POWER ELECTRONICS FOR WIND ENERGY APPLICATIONS

By

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(and borrowing from a few other folks…)
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KNOWING A LOT ABOUT RENEWABLE ENERGY IS BECOMING SEXY AT PARTIES

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Where it all started

- The earliest wind turbine generators applied induction generators (Types 1 and 2)
- They required a large short circuit ratio, above 7 to operate effectively, and power factor correction capacitors
- No power electronics

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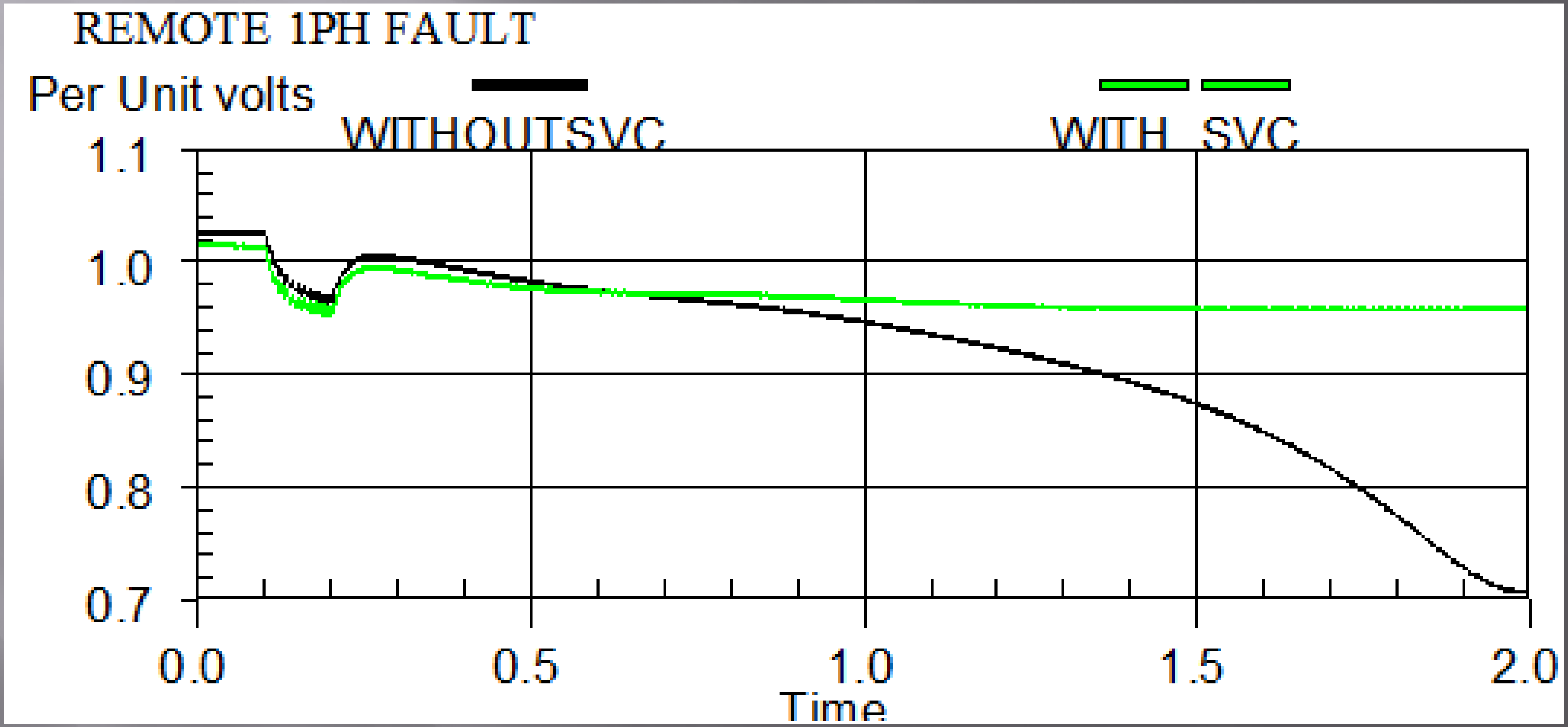
Use of SVCs and STATCOMs Consider at terminals of induction generator



Short circuit ratio less than 7 possible depending on SVC or STATCOM used

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GE's Controversial Patent

- US patent 5,083,039 granted January 21, 1992 to Richardson and Erdman and assigned to U.S. Windpower, Inc.
- Applied power electronics in a DFIG configuration
- Ended up being owned by GE
- Expired Feb 1, 2011

GE DFIG Wind Turbine Generators
Courtesy of GE

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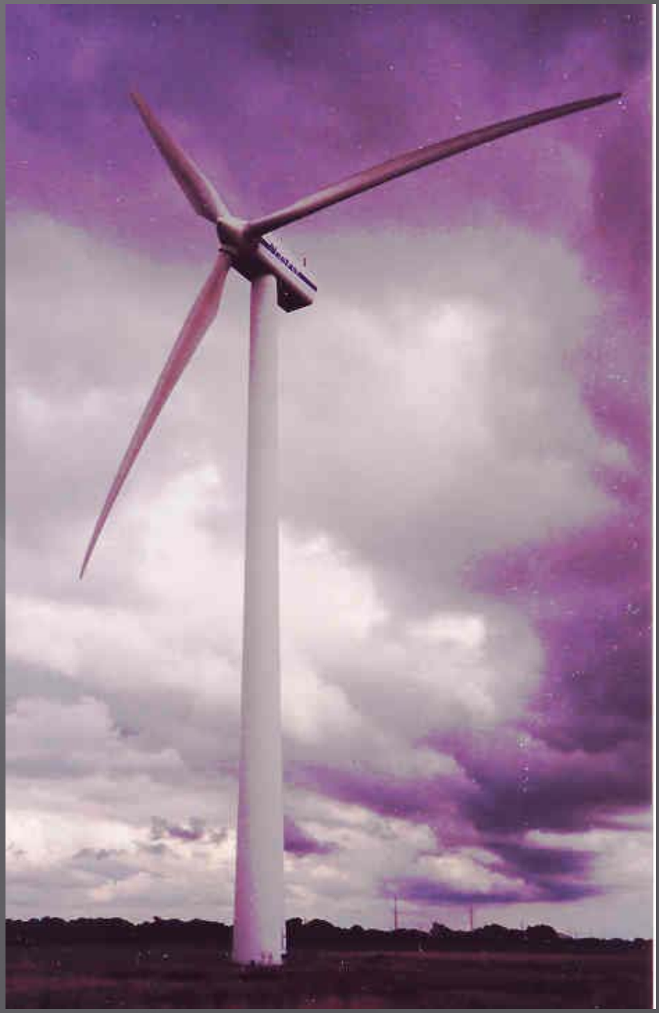
Use of Power Electronics World Wide

- The European and Asian Manufacturers of Wind Turbine Generators could use power electronics to perform AC voltage control
- However, they could not sell them in North America. No AC voltage control allowed



Vestas DFIG Wind Turbine Generator in Denmark

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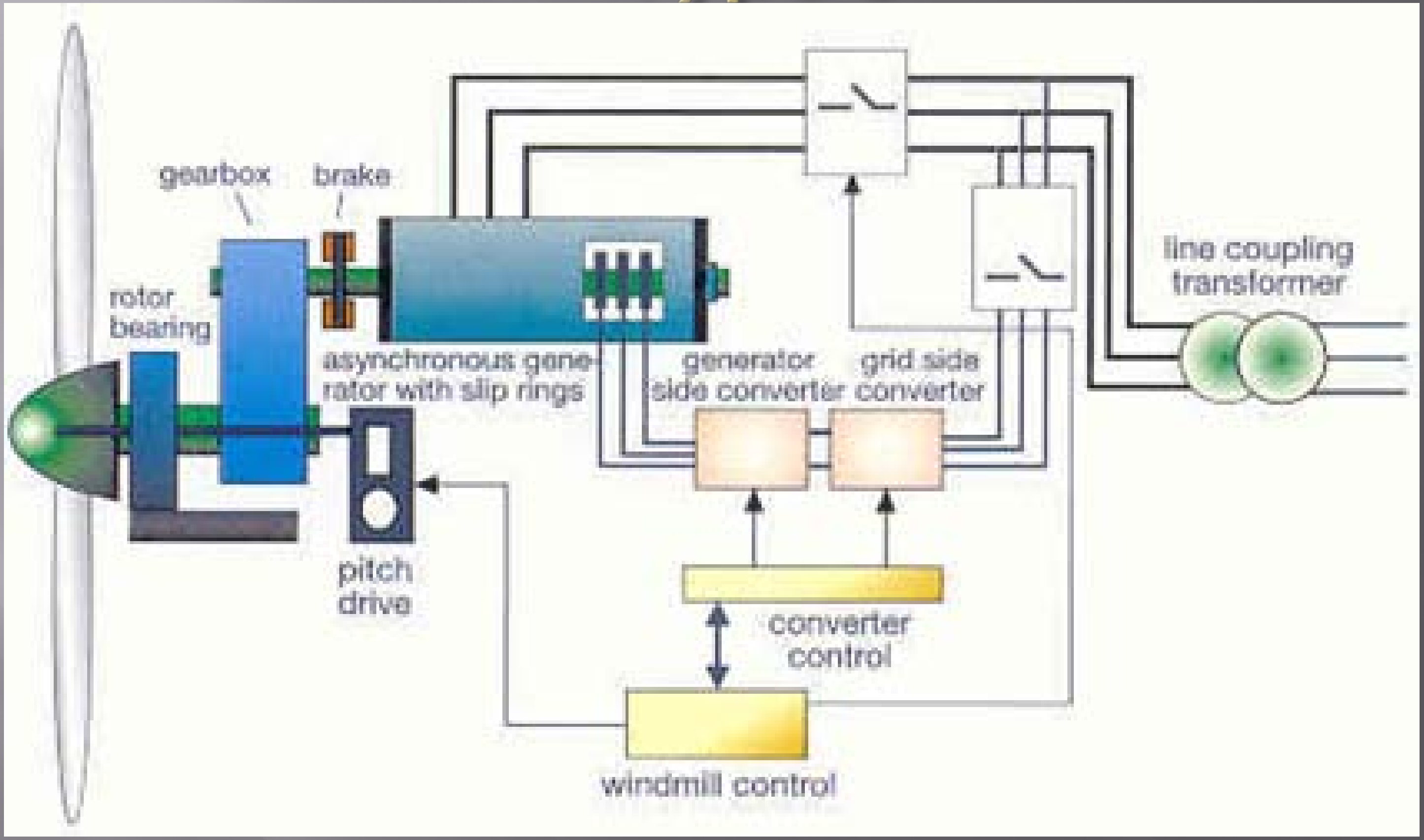
Doubly Fed Induction Generator – Type 3



Requires short circuit ratio of 2.5 (2.0 or less is possible depending on controls)

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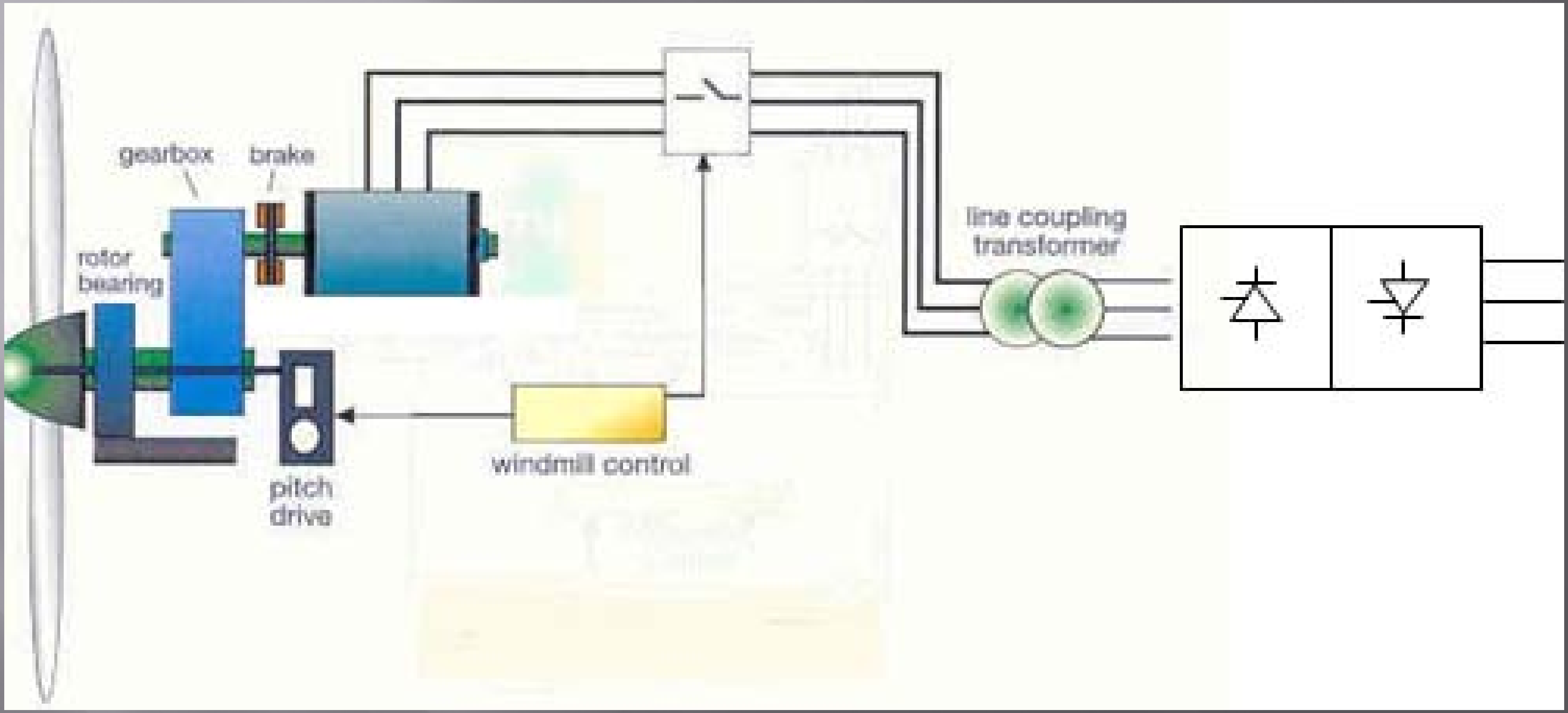
Full Power Converter – Type 4



Minimum short circuit ratio < 2 possible

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Trends in Power Systems
"Doing more with what you got"

- Numerous complex power electronic devices: Wind farms, LCC-HVDC/VSC-HVDC Transmission, PV Inverters…
- Weak systems, low ESCR, reduced system inertia
- Need for RAS schemes as the system becomes more complicated
- Series capacitors, SVCs and STATCOMs (instead of new transmission lines)
- New research required for simulation tools!

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Impact of Series Compensated Feeders

- There is a possibility of Sub-synchronous control interactions (SSCI)
- What is SSCI?
- Interactions between a power electronic controller (such as a wind turbine generator, DC link, VSC based device, etc…) and a series compensated system

Typical series compensation (Courtesy of ABB)

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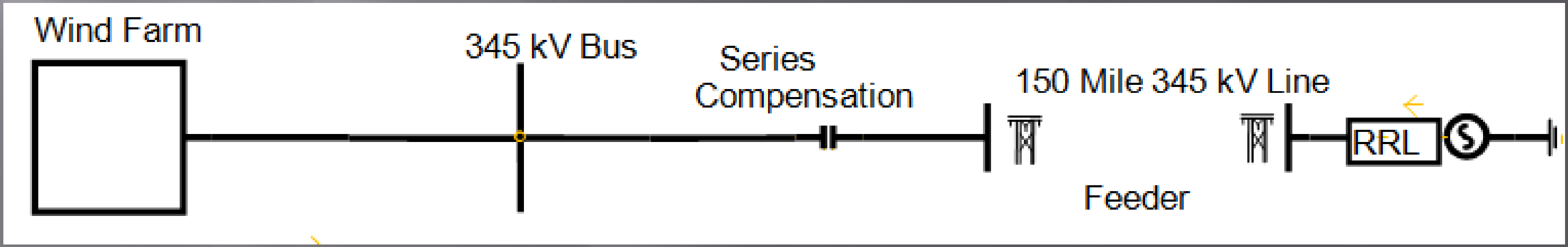
Wind Projects with Series Compensated Lines

- ERCOT CREZ system expansion
  - 345 kV series compensated lines
- PacifiCorp Gateway system expansion
  - 500 kV lines, series capacitors, SVCs
- Alberta southern system expansion
  - 230 kV lines, series capacitors, SVCs
- UK large scale transmission expansion



Example Series Compensated Feeder

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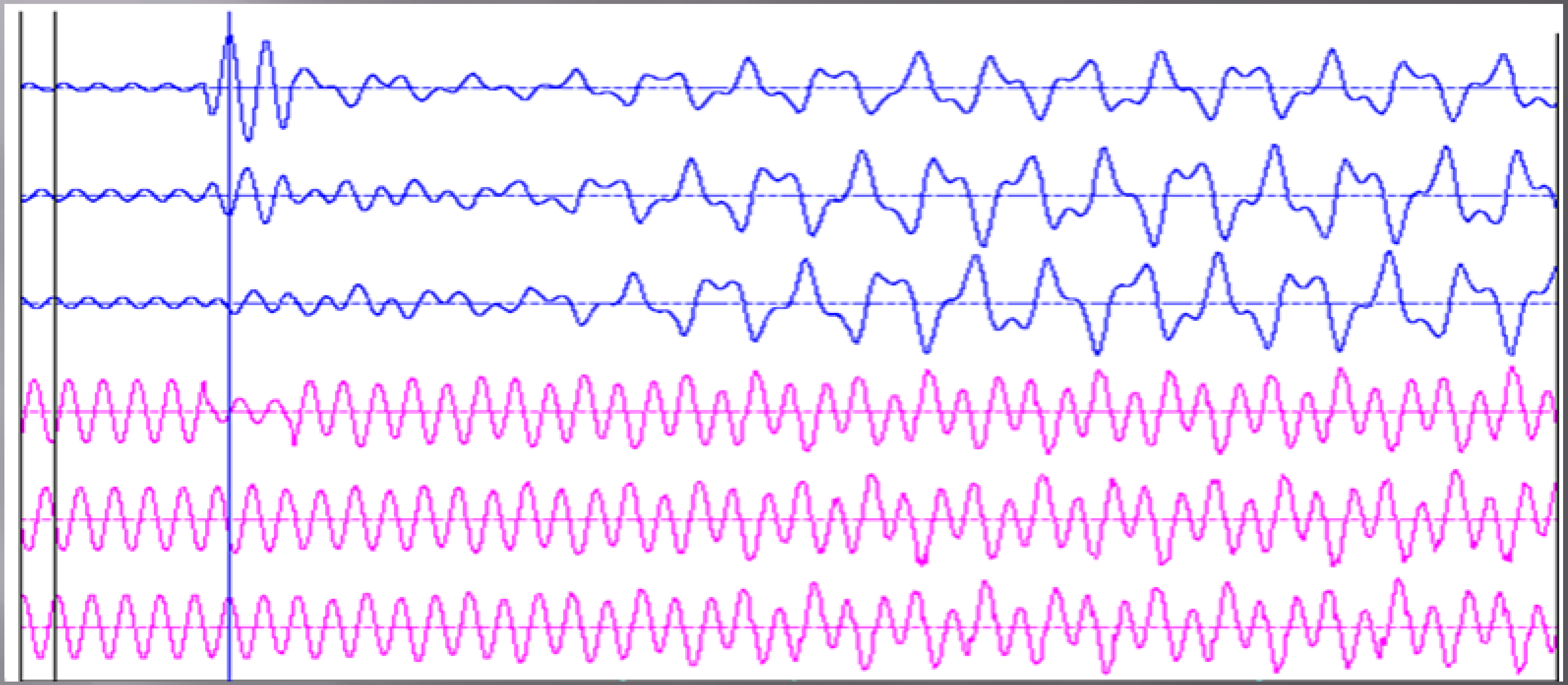
Actual SSCI Event Trace of Wind Farm in Texas

Current

Voltage



DFIG wind turbines seem to be more prone to SSCI than Full Converter

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What Can be Done About SSCI ?

- Changes to wind interconnection standards
  - Requirements to study SSCI where series capacitors are planned
- Development of a wind/series capacitor benchmark system
- Wind turbine modeling and studies
  - Detailed EMT models (using real controller code)
  - Specialized Sub-synchronous Analysis tools (Transgrid)
  - Confidentiality concerns are an issue!

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What Can be Done About SSCI ?

- Possible solutions
  - Higher voltage lines
  - TCSC (thyristor controlled series capacitors) or other FACTS devices
  - Operating restrictions
  - Selective bypassing
  - HVDC
  - Sub-synchronous blocking filter across a series capacitor segment
  - Fix controllers: "Series capacitor safe" turbines – Obtain Supplier Guarantee (RECOMMENDED SOLUTION!)

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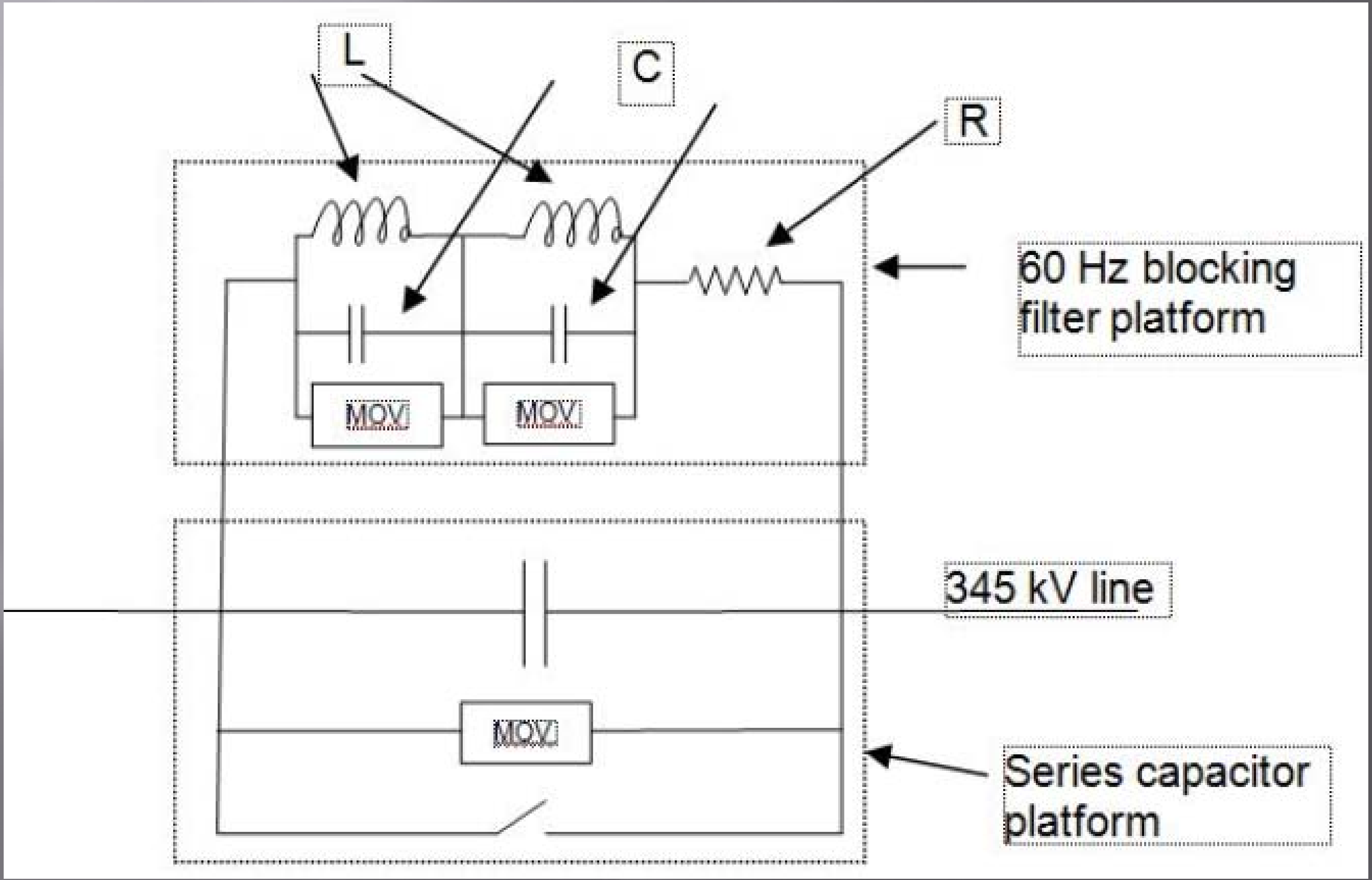
What Can be Done About SSCI ?

Blocking filter in parallel with series capacitor



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Computer Simulation Models

- Transient Stability Tools
  - PSS/E or PSLF models are required in interconnection studies in North America
  - Used for system impact and facilities studies
  - Not able to reproduce resonant conditions in the electrical system and not sufficient for SSCI interaction studies
  - Control models may not be detailed enough

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Computer Simulation Models

- EMT (electro-magnetic transients) Models:
  - PSCAD or EMTP
  - Necessary for SSR studies and control interaction studies
  - Include IGBT firing, harmonics, high speed controls, Multi-level Modular Converters (MMC), etc...
  - Often use actual code from the hardware
  - EMT studies are often not performed or needed in many installations

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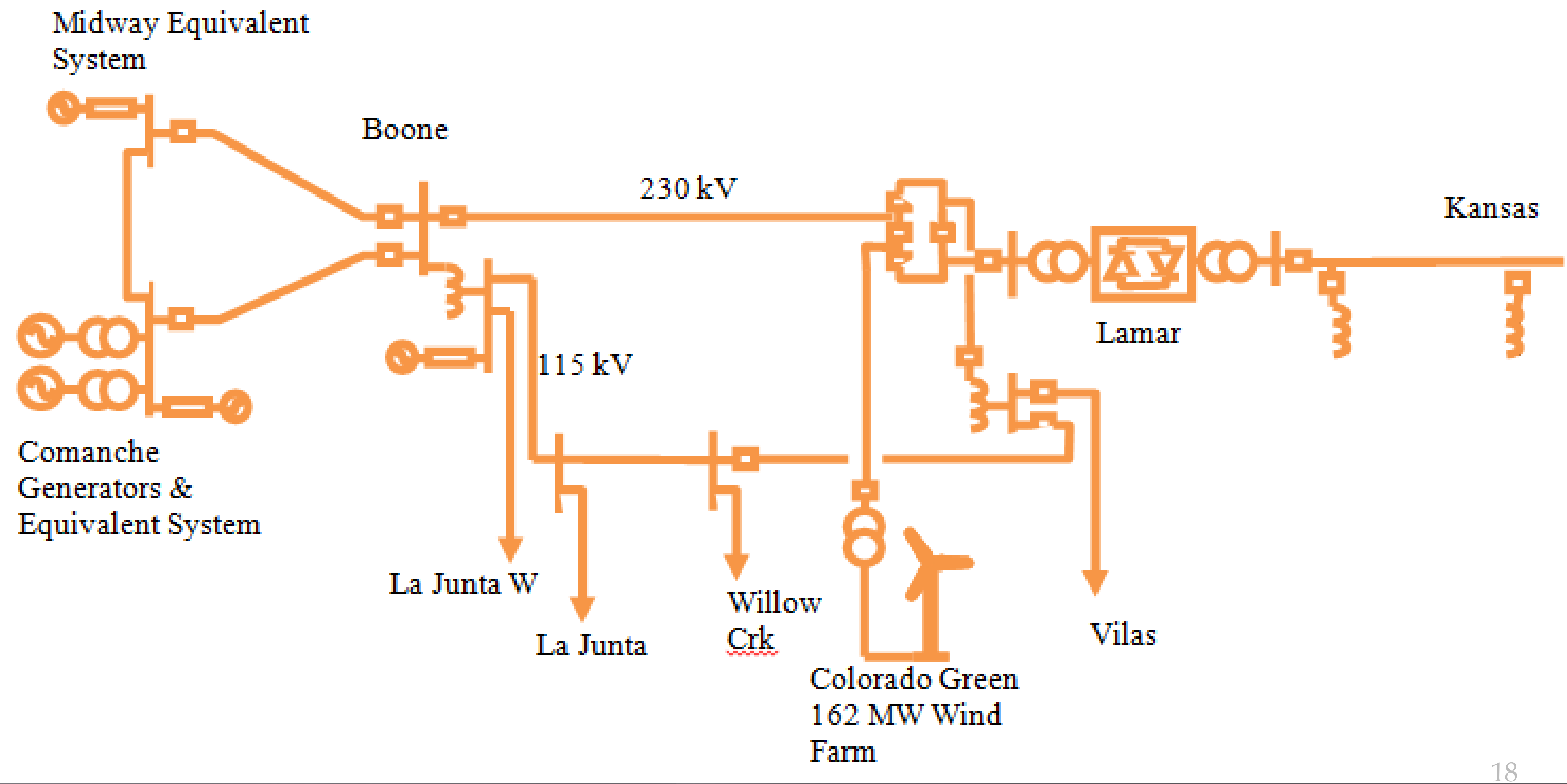
Example Reduction of AC System Inertia

- Wind farms with Types 3 & 4 wind turbines are virtually "Constant Power"
- Consider South East Colorado:



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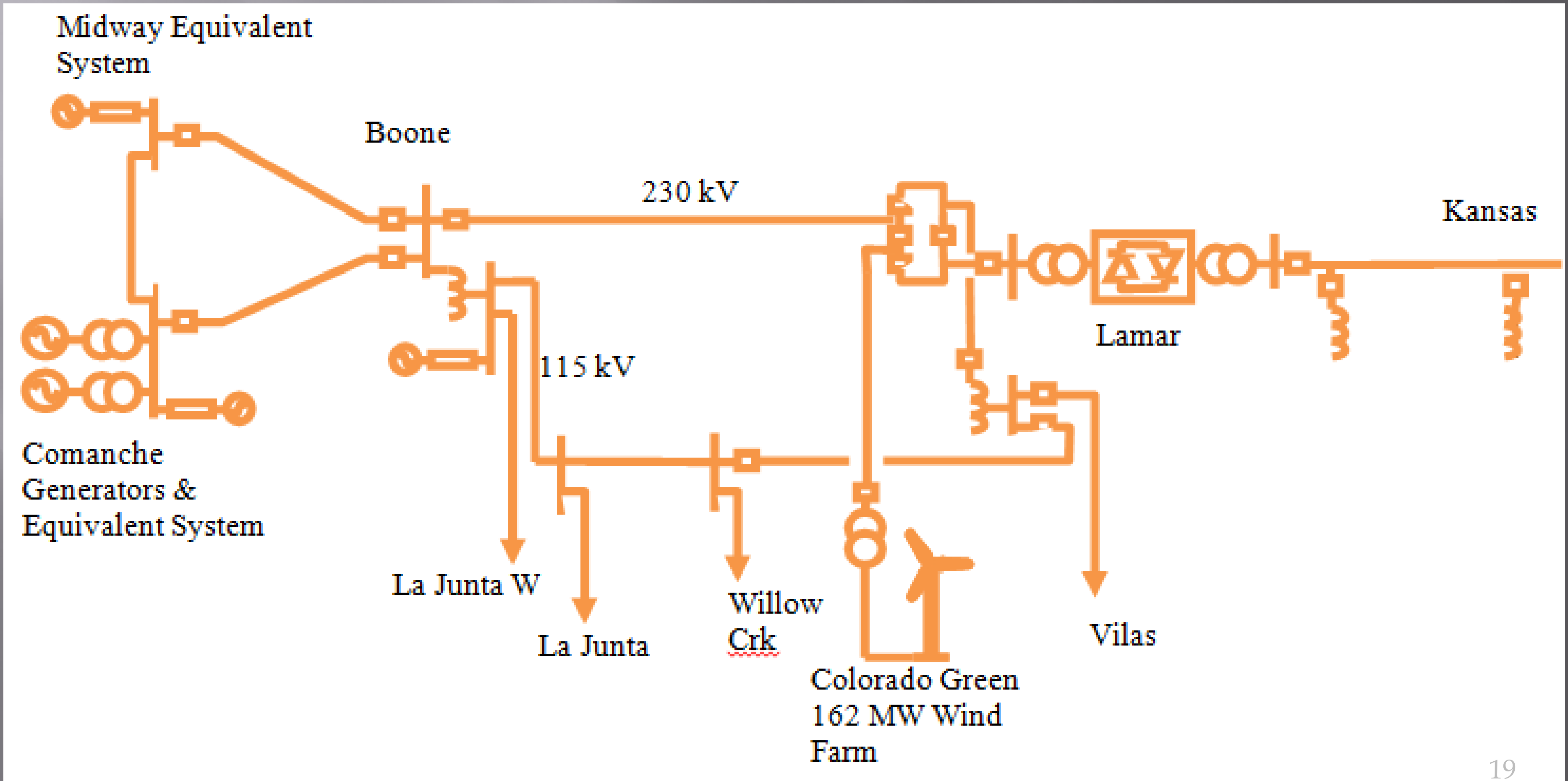
Example Reduction of AC System Inertia

- PSS/E studies showed a certain maximum power flow Kansas to Colorado
- EMT studies indicated a lower max power flow



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DC Feeders for Wind Farms

- The first DC feeder for a wind farm is the 400 MW BorWin Alpha project in the North Sea by ABB
- Other DC feeder projects are in construction by ABB and Siemens

Courtesy of ABB

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Issues With HVDC Feeders for Wind Farms

- Line commutated HVDC (LCC) thyristor rectifiers require AC short circuit capacity to operate

- Basic Type 3 and Type 4 wind turbine generators also require AC short circuit capacity to operate

- So, is an LCC rectifier realistic for a feeder for wind farms?

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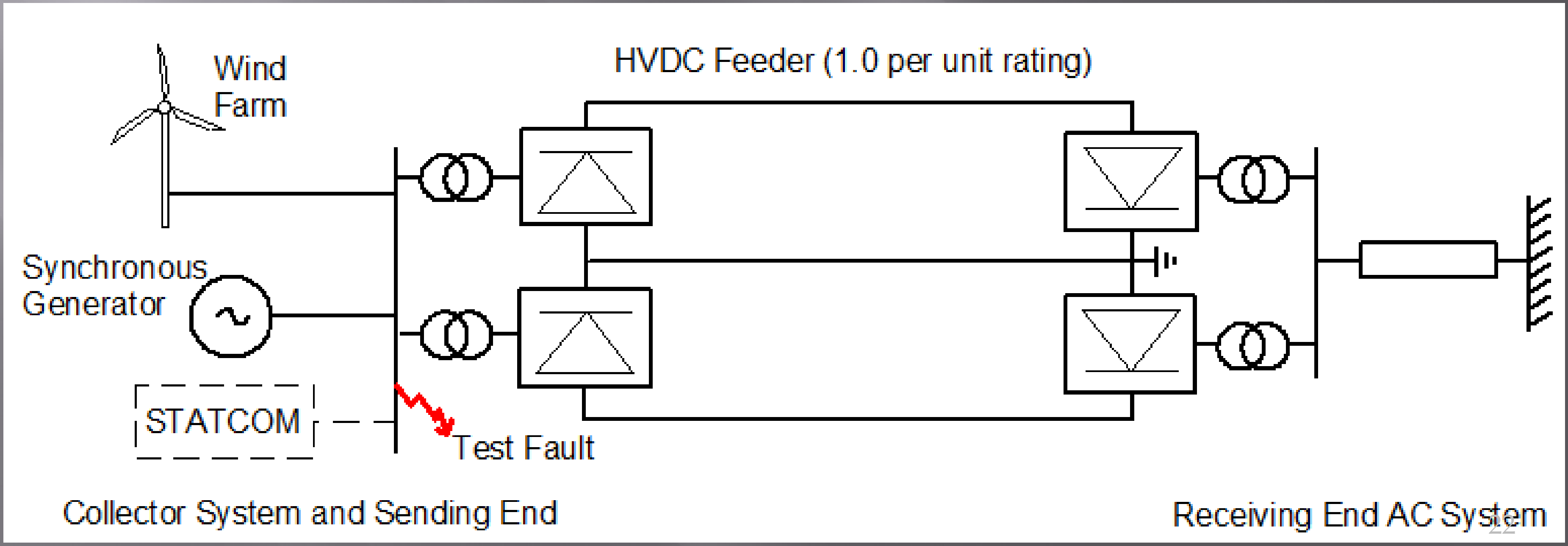
Issues With HVDC Feeders for Wind Farms

- Synchronous condenser and/or generator required at the rectifier to create the necessary short circuit capacity
- An LCC feeder may have a minimum power capability impacting wind farm stand-by energy



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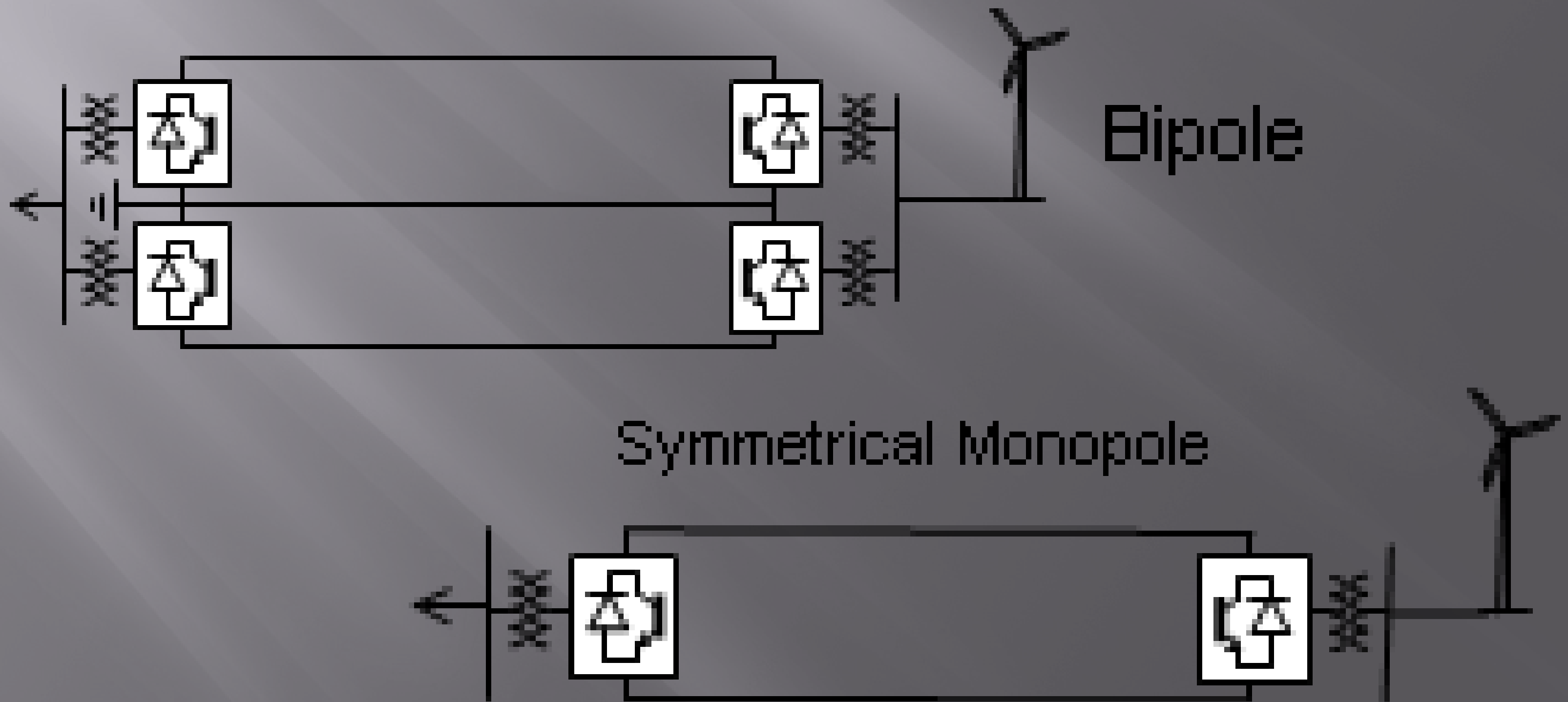
Issues With HVDC Feeders for Wind Farms

- A voltage sourced converter (VSC) for a rectifier can generate adequate and effective short circuit capacity with fixed AC bus frequency and steady AC voltage allowing most types of wind turbine generators to operate



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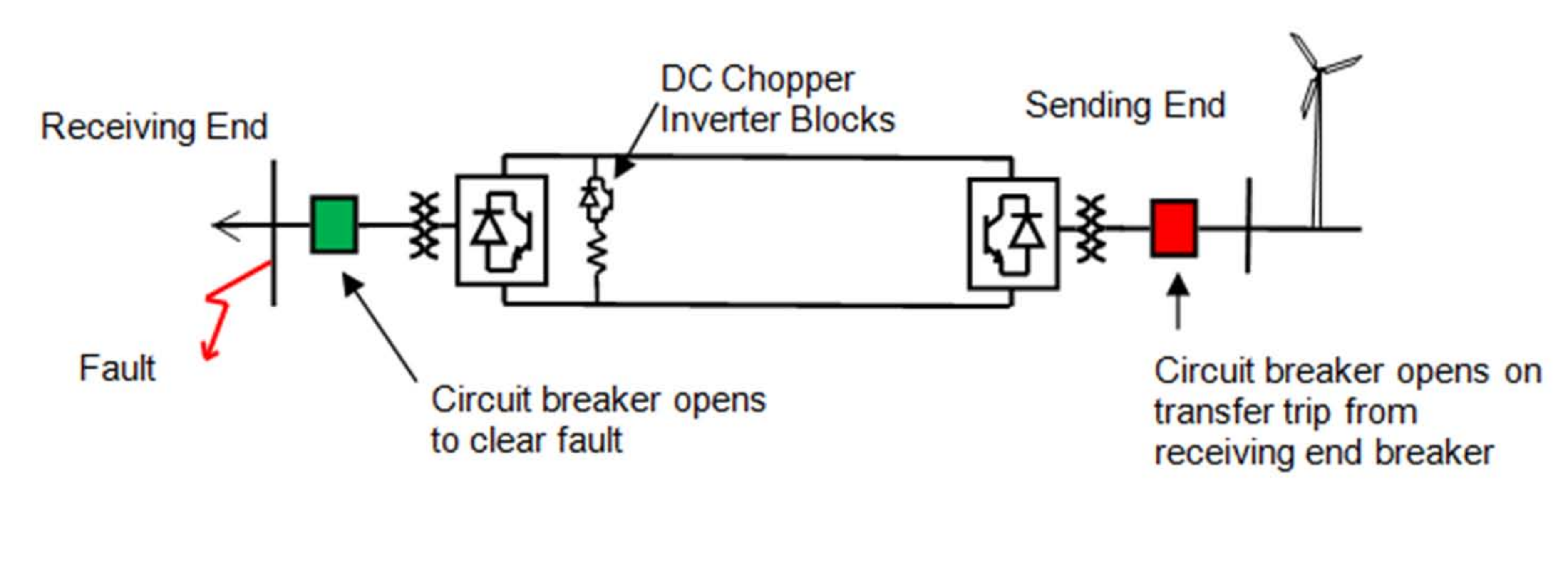
Issues With HVDC Feeders for Wind Farms

- A voltage sourced converter (VSC) feeder requires a DC Chopper to protect against DC Overvoltage



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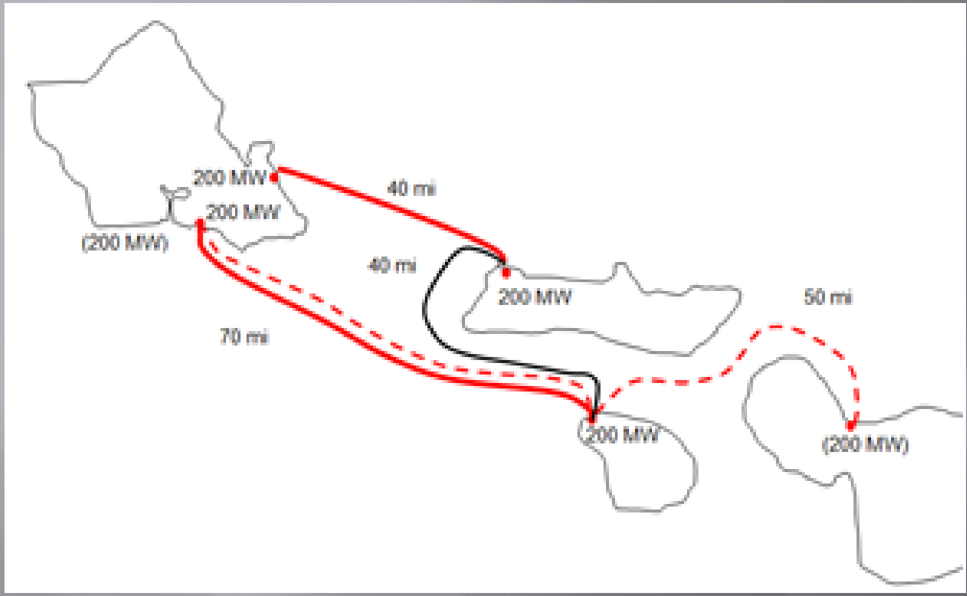
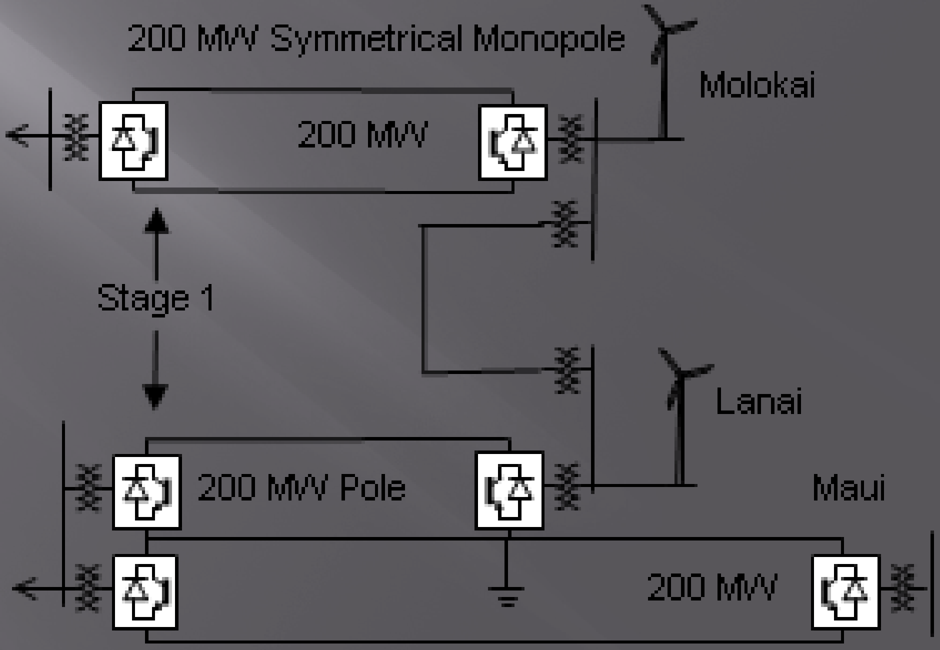
Example – Hawaiian Interconnection Project



AC cable Molokai to Lanai

One Option with VSCs



Example – Atlantic Wind Connection

- DC grid with Multi terminal VSC
- Multi terminal VSC models not available in TS programs
- Develop EMT models of onshore VSC converters, DC cables, offshore converters and turbines (PSCAD)
- Use "real controls" from VSC and wind turbine Suppliers
- Interfacing with the Eastern Interconnection (PJM) - PSSE

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Example – Proposed European DC Grid

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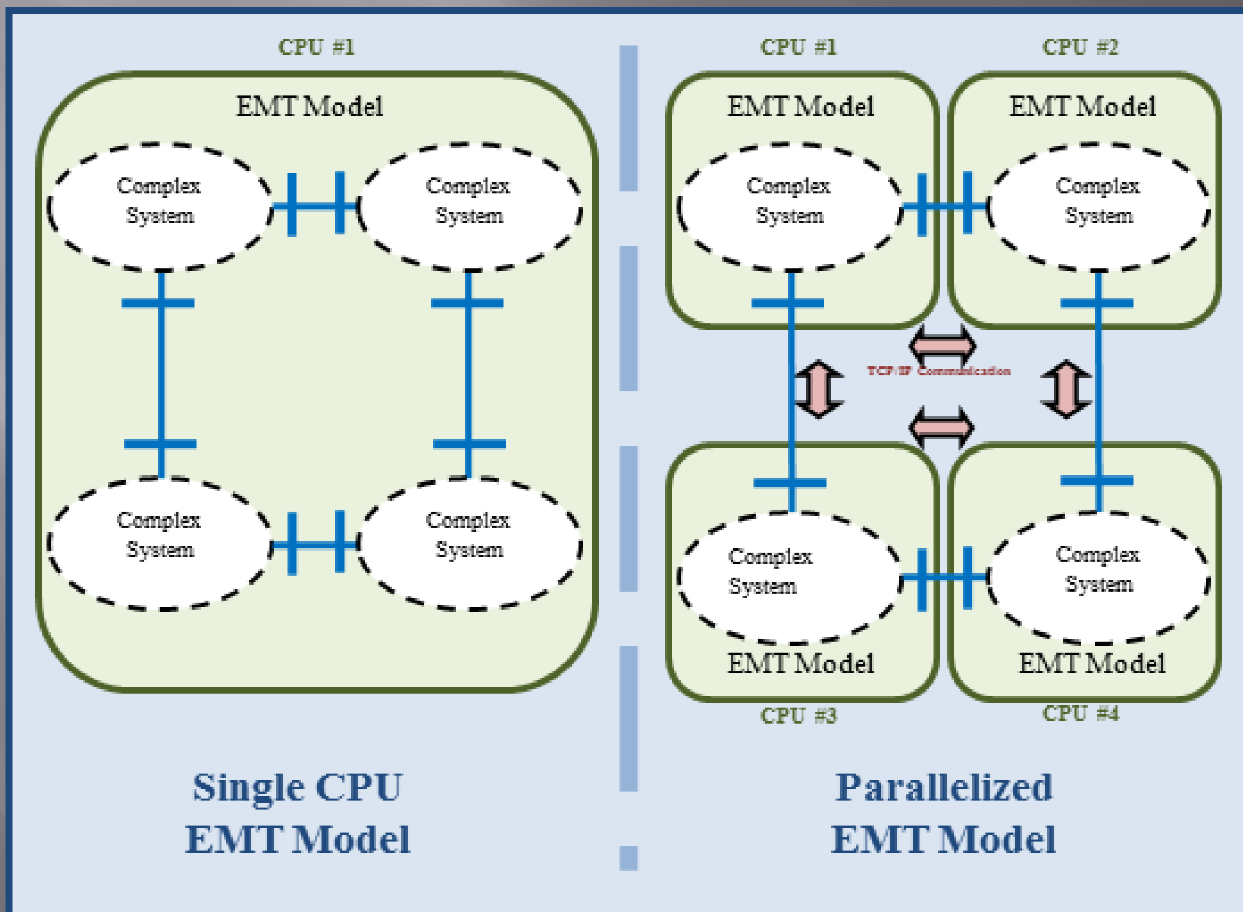
New Study Tools for Complex Networks

- Parallel Processing of EMT Simulations
  - Break the EMT simulation into several cases and run them in parallel talking to each other



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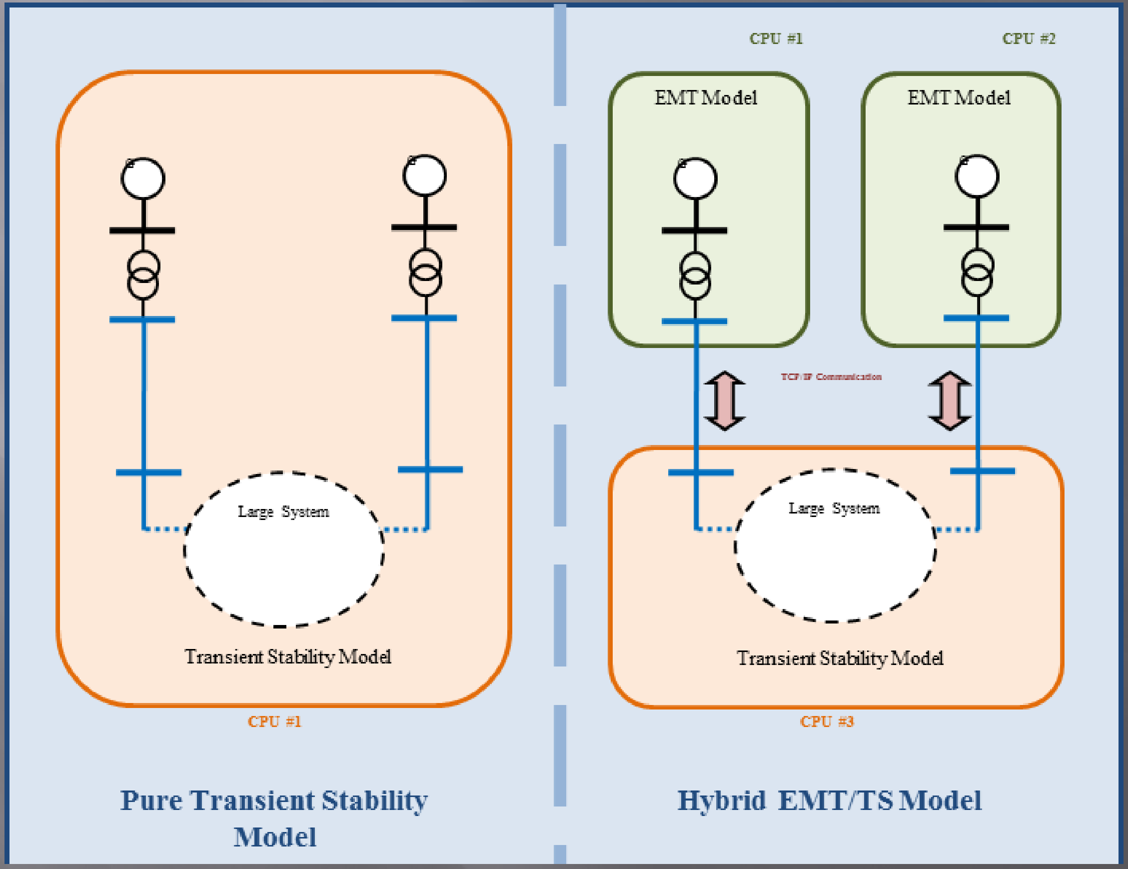
New Study Tools for Complex Networks

- Hybrid Simulations
  - EMT and Transient Stability simulations are run in parallel, talking to each other



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With Advanced Power Electronics in Wind Farms and Complex Interconnections to the AC System, Much Work Required, Otherwise this Might Happen

Thank You