# New Energy Storage Technologies and Power Converter Topologies for Wind Turbines

## (OTT1195)

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# Wind turbines and Power Conversion: Problems

**Problems:**

- Mechanical stress on gearbox and bearing
- Voltage and frequency stability problems, especially in systems with high wind energy penetration or stand alone power systems
- Transient power stability
- Low voltage ride through
- Power ramp rate
- Wind speed fluctuations cause fluctuations in the mechanical torque on the wind turbine’s rotor
- Planning and scheduling problems

# Wind turbines and Power Conversion: Problems

**Solutions**:

- Integration of ultracapacitors as an energy storage element into wind turbine systems; Electrolytic Double-Layer Capacitors (EDLC) and Lithium-ion Capacitors (LIC)

- The developed system provides protection for the turbine during grid low voltage conditions (Low voltage ride-through (LVRT) protection)

- Grid support through improved power system stability during transient dynamics by power smoothing and power ramp control

- Gearbox stress reduction using an active damping control

# Next Steps: Further Development

- This is an ongoing active research program
- A prototype turbine is built and running at UWM
- Looking for a wind energy development partner to aid in large scale testing and commercialization
- U.S. Patent 8,860,236
- This technology is available for developmental research support and/or licensing

# Market Potential

**Features and Benefits:**

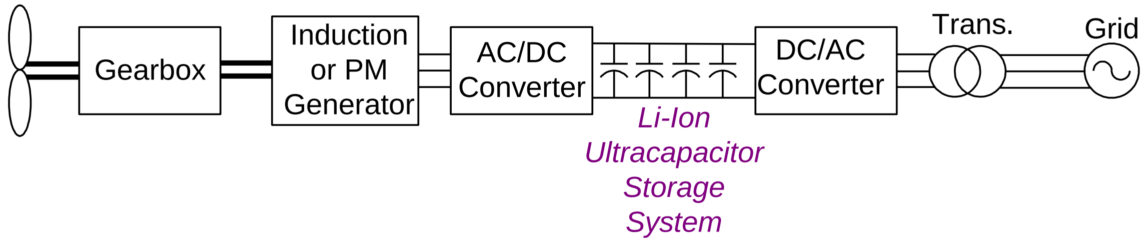
- **Less stress** - Gearbox stress and mechanical wear is reduced during wind gusts and grid disturbances
- **Grid support** - Improved power system stability during transient dynamics by power smoothing and power ramp control
- **LVRT protection** - The developed system provides protection for the turbine during grid low voltage conditions
- **Higher efficiency** – Additional power conversion stages are avoided for ultracapacitor integration
- **Lower costs** – Less maintenance for replacement of gearboxes and generators; lowers and defers power distribution and transmission costs

# Market Potential

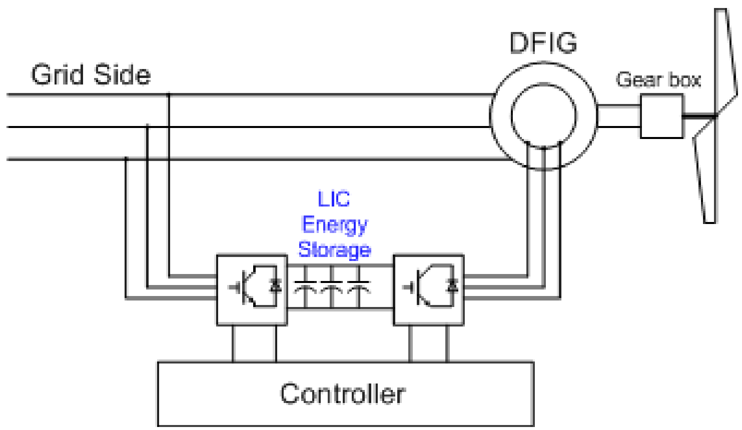
**Market:**

- With increased capacity and better generation, the wind power market share reached 4.2% in 2016 and is expected to increase to 7.1% in 2025
- Global wind power market size increased from approximately US$24 Billion in 2006 to US$100+ Billion in 2016
- One of the biggest concerns remaining in the wind industry is the reliability of the gearbox; the wind industry expects today's gearboxes to last 7–11 years
- Replacing a wind turbine gearbox involves primarily the gearbox cost itself, which typically represents around 10% of the total wind turbine cost.
- Inspections after 3–5 years performed on gearboxes of large wind turbines usually show that major gearbox overhauls or replacements will be required in the next few years

# Proposed New Topologies For Wind Turbines




Proposed topology of double-conversion wind turbine system integrated with LIC energy storage




Proposed topology of DFIG wind turbine system integrated with LIC energy storage

# Premature Mechanical Wear-out

- The fluctuating wind power creates torque pulsation.
- Due to large inertia of wind turbines, the short term (high frequency) power fluctuations are directly converted to torque fluctuations on shaft.
- These torque fluctuations create huge stress on turbine gear box.
- The cost to replace gearboxes and generators is in particular a high-cost item. They must be removed by an overhead crane at a cost often exceeding $15,000/day.
- It is expected that the majority of the existing wind turbines will need significant overhaul due to premature wear-out of the mechanical components in the next five years.

# Benefits of the Proposed New Topologies

- **Gearbox Stress Reduction**
  - A control technique is designed to regulate the generator torque during wind gust using current control of active AC/DC rectifier. This is an established method in machine drives.
  - The objective is to keep the total torque applied to the gear box constant during wind gust.
  - During this period, a lithium ion capcitor (LIC) is used to stabilize the turbine output power.
  - When the gust is over, the rotor has sped up.
  - The stored kinetic energy is discharged into the LIC while keeping gearbox torque constant.

- **Power Ramp Control**
  - Charging and discharging of the LIC storage is programmed in the control technique to limit the ramp up and down rate of the turbine.
  - The energy is stored in and taken from the LIC and is compensated with slow pace.

# Benefits of the Proposed New Topologies

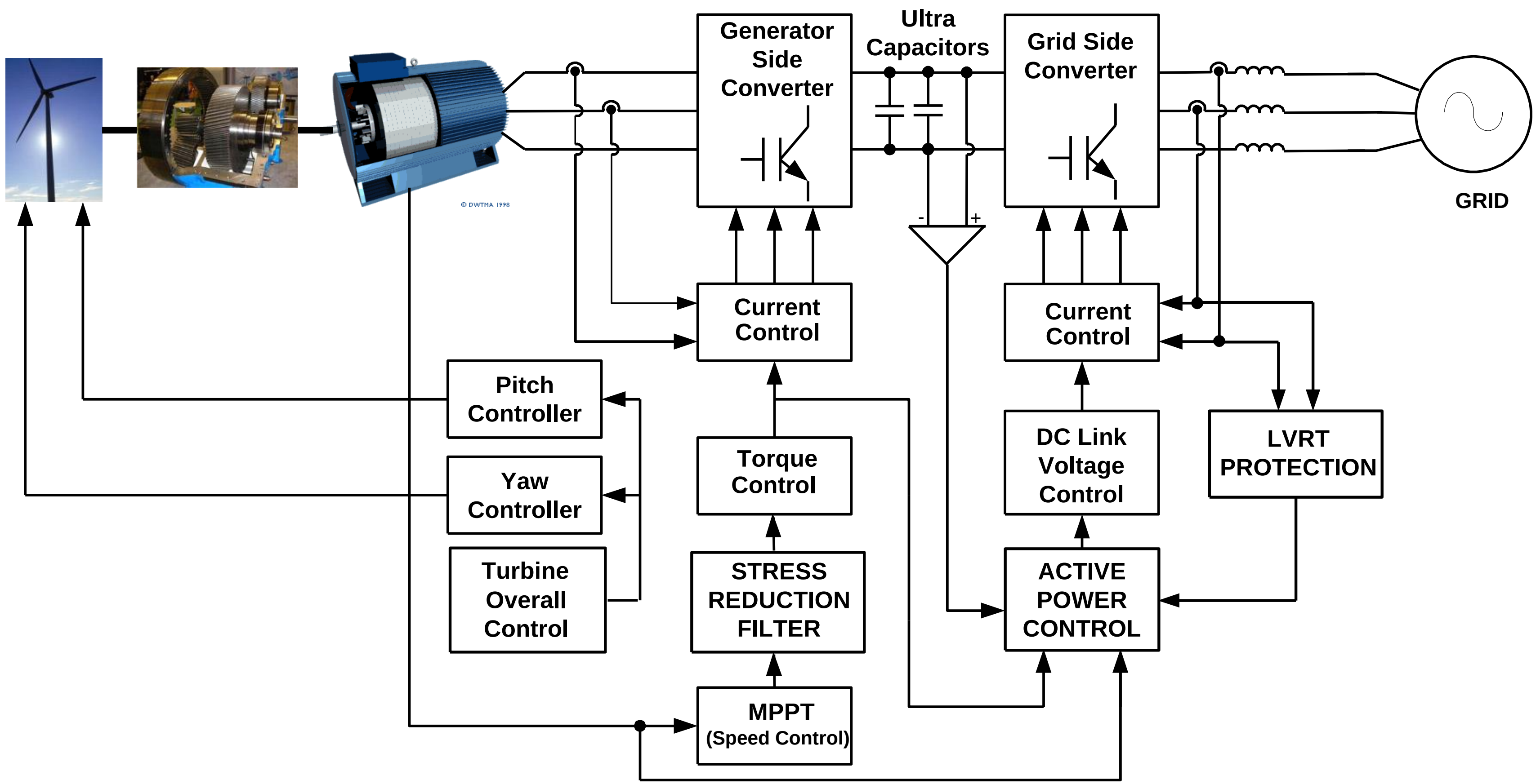
- **Frequency Droop**
  - Grid over and under frequency is modeled and simulated to include a scheme in LIC charging/discharging control technique to help the grid with active power during these occurrences.

- **LVRT (Low Voltage Ride-Through)**
  - LIC charging/discharging control technique takes under voltage and short circuit conditions on the grid side into account to support both grid and turbine.
  - Under LVRT, the ability of the turbine to export power to the grid is limited.
  - On the other hand, the grid needs support with reactive power during this time.
  - The DC/AC inverter is controlled to provide maximum reactive power to the grid to support voltage.
  - During this time, in typical wind turbine systems, the gearbox will experience step changes in torque and as a result high stress.
  - LIC capacity is used to absorb turbine energy and isolate gearbox from any torque change.

# Benefits of Ultracapacitors (Supercapacitors)

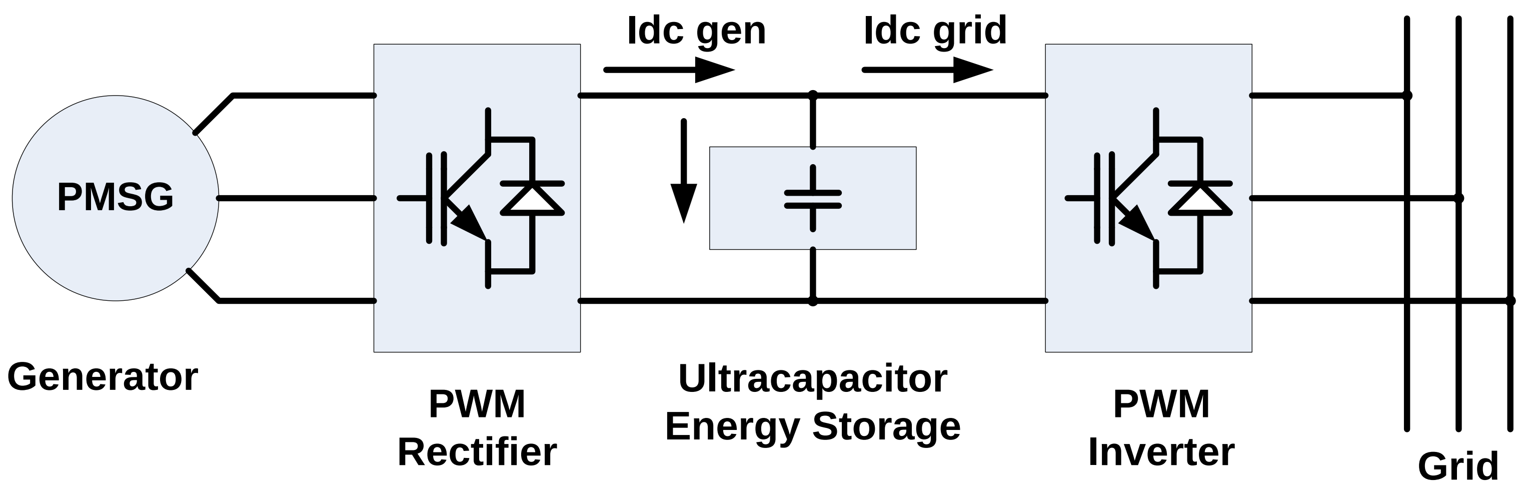
- Ultracapacitors can store large amounts of energy due to their large capacitance.
- Energy can be stored or delivered rapidly.
- Moderate energy but high power density.
- Efficient charging/discharging.
- Two major technologies: Electrolytic Double-Layer Capacitors (EDLC) and Litium-ion Capacitors (LIC).

# Wind Turbine Control Diagram



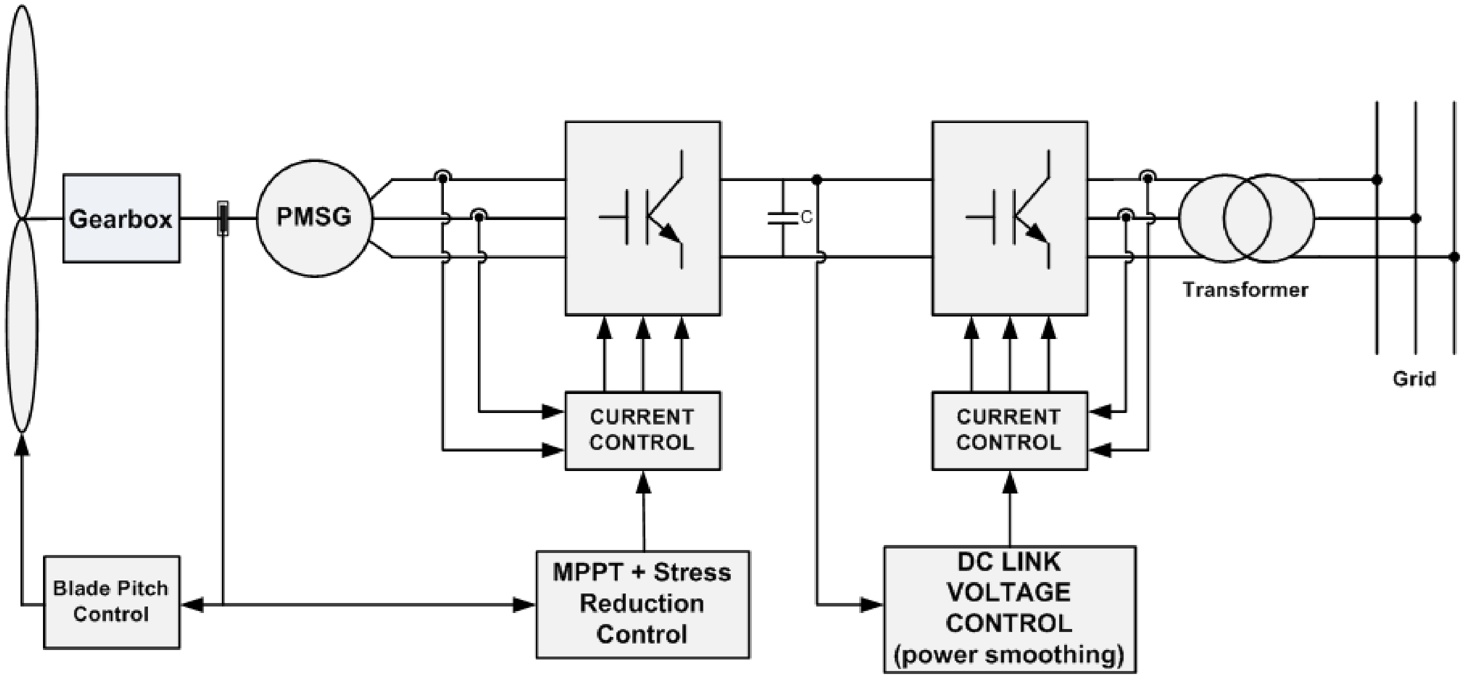

**This figure shows the control block diagram of the integrated system.**

# Existing Control Topology



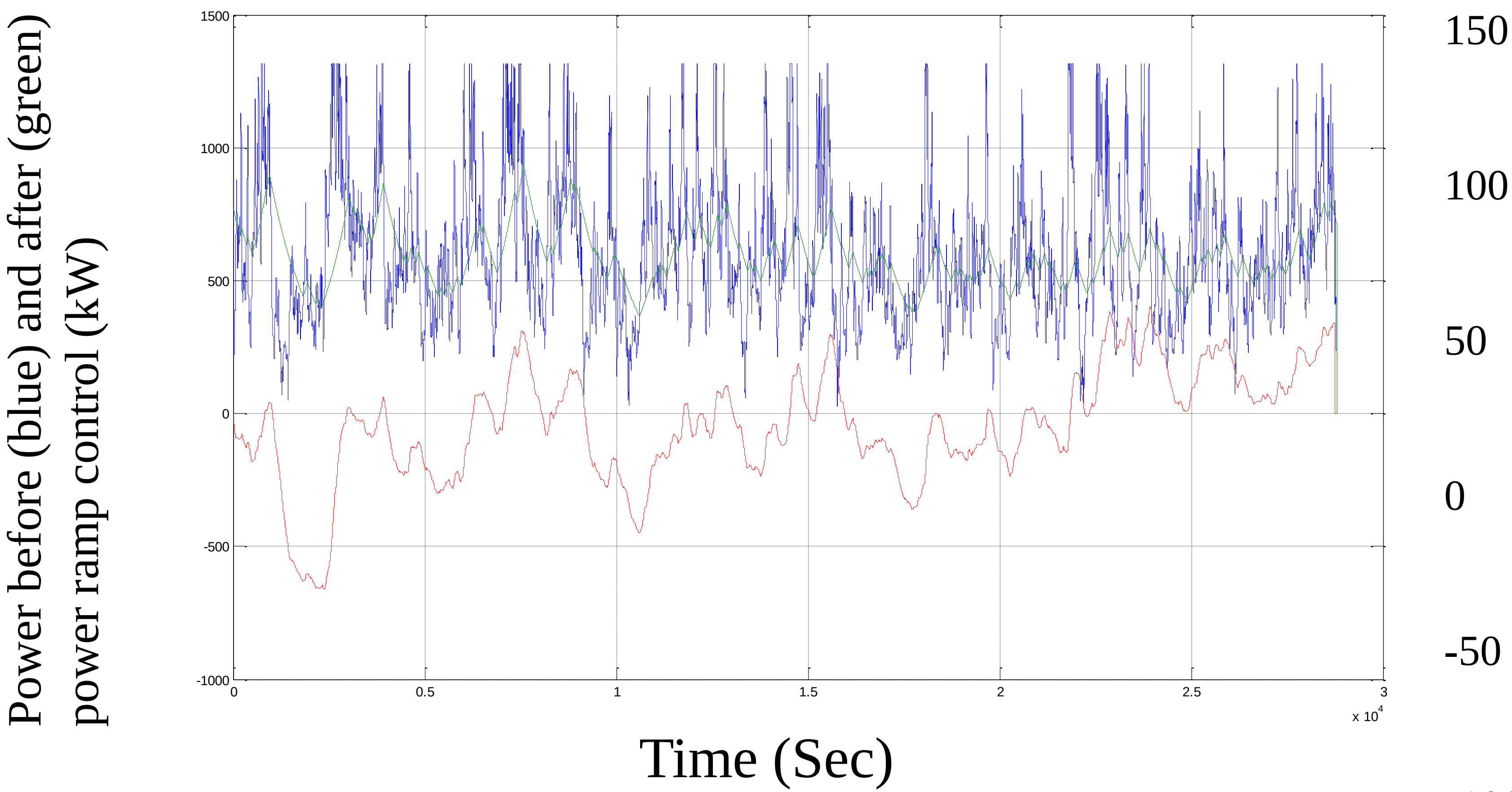

- Ultracapacitor-based energy storage is located in the DC link.
- It provides additional degree of freedom in the control of the two converters (PWM rectifier and PWM inverter).
- Generator side converter provides torque control.
- Grid side converter provides DC link voltage control.
- Issue: Control of both converters is difficult due to variable DC bus voltage.

# Enhanced Control Topology



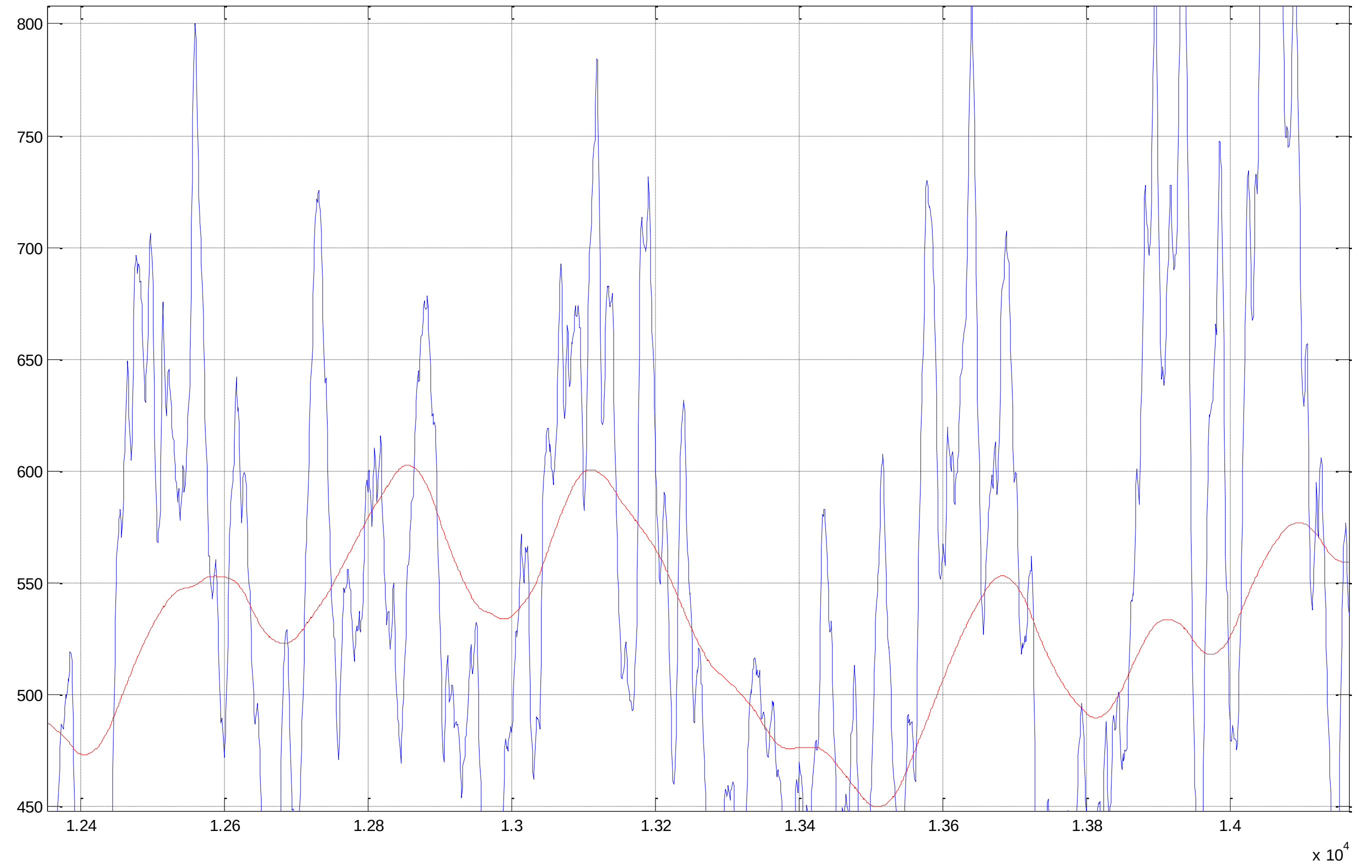

- Vector control strategy enables decoupled flux and torque control of the permanent magnet synchronous generator (PMSG).
- Decoupled control of direct and quadrature axis component of the grid side current enables active/reactive power control on the wind energy conversion system terminals.
- Blade pitch control keeps the turbine power at the generator’s rated power.

# Power Ramp Control for a Single Wind Turbine




This figure shows the output power of a turbine before (blue) and after (green) power ramp control. Red curve shows the energy trade with the ultracapcitors.

# Power Ramp Control & Power Smoothing




This figure shows the output power of a turbine before (blue) and after (red) power ramp control and power smoothing.

# LVRT Protection Strategy

- During grid low voltage condition, when the power export to the grid is limited, the wind power will be stored in the ultracapacitor and released when the voltage is restored.
- A portion of the ultracapacitor capacity is dedicated to this function.
- The capacity is enough to meet all the regulations with the support from pitch control and the generator side converter.

# Summary

- This technology for new energy storage topologies and power converter technologies for wind turbines will aid in lower costs for the maintenance replacement of gearboxes and generators and will improve the power system stability

- These improvements are accomplished through:
  - Less mechanical stress and wear
  - Improved power system stability through power smoothing, power ramp control, and protection during grid low voltage conditions

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