GE
Energy

Wind Energy Technologies

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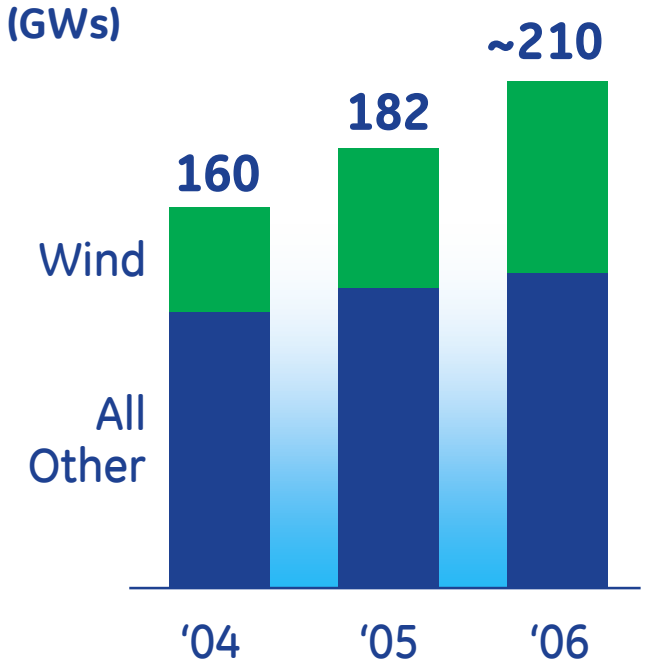
imagination at work

The need for change … and choice

- Global Population Growth
- Energy Consumption
  +50% by 2020
- Fossil Reserves ?
- Environmental Impact?
- Alternatives ?

Growing renewables demand …

Global renewable installed capacity



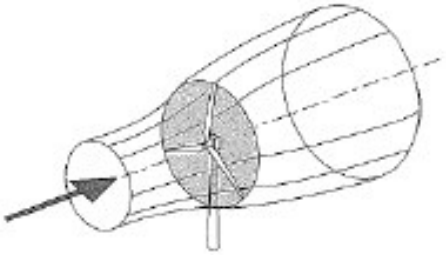
Source: REN21 2006 update + GE est (9/07)

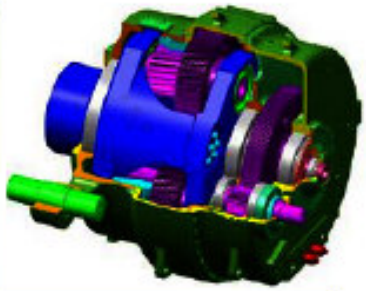
- Significant growth … 25% CAGR ('01-'06)
- 40% power capital spending
- Wind >50% of growth
- Domestic, abundant, carbon-free
- Countries & US states establishing renewable energy targets

World requiring renewable energy solutions

Wind turbine principles

The basic idea is to convert one energy form into another





Kinetic Energy	→	Mechanical Energy	→	Electrical Energy

Rotor 45 - 52%

Gearbox 95 – 97%

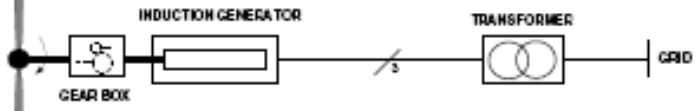
Generator + Power Converter 90 – 95%

42 – 50% Efficient Today… Theoretical Maximum is 59% (no losses)

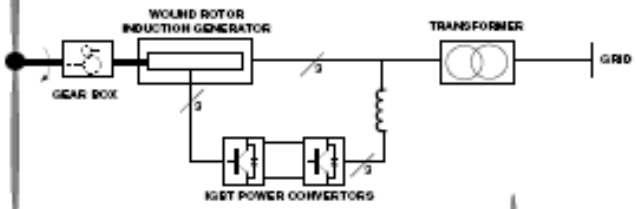
Electrical power conversion

Fixed-speed to variable-speed

Fixed Speed System

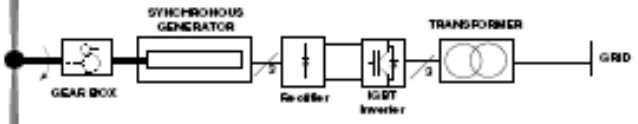


Doubly-Fed Variable Speed System



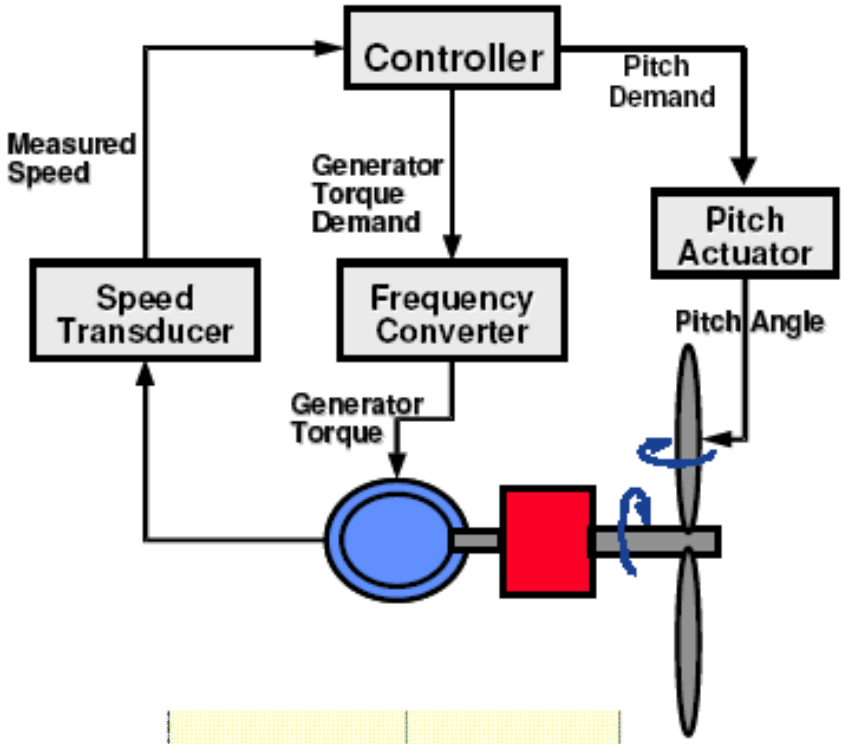
like GE 1.5 & 3.6

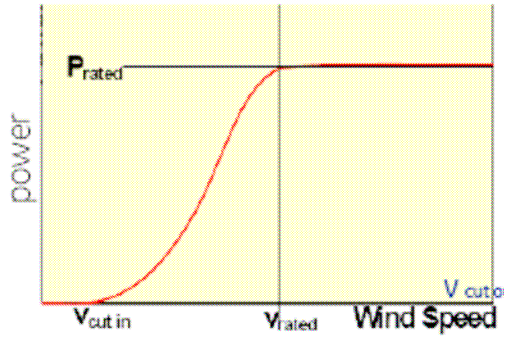
Full Conversion Variable Speed System



like GE multi-MW

Variable speed + pitch regulated control





Closed loop control based on rotor speed and torque demand

Speed and Output controlled by blade pitching

Overspeed Protection also performed by blade pitching

Maintain tip speed ratio until rated wind speed

Maintain rated output after rated speed

GE 1.5 MW turbine family

1.5 Wind Turbines				
	1.5e	**1.5se**	**1.5s**	**1.5sle**
Frequency	60Hz	50/60Hz	50/60Hz	50/60Hz
Wind Regime	IEC TC Ia+	IEC TC Ib	IEC TC IIa	TC III/s
Rotor Diameter	65m	70.5m	70.5m	77m
Rated Power	1.5 MW	1.5 MW	1.5 MW	1.5 MW
Hub Heights	65m	52-65m	65-85m	61-85m
Speed Range	11-22 rpm	11-22 rpm	11-22 rpm	10-20 rpm

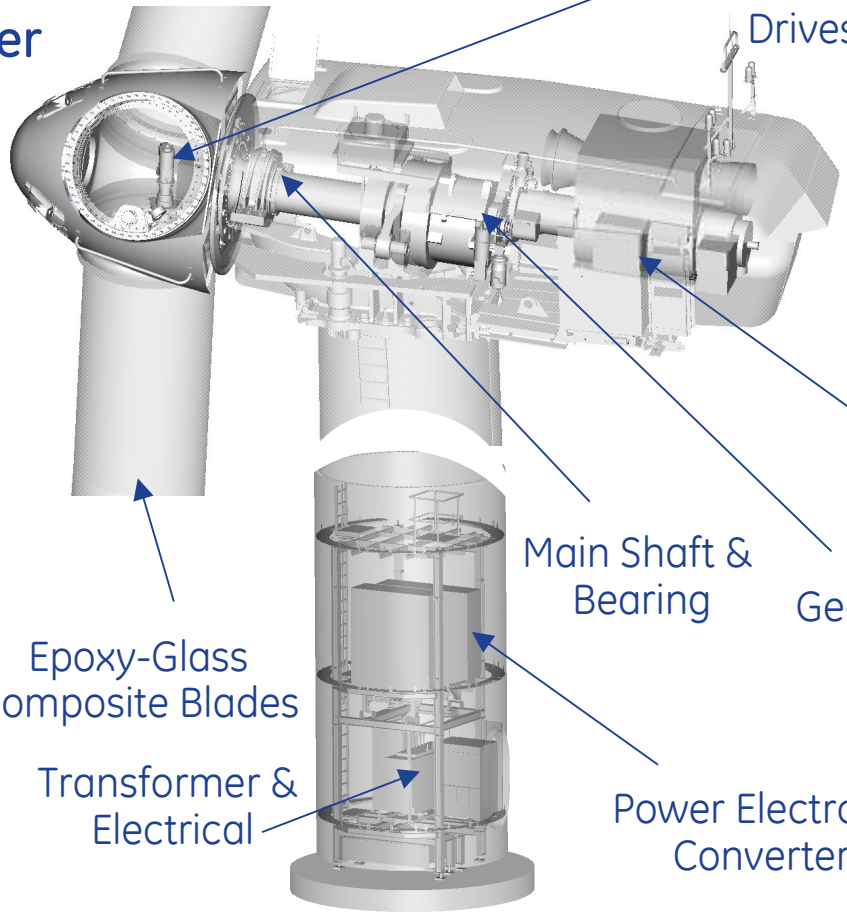
GE Developments

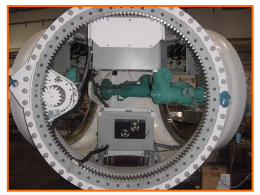
- Industry workhorse
- Reliability Growth
- COE Reduction, Global Sourcing
- Extended Operations – Temp, IEC TC I/II

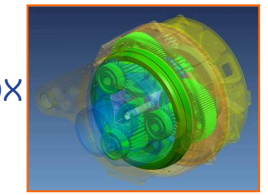
Wind turbines

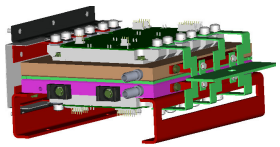
GE 1.5 MW

- 77 M Rotor Diameter
- 50-100 M Tower
- 98% Availability
- Speed 10-20 RPM
- Variable Pitch



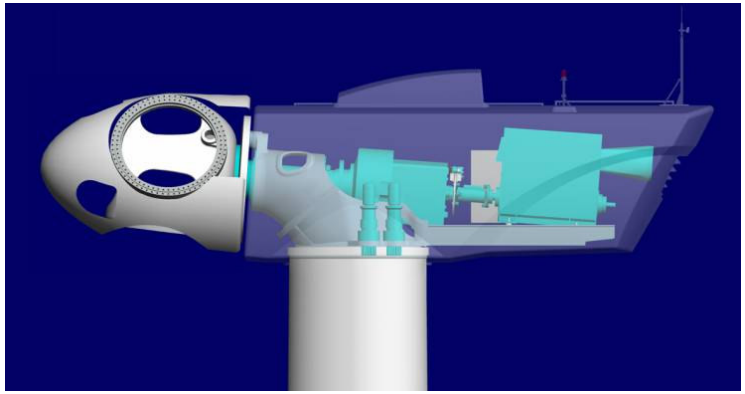


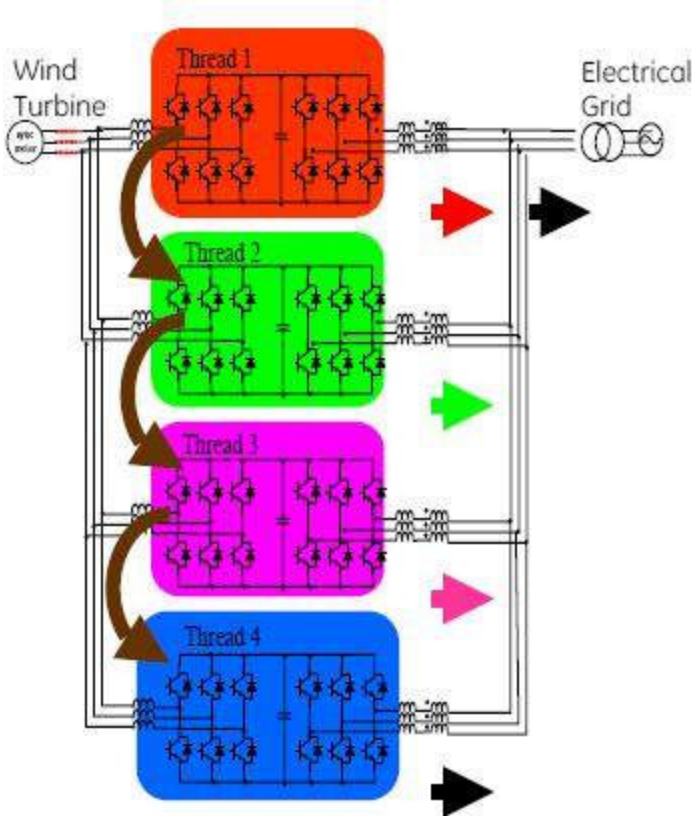




GE 2.x turbine family

2.x Wind Turbines		
	2.3	2.5
Wind Regime	IEC TC IIIa	IEC TC IIa
Rotor Diameter	94m	88m
Rated Power	2.3 MW	2.5 MW
Hub Heights	100,120m	85m
Avg Wind Speed	7.5 m/s	8.74 m/s





Features

- Common platform IEC classes
- Common 50/60 Hz design
- Full power conversion
- Double main bearings

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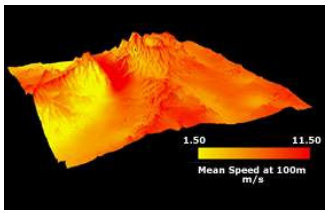
Utility scale wind generation …
5-10% penetration easily managed

150 MW Trent Mesa, TX

Danish Transmission Grid w/
Interconnects & Offshore Sites



Wind Site Forecasting

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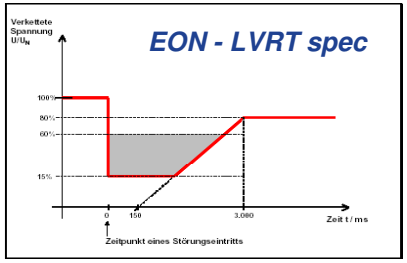
Utility Windfarms

100-500 MW Farms Being Developed

- Grid Codes Rapidly Evolving



Jutland - Western Denmark

3000 MW Wind Capacity Out of 6800 MW Total

- 20% of Average Demand Supplied by Wind
- Max 1 Hr Penetration Is 80%, max 20% change per hour
- HVDC Link to Norway, Hydro As Virtual Storage

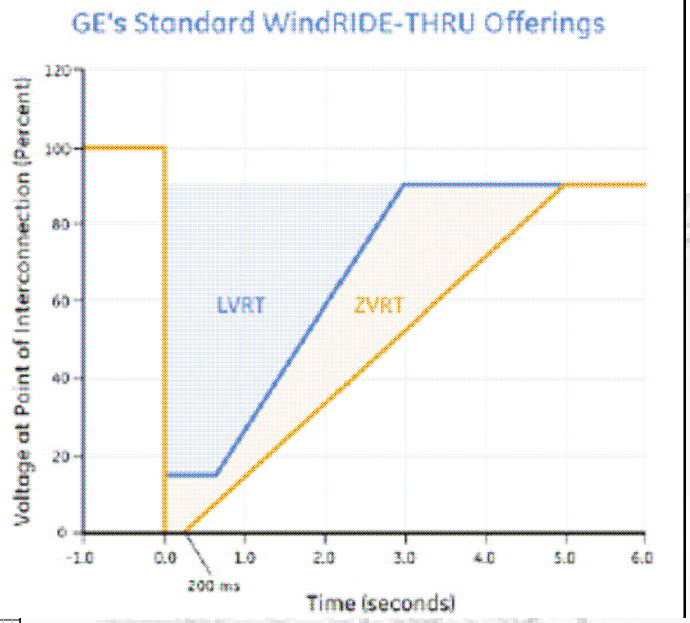
Managing a Variable Resource

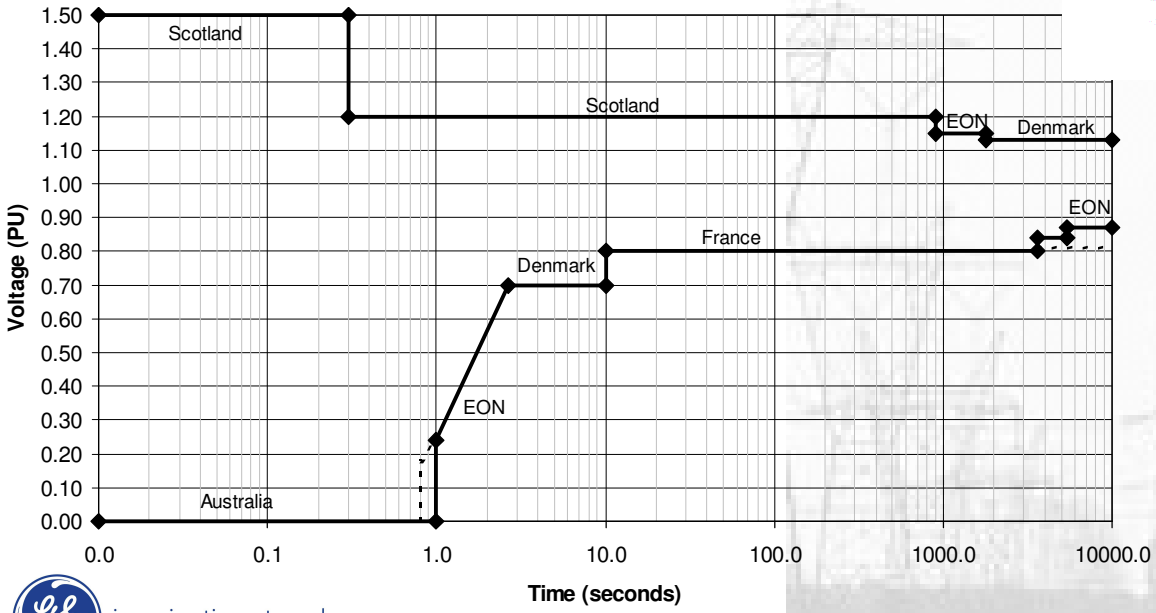
- 1 to 48 Hour Wind Forecasting
- Coordinated Economic Dispatch of Hydro, GT, ….

Grid integration ...critical for large scale wind

Rapidly Evolving Grid Codes

- Success of wind is driving sweeping changes
- New electrical control features evolving
- Ride-Thru, Real/Reactive Power control
- Wind needs to be as Grid-Friendly as Traditional Generation for 50 GW Global market





Global Transient Voltage Requirements

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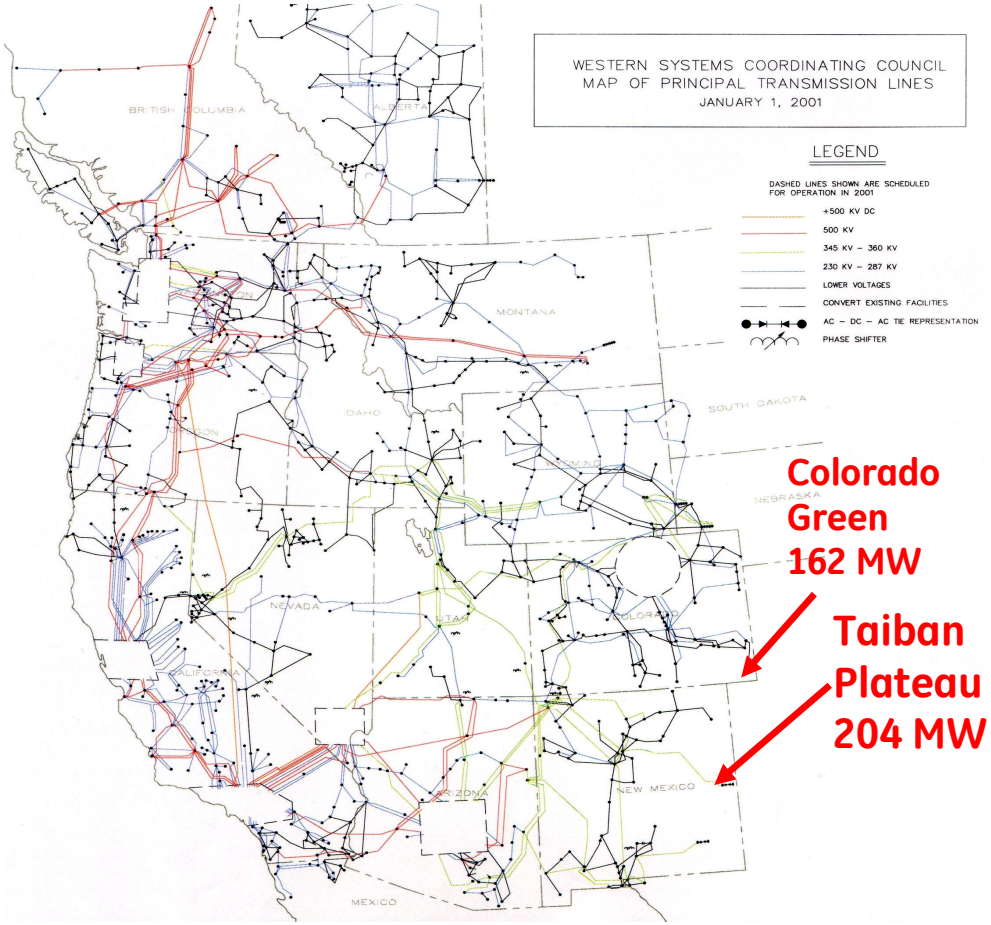
Windfarm electrics – real & reactive power control

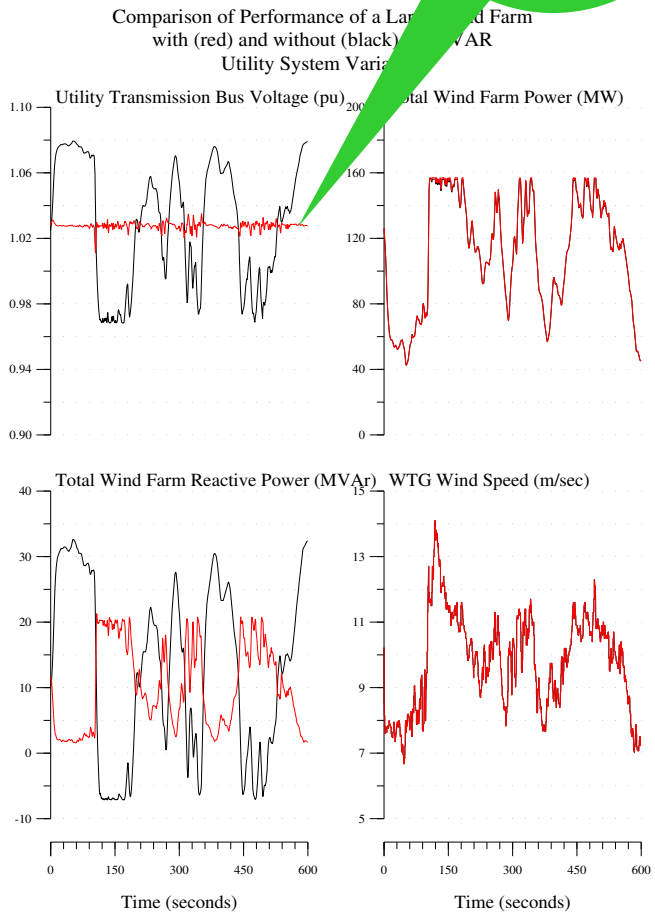


Colorado Green 162 MW

Taiban Plateau 204 MW

~ 1500 mi

Clean volts on host utility grid



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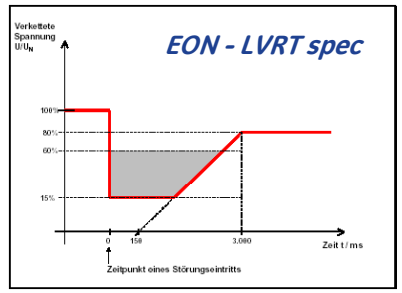
Grid requirements evolution



Performance Requirements

Advanced

Active Anti-islanding, Torsional, others | Zero Power Voltage Control | LVRT with controlled current injection | Reserve Functions

Anti-islanding | Fancy Voltage Control (WindVAR) | Zero VRT – no trip | Frequency Response

Voltage control | LVRT – no trip | Curtailment

Basic

O/U Voltage Overcurrent O/U Frequency | PF control | None | None

Protection | **Volt/VAR Control** | **LVRT** | **Active Power Control**

Application Characteristics

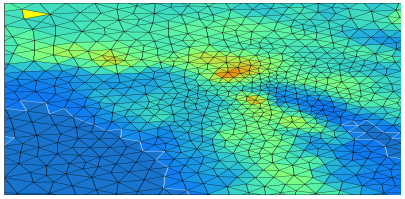
Single WTGs | Large Farms | Multiple Farms

Low Penetration | High Penetration

Power generation firming & smoothing

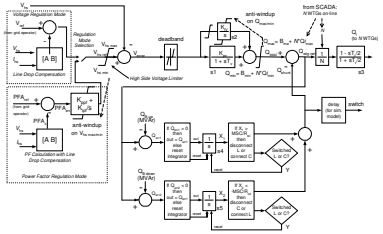
Slow - Generation Firming

Wind



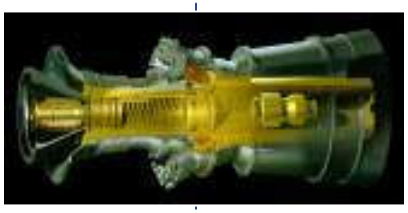
Advanced Forecasting

Fast - Generation Smoothing



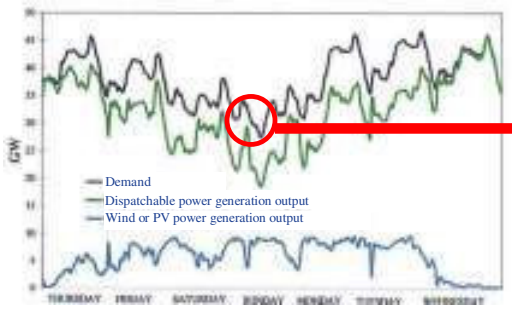
Advanced Power Controls

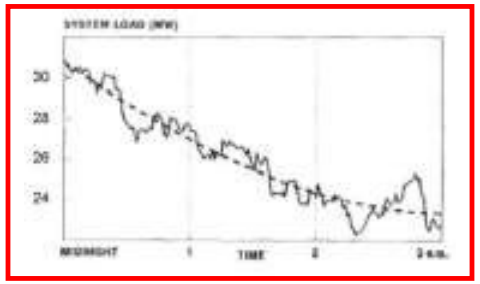
Storage



Advanced Generation

Active Demand Participation





A full suite of technologies will enable high renewables penetration:

Forecasting + Controls + Storage + Advanced GT + Active Load Control

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