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.
Installed capacity of grid tied PV systems and wind turbines

- **2012**
  - Wind non valid values
  - PV approx. 7,3 GW

**Source:** BMU, Prognos AG
Installed capacity of grid tied PV systems and wind turbines

2012: distribution grids
- Wind approx. 95%
- PV approx. 90%

Source: BMU, Prognos AG
Status of the Renewable Energy in Germany

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

- Biomass: 9.3 GW
- Photovoltaic: 39.5 GW
- Wind: 55.0 GW

Source: BEE Branchenprognose2020
Status of the Renewable Energy in Germany

- Offshore wind development

Alpha Ventus: 12 turbines 60 MW
Source: http://www.alpha-ventus.de/

Baltic 1: 21 turbines 48.3 MW
Source: http://www.enrw.de

BARD Offshore 1: 80 turbines 400 MW (2013)
Source: http://www.bard-offshore.de/
Status of the Renewable Energy in Germany

- Repowering is already in process

**2011**
- 47 TWh
- 7.7% of electricity demand

**2020**
- 150 TWh
- 25.0% of electricity demand

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

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Problems and Strategies for Grid Integration

- Conventional power systems

[Diagram showing a grid system with active and passive controlled areas, illustrating the integration of offshore wind parks and pumped hydro systems.]
Problems and Strategies for Grid Integration

- Moving towards decentralized power systems

![Diagram of power grid integration]

- Active Controlled Area
- Bidirectional supply process

Diagram details:
- 220 kV / 380 kV
- 110 kV
- 10 to 30 kV
- 400 V
- Offshore Wind Park
- Pumped Hydro
- Regional Grid
- Special Loads or Suppliers
- Power Plant
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

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Inverter as Flexible Grid Interface for Integration of DERs

Inverter is the **Essential Device** for optimal integration of DERs
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System Architecture and Control Methodology of Smart Inverter

- Technical requirements of inverter as grid integration of DERs
  - DERs integration into *Active Network*
    - Symmetrical active network
    - Asymmetrical active network
System Architecture and Control Methodology of Smart Inverter

- Technical requirements of inverter as grid integration of DERs
  - DERs integration into *Passive Network*
    - Symmetrical passive network
    - Asymmetrical passive network
Inverter feeding modes at grid side (Unit Control)

- ECS Driven Feeding
  - Grid Parallel
    - Symmetrical
    - Asymmetrical
  - Grid Forming
    - Symmetrical
    - Asymmetrical

- Grid Driven Feeding
  - Grid Supporting
    - Symmetrical
    - Asymmetrical
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: $\Delta f/\Delta P$ and $\Delta V/\Delta Q$ droop (grid side driven)
  - Coupling: $\Delta P/\Delta f$ and $\Delta Q/\Delta V$ droop (grid side driven)
  - Grid parallel: P- (and Q-) control with reference values from source (unit side driven)
Symmetrical grid forming mode inverter

Inverter Feeding Modes at Grid Side

- ECS Driven Feeding
  - Grid Parallel
    - Symmetrical
    - Asymmetrical

- Grid Driven Feeding
  - Grid Forming
    - Symmetrical
  - Grid Supporting
    - Symmetrical
    - Asymmetrical
Symmetrical current control inverter

- System Architecture and Control Methodology of Smart Inverter

\[ \text{Inverter} = 3\sim \]

\[ V_{dc} \]

\[ L_f \]

\[ C_f \]

\[ V_{\alpha_{ref}} \]

\[ V_{\beta_{ref}} \]

\[ V_q \]

\[ V_d \]

\[ I_{q_{act}} \]

\[ I_{d_{act}} \]

\[ I_{q_{ref}} \]

\[ I_{d_{ref}} \]
Symmetrical grid forming mode inverter
System Architecture and Control Methodology of Smart Inverter

- Symmetrical grid forming mode inverter with primary control

![Diagram of inverter system architecture and control methodology](image)
Symmetrical grid forming mode inverter with primary control

Proposed control schemas fulfill the requirement of decentralized generators Grid Code !!
System Architecture and Control Methodology of Smart Inverter

- Asymmetrical grid forming mode inverter

Inverter Feeding Modes at Grid Side

ECS Driven Feeding
- Grid Parallel
  - Symmetrical
  - Asymmetrical

Grid Driven Feeding
- Grid Forming
  - Asymmetrical
- Grid Supporting
  - Symmetrical
  - Asymmetrical
System Architecture and Control Methodology of Smart Inverter

- Asymmetrical grid forming mode inverter

![Diagram of system architecture and control methodology of a smart inverter](image)

- SVM
- PLL
- Inverter $= 3\sim$
- Local Grid
- Grid
- Positive sequence
- Negative sequence
- Zero sequence

Long Beach, 21.03.2013
System Architecture and Control Methodology of Smart Inverter

- Asymmetrical grid forming mode inverter with primary control
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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; \( R_A = 20\, \Omega \), \( R_B = 40\, \Omega \), \( R_C = 60\, \Omega \)

- Load Voltages

- Load Currents
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
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