IEEE Green Technology Conference
April 4-5, 2013 Denver Colorado

Latest Technology In Wind Power Generation And Near Term Projection Of Wind Power Development In North America

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DISCLAIMER

Information contained in the following expresses general views and shall merely be viewed as a contribution to the debate on the potential of wind turbines in general.

Information contained in the following shall not be construed as an expression of the policies or views of Vestas or as a detailed description of the properties or functioning of wind turbines manufactured by Vestas.

Presentation Agenda

1. A Decade of Technical Evolution in the Wind Industry
   - Larger WTGs, more and larger WPPs → More Strict Grid Codes
2. Changing market offerings
   - Lower wind speed (IEC Class II and III) WTGs
   - DFIG (Type 3) versus FSC (Type 4) WTGs
   - Increased need for higher capable controls
3. Central Power Plant control versus Turbine- based controls
   - Active/Reactive Power controls - Frequency & Voltage
   - Fault Ride-Through, Inertial contribution from WTG/WPP
4. Future trends
   - ESS, Increasing Offshore, More Exotic WTGs
5. Summary

Total Utility-Scale installed wind capacity is now 60GW

US installed twice as much in 2012 than in 2011

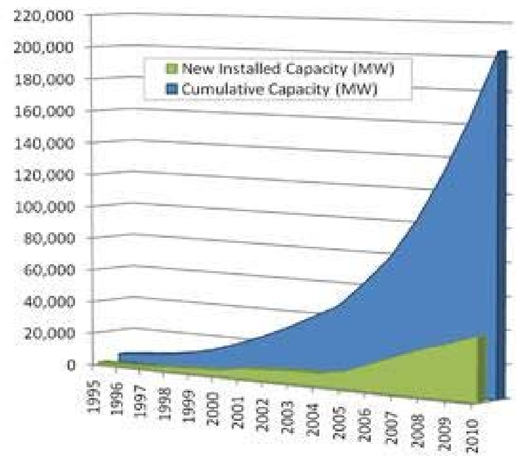
Q4-2012 installed 8 GW, mostly because of PTC uncertainty

“Renewable energy production jumped nearly 24% but remains only 11% of the US’ total energy production. But the trend lines tell the story: Wind energy, for instance, grew 89% while electricity production from nuclear power plants fell 4%.

And this factoid should warm the hearts of anti-nuke activists: The US now gets more energy from renewable sources—wind, solar, hydro, geothermal, and biomass—than it does from nuclear power plants.” (Yahoo Finance/Quartz: 3/28/13)

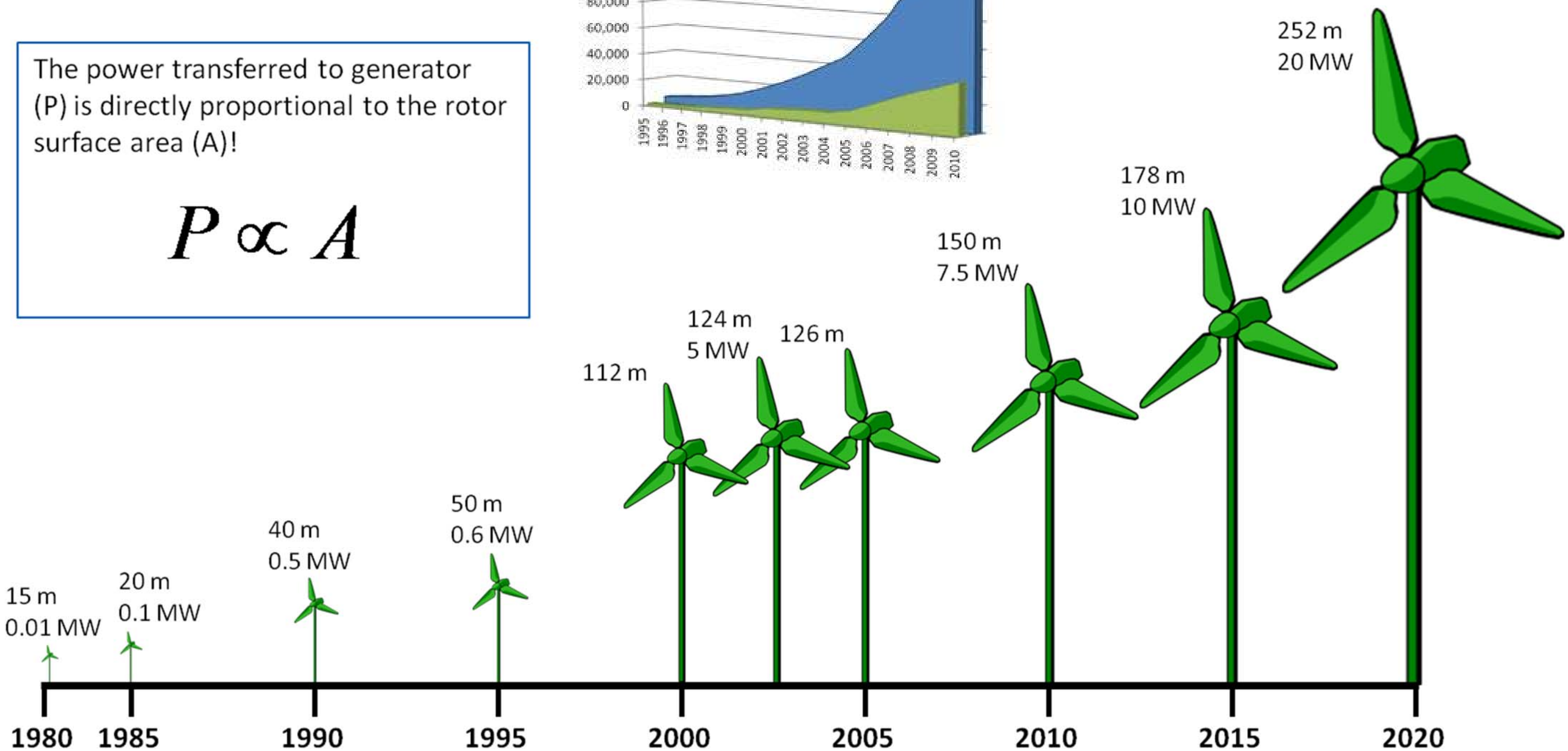
WTGs are getting larger and **larger**

WPPs are getting more numerous and higher capacity



The power transferred to generator (P) is directly proportional to the rotor surface area (A)!

$$P \propto A$$



GRID CODE REQUIREMENTS I

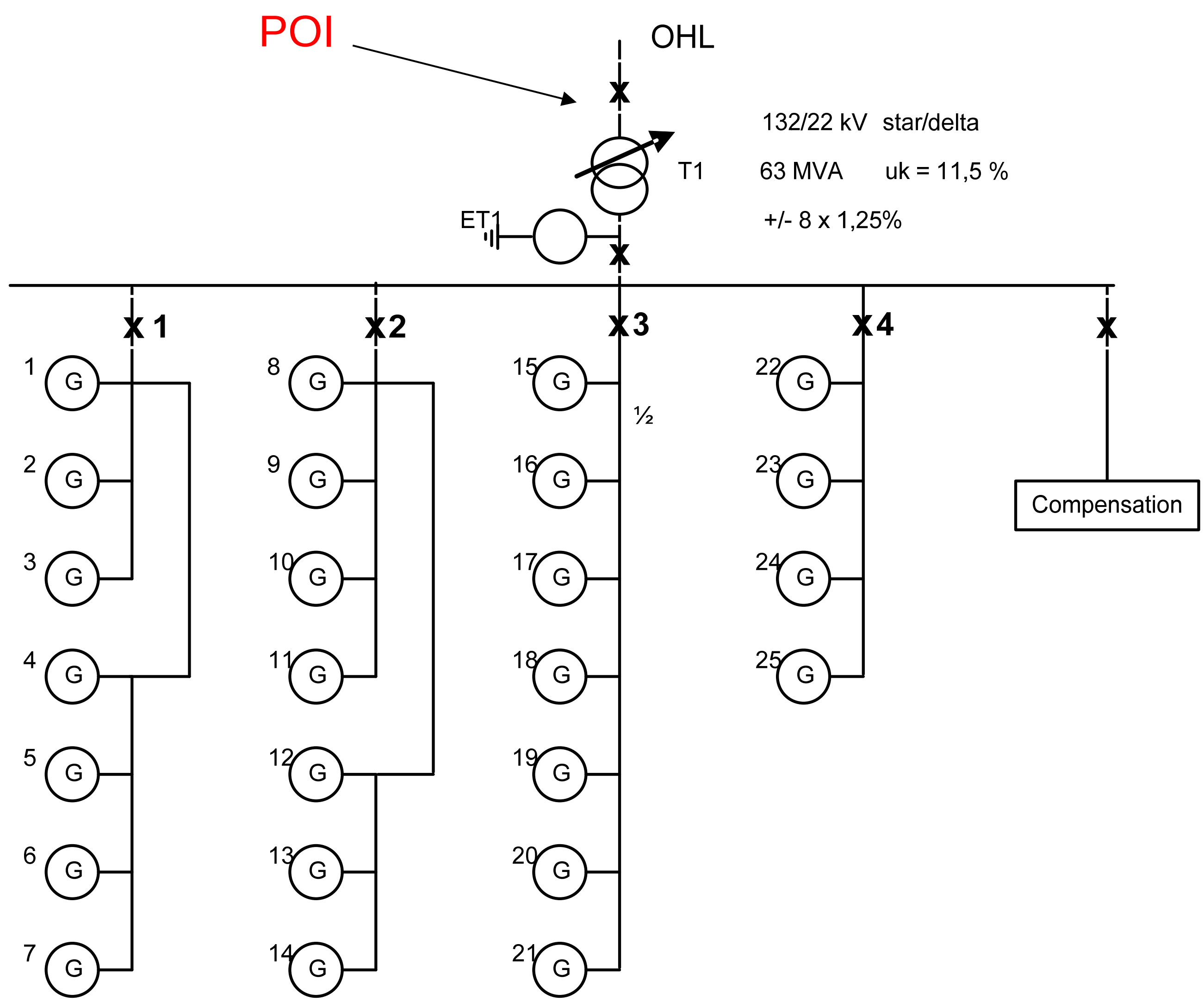
The technical evolution of the WTG has been linked to the evolution of grid codes, which is a consequence of the level of penetration for wind power on the local grid.

The traditional electrical grid, in which the power is produced at centralized power plants and delivered to the customers through transmission and distribution networks, is greatly challenged by the deregulation of the power system and the connection of wind power generation.

High wind energy penetration ratios (affect the power flows and thus node voltages and line congestion levels) together with the fact that wind power may replace conventional generators which perform voltage/frequency control requires wind plants to also contribute to voltage/frequency control, which in the end becomes reflected in the grid codes.

Wind Power Plants are viewed as any other power generation by the System Operator

Thus Grid Codes apply to the overall plant performance at the Point of Interconnection with the power grid, not necessarily to the individual wind turbine's performance.

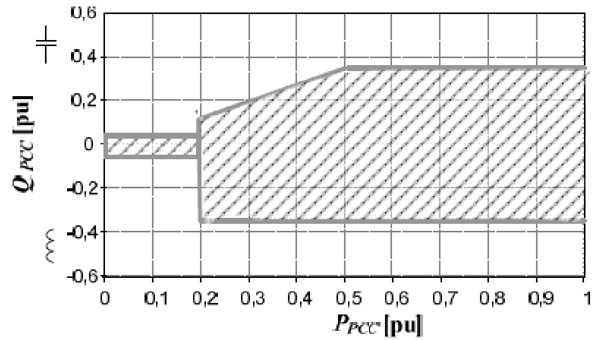


GRID CODE REQUIREMENTS II

Steady-State requirements.

– VAR requirements: P-Q chart

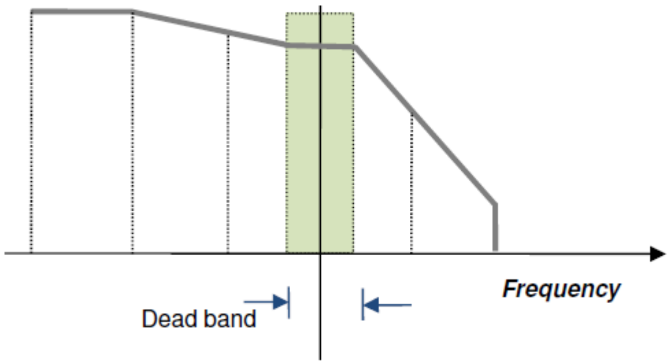
– Active power reserves: Curtailment, Ramp Rate, Fast Runback



Dynamic requirements: small disturbance

– Voltage response: Requirements for Vstep response, V regulation

– Frequency response: Requirements for frequency regulation (AGC)

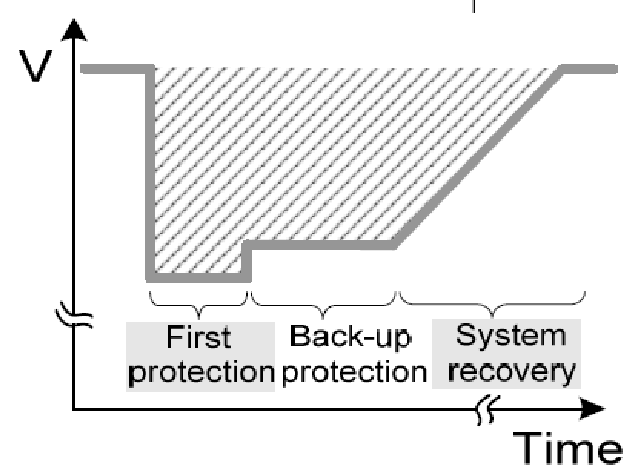


Dynamic requirements: large disturbance

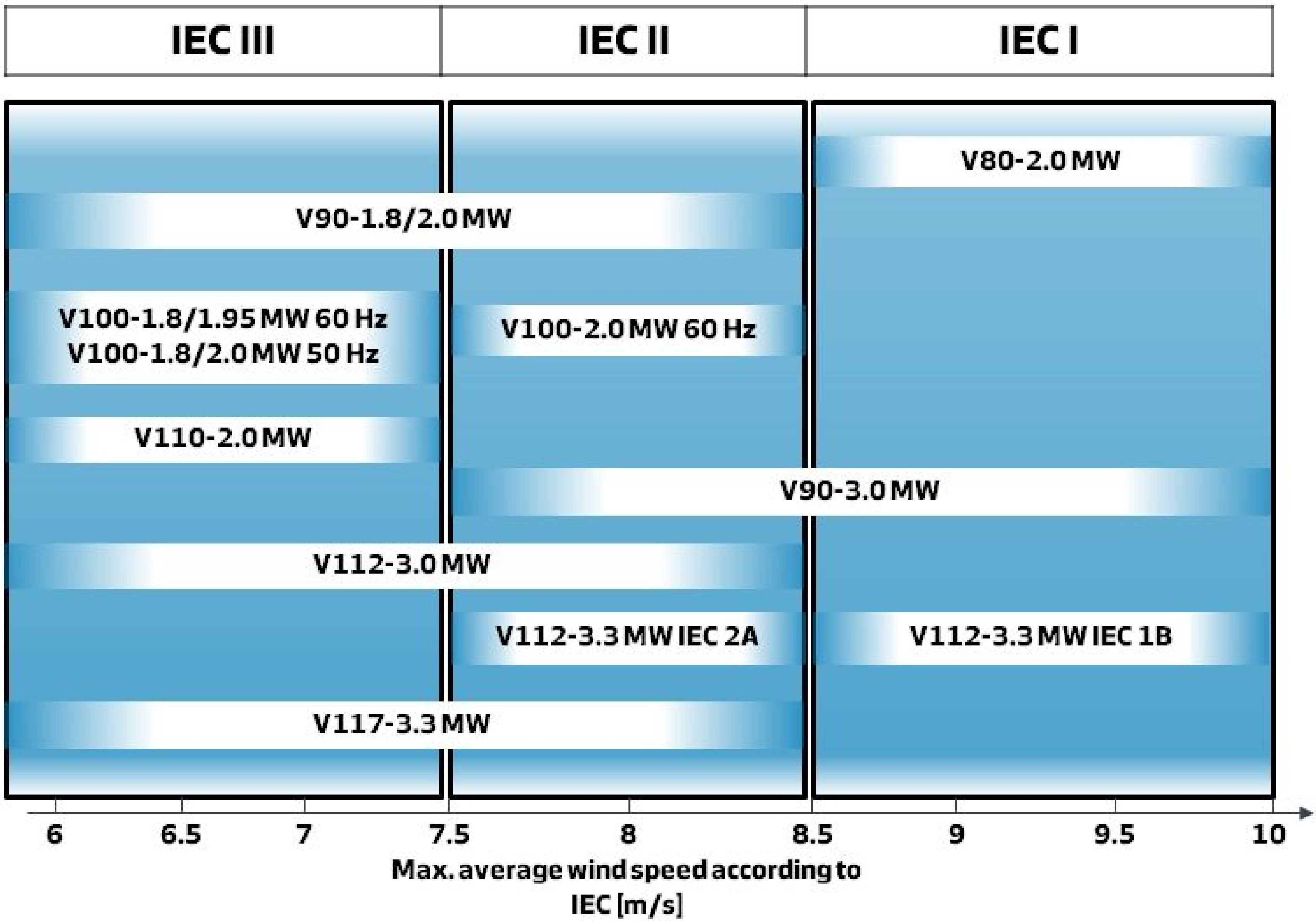
– Voltage response: HVRT, LVRT, Q injection

– Frequency response: Large frequency disturbances, RAS

– Emulated Inertia, Pri/Sec Frequency Response (Governor Response)



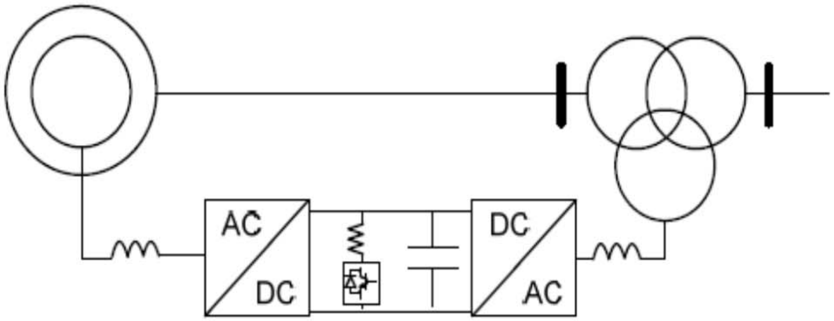
Lower Wind Class WTGs

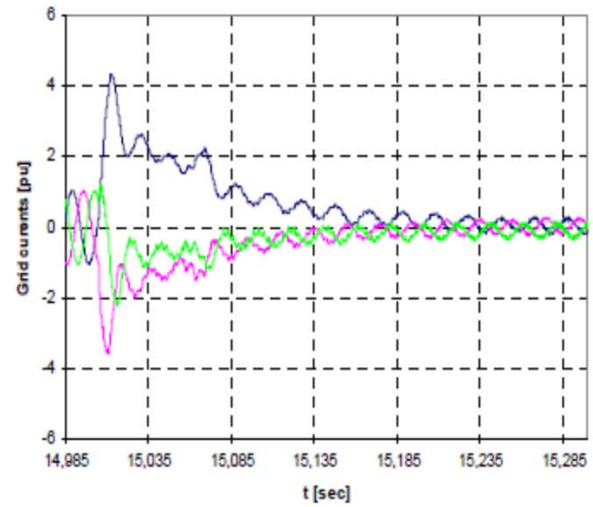


DFIG versus FSC WTGs

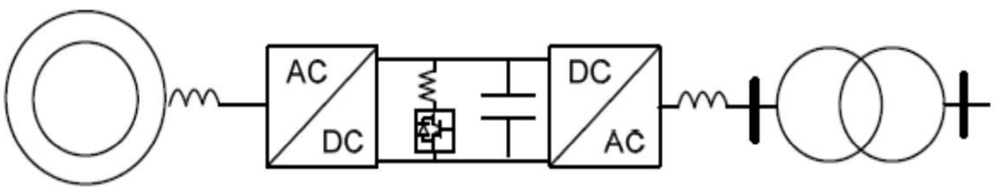
Representative Short-Circuit Behavior of Wound-Rotor Wind Turbine Generators

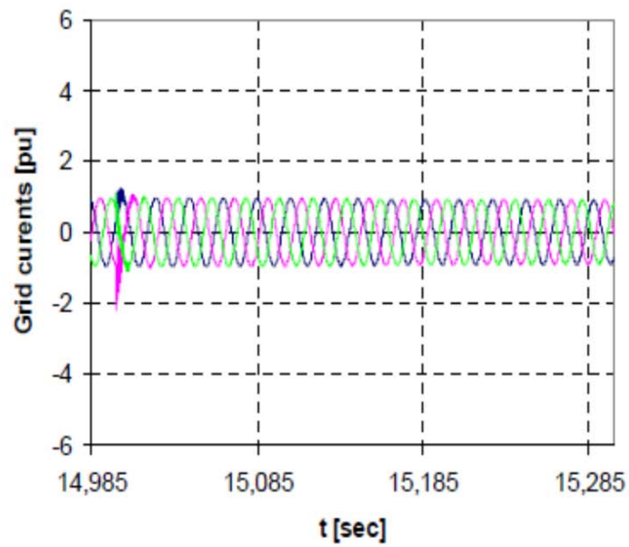
Type 3 – Double-Fed Asynchronous Generator



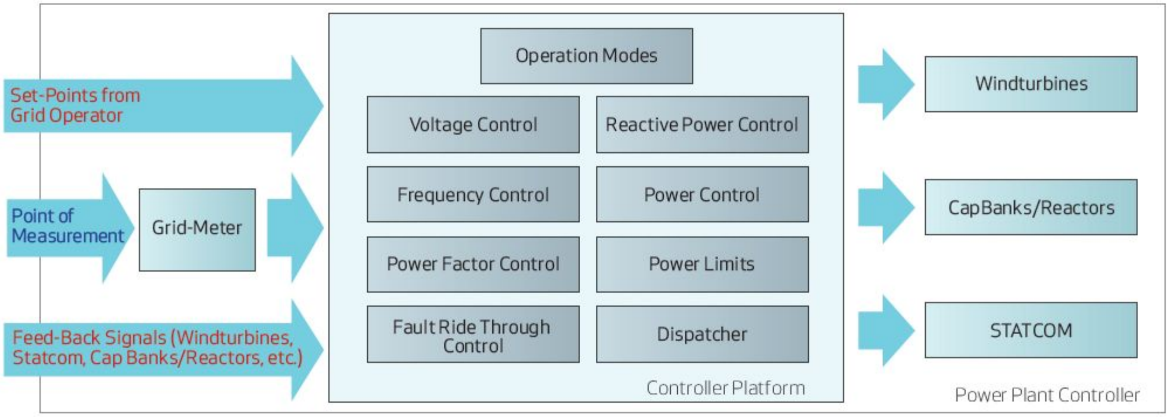


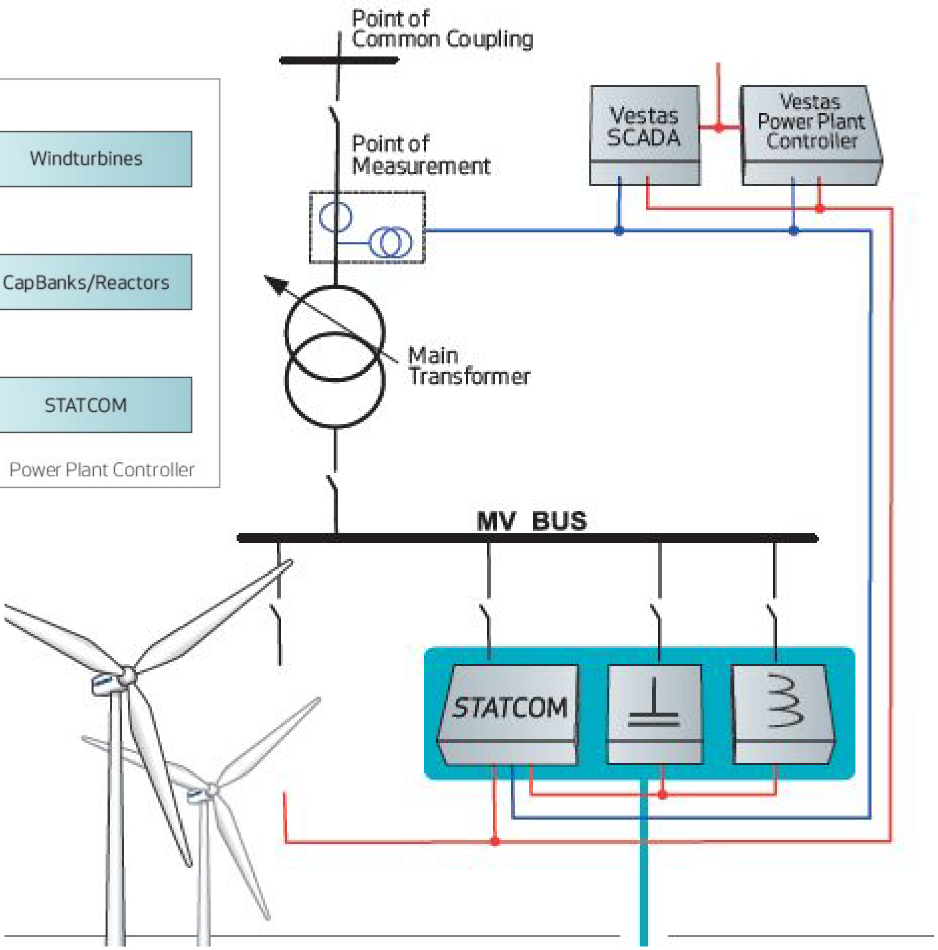
Type 4 – Universal Generator with Full-Scale Converter





Wind Power Plant Control Concept





Wind Power Plant: control features of importance

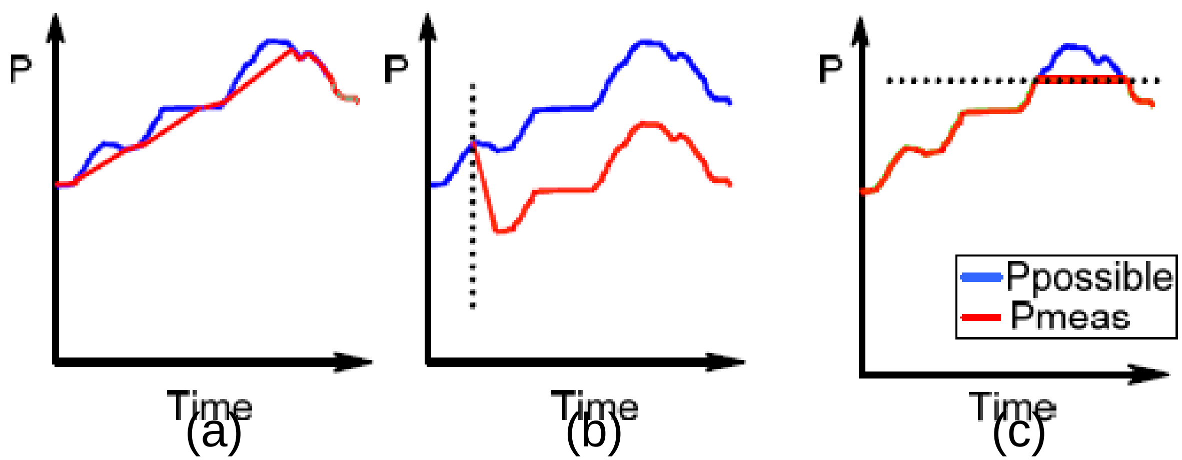
1. Power Ramp Rate control
2. Active Power Spinning Reserve (Delta control)
3. Absolute Power constraint (curtailment or other forms for derating)
4. Frequency Response (governor characteristics)
5. Inertia Response
6. Reactive Power and Power Factor control
7. Voltage control
8. Fault ride-through

Active Power Control Loops

- To coordinate and assist in system regulation, the Active Power of wind plants should at least be prepared for functionalities such as modes a,b & c.

- More advanced functions may require energy storage.

- Additionally, energy/power forecasting is very important for wind power grid integration. Transmission operators are starting to use it for Dispatch.



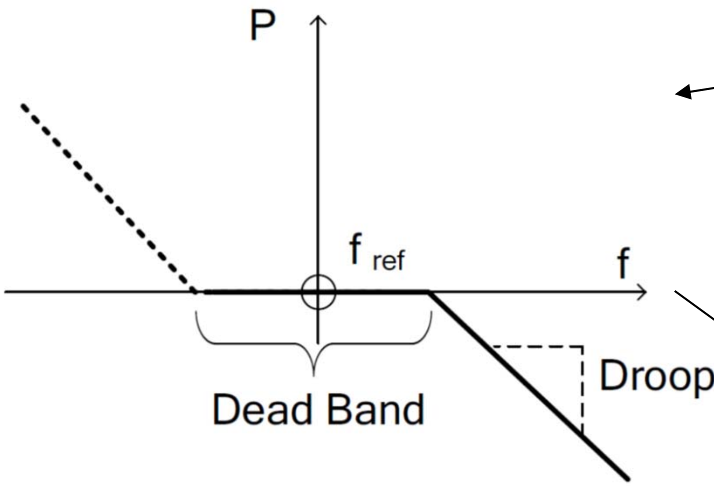
a) Active Power gradient/ramp rate mode.

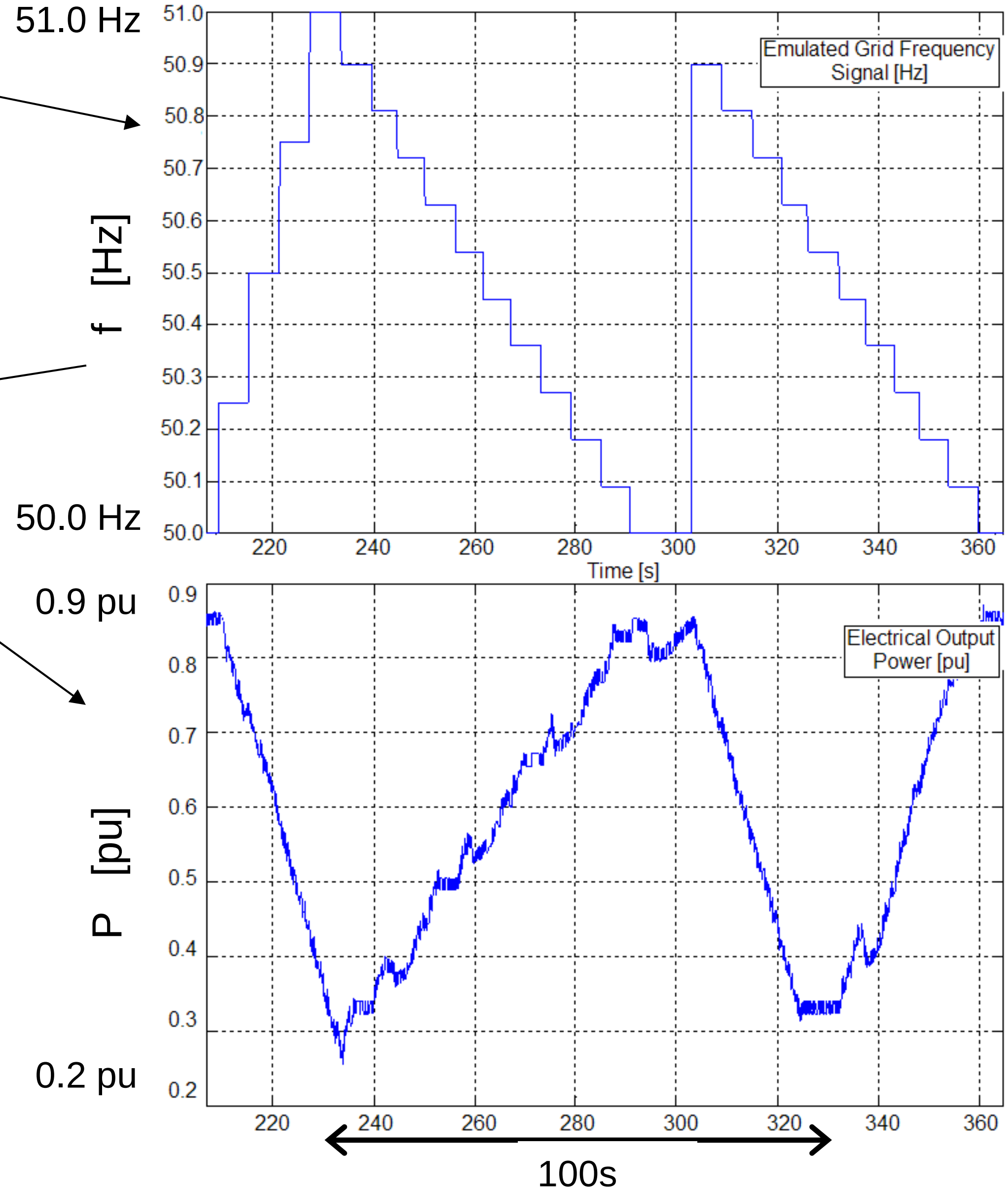
b) Active Power delta control mode.

c) Active Power limited mode (curtailment).

Frequency (Governor) Response

Simulated grid frequency excursions are fed to central plant controller and the control response command is then distributed to all turbines operating at the time.





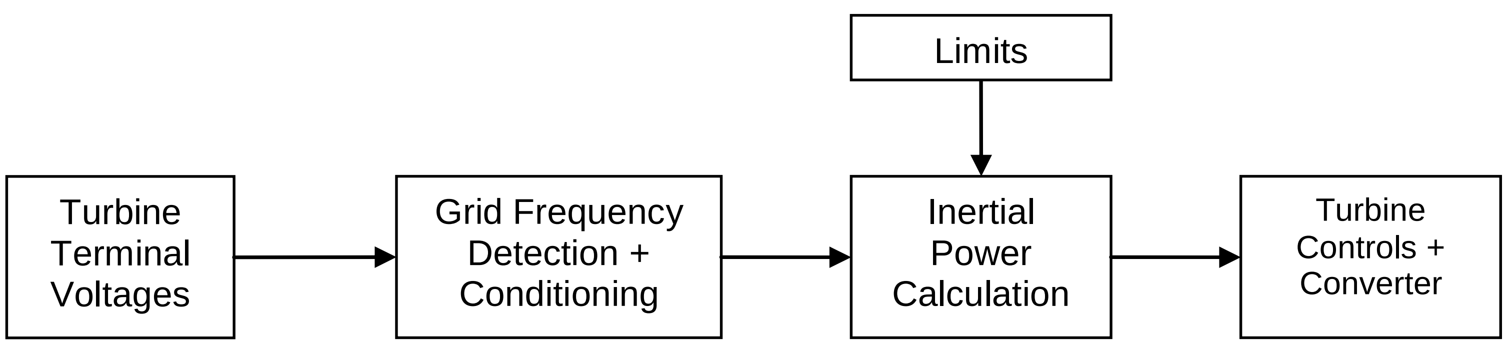
Individual wind turbines respond by pitching blades and/or controlling variable frequency converters to produce an aggregated plant response at the POI.

Wind power plant providing inertial response

Modern wind turbines do not contribute inherently to system inertia.

Modern wind plants act as ***programmable power sources***. It is therefore possible to produce an active power waveform that emulates the desired inertial response following a grid frequency disturbance.

Any wind plant inertial response to a frequency drop must be followed by a '**recovery period**' (turbine re-acceleration).



Reactive Power Control Loops

The main goals of the Reactive Power and Voltage control are the stabilization of node voltages, and avoiding violations of maximum and minimum voltage levels.

Reactive Power Management

So far, VAR/PF control is the most common way of controlling the reactive power of the wind plants (however, not commonly used in large plants).

Voltage Control

Superior voltage support performance on a transmission system is clearly offered by regulating voltage rather than VAR/PF.

Typically used voltage control law is shown below:

$$K_{slope} = \frac{100}{Slope\ [\%]} = \frac{Q_{ref} - Q_0}{V_{ref} - V_m} = \frac{\Delta Q}{\Delta V}$$

Fault Ride-Through Protection

Voltage Ride-Through

- Low Voltage settings: changed to allow turbine to “ride-through” disturbances on HV transmission system
  - Abnormal voltage operation
  - Fault occurrence
- High Voltages settings:
  - Due to voltage overshoot after fault recovery
  - Due to transmission long line charging upon open breaker at other end

Frequency Ride-Through

- Low Frequency settings: “ride-through” events when other system generators drop off-line
- High Frequency settings: “ride-through” events when large system loads drop off-line

LVRT Voltage Tolerant Designs

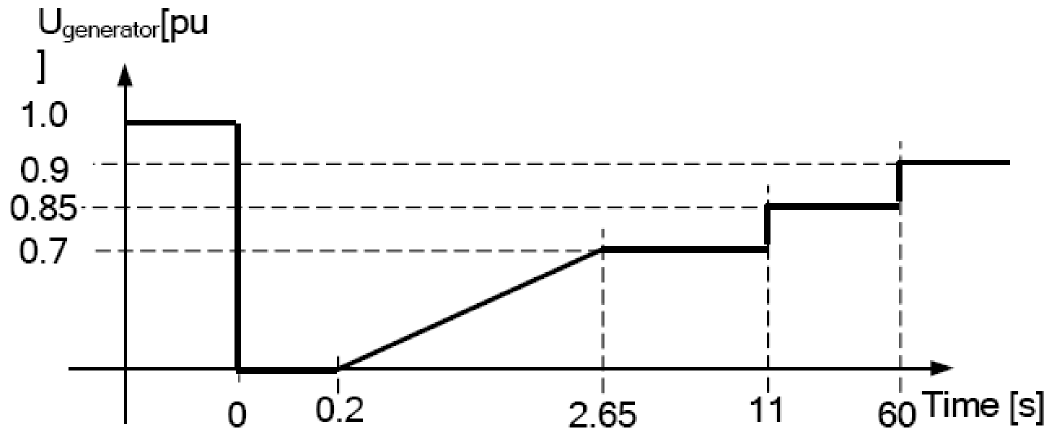
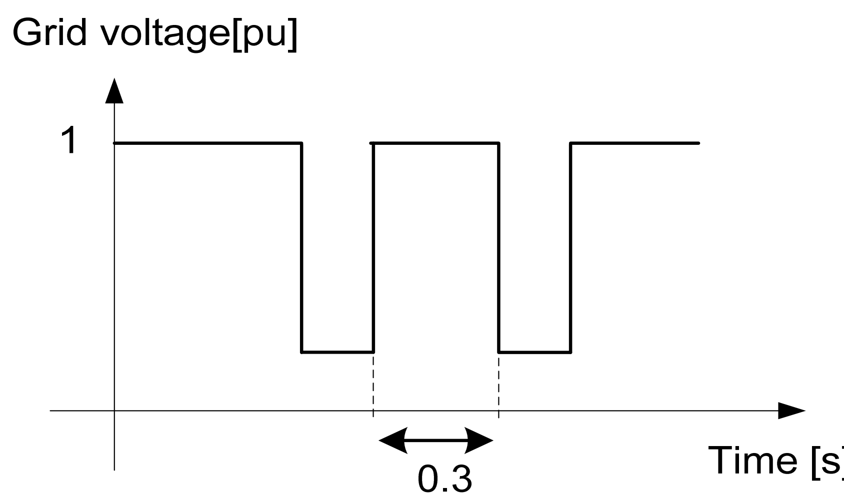


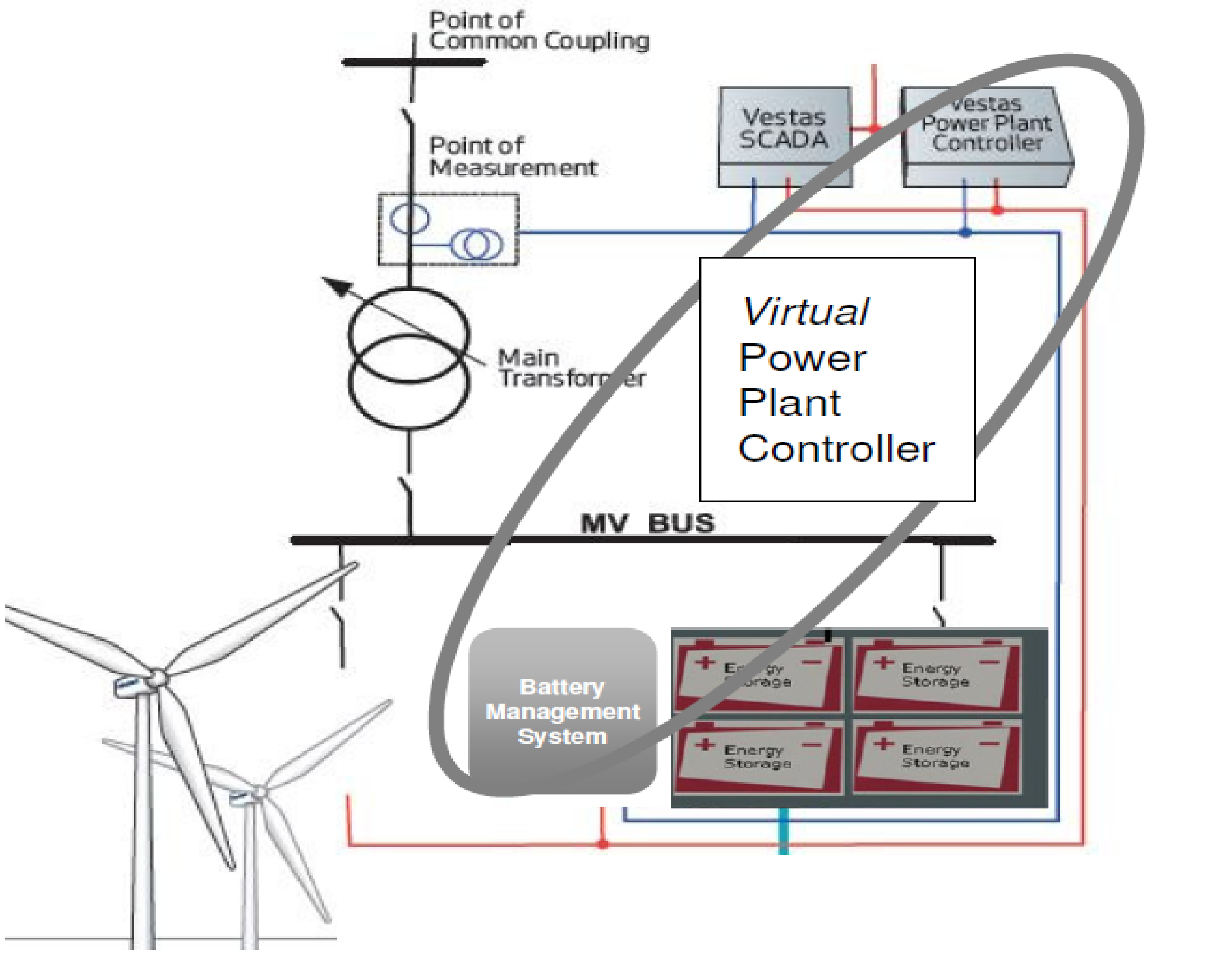
Figure 4-1: Default low voltage protection settings for symmetrical and asymmetrical faults.

Two voltage dips due to reclosing.



Energy Storage Systems - ESS

Wind Power Plant with Energy Storage



Energy Storage Systems

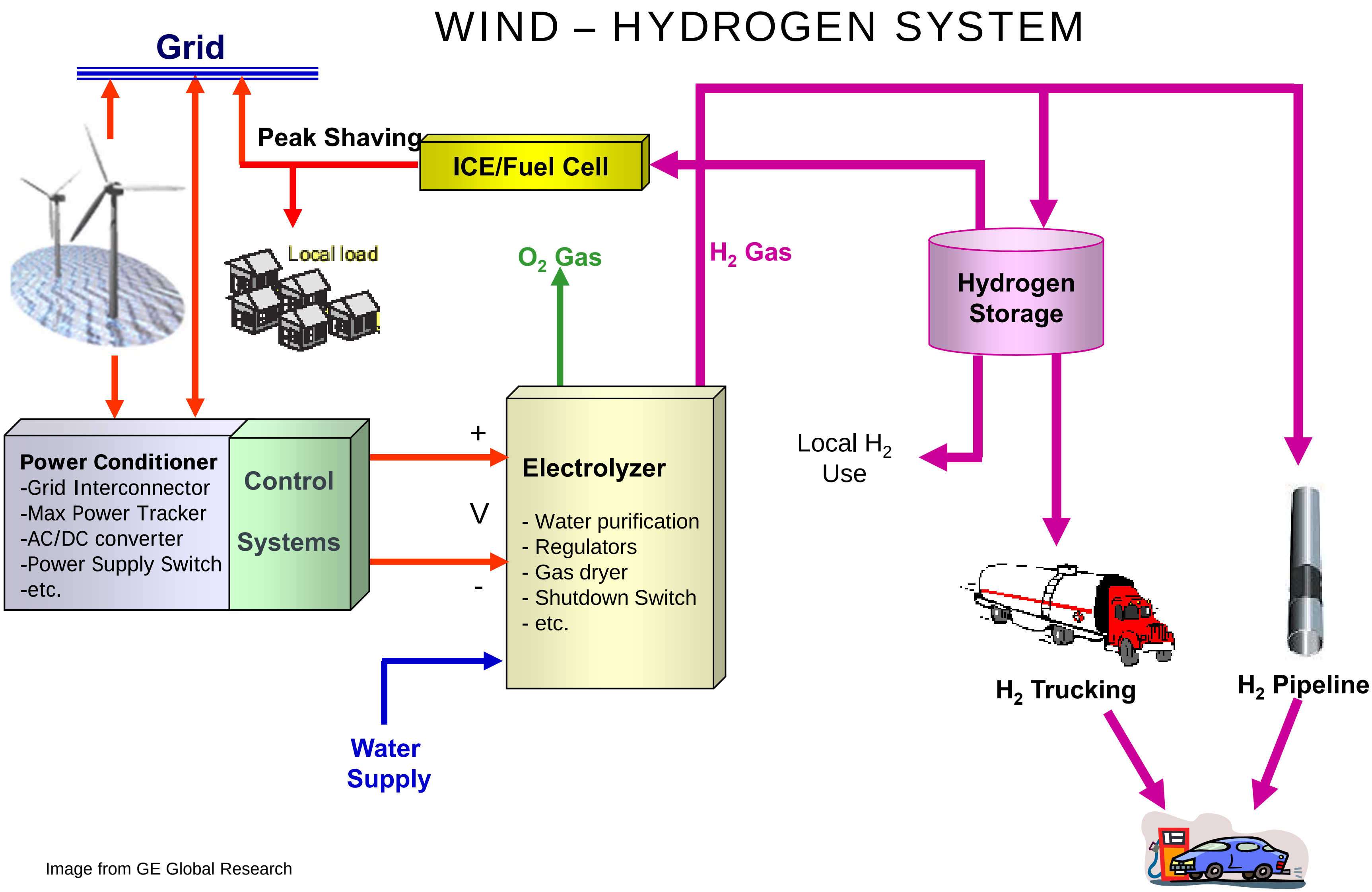
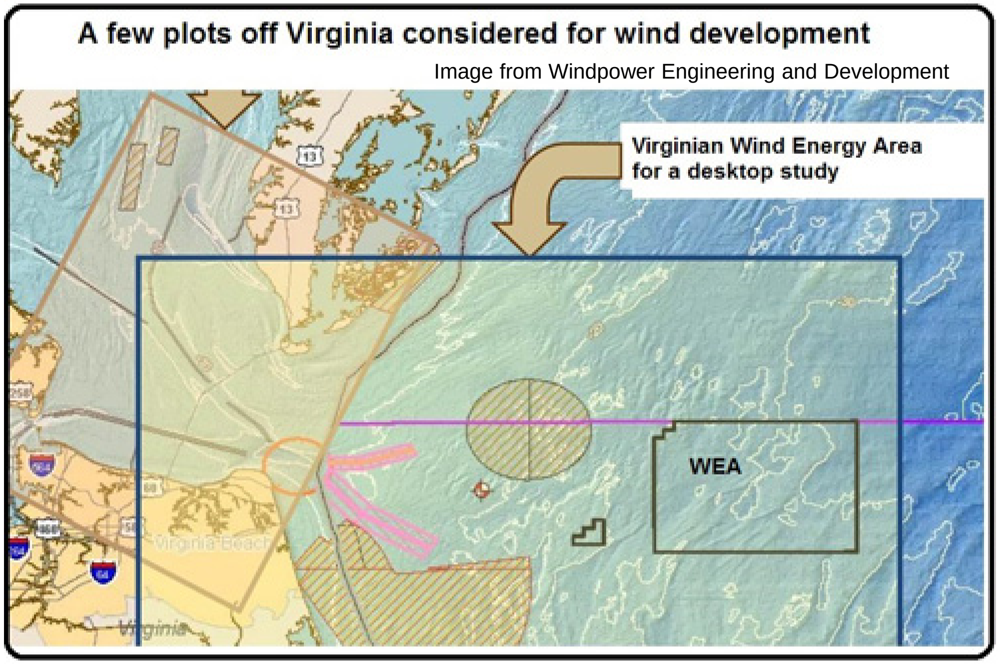
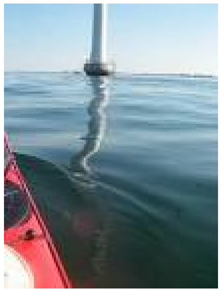


Image from GE Global Research

Offshore wind with ESS – Pumped Storage

Offshore Wind





Offshore Wind

750-meter-long floating wind farm platform supporting twenty-four 3-MW turbines

the system becomes increasingly competitive at depths greater than 40 meters

Images from Windpower Engineering and Development

Image from RESA

Image from Altaeros Energies

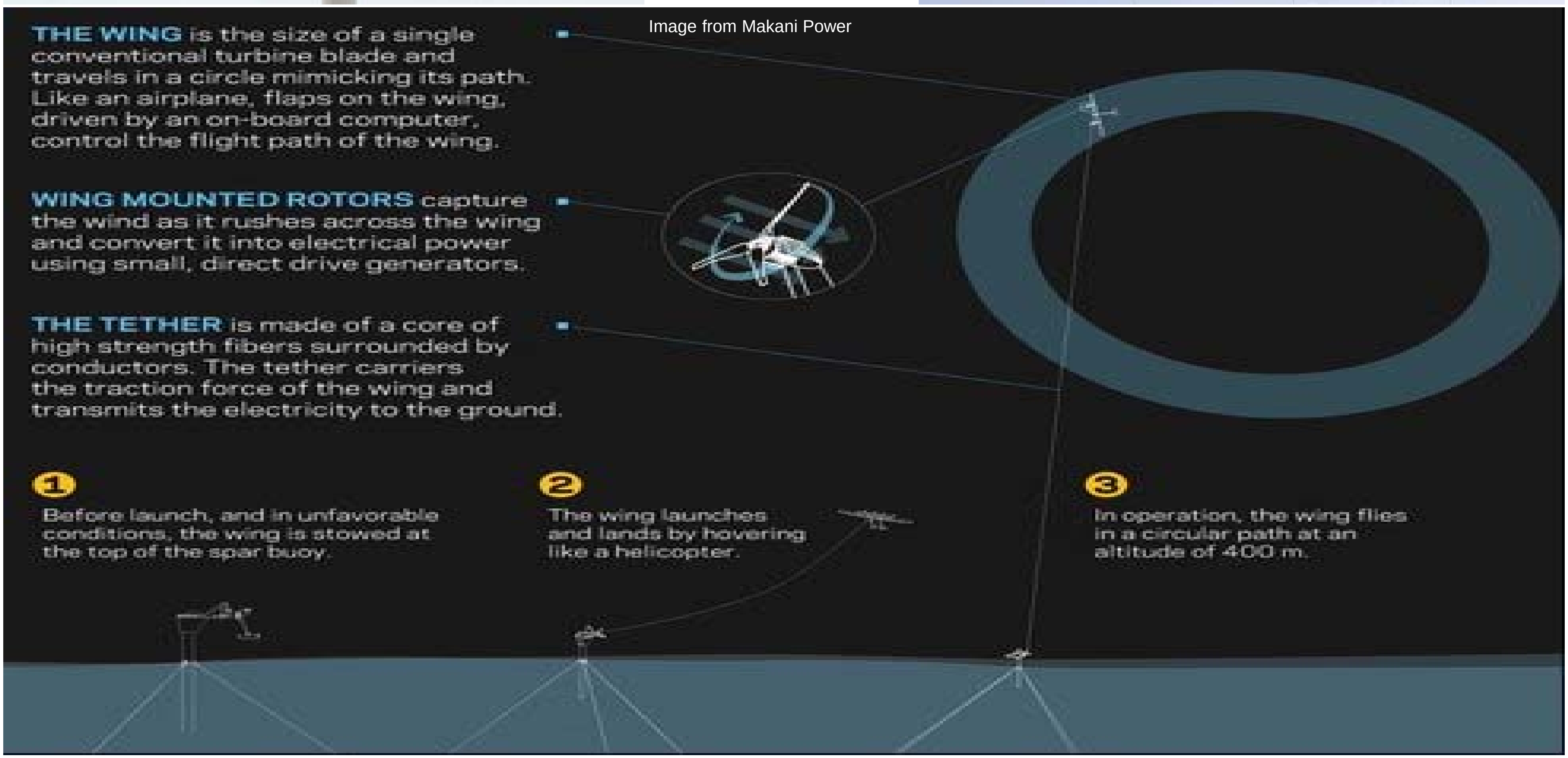


Image from Makani Power

Summary

Larger WTGs and WPPs are providing more power, leading to higher wind penetration to the electrical grid. So, to maintain system reliabilities, grid codes keep evolving with more stringent interconnection requirements forcing greater control capabilities.

Interconnection Codes should stipulate wind power plant features, performance metrics, documentation formats – but not specify implementations.

Wind power plants provide high bandwidth control of Active and Reactive Power. The applications span derating, ramp rates, frequency response, & inertia, voltage control.

Wind technology is definitely in evolution; new WTG designs and novel WPP concepts, such as ESS.

Offshore in NA is still experiencing birthing issues, but following Europe’s example it does have its proponents.

New engineers of tomorrow will write the coming chapters; such as OIT Renewable Energy Engineering degree.

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