Functional assessment of DFIG and PMSG-based wind turbines for grid support applications (S-73G)

Graduate Student and co-PI: Nicholas David
PI: Dr. Zhaoyu Wang

Sept. 1, 2016 – Aug. 31, 2018

PSERC IAB Meeting
May 16-18, 2018

Problem Summary

Problem statement: Wind turbine generators are not completely understood, and there is room to make better use of renewable energy resources to improve power system performance.

1) A discrepency exists between claimed and measured DFIG reactive power capability and requires investigation.

2) Misconceptions exist regarding the cability of DFIG rotor inertia in providing frequency regulation in high-wind power systems.

3) A gap exists in DFIG control capability when applied in low-inertia power systems.

Project Components

1) Discrepancy with turbine manufacturer and measured reactive power capability
   a. Derivation and case-studies to prove the discrepancy.
   b. Propose an improvement of range with alternative terminal connection (grid-connected rotor vs. grid-connected stator).

2) DFIG inertial frequency response capability
   a. Investigate response of electromagnetic coupling to rotor mass.
   b. Test a generator‘s inertial response with hub-emulating flywheel.
   c. Demonstrate natural frequency response capability, but what control is needed?

3) Transient frequency control for low-inertia power systems
   a. Develop control technique to complement existing DFIG systems.
   b. Creates a specified balance of ’electrical’ and ’mechanical’ dynamics (deviation of grid frequency v.s. deviation of rotor speed).

Objectives

Objective I: Verify claims of reactive power capability to meet RTE requirement of providing $Q_{grid} = \pm 0.3 P_{rated}$ VAR, particularly at low wind speeds.

Objective II: Hardware demonstration of the hypothesis that it is possible to rely on physical inertia of DFIG wind turbines to support load-transients in power systems having low inertia and portfolios rich in wind energy.

Objective III: Fill the gaps of DFIG inertial-response capability to achieve reliable frequency regulation via wind power.

Proposed Approaches

For Objective I:

a) Perform analytical derivations of reactive power generation limits over the wind speed range to validate claims.

b) Propose a type-III wind turbine configuration with grid-connected rotor windings for increased reactive power capability.

For Objective II:

a) Linearize inertial frequency response without controller influence to evaluate natural ability for load-transient support.

b) Simulate existing wind turbine inertial response to local-islanding and load-transient (step-change) operation.

For Objective III:

a) Develop new fast-transient control technique to leverage wind turbine physical inertia to support frequency during load transient.

Outcomes

- Case studies of two DFIGs (one theoretical and one in hardware) show that these generators can meet and exceed requirements of reactive power capability . We do not see theoretically diminished limitation at low wind speed.
- Theoretical inertial response analysis suggests a natural capability for stable load-change support from DFIG wind turbine generators, similar to the action of synchronous generators.
- Developed an inertial response control method to prescribe balance of transient in electrical and mechanical systems (with hardware experimental proof).

Publications:

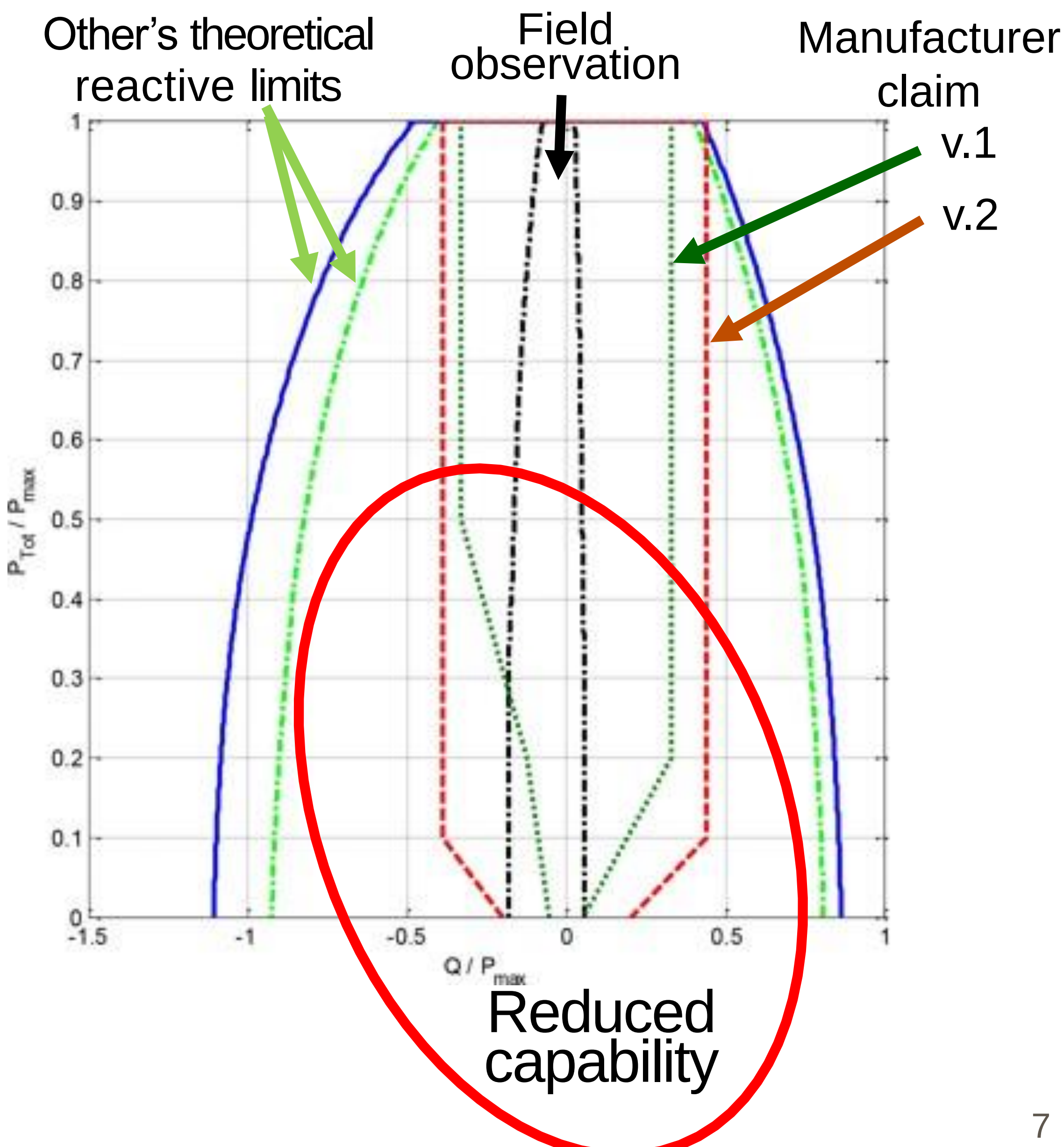
[1] N. David and Z. Wang, "Rotor-Tied Configuration of DFIG Wind Turbines for Improving Reactive Power Support Capability," accepted for *2018 IEEE General Meeting,* August 2018.

[2] N. David and Z. Wang, "Physical rotor inertia of DFIG wind turbines for short-term frequency regulation in low-inertia grids," in *2017 IEEE General Meeting,* July 2017.

[3] N. David, Z. Wang, F. Xavier, and T. Prevost, "Fast frequency response by DFIG wind turbines for power systems with low physical inertia," in review for *IEEE Transactions on Energy Conversion.*

Objective I – DFIG reactive power capability

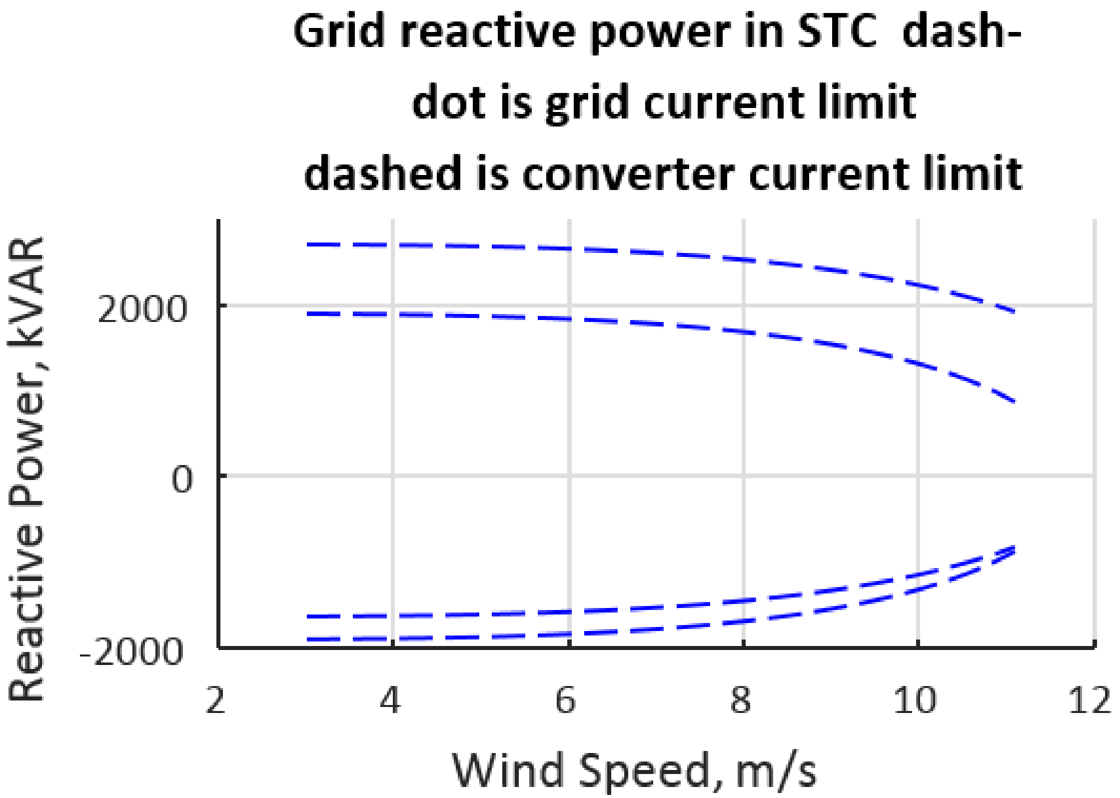
- ❑Turbine manufacturer claims ability to meet reactive requirement [1].
- ❑RTE field observation shows a discrepancy in reactive power capability [2].
  - ➢ Inability to meet $0.3P_{rated}$ reactive requirement.
  - ➢ Diminished capability at low wind speeds.
- ❑But RTE's prior simple parameter analysis suggests capability to meet and exceed requirement.
- ❑We will validate RTE's claims for ability to meet the required generator reactive power capability.



Objective I – DFIG reactive power capability

Theoretical results of machine-to-grid reactive power investigation:

- ❑ We evaluate equivalent circuit parameters, with core loss consideration, at nameplate limits.
- ❑ We Concur with notion for reactive power capability beyond RTE requirement.
- ❑ Possible cause for reduced Q at low wind – turbine is configured for high slip, and the converter voltage is low considering filter drop.



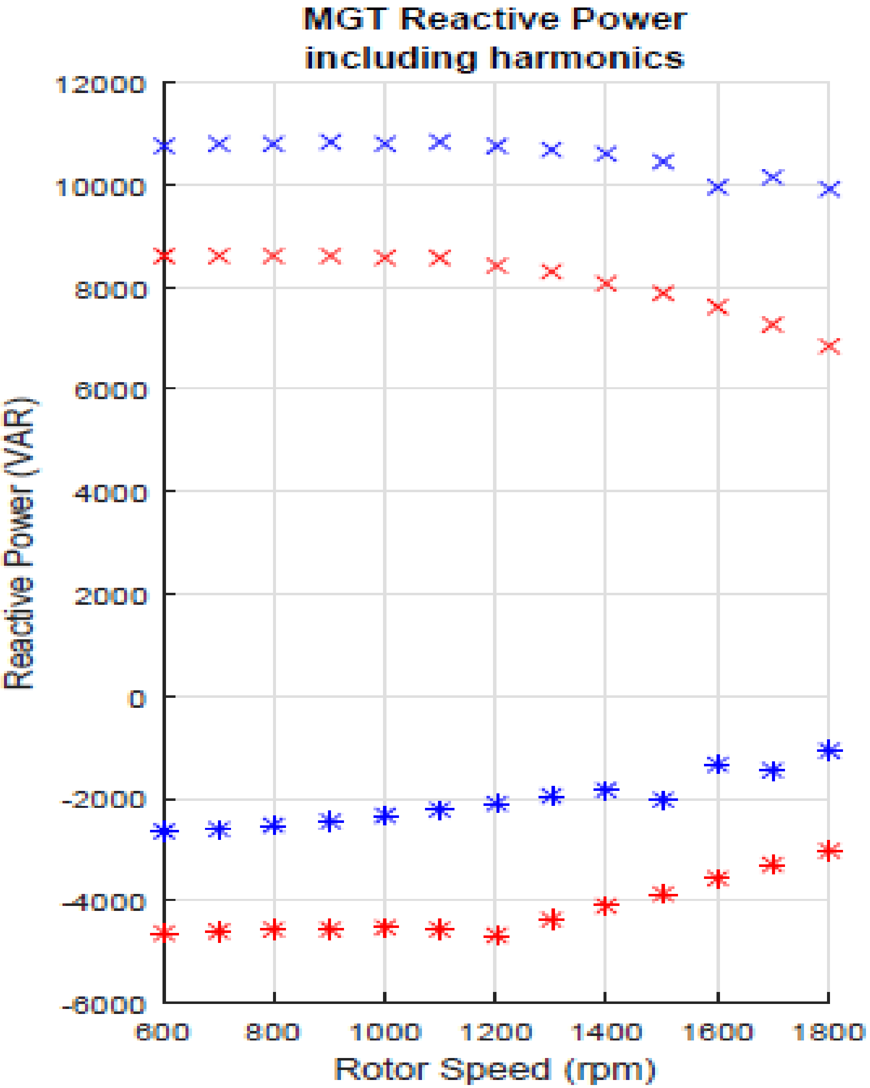
Objective I – DFIG reactive power improvement

We showed the capability, but can we improve it? Extract more??

Proposed alteration for increased generation:

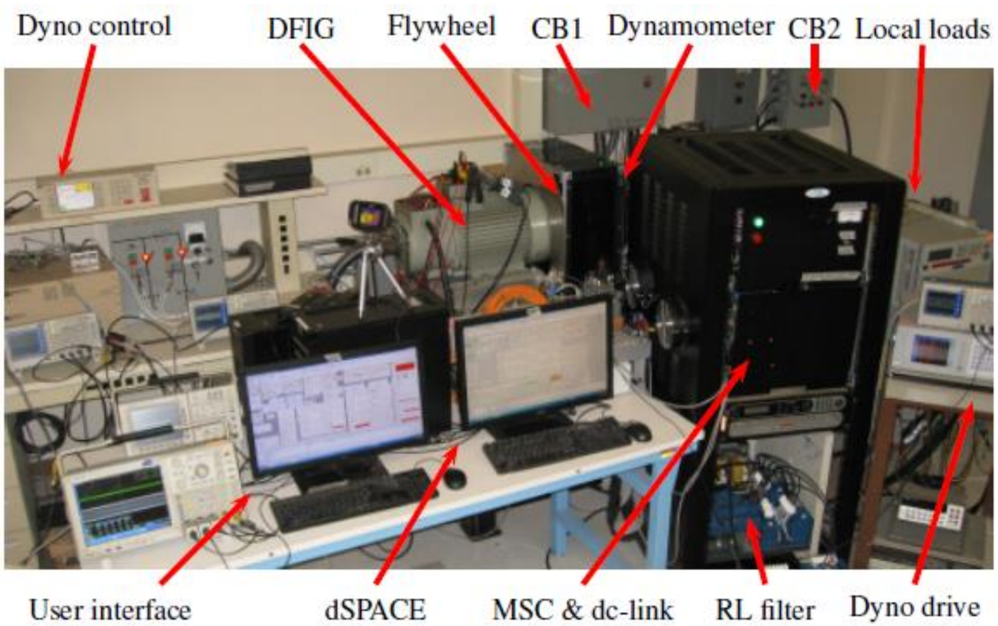
- ❑ Change from a grid-connected stator to a grid-connected rotor.
- ❑ Frequencies of current in the machine shift with connection strategy.
- ❑ Less core hysteresis loss, greater efficiency.
- ❑ Added current-headroom is useful for reactive generation.

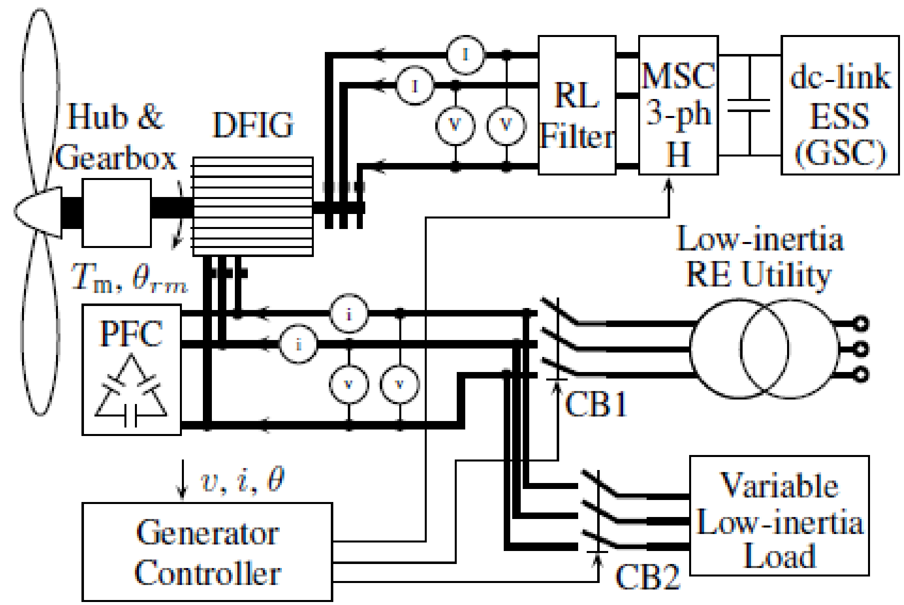
✓ Doubled reactive power generation of the laboratory generator.



Objective II – DFIG inertial capability

Experimental system:





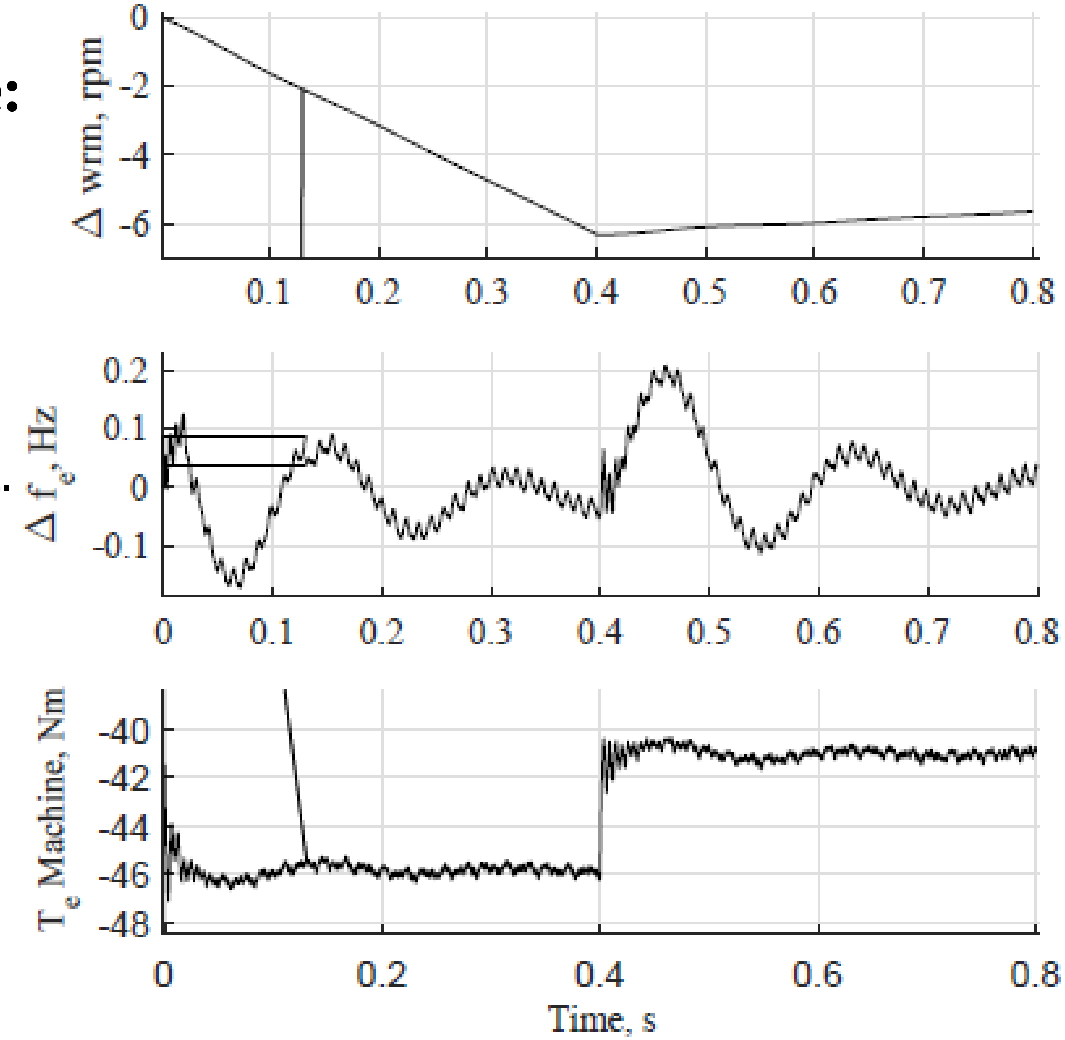
- Flywheel added for hub mass.
- Torque controlled by converter.
- Circuit breakers to induce load transient.

Objective II – DFIG inertial capability

Response to small load change:

10% increase at 0 s and

10% decrease at 0.4 s.



- Transient transferred to rotor shaft.
- Frequency is within ±500 mHz.
- Torque adjusts to match the load.

❑ Natural inertial capability (when torque and reactive power control influences are neglected) is sufficient to ride through a 10% load change

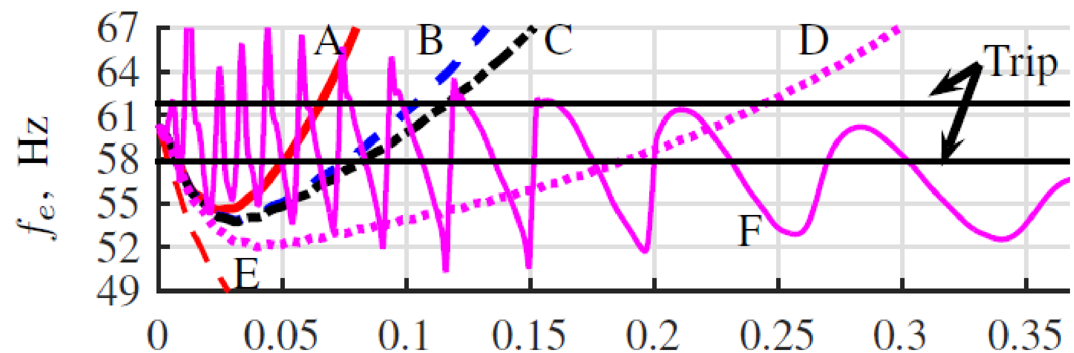
Objective III – DFIG inertial response, State of art

Deficencies:

- Droop control is a ’proportional’ method, with steady-state error and deep nadir.
- Inertia emulation cannot represent the actual rotor physical inertia.
- Direct voltage controllers are very fast but create current harmonic distortion.
- Stability of droop is not guaranteed.
- Very-fast phase-locked-loops require high-performance and expensive controllers.

Response in low-inertia system:

Slower torque control, A – E extends time to nadir. Droop control (F) oscillates.

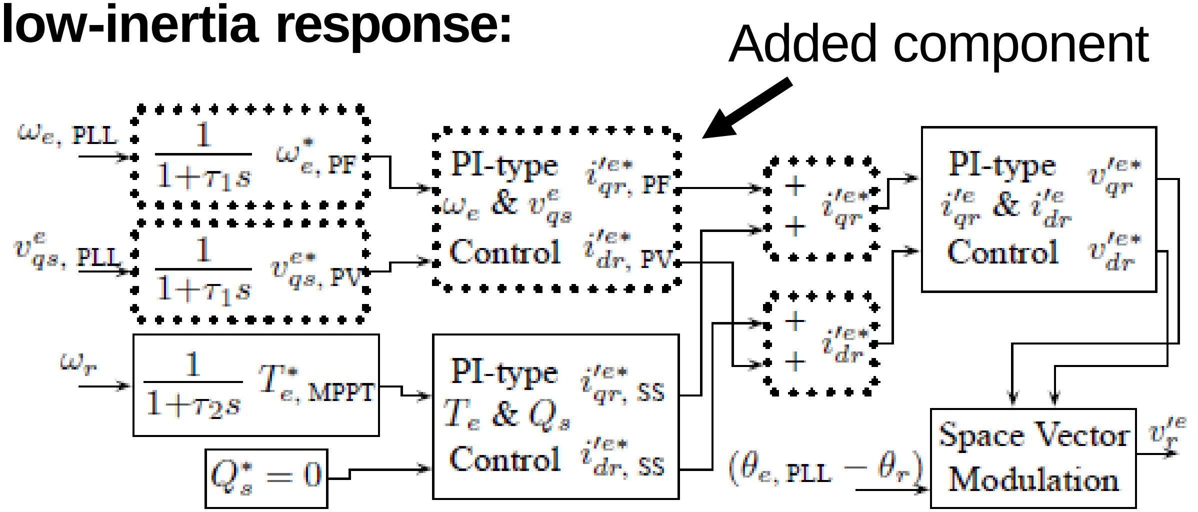


Goals to striving for:

- ❑ Frequency response which is inertial, fast, and without steady-state error.
- ❑ Capitalize on natural capability of the physical rotor inertia of DFIG turbine.

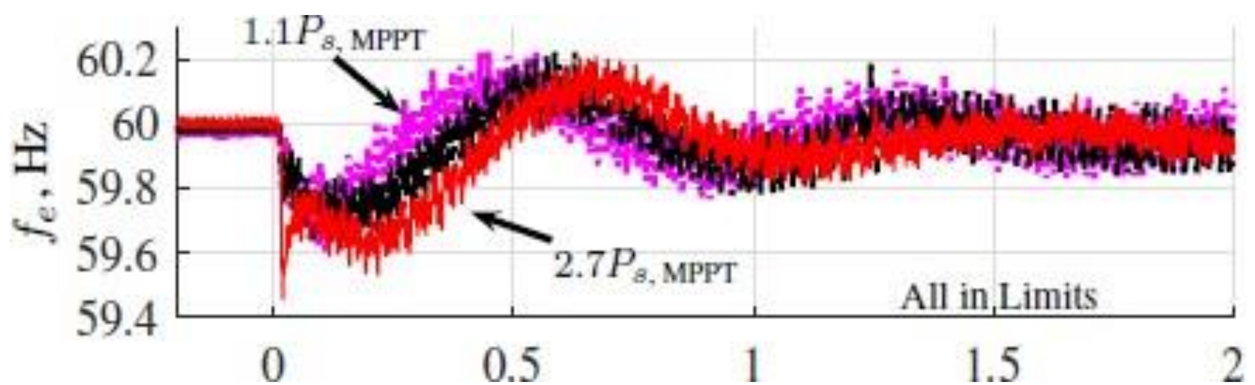
Proposed Control for fast DFIG inertial response

Adapting natural ability to low-inertia response:



- ❑ Others operate on power command.
- ❑ We operate on current command, adding faster transient response.
- ❑ Depth and duration of response is prescribed.
- ❑ No added hardware or communication.
- ❑ Effective beyond
- ❑ rated-value load-change.

Stable response for local load after grid-loss:



➢ PI control with short-term current command augmentation provides superior response.

Conclusion and Future Work

- DFIG wind turbines can be used in alternative ways which improve power system performance and reliability while making better use of the renewable energy asset.
- Stated reactive power claims may be underperforming.
- DFIG wind turbines are capable of providing inertial frequency response to support load transients.
- Depth and duration of DFIG wind turbine inertial response can be prescribed using the proposed control scheme.
- Ancillary performance benefits can be obtained without hardware or communication additions.
- We will perform similar work for PMSG in the final quarter.

[1] VEM-Motors-GmbH, "Overview wind power generators, synchronous and asynchronous generator, yaw drives." [Online]. Available: http://www.vem.fi/userData/vem/downloads/vem-motors-gmbh/tuoteluettelot/Product-overview-VEM-Windpower.pdf. [Accessed May 2, 2018].

[2] RTE-France, "A study of theoretical reactive power capacity of a wind turbine based on am asynchronous double-fed machine," Report. 2014.