POWER ELECTRONICS FOR WIND ENERGY APPLICATIONS

By
Dennis Woodford, P.Eng.
IEEE Life Fellow
daw@electranix.com

17 September, 2012

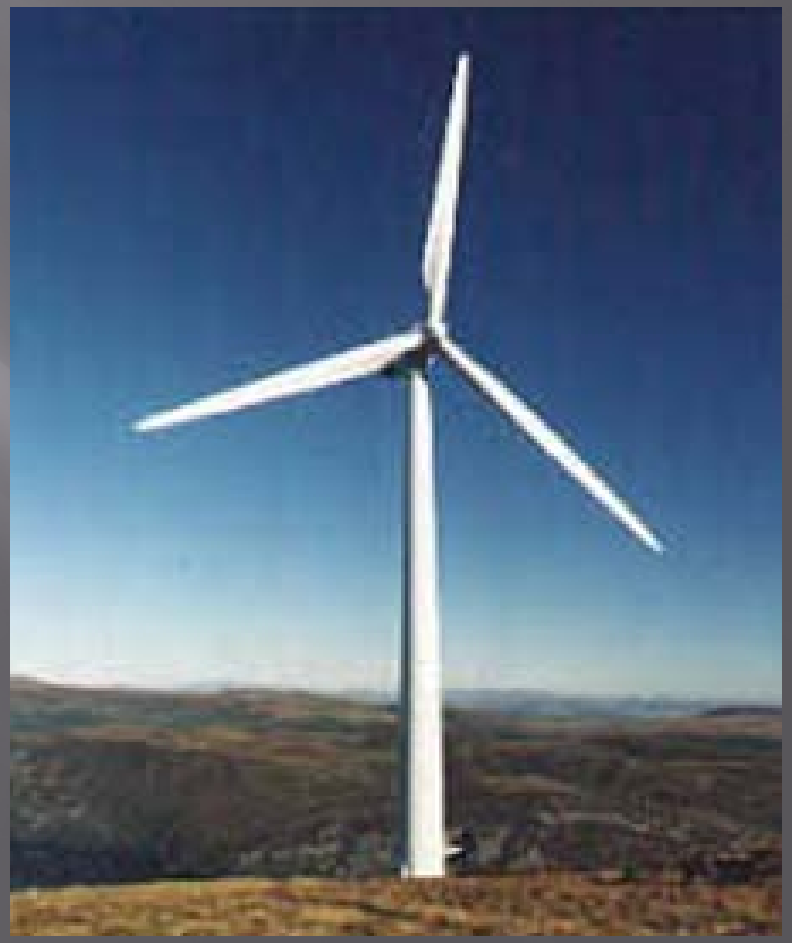
ELECTRANIX

KNOWING A LOT ABOUT RENEWABLE ENERGY IS BECOMING SEXY AT PARTIES

IEEE

Where it all started

- The earliest wind turbine generators applied induction generators (one or two speed)
- They required a large short circuit ratio, above 7 to operate effectively
- No power electronics



IEEE

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

IEEE

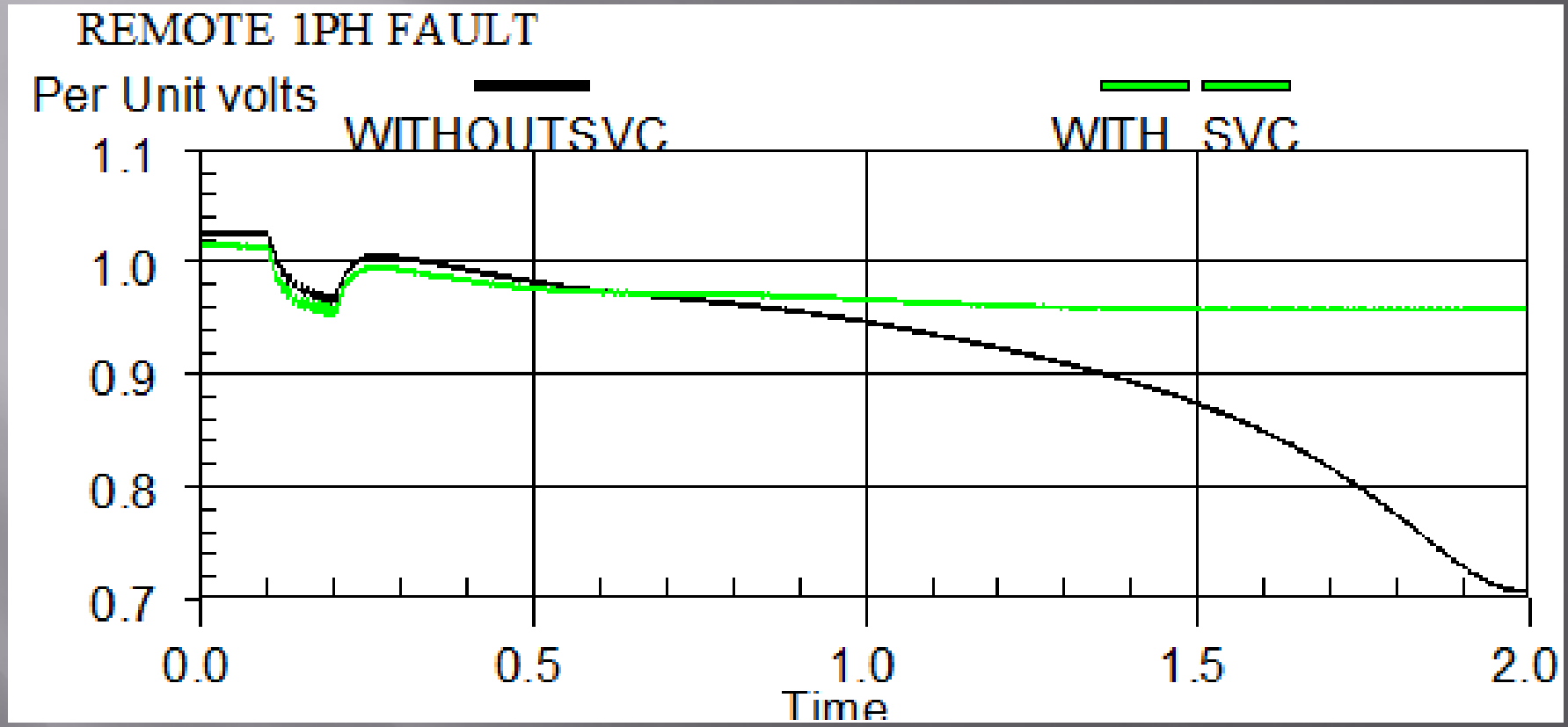
Use of Power Electronics World Wide

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

Vestas DFIG Wind Turbine Generator in Denmark

IEEE

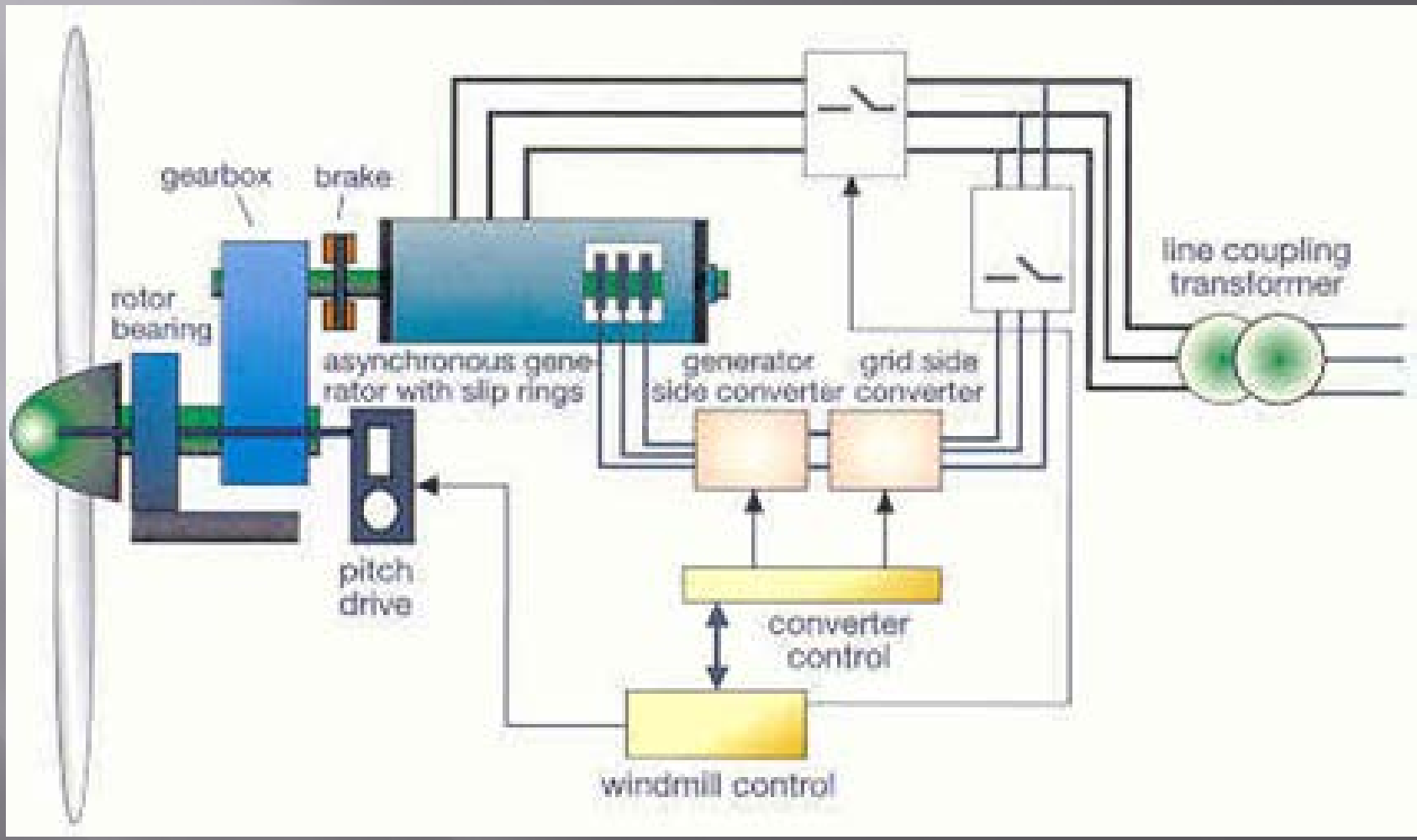
Use of SVCs and STATCOMs
Consider at terminals of induction generator



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

IEEE

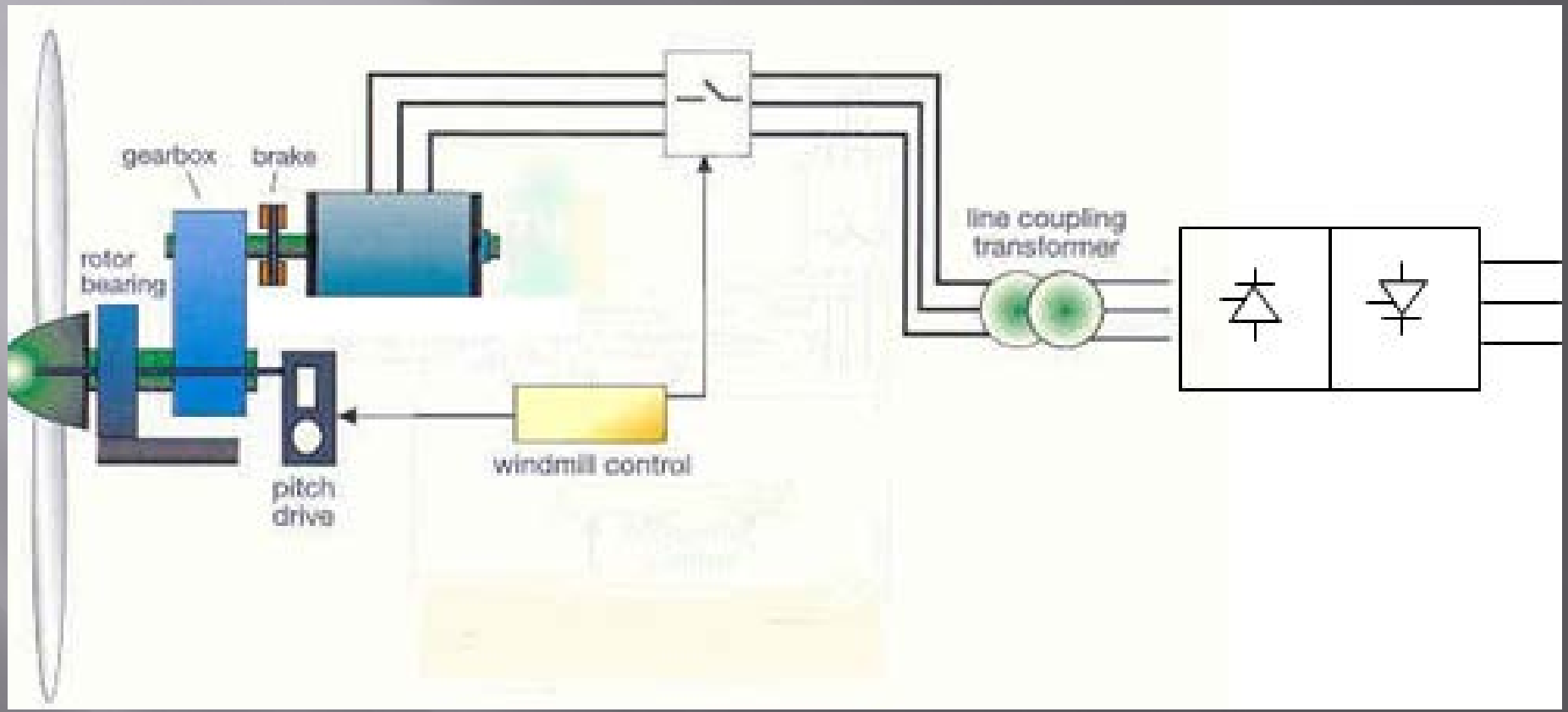
Doubly Fed Induction Generator – Type 3



Requires short circuit ratio of 2.5 (2.0 minimum)

IEEE

Full Power Converter – Type 4



Minimum short circuit ratio < 2 theoretically possible

IEEE

Trends in Power Systems

- Numerous complex power electronic devices: Wind farms, HVDC/VSC, PV Inverters...
- Weak systems, low ESCR, reduced system inertia
- Increased loads, need for RAS schemes
- Series capacitors, SVCs and STATCOMs (instead of new transmission lines)
- "Doing more with what you got"
- New research required for simulation tools!

IEEE

Impact of Series Compensated Feeders

- There is a possibility of Sub-synchronous control instability (SSCI)
- What is SSCI?

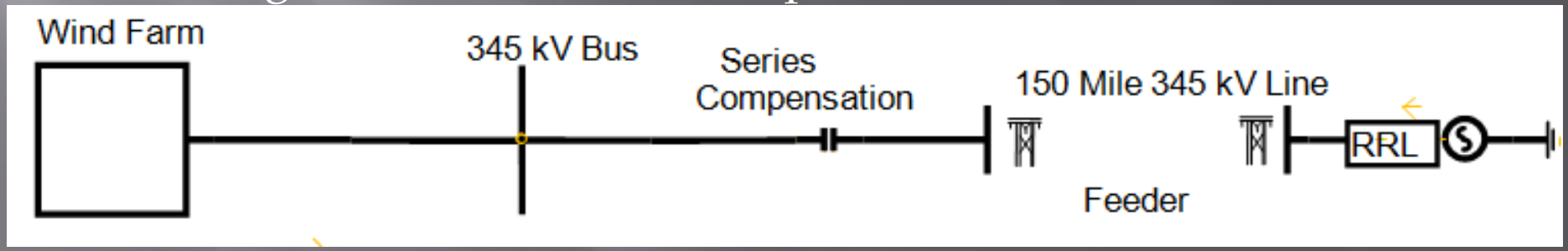
- Interactions between a power electronic controller (such as a wind turbine generator, DC link, VSC, etc…) and a series compensated system

Typical series compensation
(Courtesy of ABB)

IEEE

Wind Projects with Series Compensated Lines

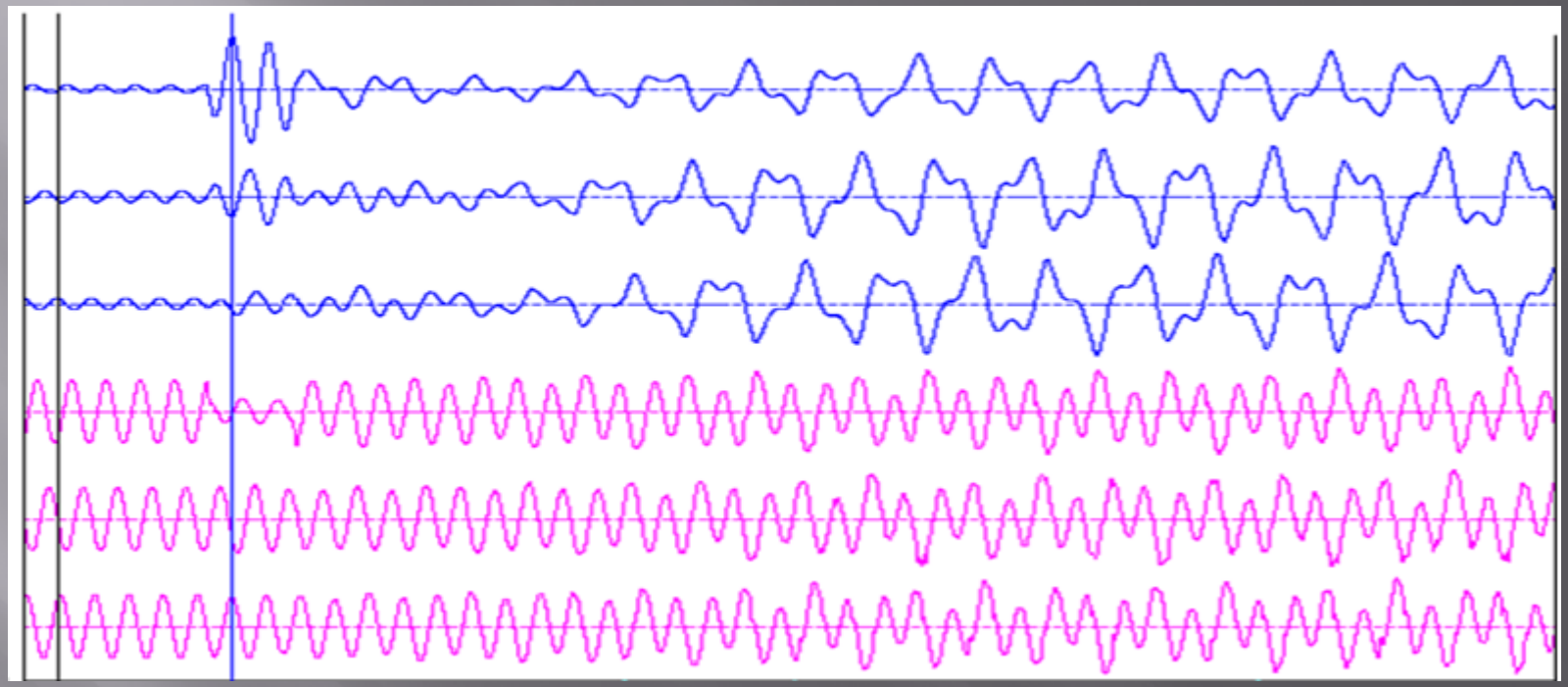
- Wind projects in Texas
  - Radial 345 kV lines
- ERCOT CREZ system expansion
  - 345 kV series compensated lines
- PacifiCorp Gateway system expansion
  - 500 kV lines, series capacitors, SVCs
- Alberta southern system expansion
  - 230 kV lines, series capacitors, SVCs
- Proposed 500 kV project in PacifiCorp
- UK large scale transmission expansion



Example Series Compensated Feeder

IEEE

Actual SSCI Event Trace of Wind Farm in Texas



DFIG wind turbines are more prone to SSCI than Full Converter

IEEE

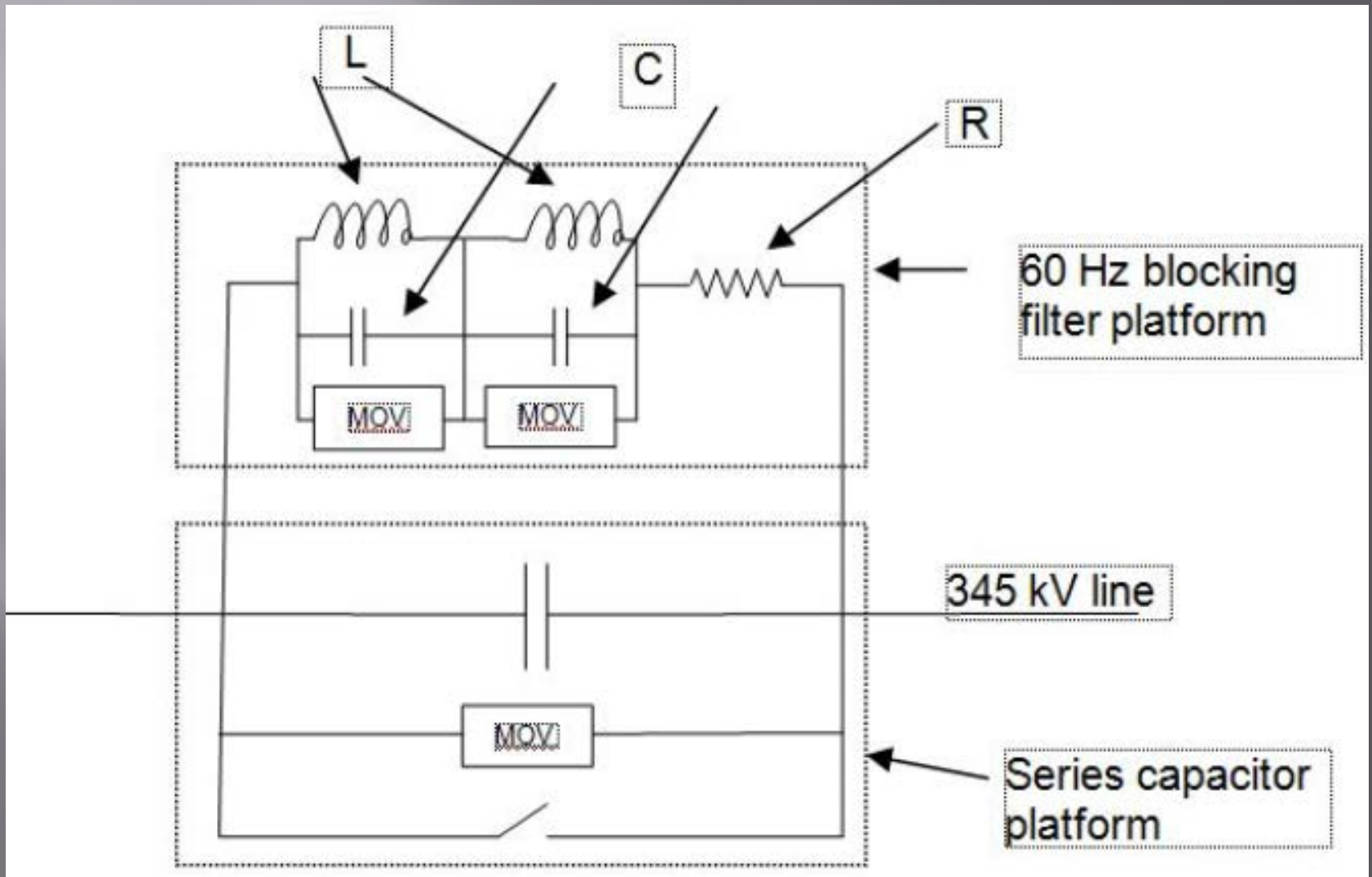
What Can be Done About SSCI ?

- Changes to wind interconnection standards
  - Requirements to study SSCI
  - "Series capacitor safe" turbines – Obtain Supplier Guarantee
- Development of a wind/series capacitor benchmark system
- Possible solutions
  - Higher voltage lines, TCSC (thyristor controlled series capacitors), operating restrictions, selective bypassing, HVDC ...
  - Sub-synchronous blocking filter across a series capacitor segment - expensive
- Wind turbine modeling
  - Detailed EMT models (using real controller code)
  - System models and model development methods
  - Confidentiality concerns

IEEE

What Can be Done About SSCI ?

Blocking filter in parallel with series capacitor



IEEE

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

IEEE

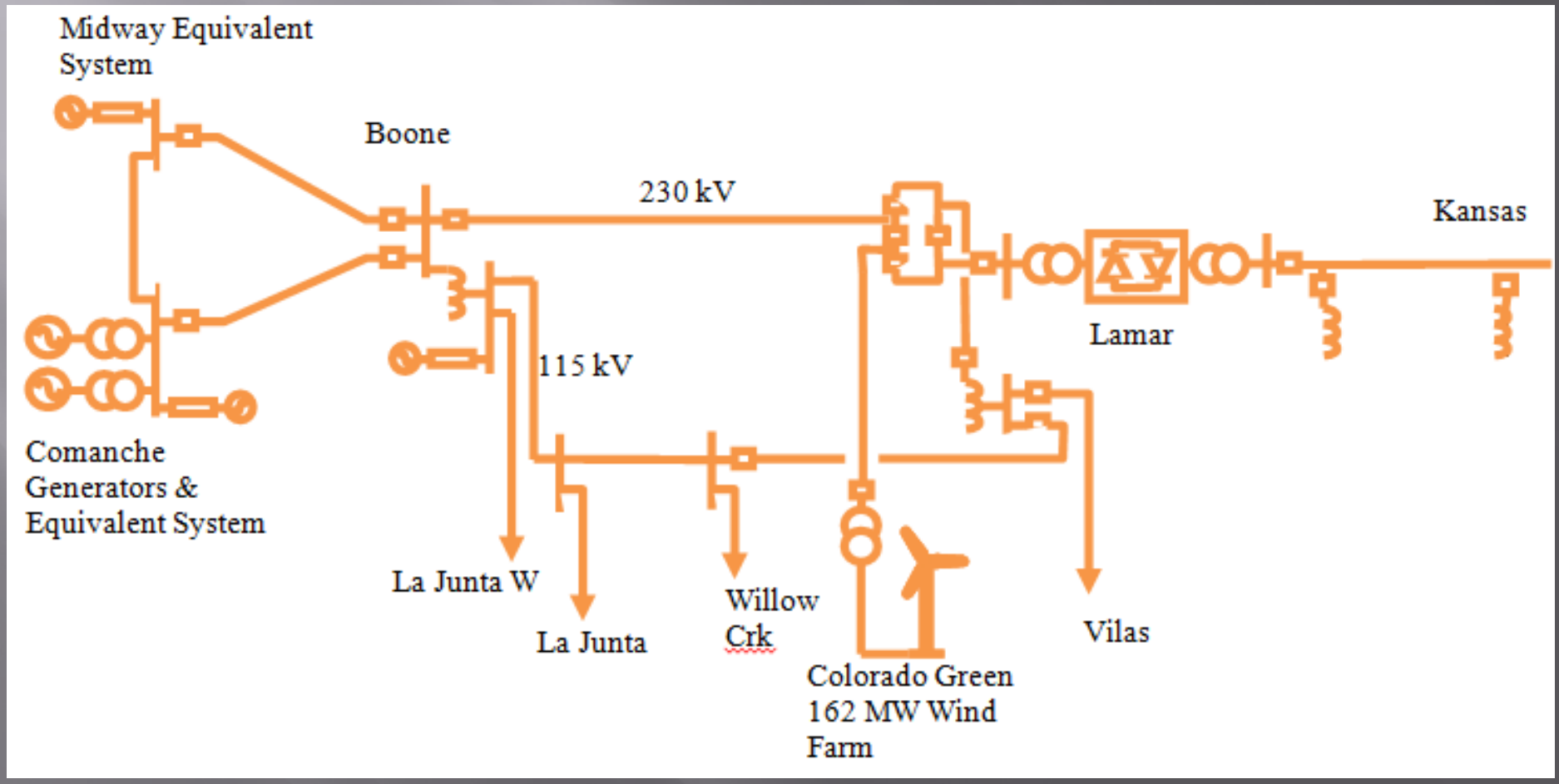
Computer Simulation Models

- 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 - confidentiality concerns
  - EMT studies are often not performed or needed in many installations

IEEE

Example Reduction of AC System Inertia

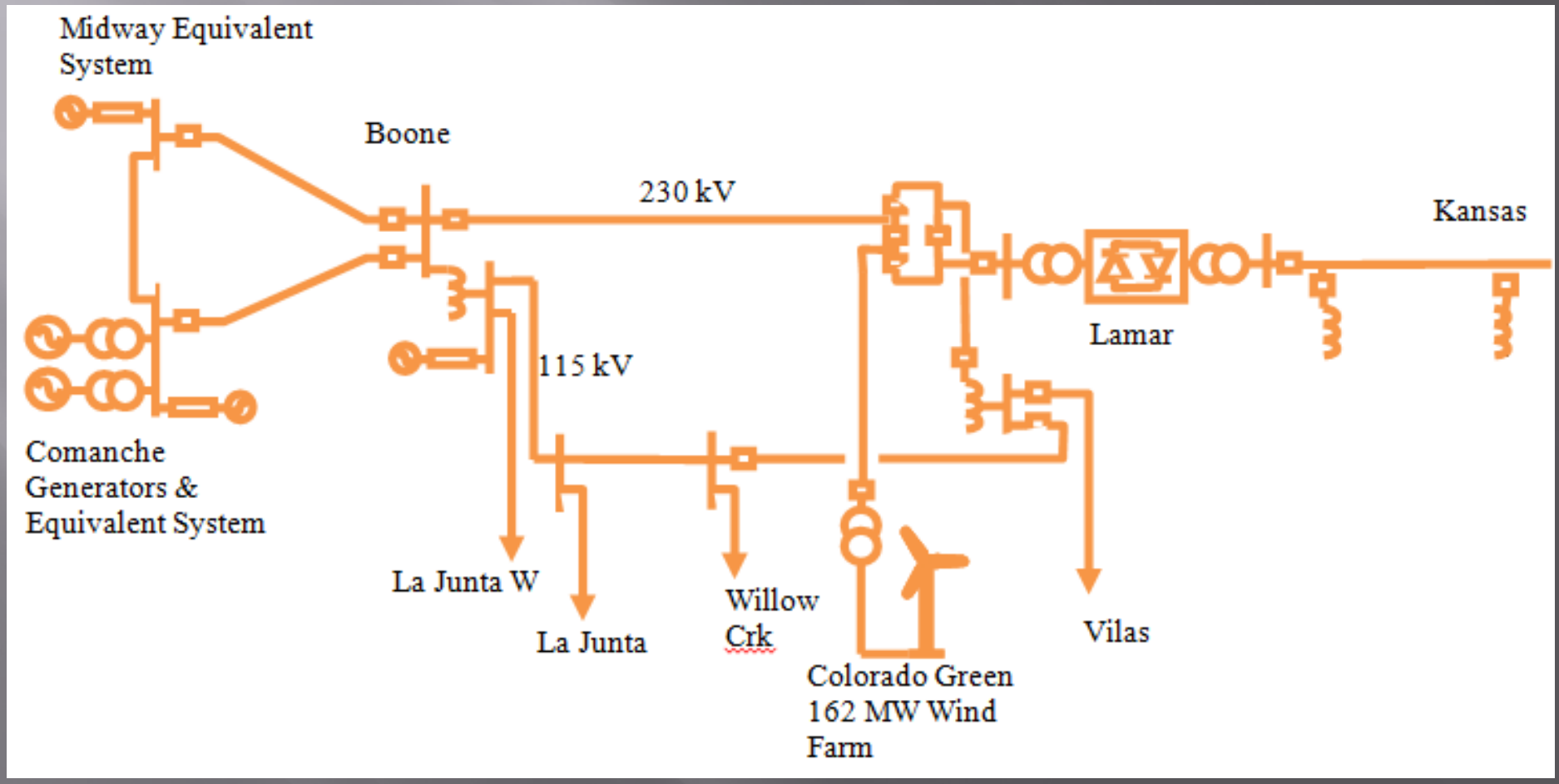
- Wind farms with Types 3 & 4 wind turbines are virtually "Constant Power"
- Consider South East Colorado:



IEEE

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



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

IEEE

Issues With HVDC Feeders for Wind Farms

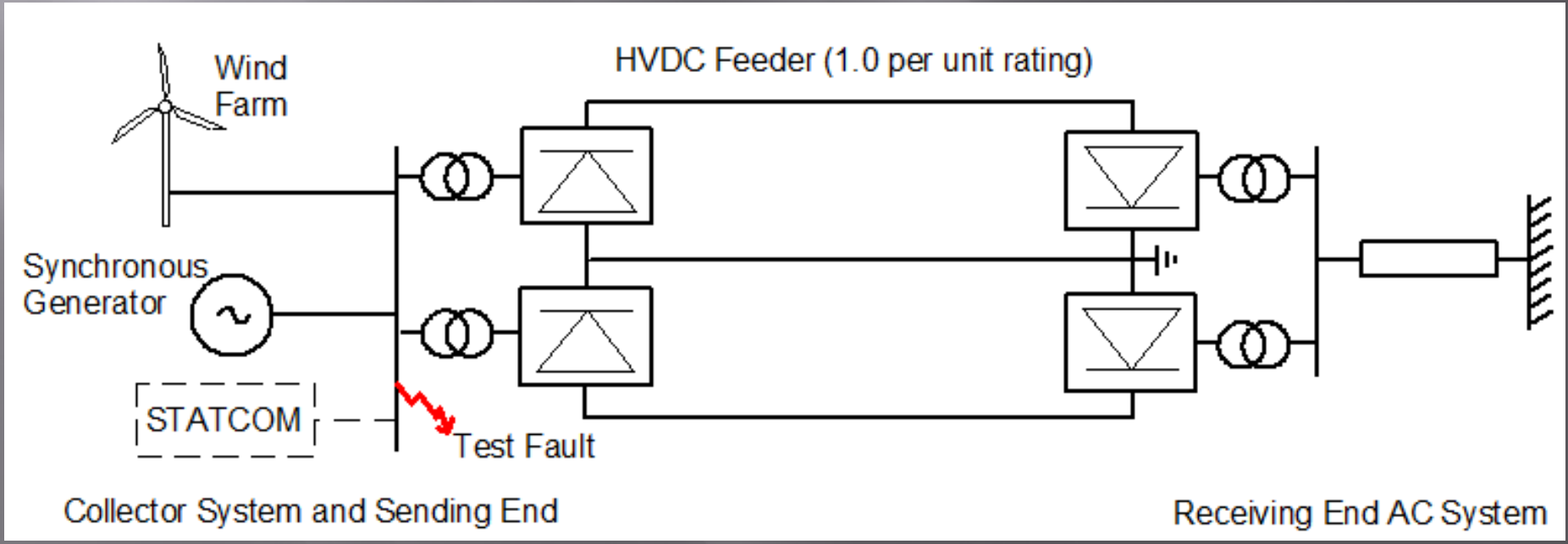
- Line commutated HVDC (LCC) thyristor rectifiers require AC short circuit capacity to operate

- 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?

IEEE

Issues With HVDC Feeders for Wind Farms

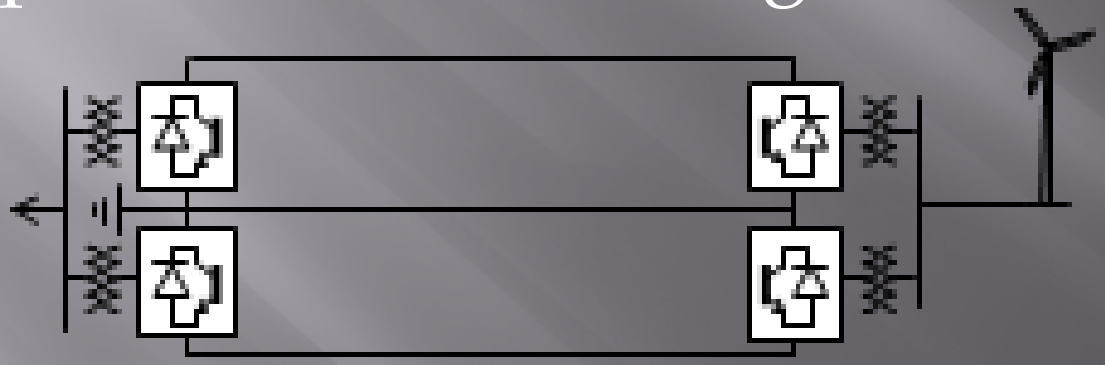
- Synchronous condenser and/or generator required at the rectifier to create the necessary short circuit capacity
- An LCC feeder may have a minimum power capability impacting wind farm stand-by energy



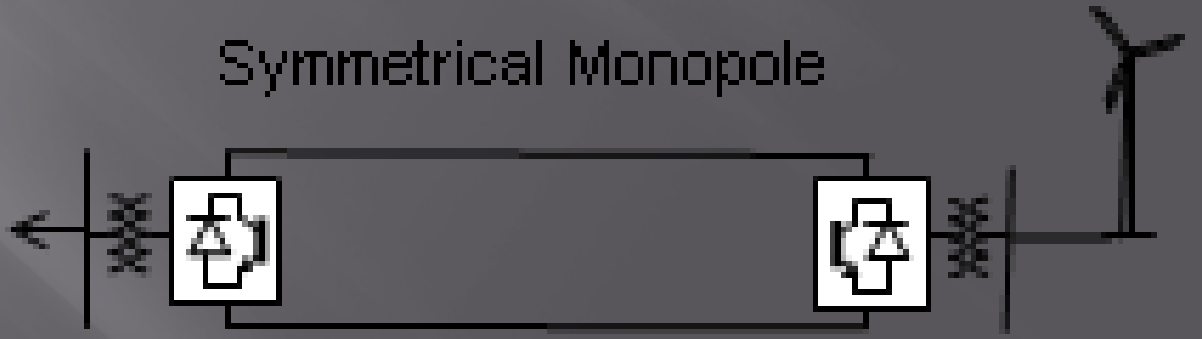
IEEE

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 busbar frequency and steady voltage allowing most types of wind turbine generators to operate



Bipole

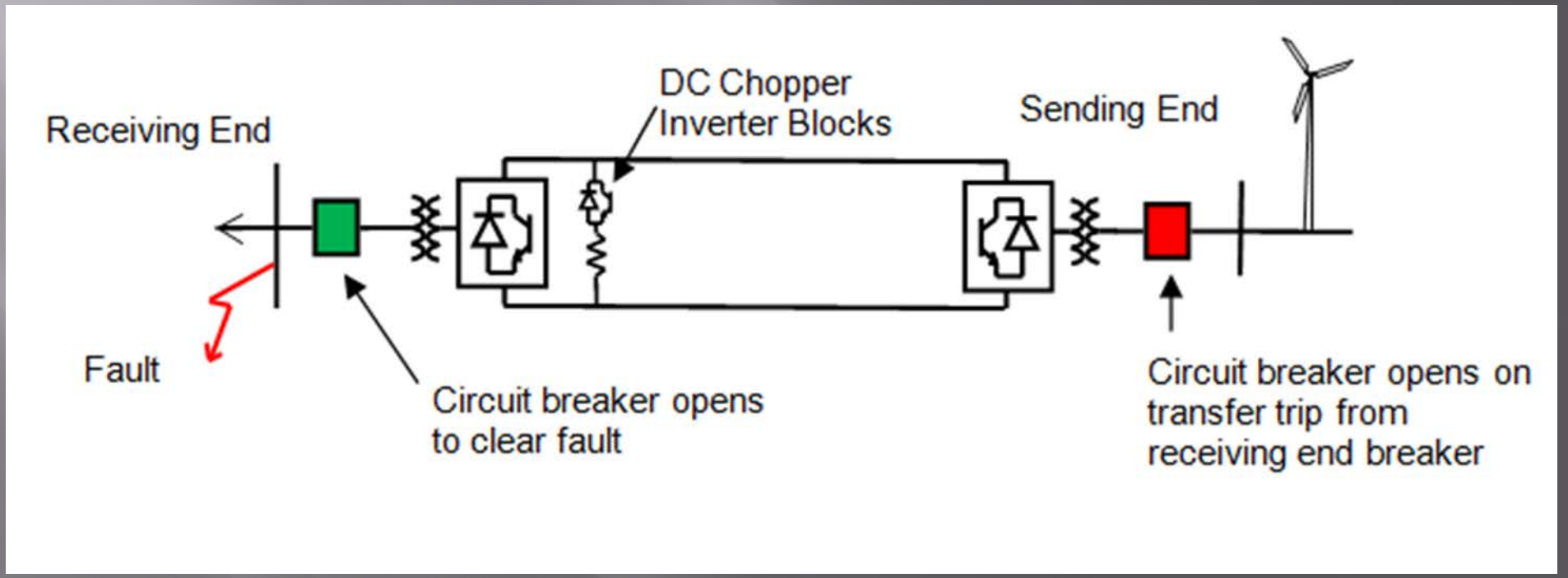


Symmetrical Monopole

IEEE

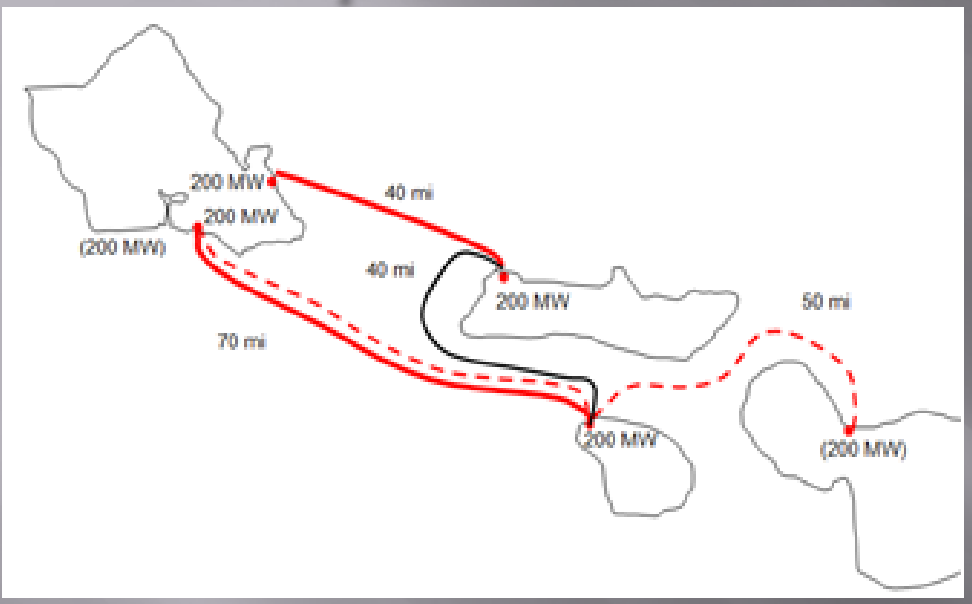
Issues With HVDC Feeders for Wind Farms

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

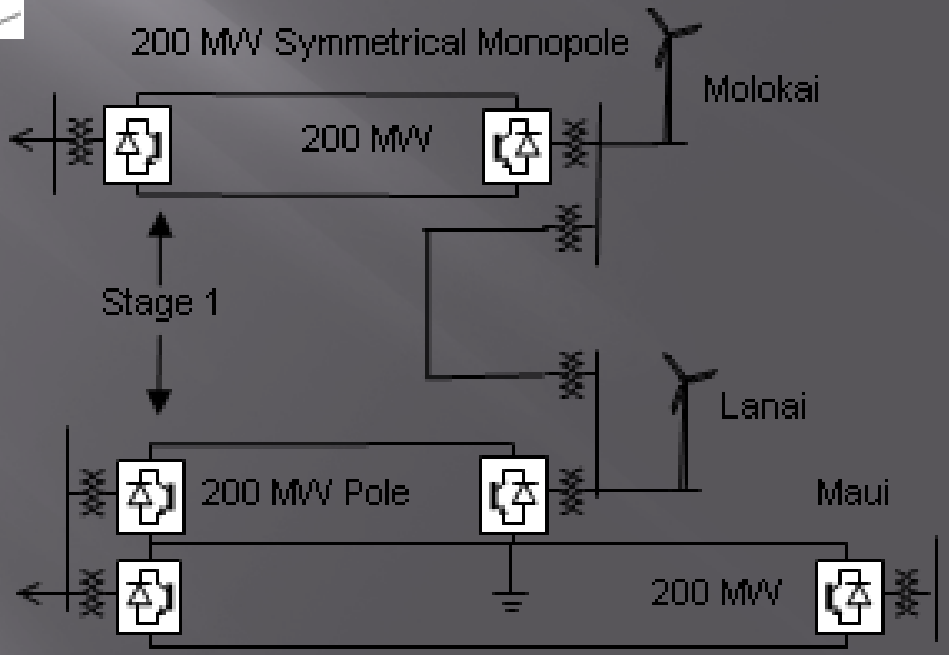


IEEE

Example – Hawaiian Interconnection Project



One Option with VSCs



AC cable Molokai to Lanai

IEEE

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

IEEE

Example – Proposed European DC Grid

IEEE

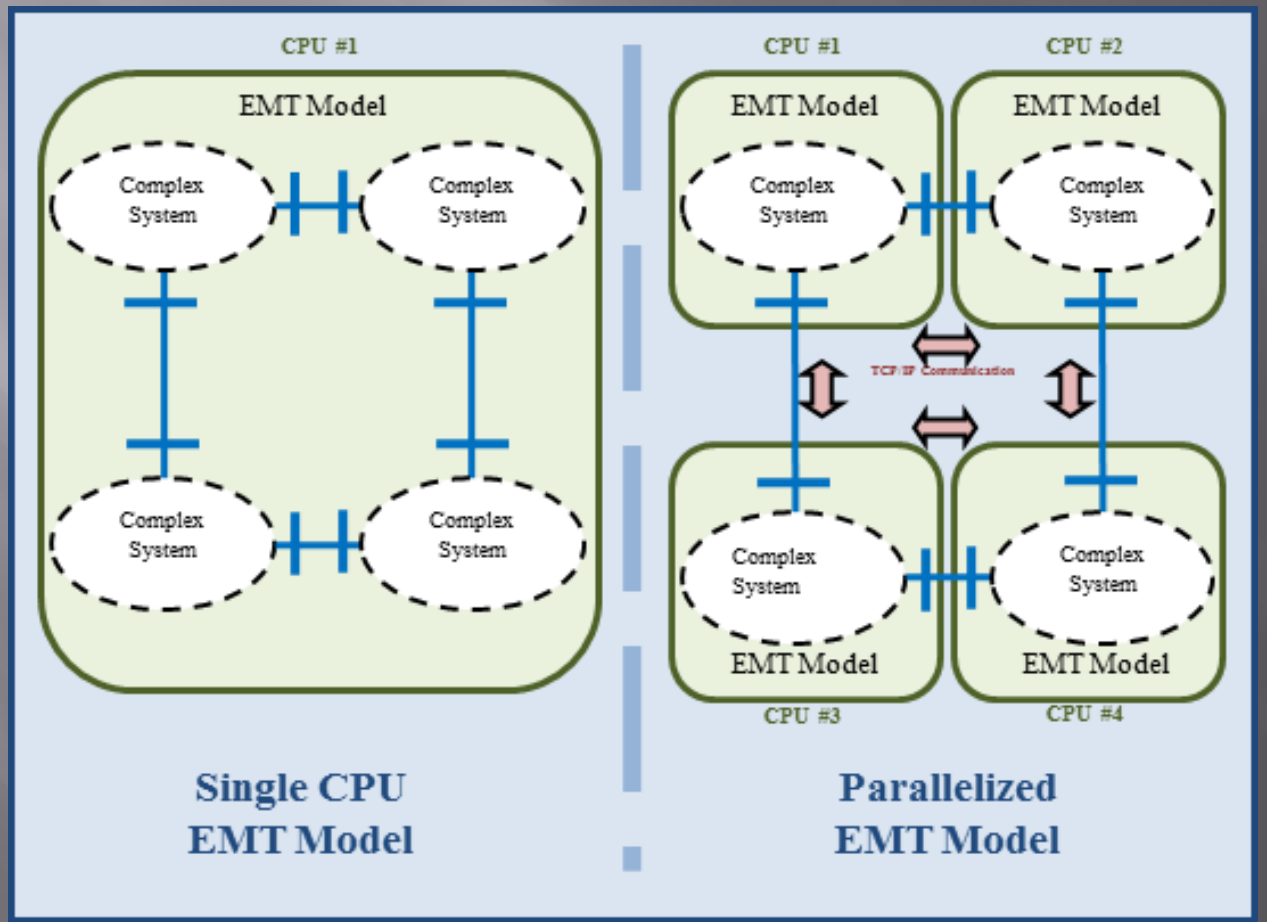
CIGRE Studying HVDC Feeders and DC Grids

- B4-55 HVDC Connection of Offshore Wind Power Plants
- B4.56 Guidelines for the Preparation of Connection Agreements for HVDC Grids
- B4-57 Development of VSC Models for HVDC Grids
- B4-58 Devices for Load Flow Control and Direct Voltage Control in a Meshed HVDC Grid
- B4-59 Control and Protection of HVDC Grids
- B4-60 Designing HVDC Grids for Optimal Reliability and Availability Performance

IEEE

New Study Tools for Complex Networks

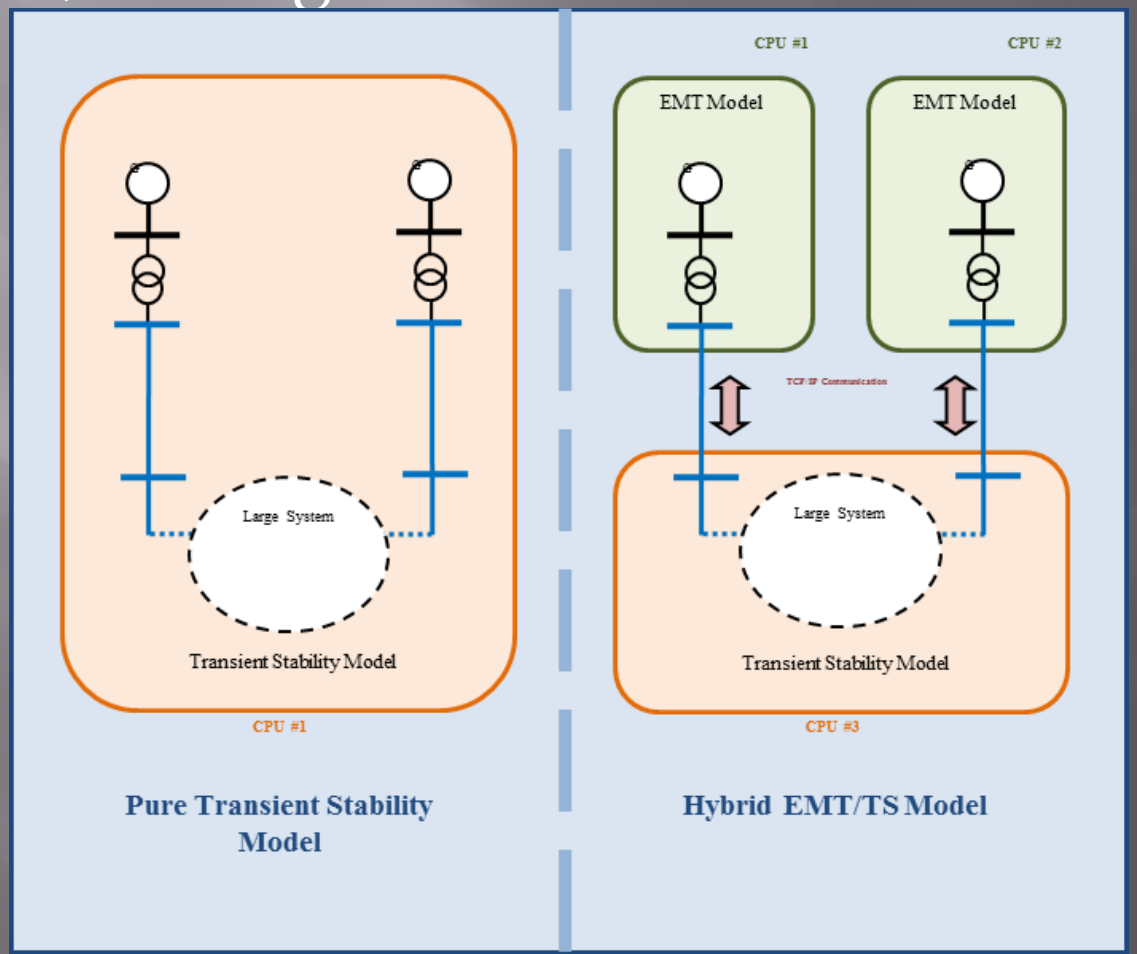
- Parallel Processing of EMT Simulations
  - Break the EMT simulation into several cases and run them in parallel talking to each other



IEEE

New Study Tools for Complex Networks

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



IEEE

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

Thank You