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CHALLENGE OF LARGE SCALE WIND POWER INTEGRATION - KEY MESSAGES FROM BEIJING WORKSHOP

WORKSHOP OBJECTIVES

- Wind power has the highest penetration level and most rapidly growing among renewable energy technology.
- Installed capacity of wind power is approximately 300 GW. Asia account for one third and China for one fourth. India is among the top five wind developers in India.
- Wind power accounts for more than 7- 8 % of installed generation capacity in China and India.
- Other Asian countries have initiated incentive programs and are on the verge of rapid expansion of wind industry

WORKSHOP OBJECTIVES

- Increasing levels of wind power (more than 5% of energy and 10% of capacity) poses several technical challenges to power utilities.
- However, wind power penetration levels of over 30% have been achieved.
- How are the capabilities of grid analyzed with regards to ability to accommodate various levels of variable generation?
- What kinds of solutions can be used to accommodate higher levels of variable generation?

WORKSHOP AGENDA

- The first session : The status of and approaches adopted by countries with high wind power installations: China, USA, India and Australia.

- The second session : Long-term strategic system-wide analysis to determine the requirements in order to achieve higher penetration of variable generation.
  - What is the acceptable level of penetration of wind power into a grid?
  - What factors determine the level of penetration ?
  - Why are some grids able to absorb higher percentage of energy from wind?
  - How can the level of penetration of wind power be increased?
  - What is the cost of higher levels of penetration of wind?

WORKSHOP AGENDA

- The third session : Grid code for interconnecting variable generation. Gird codes in USA and China will be summarized.
  - What are the requirements to make wind power plants grid friendly?
  - What power quality issues must be addressed by wind energy?
  - What types of data should the wind plants provide to dispatch center

- The fourth session : System impact studies of wind power.
  - the impact on reliability, safety and stability of the power system
  - What is the impact on system stability due to wind power?
  - What is the impact of rapid ramping up or down of wind energy generation on the grid?
  - How is the power flow in a grid impacted with high wind energy production and low demand?
  - What changes must be made to the grid to accommodate wind energy?

WORKSHOP AGENDA

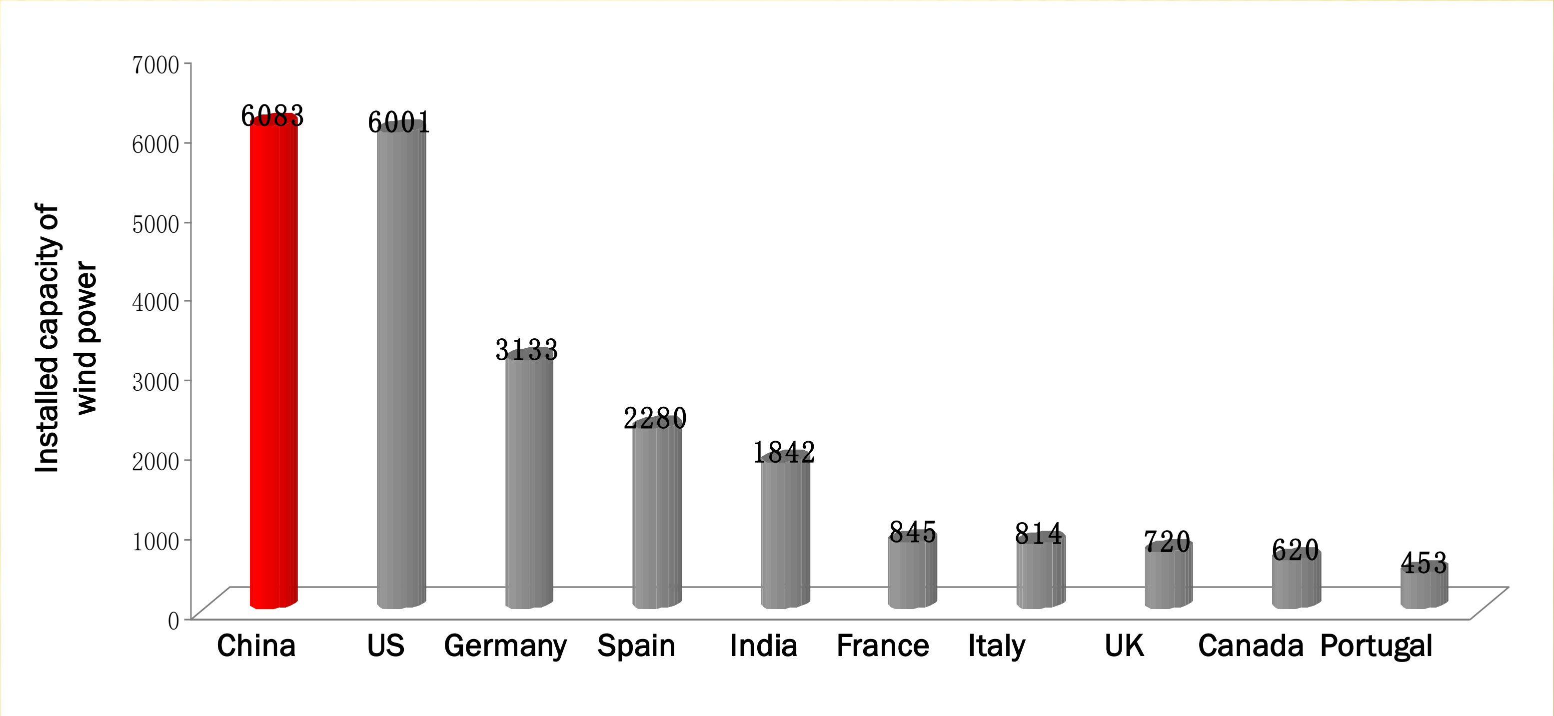
- The fifth session : Dispatching of Wind Power.
  - Is wind energy dispatchable ?
  - What methods are used by grid operators to schedule wind into in 24-hour, and hour-to-hour time window? How well can wind energy be forecasted?
  - How much spinning reserves are needed to support variability of wind energy?
- The sixth session,: emerging technologies
  - Role of storage technologies
  - wind energy forecasting
  - advances in control technologies.

WIND POWER : PERCEPTIONS & MYTHS

- Wind power increases the variability of the power system and may result in large fluctuations in the net demand. (Consumer demand – wind output).
- This requires balancing generation and higher level of spinning reserve.
- The thermal plants may have to be operated below their rated output and at lower than maximum efficiency levels.
- Efficiency penalty can be as high as 20%.
- There should be mechanism for compensating the utilities and conventional generators for this additional cost.

Status of Wind Power Development

Grid Connected wind power capacity in PRC and USA has reached 60 GW and 18 GW in India. China has also more than 5 GW waiting for grid connection.

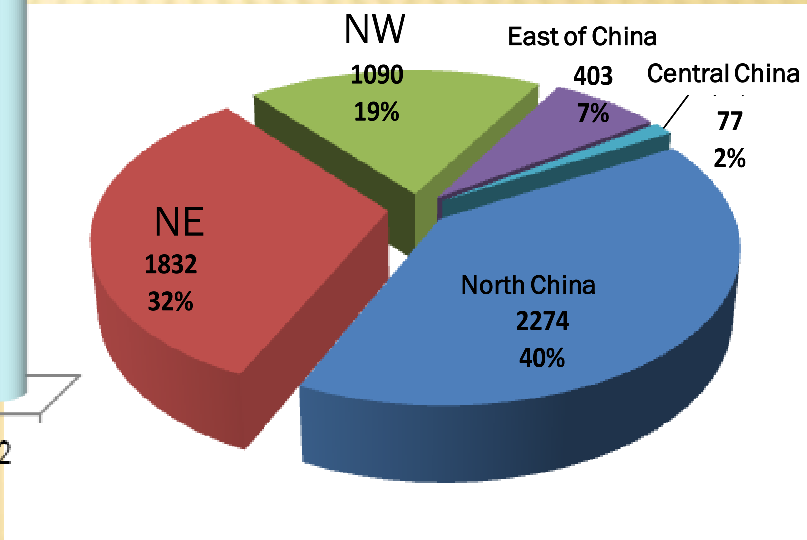


Comparison of Top 10 Countries in Wind Power Installed Capacity

Wind Power Development in China

China's Wind power capacity increased from 2 GW in 2006 to 60 GW in 2012 and produced 97 GWh.

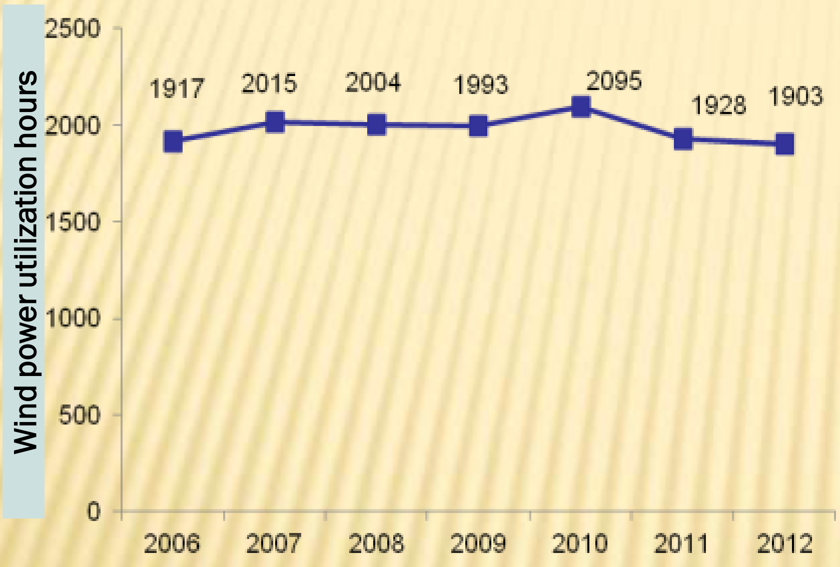
China's Wind Power Integration Capacity from 2006 to 2012 (10MW)



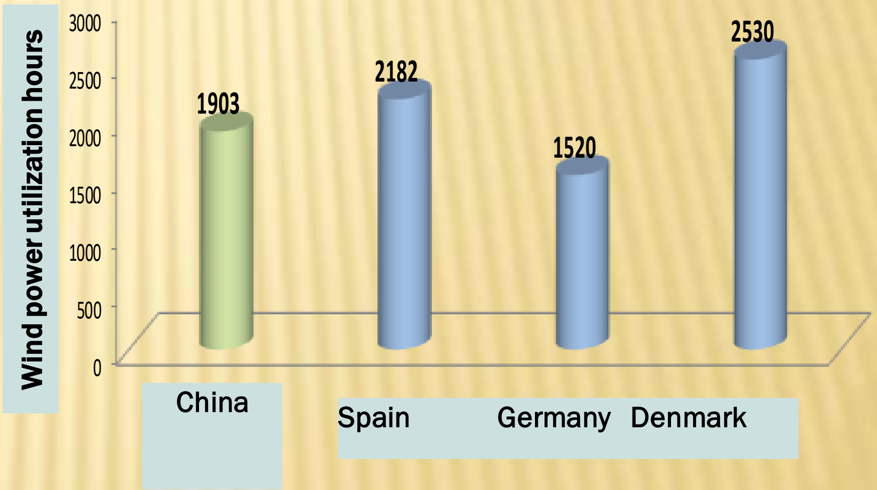
Wind Power Integration Capacity by Region in 2012 (10MW)

Wind Power Utilization in China

Wind power utilization hours in China is on a declining trend and is significantly less than European Countries. This implies increasing levels of wind power curtailment.



Wind power utilization hours in China



Comparison between domestic and international wind power utilization hours in 2012

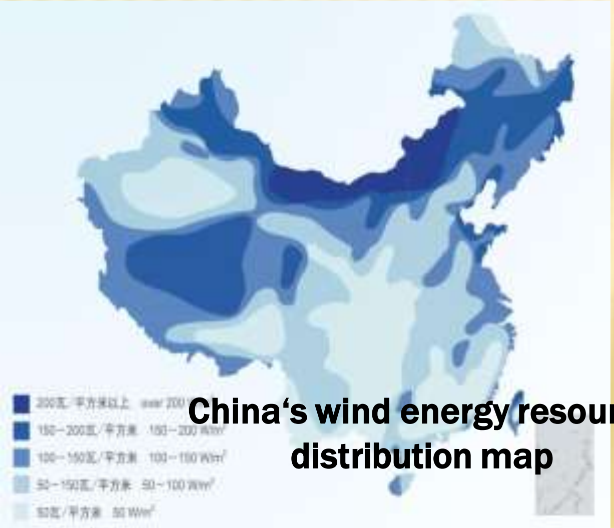
Wind energy resource and power load distribution

China‘s onshore wind energy resources are mainly in the “Three Norths” (Northwest, Northeast & North China).

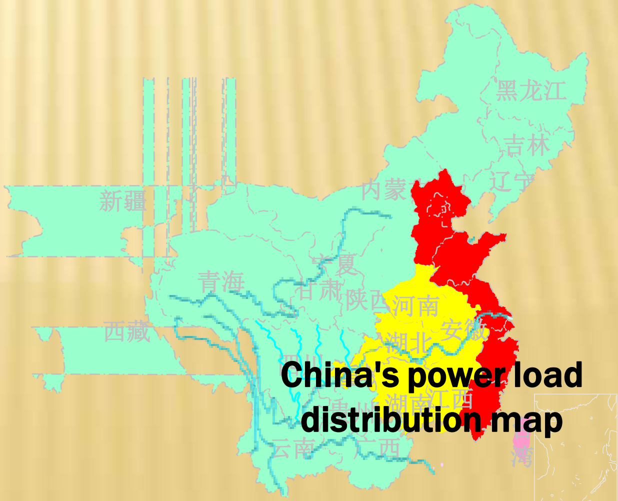
As of 2012 installed wind capacity in this region is 50 GW.

Contribute to 80% of installed capacity and is planned to reach 79 GW by 2015 and 164 GW by 2020 .

Two thirds of the power load in China is concentrated in the eastern and central regions.



China‘s wind energy resource distribution map

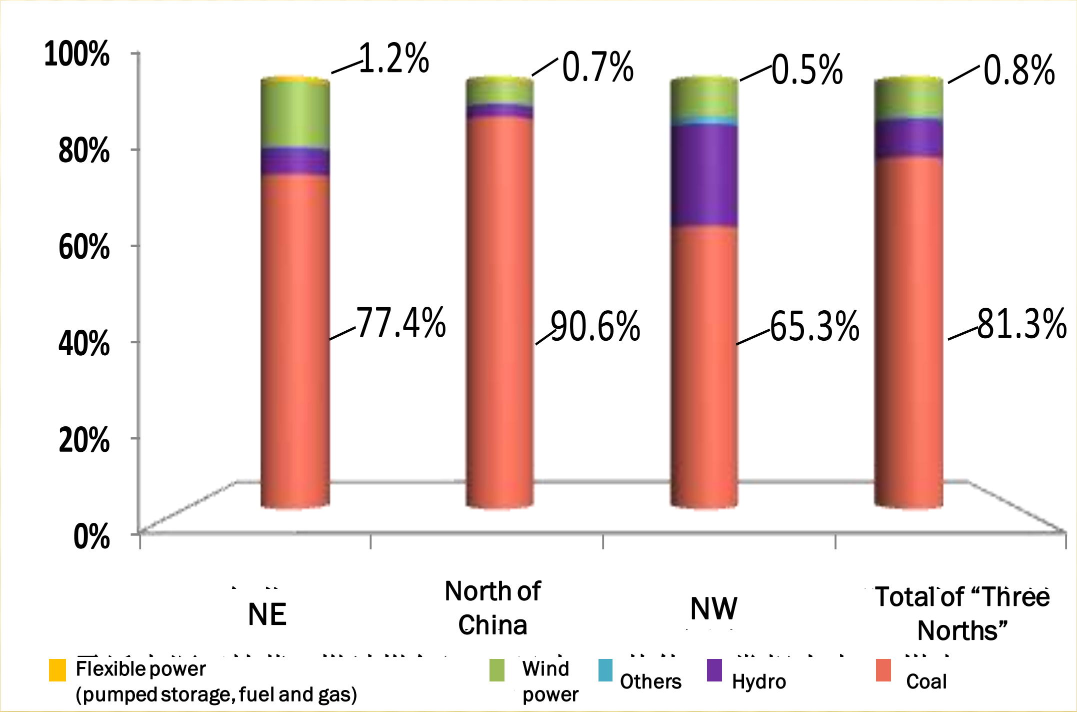


China's power load distribution map

Availability of Flexible Generation Sources

Wind power require flexible generation sources to balance out the intermittency.

In nothern China, coal power contribute over 80% of capacity and must run CHP plants are as high 60 %.



Power mix in "Three Norths"

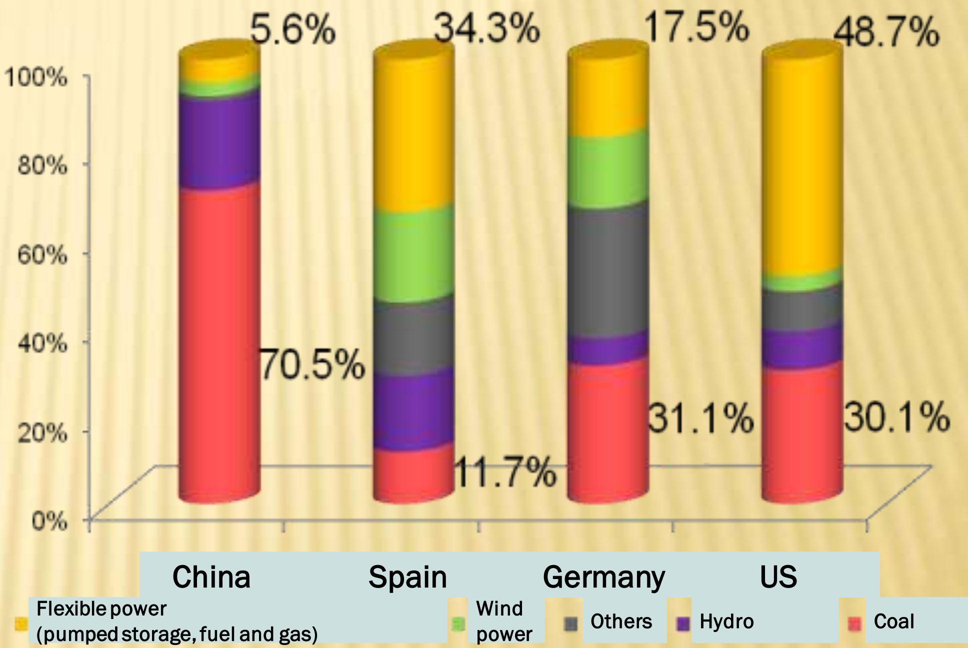
	Proportion of coal-fired thermal power	Proportion of coal-fired heat-supply units in all thermal units
Jinlin	69%	88%
Western Inner Mongolia	78%	57%
Heirongjiang	80%	68%

Availability of Flexible Generation in other leading wind power markets.

Flexible Generation in USA and Spain are 34 % and 49% of installed capacity.

Equal to 14 times and 1.7 times of Wind power Capacity.

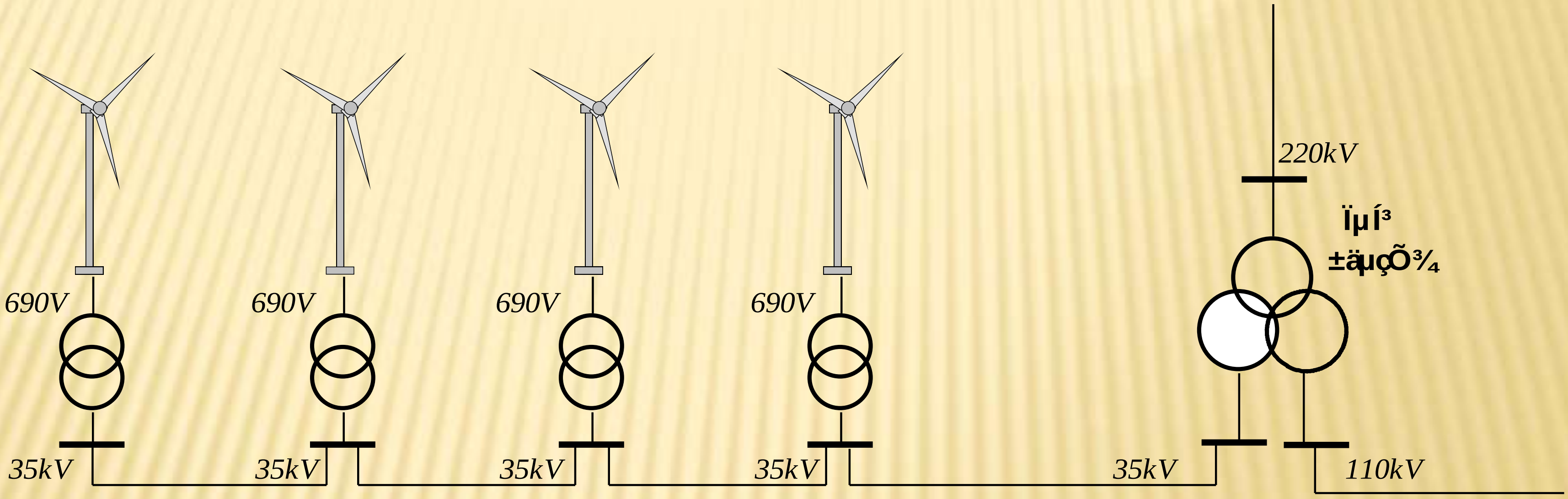
In China it is 1.1 times wind power capacity.



Comparison Diagram of Power Mix

WIND POWER DEVELOPMENT MODELS

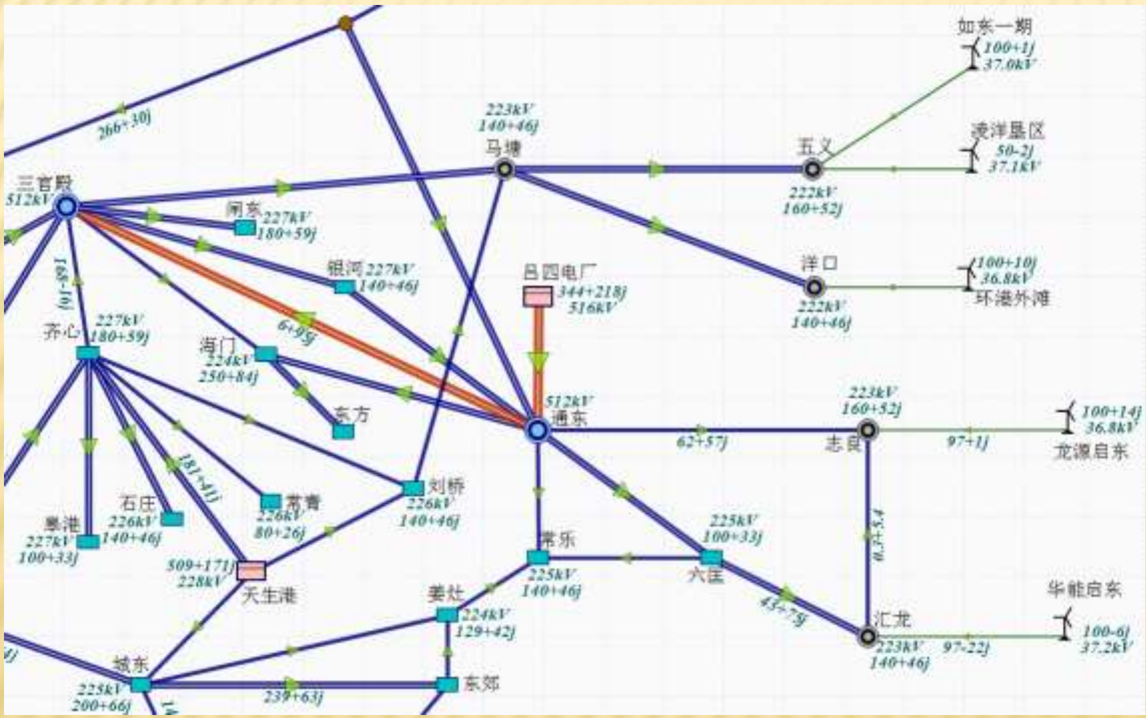
- <u>***Distributed Wind Farm***</u>

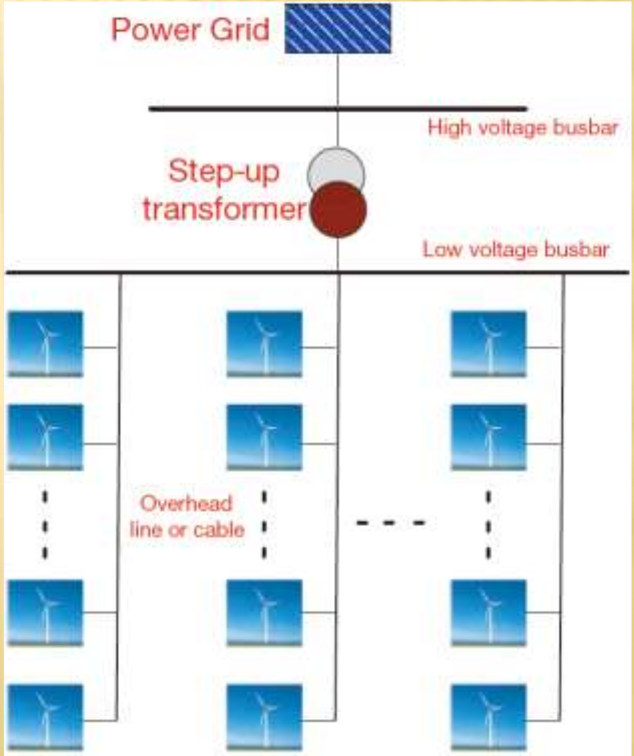


- ***Connected to local substation through 10-35kV line, long distance power transfer is not necessary.***
- ***Total installation capacity is normally less than 20MW at single PCC.***
- ***Covers a relatively small part of wind power in china.***

MODELS FOR WIND POWER DEVELOPMENT

- ***Large Scale Wind Farms （ 100's of MW Range)***

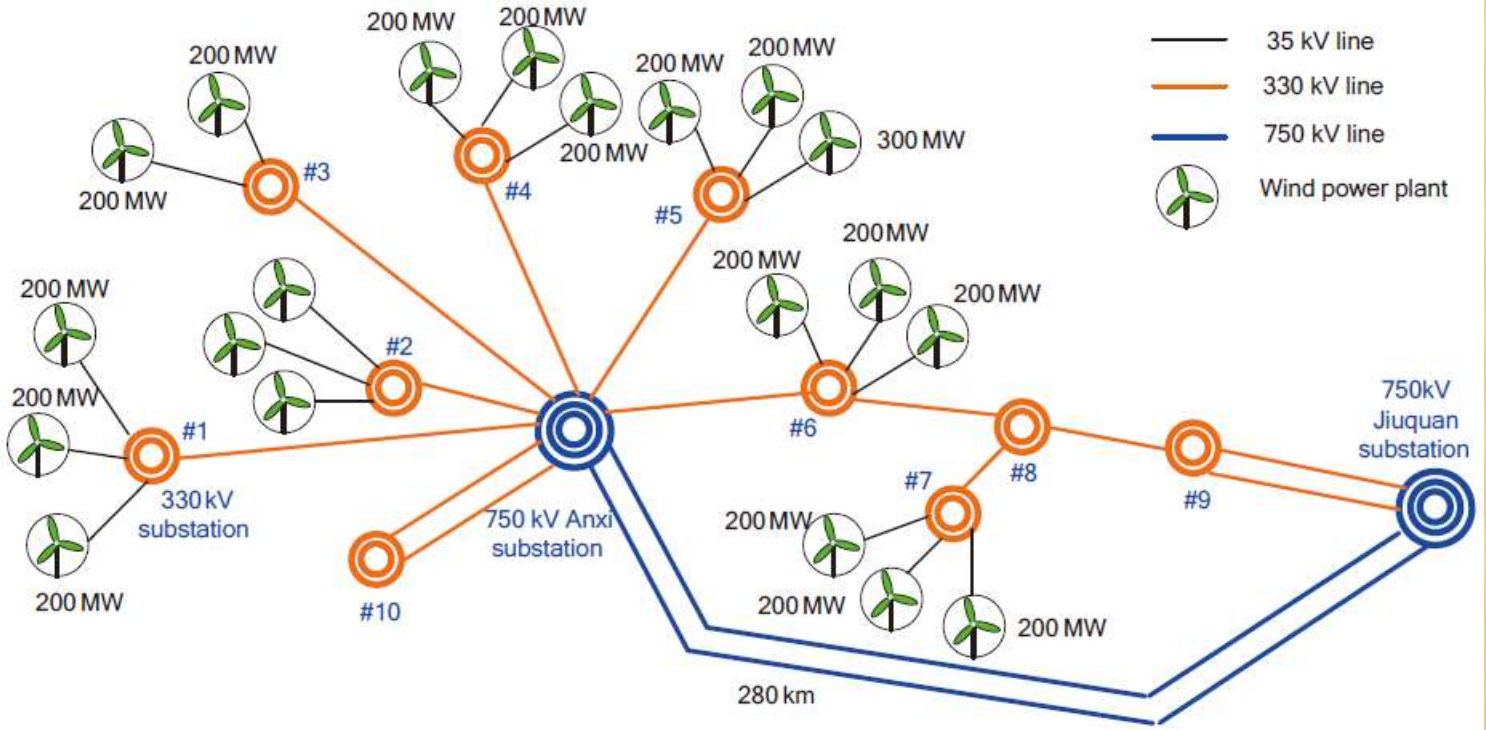




- ***Each wind farm 50-200MW （50-200MW）***
- ***Connected to the grid through 110-220kV lines***
- ***Electricity are consumed inside a province.***

MODELS FOR WIND POWER DEVELOPMENT
T

- **_Bulk Wind Power Basins (GW Scale)_**

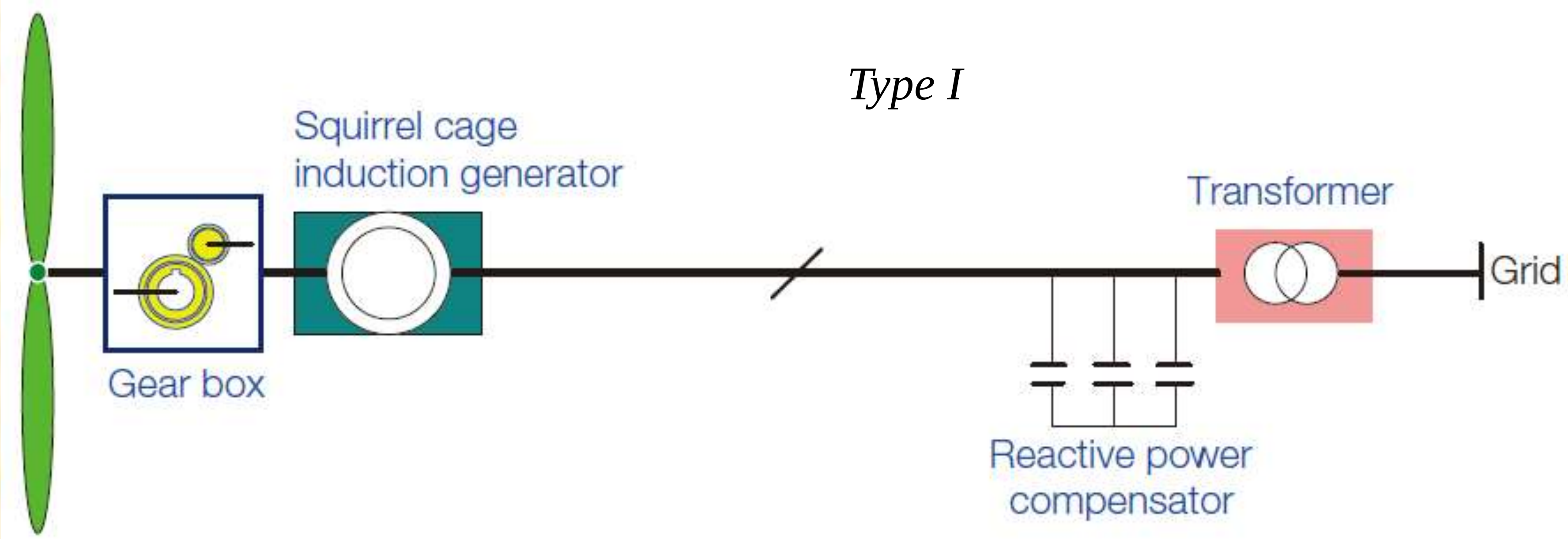


- ***Several wind farm connected collection substation, Wind power are transferred through UHV or EHV.***

DIFFERENT TYPES OF WIND TURBINES

- ***Type I Wind Turbines***

Fixed Pitch (speed) Squirrel Cage Induction Generator



- *Early Type, rarely seen in new installed wind turbines, but still in operation.*
- *Most of older wind turbines (before 2005) belong to this type.*
- *Always consume reactive power and reactive consumption increases with active power output.*
- *Fixed speed and creates high mechanic*al stress on gear box and rotor.

DIFFERENT TYPES OF WIND TURBINES

Type II Wind Generator

Variable Speed variable resistance Rotor Induction Generator

By varying the rotor resistance and rotor voltage and active power output can be controlled. However range of active power control and speed of active power control is limited.

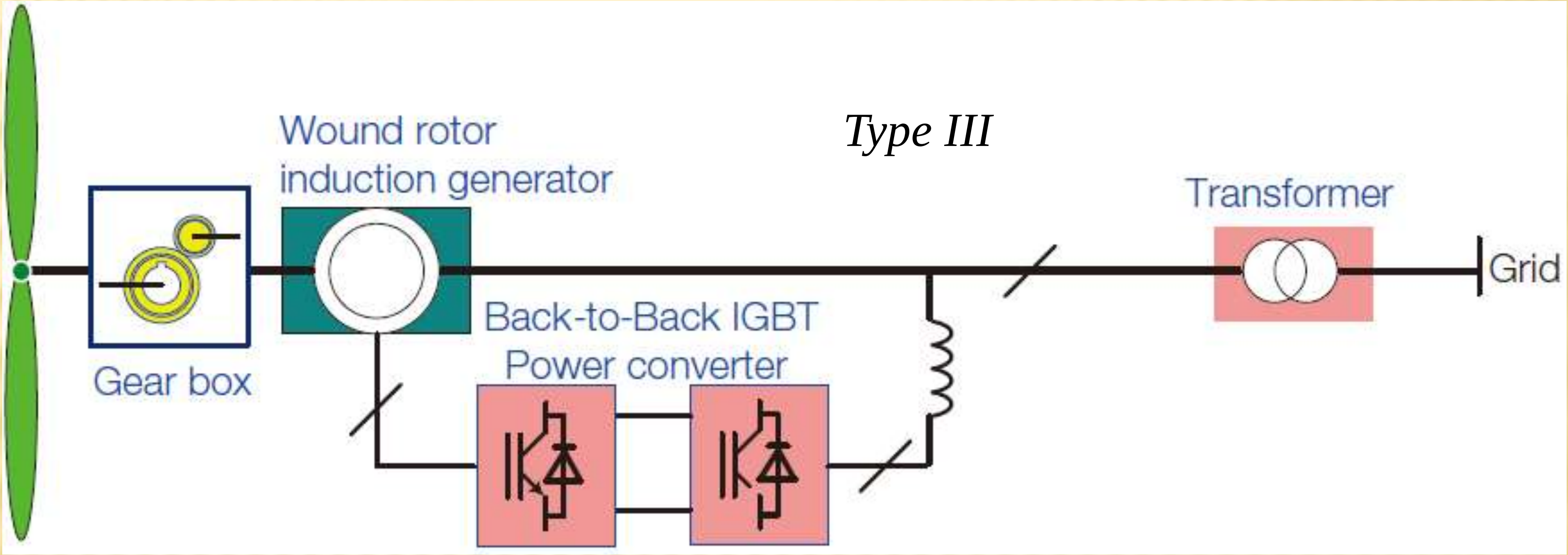
Enable limited speed control (+ or – 15%) of wind turbines and reduces the mechanical stresses.

Does not provide reactive power control and requires reactive power compensation is Type 1 generators.

DIFFERENT TYPES OF WIND TURBINES

Type III Wind Generator

Doubly Feed Asynchronous Induction Generator (DFIG/DFAG)

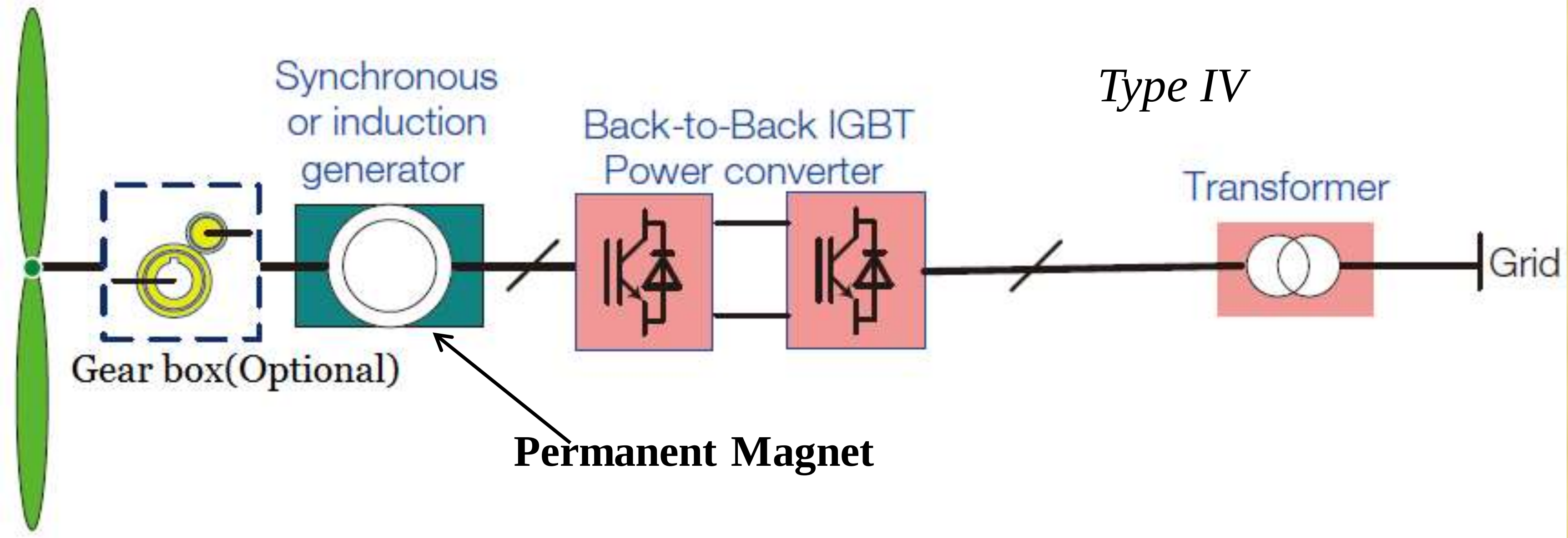


Most popular types of wind turbines at present. (75 % market share). Part of stator output (30%) is fed back to the rotor through a power converter to the rotor. The voltage and frequency of rotor circuit can be controlled by power electronics. This enable the control of both active and reactive power output.

DIFFERENT TYPES OF WIND TURBINES

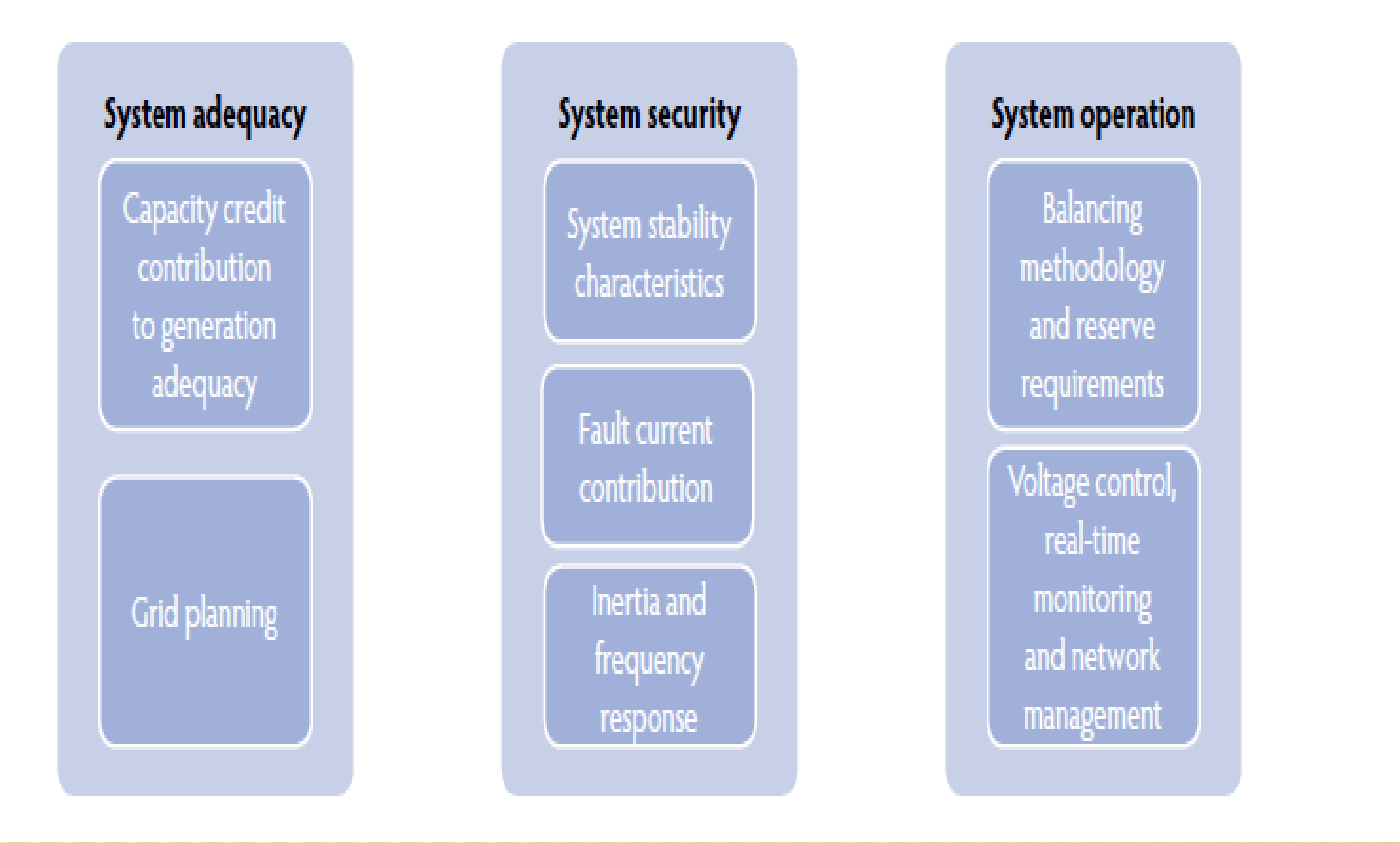
- ***Type IV Wind Turbines***

Permanent Magnet Synchronous Generator(PMSG) with Full rated Converter



- *Increasing market share and covers about 25% of new installed wind turbines.*
- *As the wind turbine is completely decouple from the grid, full control over active power and reactive power can be achieved through power electronics. Can meet most of the requirements of grid codes.*

SPECIFIC ISSUES WITH WIND POWER INTEGRATION



ENERGY & CAPACITY ADEQUACY

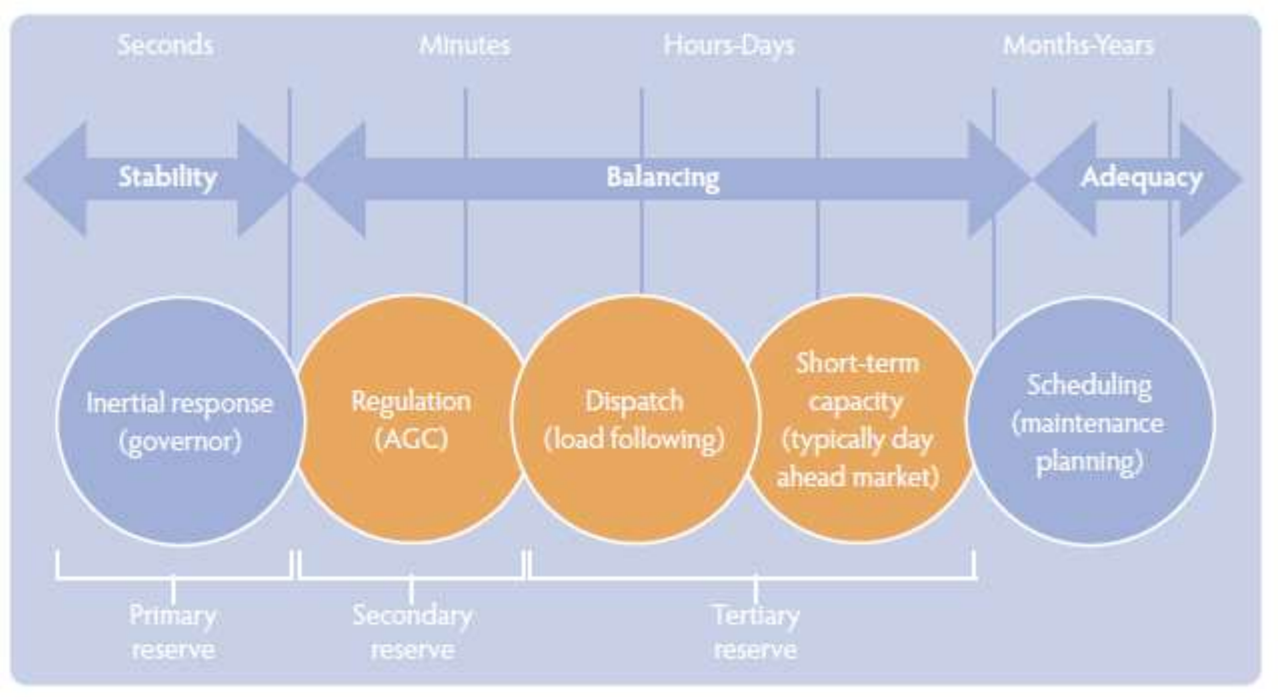
- The Power System must have adequate generation capacity to meet the demand at all times.
- Probabilistic methods have to be used to compute the firm generation capacity of wind power plants due to the intermittency.
- This depend on the correlation of the wind power output and peak demand.
- Firm capacity of wind power is usually about 10% of the name plate capacity.
- The contribution of Wind power to energy adequacy (TWh) is much greater than its contribution to capacity adequacy.
- If wind power is replacing conventional plants, more wind capacity than the replaced conventional plant is required to maintain the same level of reliability

GRID PLANNING & GRID ADEQUACY

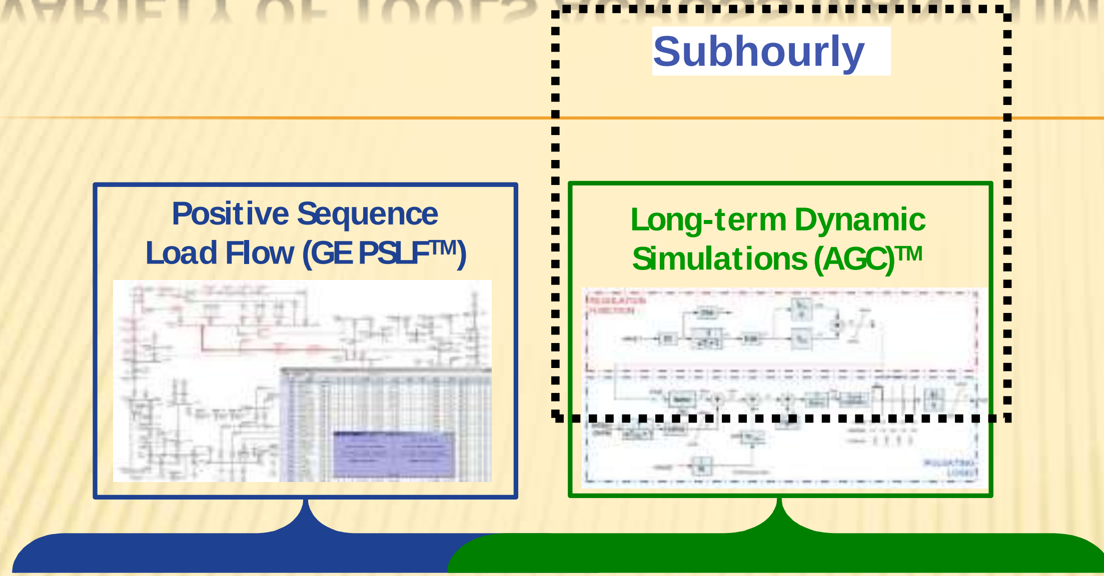
- Ability to deliver energy generated to demand centers subject to N-1 contingency requirement.
- Wind power is usually located far from load centers and at the end of transmission network. Some times wind plants are connected to medium voltage network.
- Wind plants have a shorter construction time than the time taken to build new transmission lines. Transmission planning need to take into account this to avoid delays in connecting newly built wind plants.
- Wind plants may alter the power flows in the network and may cause over loading of certain lines and substations.
- Load flow analysis need to be undertaken to identify potential bottlenecks and network need to be augmented if necessary. Smart Grid technologies and FACT Devices (Power Electronic) can be used to address this issue.

BALANCING GENERATION REQUIREMENT

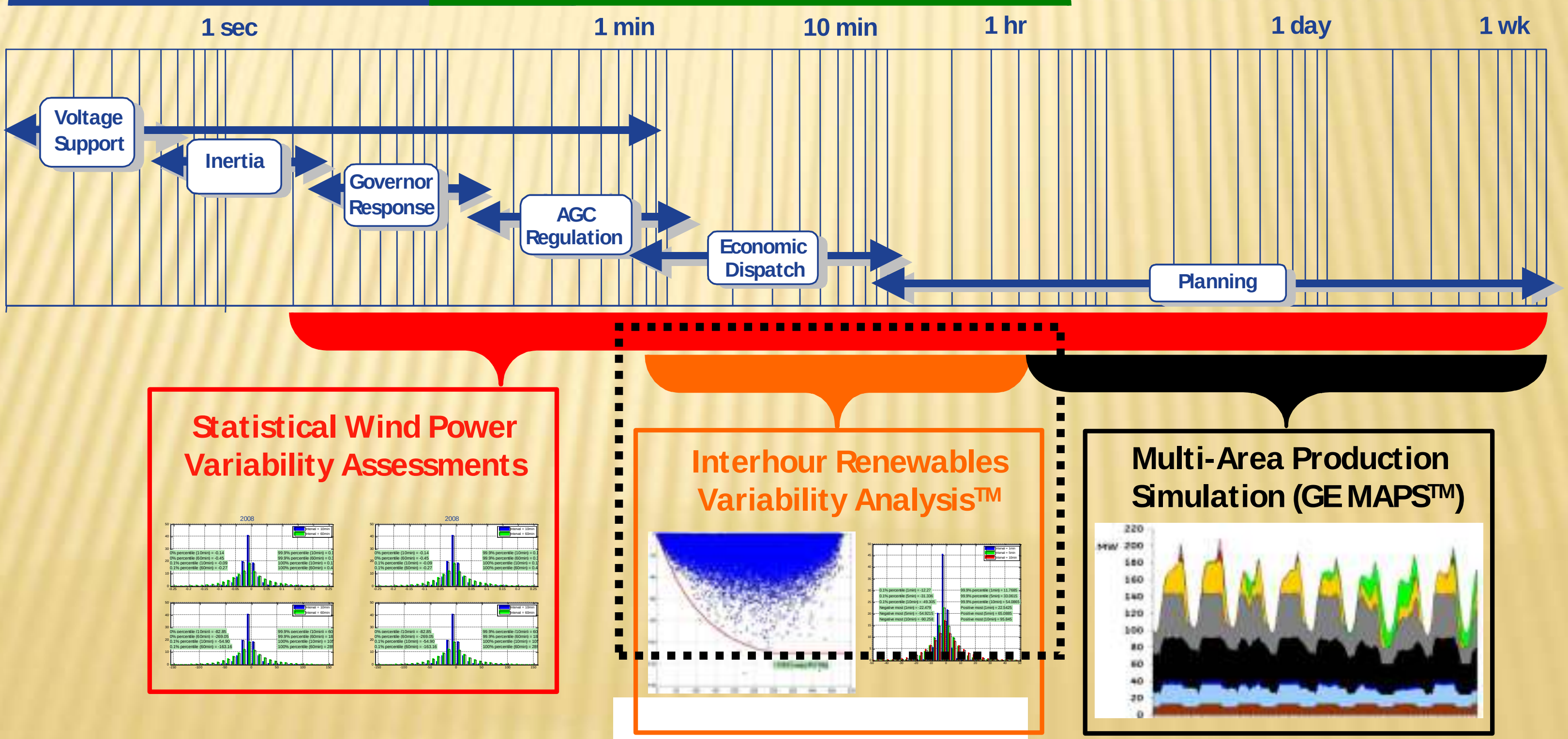
- Higher wind penetration levels result in bigger fluctuation in net demand and require larger amount of balancing generation capacity.
- Balancing generation capacity is provided by power plants which are capable of rapidly changing their output (ramping) and fast start up. (gas turbines & hydro)



A VARIETY OF TOOLS ACROSS MANY TIMESCALES…



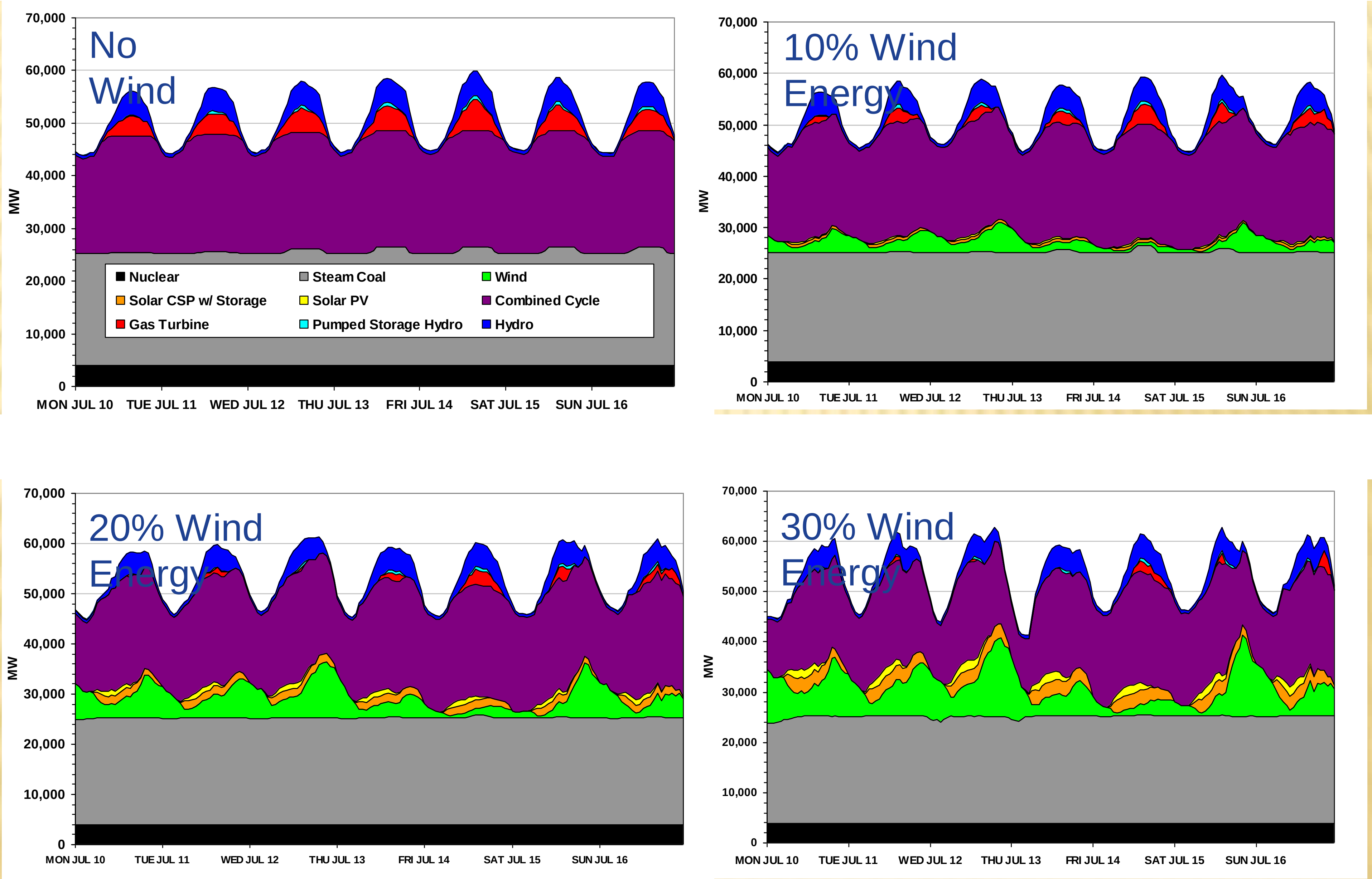
These tools are used together to identify, assess and propose solutions for managing the wind integration challenges



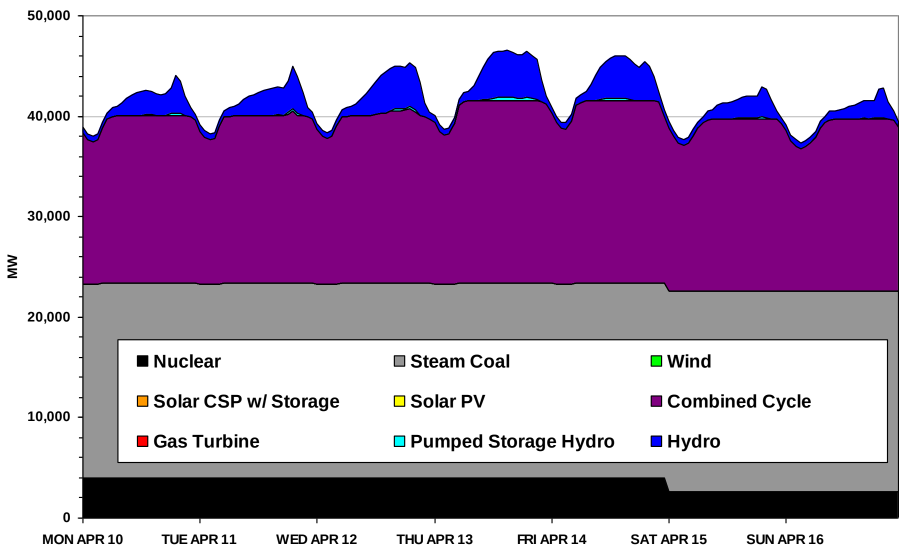
BALANCING GENERATION REQUIREMENT

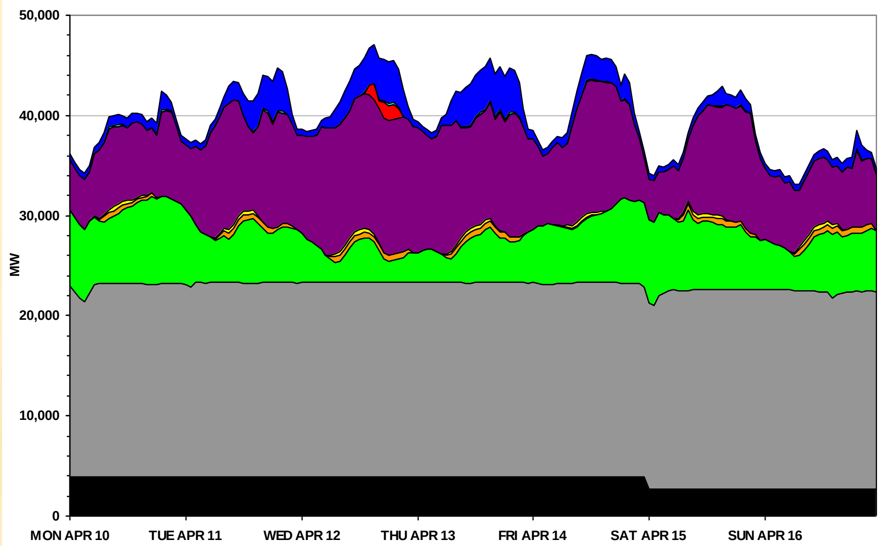
- Fluctuations in wind turbine output are smoothed out when large number of turbines are aggregated as a wind power plants (from seconds to minutes) and as wind power basins of > 1 GW (from minutes to hours) .
- Balancing generation is provided by ;
  - Automatic Generation Control (AGC) { minutes}
  - Dispatching & Load Following { 30 minutes to hours }
  - Short term capacity contracting { day ahead }
- Wind power prediction can reduce the balancing generation requirement at more than 30 minutes.
- Balancing generation requirement is usually about 20% of wind power capacity and about 5% should be provided by AGC.

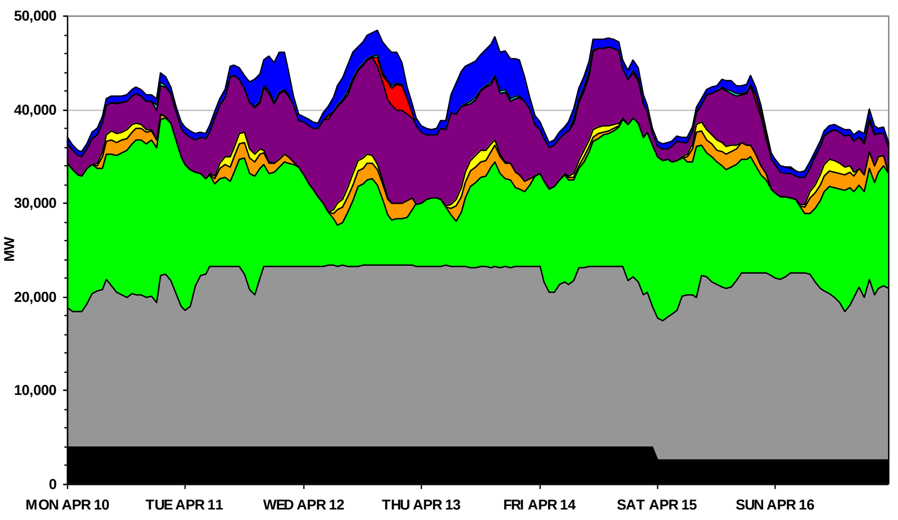
Week of July 10th *(Peak-Load Season)*

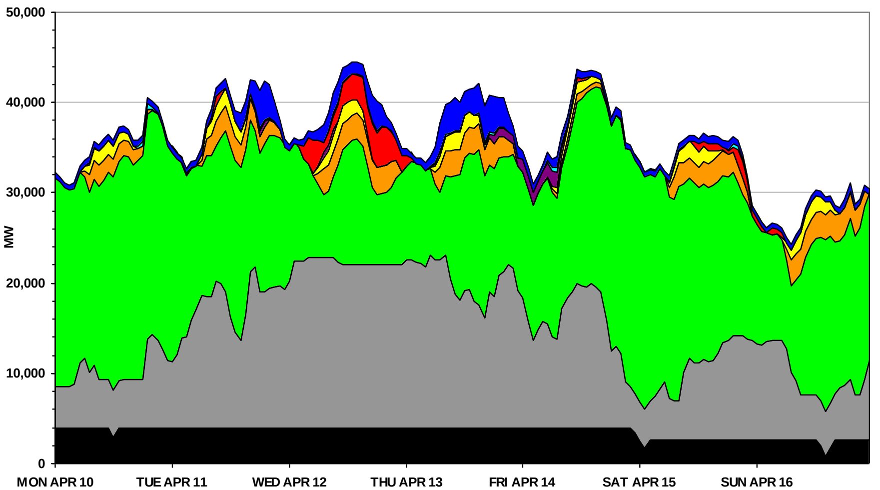


Week of April 10th *(Loads are lower, winds are higher)*









GRID CONNECTIVITY REQUIREMENTS FOR WIND TURBINES : GRID CODE?

- Reactive Power: +/- 0.95 pf @ POI
- Voltage Control: required, with ISO voltage set points
- Frequency Tolerance: +/- 3 hz continuous
- Voltage Tolerance (Low Voltage Ride-Through): ZVRT
- Models and Data: required cooperation
- Telemetry and Metering: specific minima
- Power Quality: IEEE 519 for Harmonics and Flicker
- Frequency Control: debate just starting

Chinese Grid Code for Wind Power Connection


GB

中华人民共和国国家标准

GB/T 19963

代替 GB/Z 19963-2005

风电场接入电力系统技术规定

Technical rule for connecting wind farm to power system

2011-12-31 发布　　2012-06-01 实施

中华人民共和国国家质量监督检验检疫总局　发布

- Main aspects：
  - Wind power forecast
  - Active power control
  - Reactive Power capacity
  - Voltage control
  - Low Voltage Ride Through Capability
  - Grid compliance test of Wind Turbines

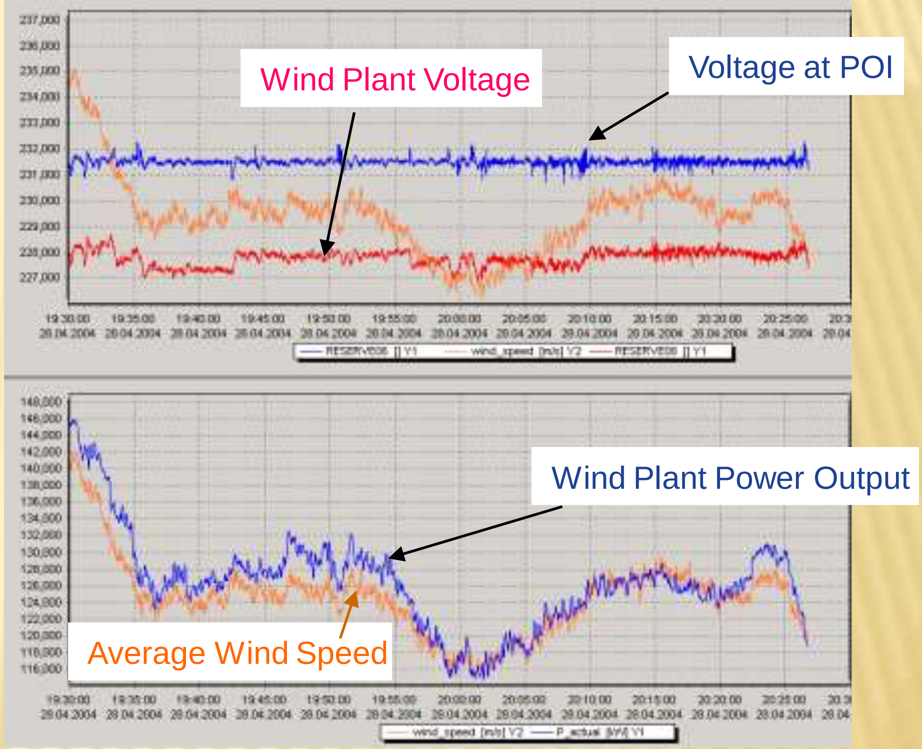
VOLTAGE CONTROL

- Reactive power supply at key points of the transmission network is required to maintain the voltage profile within acceptable values.
- Older generations of Wind turbines have limited capability of providing reactive power and voltage support compared to conventional thermal plants.
- Additional reactive power sources (i.e. static VAR compensators) may be required for systems with high wind penetration.
- Some of the conventional plants may have to be operated as reactive power sources even when they are not providing active power.

VOLTAGE CONTROL

- Regulates Grid Voltage at Point of Interconnection
- Minimizes Grid Voltage Fluctuations Even Under Varying Wind Conditions
- Regulates Total Wind Plant Active and Reactive Power through Control of Individual Turbines

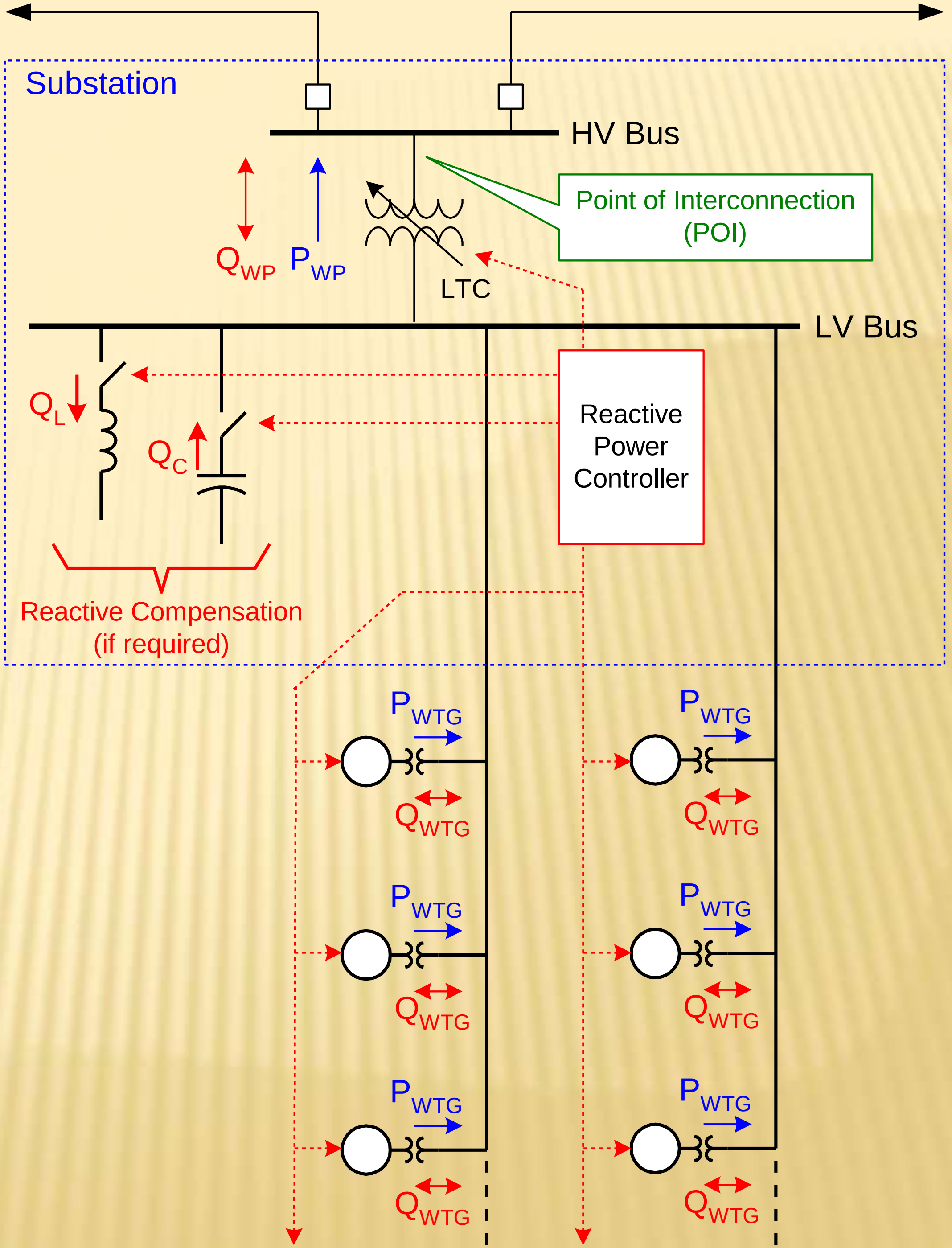
Actual measurements from a 162MW wind plant



Voltage and Reactive Power Regulation Like A Conventional Power Plant

Plant Level Control System

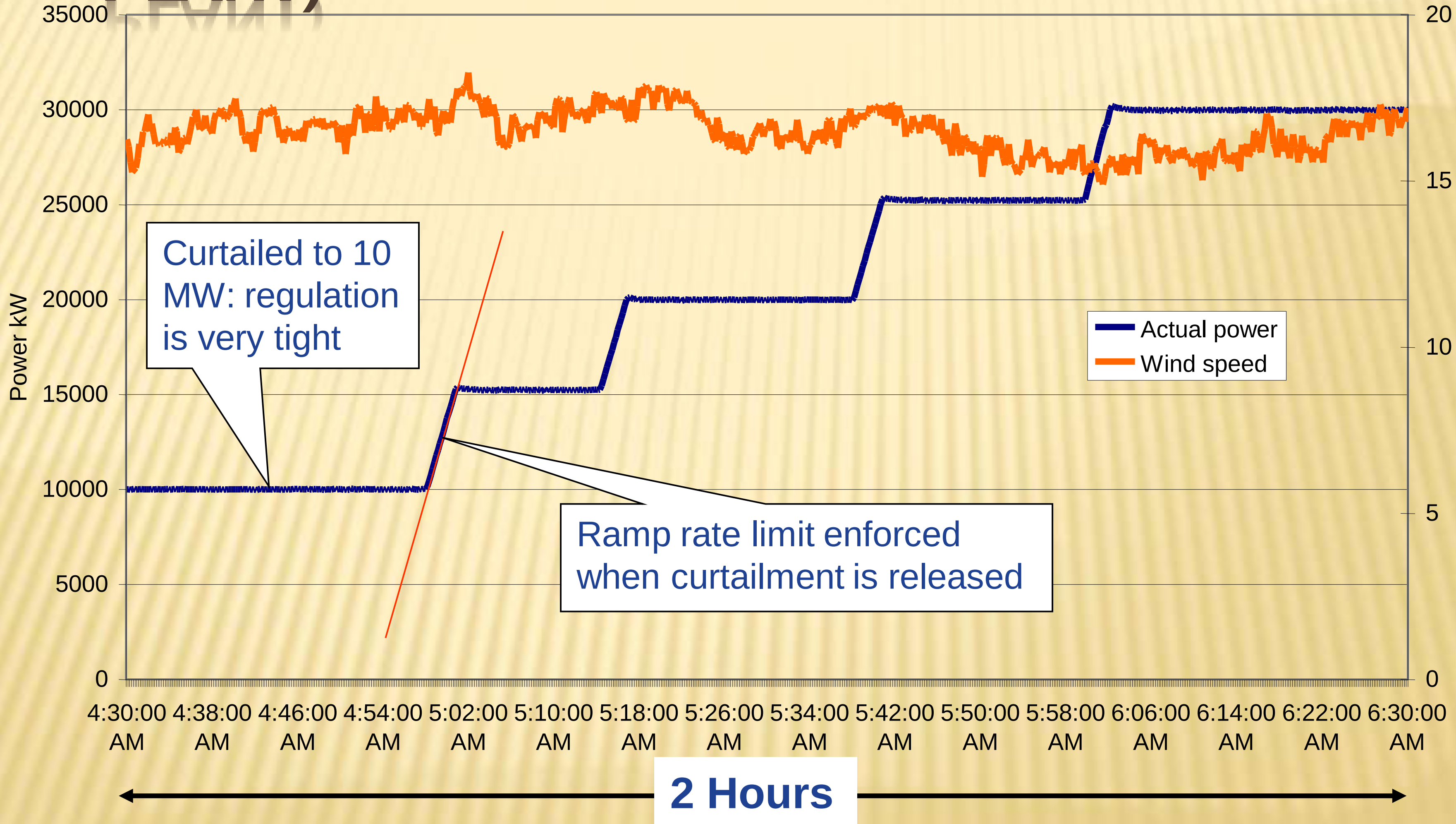
- Coordinated turbine and plant supervisory control structure
- Voltage, VAR, & PF control
- PF requirements primarily met by WTG reactive capability, but augmented by mechanically switched shunt devices if necessary
- Combined plant response eliminates need for SVC, STATCOM, or other expensive equipment
- Integrated with substation SCADA



ACTIVE POWER CONTROL CAPABILITY

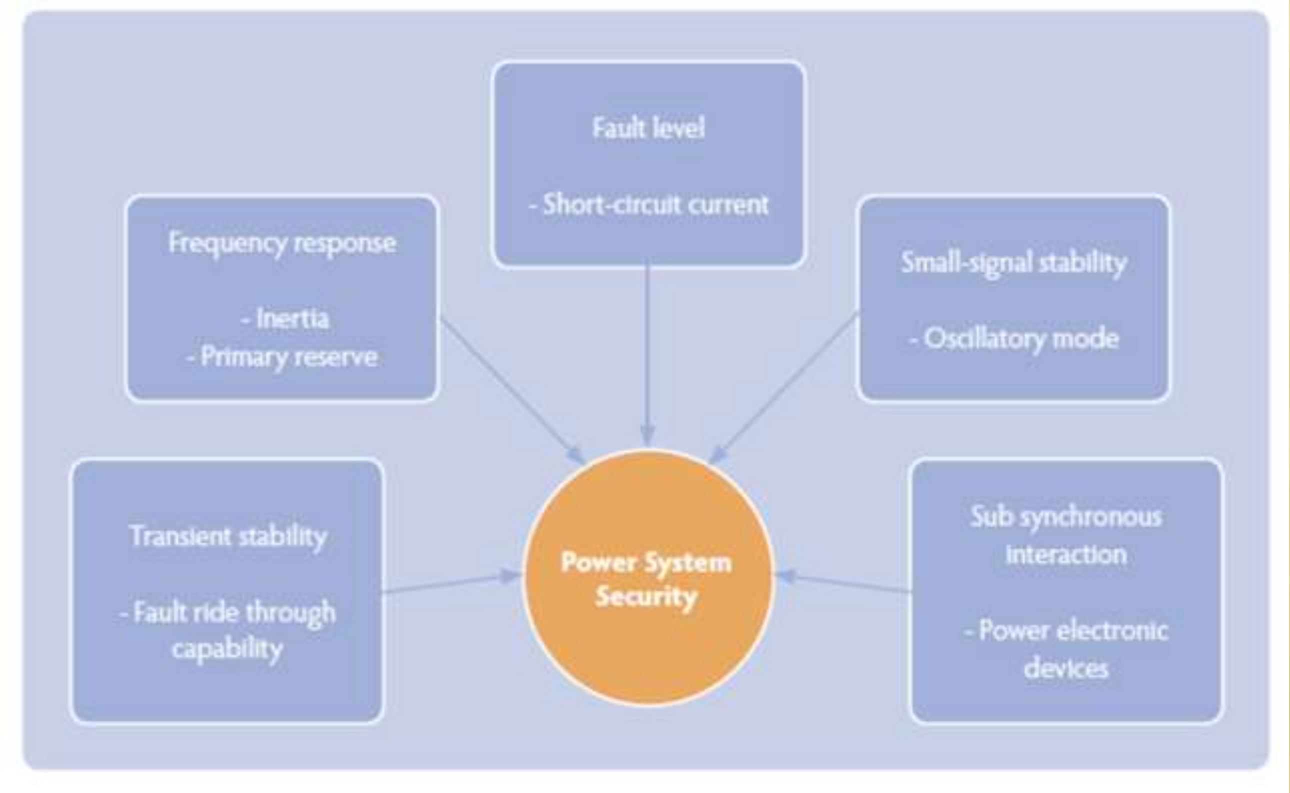
- Advanced plant controls power response to variations in wind and system frequency
- **Power Ramp Rate** – Limits the rate of change of Active power from variations in wind speed
- **Startup and Shutdown** – Control the insertion and removal of large power blocks
- **Frequency Response / Droop** – React to changes in system frequency

CURTAILMENT AND RAMP EXAMPLE (30 MW PLANT)



POWER SYSTEM SECURITY & WIND PENETRATION

- Power system security is ability to regain the steady state when subjected to a disturbance such as tripping of major power plant.
- Higher levels of wind power penetration contributes to enhanced power system stability / security concerns as wind turbines have limited capabilities for grid support compared to conventional power plants.

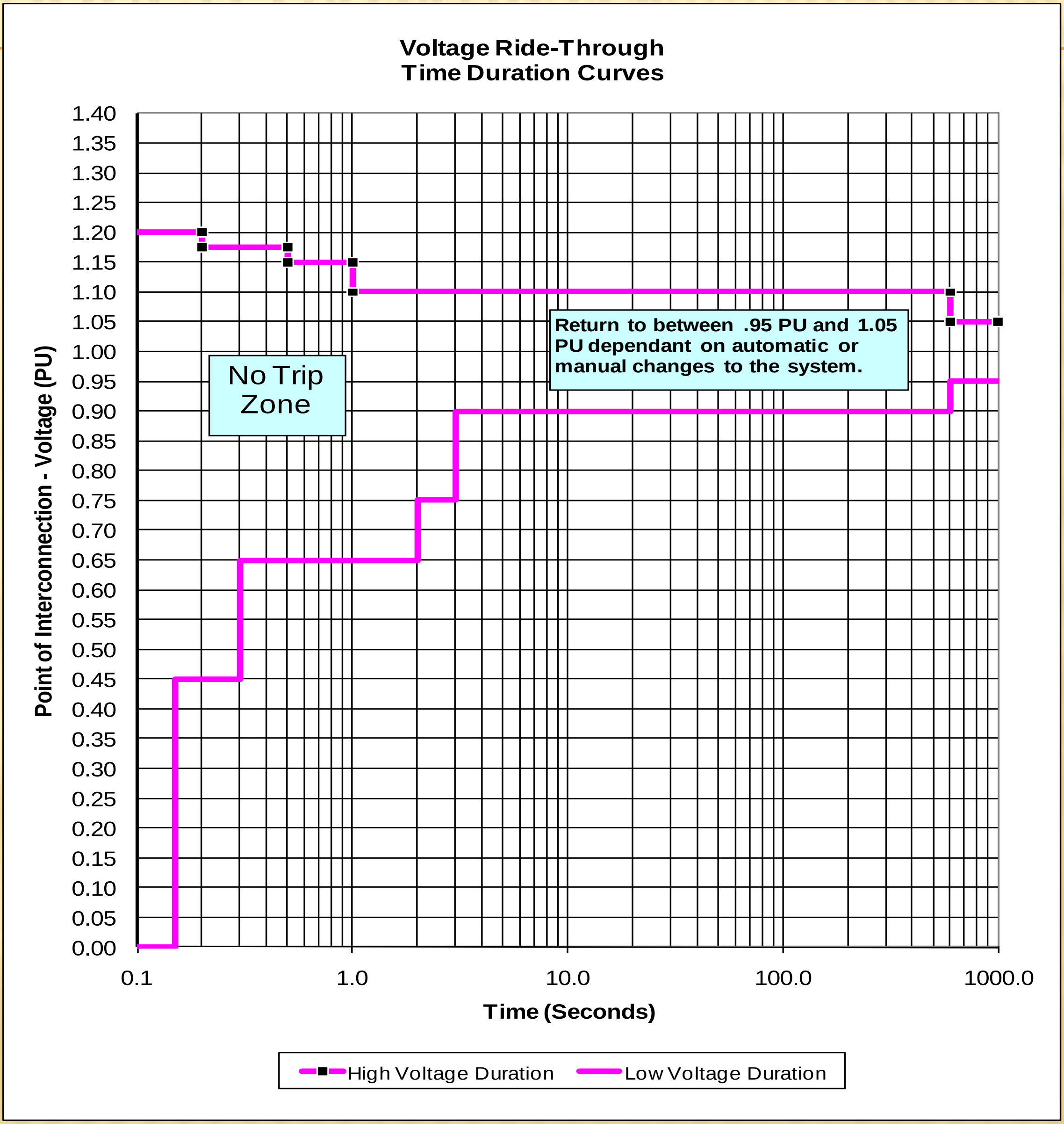


VOLTAGE RIDE-THROUGH CAPABILITY

HVRT DURATION		LVRT DURATION	
Time (Sec)	Voltage (p.u.)	Time (Sec)	Voltage (p.u.)
0.20	1.200	0.15	0.000
0.50	1.175	0.30	0.450
1.00	1.150	2.00	0.650
600	1.100	3.00	0.750
		600	0.900

Generators / Plant must not trip for credible faults inside the zone unless:

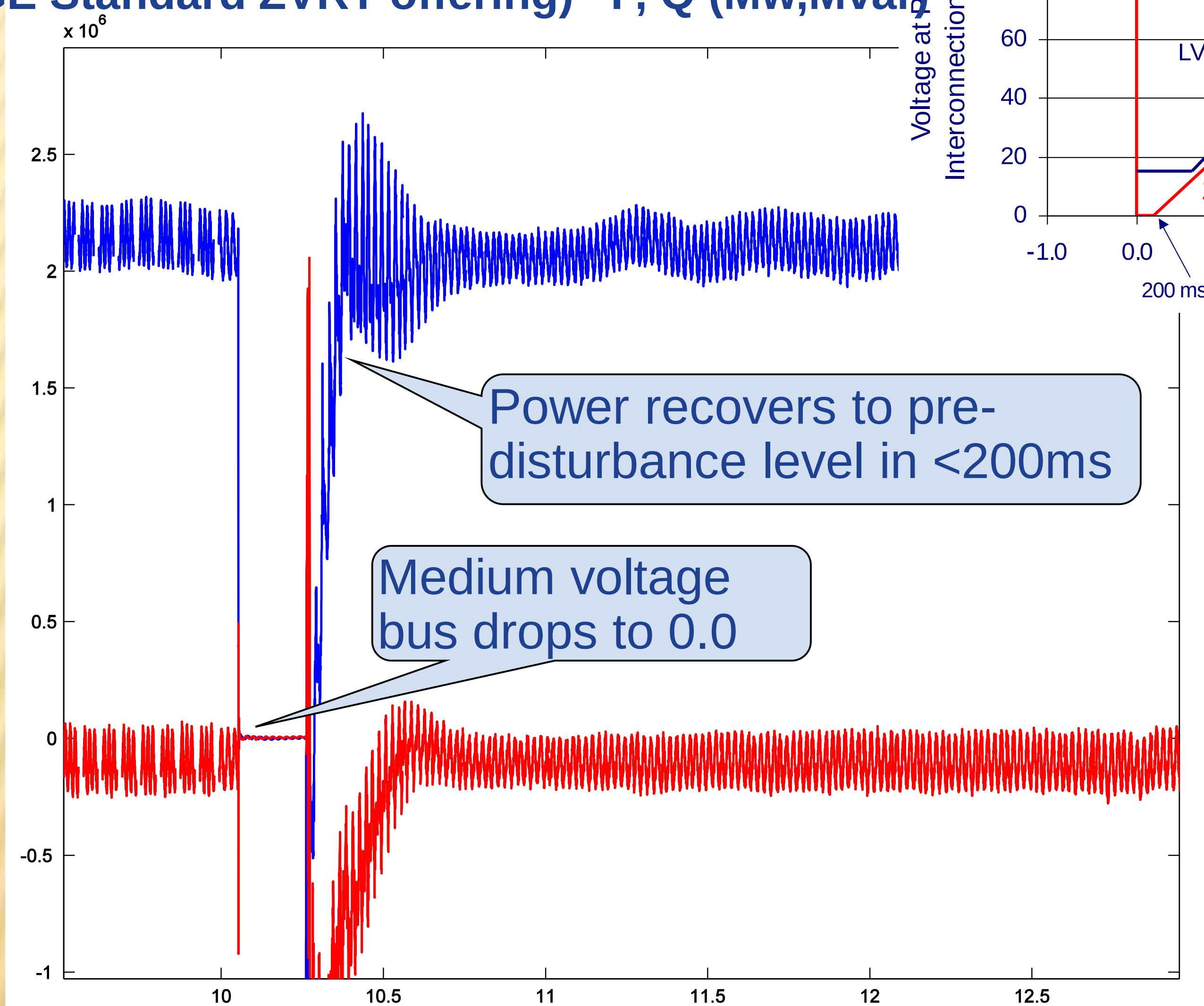
- SPS / RAS requires it
- Generator critical clearing time requires it (synchronous generators)

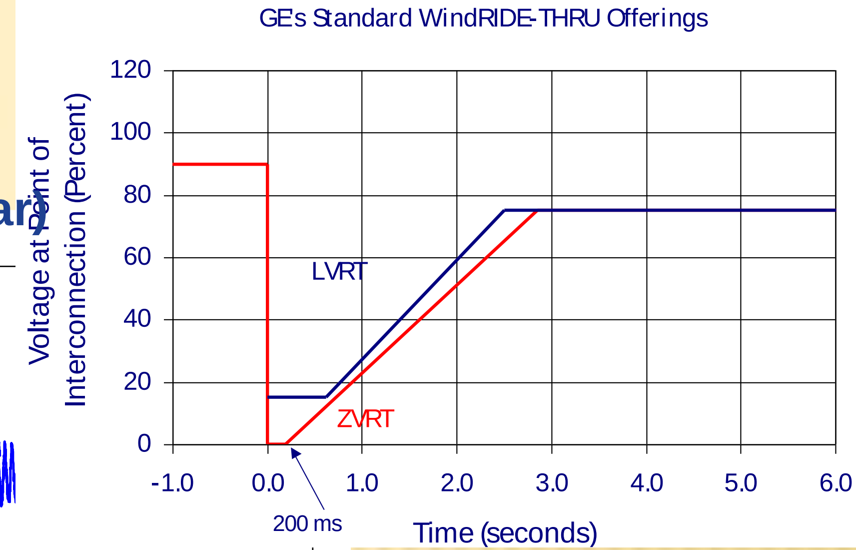


Ride-Thru Capabilities

3-phase zero retained voltage, 200ms fault:

(GE Standard ZVRT offering) P, Q (Mw,Mvar)





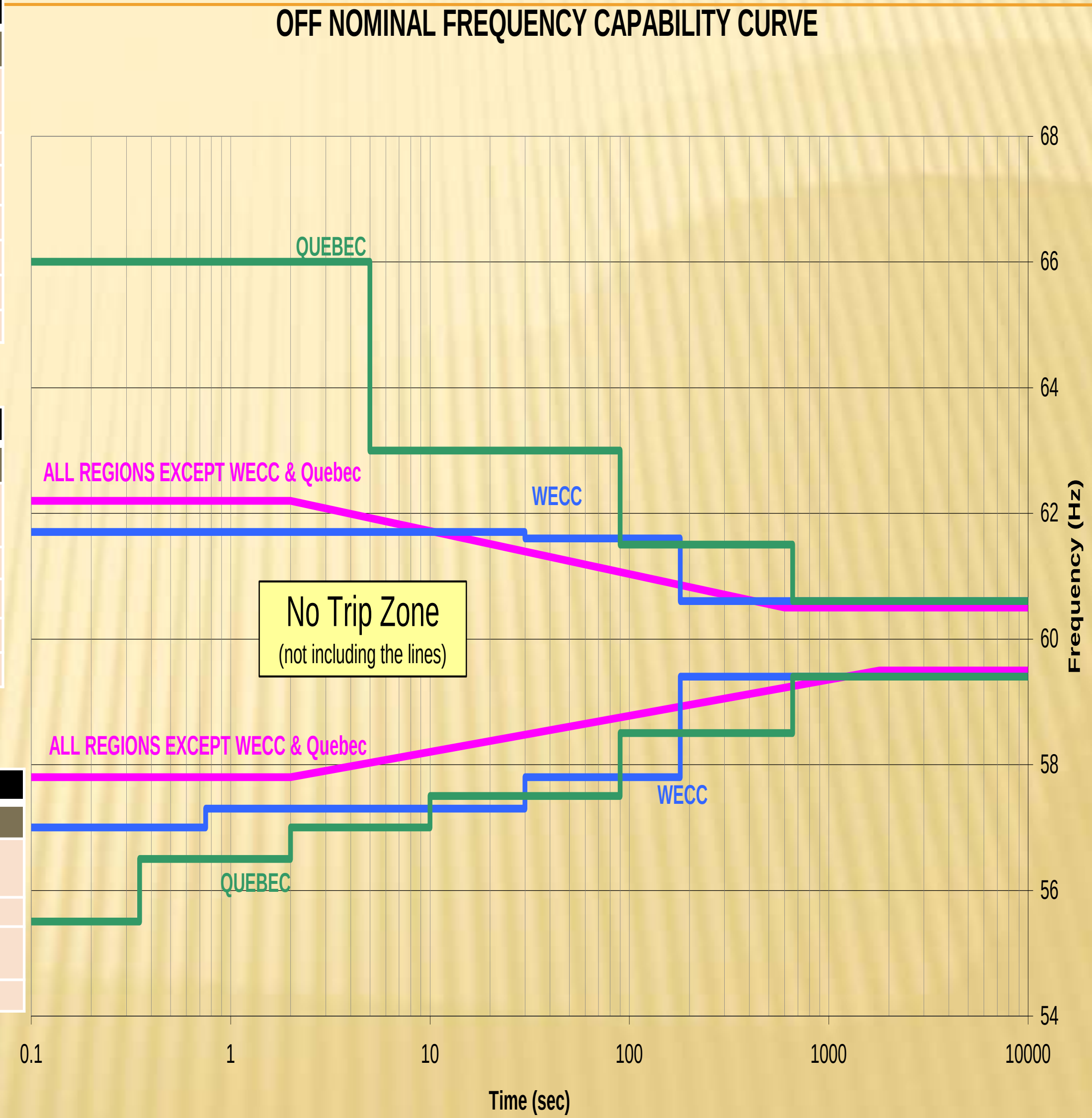
Field Test Results (2.5 unit)

FREQUENCY RIDE THROUGH CAPABILITY

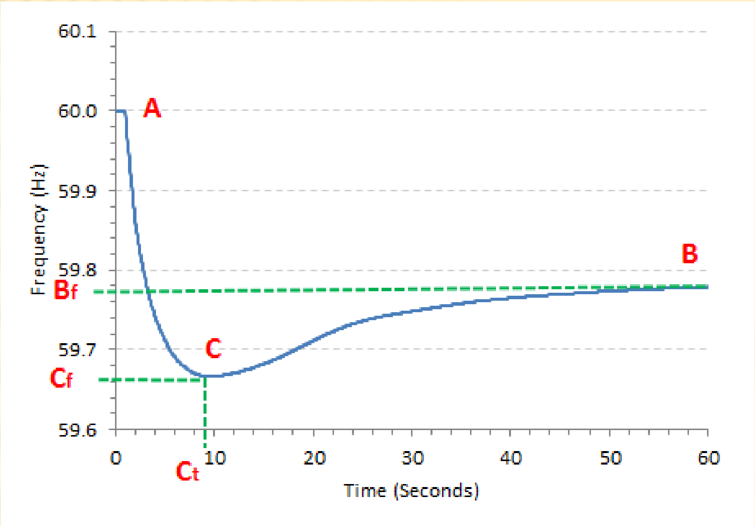
QUEBEC			
High Frequency		Low Frequency	
Time (Sec)	Frequency (Hz)	Time (Sec)	Frequency (Hz)
0 - 5	66	0 – 0.35	55.5
5 -90	63	0.35 - 2	56.5
90 - 660	61.5	2 - 10	57
> 660	60.6	10 - 90	57.5
		90 - 660	58.5
		> 660	59.4

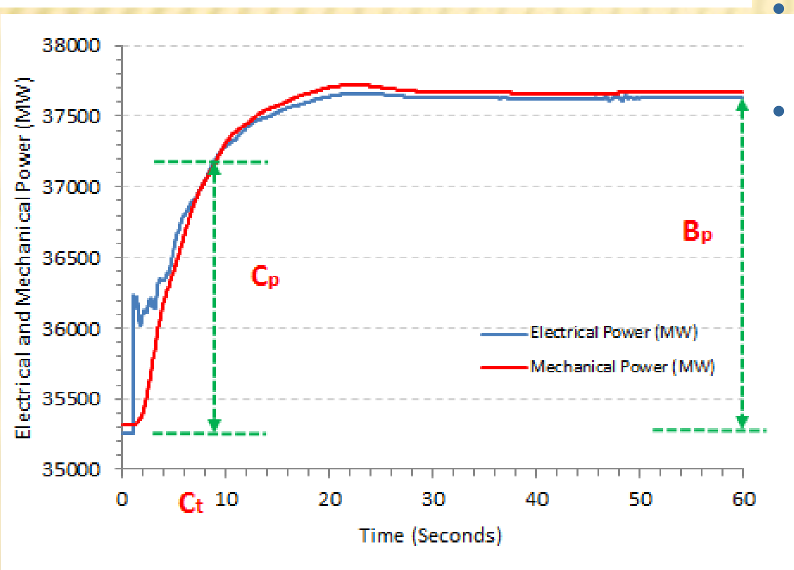
WECC			
High Frequency		Low Frequency	
Time (Sec)	Frequency (Hz)	Time (Sec)	Frequency (Hz)
0 – 30	61.7	0 – 0.75	57
30 – 180	61.6	0.75 - 30	57.3
>180	60.6	30 - 180	57.8
		>180	59.4

ALL OTHERS			
High Frequency		Low Frequency	
Time (Sec)	Frequency (Hz)	Time (Sec)	Frequency (Hz)
0 - 2	62.2	0 - 2	57.8
2 - 600	62.41 – 0.686 log(t)	2 - 1800	57.63 + 0.575 log(t)
>600	60.5	>1800	59.5



Frequency response to loss of generation for the base case





- **Frequency Nadir (Cf)**
- **Frequency Nadir Time (Ct)**
- **LBNL Nadir-Based Frequency Response (MW Loss/Δf_c*0.1)**
- **GE-CAISO Nadir-Based Frequency Response (Δ MW/Δf_c *0.1)**
- **Settling Frequency (Bf)**
- **NERC Frequency Response (MW Loss/Δf_b*0.1)**
- **GE-CAISO Settling-Based Frequency Response (Δ MW/Δf_b*0.1)**

Frequency Nadir (Hz)	59.67
Frequency Nadir Time (Seconds)	9.8
LNBL Nadir-Based Frequency Response (MW/0.1Hz)	806
GR Nadir-Based Frequency Response (MW/0.1Hz)	641
Settling Frequency (Hz)	59.78
NERC Frequency Response (MW/0.1Hz)	1218
GR Settling-Based Frequency Response (MW/0.1Hz)	968

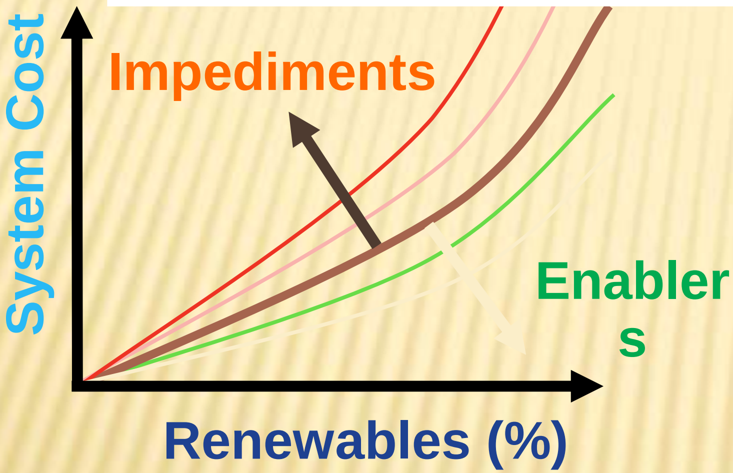
SHORT CIRCUIT CAPACITY ASSESSMENT FOR WIND INTEGRATION

- What is it?
  - Usually measured in short circuit MVA
  - $MVA_{sc} = kV_b^2/X_{sc} = 3^{½}kV_bkI_{sc}$
- Why is it the single most important factor?
  - Maximum short circuit (I.e. max kI_{sc} or min X_{sc}) dictates breaker duties, many equipment ratings
  - The ratio between the Short circuit MVA and wind power capacity should not be more than 3 – 5.

LESSONS LEARNED

- System Cost

Unserved Energy
Missing Wind/Solar Target
Higher Cost of Electricity



Impediments

- Lack of transmission
- Lack of control area cooperation
- Market rules / contracts constraints
- Unobservable DG – "behind the fence"
- Inflexible operation strategies during light load & high risk periods

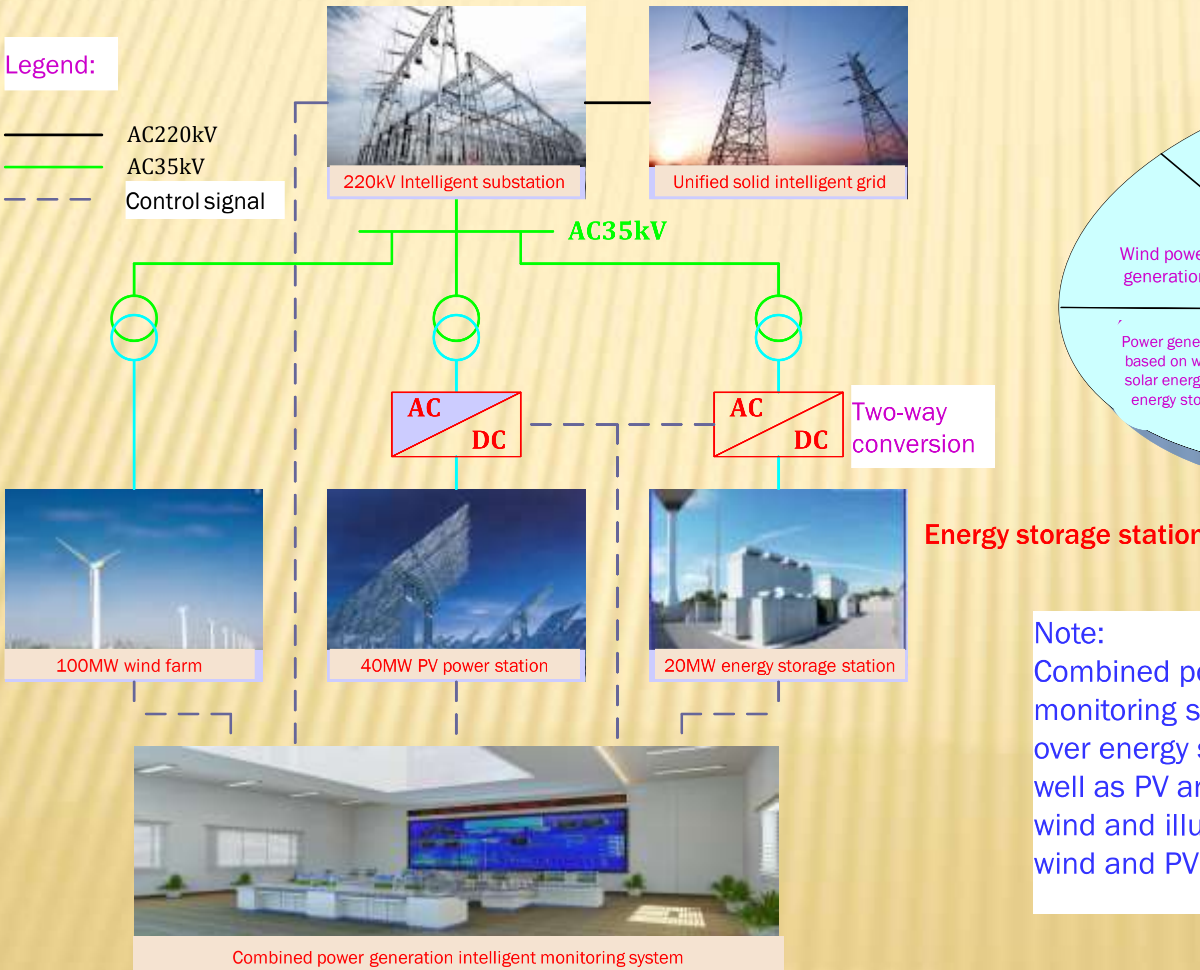
Enablers

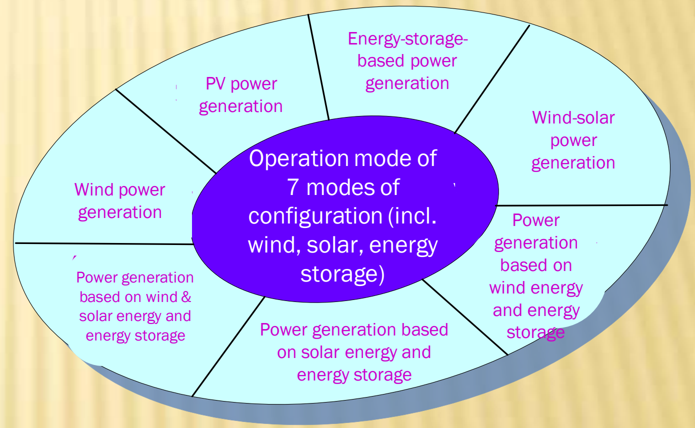
- Wind Forecasting
- Flexible Thermal fleet
  - Faster quick starts
  - Deeper turn-down
  - Faster ramps
- More spatial diversity of wind/solar
- Grid-friendly wind and solar
- Demand response ancillary services

All grid can accommodate substantial levels of wind and solar power … There is never a hard limit

Wind – Solar – Storage Integration Demonstration Project

General structure of wind-PV storage and transmission system





Note:
Combined power generation intelligent monitoring system can perform optimal control over energy storage devices, wind power units as well as PV array according to dispatch curves, wind and illumination, which can turn fluctuating wind and PV power into high-quality electric power.