Intermittency Analysis Project

Task 1: Impact of Wind Turbine Technologies on Transmission System Operation and Performance

Bill Erdman & Mike Behnke
Principal Engineers
BEW Engineering, Inc.
San Ramon, CA

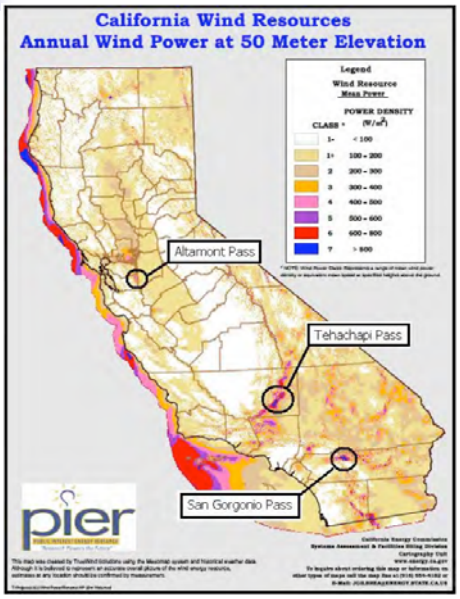
Outline

- A Brief History of Wind Power Development in California
- Historic Transmission and Interconnection Issues at California's Major Wind Development Areas
- Present Day Wind Energy Technology Review
- New Transmission and Interconnection Issues for High Wind Penetration Scenarios
- Future Wind Turbine Technology Enhancements for Improved Grid Compatibility

History of California Wind

- Drivers:
  - 1978 Passage of PURPA: creation of the QF
  - High fossil fuel prices following early oil embargo; expectation that utilities' avoided costs only moving in one direction
  - State mandating of SO4 contracts: long-term (20- to 30-year) with 10 years of fixed, above-market feed-in tariffs
  - Combined federal/state ITC and other credits creating effective tax credit of nearly 50%
- Result:
  - Start of the modern wind energy "industry"
  - Birth of the "wind farm" concept
  - 1600 MW of wind in California by 1988 (90% of global capacity)

History of California Wind (Cont'd)



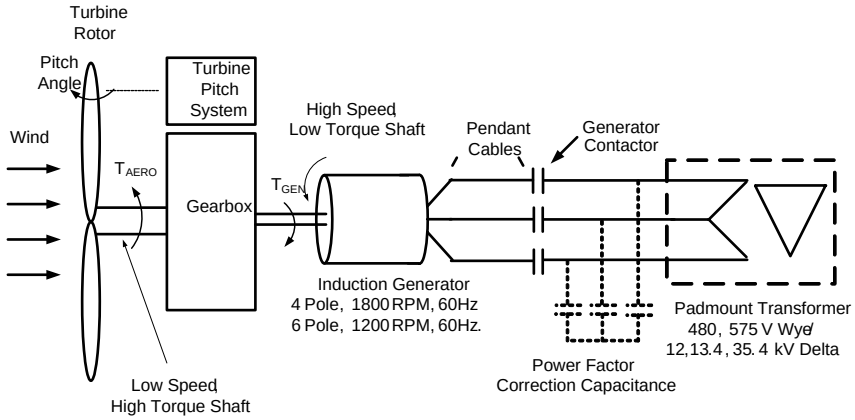
- 99% of capacity installed in Altamont, Tehachapi and San Gorgonio passes
- Steady, predictable thermally induced winds
- Ready access to underutilized transmission capacity

History of California Wind (Cont'd)

- Major investment tax credits expired between 1984 and 1986
- New Standard Offer (SO4) contracts eliminated in 1988
- Impact:
  - No net increase in installed capacity from 1990 through 2004 (actual net decrease)
  - New wind turbine installations limited to re-powering projects with newer and more reliable turbine technology

Transmission and Interconnection Issues (Early Days '80s Technologies)

- Constant speed induction generator based turbines were the workhorses



Transmission and Interconnection Issues (Early Days '80s Technologies)

- Voltage Regulation Issues and Mitigation
  - Result of uncompensated generator excitation
  - PG&E: kVAr-hr penalties
  - SCE: curtailment with payment for undelivered energy
- Power Quality Issues and Mitigation
  - Harmonics: Transformers and generators designed close to magnetic saturation limits; exacerbated by PFC capacitors
  - Flicker: Primarily due to magnetizing inrush current at startup
- System Protection and Reliability Issues and Mitigation
  - Wind turbines were weak source of short circuit current
  - Interconnections were simple (single breaker) taps to lines
  - PFC capacitors created self-excitation concerns
  - Direct transfer trip was installed (or retrofitted)

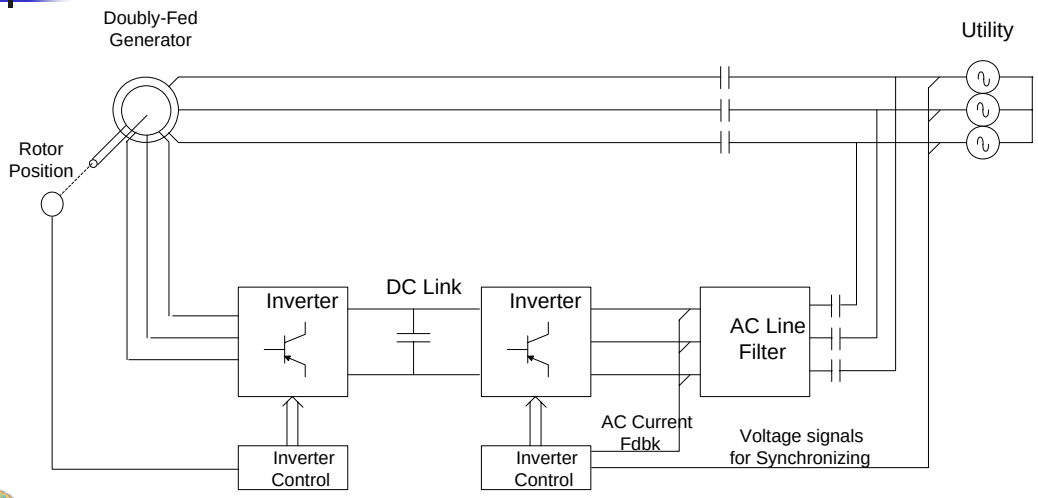
Transmission and Interconnection Issues (Early Days)

- Despite California's global lead in wind power capacity, penetrations levels were low by today's standards
- No changes in operating practice with regard to spinning reserve
- California RPS-level penetration levels with 1980's wind turbine technology would have a drastically different impact on grid reliability
- 1990's bust in California was accompanied by a boom in Europe, preventing a stall in the evolution of wind turbine technology

Present Day Wind Energy Technology Review

- Constant speed induction generator based wind turbines are a dying breed
- Variable speed machines are nearly universally installed in new North American wind plants
- General Advantages (versus Constant Speed)
  - Higher energy capture at partial load due to optimized aerodynamic efficiency
  - Fast torque control -- limits loads on blades, drive train and tower (may be able to pull material cost of out these systems)
  - Continuous control of power factor
- General Disadvantages (versus Constant Speed)
  - More parts, more complexity
  - Potentially lower reliability than simpler machines

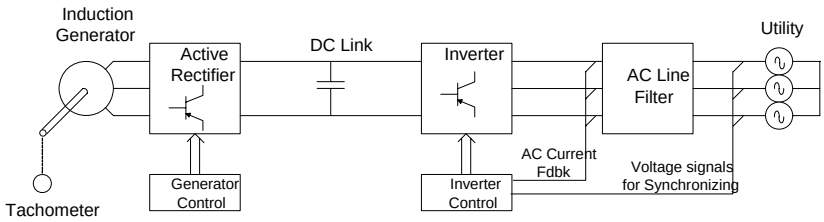
Variable Speed Doubly Fed Induction Generator (DFIG)

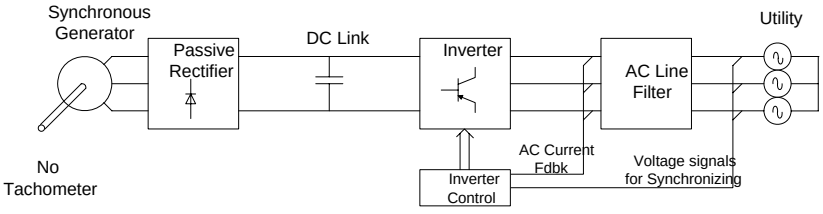


Variable Speed Doubly Fed Induction Generator (DFIG)

- Advantages
  - Partial conversion (only a fraction of output power passing through power electronic converter) brings:
    - Smaller rating/cost of converter versus full conversion
    - Slightly higher electrical efficiency
  - Inrush current during startup is virtually nil
- Disadvantages
  - Slip rings and brushes for rotor winding are maintenance and reliability concerns
  - Speed range generally narrower than for most full conversion designs

Variable speed full conversion





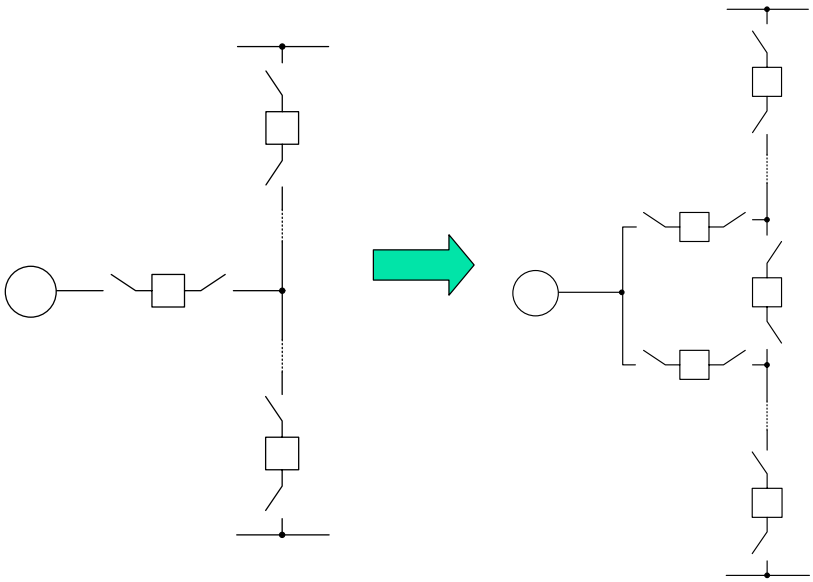
Variable speed full conversion

- Advantages
  - Very wide speed range, typically greater than 2:1
  - No slip rings or brushes
  - Inrush current during startup is virtually nil
  - Complete decoupling of generator from grid – important with regard to grid event immunity
- Disadvantages
  - Higher converter rating needed relative to DFIG (higher cost)

Balance of System

- Reactive Power Compensation Systems
  - AVCs, D-VARs, STATCOMs, et. al.
  - Employ power electronic switching
  - Very fast dynamic response relative to synchronous generator excitation systems
- Interconnection Stations
  - Ring bus switching station has replaced single breaker tap as industry standard
  - Eliminates weak in-feed protection issue

Balance of System



REMOTE S

New Transmission and Interconnection Issues Arising as Result of Higher Penetration Levels

- Voltage Regulation
  - Increased use of wind turbine technology and external devices for VAR compensation
  - 0.95 leading to 0.95 lagging power factor capability mandate in FERC Order 661
- Short Circuit Duty Contribution
  - Some new topologies has synchronous generator-like short circuit capability (pluses and minuses)
- Transient Stability
  - Grid disturbance ride-through capability mandated in FERC Order 661

PCC

New Transmission and Interconnection Issues Arising as Result of Higher Penetration Levels

- Steady-State/Dynamic Stability
  - dP/dt (ramp rate) control
  - Frequency regulation participation
- Analysis via "Conventional" Utility Planning Tools (e.g., PSLF and PSS/E)
  - System impact study process more rigorous than in 1980's
  - Wind turbine models are immature; WECC task force to improve and develop generic models
- High penetration levels in Europe have already driven wind turbine design evolution in these areas; the technology to meet these requirements when California needs them exists

Final Report

- Complete report available at:

http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2006-050.html