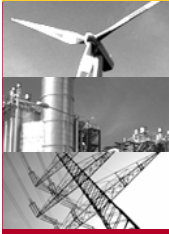




Workshop 2 - Grid Code Compliance Studies of a 100MW Wind Farm

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Relevant Aspects, Required Network Calculations

- Grid Repercussions
- Reactive Power Availability on the Grid Connection Point
- Behavior of Voltage Dips (FRT/LVRT-Behavior)



Power Quality



Power Quality – German Grid Codes (example)

- German Standards:
 - Transmission Code/SDLV:
 - Compliance with EN50160 in low voltage networks

 - Technical Guideline - Generating plants connected to the medium-voltage network:
 - Reference to international standards (EN50160, IEC 61000-3-6, IEC 61000-3-7, IEC 61400-21, etc.), with variances
- International Practice:
 - According to IEC 61400-21



Power Quality - Medium Voltage Guideline

- Voltage increase at the connection point ($<2\%$)
- Fast voltage changes (d in %)
- Flicker
 - Continuous Flicker
 - Flicker because of Switching Actions
- Harmonics
 - Simplified verification based on current injection at the connection point
 - Complex topologies: Based on voltage distortion (e.g. application of EN50160 limits)

Power Quality - Verification

- Voltage increase at the connection point ($<2\%$):
 - Recommended Procedure: Application of the complex load flow calculation, taking into account the active and reactive power possibilities of the wind farm.
- Fast voltage changes (d%):
 - Calculation according to IEC 61400-21, using the (minimum) equivalent short circuit power at the connection point and on PCC point, the factor k_u and nominal power of a wind turbine.



Grid Repercussions - Verification

- Flicker:
 - Verification based on the procedure according to IEC 61400-21, using the minimum short-circuit power at the connection point - and- PCC, the Flicker coefficient c , the Flicker step factor, k_f , and the switching frequencies N10 and N120.
- Harmonics:
 - Simple Wind Farm Structure: Verification based on a simple calculation of total harmonic current that is fed into the network.
 - Complex Wind Farm Structure (with significant cable capacitance): Calculation of the injected harmonic currents according to IEC 61400-21 with the help of a network calculation software, taking into account the influence of cables etc.
 - In the presence of high harmonic currents or known resonance problems at network side: calculate and check harmonic voltages for compatibility with EN50160.



Reactive Power Capabiltiy during Normal Operation



Reactive Power Availability – Medium Voltage Networks

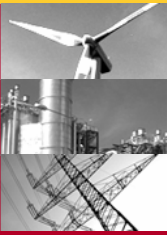


- Typical Requirement: Constant Power factor 0,95 ind./kap. at connection point.
- Adjustable:
 - Fixed $\cos(\phi)$
 - Curve $\cos(\phi)(P)$
 - Controlled reactive power setpoint
 - Reactive power-Voltage curve $Q(U)$
- Dynamic: Within 10s at $\cos(\phi)(P)$ -Curve
- Between 10s and 1Minute at $Q(U)$ -Curve
- -> Fast regulation required, e.g. on installations

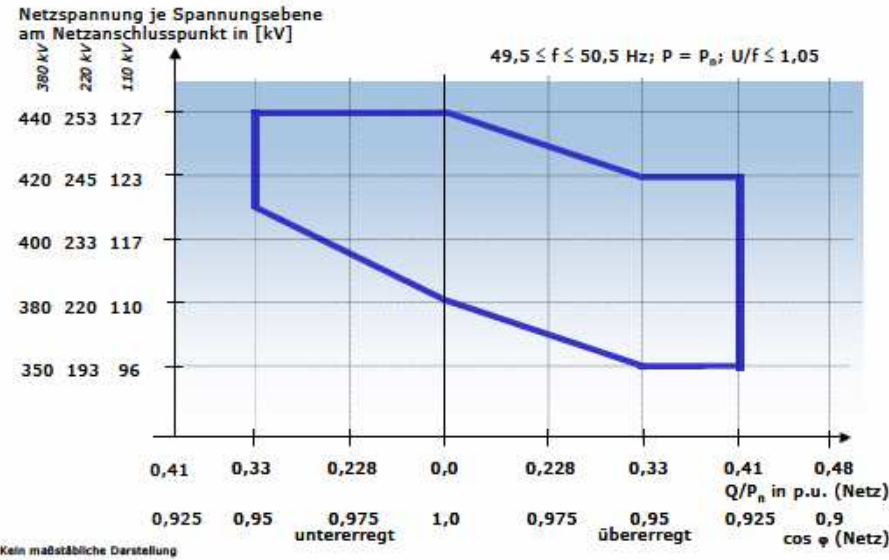


Reactive Power Availability – Transmission Code/SDLV

- Voltage-Reactive Power Curve at full load
- Partial load according to SDLV
- Dynamic requirement: Minute range (Slow Voltage Regulation)

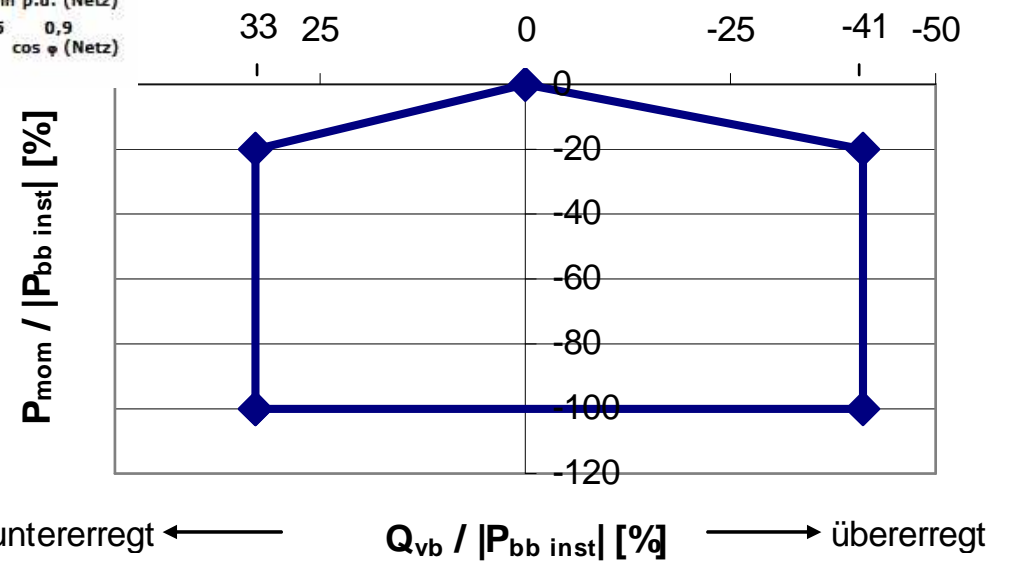


Reactive Power Availability – Transmission Code

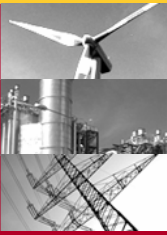


PQ-Diagramm im VZS für Bild 3.3b

bei 409-420 kV / 239-245 kV / 120-123 kV

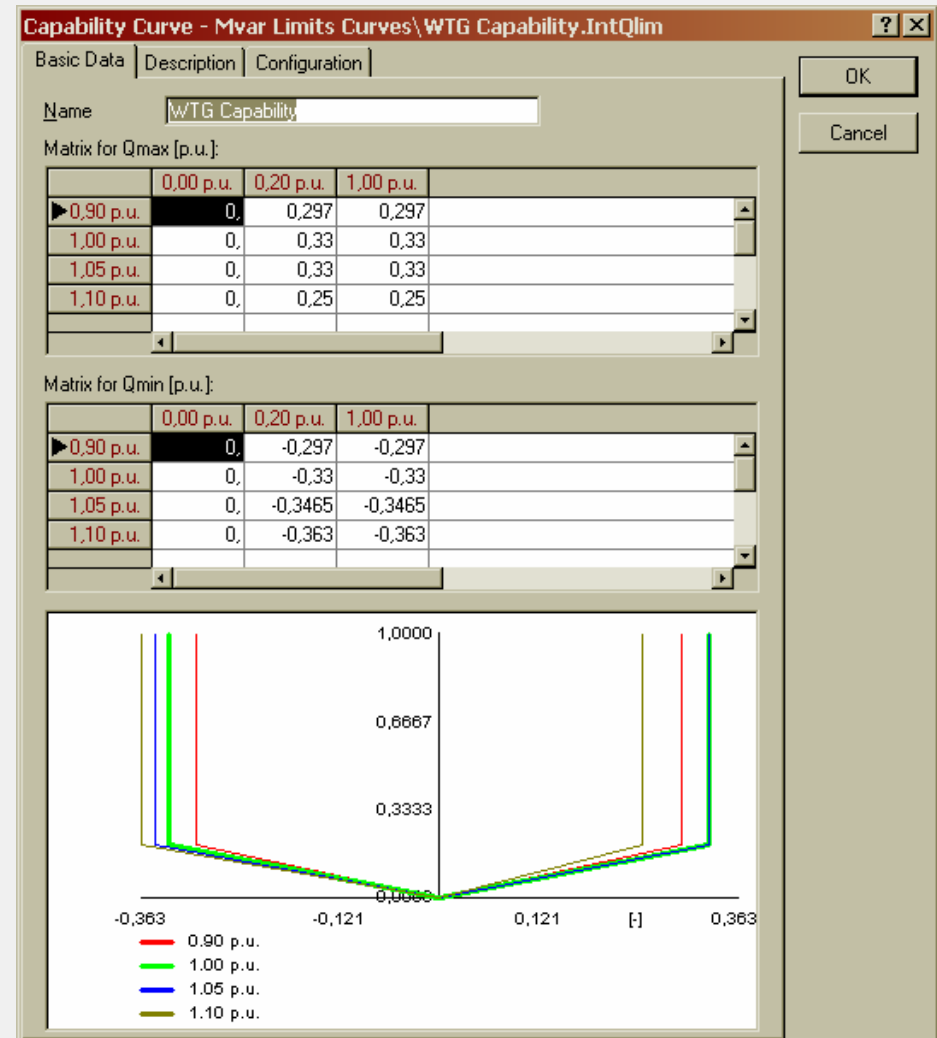


Example



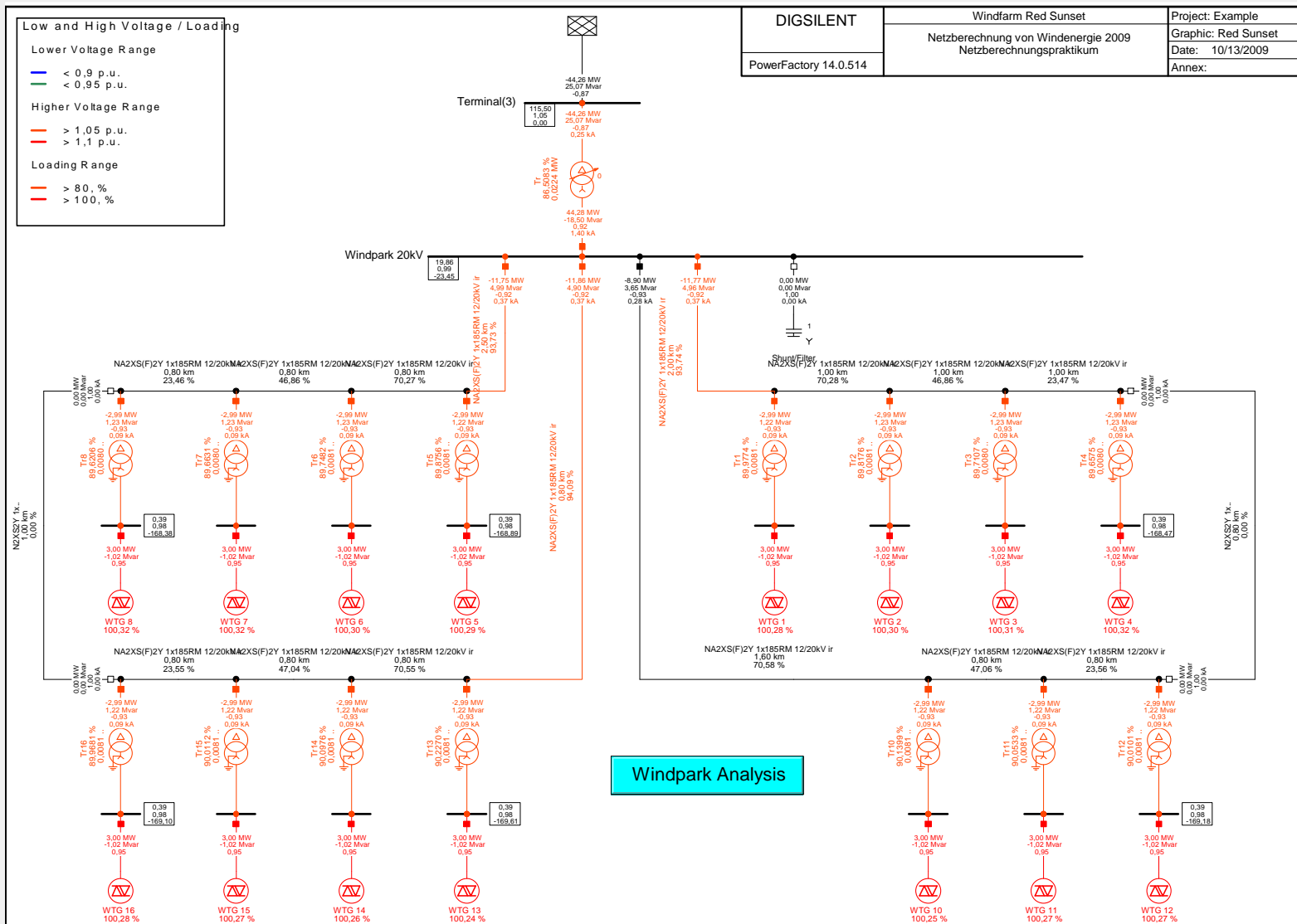
Reactive Power Availability – WTG Modeling

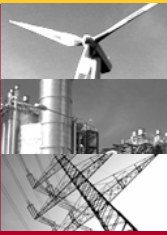
- Voltage dependence of the Capability Curve



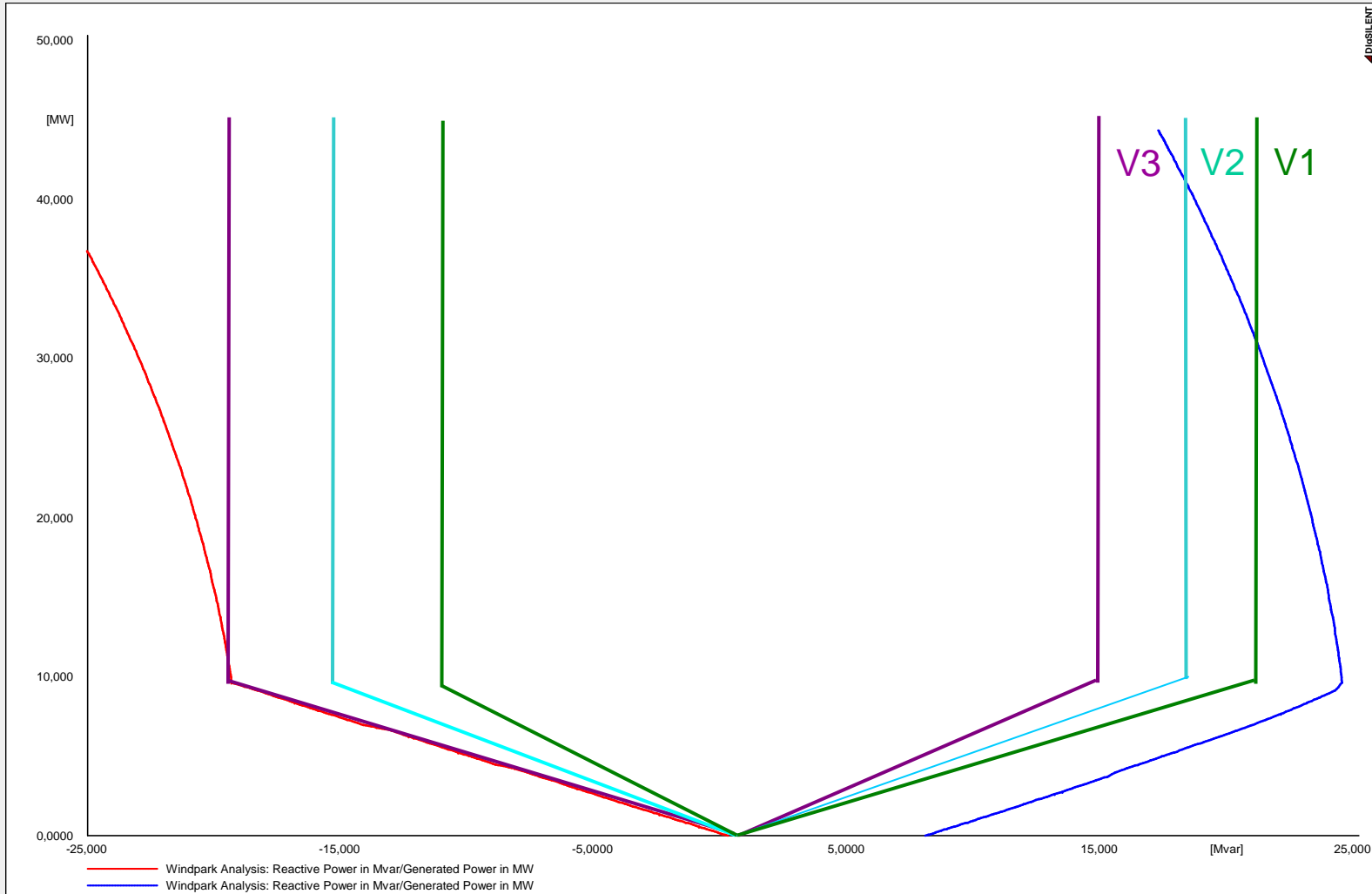


Reactive Power Capability – Wind Park Modeling (50MW Wind Farm)





Reactive Power Capability – Capability Curve at the Network Connection Point (SDLV)



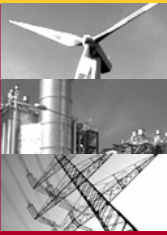
DIGSILENT	PQ-Diagram	Windfarm Red Sunset	PQ_Diagram	Date: 10/26/2009
				Annex: /1



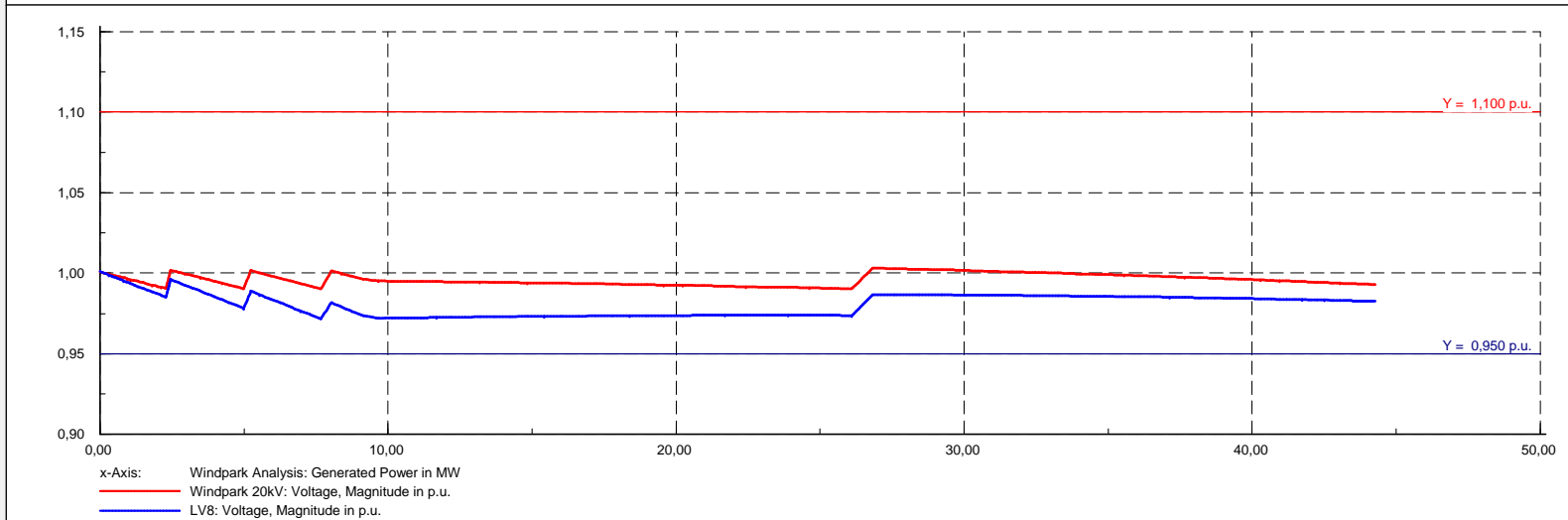
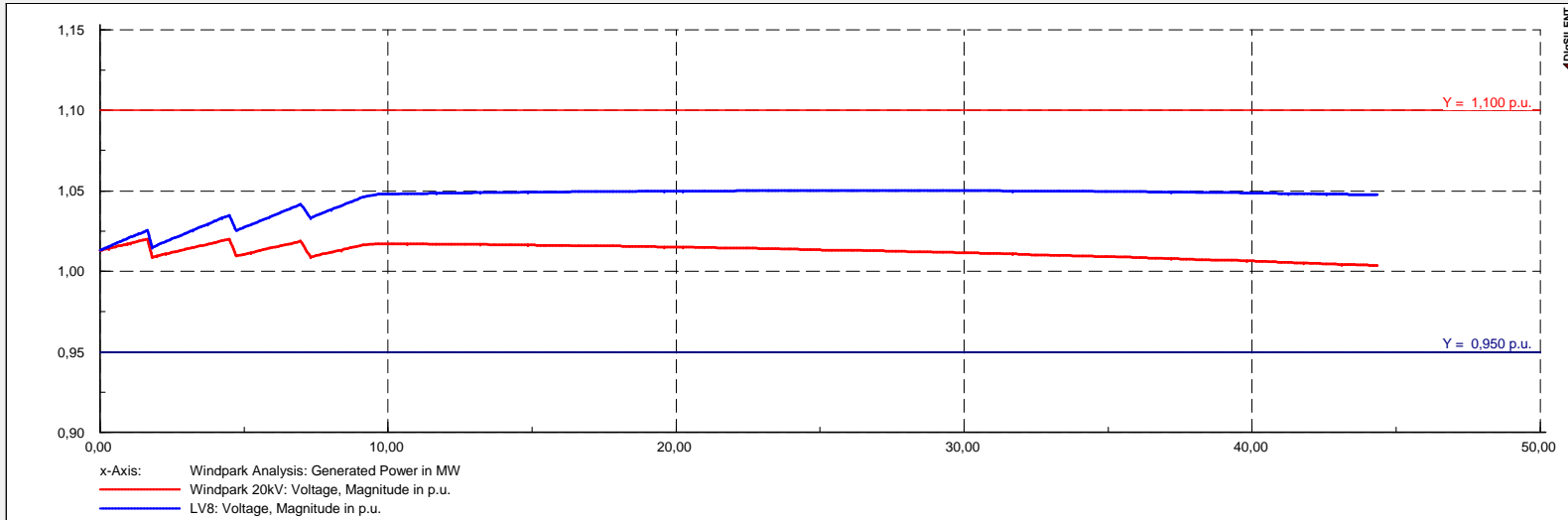
Reactive Power Availability – Capability Curve at the Network Connection Point (SDLV)

Result of the Investigation :

- Compliance of V3
- Violation of Q_{max} at V1 and V2



Reactive Power Capability – Verification of the WTGs Voltage Range



DIGSILENT	Voltages	Windfarm Red Sunset	Voltages	Date: 10/13/2009
				Annex:



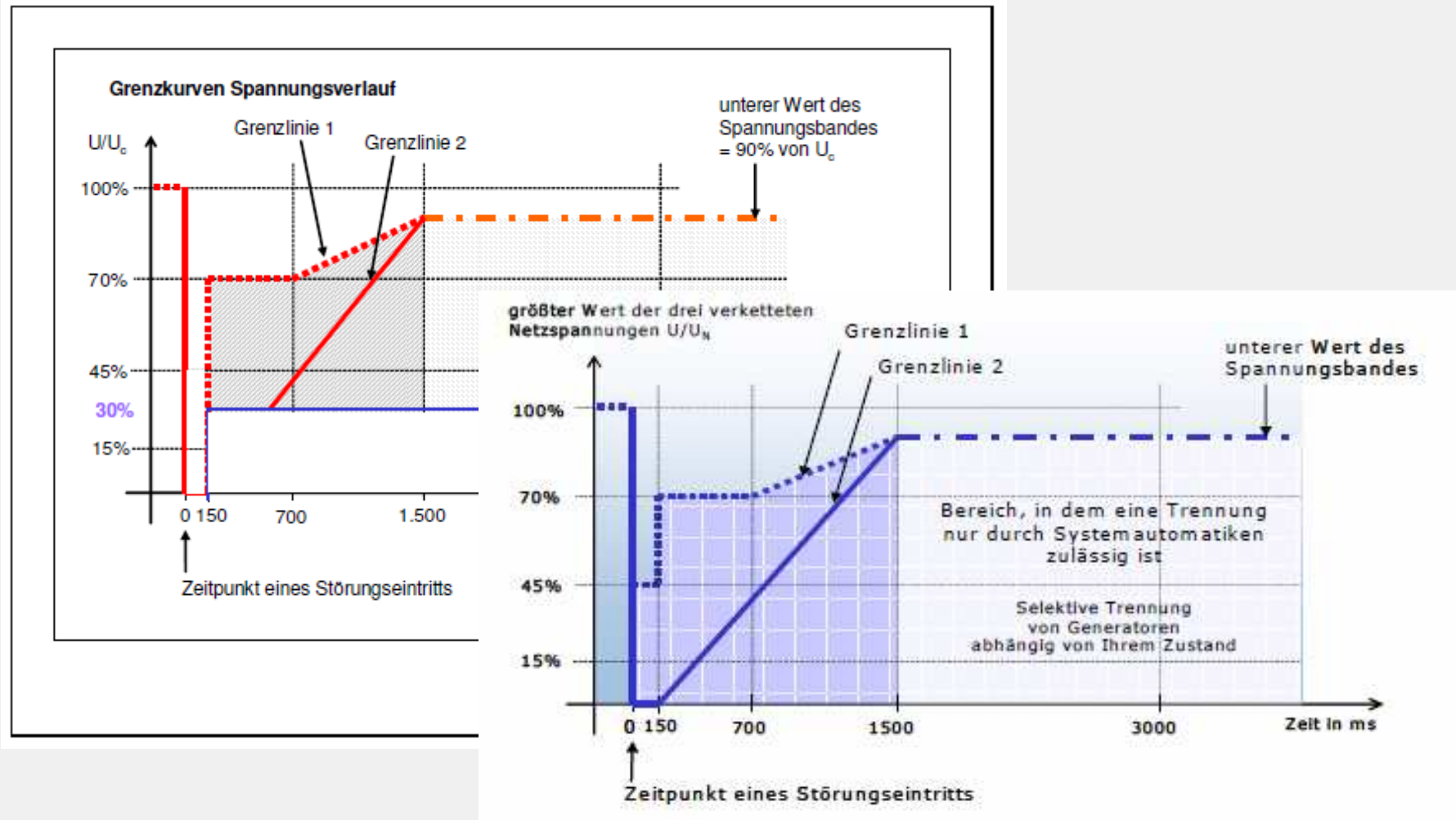
Reactive Power Capability - Verification

- Verification by Load Flow Calculations
- Considering:
 - (Voltage dependence) capability curve of individual WTGs
 - Thermal loading of the cables in the Wind Park
 - Compliance with the permissible voltage bands in all medium-and low voltage nodes



Fault Ride-Through/Low Voltage Ride-Through Capabiltiy

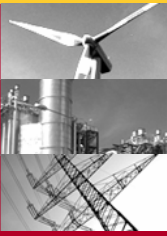
FRT/LVRT: German Grid Codes



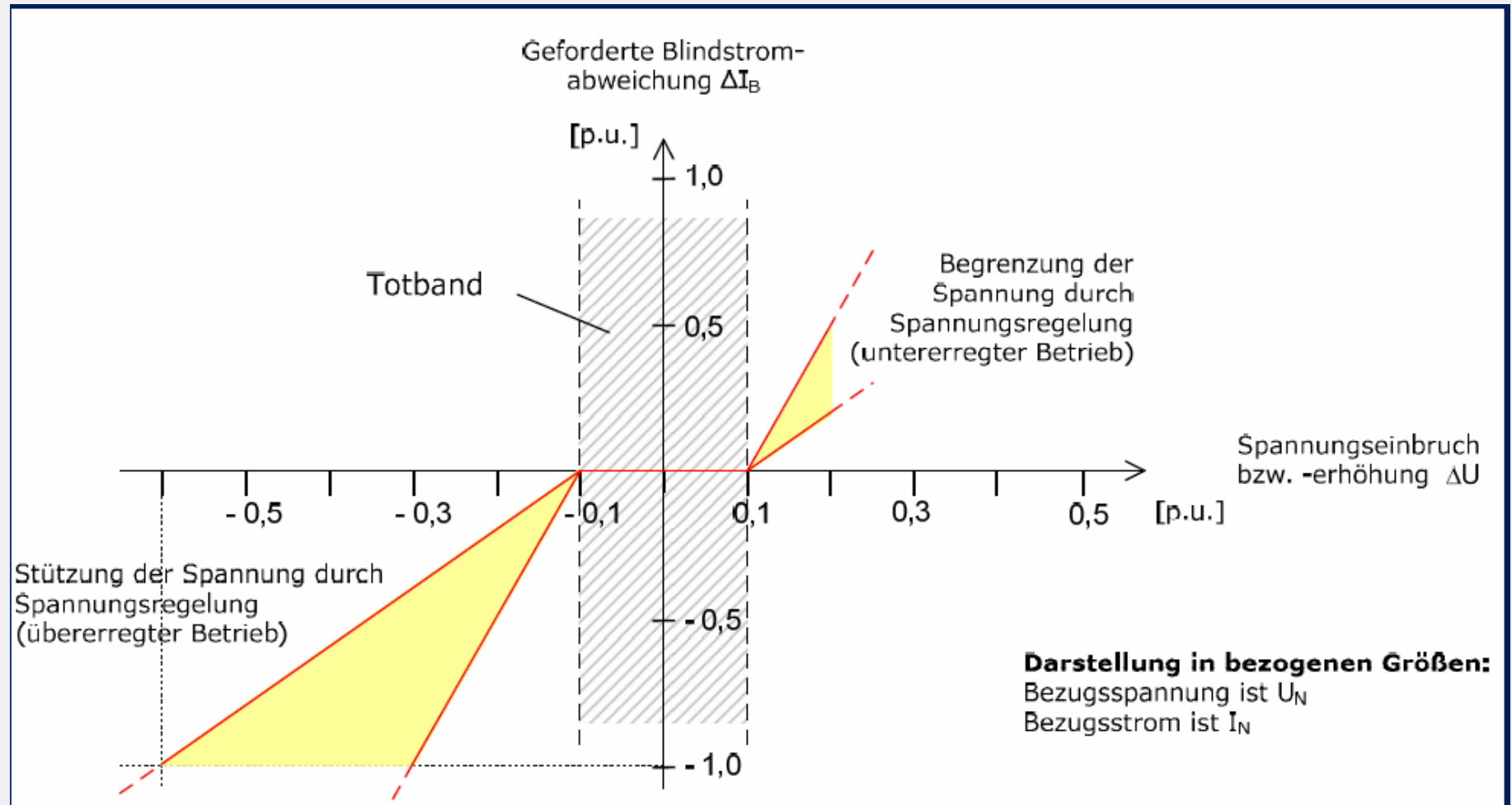


FRT/LVRT

- Above Borderline 1: No separation is allowed
- Above Borderline 2: fast reclosing in coordination with network operators allowed
- Below Borderline 2: fast reclosing always allowed
- Fast reclosing:
 - Reconnection no later than 2s after fault clearance
 - Active Power Increase: 10% pro s, based on generator power
- Requirements apply in principle also for 2-phase faults.
- During voltage recovery: No reactive power absorption is permitted



FRT/LVRT – Reactive Current Support (SDLV)





FRT/LVRT

- Additional reactive current should be proportional to the voltage dip.
- Voltage dip and reactive current defined as the positive sequence component of the fundamental frequency component.
- Total reactive current can be limited to 100% of rated current .
- Active current is to be lowered in favor of the reactive current.
- Also continuous voltage control without dead band possible (indeed desirable).
- Dynamic range: up time 30ms, Response time: 60ms
- Voltages in not faulted phases $< 1,1 U_n$

FRT/LVRT - Verification

- Verification of the required FRT / LVRT capabilities of an individual turbine by performing measurements, in the context of the unit certificate (FGW TR3)
- Verification of the required FRT / LVRT capabilities of a wind farm (plant) by performing time domain simulations using models that have been implemented and validated within the framework of the unit certificate.



Summary



Summary – Grid Code Compliance Studies of Wind Farms

- Load Flow Calculations for the verification of:
 - Wind Park Capability Curve at the network connection point.
 - Impact on voltage variations.
 - Impact on thermal loading of network branches.
- Determine the minimum short-circuit level at the connection point for Flicker Assessment according to IEC61400-21
- Harmonic Load Flow Calculations for the verification of :
 - Compliance with the limits for harmonic currents at the connection point, or the harmonic voltages at the PCC (according to EN50160). In simple wind park topologies hand calculation is possible.
- Time Domain Simulations (RMS or EMT):
 - Investigation of the FRT/LVRT-Capabilities