University of Pittsburgh

Virtual Inertia: Designing Power Electronic Systems to Behave like Synchronous Machines

Power Electronics Workshop
Sandia National Lab

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University of Pittsburgh Energy GRID Institute

Leadership in this sector is part of Pittsburgh's Heritage; and advancing this legacy is now part of our Responsibility.

The Vision:

1 – Create a national/international consortium focused on serving the electric utility industry and government entities (ONR, DoD, DoE, etc).

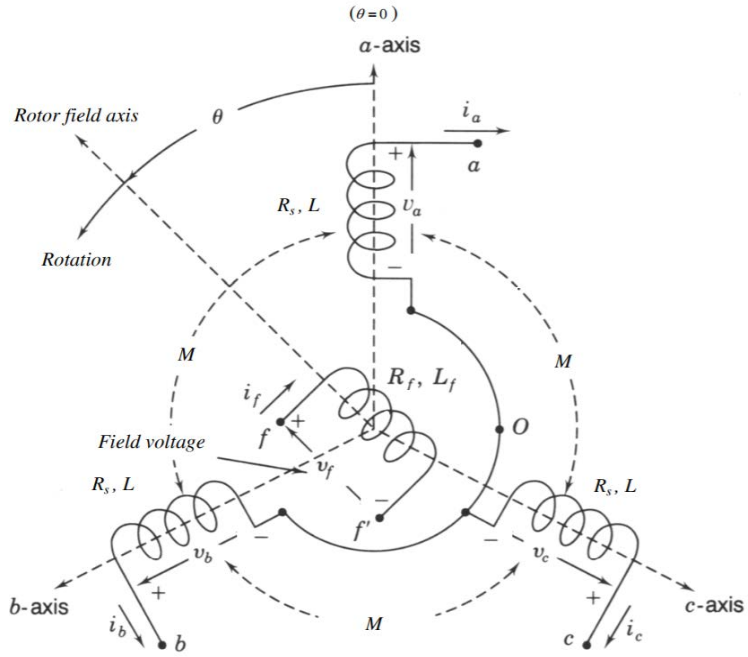
2 – Evaluate and assess both major industry-wide and individual issues and grand challenges.

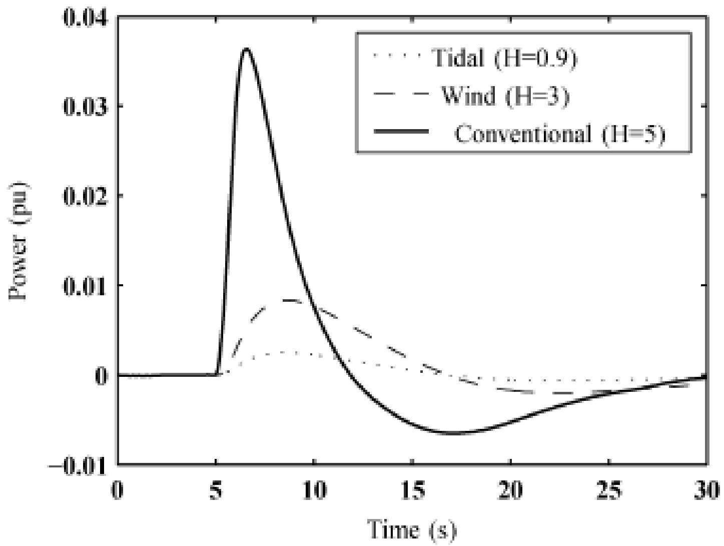
3 – Work in collaboration with various partners towards the development, demonstration, and first-generation deployment of solutions across a broad area of grid technologies, systems, designs, operations, and regulation, as well as addressing market forces and business considerations.

13.8 kV / 4.16kV portion of High Voltage Laboratory at the University of Pittsburgh GRID Institute

Benefits of System Inertia

Review of Mechanical Inertia





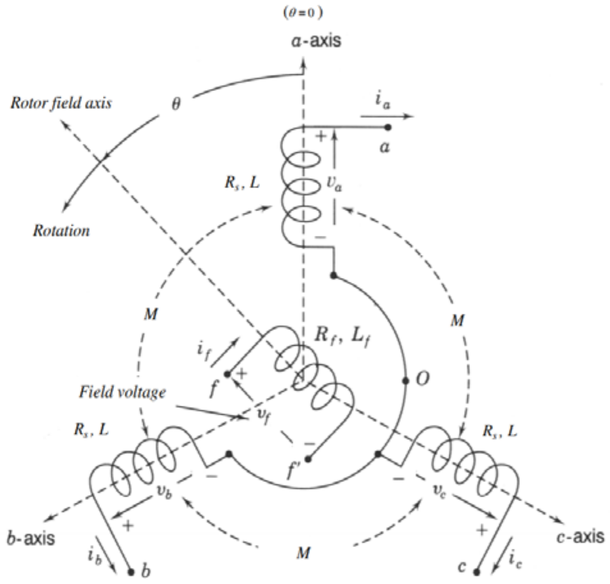
The inertia constant, H, is the amount of stored kinetic energy in the turbine and generator system and is defined below.

$$H = \frac{J\omega_o^2}{2S_N}$$

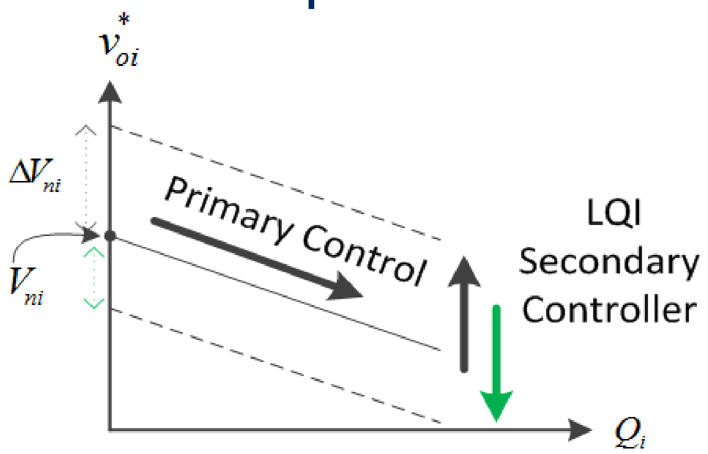
A. Mullane, G. Bryans, and M. O'Malley, "Kinetic energy and frequency response comparison for renewable generation systems," in *2005 International Conference on Future Power Systems*, 2005, p. 6

Q.-C. Zhong and G. Weiss, "Static synchronous generators for distributed generation and renewable energy," in *2009 IEEE/PES Power Systems Conference and Exposition*, 2009, pp. 1–6.

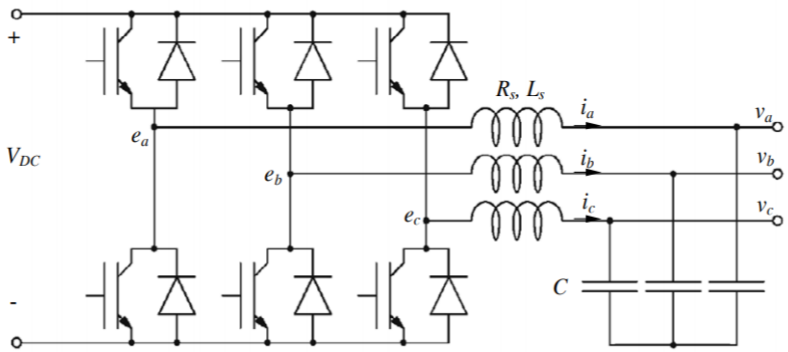
Synchronizing Electric Machines to the Electric Grid



Droop Curves

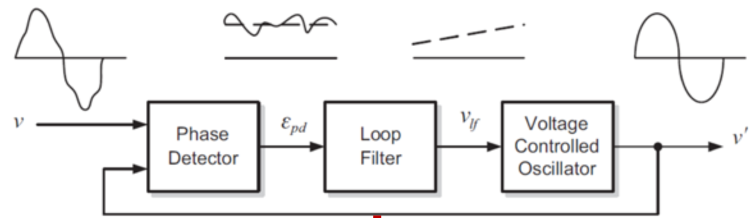


Synchronizing Power Electronics to the Power Grid



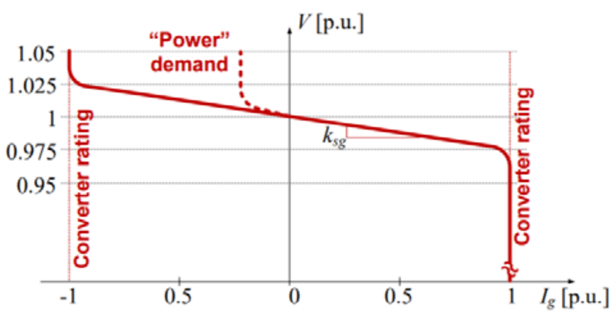
Option #1

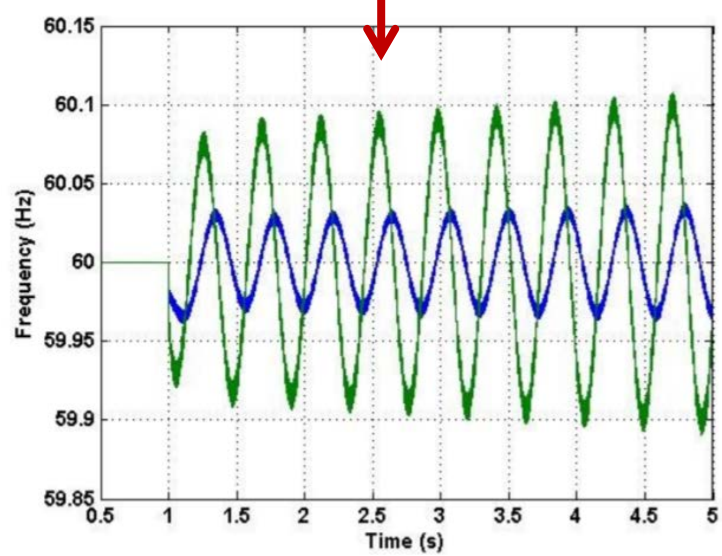
Phase Lock Loops
(Stability Concerns)



Option #2

Static Droop

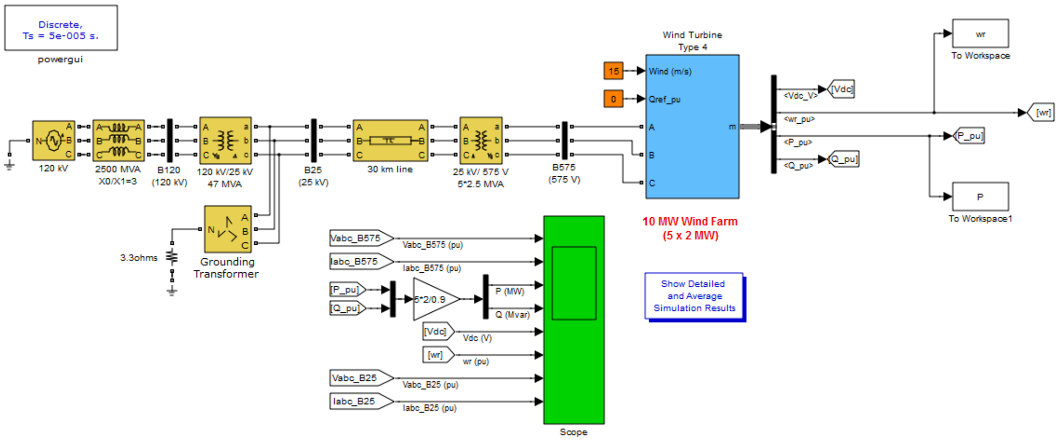




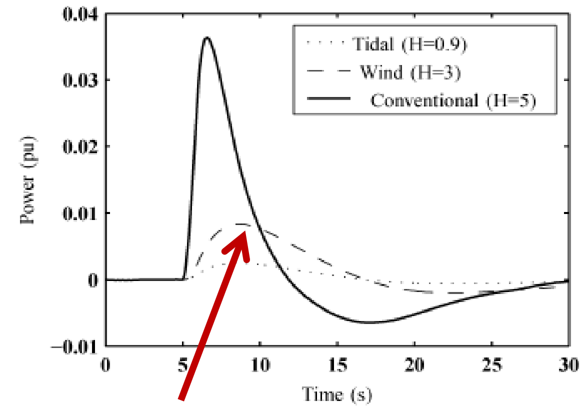
D. Dong, "AC-DC Bus-Interface Bi-directional Converters in Renewable Energy Systems," PhD Dissertation, Virginia Tech, 2012.

I. Cvetkovic, "Modeling, Analysis, and Design of Renewable Energy Nanogrid Systems," MS Thesis, Virginia Tech, 2010.

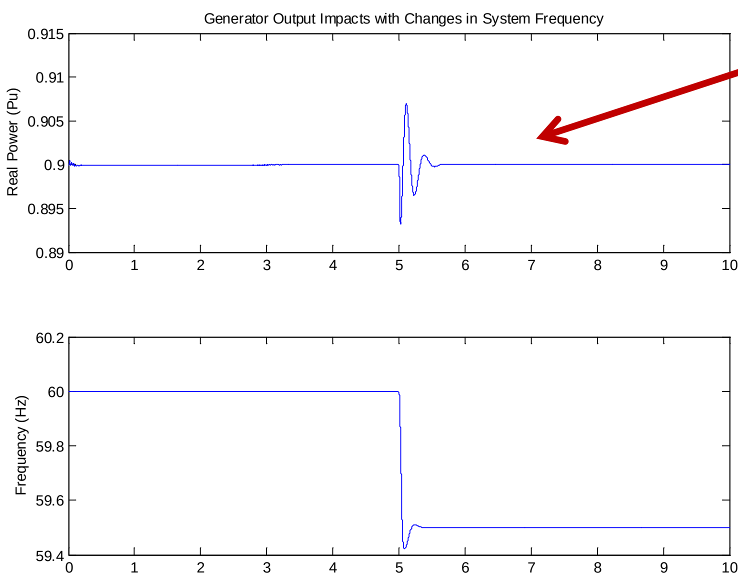
Power Electronic Decoupling & Impacts on System Behavior



Wind Turbine Set-Up in Simulink Demo Models



Full Converter Interface



Generator not dynamically responding (decoupled) with frequency change.

<u>Other Areas</u>

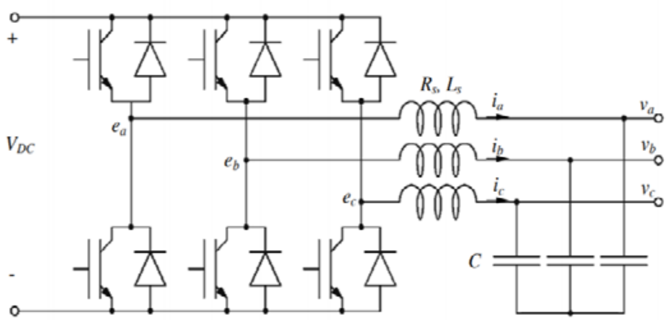
1. HVDC Grids – decoupling effect is <u>**beneficial**</u> to prevent widespread system impacts.

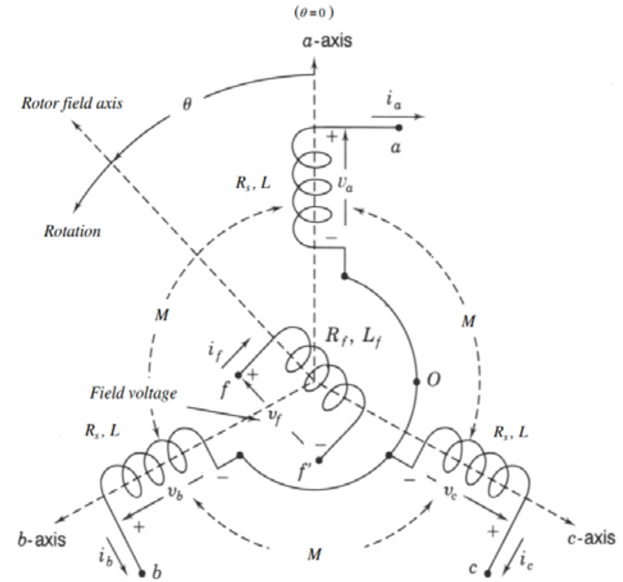
2. Microgrids – <u>**Warning**</u>. Nominal current and fault current are on the same order of magnitude because the inertia response is not prominent.

Growing Trend of Virtual Inertia

Virtual Synchronous Machine Control

How can we make power electronics behave like synchronous machines? Through system control.





Mechanical systems		Electrical systems
Torque T	≡	Current I_{dc}
Angular speed Ω	≡	Voltage v_{dc}
Moment of Inertia J	≡	Capacitance C
Friction k_f	≡	Conductance G

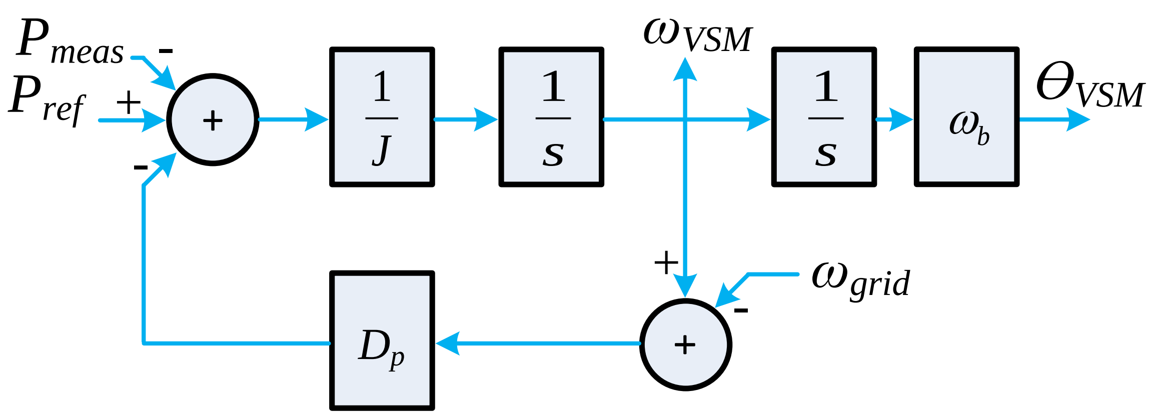
I. Cvetkovic *et al.*, "Experimental verification of a virtual synchronous generator control concept," *2016 IEEE 17th Workshop on Control and Modeling for Power Electronics (COMPEL)*, Trondheim, 2016, pp. 1-8

Virtual Synchronous Machine Control

- It is well known that a synchronous machine (SM) can synchronize with each other or with the power supply autonomously without the need for external communications.
- VSM control follows the swing equation in order to mimic the desirable inertial dynamics inherent to synchronous machines.

$$J\ddot{\theta} = \left(T_m - T_e - D_p\dot{\theta}\right)$$

$$\ddot{\theta}_{VSM} = \frac{1}{J}\left[P_{ref} - P_{meas} - D_p\left(\omega_{VSM} - \omega_{grid}\right)\right]$$



Swing equation implemented into system control architecture for VSM

Where,
$P = T\omega$
$\omega = \dot{\theta}$

Electrical Stability Performance of the VSM

- Regulation of frequency for a phase disturbance with varying values of damping D_p and inertia J

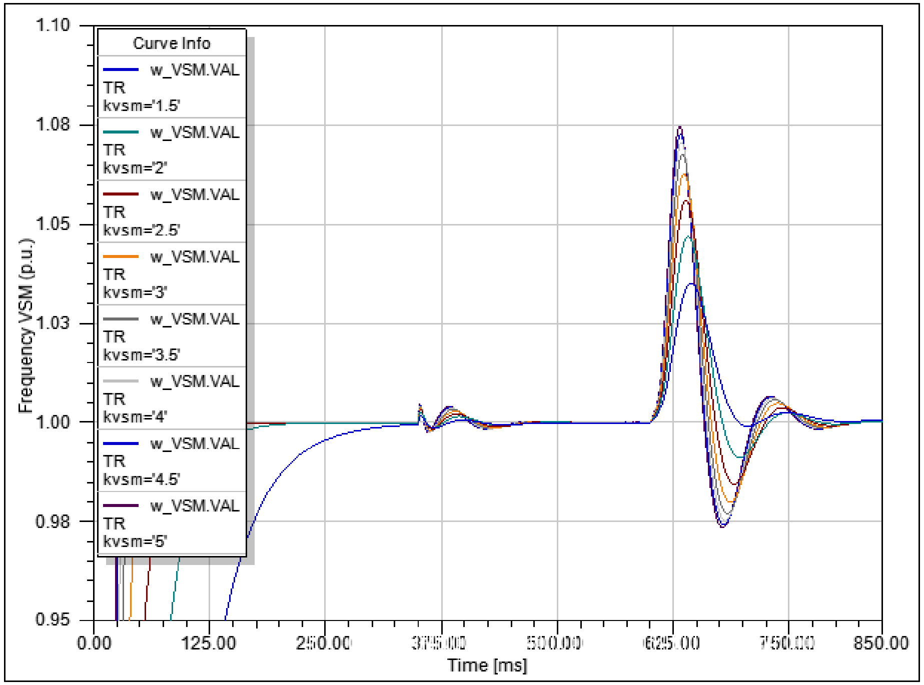
$$Js^2 + D_p s = T_m - T_e = 0$$

$$\rightarrow \quad s(Js + D_p) = 0$$

$$\rightarrow \quad Js = -D_p$$

$$\rightarrow \quad s = -D_p/J$$

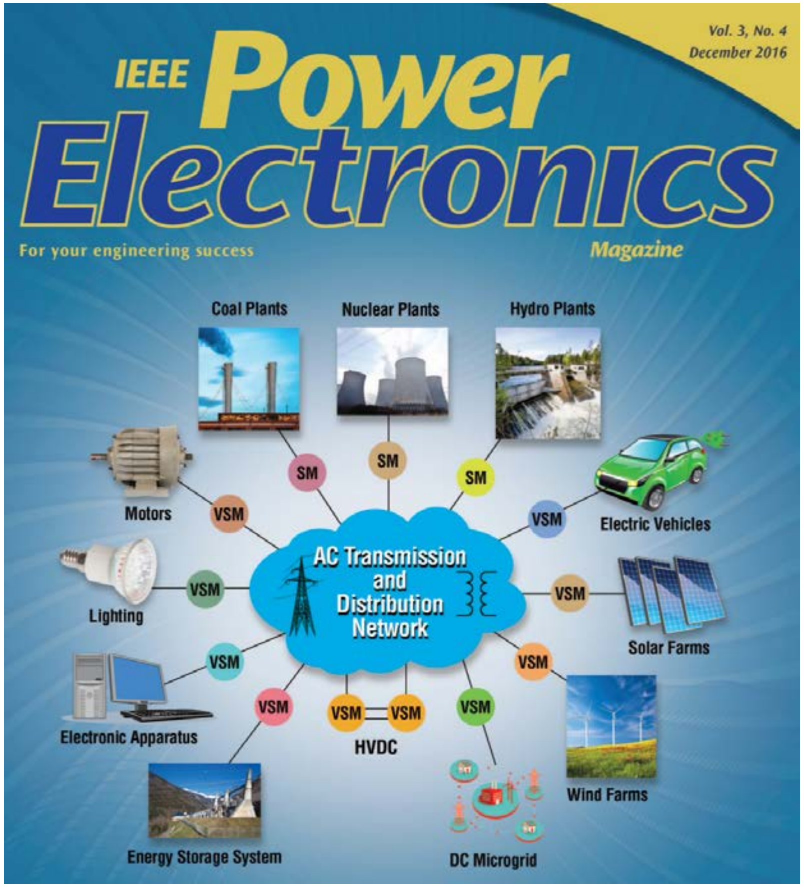
Elements	Description	Value
J	Moment of inertia	{1.5, 2, 2.5, 3, 3.5, 4, 4.5, 5}
D_p	Friction coefficient	{15, 20, 25, 30, 35, 40, 45, 50}
$-D_p/J$	Case ratio with k_{VSM}	-10



VSM frequency for varying values of D_p and J

Concepts Penetrating the Engineering Community

Academia vs. Practicing Engineers



When first exposed to concept, engineers have asked:

1. Where is the inertia physically coming from for the power electronics system?
2. Are we truly advancing by looking at mimicking a synchronous machine?
3. Is synchroverter a good name given the speed of response of power electronics compared to generators?

Questions?

Contact Information

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