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Virtual Synchronous Machines for Supporting Flexible Operation of Distribution Systems

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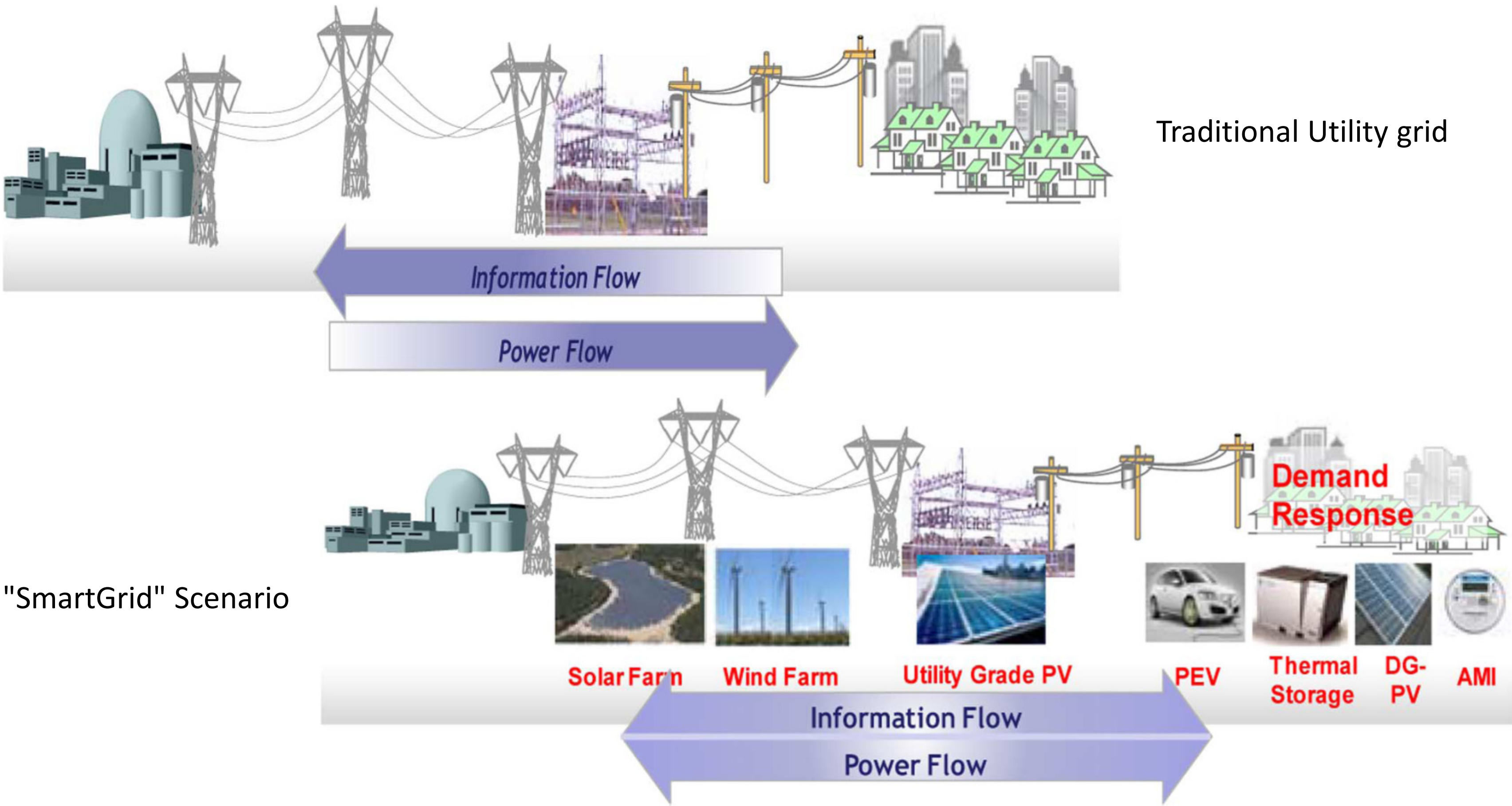
Traditional grids vs. "SmartGrids"

Traditional Utility grid



"SmartGrid" Scenario

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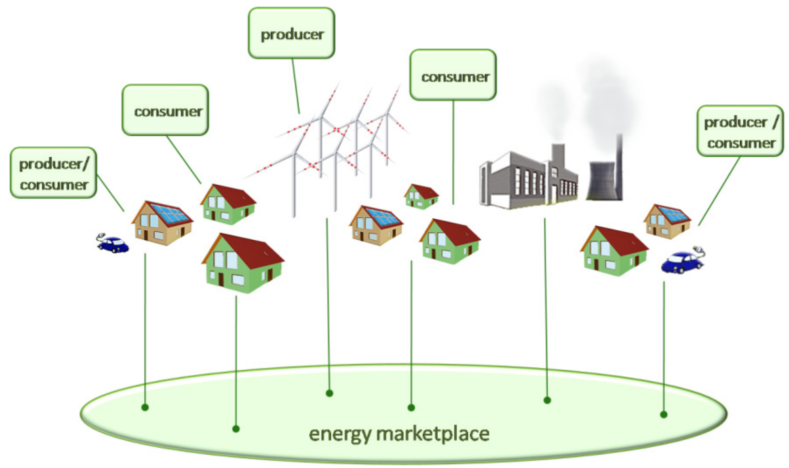
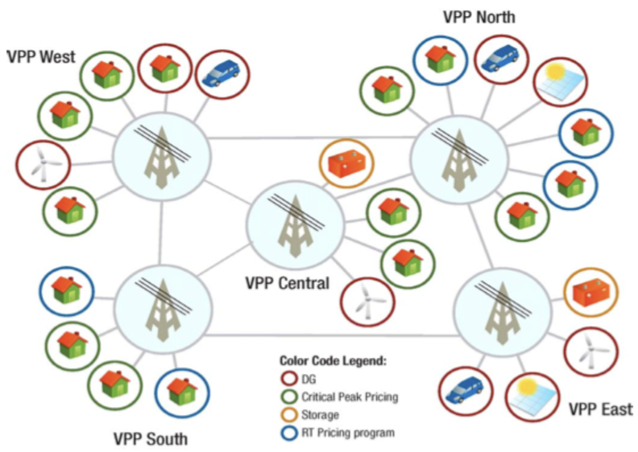
Virtual Power Plant (VPP)

- Aggregating energy resources for dispatchable operation
- Commercial VPP
  - For operation in the market
- Technical VPP
  - For power system operation and control
    - Demand-Response VPP (load)
    - Supply-Side VPP (generation)
    - Mixed-Asset VPP (generation load and storage)
- Requires extensive ability for:
  - Data acquisition and communication
  - Remote and local control



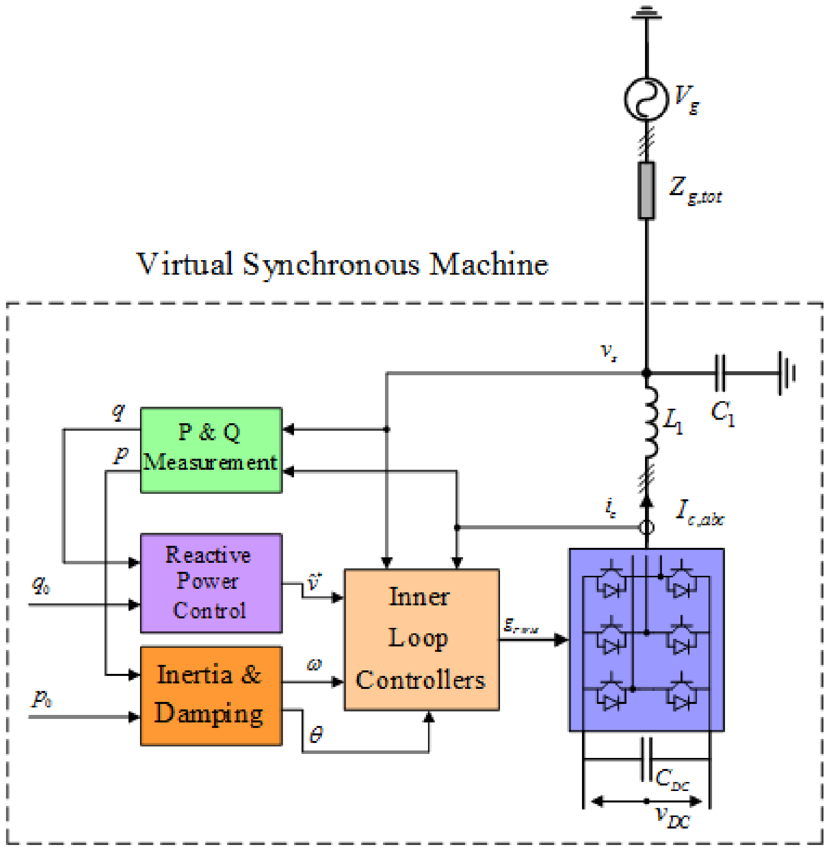
Aggregations of Demand Response & Distributed Generation



D. Pudjianto, C. Ramsay, G. Strbac, "Virtual power plant and systems integration of distributed energy resources," in *IET Renewable Power Generation, Vol. 1, No. 1, 2007, pp. 10-16*
Karlsruhe Institute of Technology, http://www.commputation.kit.edu/73.php
http://envirosynthesis.blogspot.com/2010/05/ventyx-virtual-power-plants.html

Virtual Synchronous Machine (VSM)

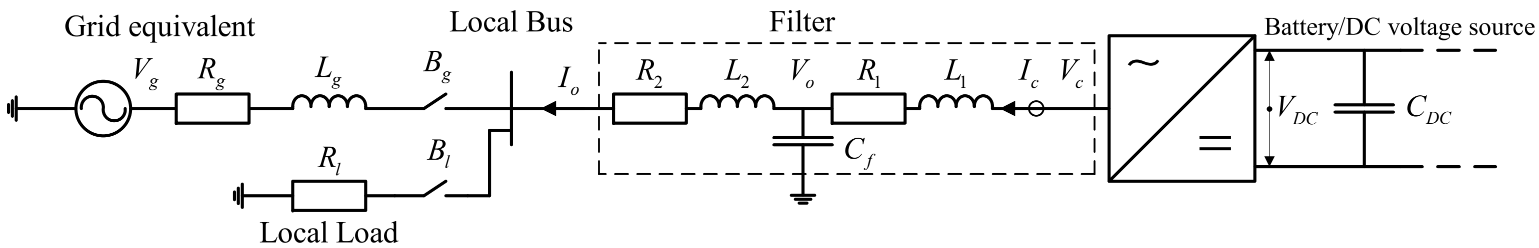
- Power Electronic converter controlled to emulate the behavioral characteristics of synchronous machines
- Concept first introduced about one decade ago
  - Several possible implementations
- Parameters are not limited by physical design constraints
- Emulated characteristics:
  - Inertia and damping
  - Corresponding power-balance-based grid synchronization mechanism
  - Active and reactive power control mechanisms



S. D'Arco, J. A. Suul, "Virtual Synchronous Machines – Classification of Implementations and Analysis of Equivalence to Droop Controllers for Microgrids," in *Proceedings of IEEE PES PowerTech 2013*, Grenoble, France, 16-20 June 2013, 7 pp.

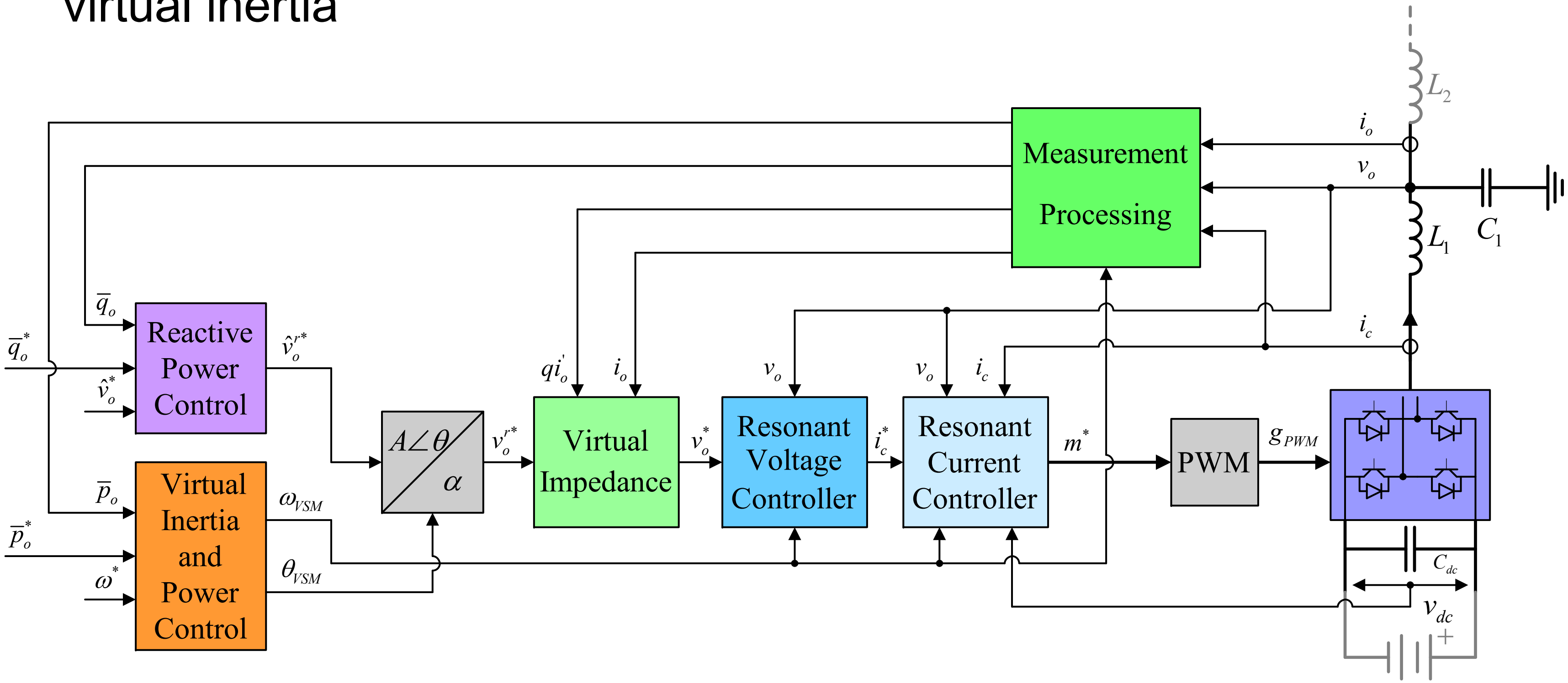
VSMs in distribution systems

- VSMs can provide ancillary services in local grids:
  - Power-frequency control
  - Reactive power control
  - Inertia emulation
  - MicroGrid operation with temporary islanding
- Most residential sources and loads in distribution systems have single-phase grid interfaces
  - EV chargers
    - Load with storage
    - Possibility for temporary islanding
  - Domestic PV systems
    - Down-regulation capability
- Typical configuration:



Single-phase VSM for EV charger

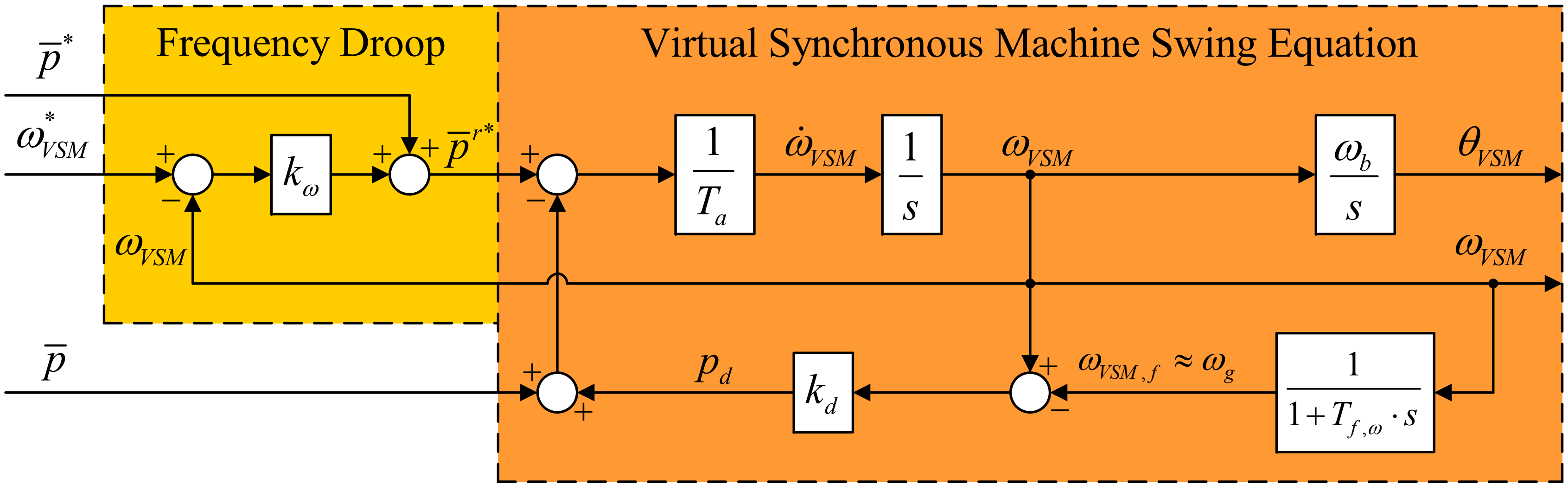
- Assuming bi-directional EV charger for V2G/V2H operation
- Single-phase VSMs require particular attention to implementation of virtual inertia



J. A. Suul, S. D'Arco, G, Guidi, "Virtual Synchronous Machine-based Control of a Single-phase Bi-directional Battery Charger for Providing Vehicle-to-Grid Services," in *Proceedings of the 9th International Conference on Power Electronics*, ICPE – ECCE Asia, Seoul, Korea, 1-5 June 2015, 8 pp.

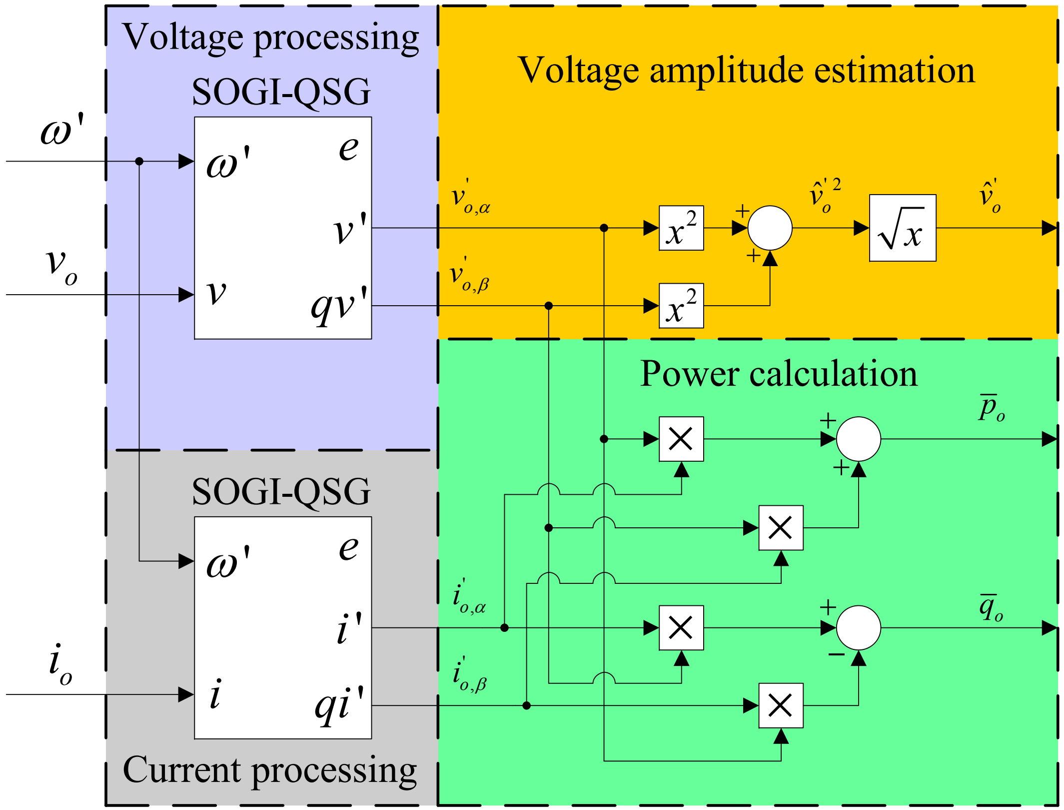
VSM Power Control Mechanism

- Based on synchronous machine swing equation
  - Reduced order approximation of the inertia and damping of a traditional synchronous machine
  - Provides a frequency and phase angle reference that can be used to control the converter
- Reactive power controller can provide voltage amplitude reference



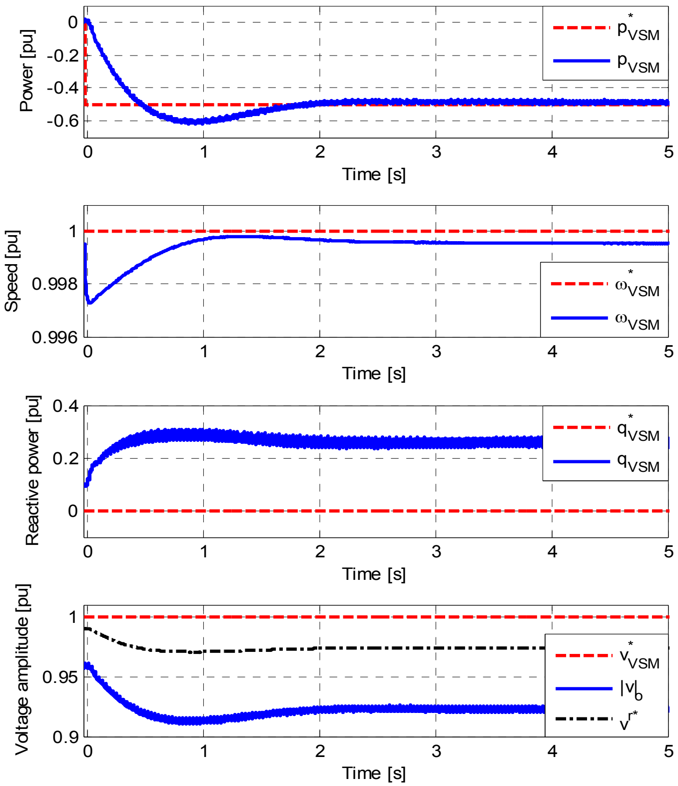
Active and reactive power feedback

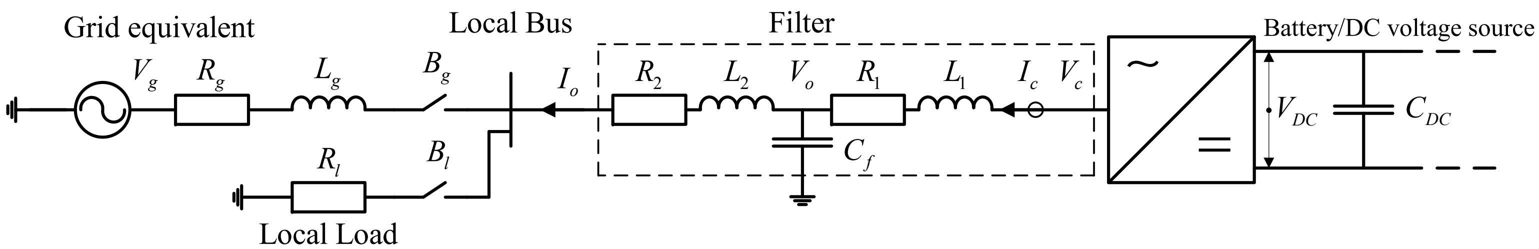
- Single-phase power circuit implies double frequency oscillations in active and reactive power
- A virtual two-phase system is established to calculate active and reactive power feedback
  - Avoids influence of double frequency power oscillations on virtual inertia



Examples of results – dynamic response

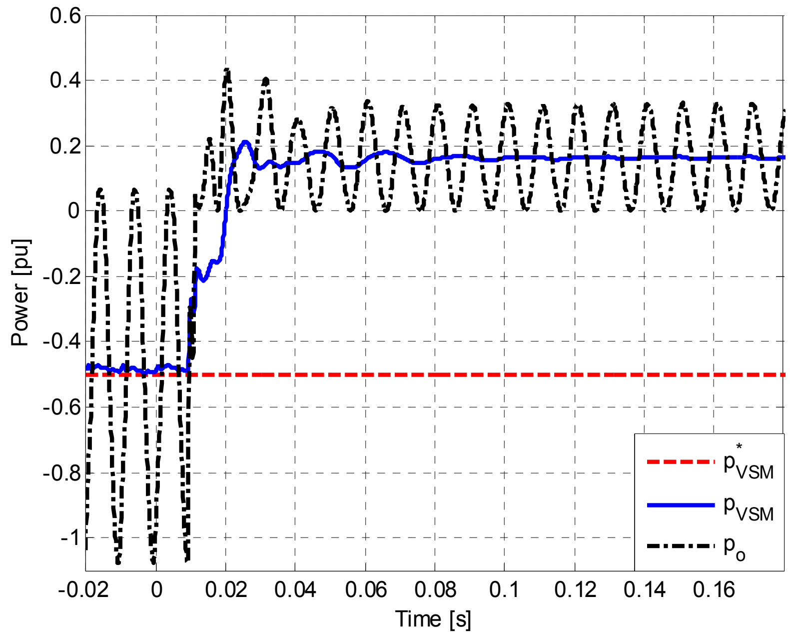
- Single-phase EV-charger
  - 3.3 kVA, 230 V_{RMS}
- Response to power step
  - Well damped emulation of inertial behavior
  - Reactive power droop control on voltage amplitude ensures reactive power compensation when voltage drops due to increased load

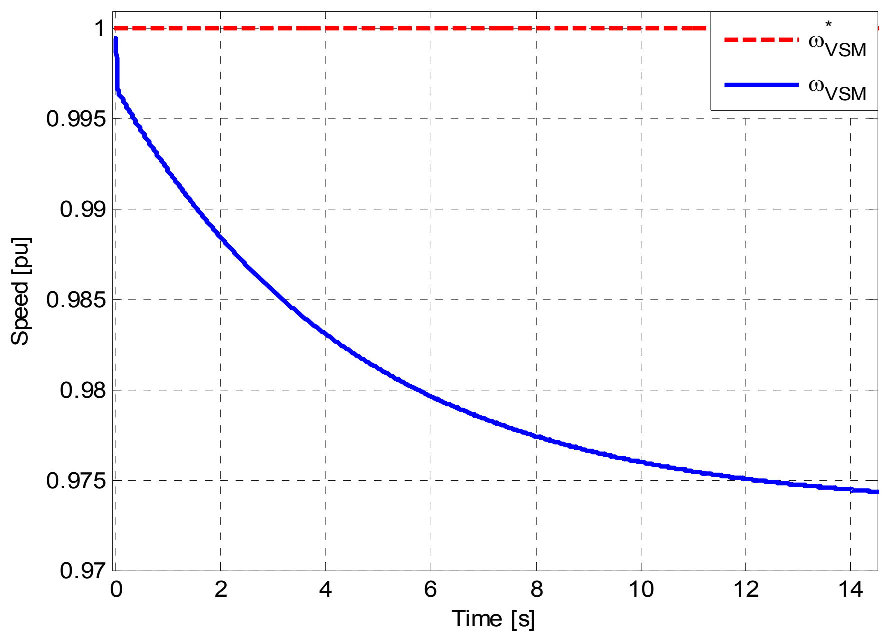




Examples of results - islanding

- Response to sudden islanding
  - Power of local load is immediately supplied from the EV battery
  - No severe transients
  - Local frequency slowly settles to new value according to droop settings





Summary

- Virtual Synchronous Machines can provide ancillary services and support flexible operation of distribution systems
  - Inertia emulation, active and reactive power control based on local measurements
  - References and operational settings provided from higher level system controllers
  - Can operate as part of Virtual Power Plants or any other system-level control
  - Can ensure control of local MicroGrids in grid-connected and islanded modes
- Load and generation at distribution system level are often based on single-phase grid interfaces
  - Three-phase VSM implementations cannot be directly applied for single-phase systems
  - Active and reactive power oscillations of single-phase systems can be avoided in the VSM-based control by utilizing a virtual two-phase system for calculating local feedback signals
- With both three-phase and single-phase implementations VSMs provide a suitable general framework for local control that can support flexible operation of distribution systems

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