Smart Inverter Technology for High PV Penetration

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- Background – Changing role of PV inverters
- Advanced functions of PV inverters
- Summary & recommendations

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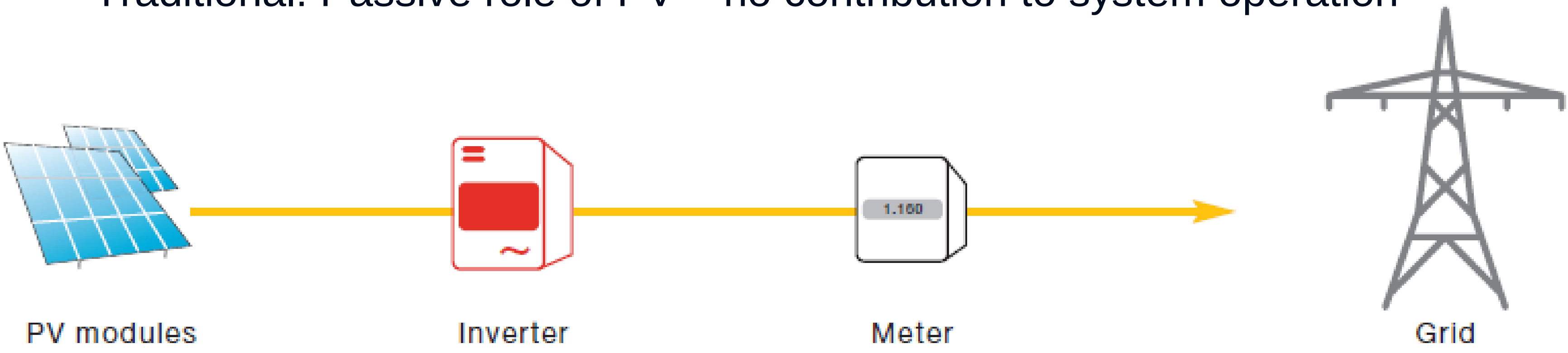
Integrating PV in the electricity grids
Changing the role of PV

- Traditional: Passive role of PV – no contribution to system operation

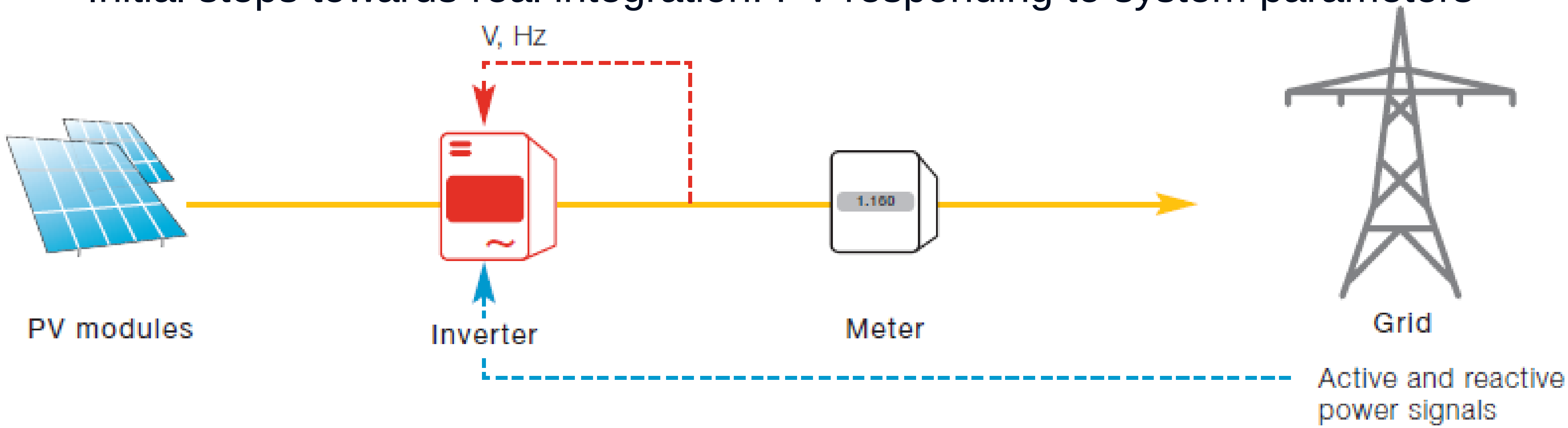


source: EPIA, based on SMA analysis, 2012

- Features
  - Feed-in of active power only → operation at unity power factor
  - Rapid disconnection at over/under voltage/frequency with narrow window
  - Anti-islanding as main concern ("disconnect at first sign of trouble")

Integrating PV in the electricity grids
Changing the role of PV

- Initial steps towards real integration: PV responding to system parameters

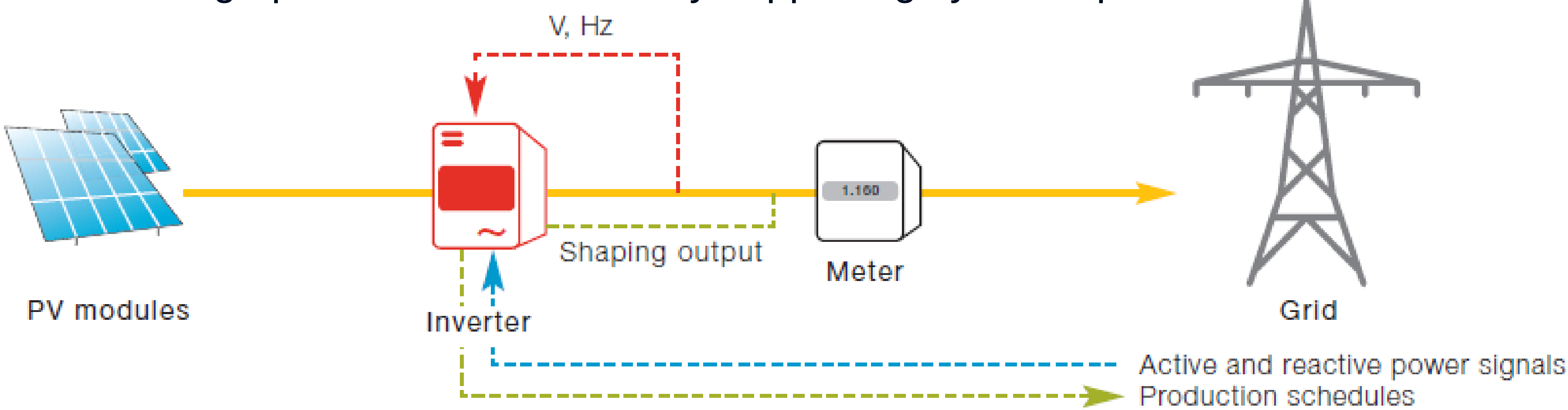


source: EPIA, based on SMA analysis, 2012

- Additional features
  - Active power reduction in case of over-frequency → ensure system stability
  - Fault-Ride-Through (LVRT) capability (for larger units)
  - Reactive power provision → limit voltage rise
  - Limitation of active power feed-in during critical situations

Integrating PV in the electricity grids
Changing the role of PV

- With high penetration: PV actively supporting system operation



source: EPIA, based on SMA analysis, 2012

- Additional features
  - Remote control of set-points for active and reactive power
  - Communication of current production and schedule
  - Integration into Smart Grid operation

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Overview of advanced grid support and PV inverter features

Reactive power control
- On demand, schedule or characteristics
- cos(phi) = f(P)
- cos(phi) = f(U) (optional)

Active power control
- Reduction of active power at over frequency
- Active power feed-in at under frequency

Grid management
- Temporary limitation of active power output at congestion in the grid
- Controlled on demand by grid operator

Dynamic grid support
- LVRT (Low Voltage Ride Through)
- Contribution to short-circuit current

Overview of advanced grid support and PV inverter features

Reactive power control	• On demand, schedule or characteristics • cos(phi) = f(P) • cos(phi) = f(U) (optional)
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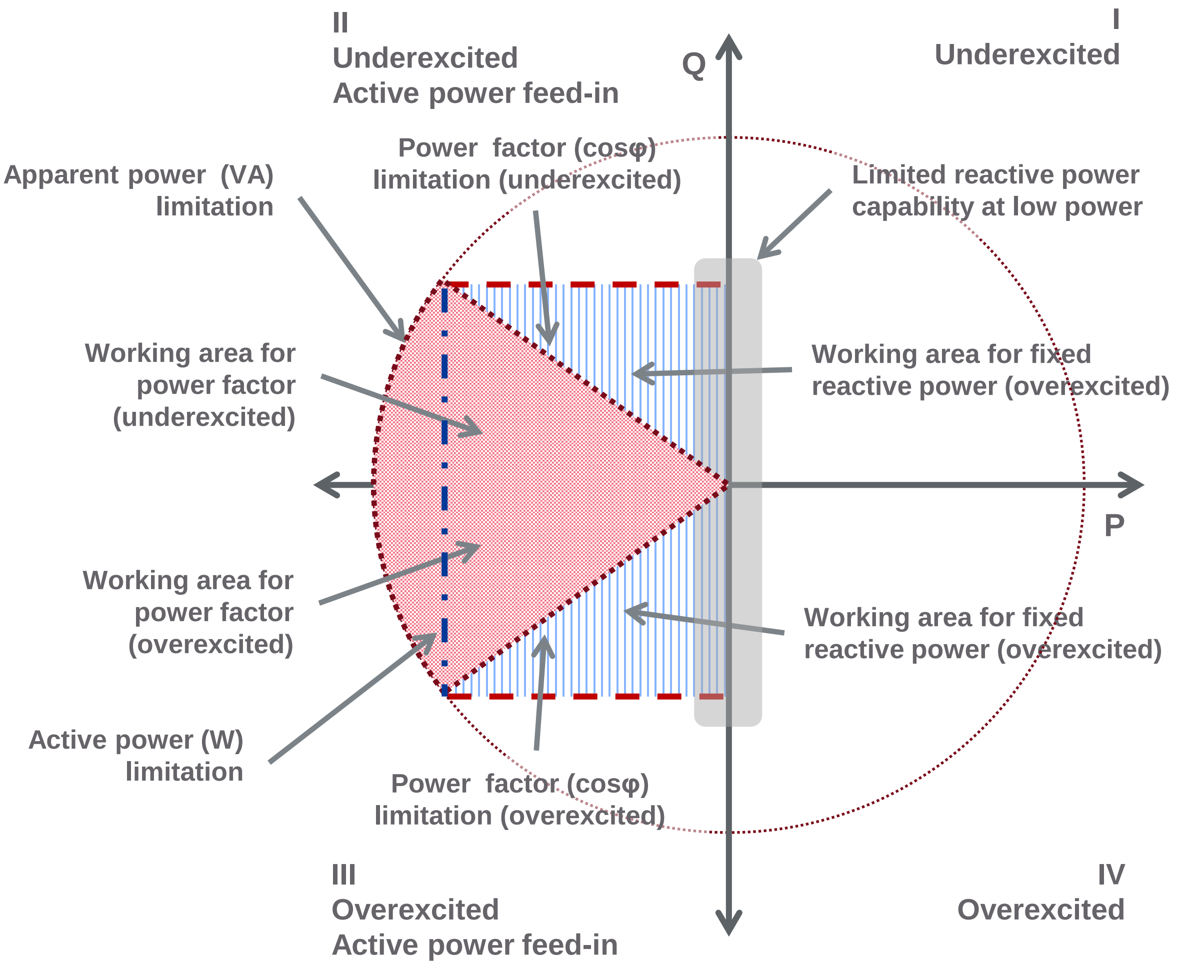
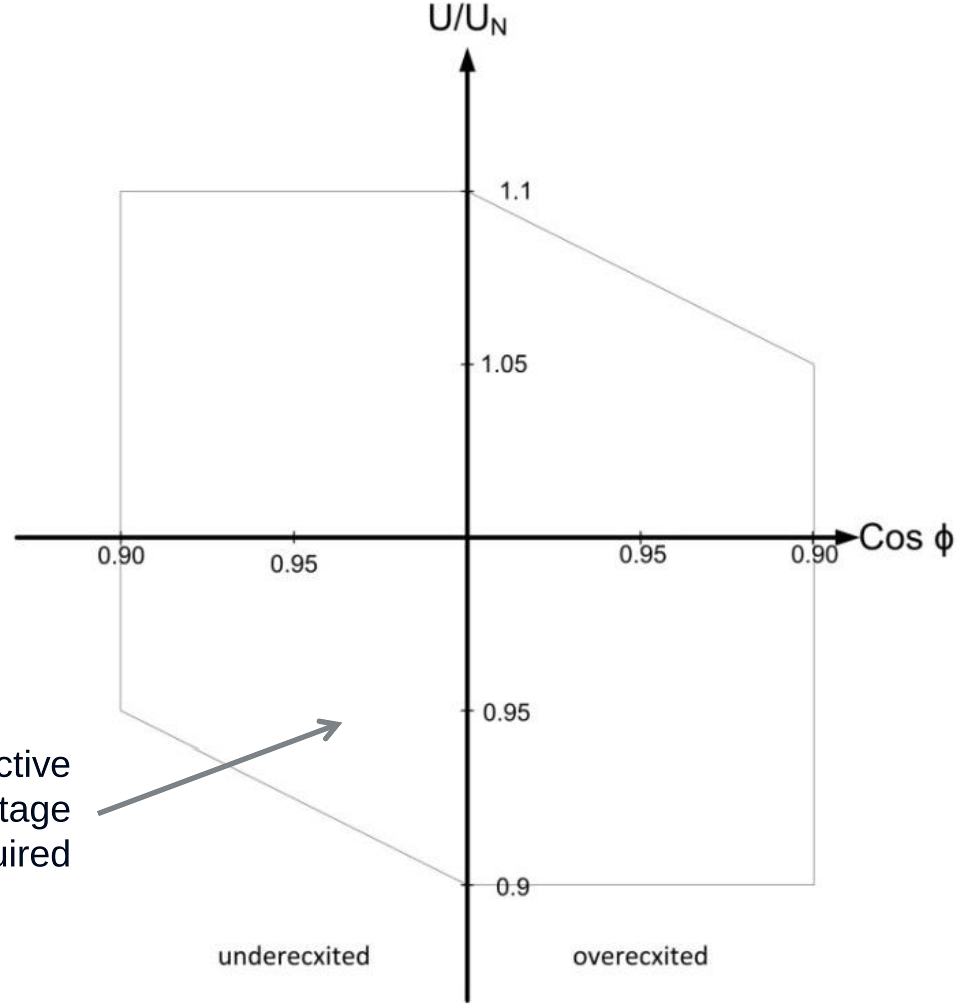
Advanced grid support features of PV inverters
Reactive power: Basics and limitations



Load-reference arrow system/ consumer reference frame (CRF)

Advanced grid support features of PV inverters
Reactive power: Operational requirements



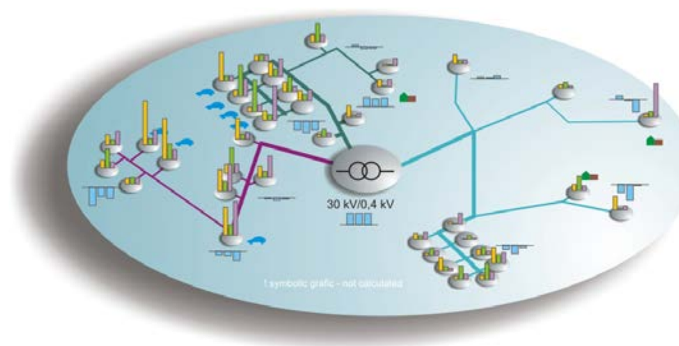
Provision of reactive power at low-voltage required

CLC/FprTS 50549-2:2011

Requirements for the connection of generators above 16 A per phase - Part 2: Connection to the MV distribution system

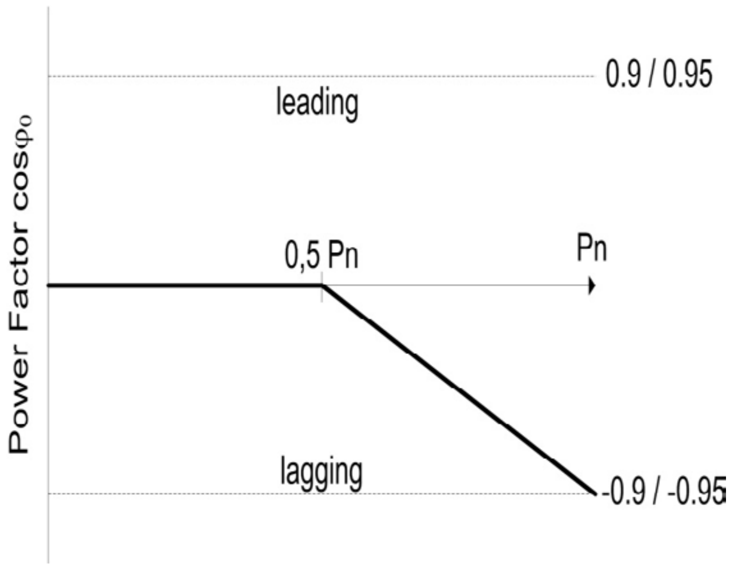
Advanced grid support features of PV inverters
Reactive power control strategies

- Basic (local) reactive power control
  - $\cos\varphi$ = constant
  - $\cos\varphi = f(P)$
  - $Q = f(U)$
  - $Q = f(U,P)$
  - …
- Coordinated control (requires communication)
  - $\cos\varphi$ = remote setpoint
  - …
- Selection criteria
  - Characteristics of the electric grid (impedance, angle...)
  - Grid losses
  - Available control and communications infrastructure
  - …

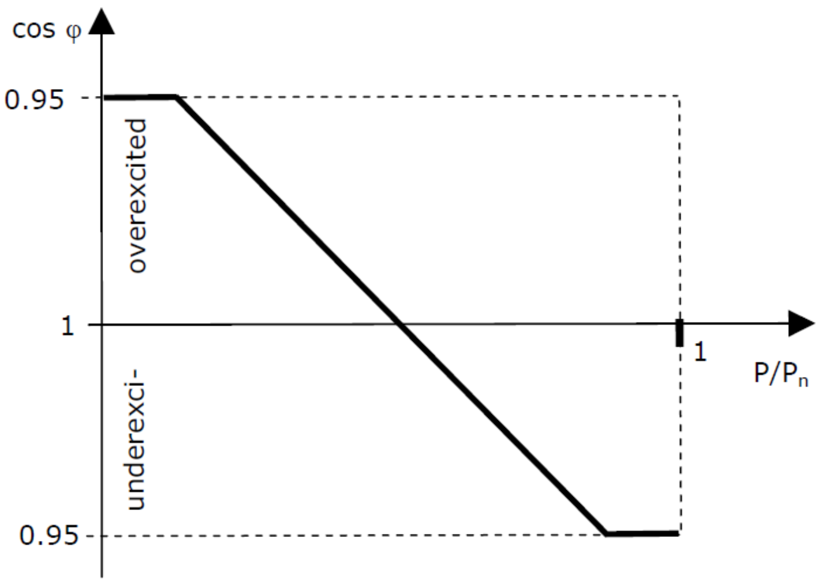


Advanced grid support features of PV inverters
Reactive power control strategies: cosφ = f(P)

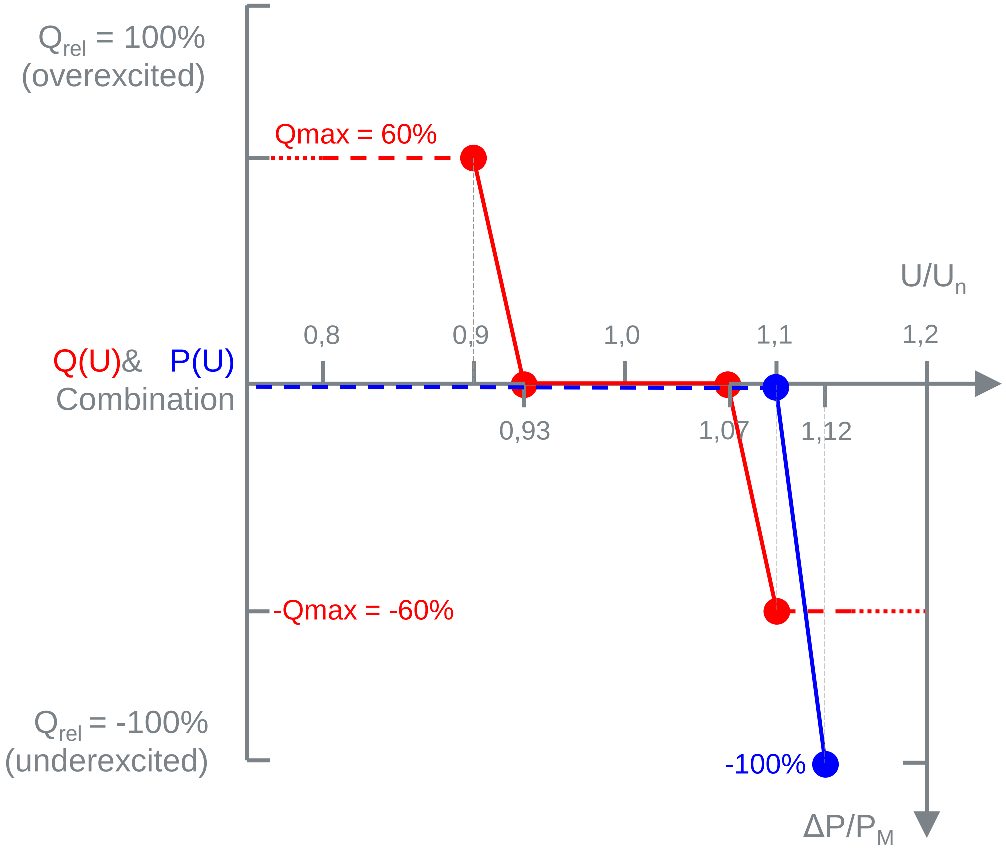
- Requirement (default characteristics) according to German LV Code:



- Requirement (exemplary characteristics) according to German MV Code:



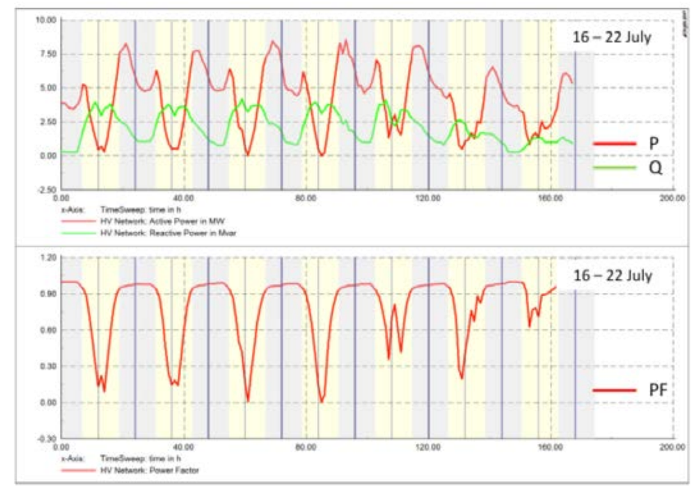
Advanced grid support features of PV inverters
Reactive power control strategies: Q(U) and Q&P(U)

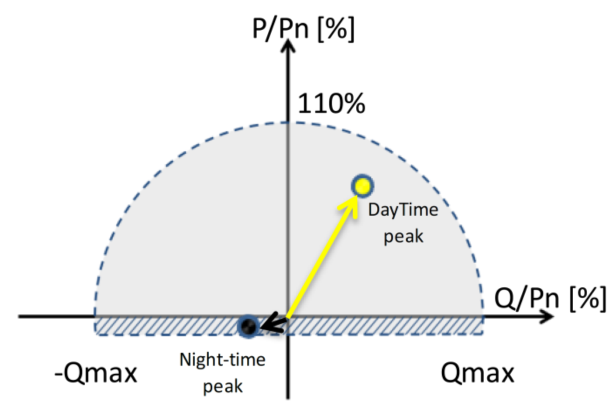


- Currently being tested in high-penetration PV demo projects

Advanced grid support features of PV inverters
Reactive power control: Specific aspects

- Reactive power balance issues with high PV penetration
  - Overall PF decreases due to PV feed-in (P goes down, Q demand of load remains constant)
  - Over-supply of reactive power during the night (low-load) in MV cable grids
- Solution
  - Provision of reactive power by PV also during nighttime
  - Some PV inverters already offer necessary features





Gabriele Monfredini et al., PV inverter extended grid services – from "day-time" to "full-time" operation

Overview of advanced grid support and PV inverter features

Reactive power control	• On demand, schedule or characteristics • cos(phi) = f(P) • cos(phi) = f(U) (optional)
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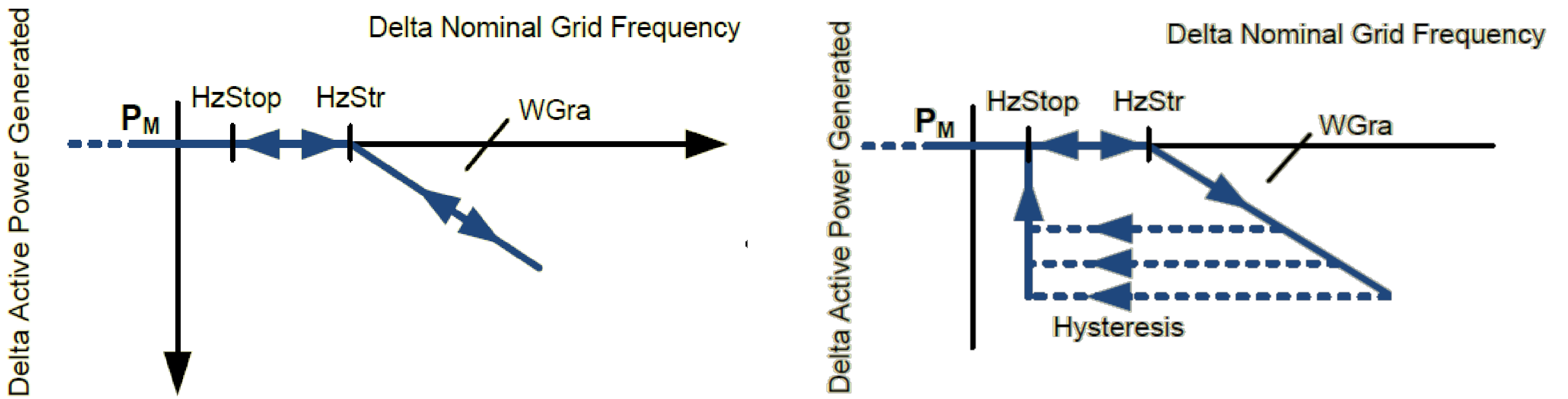
Advanced grid support features of PV inverters
Active power control/frequency control: Standard functions

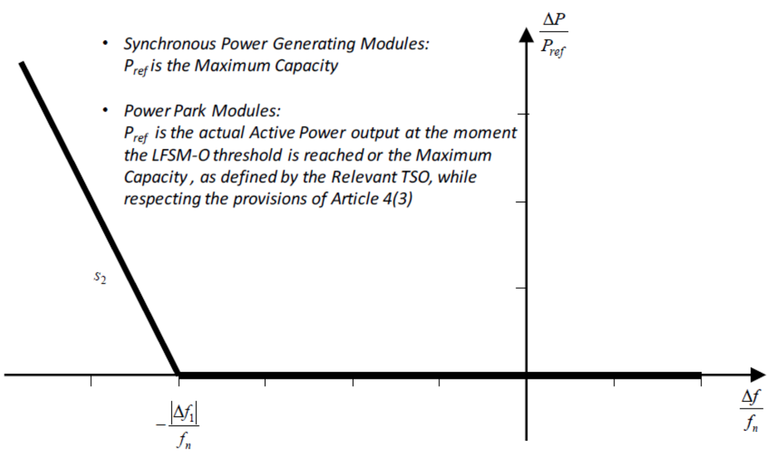
- Reduction of active power at over-frequency
  Limited Frequency Sensitive Mode – Overfrequency (LFSM-O)
  - With or without hysteresis



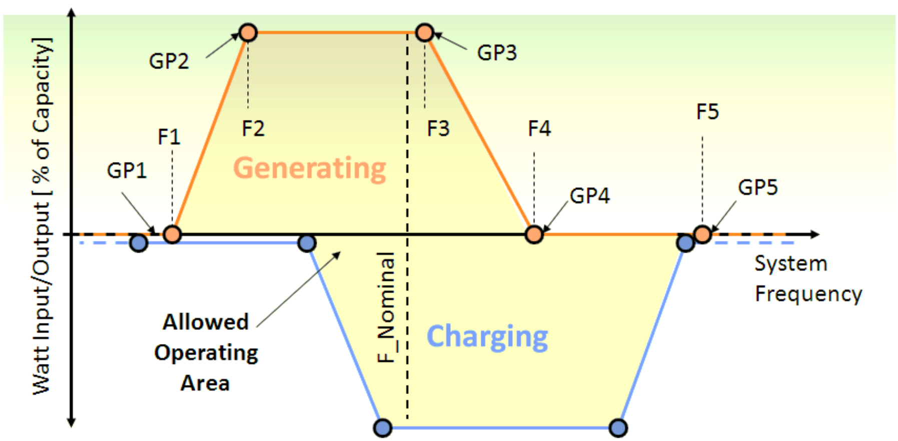
- Active power feed-in at under-frequency

Advanced grid support features of PV inverters
Active power control/frequency control: Extended functions

- Active power increase at under-frequency
  Limited Frequency Sensitive Mode – Underfrequency (LFSM-U)
  - Available in combination with local storage



Source: ENTSO-E Network Code for Requirements for Grid Connection Applicable to all Generators



Source: Advanced Functions for DER Inverters Modeled in IEC 61850-90-7

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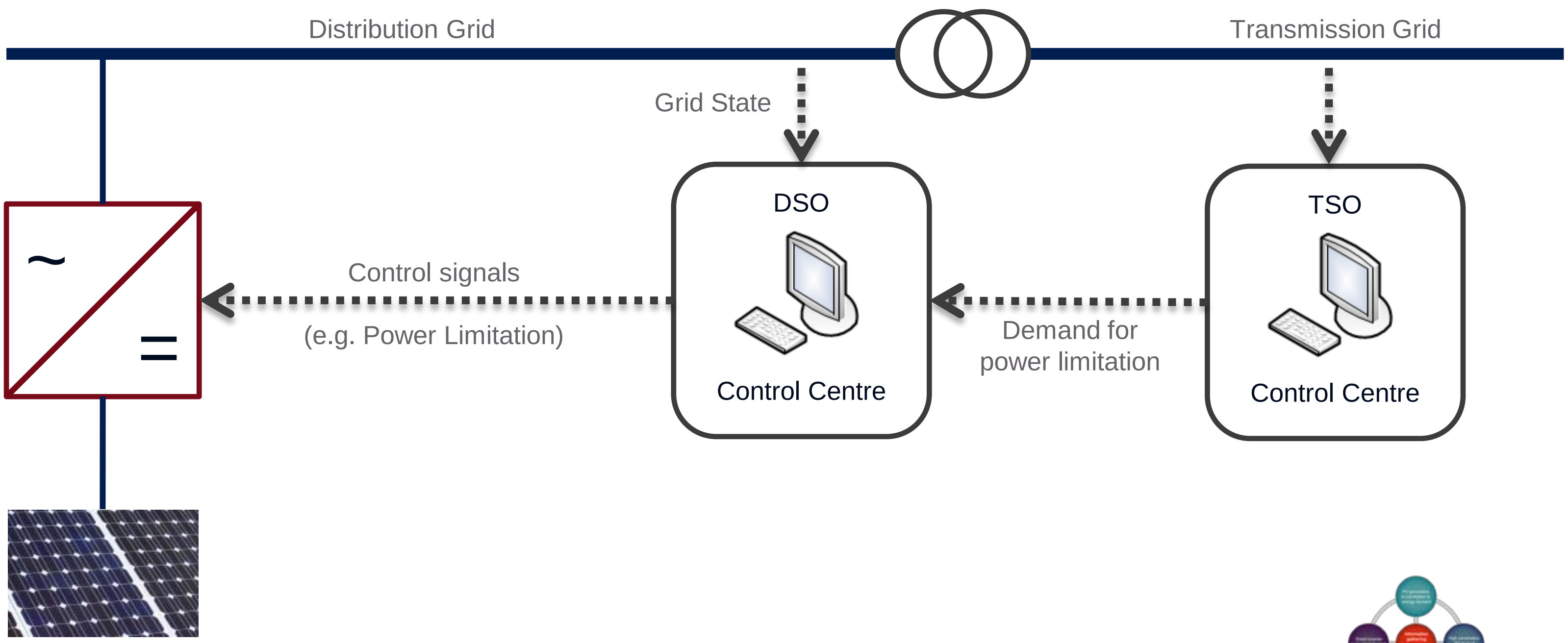
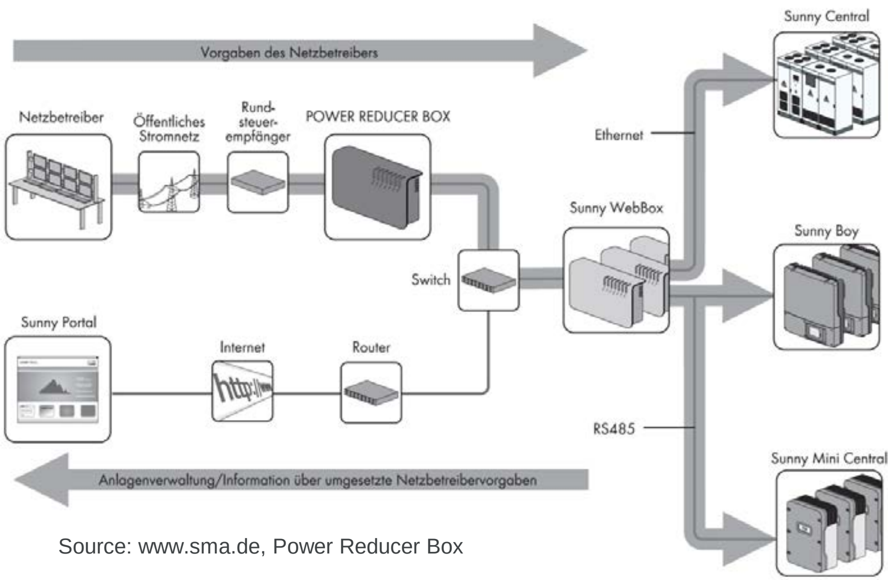
Advanced grid support features of PV inverters
Grid management

- Possibility for DSO to send setpoint values to generators
  - Reduce the active power output or change the cos(phi).
  - Guarantee grid stability in case of emergency situations or congestion



Advanced grid support features of PV inverters Grid management: Exemplary implementation

- Communication paths and protocols:
  - Audio or radio frequency ripple control
  - DNP3
  - IEC 60870-5-104
  - IEC 61850-90-7



Source: www.sma.de, Power Reducer Box

www.fronius.com, Power Control Box

www.sma.de, Power Reducer Box

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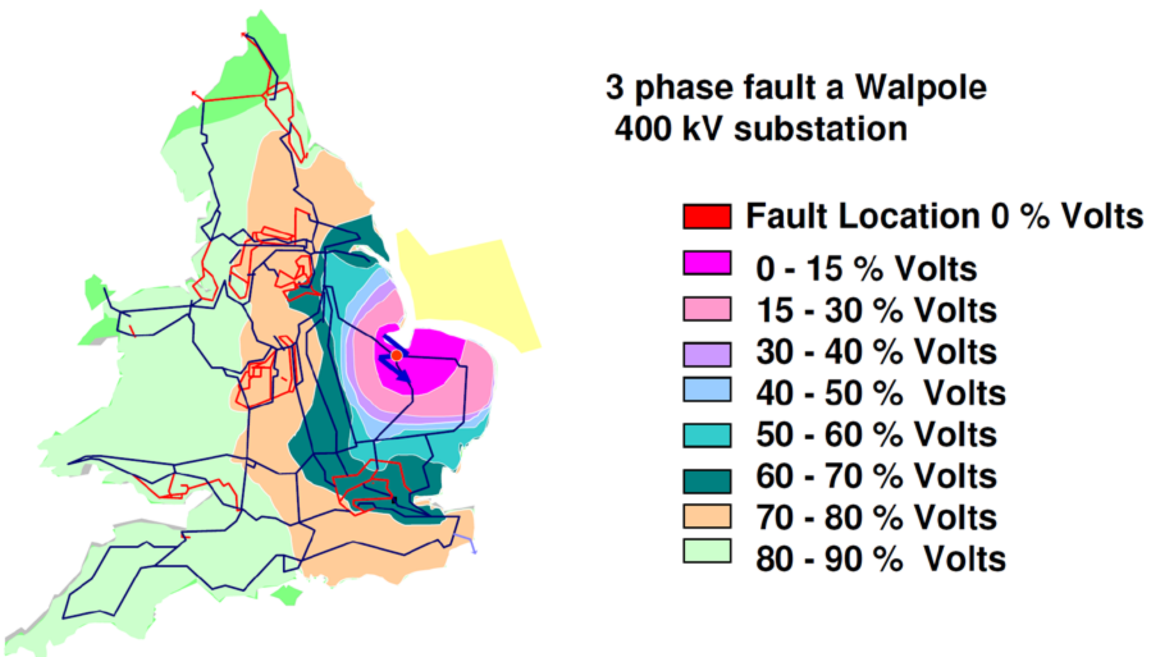
Advanced grid support features of PV inverters
Dynamic grid support: „LVRT Low Voltage Ride Through“

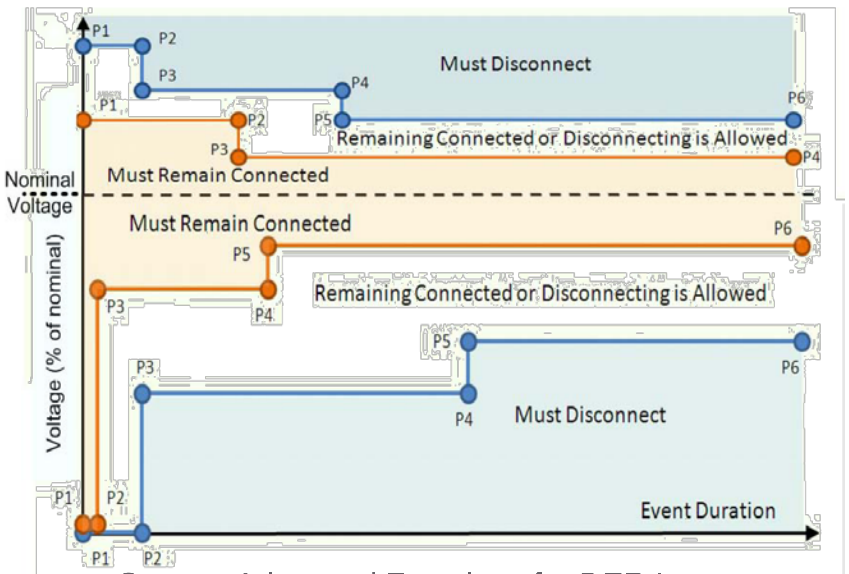
- Wide area voltage dips due to faults in the transmission grid
  - Threat: Simultaneous loss of several GW of PV (DR)
  - Possible wide area black-out due to lack of generation



Source: Antony Johnson, National Grid

Advanced grid support features of PV inverters
Dynamic grid support: „Low/High Voltage Ride Through“

- Basic requirements
  - Remain connected to grid
  - Provide reactive current



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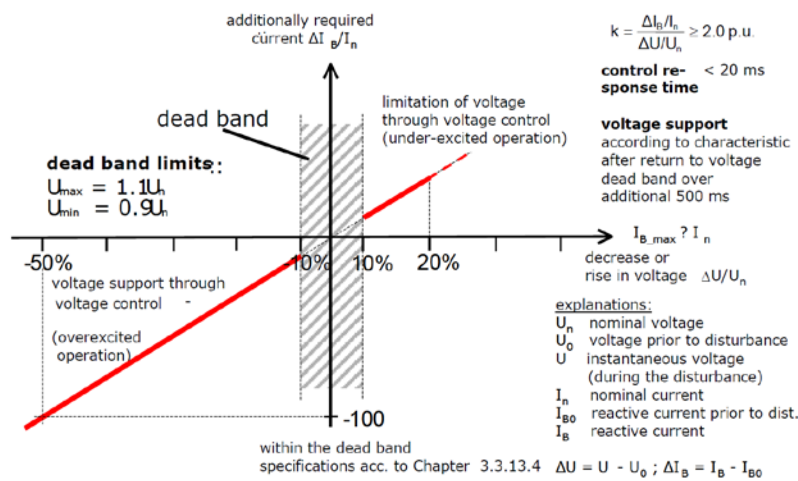

Source: German Transmission Code

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Smart PV inverters as key elements for the integration of high penetration PV

- Main challenges
  - Numbers and capacity of interconnected PV systems are increasing rapidly
  - PV and other DR challenge traditional power system management
- Opportunities
  - PV Inverters can be very powerful tools in managing the power system for reliability and efficiency
  - PV inverters are becoming quite “smart” and can perform autonomously
    - sense local conditions of voltage levels, frequency deviations and temperature,
    - receive commands and signals, which allow them to modify their active and reactive power output

► Providing access to these capabilities will be the key to improve system reliability and efficiency and enable further deployment of PV.

Thank you very much for your attention!

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