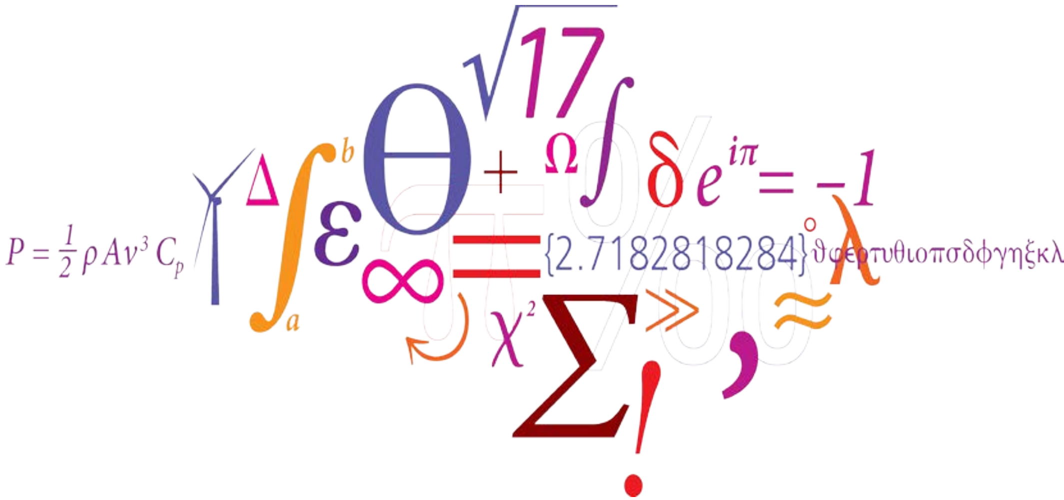
# Enhanced Frequency Control Capability from Wind Turbine Generators and Wind Power Plants

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# Outline

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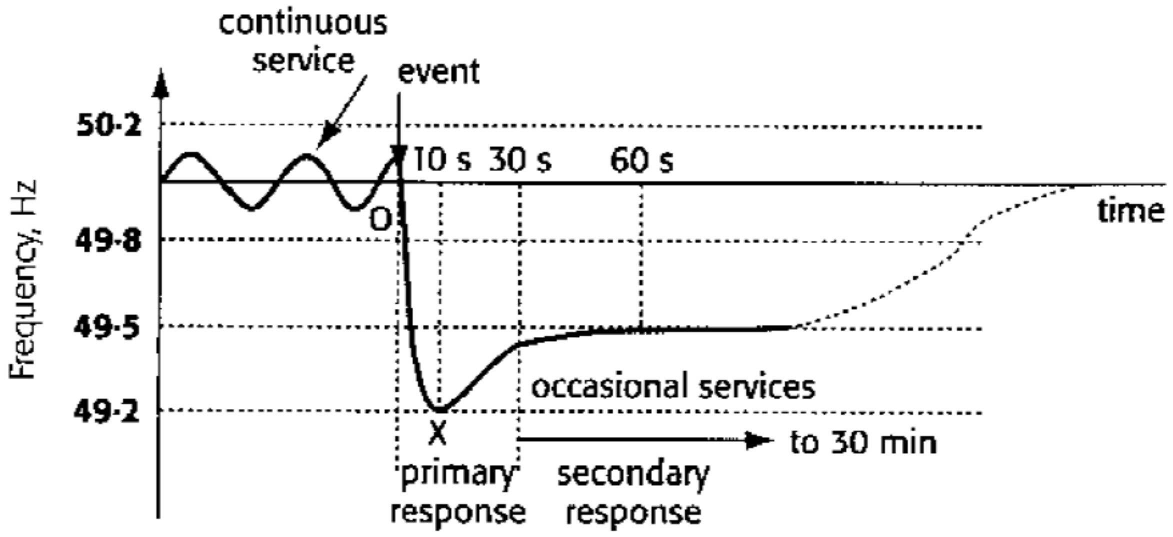
# PFC (Primary Frequency Control)

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

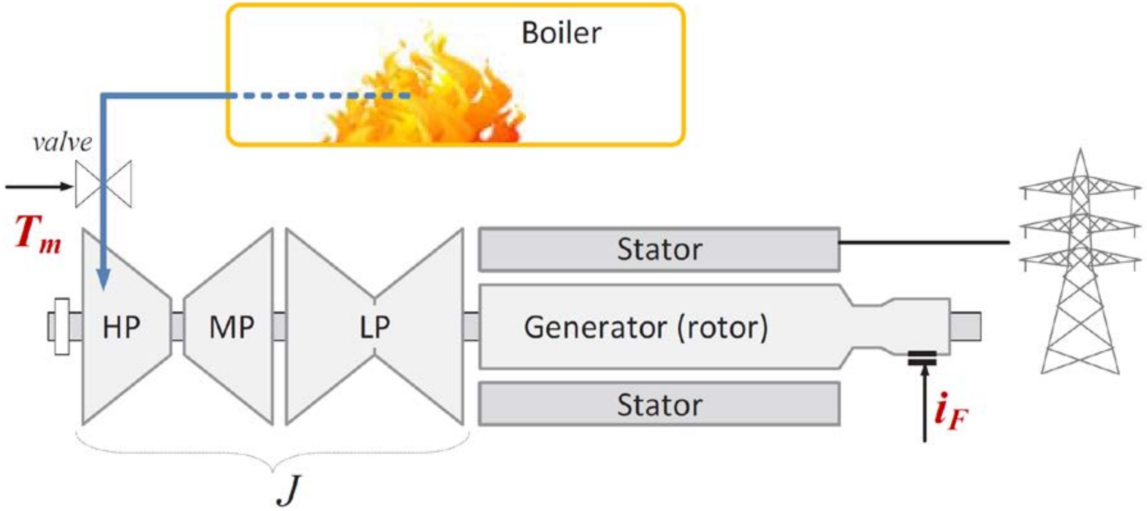





Ekanayake, Janaka, Lee Holdsworth, and Nick Jenkins. "Control of DFIG wind turbines." Power Engineer 17, no. 1 (2003): 28-32.

# 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;

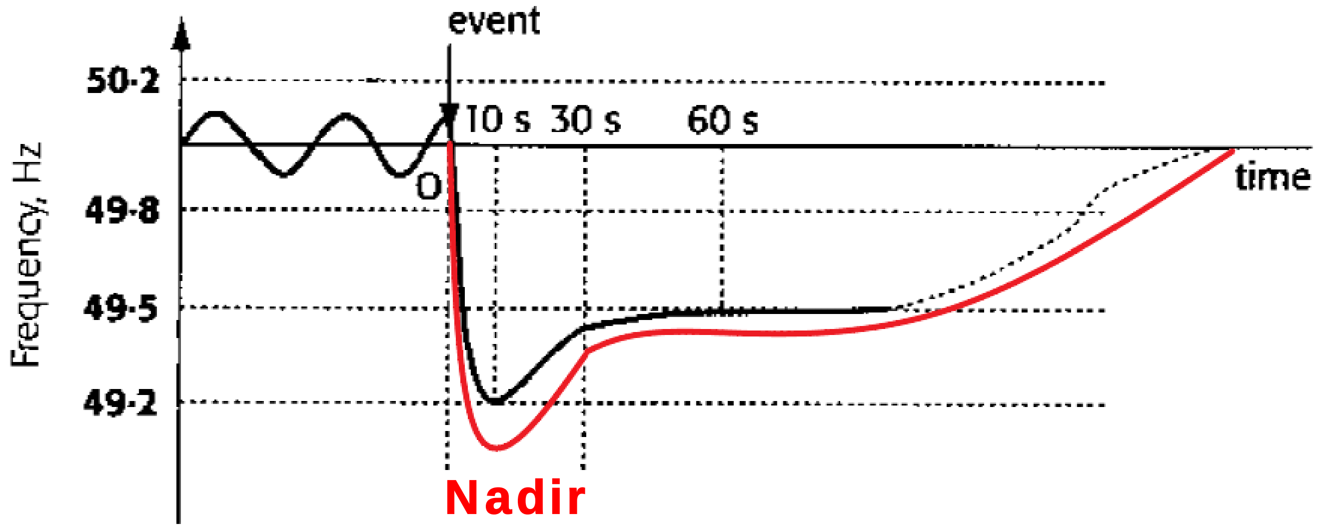





Cvetkovic, Igor, Dushan Boroyevich, Rolando Burgos, Chi Li, and Paolo Mattavelli. "Modeling and control of grid-connected voltage-source converters emulating isotropic and anisotropic synchronous machines." In Control and Modeling for Power Electronics (COMPEL), 2015 IEEE 16th Workshop on, pp. 1-5. IEEE, 2015.

# 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;





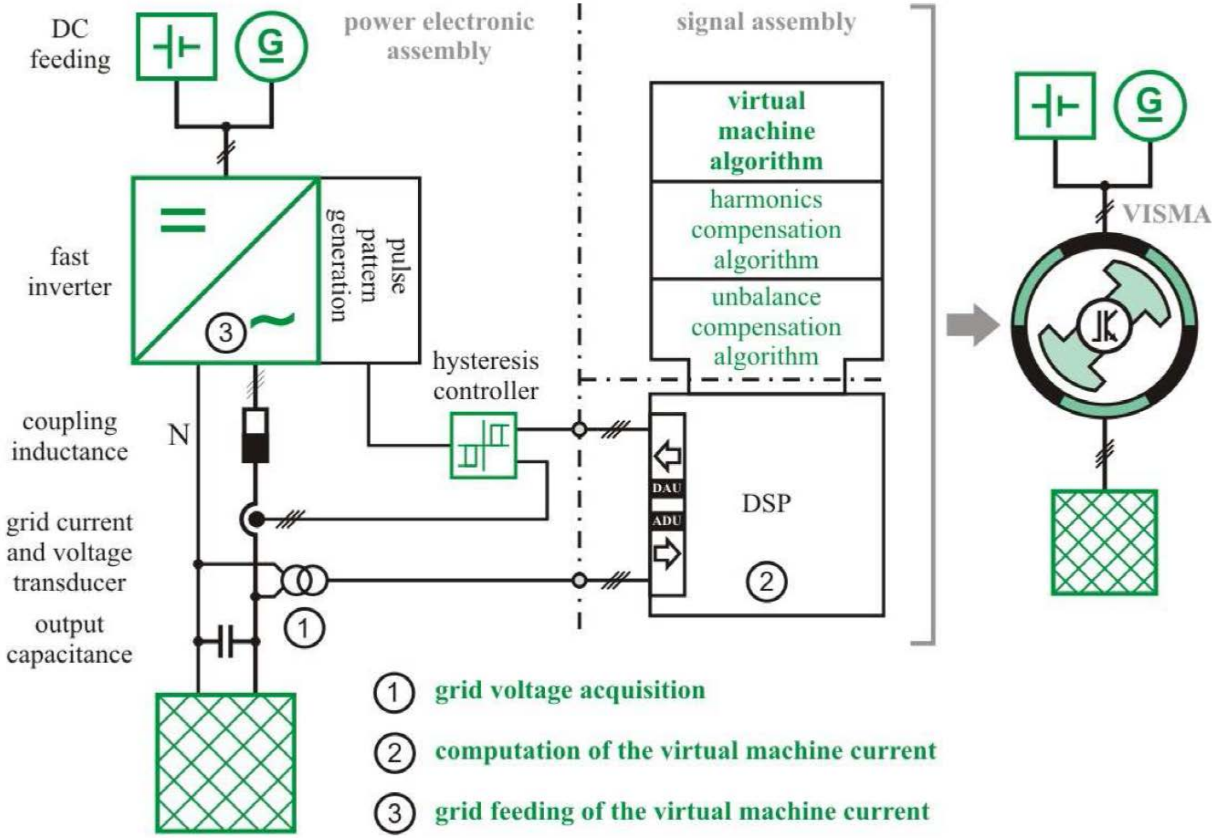

Ekanayake, Janaka, Lee Holdsworth, and Nick Jenkins. "Control of DFIG wind turbines." Power Engineer 17, no. 1 (2003): 28-32.

# Outline

# 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;



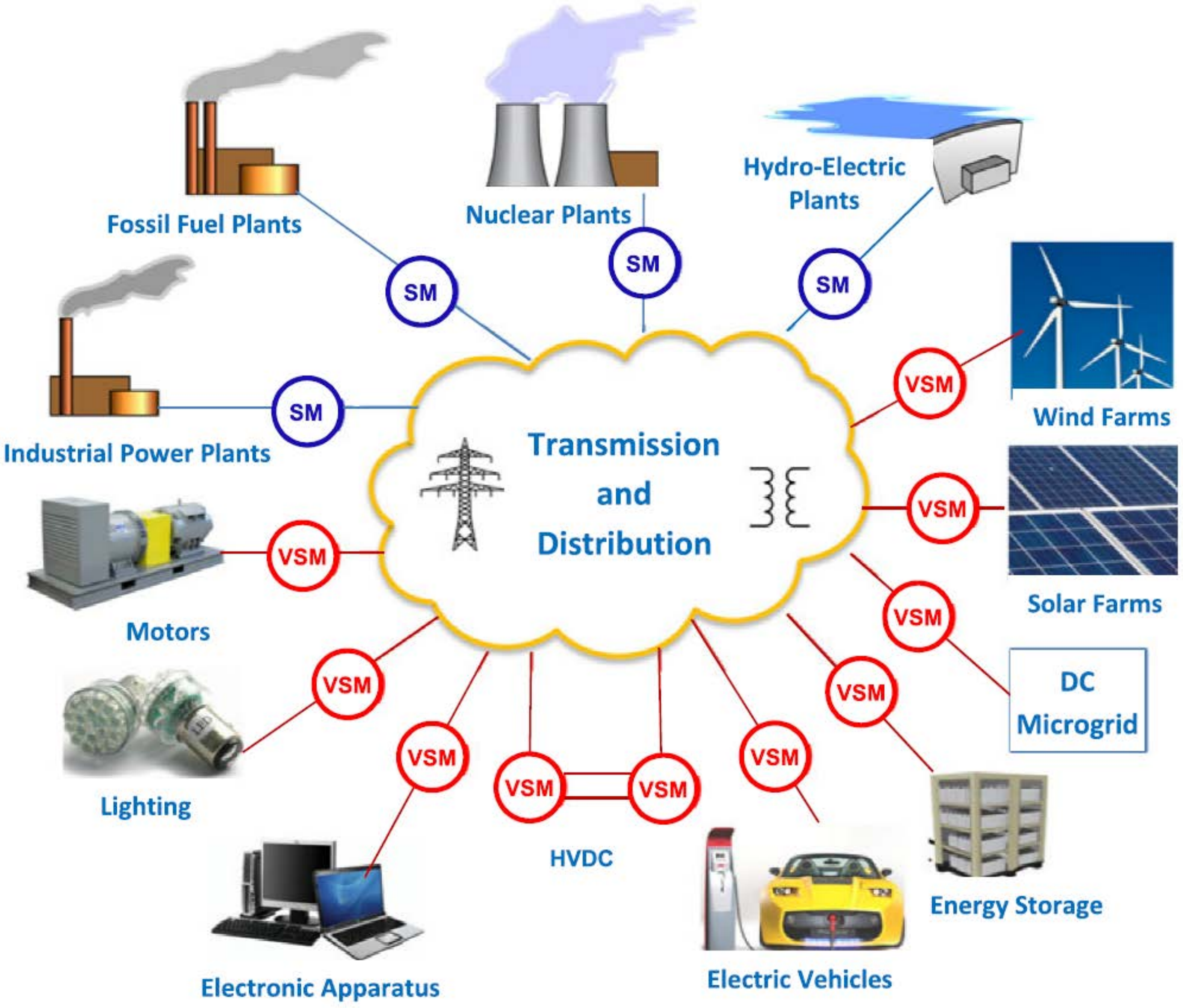


BECK, Hans-Peter; HESSE, Ralf. Virtual synchronous machine. In: Electrical Power Quality and Utilisation, 2007. EPQU 2007. 9th International Conference on. IEEE, 2007. p. 1-6.

Hesse, Ralf, Dirk Turschner, and Hans-Peter Beck. "Micro grid stabilization using the Virtual Synchronous Machine (VISMA)." In *Proceedings of the International Conference on Renewable Energies and Power Quality (ICREPQ'09), Valencia, Spain*, pp. 15-17. 2009.

# VSM (Virtual Synchronous Machine)

- A unified interface of converter for grid integration






ZHONG, Qing-Chang. Power-electronics-enabled autonomous power systems: Architecture and technical routes. IEEE Transactions on Industrial Electronics, 2017, 64.7: 5907-5918.

# VSM (Virtual Synchronous Machine)

- From Swing Equation to VSM Control

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

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

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

$$K_I = J\omega_n = \frac{2HS_n}{\omega_n}, \left(H = \frac{J\omega_n^2}{2S_n}\right)$$

$$K_P = D\omega_n$$

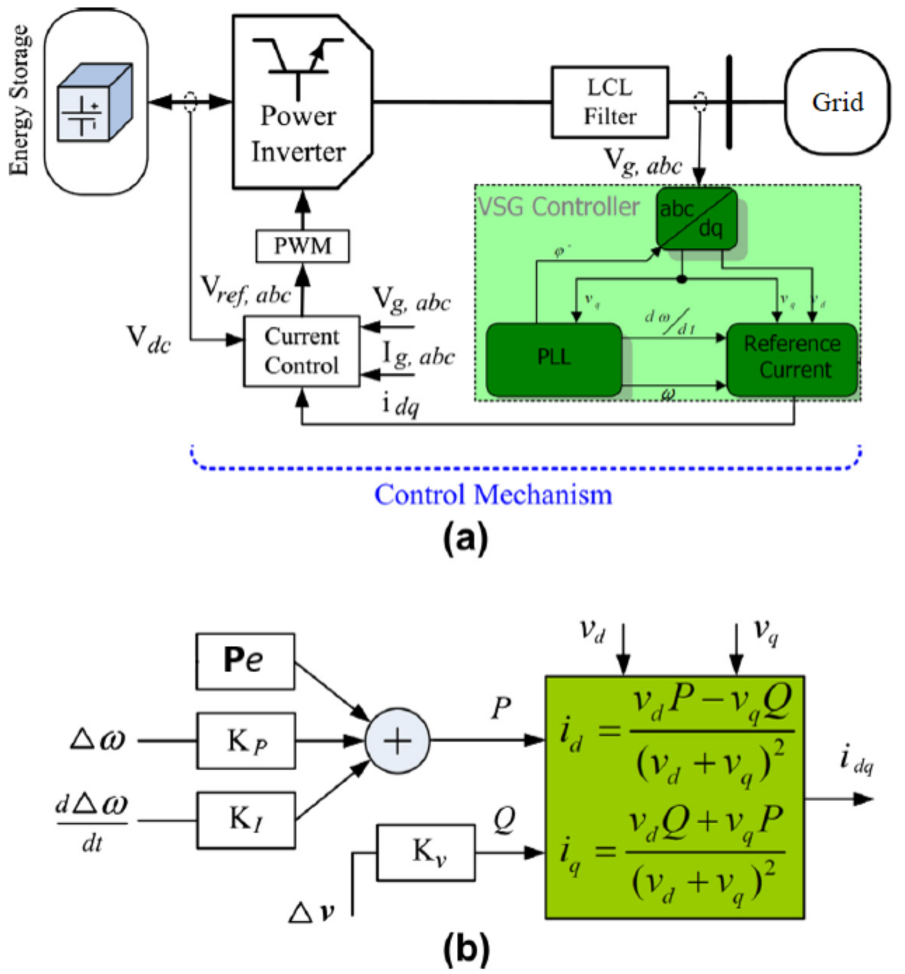



Fig. 5. VSG structure using PLL: (a) detailed framework, (b) reference current block.


BEVRANI, Hassan; ISE, Toshifumi; MIURA, Yushi. Virtual synchronous generators: A survey and new perspectives. International Journal of Electrical Power & Energy Systems, 2014, 54: 244-254.

# Type 4 WTG (Wind Turbine Generator)

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

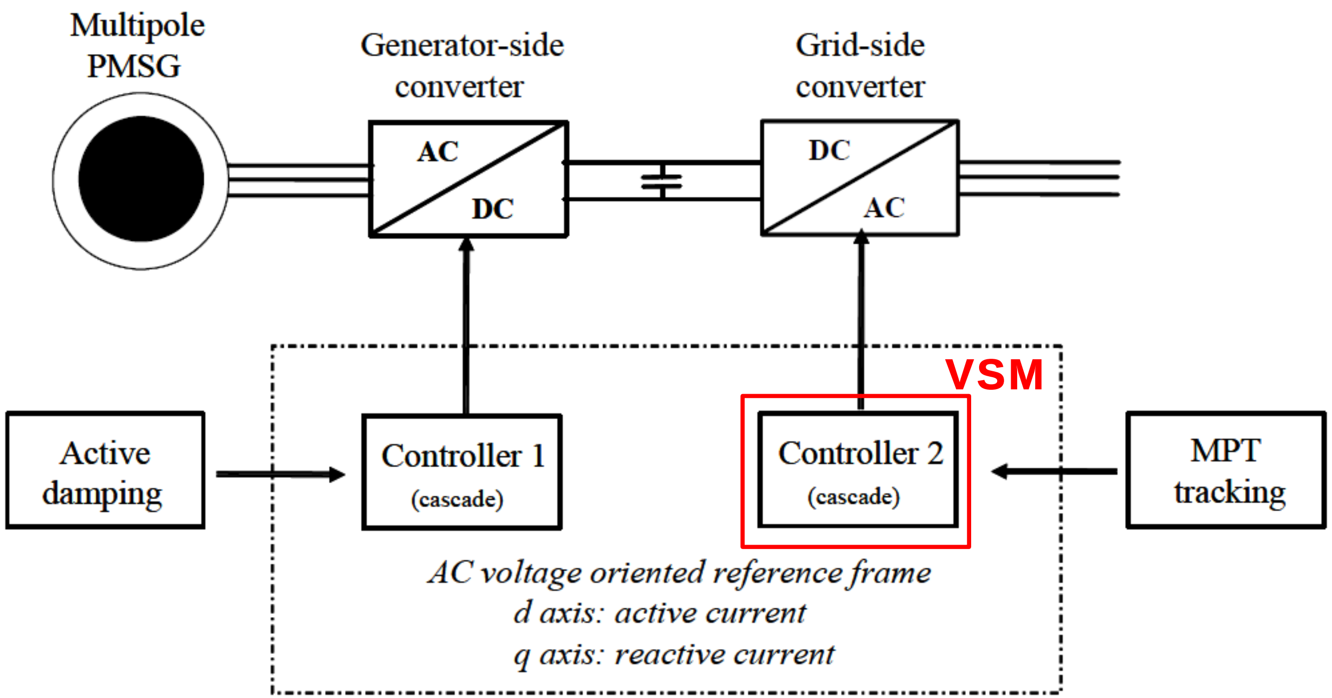



*Figure 142: Power converter control in the variable speed multi-pole PMSG wind turbine.*



HANSEN, Anca D., et al. Dynamic wind turbine models in power system simulation tool DIgSILENT. Report Risoe , 2003, 1-80.

# Type 4 WTG (Wind Turbine Generator)

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

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

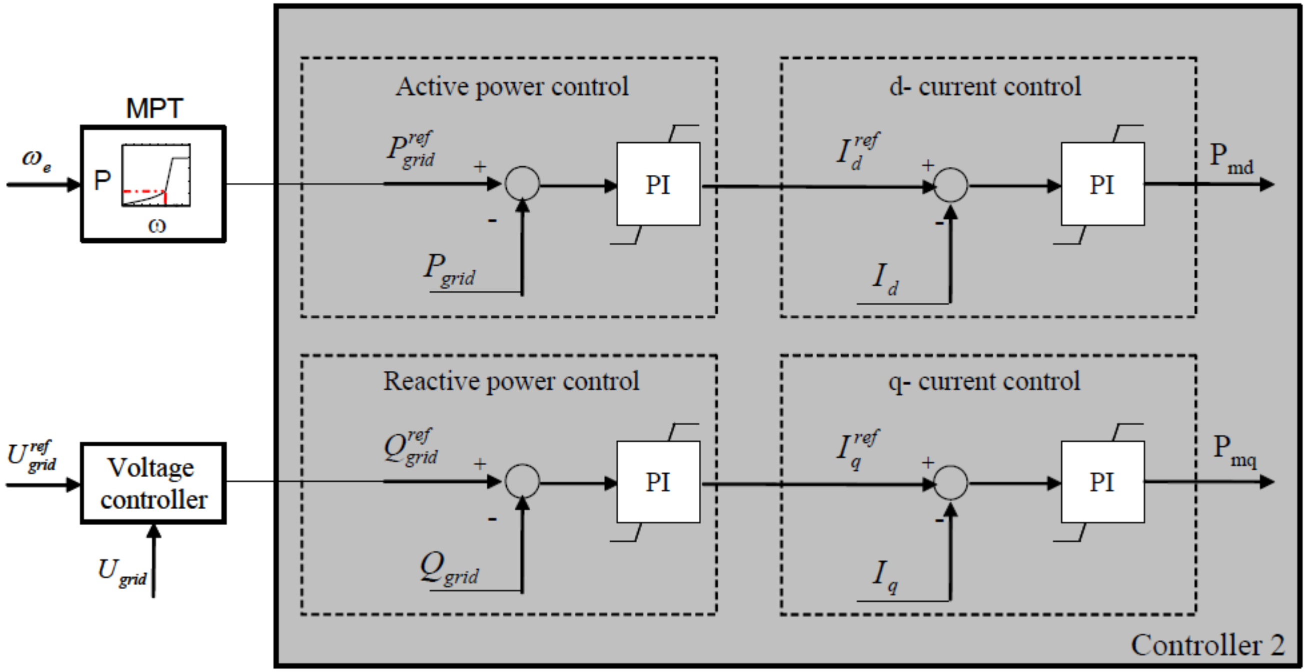



*Figure 151: Grid-side converter control (controller 2).*



HANSEN, Anca D., et al. Dynamic wind turbine models in power system simulation tool DIgSILENT. Report Risoe , 2003, 1-80.

# ES (Energy Storage)

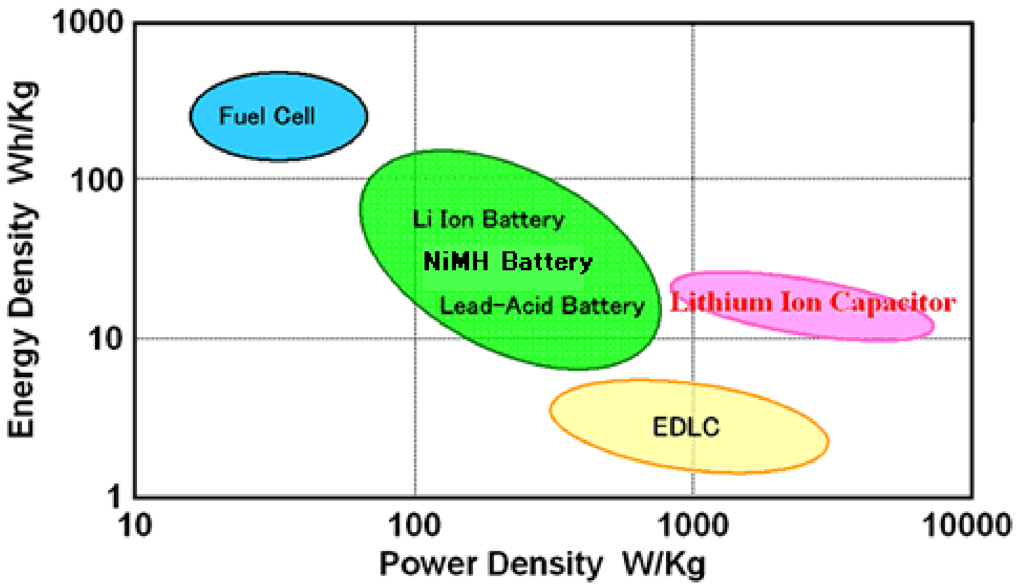
## --LIC (Lithium-Ion Capacitor)

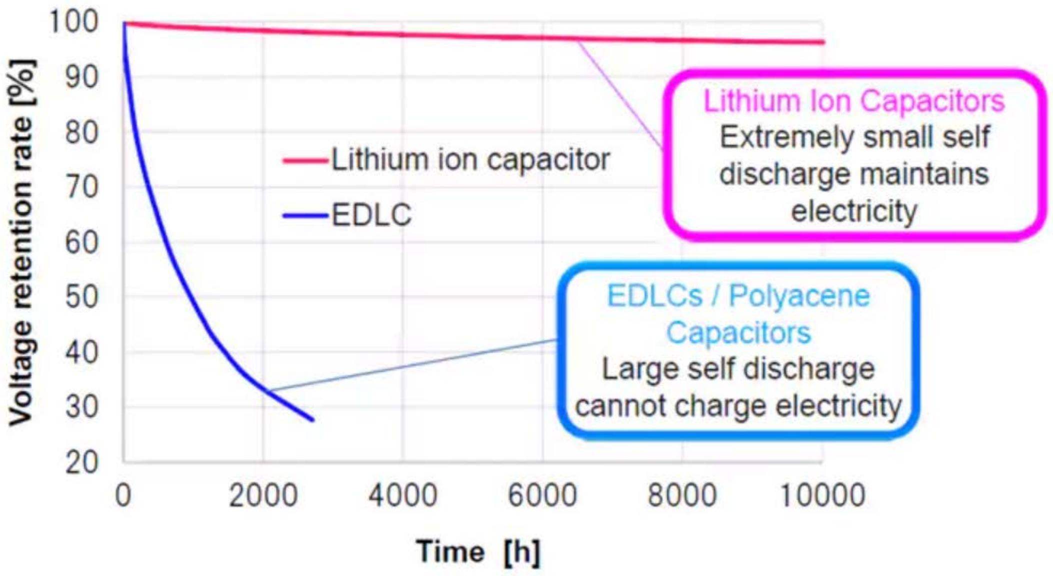
- A lithium-ion capacitor (LIC) is a hybrid electrochemical energy storage device which combines the intercalation mechanism of a lithium-ion battery anode with the double layer mechanism of the cathode of an electric double-layer capacitor (EDLC).
  - A type of supercapacitor
  - Cathode: activated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


*en.wikipedia.org/wiki/Lithium-ion_capacitora*

# 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.



*en.wikipedia.org/wiki/Lithium-ion_capacitora*

*www.mouser.dk/new/taiyo-yuden/taiyo-yuden-lithium-ion-capacitors/*

# 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℃ over three months)
  - High reliability
  - Operating temperature ranging from -20℃ to 70℃

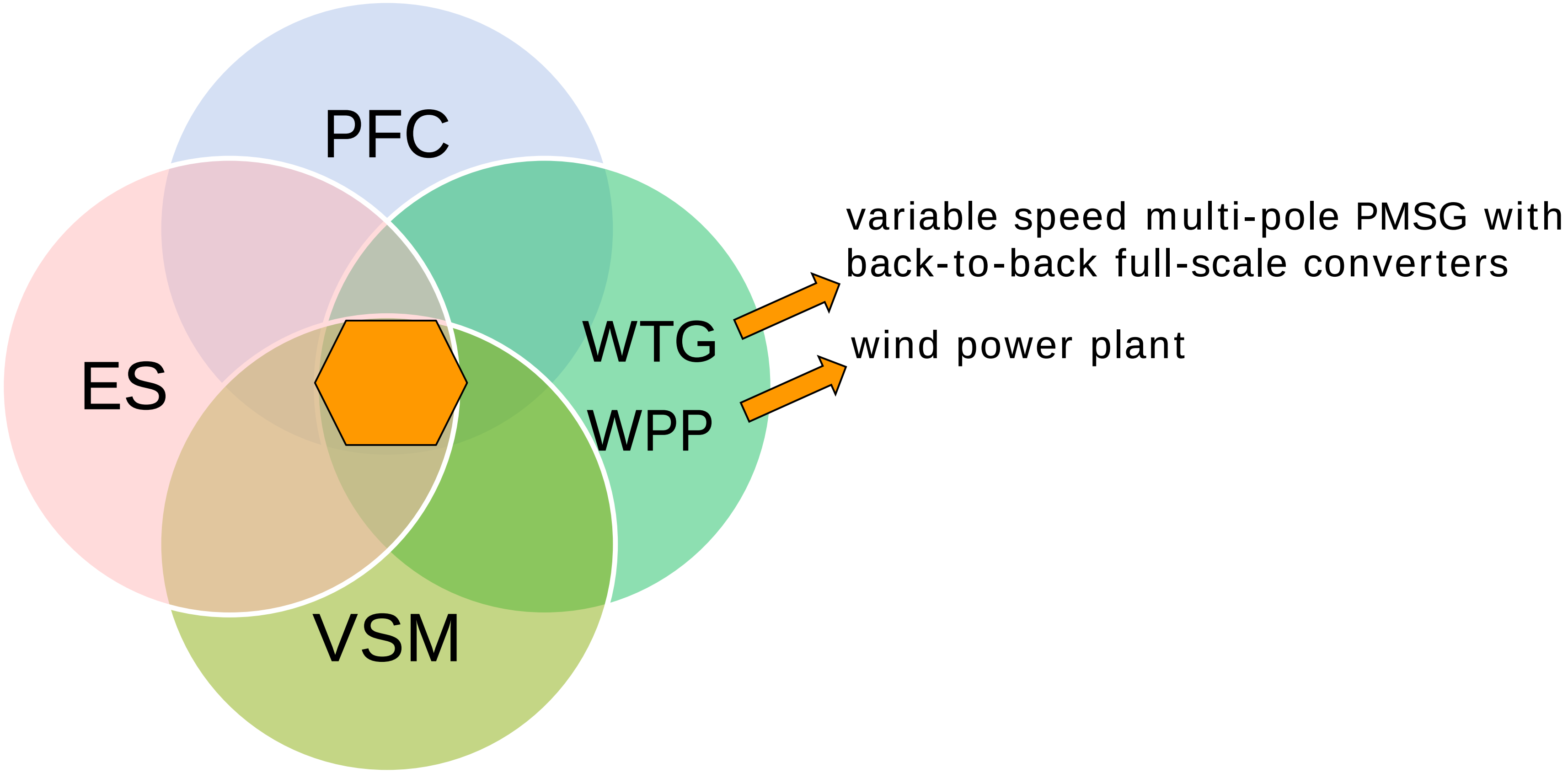
LICs are quite suitable for applications which require a high energy density, high power density and excellent durability.

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



*en.wikipedia.org/wiki/Lithium-ion_capacitora*

# Keywords




**PFC Capability of WTG and WPP with VSM and ES**

# Outline

1 PFC (Primary Frequency Control)

2 VSM (Virtual Synchronous Machine)

3 **Research Plan**

# 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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