Stable Renewable Plant Voltage and Reactive Power Control

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imagination at work

Topics

- Features of modern wind turbine generators and wind plants
- Voltage vs. power factor control in wind plants
- Weak system control stability with PE sources
- Response coordination of multiple wind plants
- Summary

What makes a Wind Plant "Grid Friendly"?

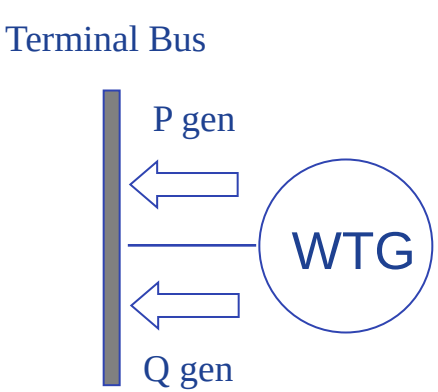
- Not trip during Faults and other System Disturbances … *ride through capability*
- **Regulate Plant Voltage and Reactive Power**
- Limits the Rate of Change of Power from Variations in Wind Speed … *Ramp Rate Control*
- React to Changes in Grid Frequency … *Frequency Droop*
- **Provide reactive power all the time**
- Provide inertial response to large under-frequency events: WindINERTIA™
- Reliable operation with series compensated lines
- **Reliable operation with low system strength**

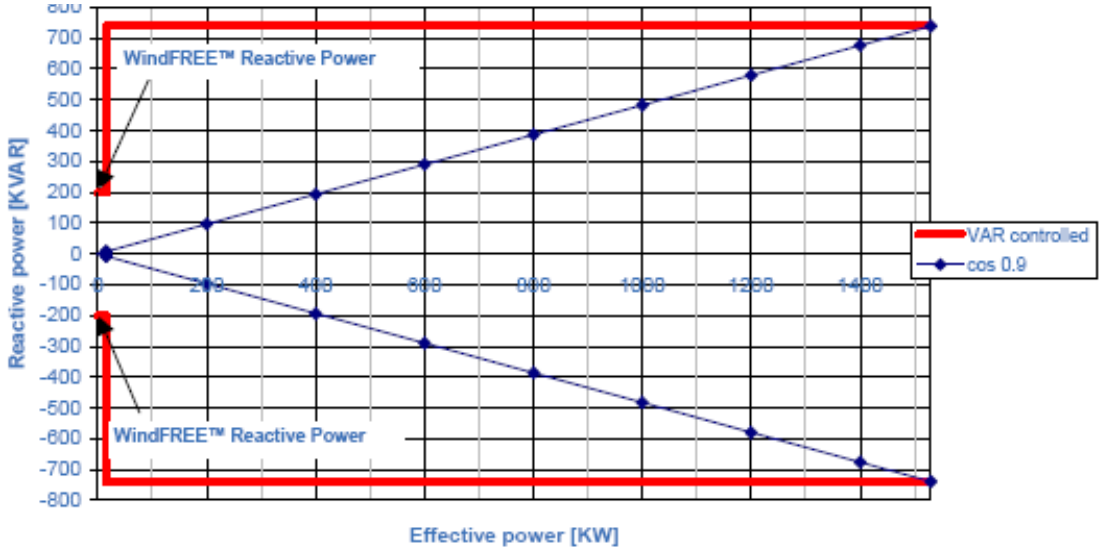
Wind Turbines and Reactive Power Control

WTG Reactive Power Capability

Reactive Power for Voltage Support

- Steady-state PF range - 0.90 under-excited/0.90 over-excited
- Dynamic range meets or exceeds steady-state range
- WTG reactive capability often sufficient to satisfy PF requirements at POI
- VAR capability reduced at low power due to units cycling off-line
- GE offers reactive power capability with no wind



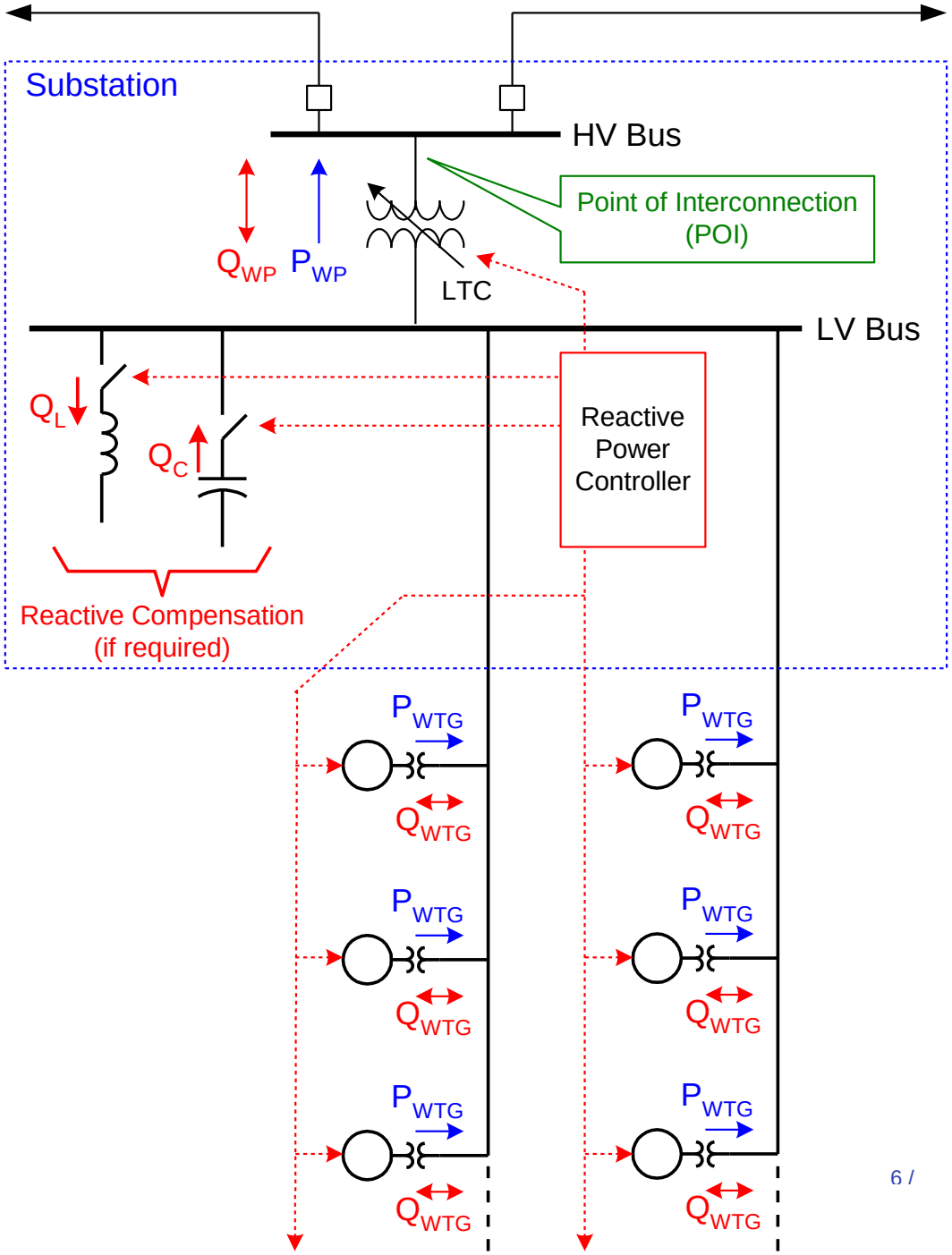


Reactive Capability *all the time* is valuable!

WindCONTROL

Plant Level Control System

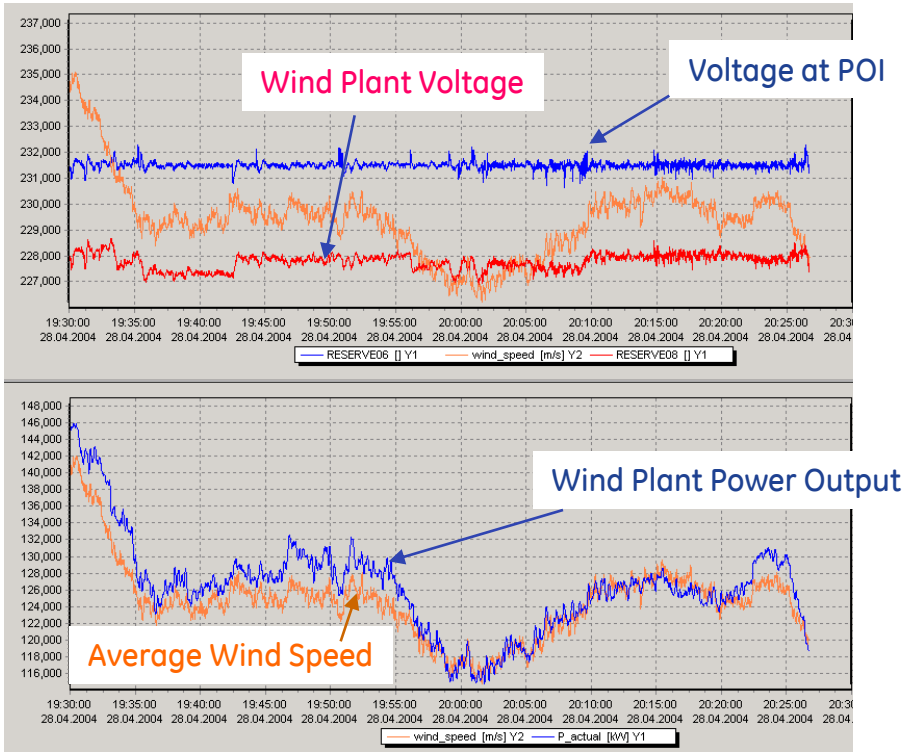
- Coordinated turbine and plant supervisory control structure
  - Fast WTG controls
  - Slower plant controls
- Voltage, VAR, & PF control
- Active Power control
- PF requirements primarily met by WTG reactive capability, but augmented by mechanically switched shunt devices if necessary
- Integrated with substation SCADA



Voltage & Reactive Power Controls

- Regulates Grid Voltage at Point of Interconnection
- Minimizes Grid Voltage Fluctuations Even Under Varying Wind Conditions
- Regulates Total Wind Plant Reactive Power through Control of Individual Turbines

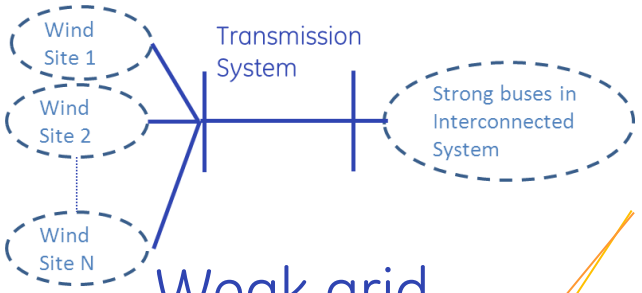
Actual measurements from a 162MW wind plant



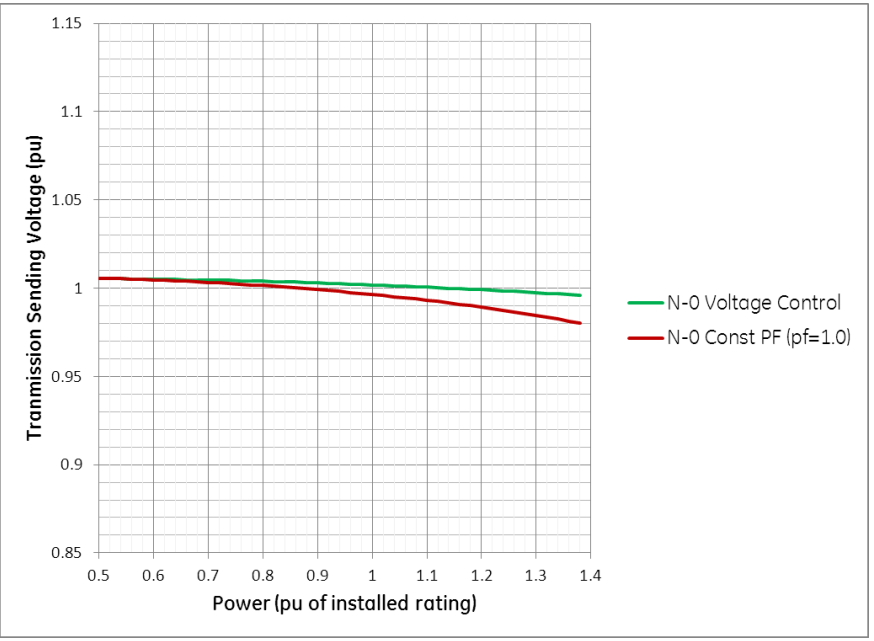
Voltage and Reactive Power Regulation Like A Conventional Power Plant

Network Stability: Voltage or Power Factor Control?

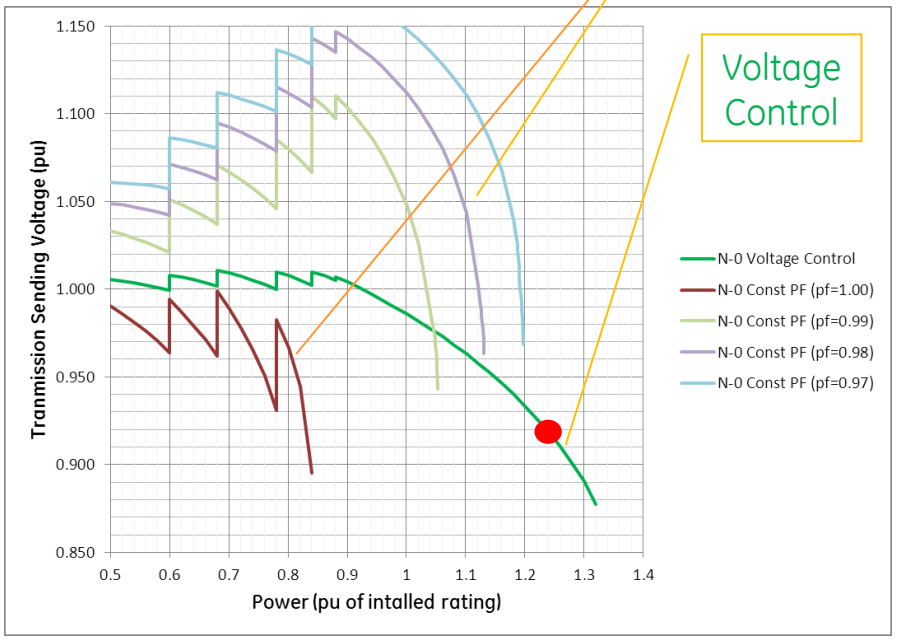
Steady State considerations



Strong grid



Weak grid



- Insufficient margin and challenging operation in PF control

Plant level voltage control improves *network voltage stability* performance in constrained transmission systems

Control Stability of Power Electronic Sources in Weak Grids

Conventional and Power-Electronic sources

- Relevant electrical characteristics of Power-Electronic (PE) sources

Performance aspect	Conventional generation	Power-Electronic Sources
Short circuit contribution (system strength)	Around 3 pu	Small/none
Current sharing/distribution	Inherent to design characteristics. Sharing depends on size and impedances of the machines	Fast current controls force current sharing

- All current-controlled PE sources require grid strength to operate reliably and stably
- Grid strength is high when electrically close to conventional generation

Conventional and Power-Electronic sources

- Long transmission corridors (low system strength) typically have power transfer limited below thermal limits due to stability challenges

Conventional generation	Power-Electronic Sources
Transient Stability Dynamic stability Voltage stability	Voltage stability Fast control stability

- Fast control stability refers to interactions between transmission system and PE sources (Wind Turbine Generators, SVCs, STATCOMs, etc.)

Wind turbine generators and system strength

Modern WTGs are PE sources

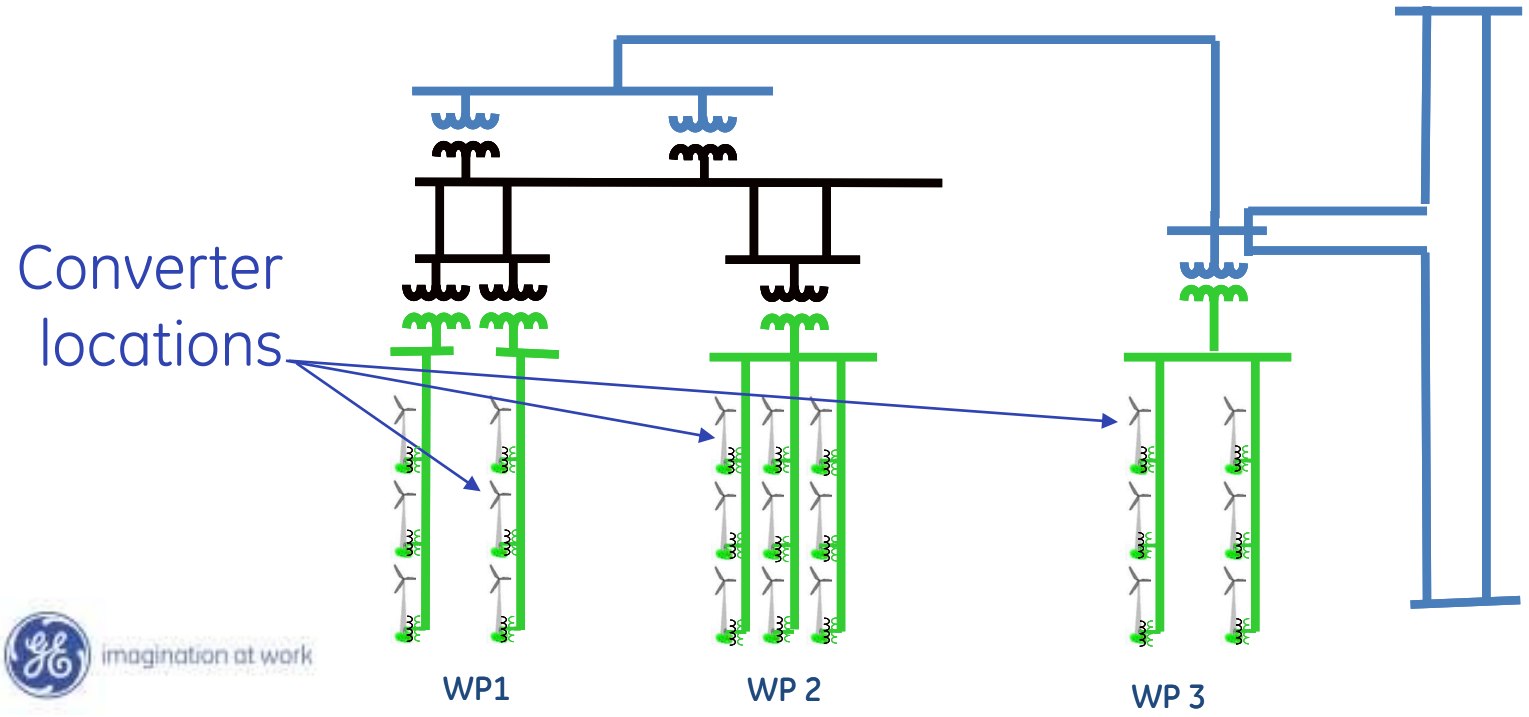
Some applications ***may*** need mitigations to achieve desired system performance under very low system strength conditions:

- Transmission upgrades
  - » New lines
  - » Updated Topology (meshed vs. radial)
  - » Series compensation
  - » Synchronous condensers (System strength, dyn VARs)
  - » SVC, STATCOM (dyn VARs, control challenges)
- Special protection schemes (such as transfer trips)
- GE offers control features to improve performance in low SCR conditions

More than one mitigation mechanism may be used and system coordination of multiple mechanisms is highly desirable and very effective (e.g. Wind Plant + Condenser)

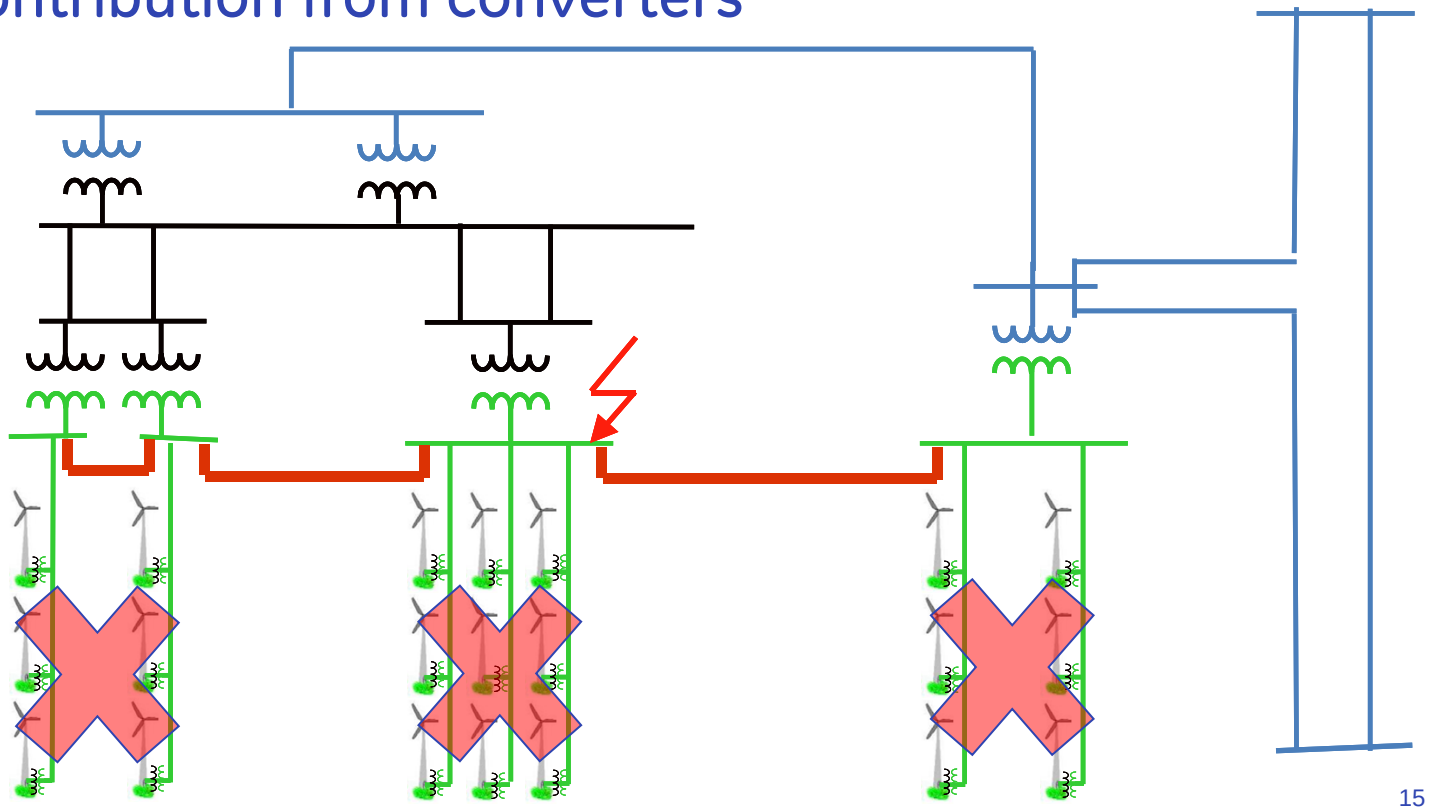
SCR applied to Wind Plants

- In the case of Wind Plants, the characterization of system strength has to take into account all electrically close converters (Multi-infeed)
- ***Composite SCR*** (CSCR) considers the grid strength as seen by ***all*** electrically close converters and is used for wind plants.



Composite SCR

- Composite short circuit level:
  - 3Ph short circuit at 34.5 KV buses - ***all interconnected***
  - Low load conditions (low/realistic commitment of conventional generation)
  - Contingency conditions also considered
  - No contribution from converters



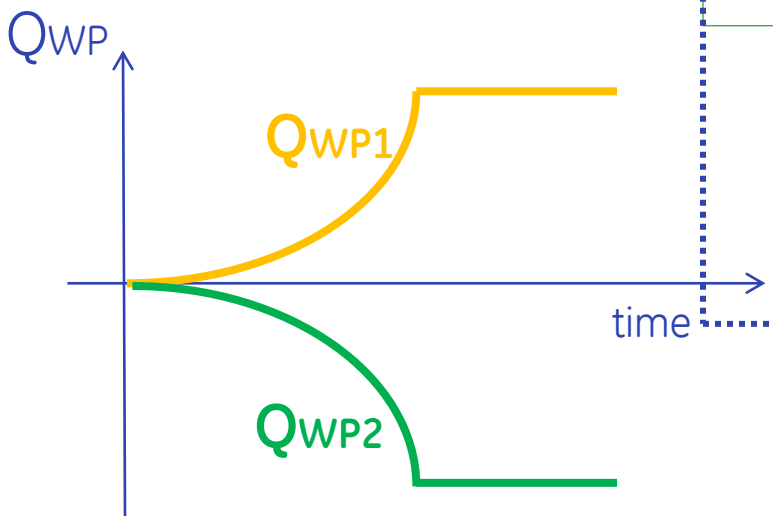
Composite SCR: Recommended Practice

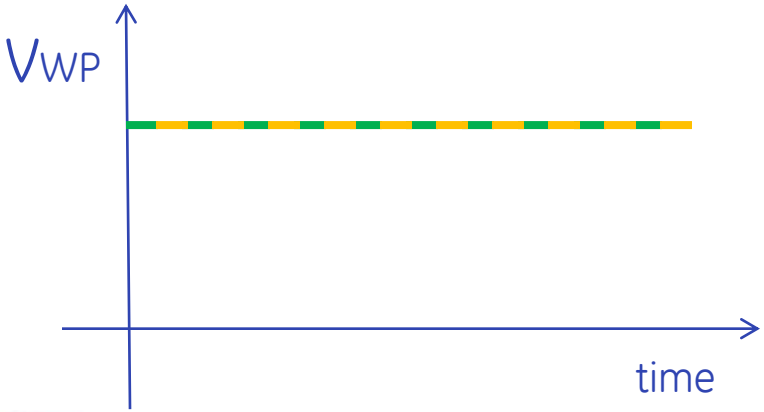
$$CSCR = \frac{Composite\ SC\ MVA}{\sum converter\ MW\ rating}$$

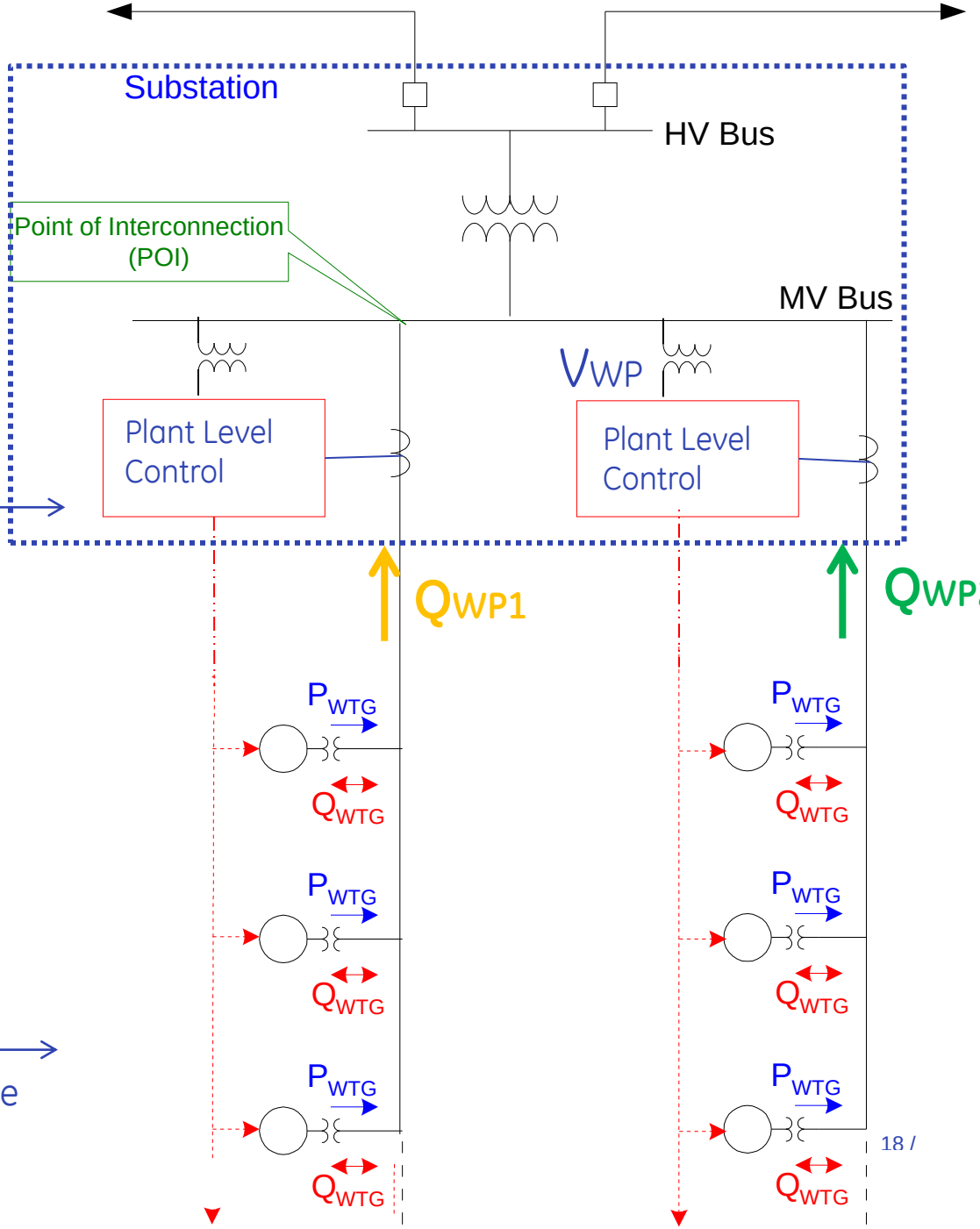
- Composite SCR is useful to characterize grid strength and screen for system stability risks
- Understanding of the grid parameters, system operation and future wind projects is required to meaningfully estimate CSCR
- Grid entities should estimate this parameter for normal and contingency operation and communicate to developers.
- For very low CSCR applications, dedicated detailed analysis is recommended

Coordinated response of electrically close wind plant level controllers

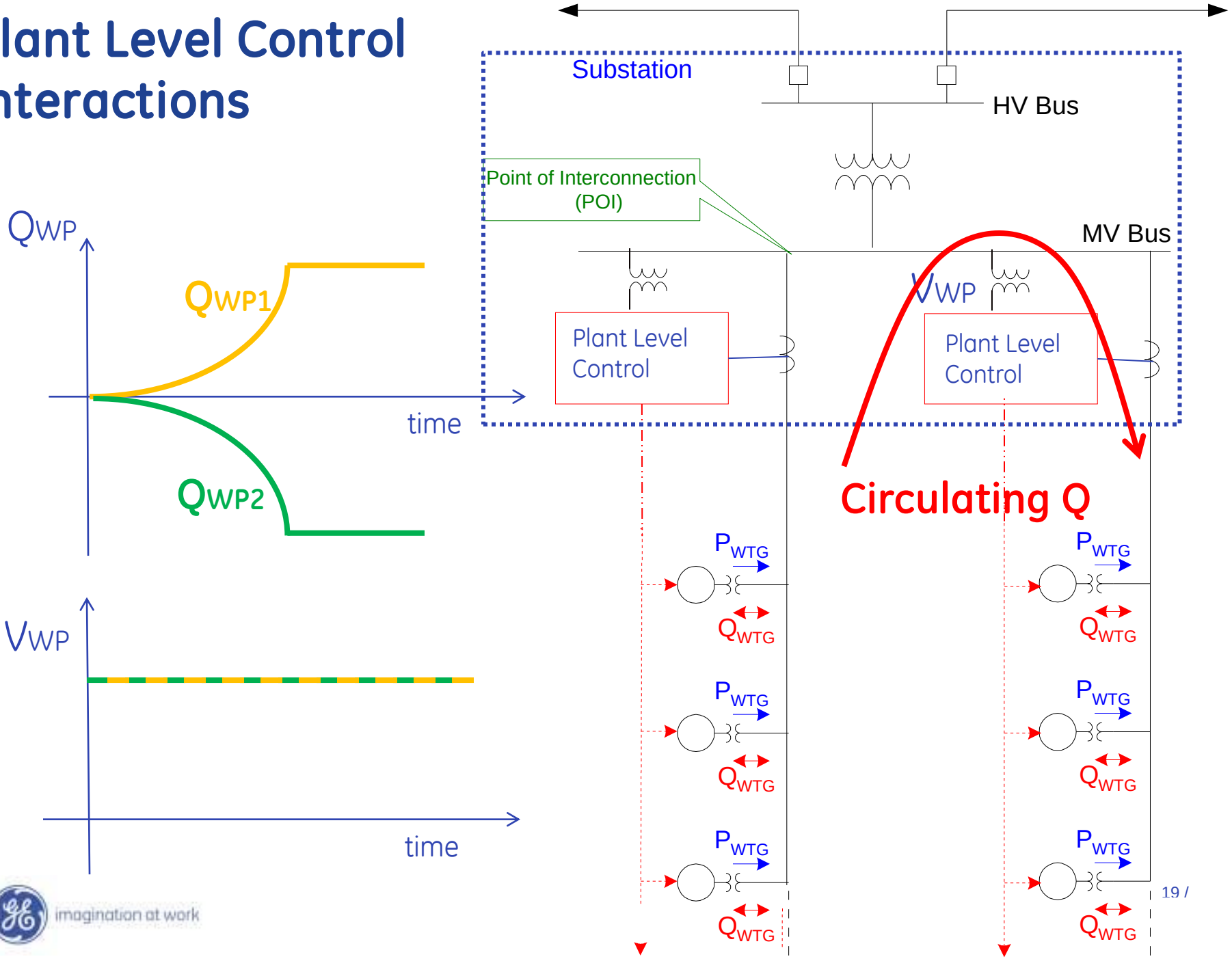
Plant Level Control Interactions





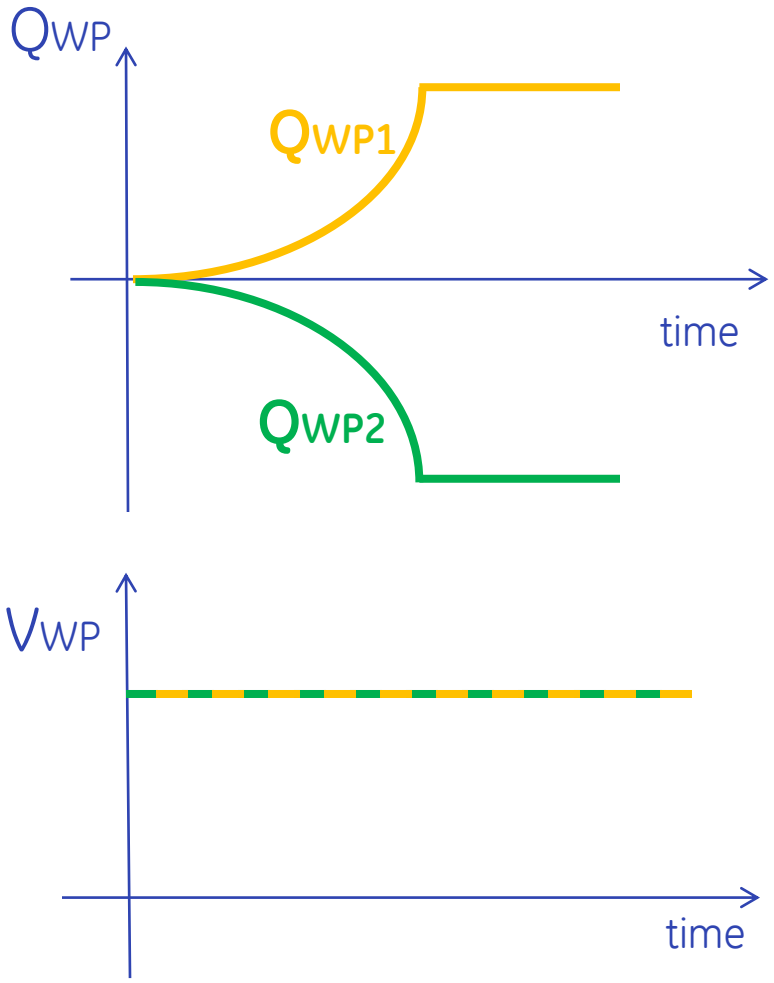


Plant Level Control Interactions

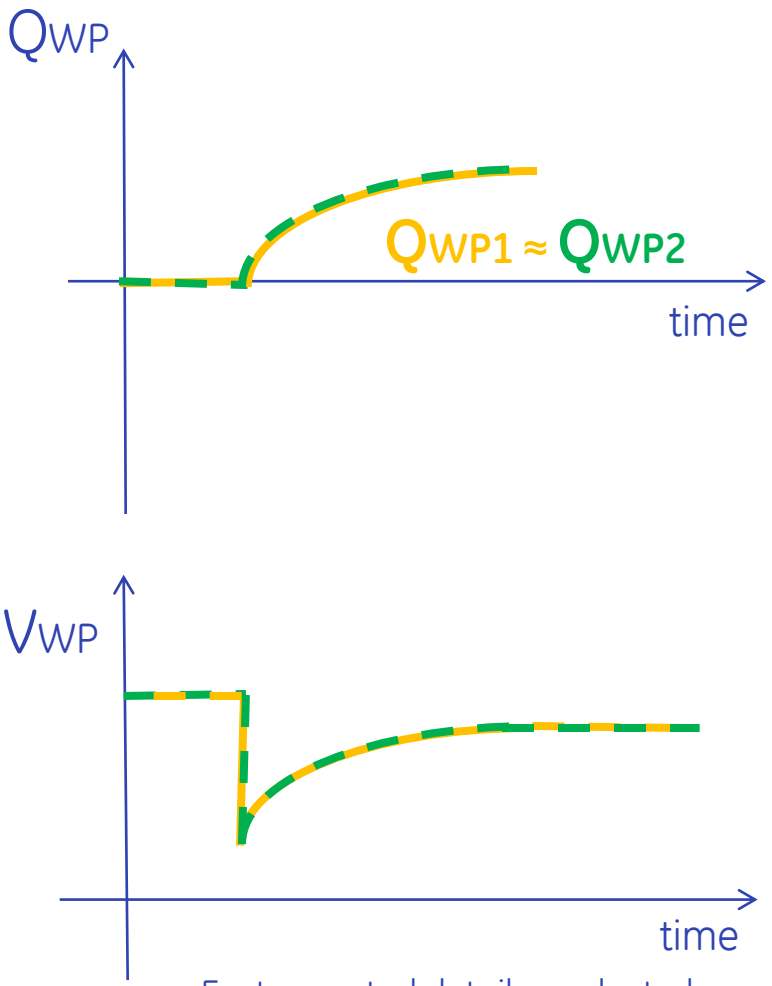


Plant Level Control Interactions: Voltage Droop

Uncoordinated Without Voltage Droop
Effect of voltage setpoint differences or PT errors



Coordinated With Droop
Effect of system event



- Faster control details neglected for this discussion
- Dynamic response coordination also assumed

Summary

Summary

- Coordinated plant level voltage control improves voltage stability performance in weak grid applications
- Fast terminal voltage control significantly improves the system performance during contingencies in weak grid applications
- Providing Reactive power all the time is valuable for system stability
- Understanding and potential remediation of very low grid strength wind plant operation is critical to maintain stability
- This requires collaboration between system operator, planners, developers and OEMs. CSCR estimation is an initial step in such collaboration
- Electrically close plant level controls require coordination to avoid negative interactions of reactive power

These issues are resolvable if known and included in the planning/development process

Thank you!

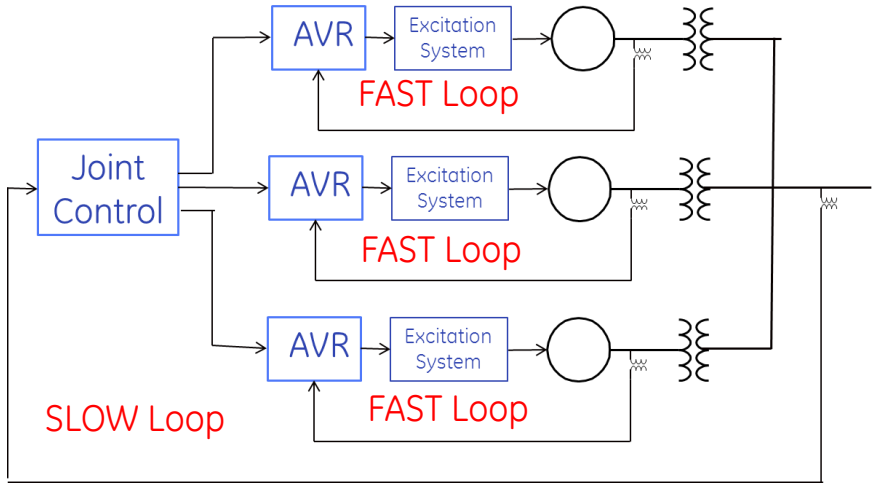
Questions?

Back-up

Fast or Slow Voltage Control?

Conventional Generation

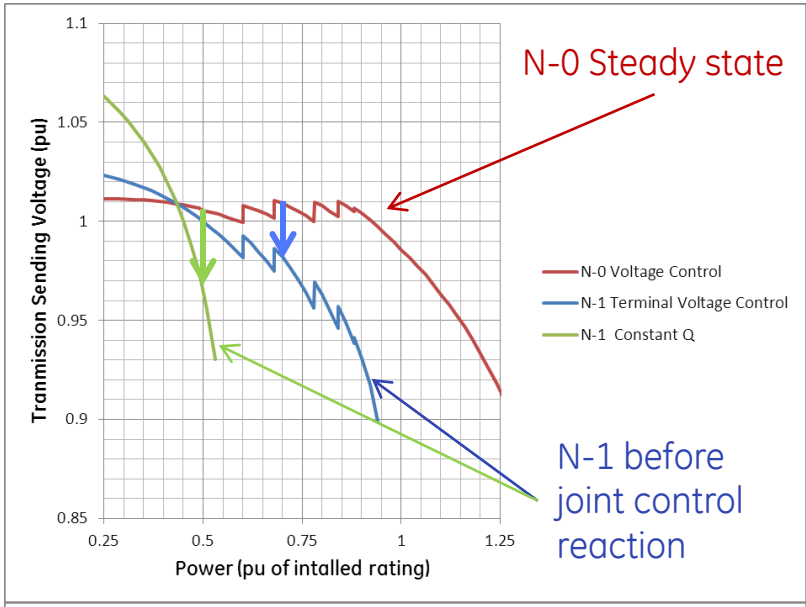
- Fast acting Automatic Voltage Regulator (AVR)
  - Quick an effective system support to improve stability
  - Limits voltage variations at equipment
- Slower acting joint control
  - Optimizes steady state operation
  - Does not interfere with inner control loops
  - Reduced risk of instabilities due to communication delays



A reasonable and valuable concept

Contingency operation of Wind Plants

- Contingency operation requires higher reactive power for stable operation with same power level
- Joint control is typically slower than WTG active power recovery
- Fast WTG terminal voltage control keeps system stable for wider range of operating conditions
- Joint control further optimizes operating condition in steady state



How “strong” are grid conditions?

- The industry has used the Short Circuit Ratio (SCR) to assess the system strength for the connection of power electronic converters
- SCR varies with system conditions
- There are few different SCR calculation methods proposed in the industry

$$SCR = \frac{short\ circuit\ MVA\ of\ AC\ System}{converter\ MW\ rating}$$