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Voltage and Reactive Power Control by Wind Turbines

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Voltage and Reactive Power Control by Wind Turbines

Starting point is the behavior of a synchronous generators

Questions for the turbine reactive power control design:

1. How should we operate a wind turbine to offer the best grid support possible ?
2. How do conventional power stations contribute to grid stability ?
3. How should wind turbines behave to replace conventional power stations with no need for further grid reinforcement or grid equipment ?

Can we do even better (than conventional power stations) ?

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Why consider dynamic requirements?

Static requirements: reactive current during normal operation
Dynamic requirements: reactive current if voltage changes

1 Initially (before E.ON 2003): no dynamic requirement
=> all conventional power stations must stay in operation

2 Now: (SDLWindV): some dynamic requirements
=> most conventional power stations must stay in operation

3 Future (starting already…): fully replace conventional power stations
=> conventional power stations may shut down

Agenda

1. Basis: Behaviour of synchronous generators
2. Wind plant implementation
3. Simulations
4. Conclusion

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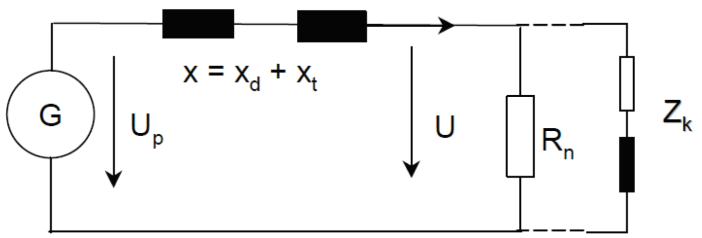
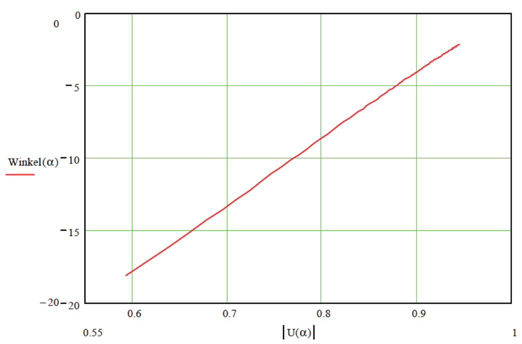
Voltage and Reactive Power Control by Wind Turbines

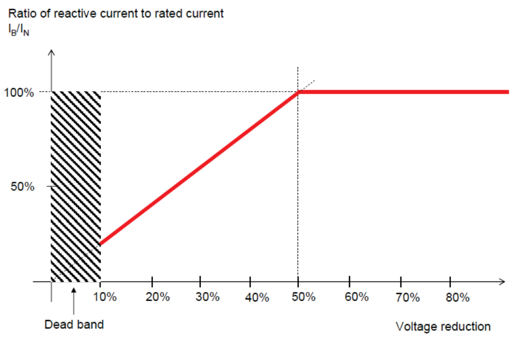
Starting of E.ON Netz in 2003

Analysis of E.ON Netz from 2003:
Response of a synchronous generator of a conventional power station



Source: Kühn, Radtke, "Der Einfluss von Windenergie auf das Verbundnetz", E.ON Netz 2003

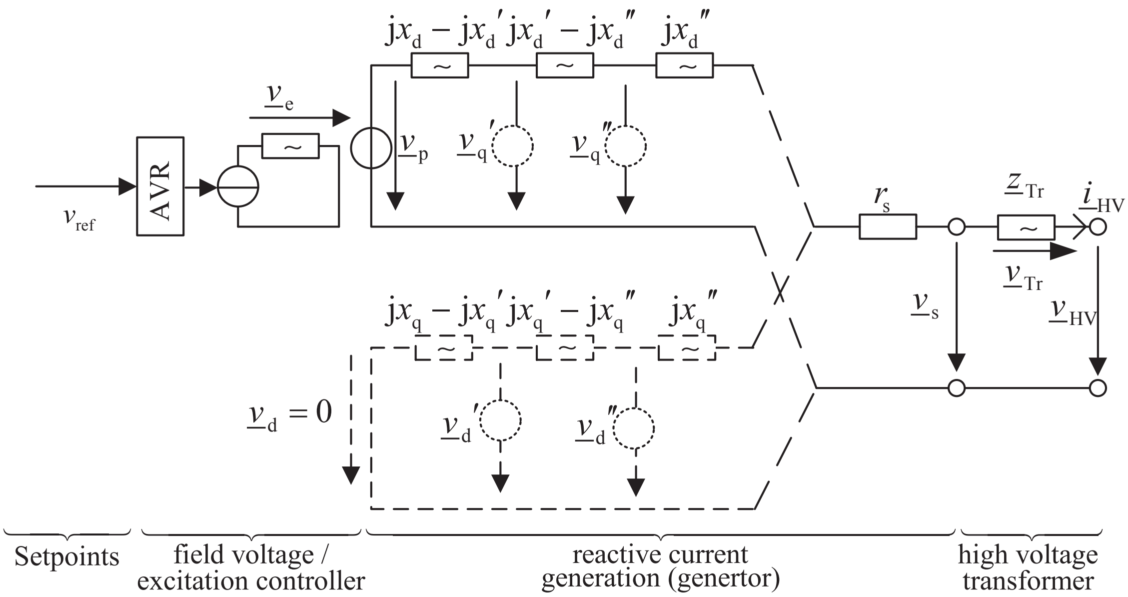




Voltage and Reactive Power Control by Wind Turbines

Starting point is the behavior of a synchronous generators

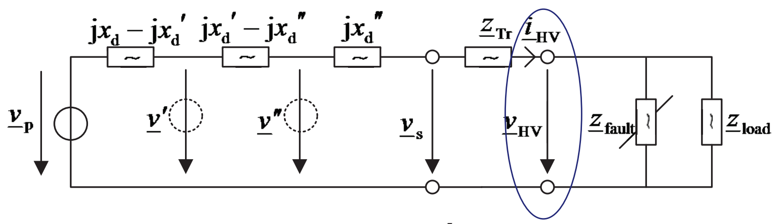
Starting point – diagram of a synchronous generator of a conventional power station

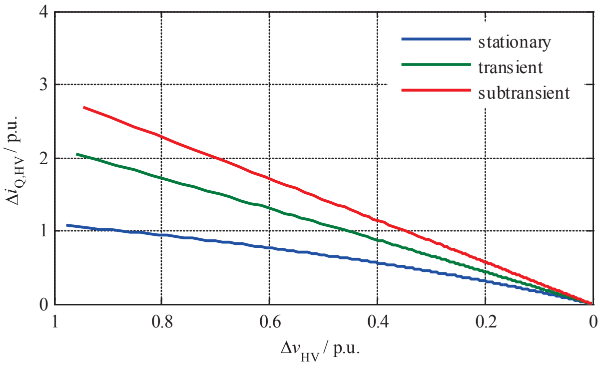


Voltage and Reactive Power Control by Wind Turbines

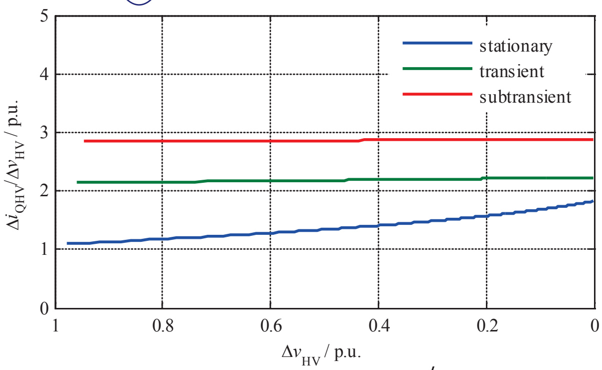
Change of reactive current and reactive current gain of a synchronous generators during grid faults, high voltage terminals

Static calculation – behavior of a synchronous generator during grid faults, HV-level





Reactive current change of a synchronous generator during grid faults as function of voltage change at HV-level.

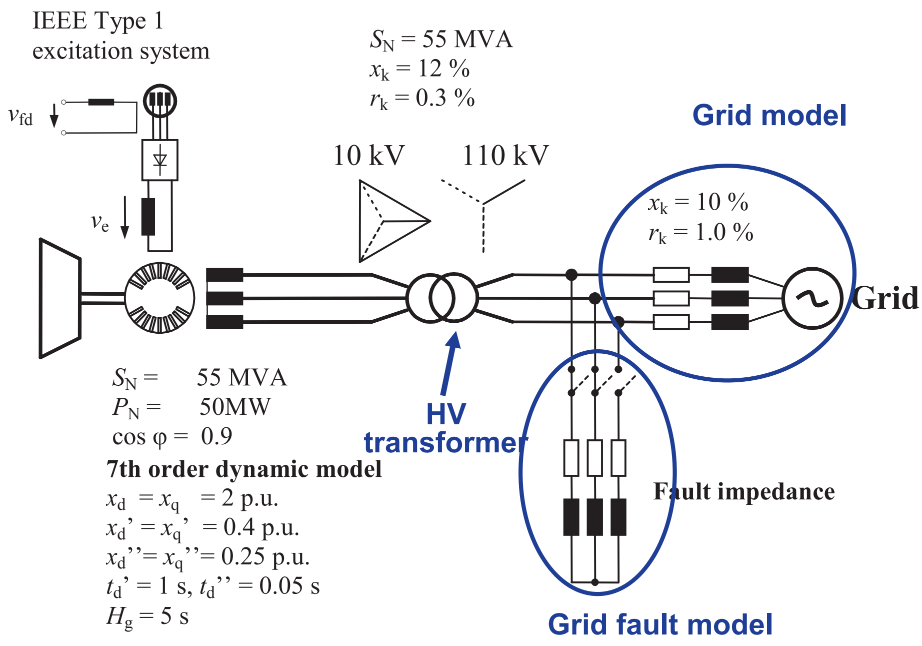


Reactive current gain $\Delta i_{QHV}/\Delta u_{HV}$ of a synchronous generators during grid faults as function of voltage change on HV-level.

Voltage and Reactive Power Control by Wind Turbines

Synchronous generator model used for dynamic simulation

Dynamic simulation – 7th order SG model and fault model



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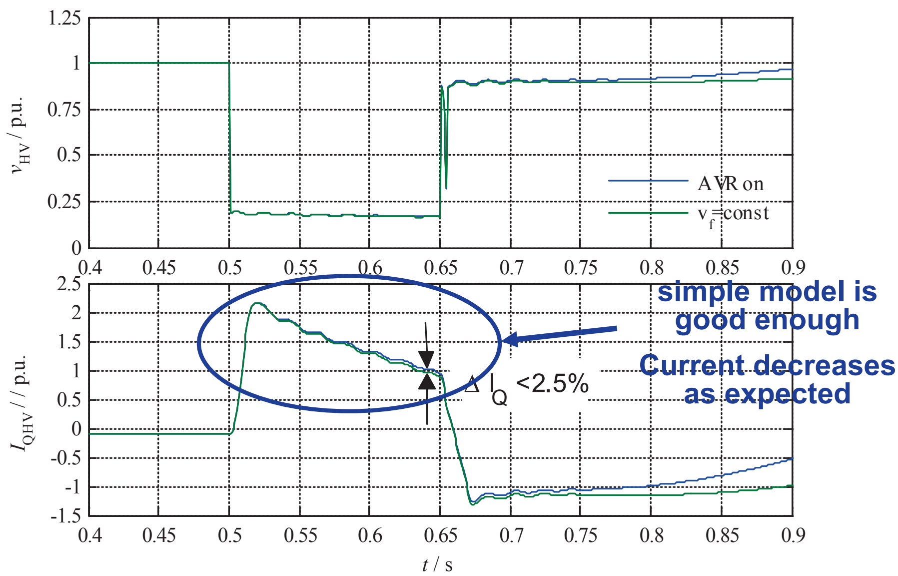
Reactive current of a synchronous generators during grid faults

Dynamic simulation – reactive current of a SG during grid faults, HV-level

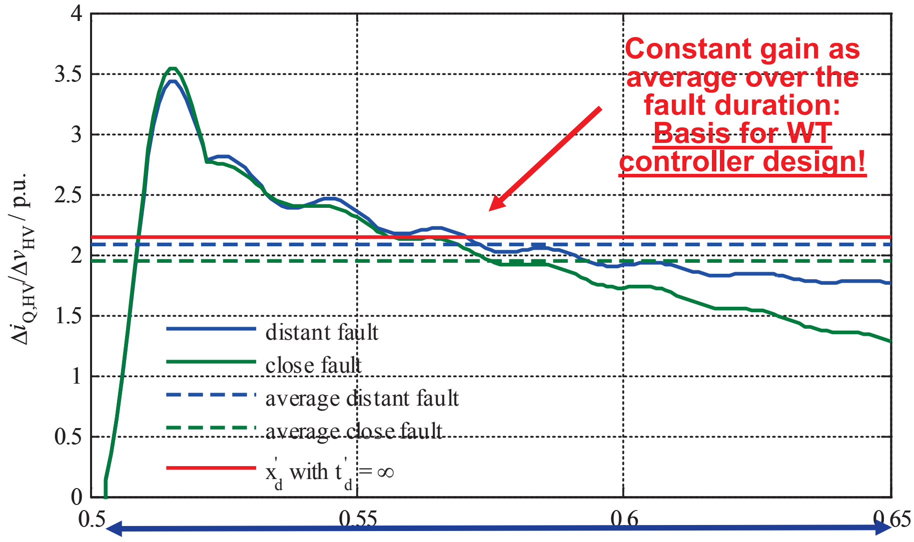


Voltage and reactive current of a synchronous generators during grid faults at HV-level
Parameter: field control on/off

Voltage and Reactive Power Control by Wind Turbines

Reactive current gain of asynchronous generators during grid faults

Dynamic simulation - gain $\Delta i_{QHV}/\Delta u_{HV}$ of a synchronous generator during grid faults



Reactive current gain $\Delta i_{QHV}/\Delta u_{HV}$ over time of a synchronous generators during grid faults at the high voltage terminals.
Parameter: (electrically) distant fault / close fault

Voltage and Reactive Power Control by Wind Turbines

2. Wind plant implementation

1. Basis: Behaviour of synchronous generators

2. Wind plant implementation

3. Simulations

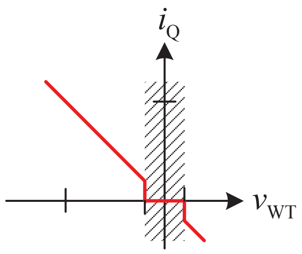
4. Conclusion

Voltage and Reactive Power Control by Wind Turbines

Comparison of different reactive current control concepts during grid faults

Development of reactive current control during grid faults

1. First control approach with dead-band

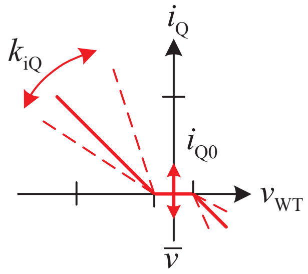


$$i_{Q,ref} = \begin{cases} \frac{p}{v}\sin(\varphi_{ref}) & \text{for } 0.9 \le v \le 1.1 \\ -2\cdot(v-\overline{v}_0) & \text{for } v < 0.9 \text{ and } v > 1.1 \end{cases}$$

„historic“ approach based on concept of loads:
- cos(φ) for normal operation
- Voltage control during fault

E.ON 2003, E.ON 2006,

2. Modified control approach with dead-band

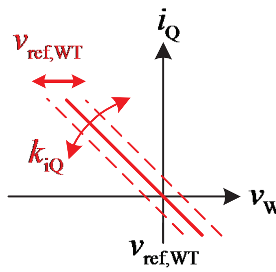


$$i_{Q,ref} = \begin{cases} \frac{p}{v}\sin(\varphi_{ref}) \text{ or } \frac{q_{ref}}{v} & \text{for } 0.9 \le v \le 1.1 \\ k_{iQ}\cdot(v-\overline{v}+\Delta v_0)+\overline{i}_{Q0} & \text{for } v < 0.9 \\ k_{iQ}\cdot(v-\overline{v}-\Delta v_0)+\overline{i}_{Q0} & \text{for } v > 1.1 \end{cases}$$

-Avoid discontinuity
- dead-band adjustable,
- gain adjustable

SDLWindV

3. Control without dead-band



$$i_{Qref} = k_{iQ}\left(v_{ref,WT} - v_{WT}\right)$$

Analogous to synchronous generator, but with adjustable gain

SDLWindV, Tennet,…

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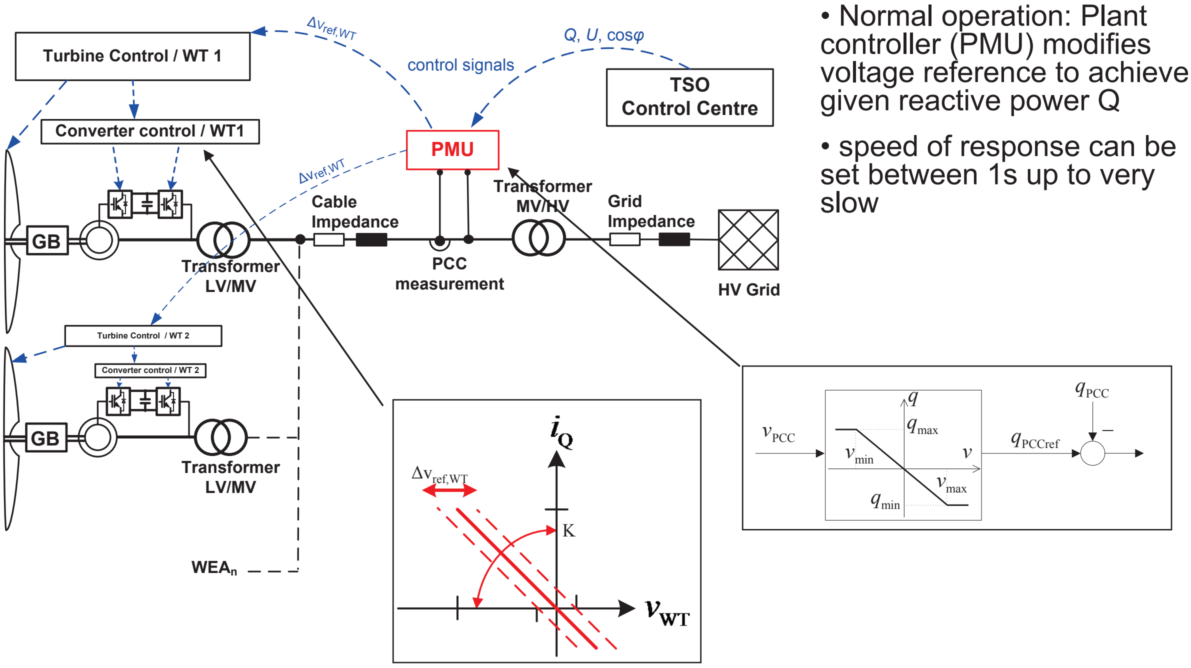
Wind plant reactive power control

Reactive power control of wind plant during normal operation



- Normal operation: Plant controller (PMU) modifies voltage reference to achieve given reactive power Q
- speed of response can be set between 1s up to very slow

Voltage and Reactive Power Control by Wind Turbines

3. Simulations

- 1. Basis: Behaviour of synchronous generators
- 2. Wind plant implementation
- 3. Simulations
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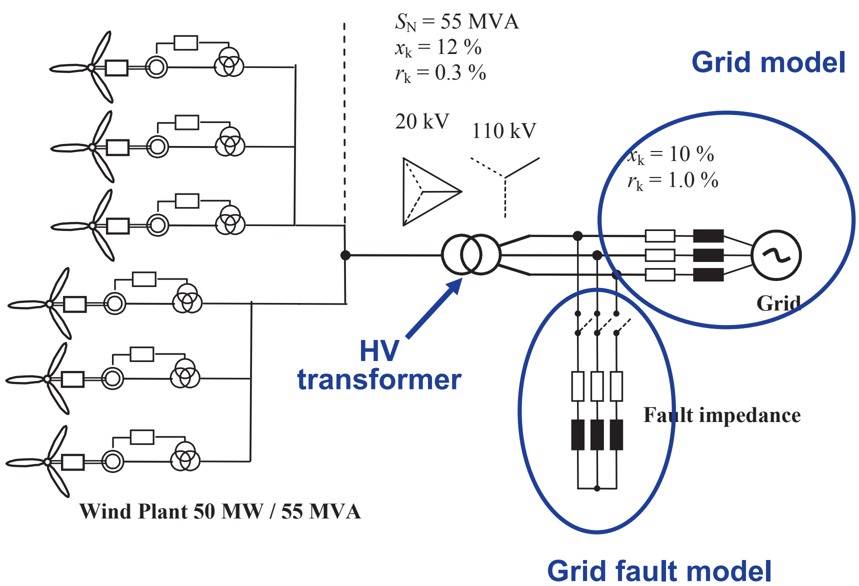
Voltage and Reactive Power Control by Wind Turbines

Wind plant model used for dynamic simulation

Dynamic simulation – model of wind plant used for simulation



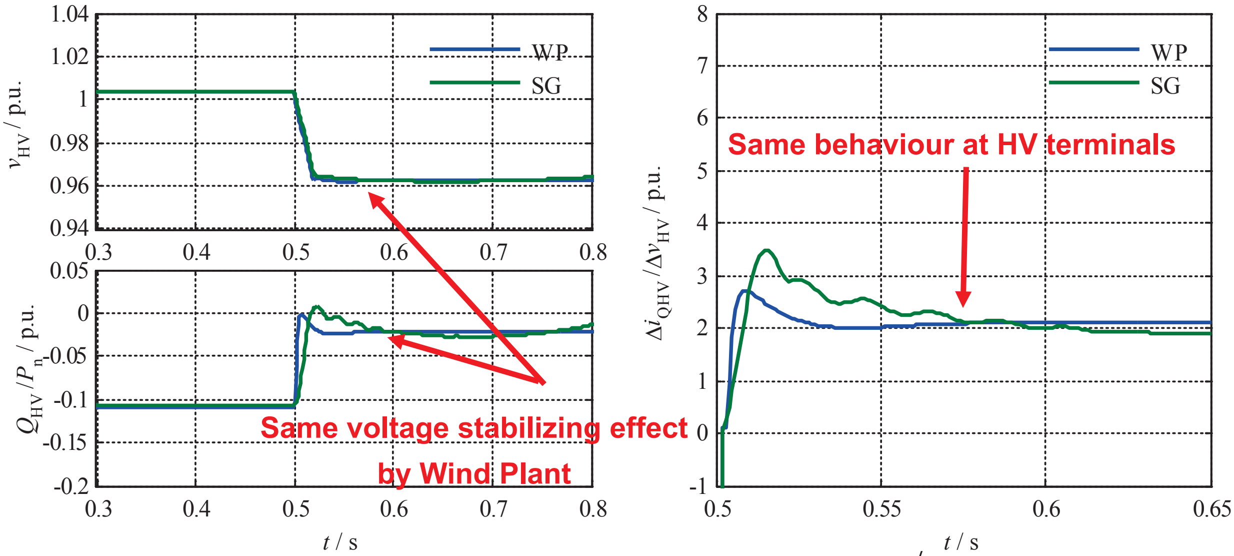
Wind plant with 50 MW

Voltage and Reactive Power Control by Wind Turbines

Response to voltage drop of 5% (= switching operation in the grid)

REpower Systems

Voltage drop by 5% in the high voltage grid: Wind Plant and Synchronous Generator



Reactive current of synchronous generator (green) and wind plant (blue) at voltage drop of 5% in the HV grid.

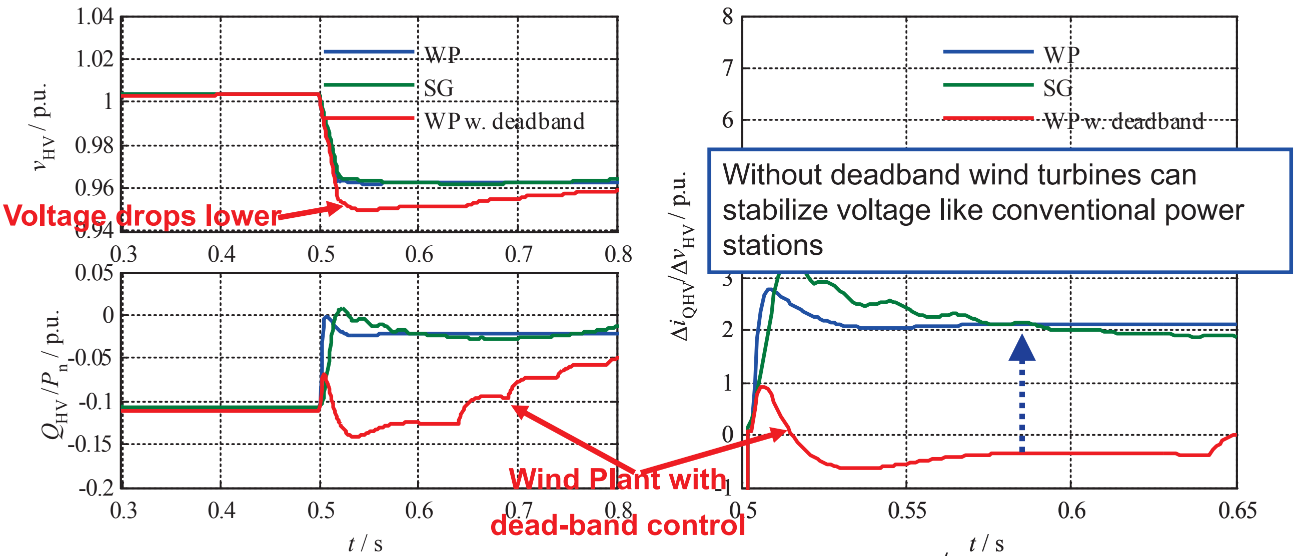
Effective gain $\Delta i_Q/\Delta v$ at HV-level at voltage drop by 5% for synchronous generator (green), wind plant as proposed (blue).

Voltage and Reactive Power Control by Wind Turbines

Response to voltage drop of 5% (= switching operation in the grid)

REpower Systems

Voltage drop by 5% in the high voltage grid:
Synchronous Generator, Wind Pant, Wind Plant with deadband



Reactive current of synchronous generator (green) and wind plant (blue) at voltage drop of 5% in the HV grid. Comparison to wind plant with dead-band (red)

Effective gain $\Delta i_Q/\Delta v$ at HV-level at voltage drop by 5% for synchronous generator (green), wind plant as proposed (blue) and wind plant using dead-band (red).

Conclusion

1. Basis: Behaviour of synchronous generators

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Voltage and Reactive Power Control by Wind Turbines

Conclusion: WEC reactive power control without deadband

Reactive current control equivalent to synchronous generators

Technical issues

- Reactive current control equivalent to synchronous generators
- fast response to voltage changes, slow response to setpoint changes
- reactive current proportional to voltage change
- damping of voltage changes in the grid
- no deadband

Key points

- Use of deadband risks voltage stability at very high wind penetration
- fast voltage control equivalent to synchronous generators stabilizes grid voltage

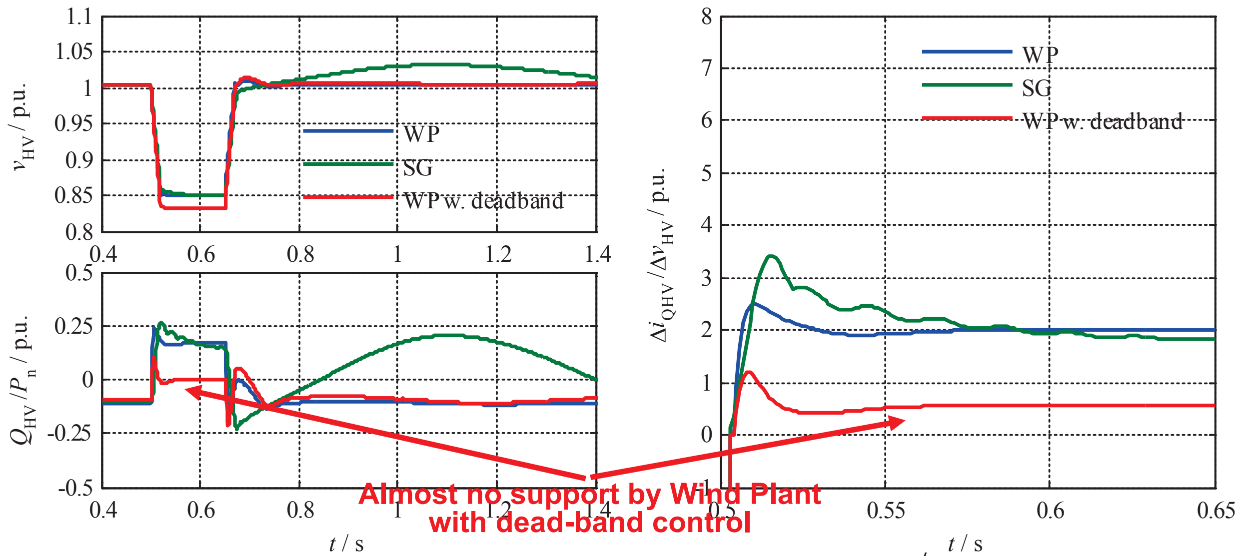
- Technology available for different wind turbine control implementations

=> Technology ready for the grids of the future

Voltage and Reactive Power Control by Wind Turbines

Response to voltage dip by 15% (= distant fault)

Voltage dip of 15% in the high voltage grid : SyncGen, WP, WP with deadband



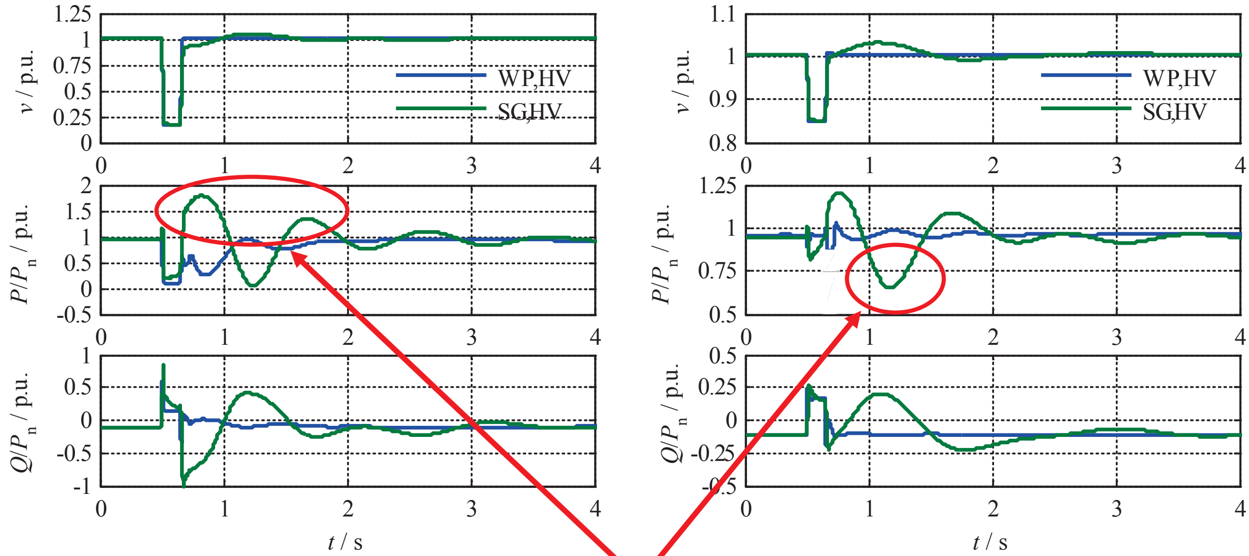
Reactive current of synchronous generator (green) and wind plant (blue) at voltage dip of 15% in the HV grid. Comparison to wind plant with dead-band (red)

Effective gain $\Delta i_Q / \Delta v$ at HV-level at voltage dip of 15% for synchronous generator (green), wind plant as proposed (blue) and wind plant using dead-band (red).

Voltage and Reactive Power Control by Wind Turbines

Comparison of synchronous generator and wind plant using proposed control

Voltage in the high voltage grid: Synchronous Generator and Wind Plant



Voltage dip by 80%

Voltage dip by 15%

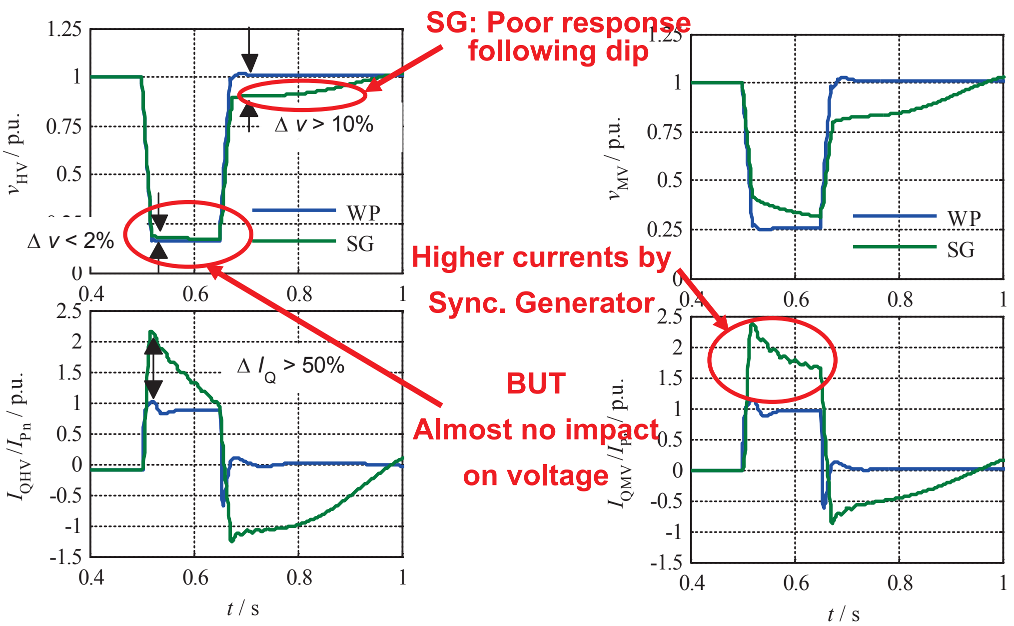
Severe oscillations of Sync. Generator

Almost no oscillations by Wind Plant

Voltage and Reactive Power Control by Wind Turbines

Comparison of synchronous generator and wind plant using proposed control

Voltage dip by 80% in the high voltage grid: Synchronous Generator and Wind Plant



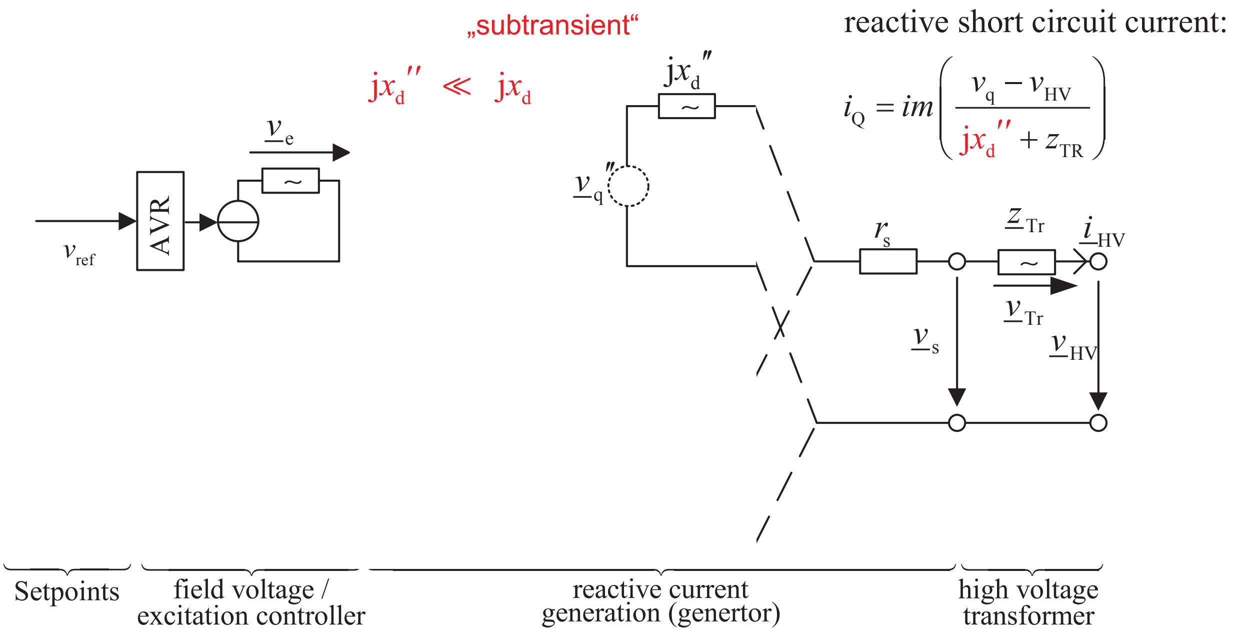
Voltage and Currents at HV side

Voltage and Currents at MV side

Voltage and Reactive Power Control by Wind Turbines

Starting point is the behavior of a synchronous generators

Starting point – diagram of a synchronous generator of a conventional power station



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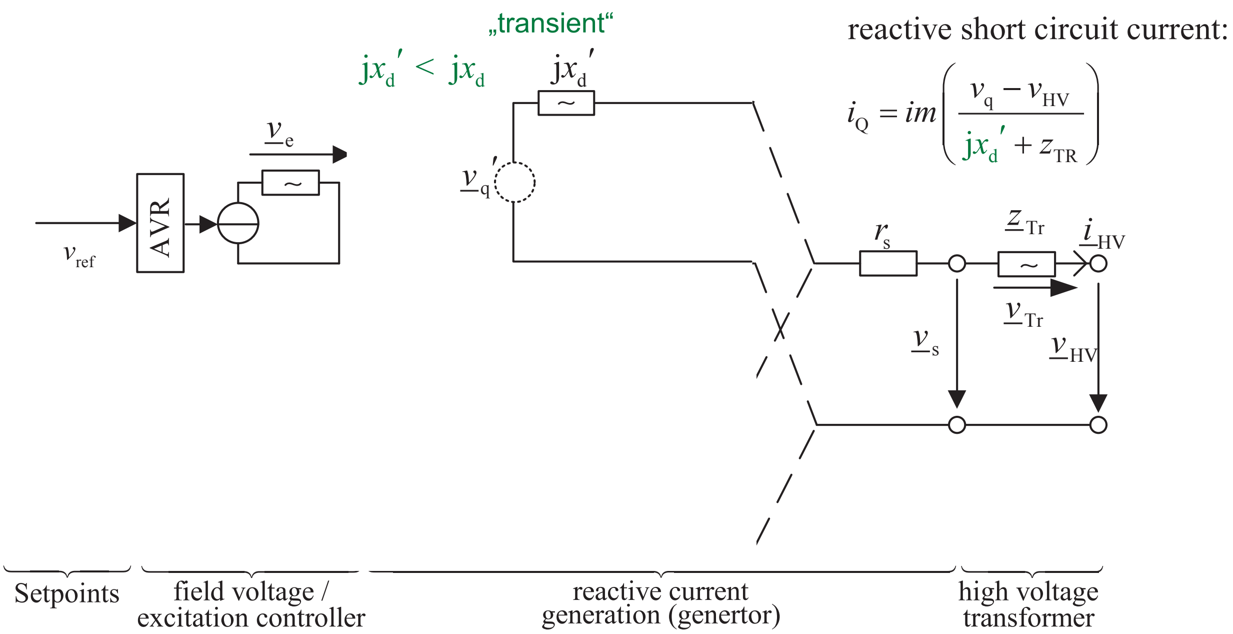

Voltage and Reactive Power Control by Wind Turbines

Starting point is the behavior of a synchronous generators

Starting point – diagram of a synchronous generator of a conventional power station