Enhanced Frequency Control Capability
from Wind Turbine Generators and Wind Power Plants

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Outline

1. PFC (Primary Frequency Control)
2. VSM (Virtual Synchronous Machine)
3. Research Plan
PFC (Primary Frequency Control)

- Frequency Event
  - When there is a sudden large loss of generation or load;
  - To cause a big frequency change out of normal fluctuation range;

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PFC (Primary Frequency Control)

• For traditional power systems
  – Mainly composed of synchronous generators;
  – Rotor speed coupled with grid frequency;
  – Large inertia will benefit the frequency stability;

PFC (Primary Frequency Control)

• For traditional power systems
  – Mainly composed of synchronous generators;
  – Rotor speed coupled with grid frequency;
  – Large inertia will benefit the frequency stability;

• For power systems with renewable power integration
  – Integration through power electronics devices, decoupled;
  – Less inertia;

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VSM (Virtual Synchronous Machine)
-- VSG (Virtual Synchronous Generator) or Synchronverter (Synchronous+Converter)

- A control scheme applied to the inverter in order to support system frequency stability by imitating the behavior of SM (Synchronous Machine) by using models of SM within the control scheme;


VSM (Virtual Synchronous Machine)

- A unified interface of converter for grid integration
VSM (Virtual Synchronous Machine)

• From Swing Equation to VSM Control

\[ T_m - T_e = J \frac{d\Delta \omega}{dt} + D\Delta \omega \]

\[ P_m - P_e = J \omega_n \frac{d\Delta \omega}{dt} + D\omega_n \Delta \omega \]

\[ P_m = P_e + K_I \frac{d\Delta \omega}{dt} + K_P \Delta \omega \]

\[ K_I = J \omega_n \frac{2HS_n}{\omega_n}, \quad H = \frac{J\omega_n^2}{2S_n} \]

\[ K_P = D \omega_n \]

Type 4 WTG (Wind Turbine Generator)

--Variable Speed Multi-Pole PMSG with Back-to-Back Full-Scale Converters

Figure 142: Power converter control in the variable speed multi-pole PMSG wind turbine.
Type 4 WTG (Wind Turbine Generator)

--Variable Speed Multi-Pole PMSG with Back-to-Back Full-Scale Converters

\[ P_m = P_e + K_i \frac{d\Delta\omega}{dt} + K_p \Delta\omega \]

Figure 151: Grid-side converter control (controller 2).

ES (Energy Storage)

--LIC (Lithium-Ion Capacitor)

- A lithium-ion capacitor (LIC) is a hybrid electrochemical energy storage device which combines the intercalation mechanism of a lithium-ion battery anode with the double layer mechanism of the cathode of an electric double-layer capacitor (EDLC).
  - A type of supercapacitor
  - Cathode: activated carbon
  - Anode: carbon material pre-doped with lithium ions
ES (Energy Storage)

--LIC (Lithium-Ion Capacitor)

- LIC has a higher power density than battery, and is safer than lithium-ion battery (LIB), in which runaway reactions may occur;
- LIC has a higher energy density than EDLC, although they have similar power densities. LIC has a much lower self-discharge.

[Diagram showing energy density vs. power density with regions for different storage types: Fuel Cell, Li Ion Battery, NiMH Battery, Lead-Acid Battery, Lithium Ion Capacitor, EDLC, LIC, and EDLCs / Polyacene Capacitors.]

[Graph showing voltage retention rate over time for different storage types: Lithium ion capacitor, EDLC.]

[Web links:
en.wikipedia.org/wiki/Lithium-ion_capacitor
www.mouser.dk/new/taiyo-yuden/taiyo-yuden-lithium-ion-capacitors/]

DTU Wind Energy, Technical University of Denmark
ES (Energy Storage)
--LIC (Lithium-Ion Capacitor)

• Properties
  – High capacitance compared to a capacitor, though low capacity compared to a Li-ion cell
  – High energy density compared to a capacitor, though lower than a Li-ion cell
  – High power density
  – Low self-discharge (<5% voltage drop at 25°C over three months)
  – High reliability
  – Operating temperature ranging from -20°C to 70°C

LICs are quite suitable for applications which require a high energy density, high power density and excellent durability.

Potential applications are, for example, in the fields of wind power generation systems, photovoltaic power generation systems, UPS, voltage sag compensation.
Keywords

variable speed multi-pole PMSG with back-to-back full-scale converters
wind power plant

PFC Capability of WTG and WPP with VSM and ES
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What To Do -- VSM

• Different control methods
  – Power-Angle control or Vector-Current control
  – Converter works as a current source or voltage source

• Adaptive parameter adjustment
  – Real time selection of the moment of inertia in different phases of oscillation

• Without dedicated PLL

• Different control schemes based on different models of SG (Synchronous Generator)
  – Not only frequency control, but also voltage control
  – Additional harmonics and unbalance compensation
  – FRT (Fault Ride Through) capability
What To Do

• Energy Storage
  – Type selection: what kind of parameters should be considered, values
  – Location: DC bus or PCC

• PFC Capability of Wind Power Plants with VSM and ES
Thank you for your time!

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