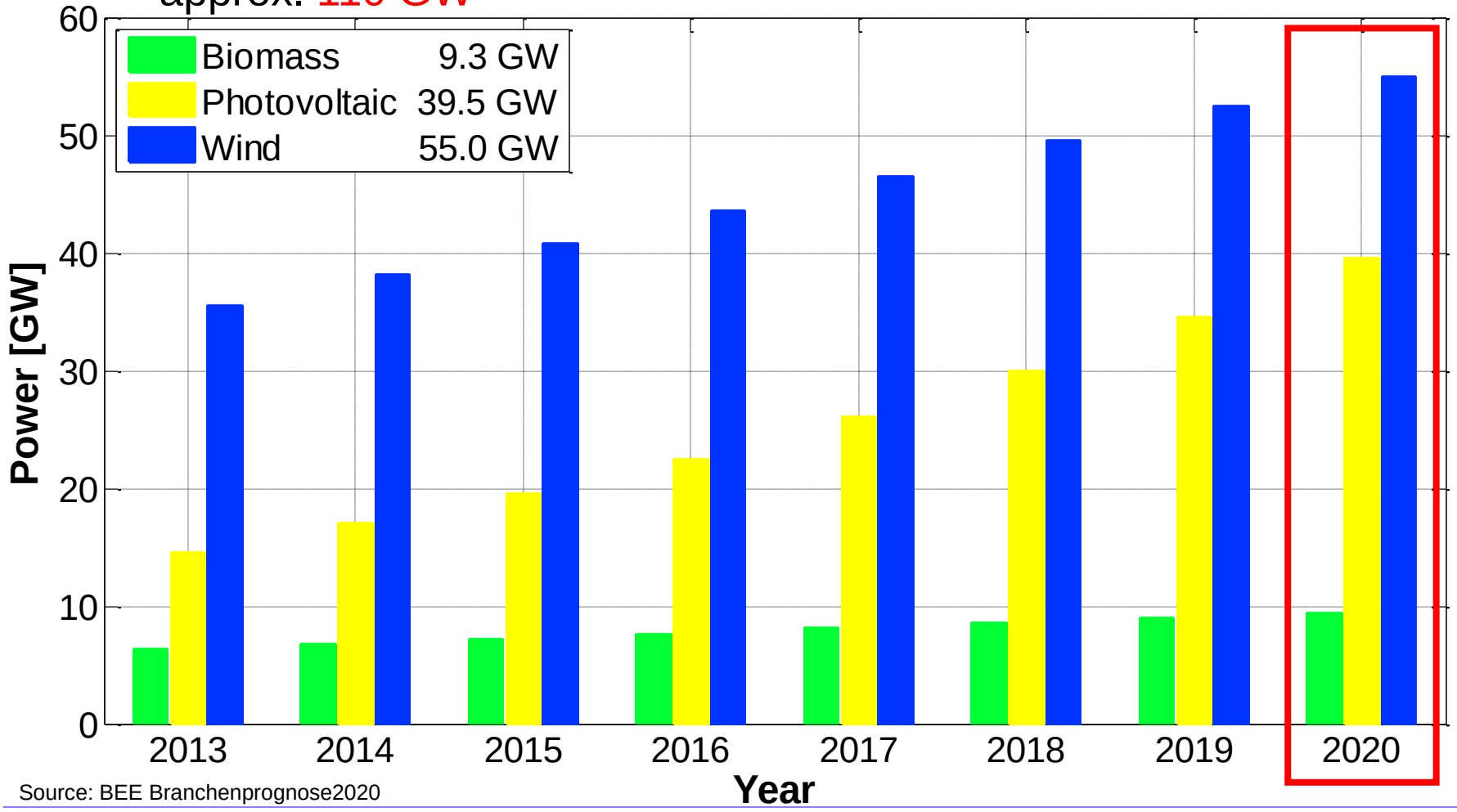
- Installed capacity of grid tied PV systems and wind turbines




Source: BMU, Prognos AG

# Status of the Renewable Energy in Germany

- Estimated electrical capacity of RES in Germany up to 2020
  - approx. 110 GW




Source: BEE Branchenprognose2020

# Status of the Renewable Energy in Germany

- Offshore wind development

Source: http://www.alpha-ventus.de/

Alpha Ventus:
12 turbines
60 MW

Source: http://www.enrw.de

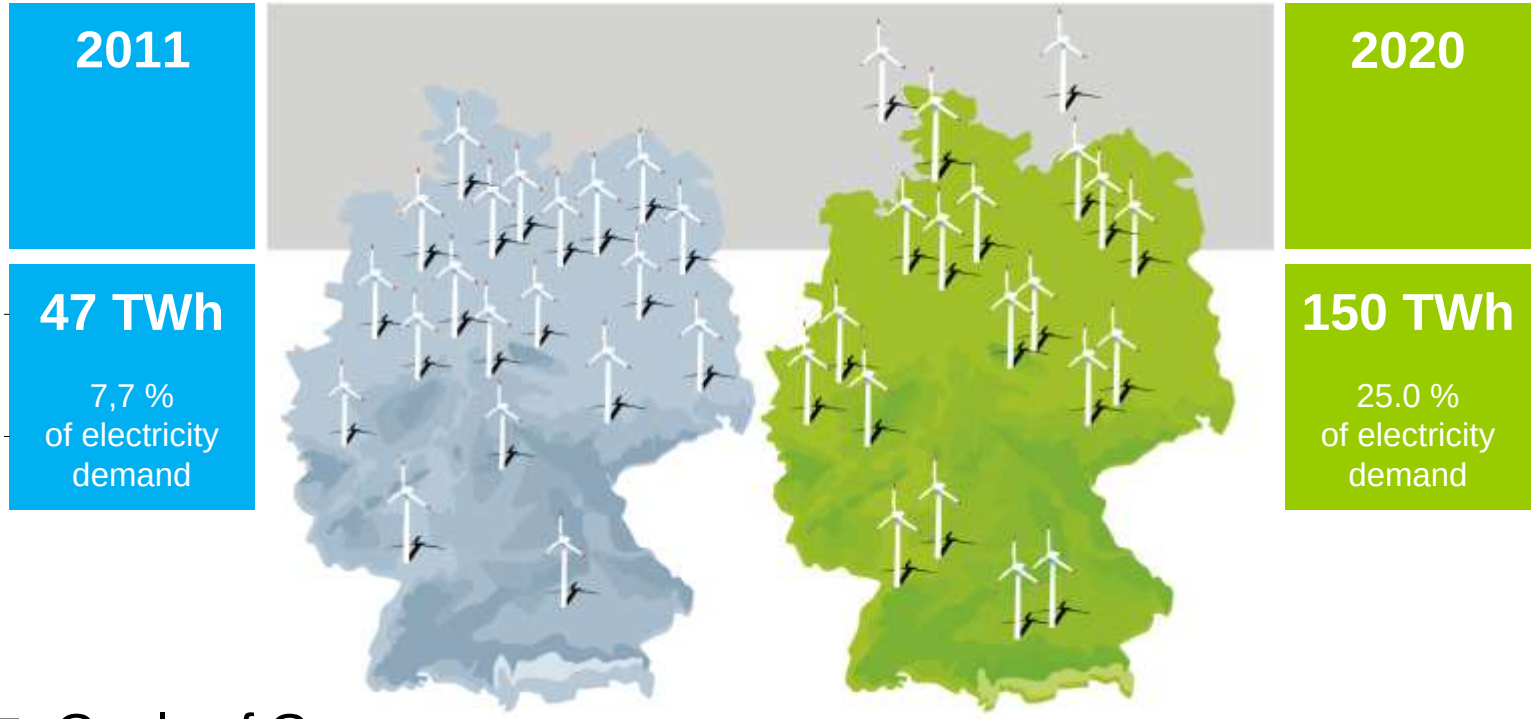
Baltic 1:
21 turbines
48.3 MW

Source: http://www.bard-offshore.de/

BARD Offshore 1:
80 turbines
400 MW (2013)

# Status of the Renewable Energy in Germany

- Repowering is already in process




  - Goals of Germany:
    - Halving the number of wind turbines
    - Double the installed wind power
    - Triple the electricity generation related to 2011

Source: http://www.wind-energie.de/ (recalculated for 2011)

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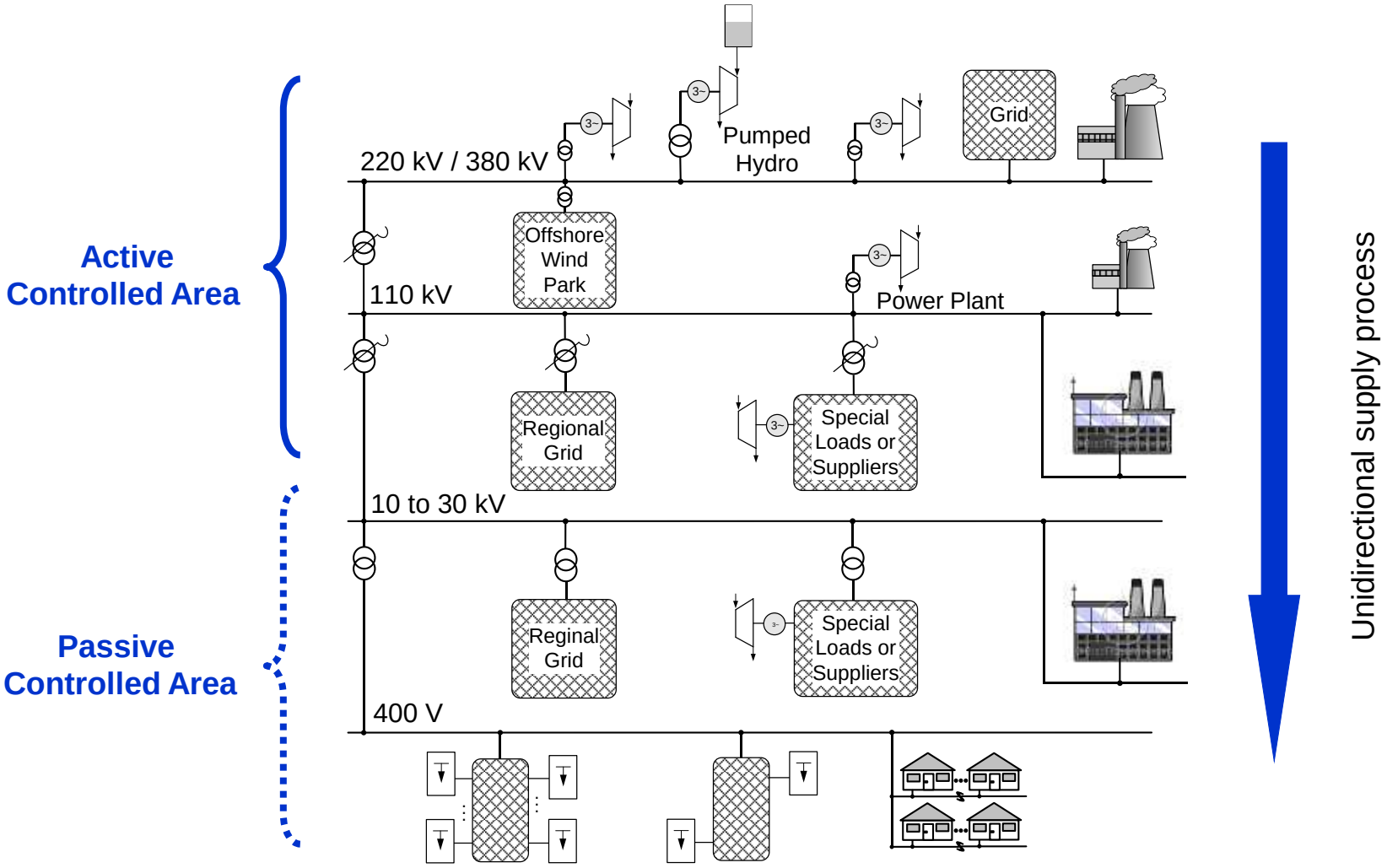
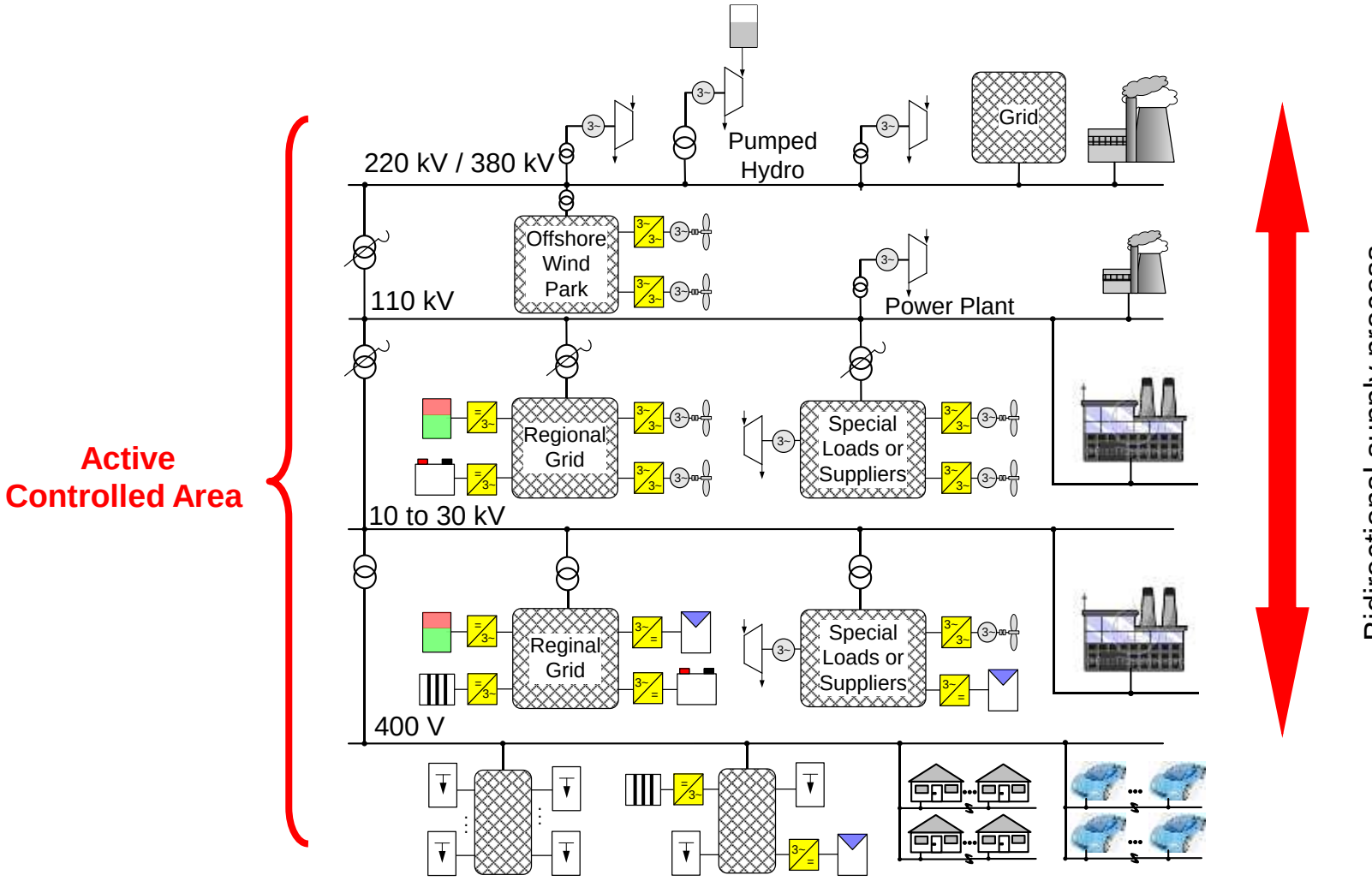
# Problems and Strategies for Grid Integration

- Conventional power systems



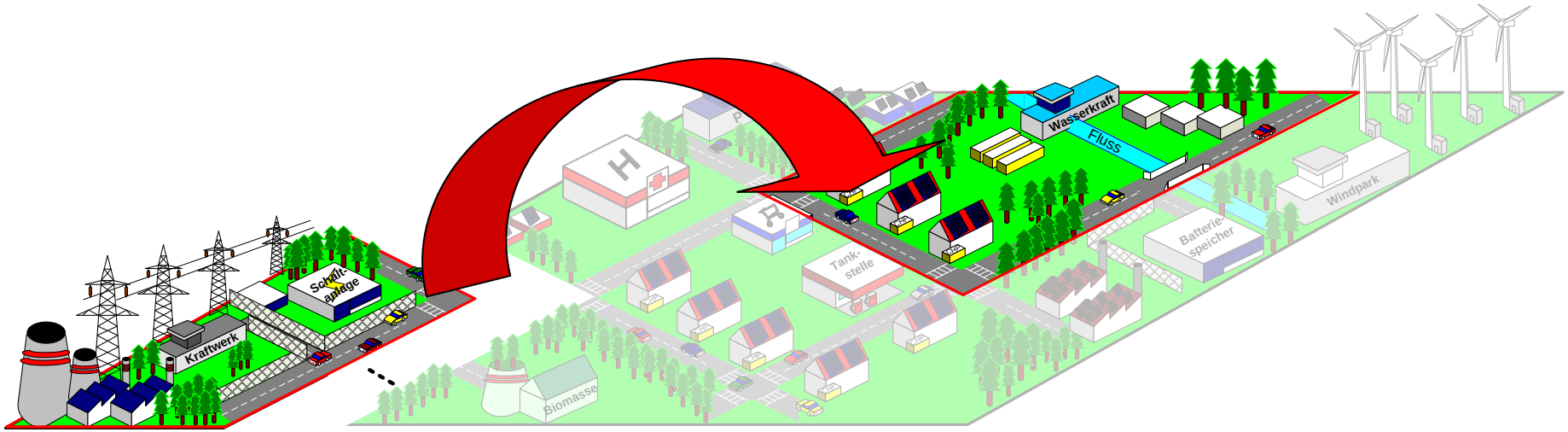
# Problems and Strategies for Grid Integration

- Moving towards decentralized power systems



# Problems and Strategies for Grid Integration

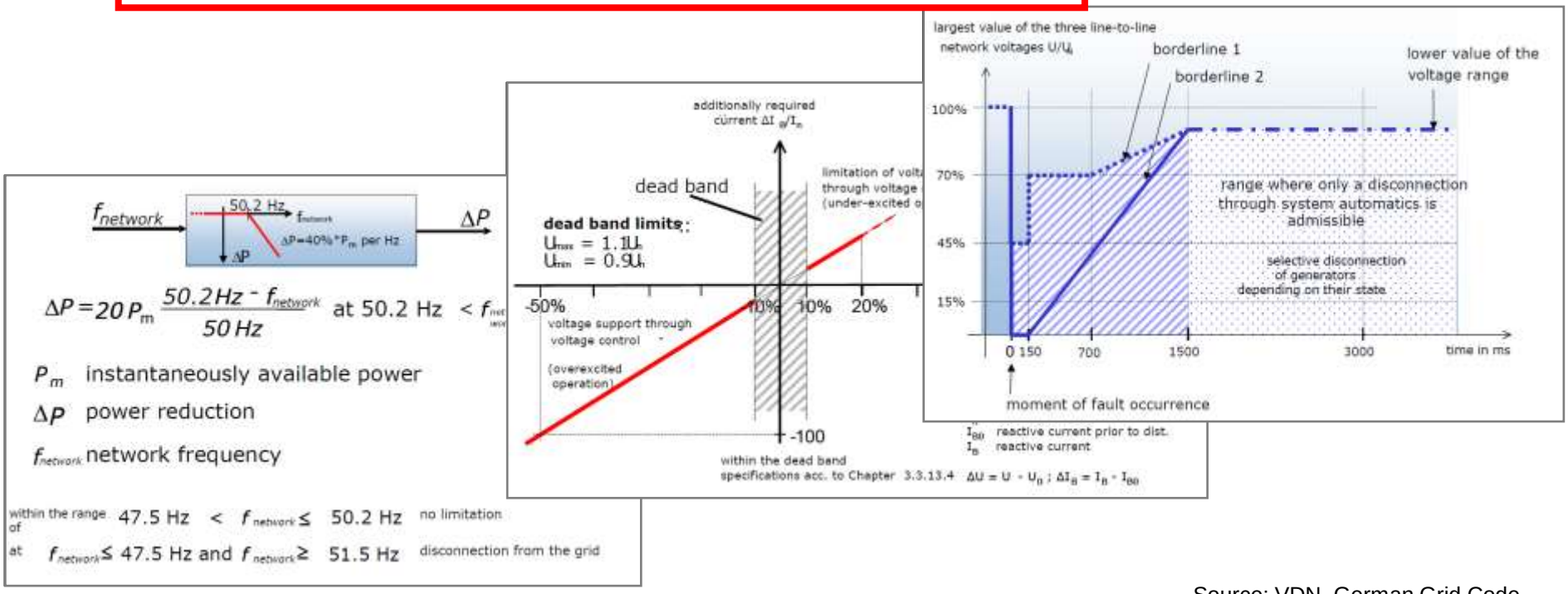
- Transfer of the conventional control schemas into all grid levels




Conventional control schemas of transmission networks must be extended to distribution networks !

# Problems and Strategies for Grid Integration

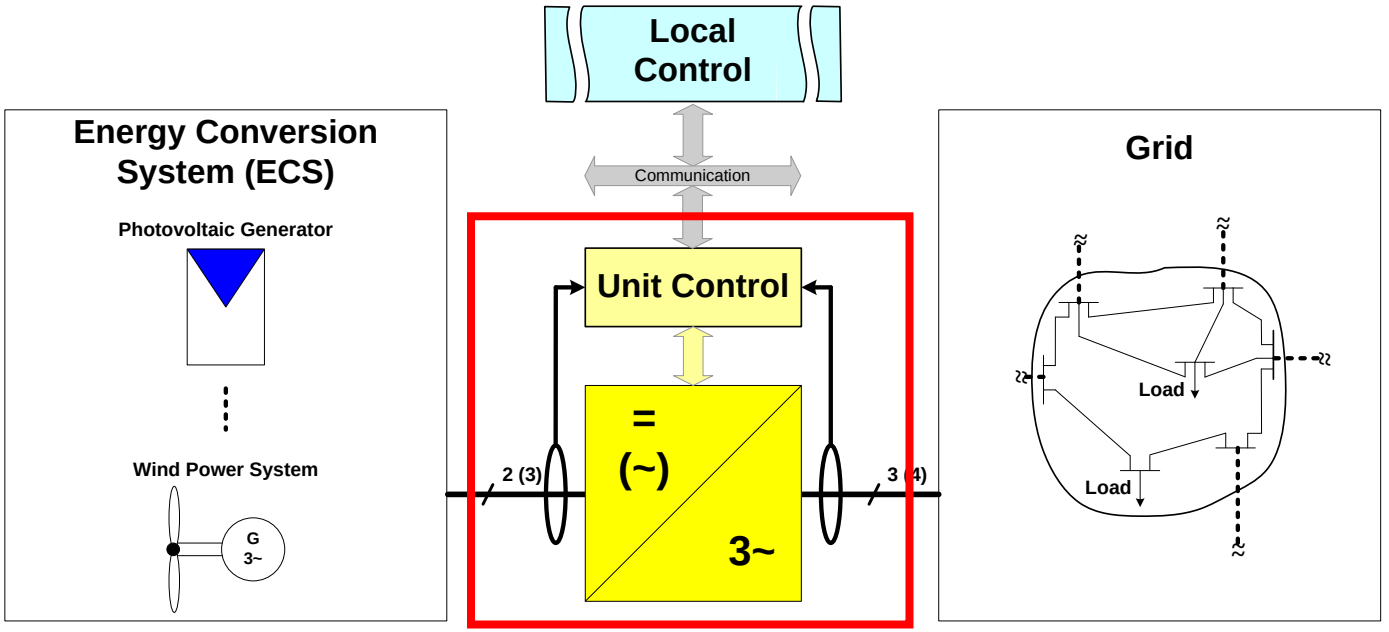
- Grid Code for decentralized generators in Germany
  - Power reduction (supervisory side)
  - Frequency and voltage droop (unit side)
  - Fault Right Through (unit side)




Source: VDN, German Grid Code

# Problems and Strategies for Grid Integration

- Inverter as Flexible Grid Interface for Integration of DERs




Inverter is the **Essential Device** for optimal integration of DERs

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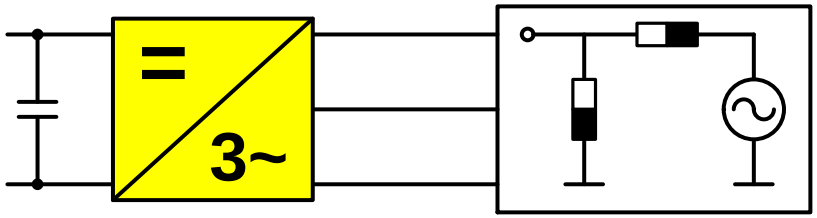
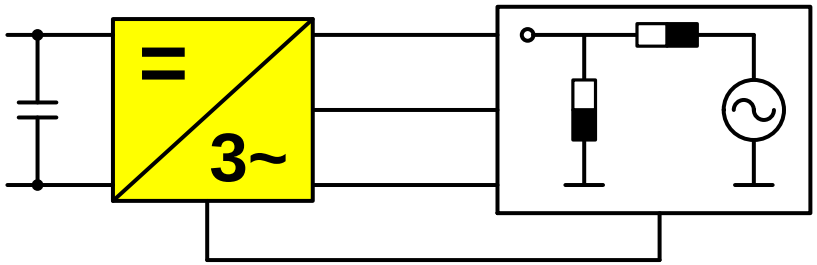
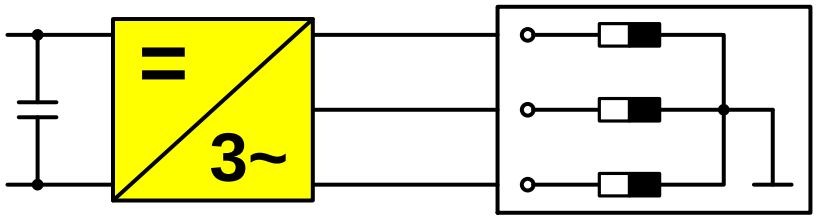
- Technical requirements of inverter as grid integration of DERs
  - DERs integration into ***Active Network***
    - Symmetrical active network



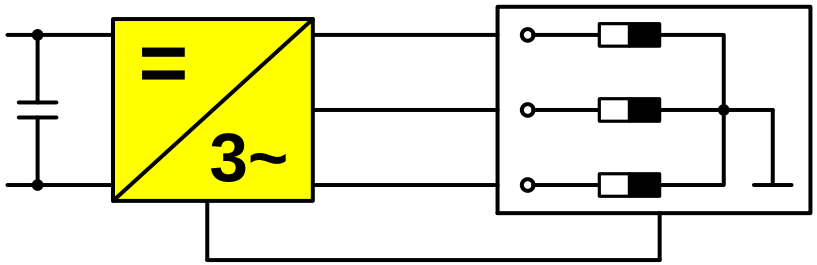

    - Asymmetrical active network



- Technical requirements of inverter as grid integration of DERs
  - DERs integration into ***Passive Network***
    - Symmetrical passive network

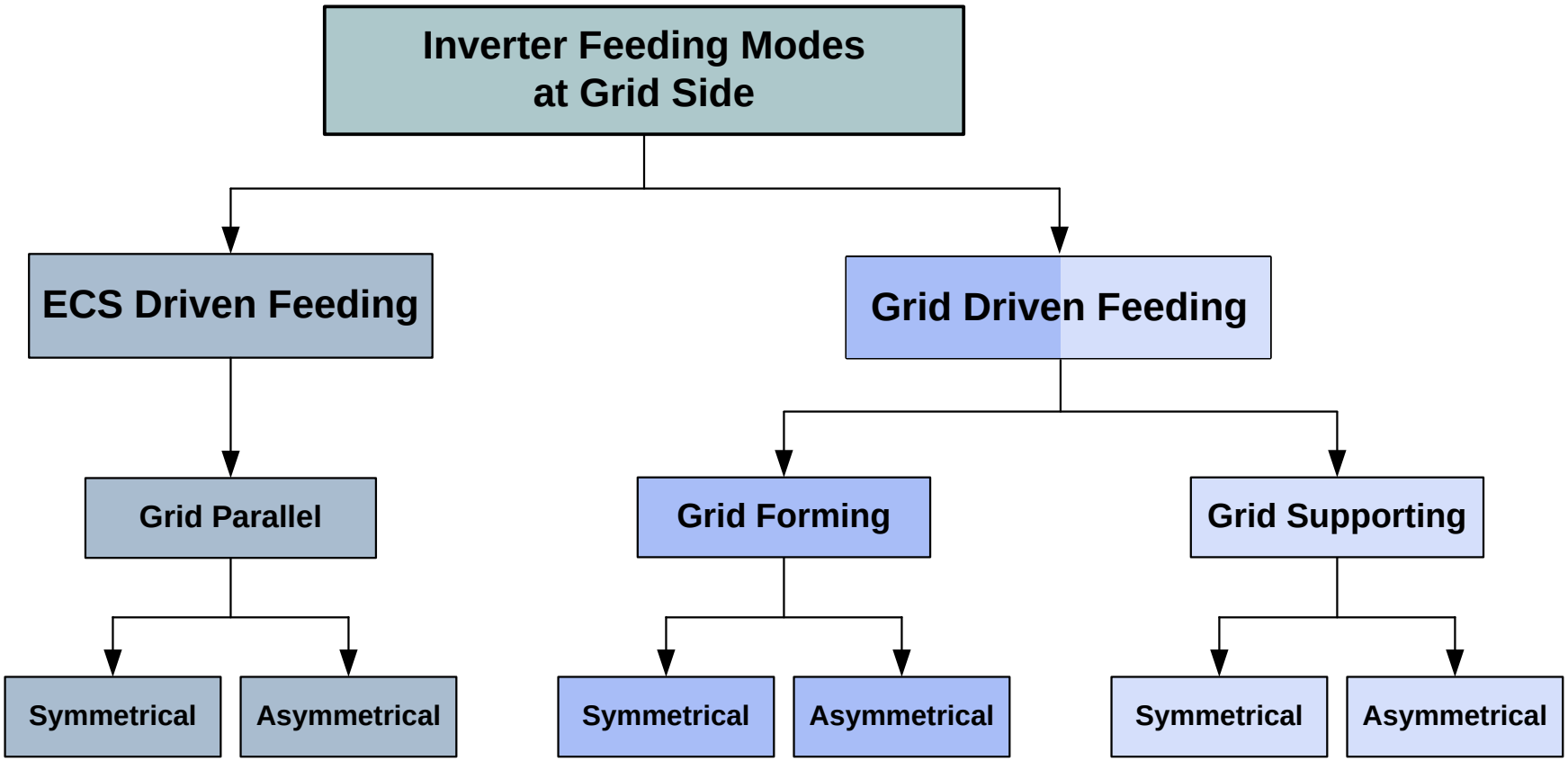



    - Asymmetrical passive network



# System Architecture and Control Methodology of Smart Inverter

- Inverter feeding modes at grid side (Unit Control)

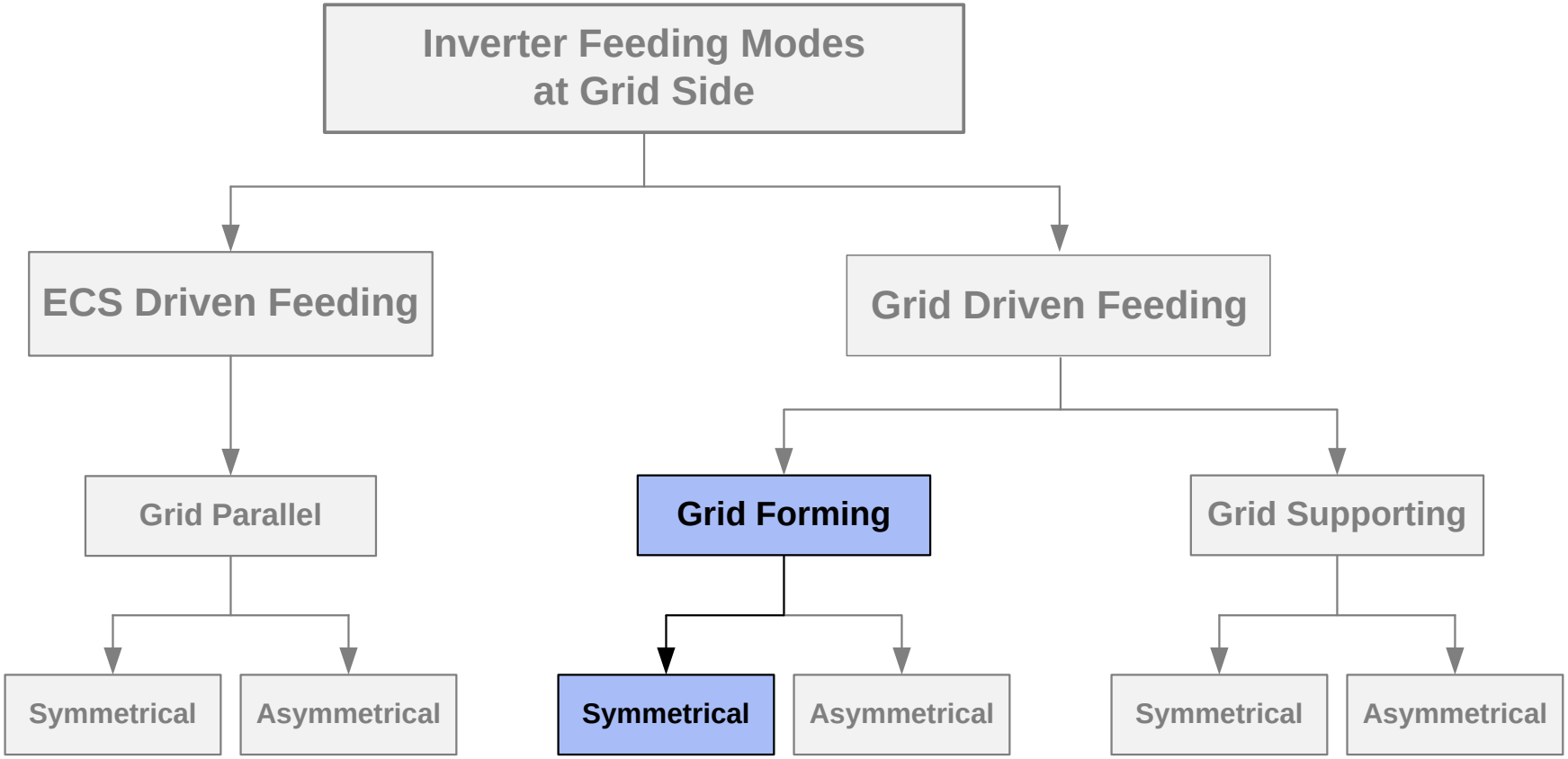


# System Architecture and Control Methodology of Smart Inverter

- Inverter feeding modes at grid side (Unit Control)

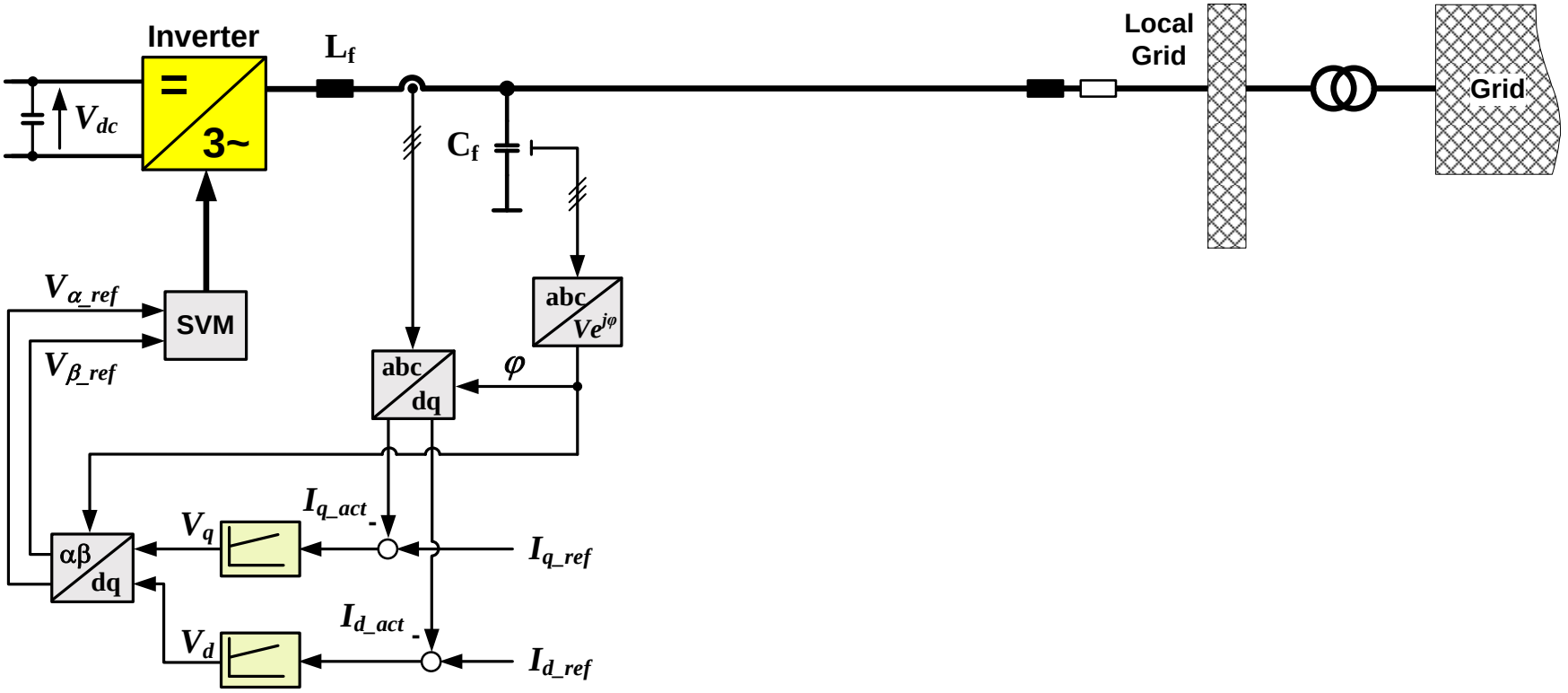
| | |
|---|---|
| Grid forming: | f- and V-control with nominal reference values (grid side driven) |
| Grid supporting: | P- and Q-control with external reference values from load dispatcher (grid side driven) |
| Grid supporting: | P- and V-control with external reference values from load dispatcher (grid side driven) |
| Coupling: | Δf/ΔP and ΔV/ΔQ droop (grid side driven)<br>ΔP/Δf and ΔQ/ΔV droop (grid side driven) |
| Grid parallel: | P- (and Q-) control with reference values from source (unit side driven) |

- Symmetrical grid forming mode inverter



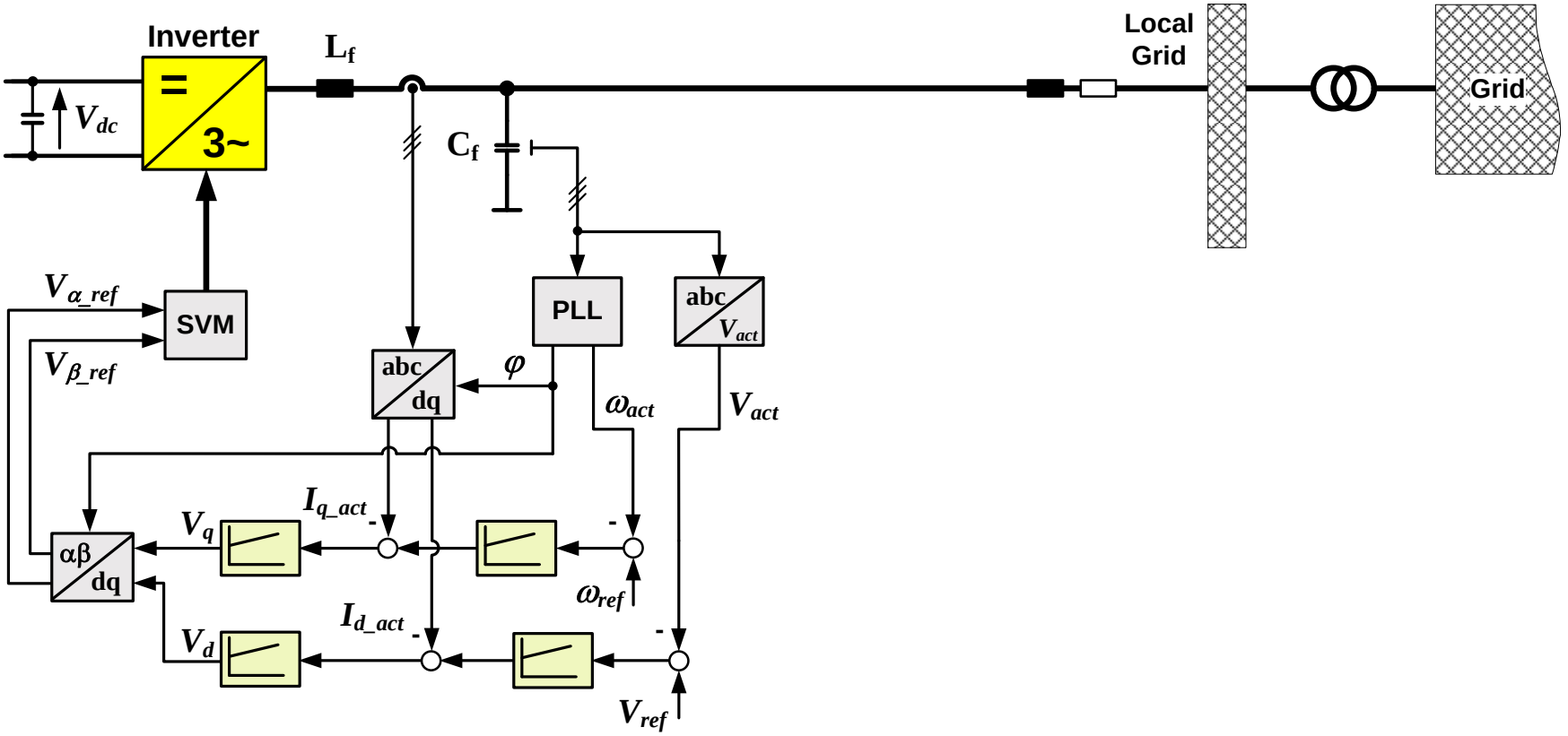
# System Architecture and Control Methodology of Smart Inverter

- Symmetrical current control inverter



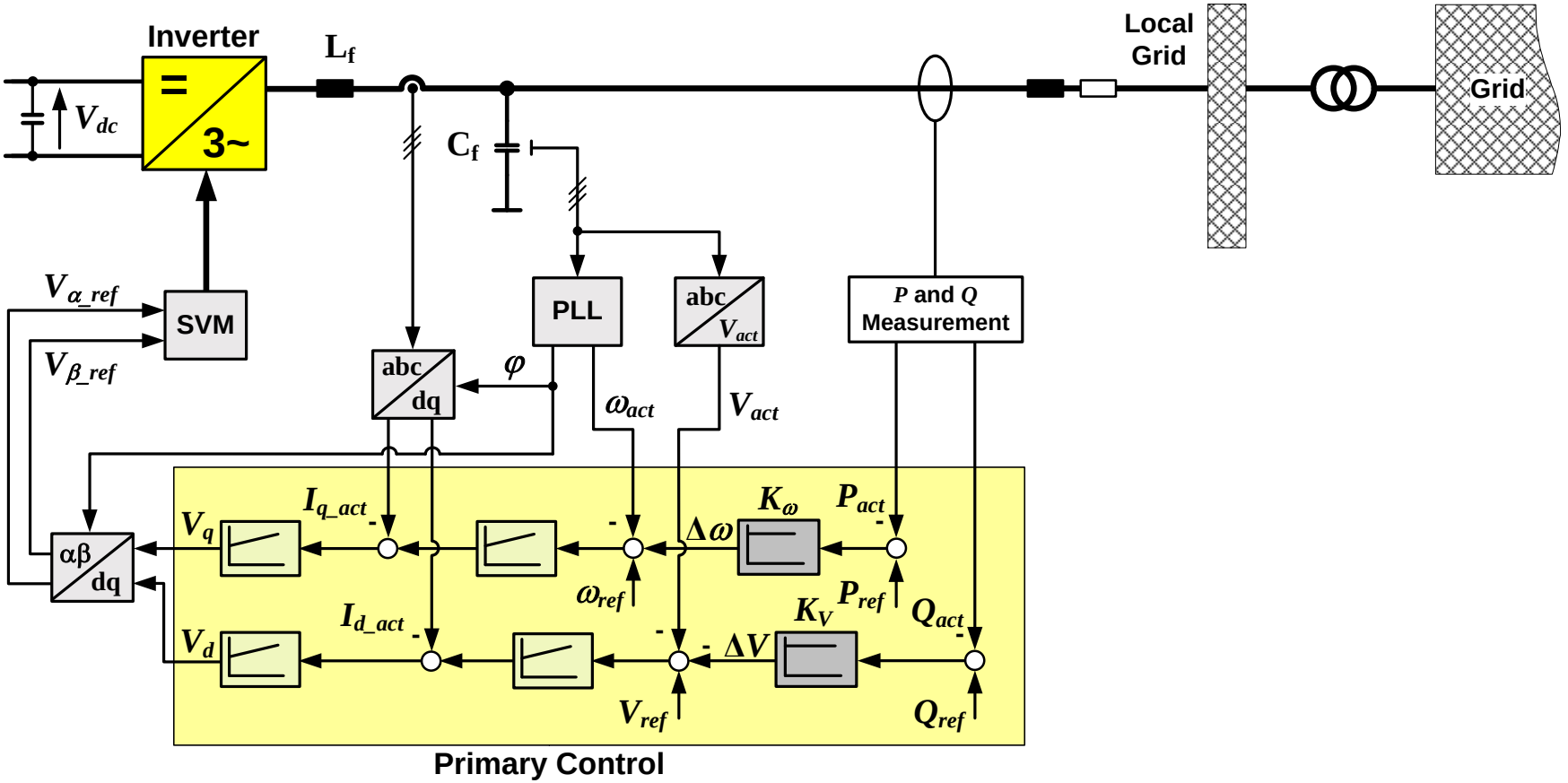
# System Architecture and Control Methodology of Smart Inverter

- Symmetrical grid forming mode inverter



# System Architecture and Control Methodology of Smart Inverter

- Symmetrical grid forming mode inverter with primary control



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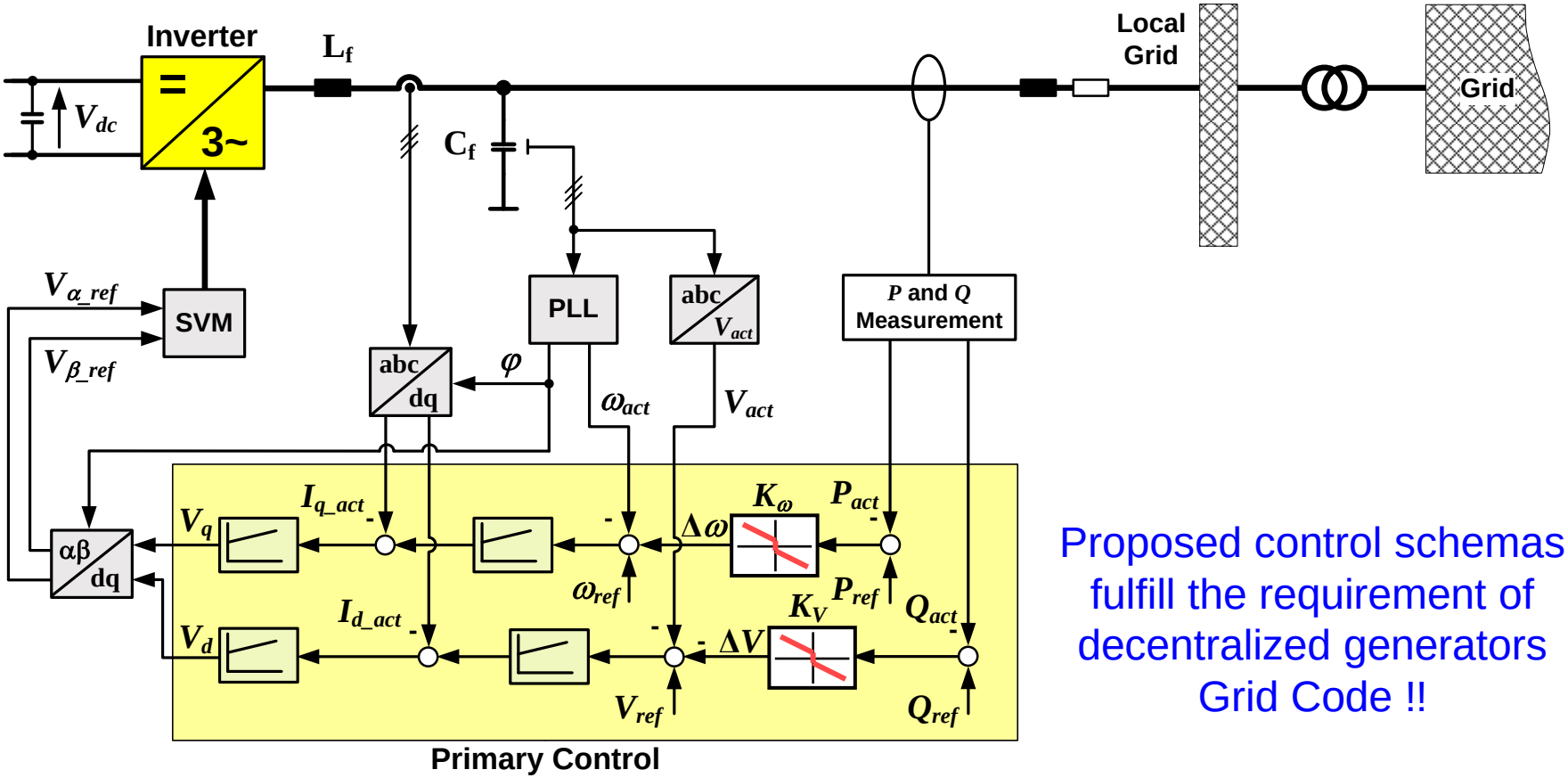
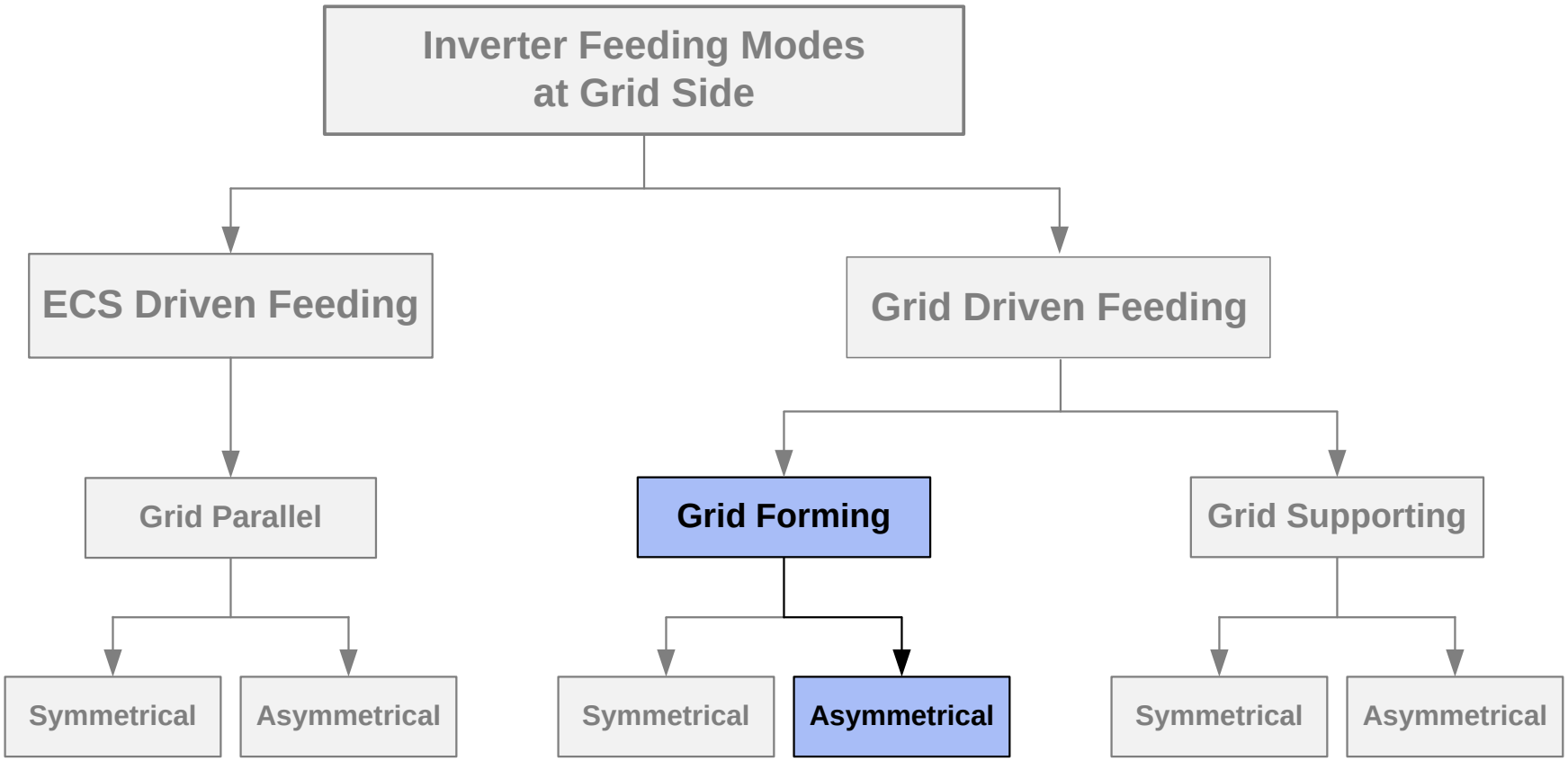



Proposed control schemas fulfill the requirement of decentralized generators Grid Code !!

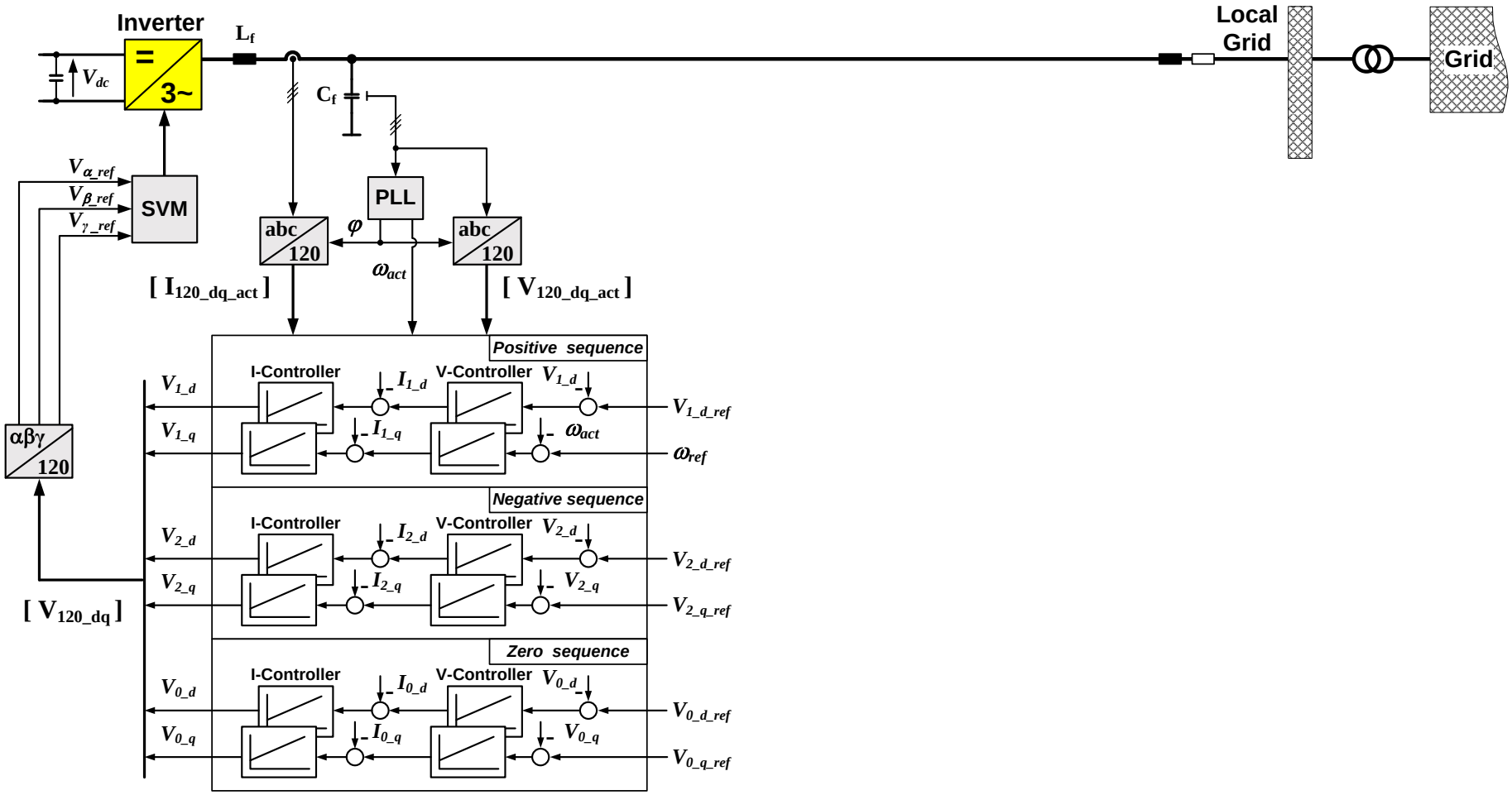
# System Architecture and Control Methodology of Smart Inverter

- Asymmetrical grid forming mode inverter



# System Architecture and Control Methodology of Smart Inverter

- Asymmetrical grid forming mode inverter



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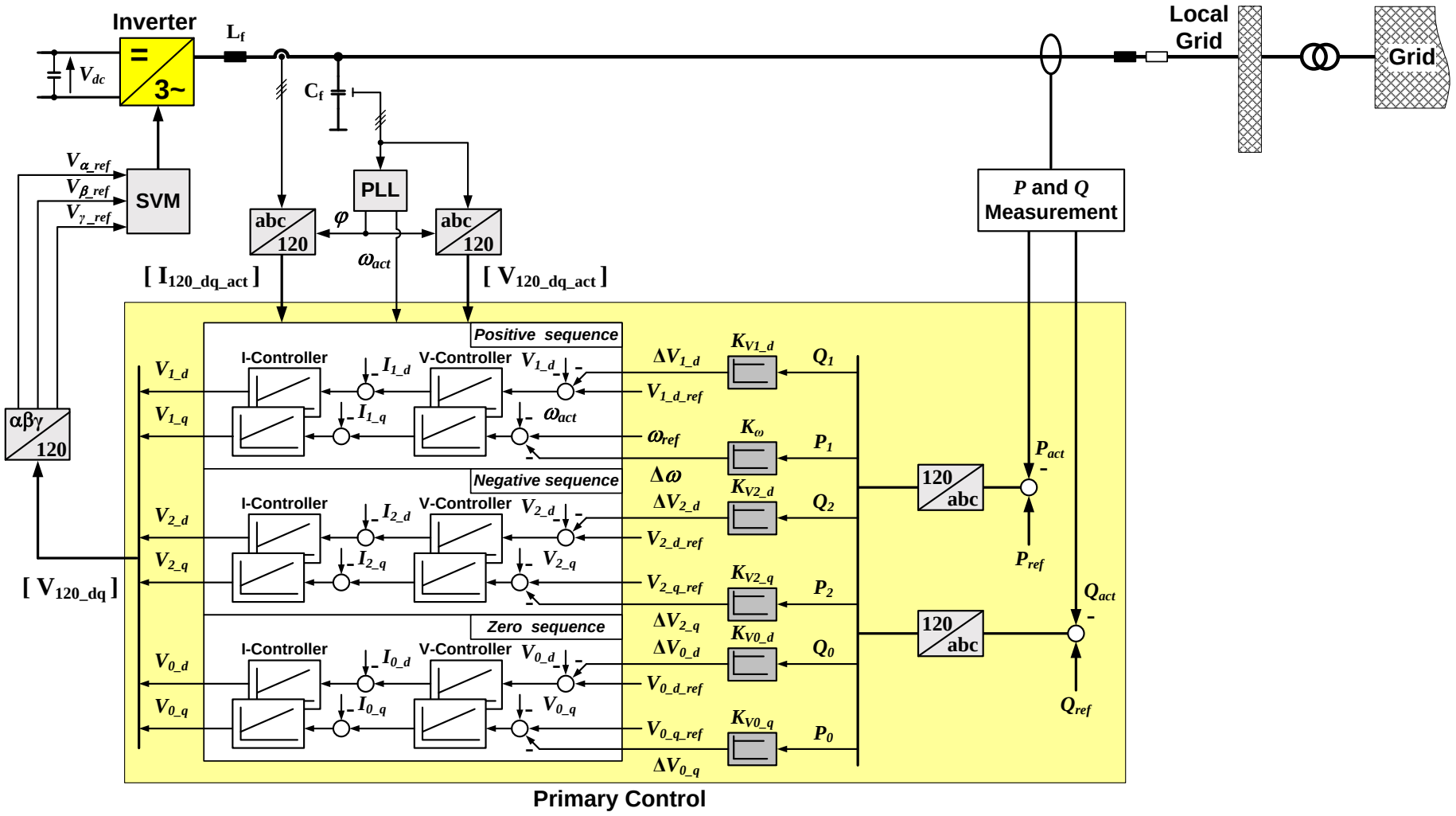
- Asymmetrical grid forming mode inverter with primary control




Primary Control

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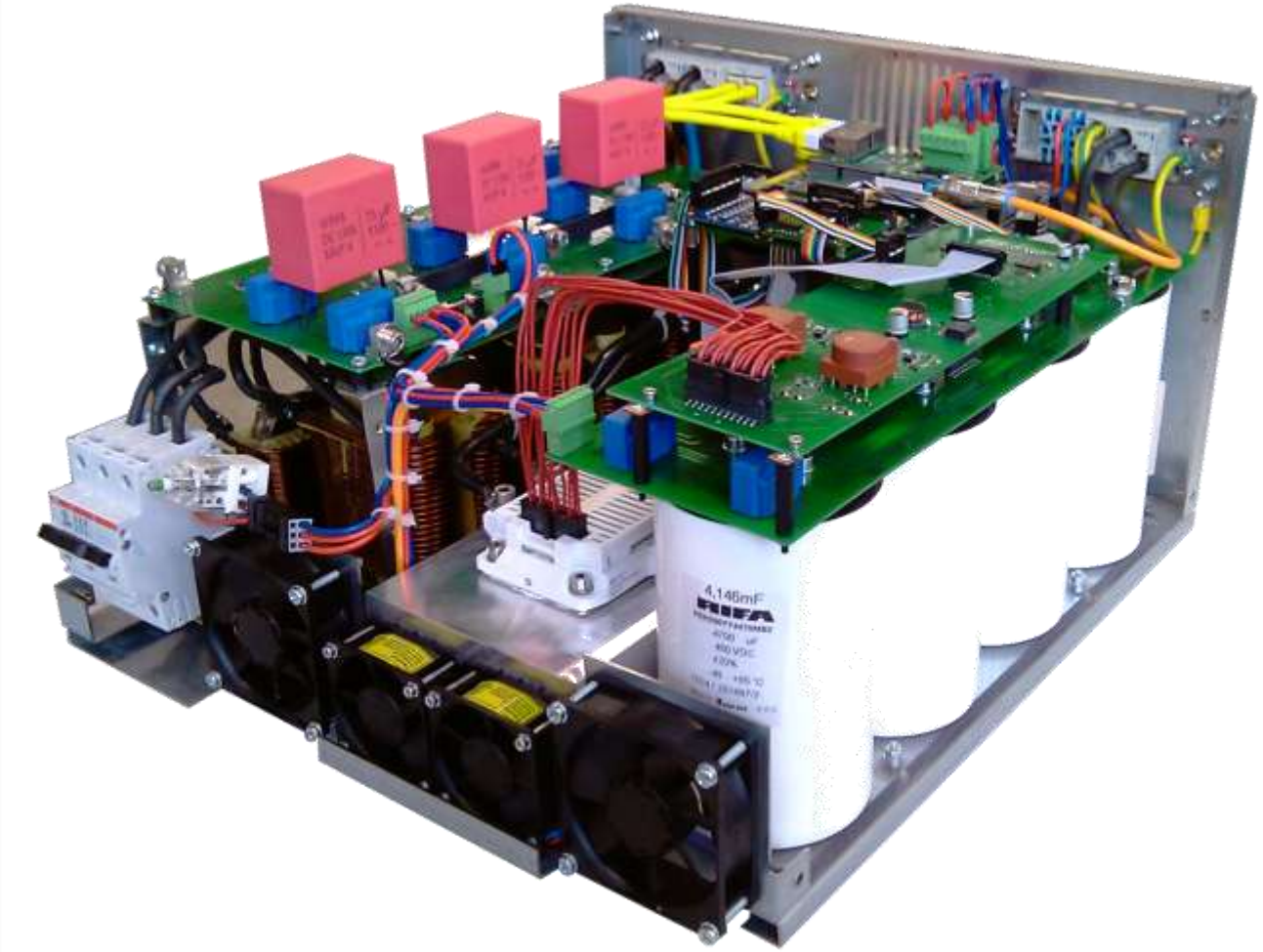
# Implementation and Verification of Smart Inverter

- Developed smart inverter: technical specifications

| | |
|---|---|
| Total Power | 100.0 kVA |
| 2 x Module | 12.5 kVA |
| 1 x Module | 25.0 kVA |
| 1 x Module | 50.0 kVA |
| Max. Input Voltage | 800 V (DC) |
| Output Voltage | 3 x 400 V (AC) |
| Max. Efficiency | 95 % |

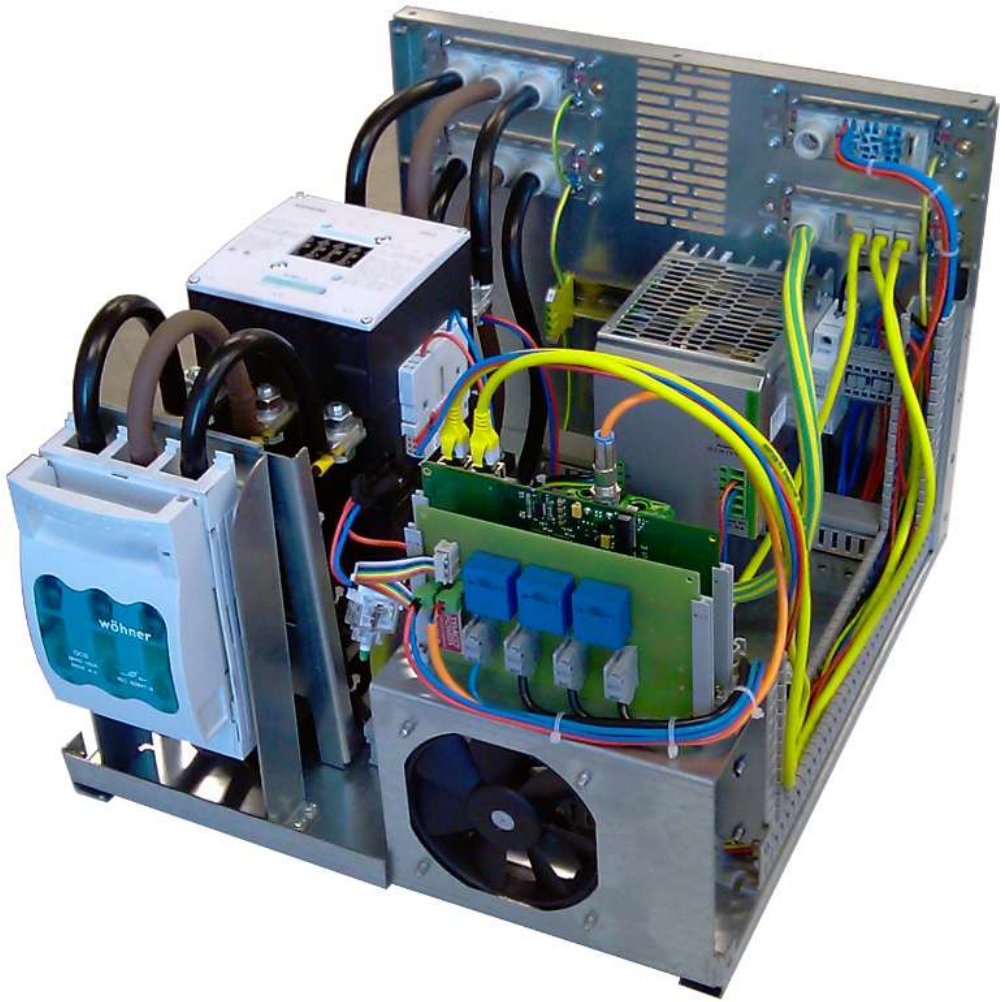
# Implementation and Verification of Smart Inverter

- 50.0 kVA inverter module



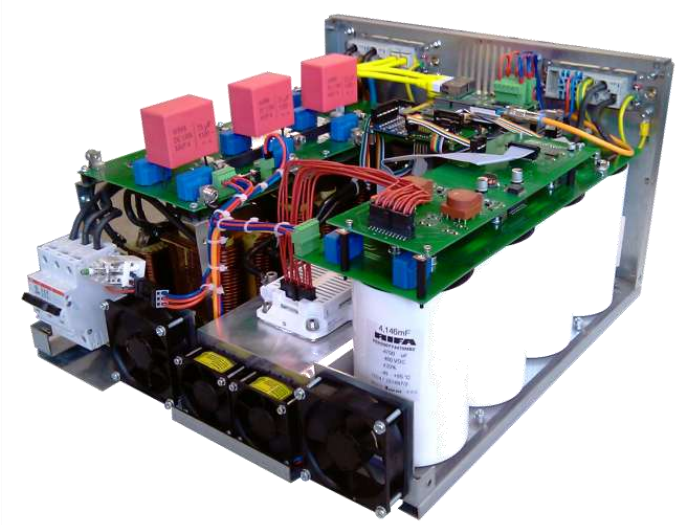
# Implementation and Verification of Smart Inverter

- AC Connection module

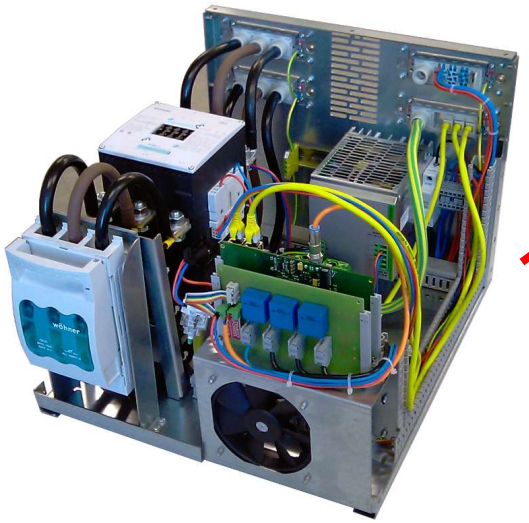


# Implementation and Verification of Smart Inverter

- Developed smart inverter
  - 50 kVA inverter module

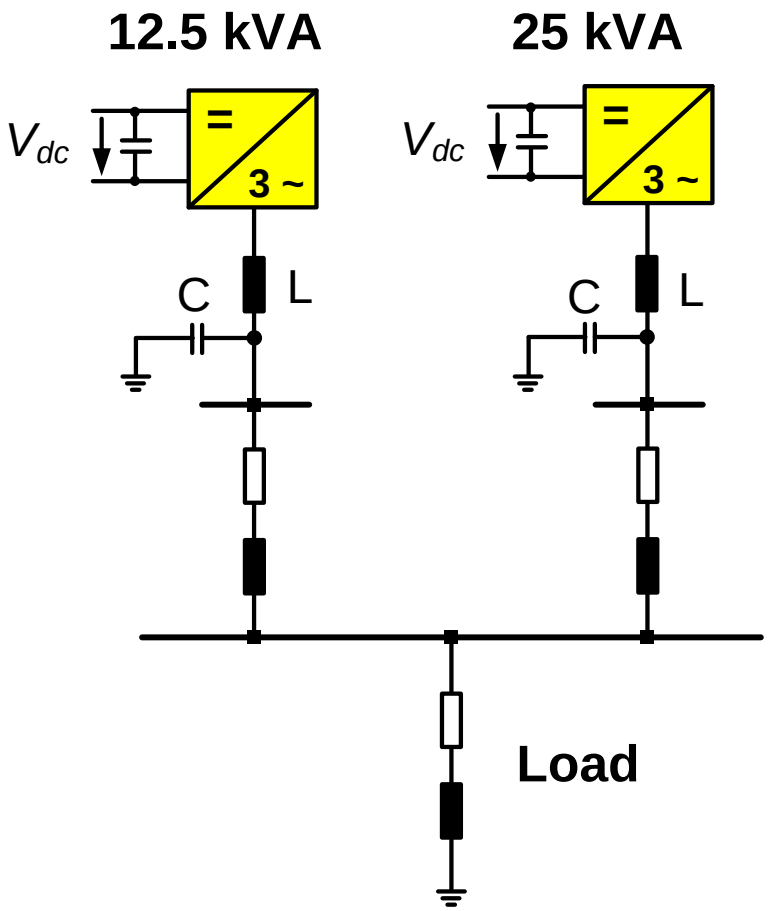


  - AC Connection module



# Implementation and Verification of Smart Inverter

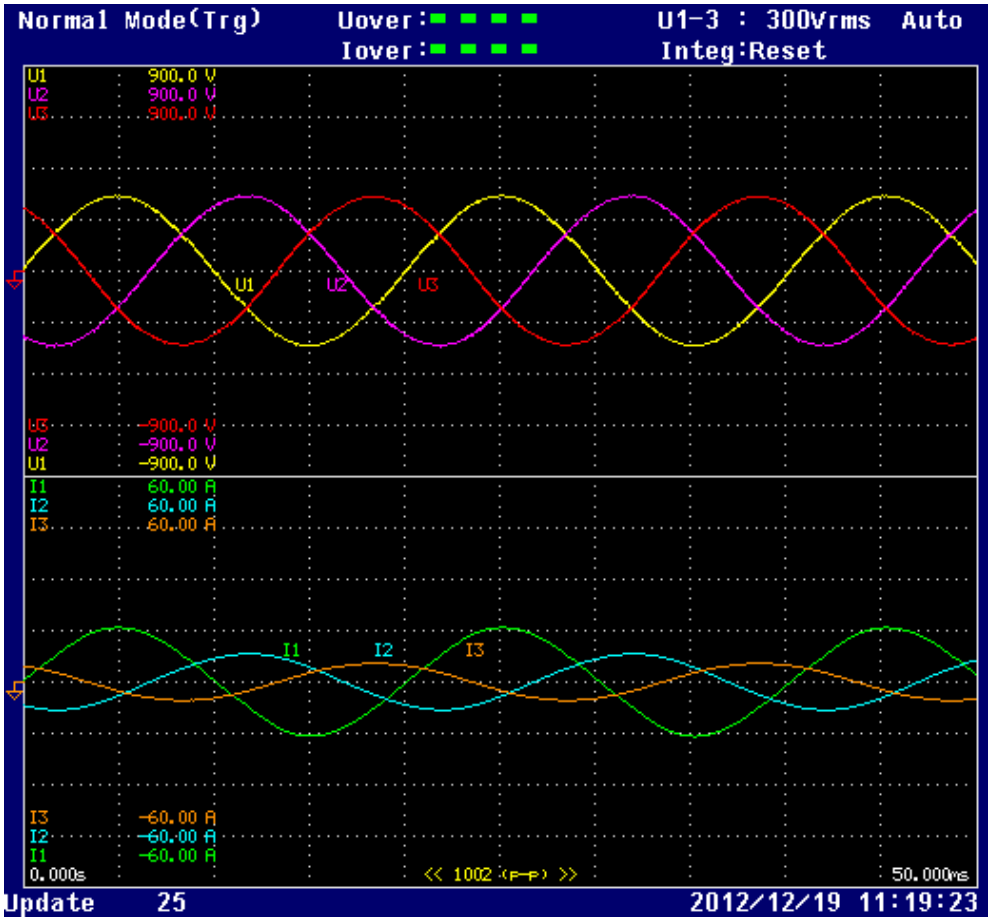
- Verification of proposed control methodology of smart inverter




- Parallel operation of 2 Asymmetrical Grid Forming with Primary Control inverters are examined.
- Inverter Parameters:
  - $V_{dc}$ = 780 V
  - $V_{ref}$ = 230 V
  - $f_{ref}$ = 50 Hz
  - $V_{droop}$ = 4 %
  - $f_{droop}$ = 4 %

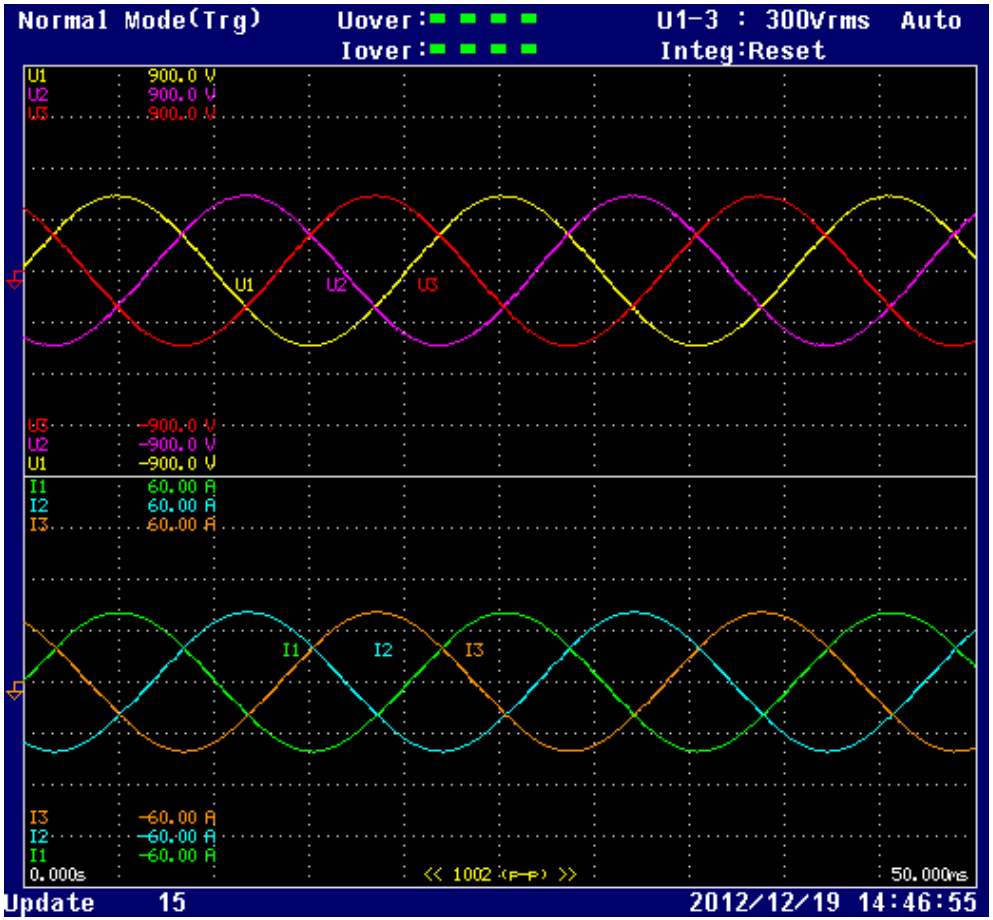
# Implementation and Verification of Smart Inverter

- Asymmetrical Grid Forming with Primary Control
  - Asymmetrical load; $R_A$=20Ω, $R_B$=40 Ω, $R_C$=60 Ω
  - Load Voltages
  - Load Currents



# Implementation and Verification of Smart Inverter

- Asymmetrical Grid Forming with Primary Control
  - Symmetrical load; $R_A = R_B = R_C = 16\ \Omega$
  - Load Voltages
  - Load Currents



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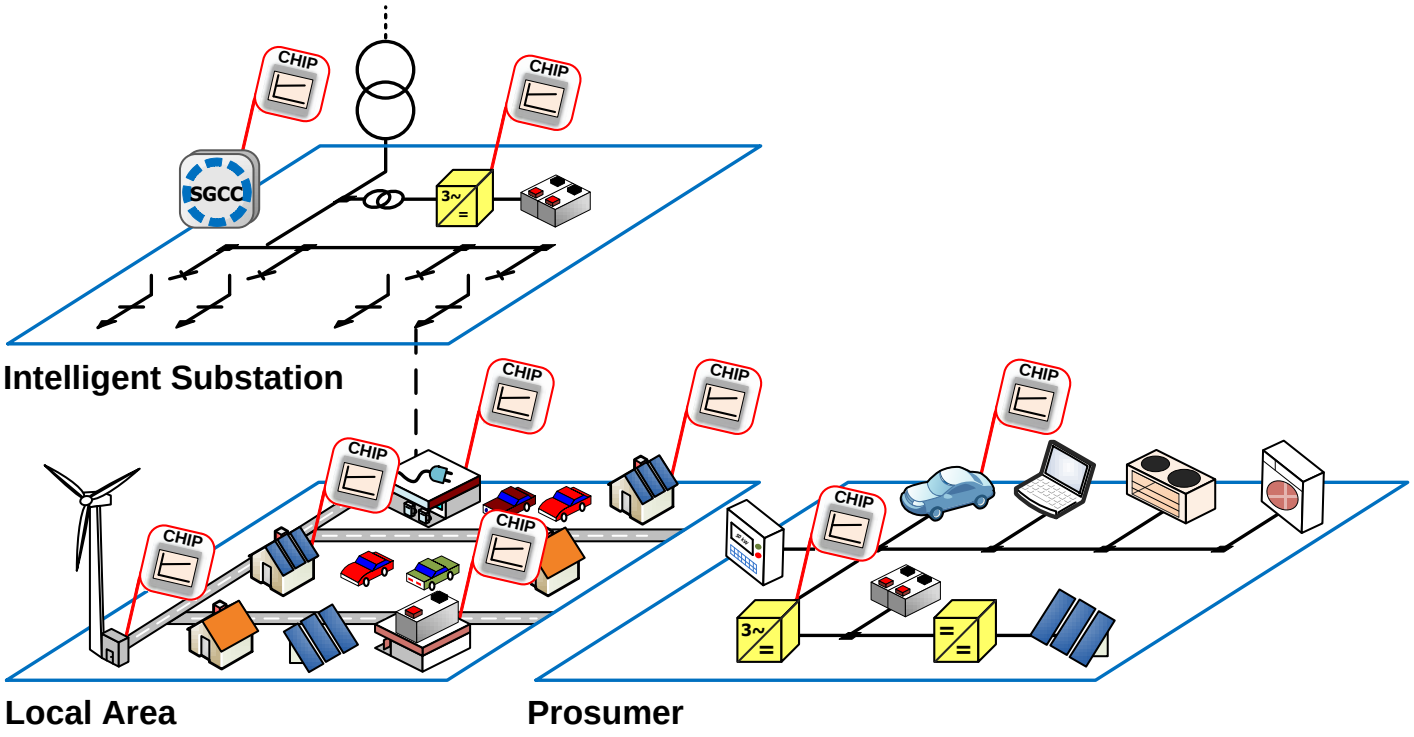
# Conclusion

- Characteristics of the proposed smart inverter control architectures:
  - The introduced control architectures enable reliable, fast and efficient control of future oriented power systems
  - Increase the flexibility and adaptability for DERs grid integration into conventional grids
  - Support the conventional control schemas, which are consequently down sized to the low voltage level
  - Give an opportunity to establish an advance control function down to local level

# Conclusion

- Change the ordinary DERs integration to be a part of the dynamic grid control and management

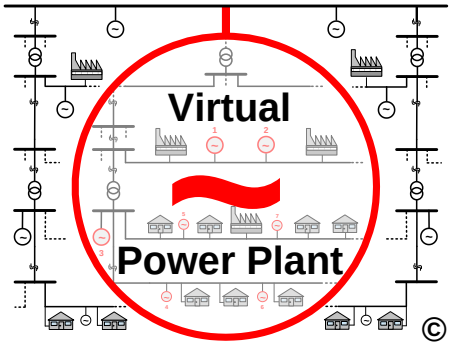
- Empower and turn distribution network to be the active control area with Smart Inverter



# Acknowledgement


- This research work is supported by

# Thank You For Your Attention!

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