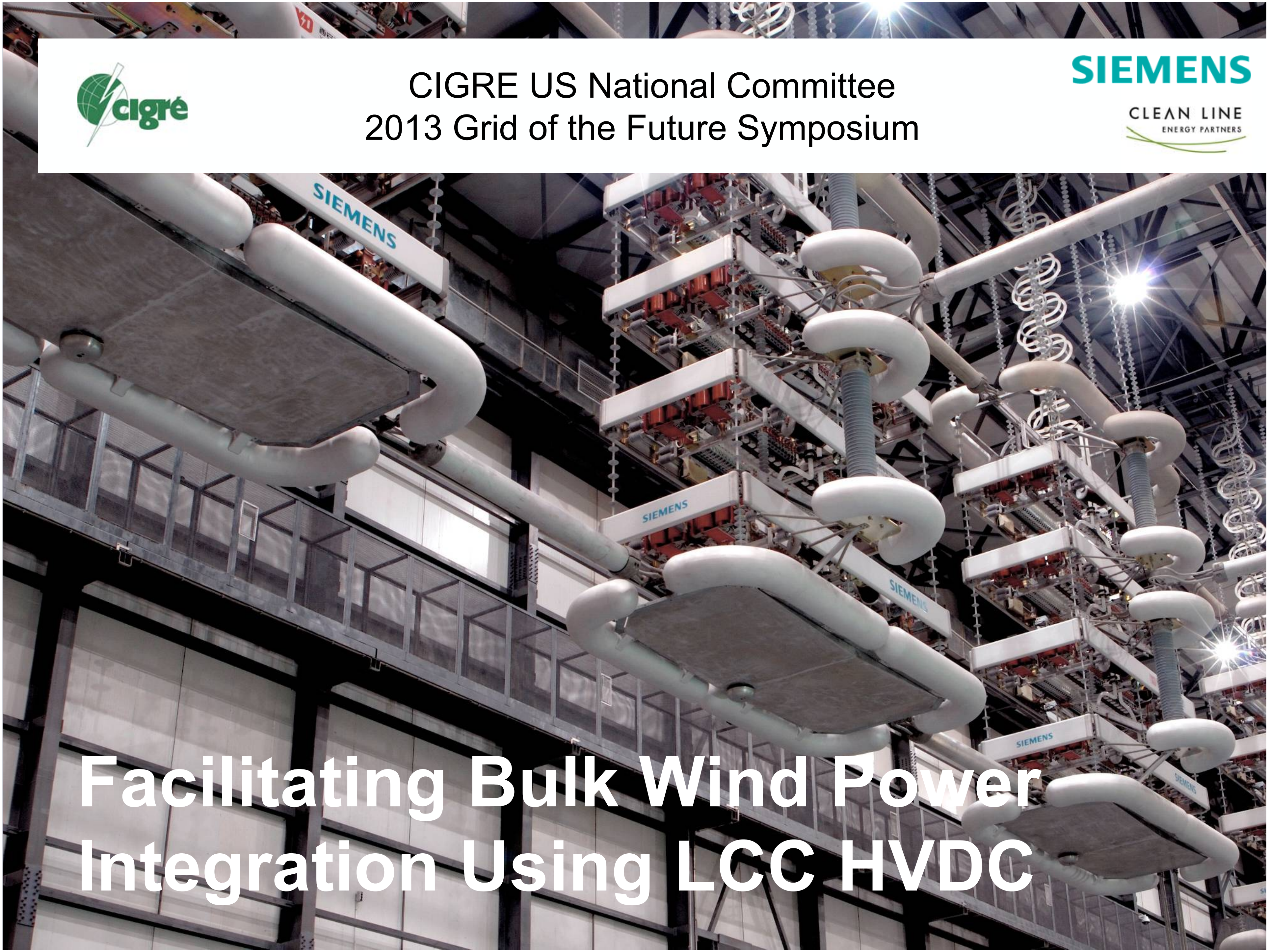
CIGRE US National Committee
2013 Grid of the Future Symposium



Facilitating Bulk Wind Power Integration Using LCC HVDC

Introduction

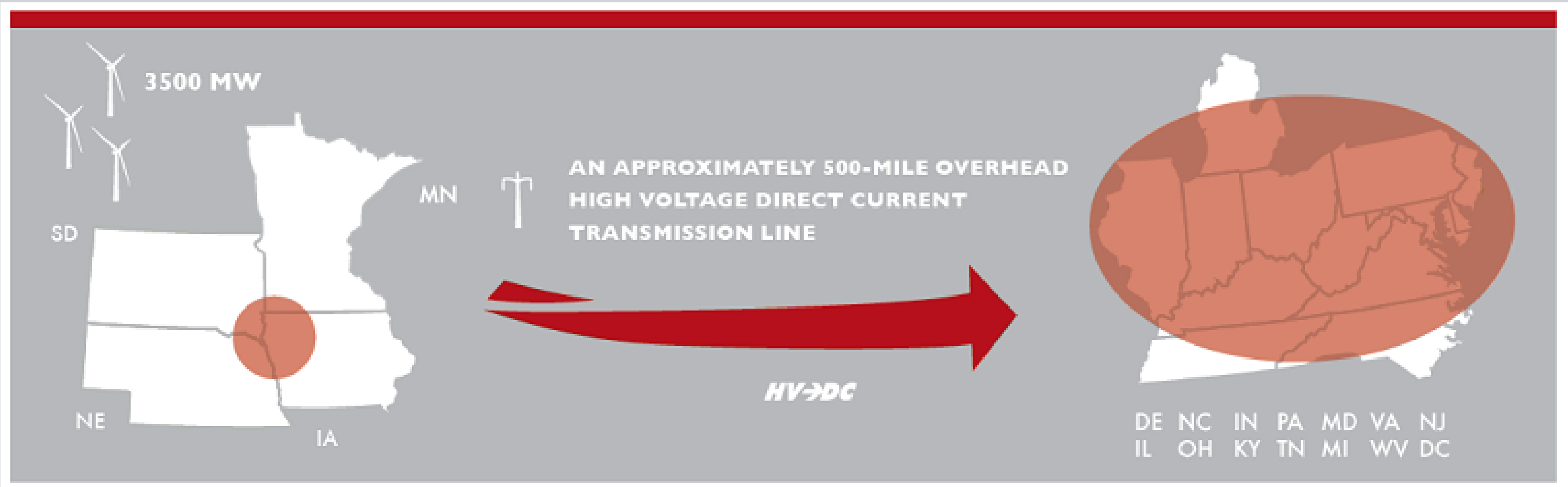
- **Many states in US need to meet their renewable energy mandate**
- **Wind energy is the predominant source of such energy**
- **There exist a number of challenges**:
  - Existing transmission infrastructure is not capable of wind integration
  - Idea wind resources are located far out from load centers
  - Necessitate long distance high power (~ 3.5GW) transmission
  - Surrounding AC systems might be weak in nature
- **HVDC is best suitable due to low loss/controllability**
- **Due to high ratings of such lines HVDC Classic is preferred technology**

Identified Challenges

Integrating large amount of Wind power using HVDC Classic has some inherent challenges:

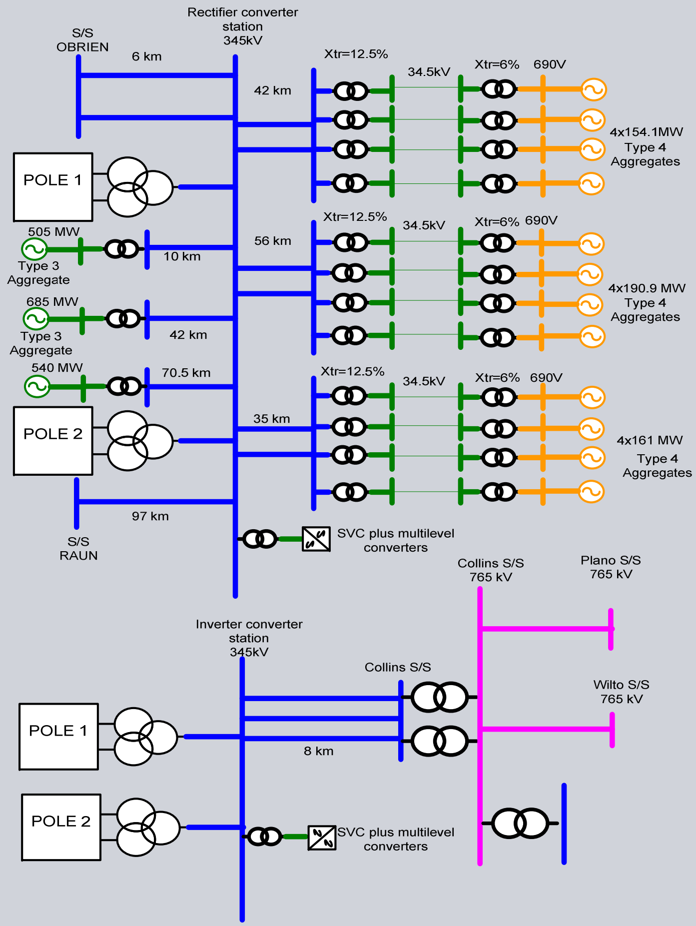
- Need for an optimized reactive power control scheme
- Operating with low short circuit levels
- Lack of significant inertia associated with wind generation
- Any need for communication between HVDC and central Wind park controllers

Clean Line Energy
Rock Island HVDC project



- The Rock Island Clean Line is a 500-mile, ± 600 kV HVDC system
- It will deliver 3500MW of wind power from Iowa, Nebraska, South Dakota and Minnesota to Illinois

Project Schematics



- Rectifier side is relatively weak wrt the size of converter and associated wind generation
- Six different wind clusters between 500 – 800MW
- Mix of type 4 and type 3 WTG
- Type 4 clusters are equipped with central park pilot controls
- Park pilot has a frequency and voltage controls and are set to control the 345kV PCC

Project Specific Challenges

- **Temporary / Transient over-voltages**
  - In case of both AC and DC faults there is an increased consumption of reactive power
  - Possible commutation failure
  - Coordination of reactive power during HVDC recovery
  - Use of STATCOM (SVC PLUS) is instrumental
- **Frequency deviations**
  - Due to large amount of wind generation frequency deviation is an issue
  - Proper modulation of active power is needed
  - Use of synchronous condensers might be sought

Project Specific Challenges (contd..)

- **Stable DC power recovery**
  - The AC systems becomes very weak in the face of some critical contingencies: May lead to multiple commutation failures
  - Use of STATCOM (SVC PLUS) improves the condition drastically
- **Active power exchange with the AC rectifier network**
  - It is necessary to control the active power exchange between wind parks, HVDC converters and AC systems connected
  - A power exchange controller is designed and implemented
    - There exists a pre defined dead band
    - It is a proportional integral type controls
    - Band width is chosen to ensure a slow following of active power exchange in the face to varying wind power

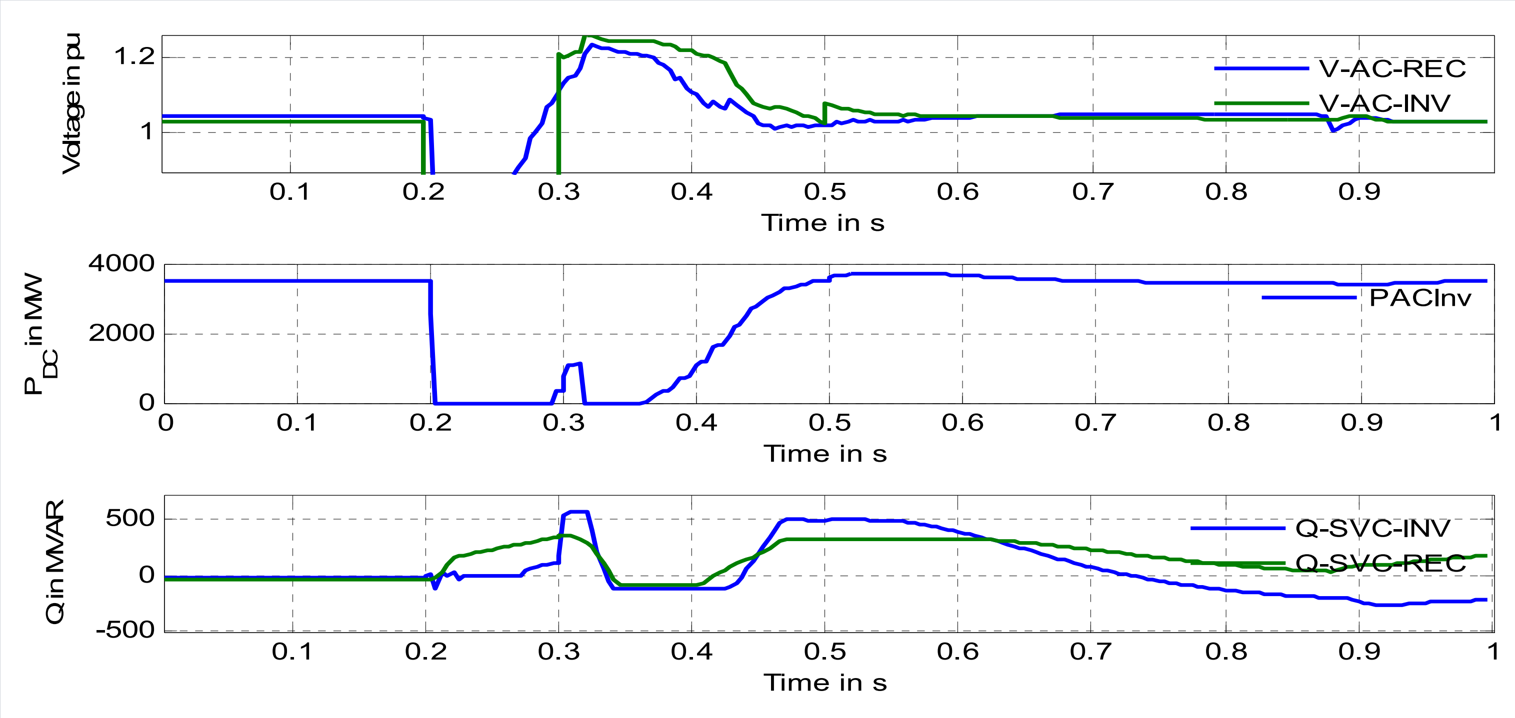
Project Specific Challenges (contd..)

- **Control Coordination**
  - HVDC converter controls and wind park central control needs to be coordinated
  - Slow communication between HVDC and central wind park control
- **Reactive Power exchange with the AC network**
  - HVDC operates in “Q” mode to maintain the reactive power exchange with AC systems
  - Needs to be coordinated with wind park

Following critical contingencies are considered

- AC faults at or in close proximity to the converter stations with the trip of important transmission lines resulting in a weaker AC system (extreme low short circuit levels) after fault clearing
- Faults resulting in loss of generation
- Remote faults in the AC system(s)
- HVDC permanent or partial load rejection

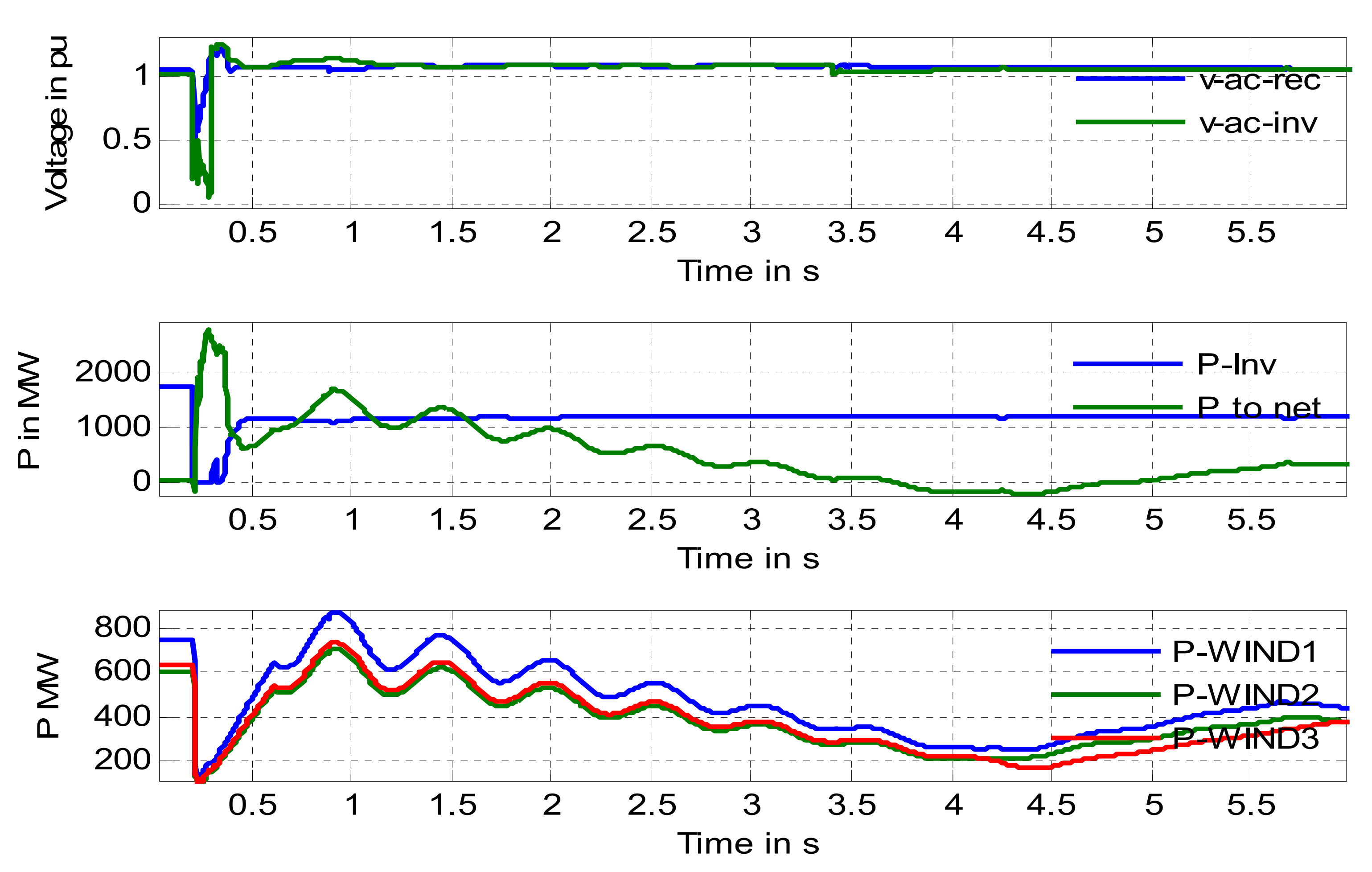
AC Fault at the Inverter Side



- A 3-phase to ground fault is applied at inverter side and cleared by tripping a 765kV line
- STATCOM (SVC PLUS) supports the voltage recovery

AC fault at the Inverter side

Resulting in an Extremely Weak System

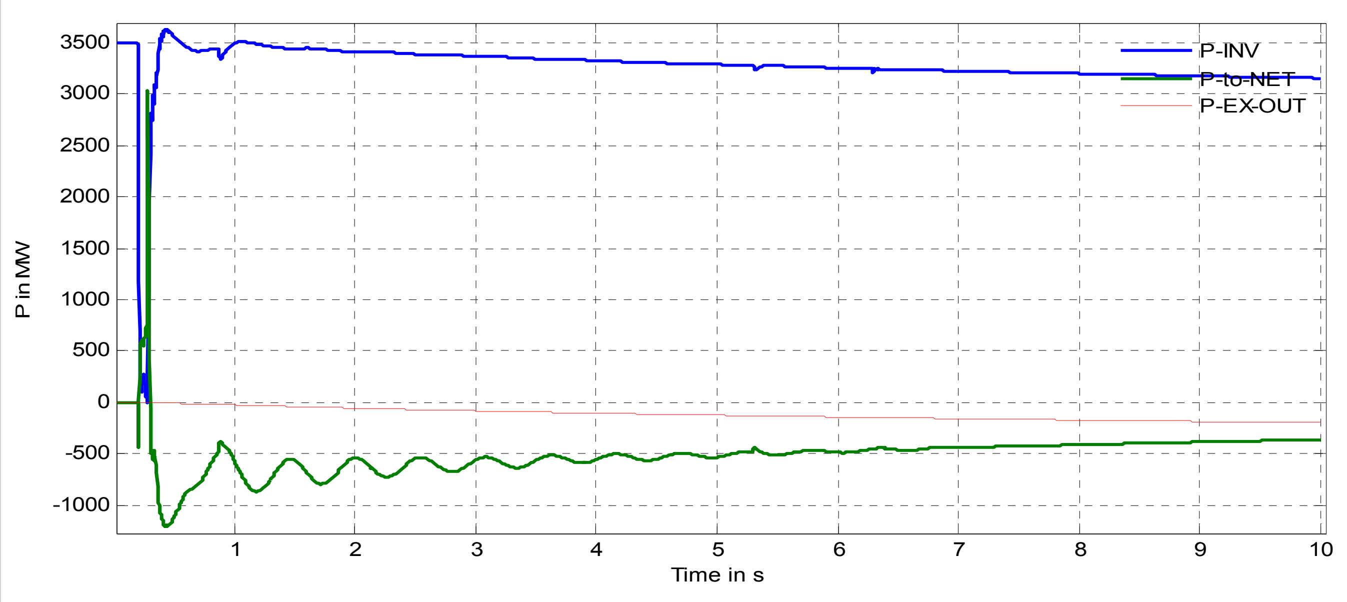


AC fault at the Inverter side

Resulting in an Extremely Weak System (contd..)

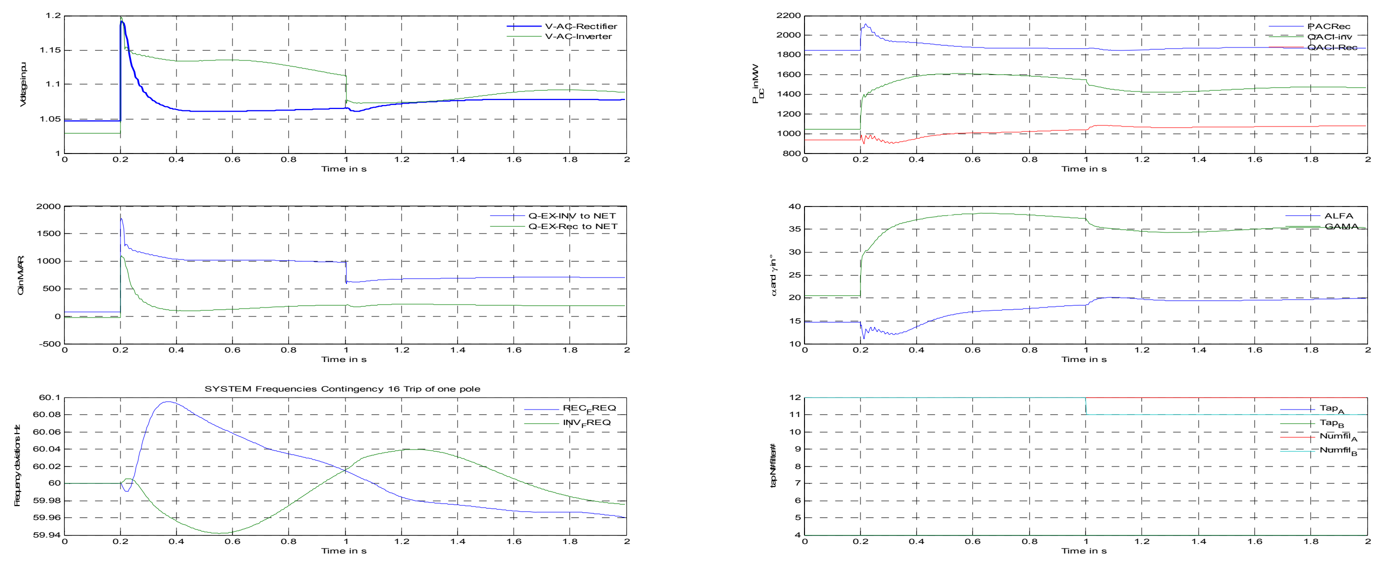
- A 3-phase-to-ground fault is applied to an N-1 pre-fault condition
- The fault is cleared after five cycles by tripping another key 765 kV line
- AC system was not strong enough to enable a fast recovery of the HVDC system to 100% pre-disturbance levels
- A run back was initiated to reduce the power transmission level to 60% of pre fault condition
- This power run-back function is very important to retain system stability and to avoid repetitive commutation failures
- Some generated wind power started flowing into AC systems
- A signal was sent to central wind park controller from HVDC to reduce the power output

AC fault at rectifier side
Power Exchange Control



- A 3-phase-to-ground fault is applied close to the rectifier station resulting in the trip of a 700 MW wind park
- Lost wind power is drawn from AC network
- Power exchange controller slowly adjust the power transfer level to maintain the power exchange within dead band

HVDC Load Rejection



- Trip of a monopole
- Reduction in reactive power consumption leads to over voltage
- Frequency deviation

Control Coordination

Proper coordination between the controllers is required to avoid hunting effects and mal-operation

- Fast communication between the HVDC control and the wind power plant controllers is necessary in case a runback is activated at the HVDC controls (or in case of a pole trip).
- A power limitation (run-back) request is sent to the wind power plant controllers, to limit their MW-output accordingly. In the study, realistic signal processing times have been considered
- The active power exchange controller is designed so that it slowly and continuously modulates DC power without interacting with the very fast power oscillations that could occur during contingencies

Thank you!

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