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# Wind Turbine Generators (WTGs) – Physical Principles and Generator Concepts

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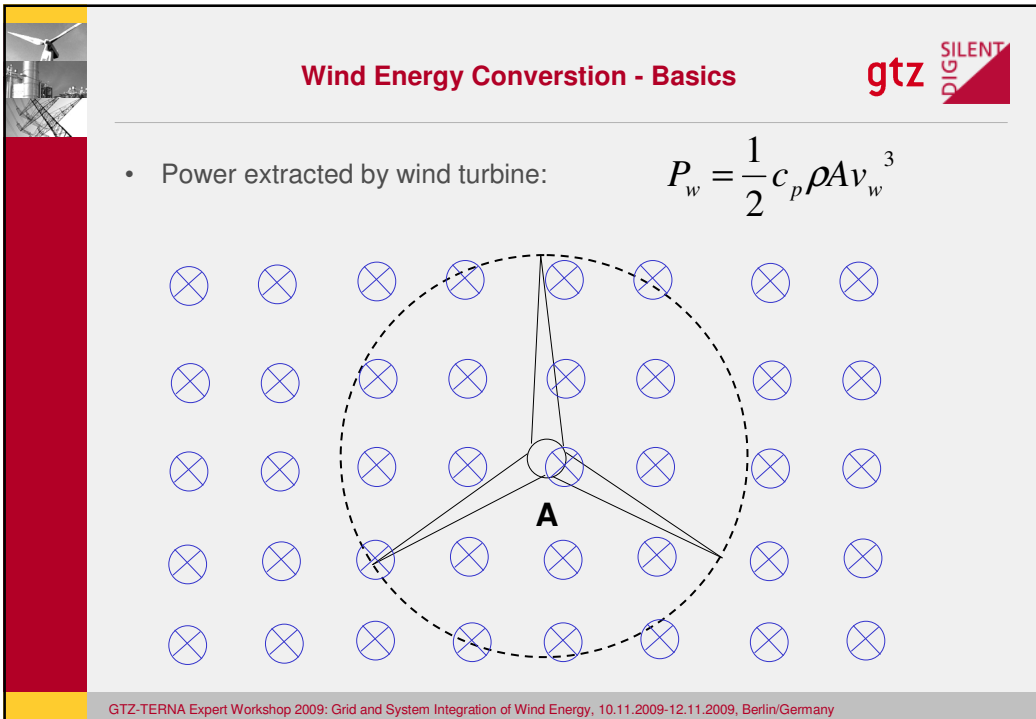
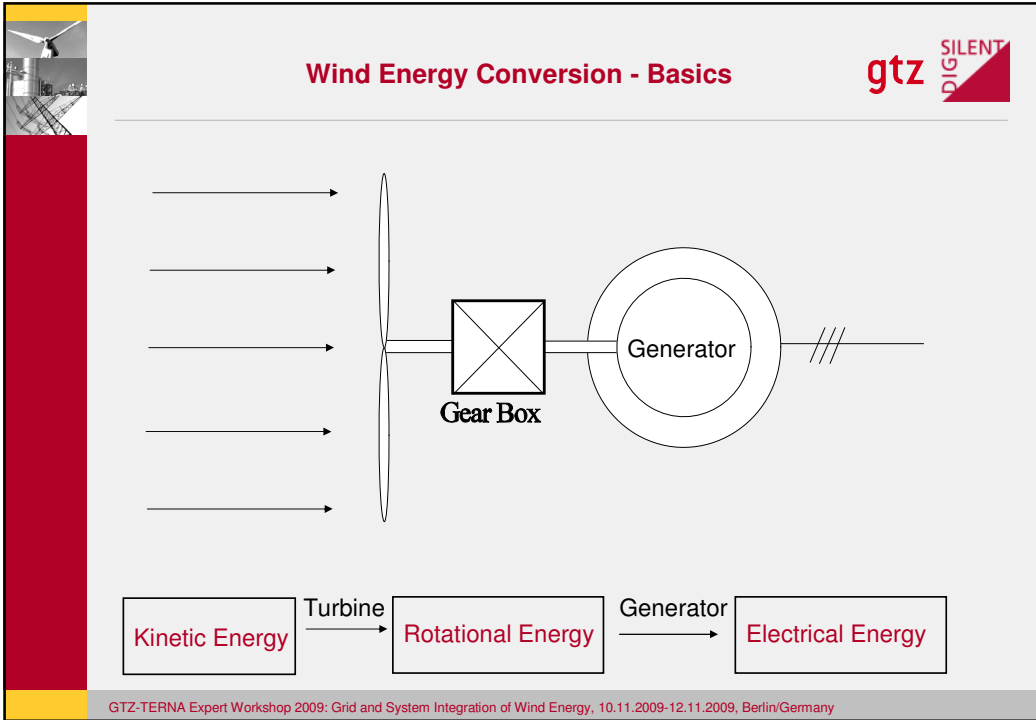
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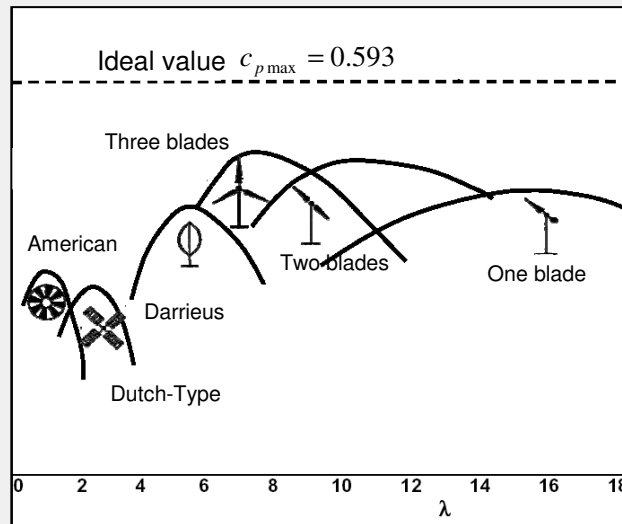


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# Wind Energy Conversion

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## Summary

- Power in the wind increases with  $v_w^3$
- Power is proportional to swept area  $A$ , hence increases quadratically with increasing rotor diameter
- Power coefficient depends on
  - Wind speed
  - Rotor speed
  - Number of blades
  - Blade design
  - Blade angle

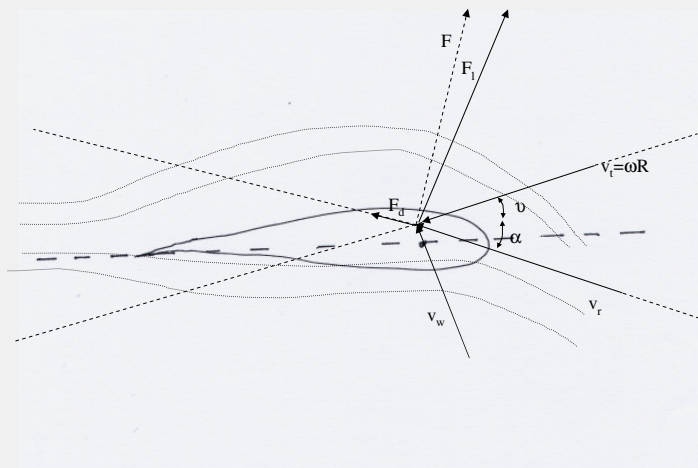
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## Turbine Control Concepts

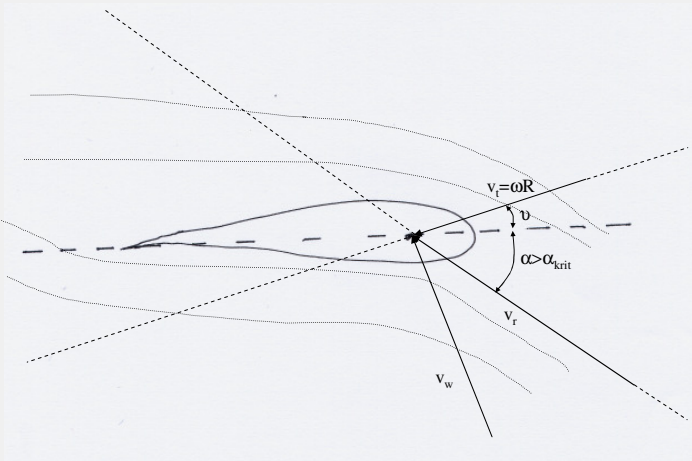


## Aerodynamics




**Stall**

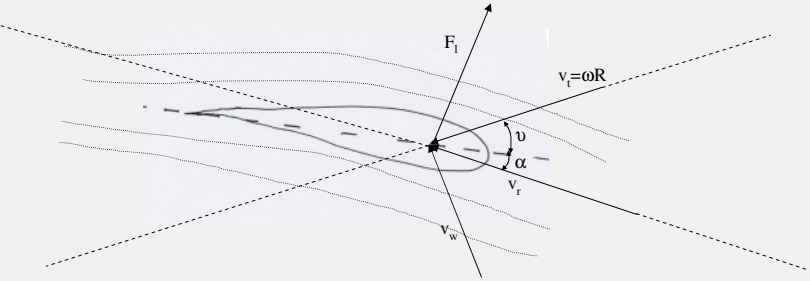




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**Pitching**





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## Turbine Control Concepts



- **Stall Control:**
  - **Passive Stall:**  
Power of the wind turbine is limited by the aerodynamic characteristics of the turbine.
  - **Active stall:**  
Power of the wind turbine is limited additionally by decreasing the pitch angle (increasing the inflow angle).
- **Pitch Control:**
  - Power of the wind turbine is limited by increasing the pitch angle (decreasing the inflow angle)

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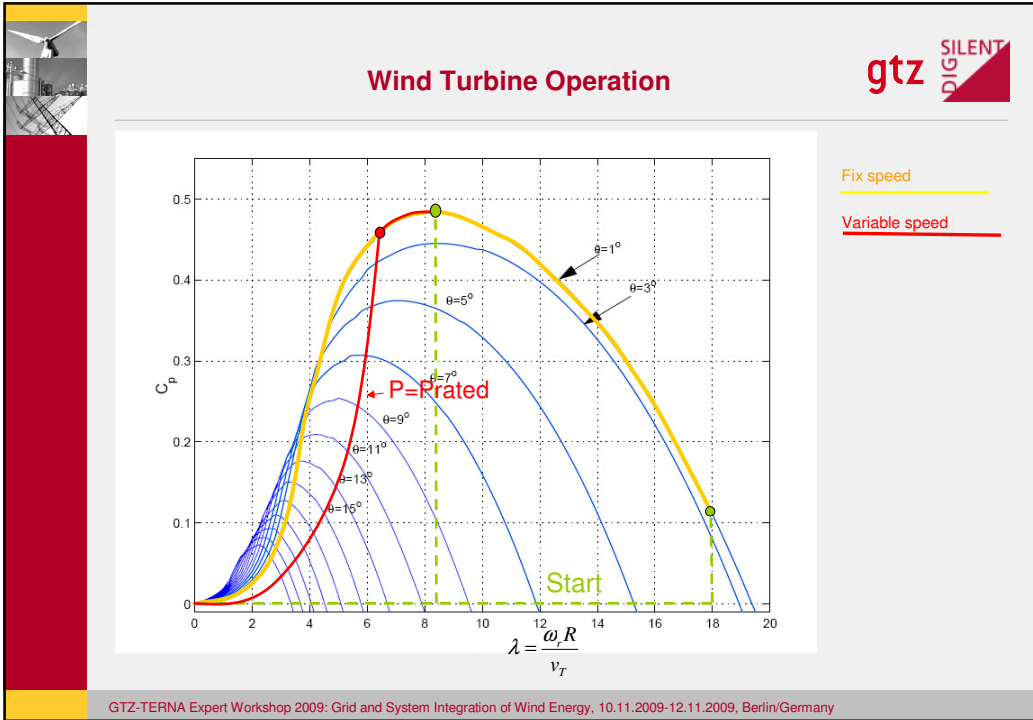



## Turbine Control Concepts



- **Stall Control:**
  - Cost effective
  - Fast limitation of active power
  - Fixed speed operation possible
- **Pitch Control:**
  - Accurate power control possible
  - Variable speed operation required

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- ### Operation of Fix Speed Wind Turbine (passive stall)
- 
- Start up (with open breaker) if wind speed > cut-in wind speed
  - Close breaker
  - Operation at constant blade angle over the whole wind speed range
  - In case of large wind speeds: Power limited by aerodynamic profile.
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## Operation of Variable Speed Wind-Turbines

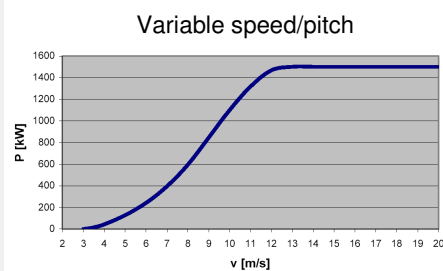
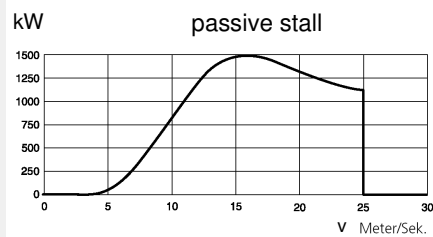


- Start up (with open breaker) if wind speed > cut-in wind speed
- Close breaker
- Below rated wind-speed
  - Maximum power coefficient (Max. Power Tracking)
  - Evt: Speed Limitation
- Above rated wind-speed:
  - $P = P_{\text{rated}}$  (Limited by power electronics converter)
  - Pitching
- Advantages of variable speed operation:
  - Lower cut-in wind speeds
  - Higher efficiency, especially at low wind speeds
  - Lower power variations (compared to fixed speed turbines)
- Disadvantage: More expensive!

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## Wind Turbine Operation – Typical Power Curves



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## Generator Concepts

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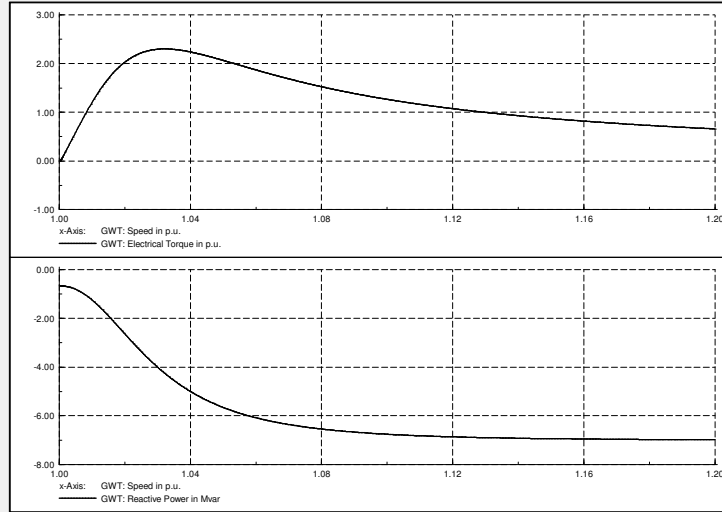
### Fixed Speed Induction Generator

The diagram illustrates the power flow in a fixed-speed induction generator system. It starts with a wind turbine rotor on the left, which is connected to a square box labeled "Gear Box". The gear box is connected to a circular component labeled "IG" (Induction Generator). The IG is connected to a power line that includes a ground connection symbol. This line then passes through a transformer (represented by two overlapping circles) and is finally connected to a hatched rectangular box labeled "Grid".

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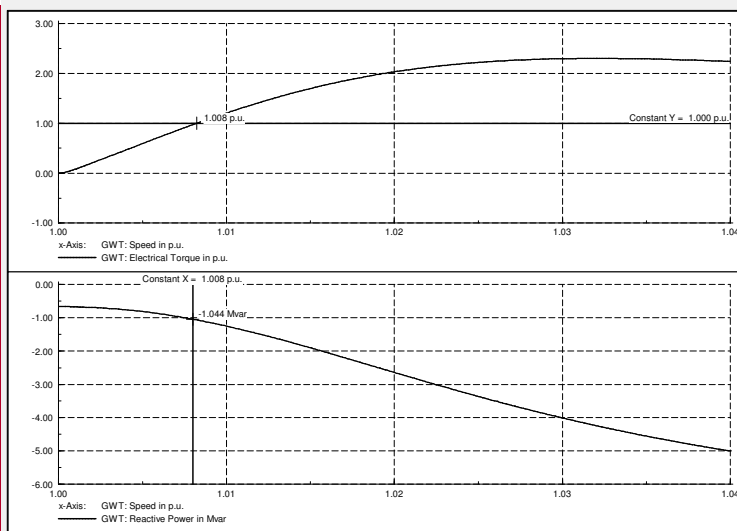
## Induction Generator



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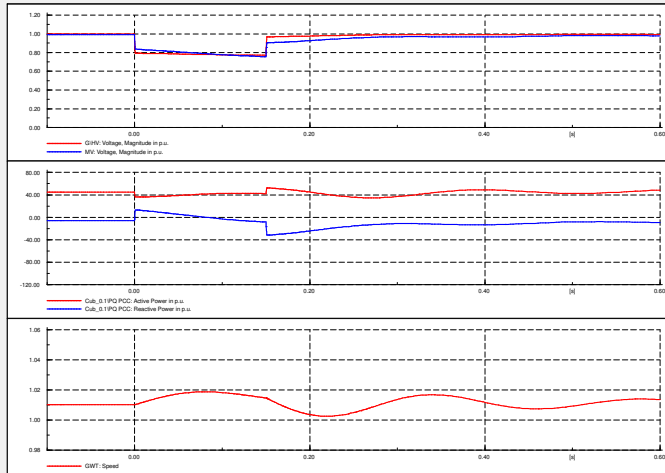
## Induction Generator



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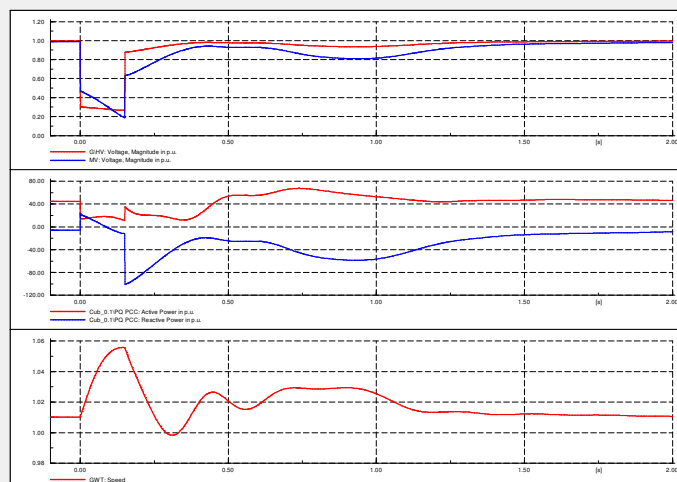
## Induction Generator – LVRT-Behaviour



Induction generator response to a weak voltage dip



## Induction Generator – LVRT Behaviour



Induction generator response to a strong voltage dip



## Induction Generator - Summary

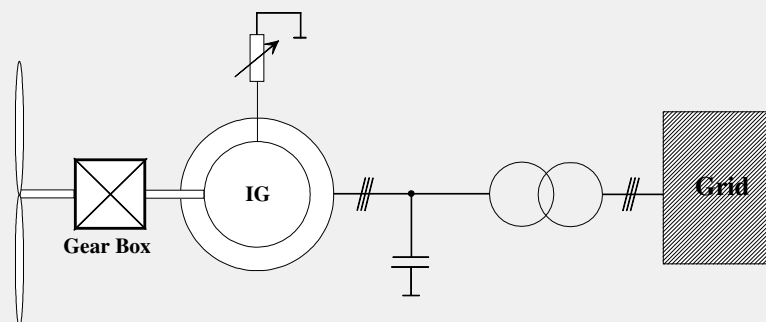


- Only fix speed operation possible (stall control required)
- Reactive power compensation required
- No reactive power control capability. Additional devices required:
  - TSCs (Thyristor switched capacitors)
  - STATCOMs
- Risk of dynamic voltage collapse
  - > Typically, wind generators based on induction generators are asked to disconnect in case of voltage dips

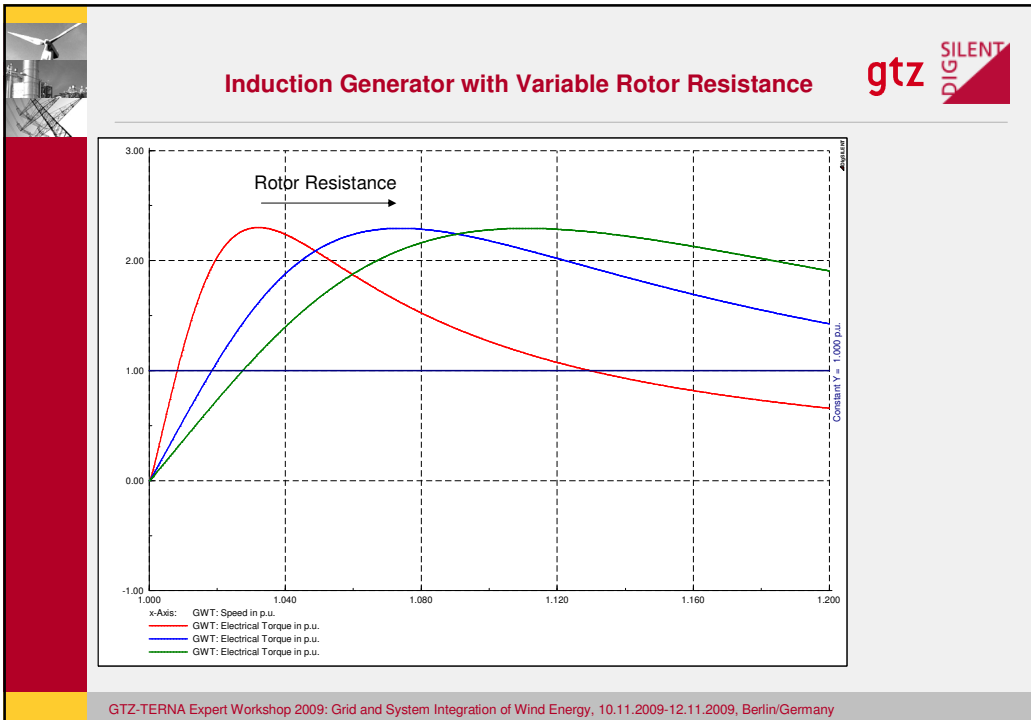
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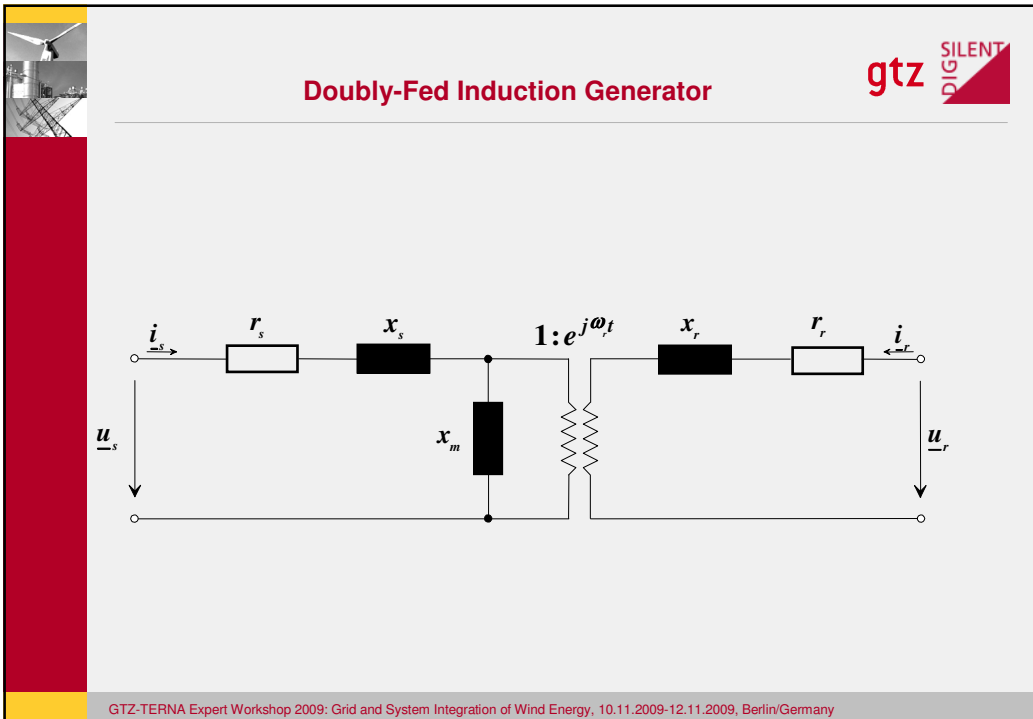
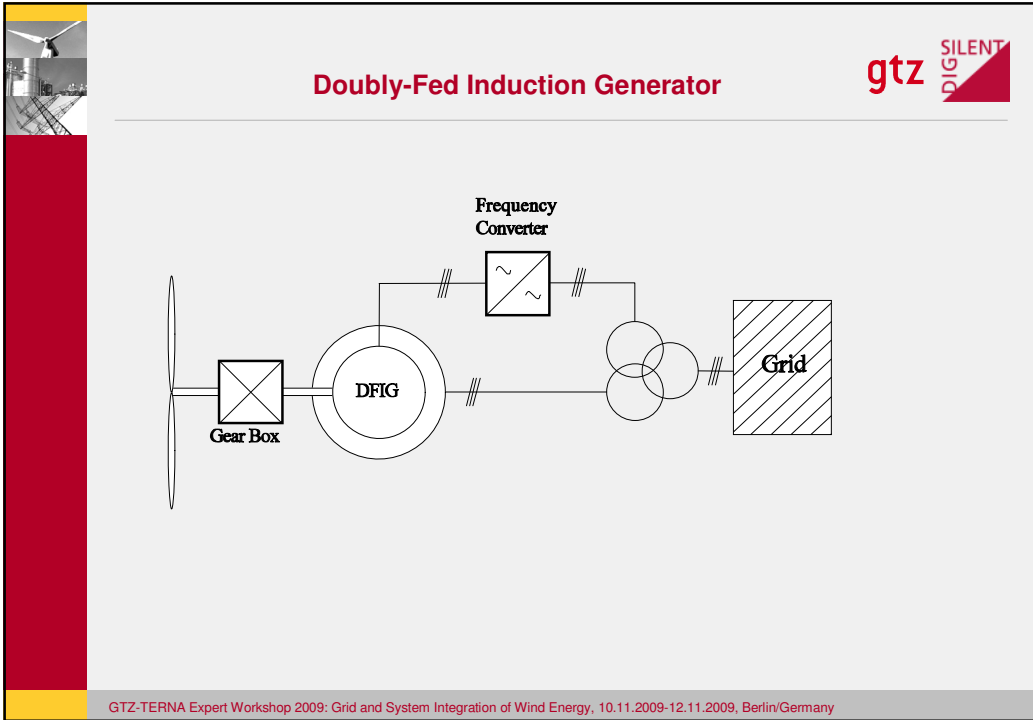
## Induction Generator with Variable Rotor Resistance

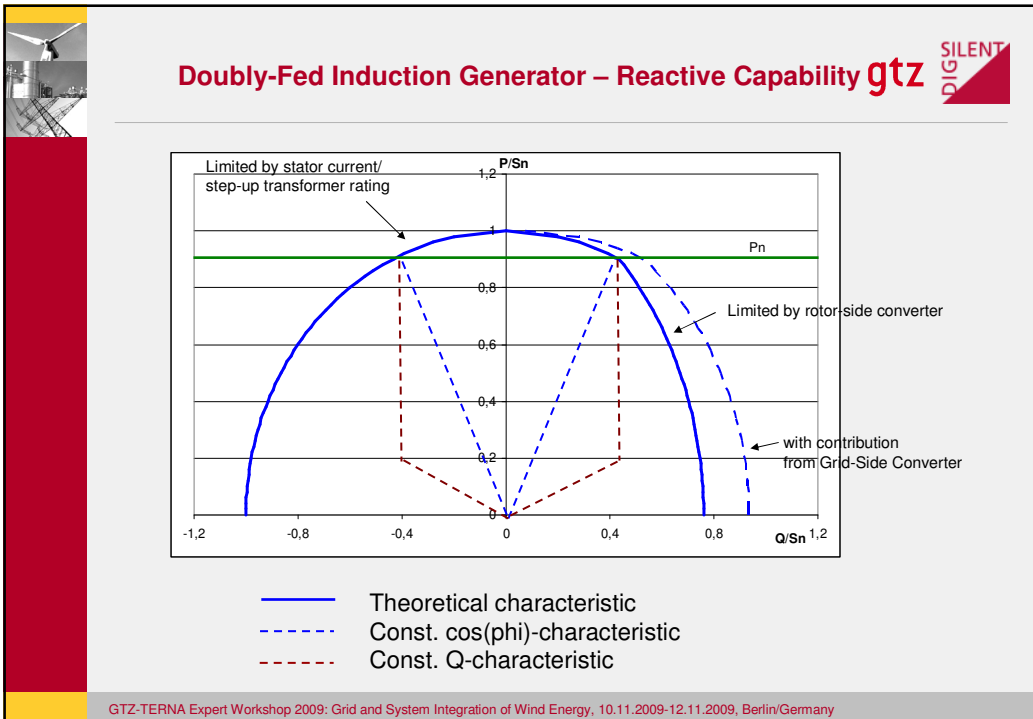
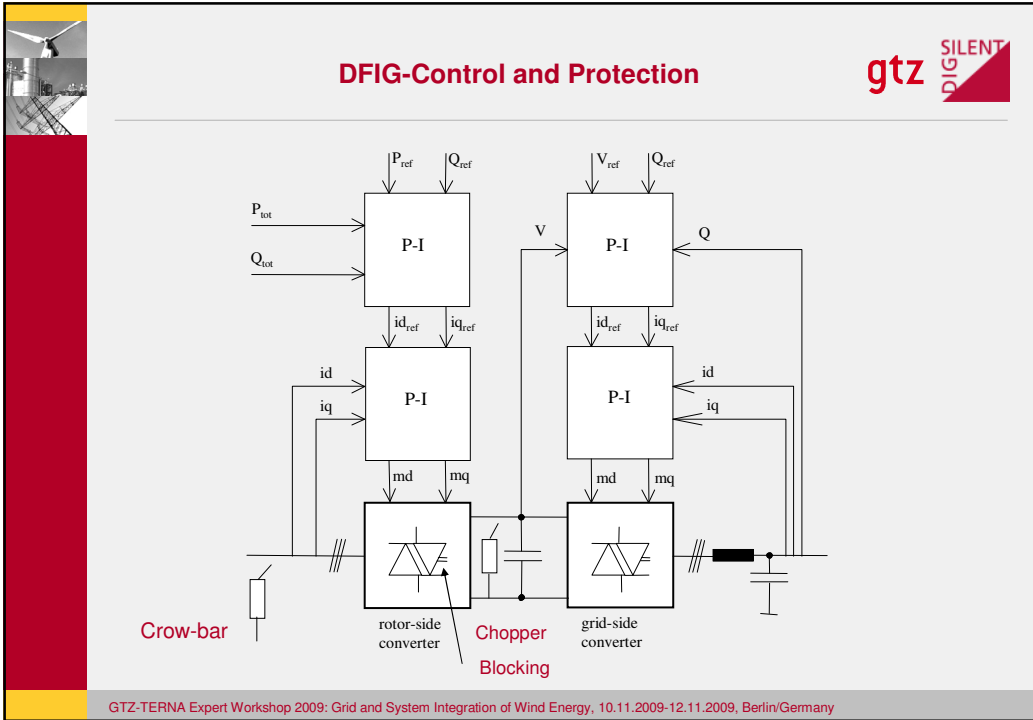


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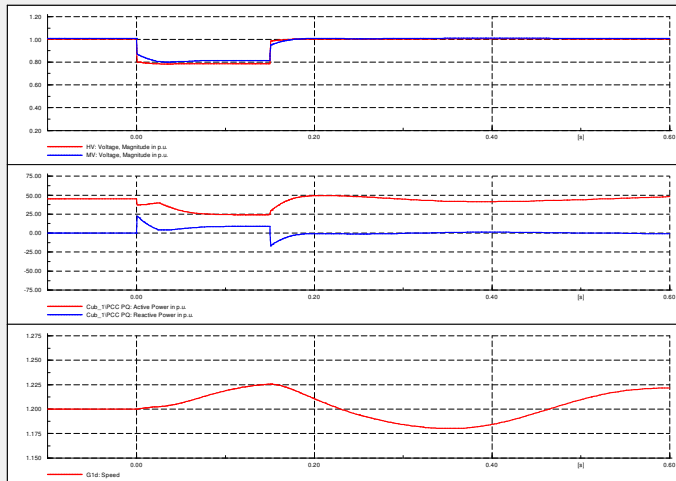
- 
- Induction Generator with Variable Rotor Resistance - Summary**
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- Simple concept for variable speed operation.
  - Reactive power compensation required.
  - No reactive power control capability. Additional devices required:
    - TSCs (Thyristor switched capacitors)
    - STATCOMs
  - Limited LVRT capability. Dynamic voltage collapse problems have to be mitigated by:
    - Fast increase of rotor resistance during faults
    - Additional reactive power compensation devices (typically TSCs)
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## Doubly-Fed Induction Generator – LVRT-Behaviour

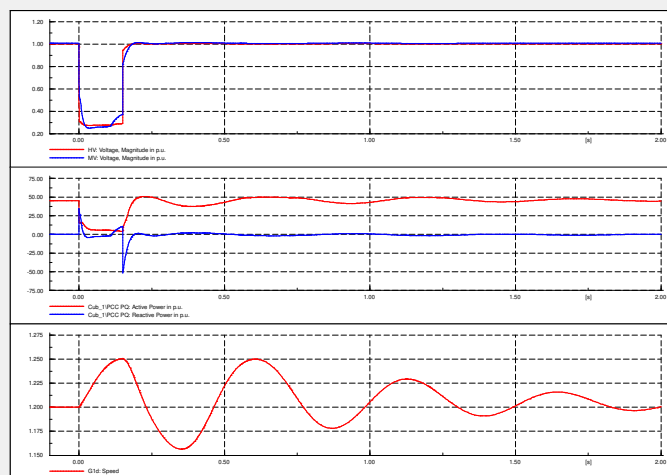


DFIG response to a weak voltage dip

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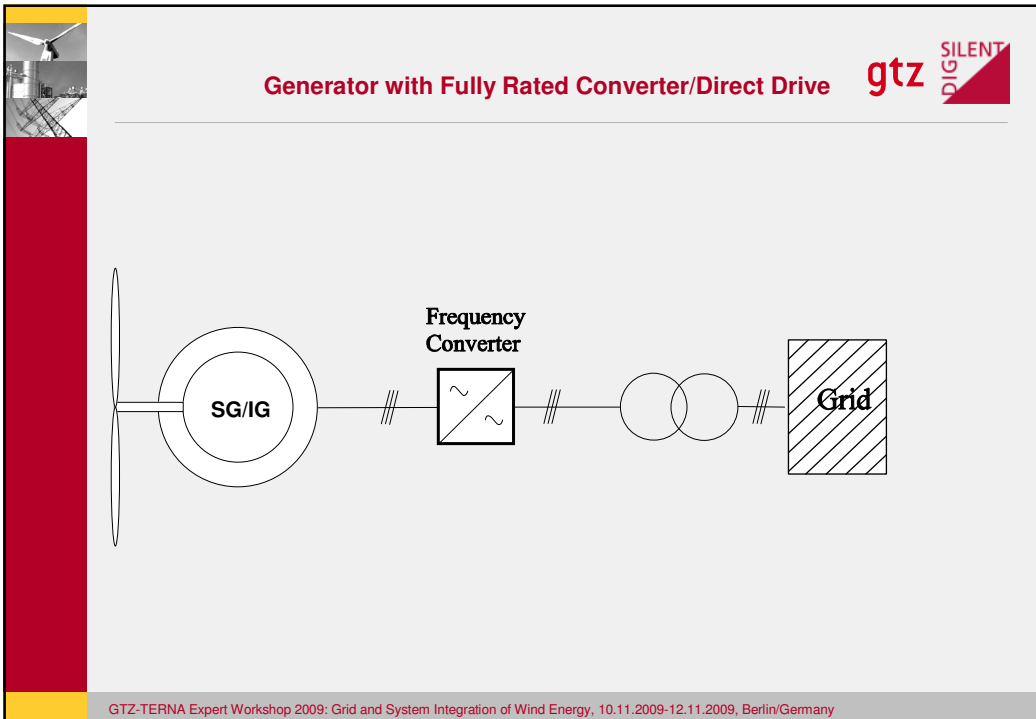
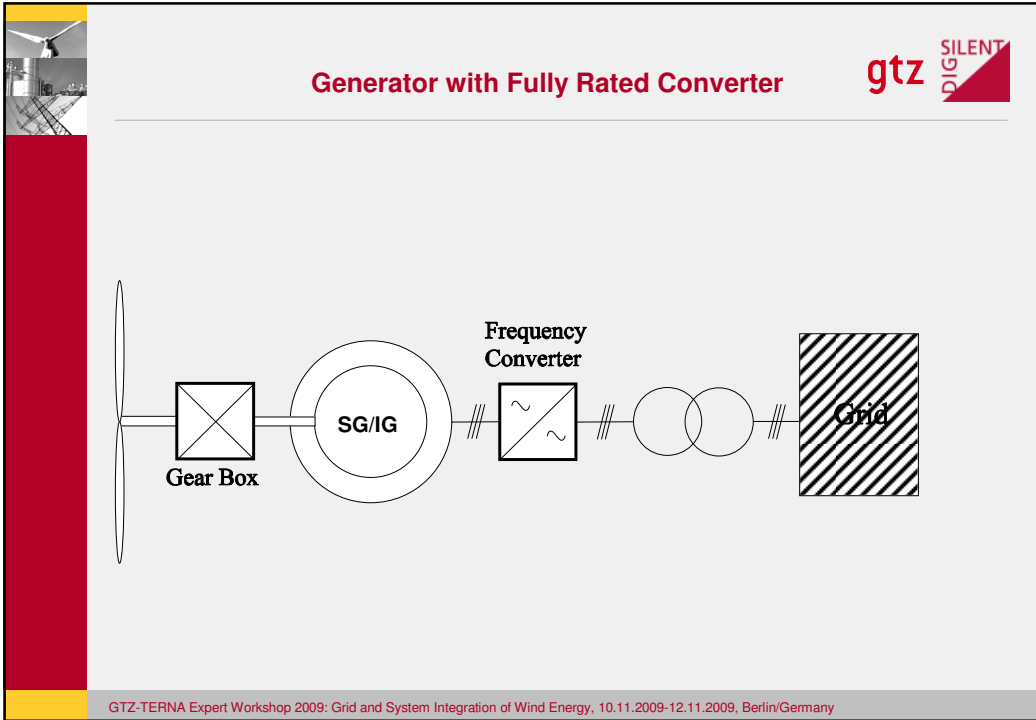


## Doubly-Fed Induction Generator – LVRT-Behaviour



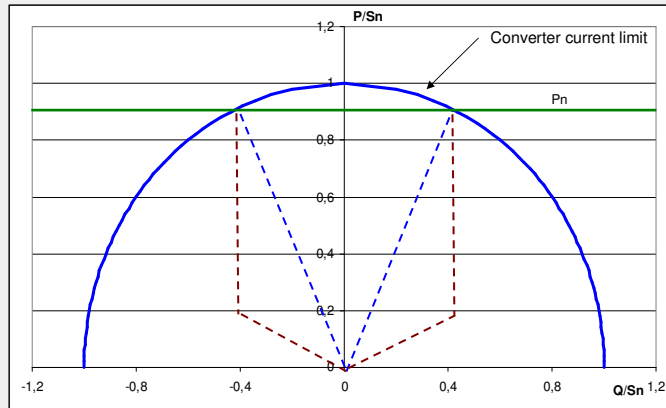
DFIG response to a strong voltage dip (crow-bar operation)

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## Generator with Fully Rated Converter – Reactive Capability

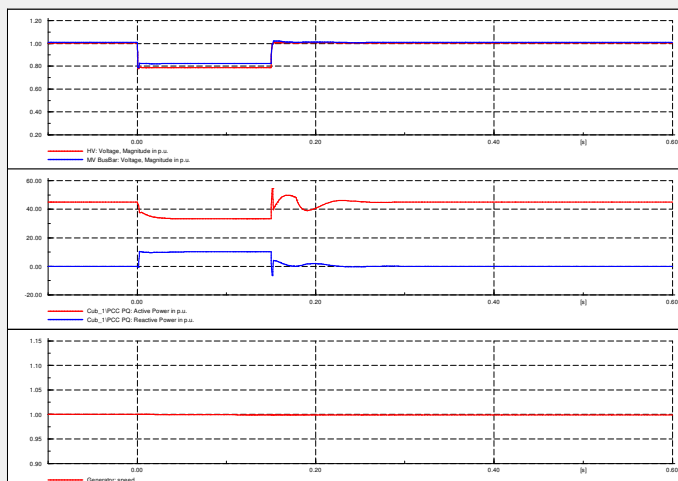


- Theoretical characteristic
- - - Const.  $\cos(\phi)$ -characteristic
- - - Const. Q-characteristic

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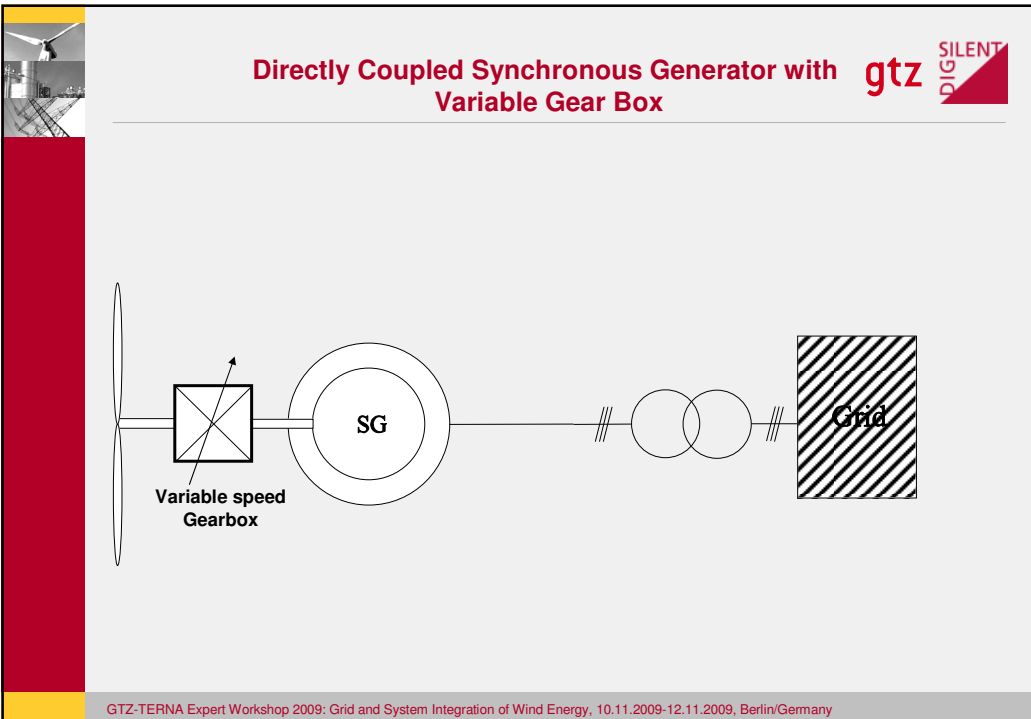
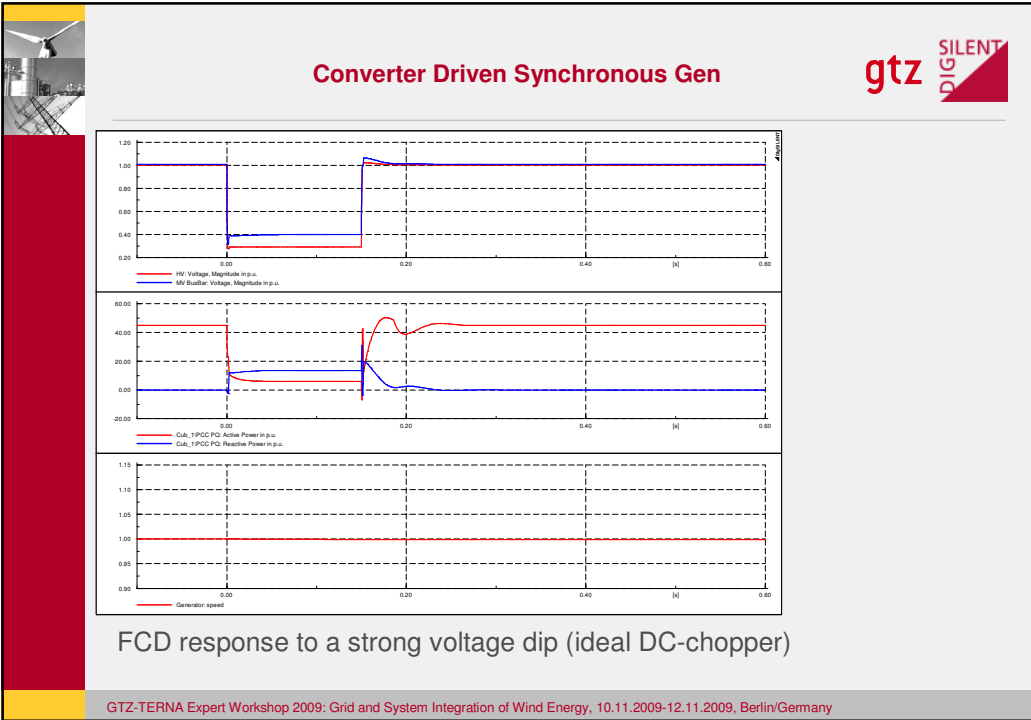


## Converter Driven Synchronous Gen



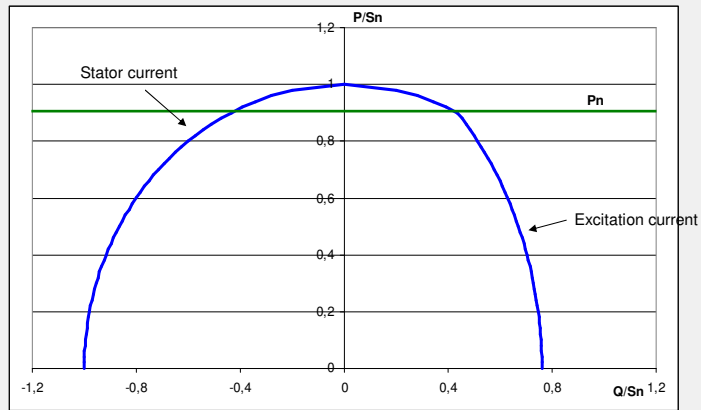
FCD response to a weak voltage dip (ideal DC-chopper)

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## Synchronous Generator – Reactive Capability

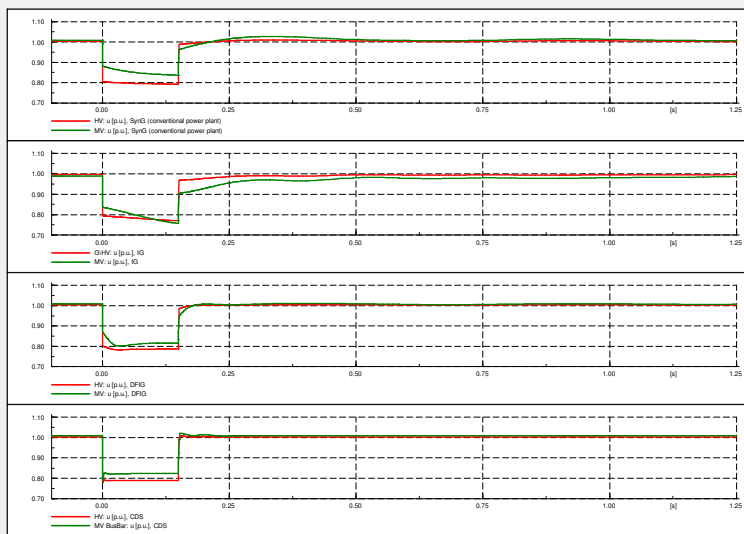


— Reactive Capability

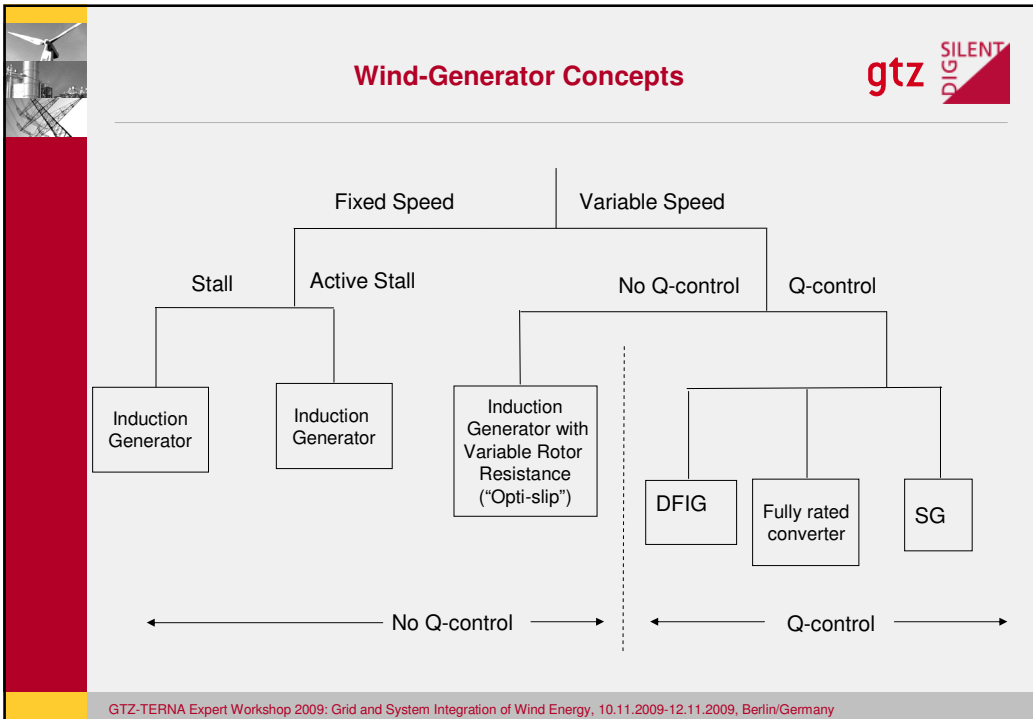
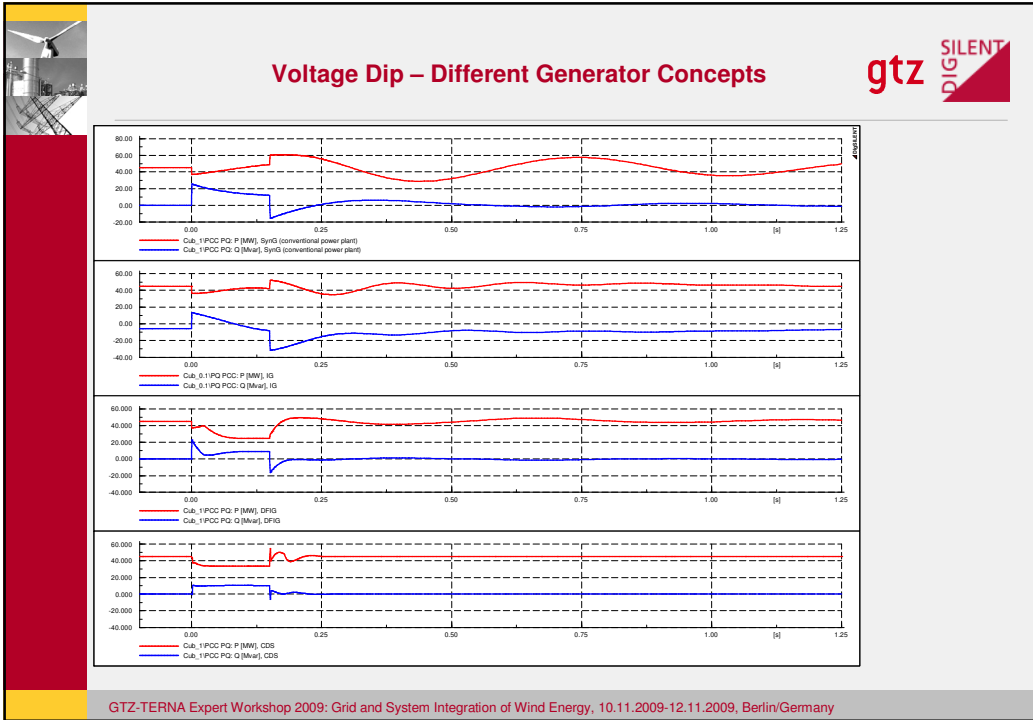
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## Voltage Dip – Different Generator Concepts



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Thank You



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