Dynamic Wind Power Control for System Integration

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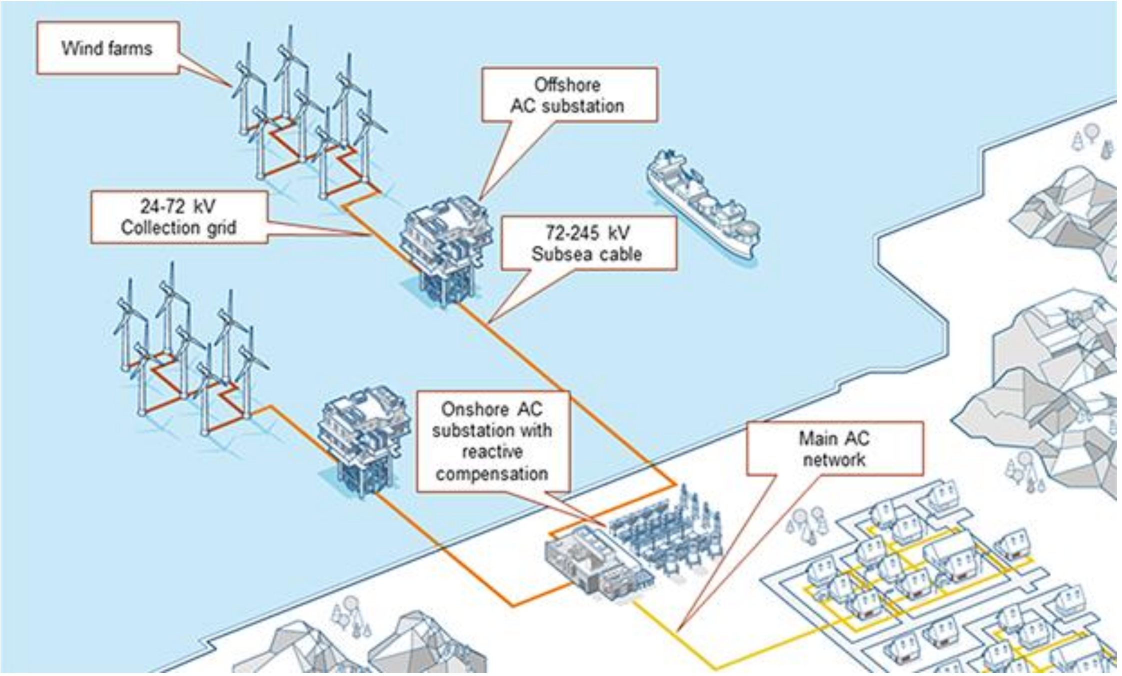
- Review of PAC Controller
- The Generator-Response Following concept
- Feedforward Controller for stable use of the Generator-Response Following concept
- Part 2: Experimental DFIG prototype
- Questions



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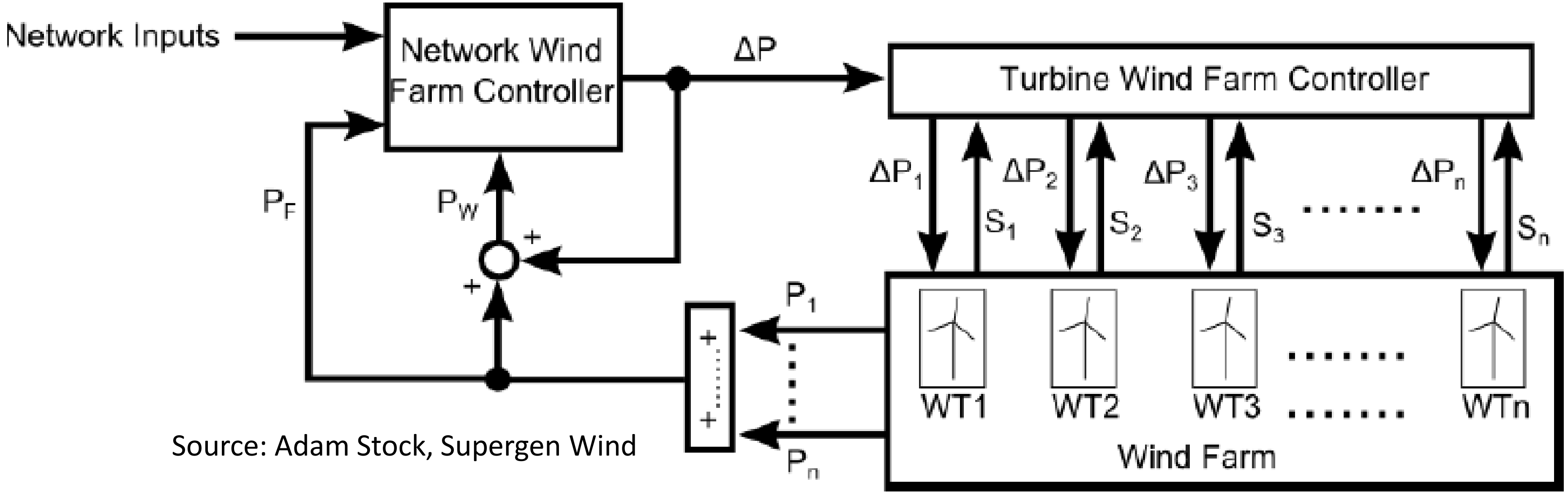
University of Strathclyde, Glasgow, UK.

SUPERGEN Wind General Assembly November 2017

PAC and the wind power plant controller (WPPC)

The WPP controller enables a wind power plant to provide the full range of ancillary services including synthetic inertia at the wind far level rather than a single turbine level.



Source: Adam Stock, Supergen Wind

- Power adjusting controller (PAC) applied to each rotor
- PAC adjusts the output from rotor i by ΔP_i
- Acts on information regarding state of each turbine to adjust operating point
- WPP controller determines the adjustments ΔP_i as required to meet objectives.

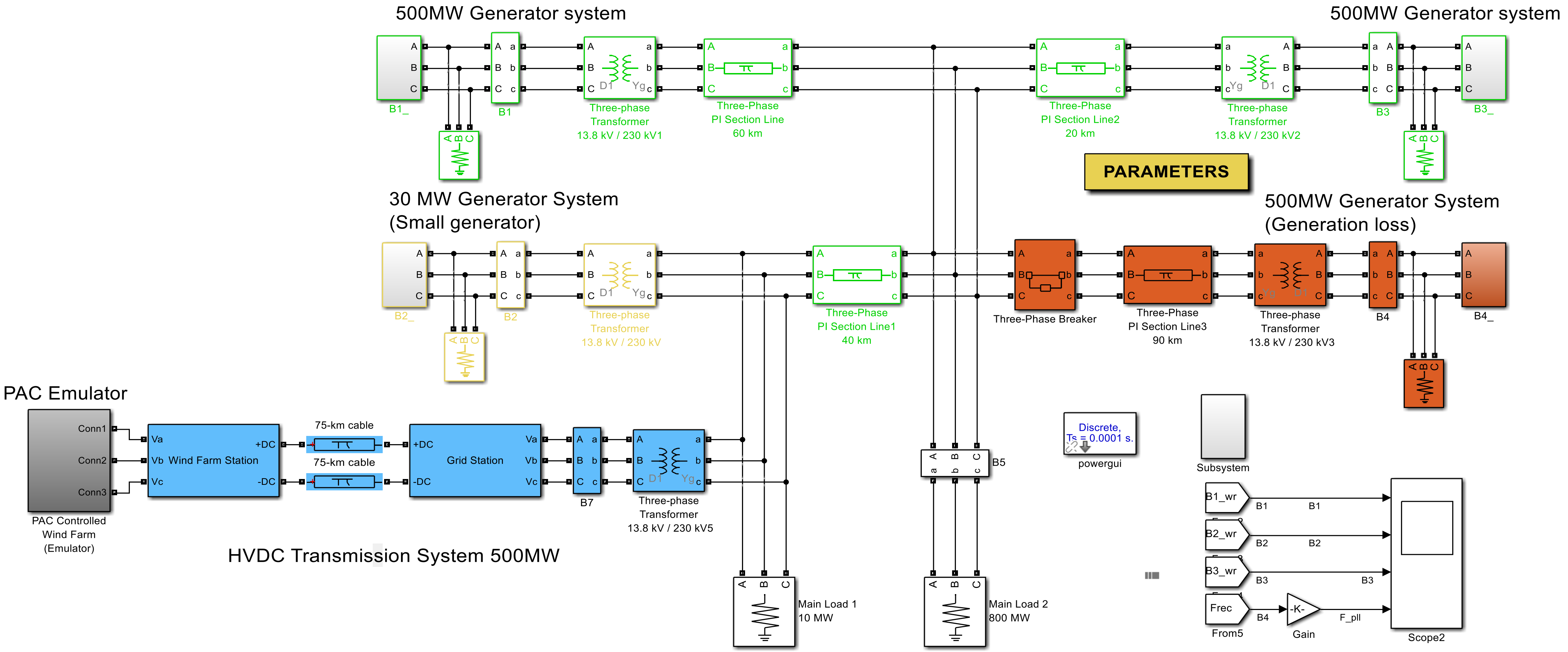
Novel approach to provide ancillary services to the power grid from Wind Farms using PAC: The Generator-Response Following (GRF)

- Connect at the Point of Connection of the wind farm a fully instrumented small/medium synchronous generator to which the wind farm is slaved (using PAC) in order to provide a wide range of ancillary services by scaling up the response of small generator.

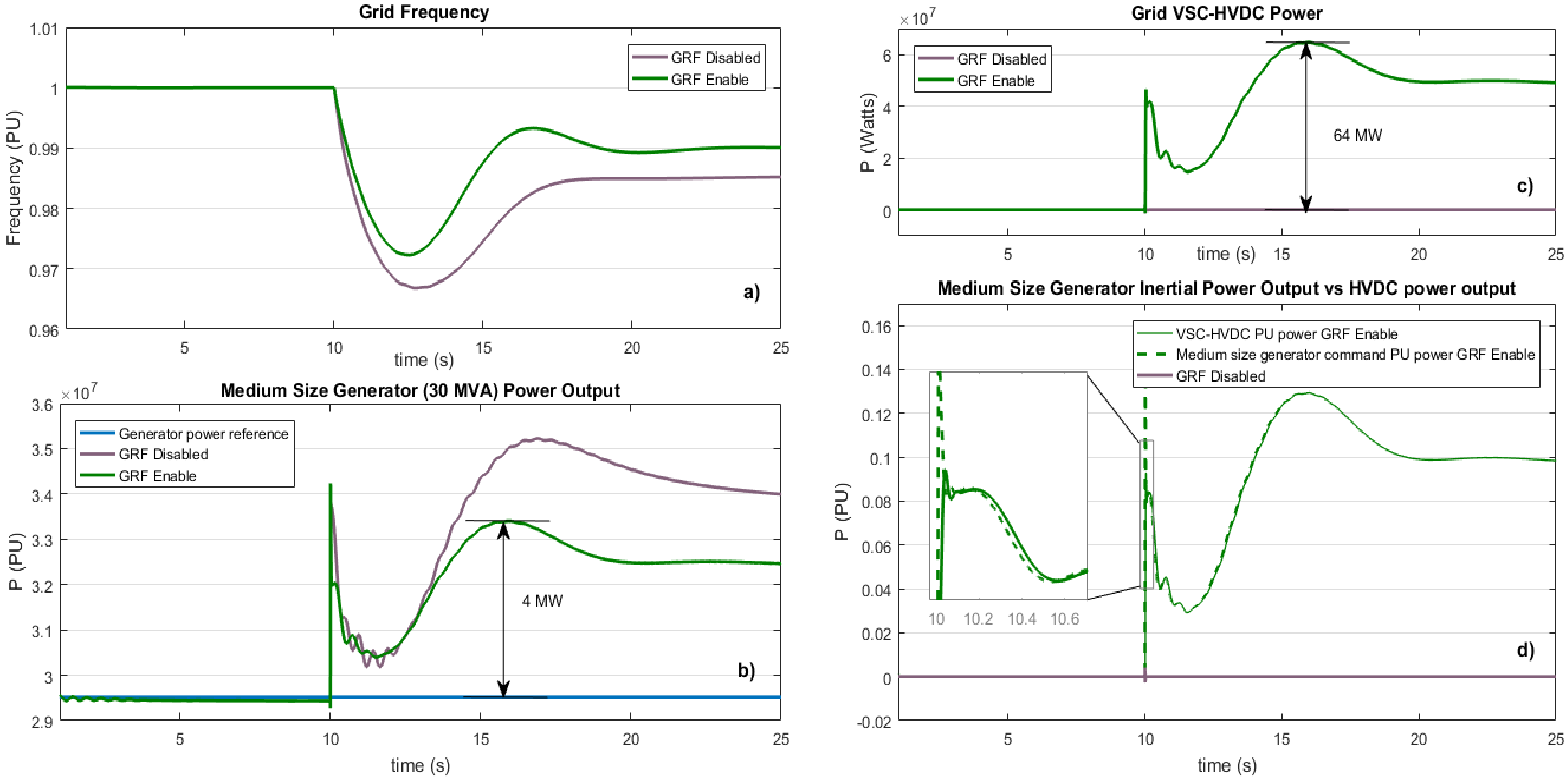
Advantages

- No direct power frequency measurements, which would be prone to high noise and lack of accuracy
- Capable of providing a full range of ancillary services, inertia, governor-droop control, reactive power, reserve, curtailment etc.
- Grid Code Compliant

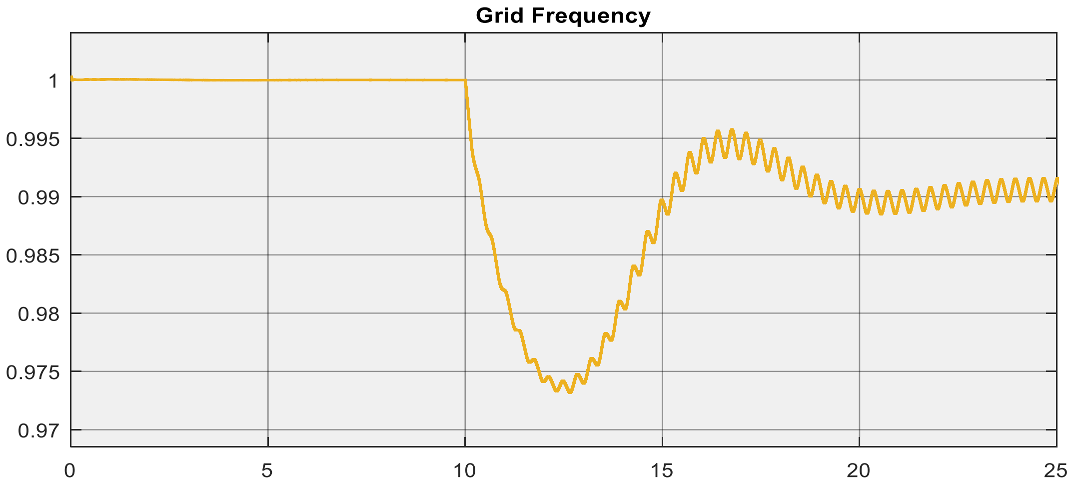
Test network for GRF concept

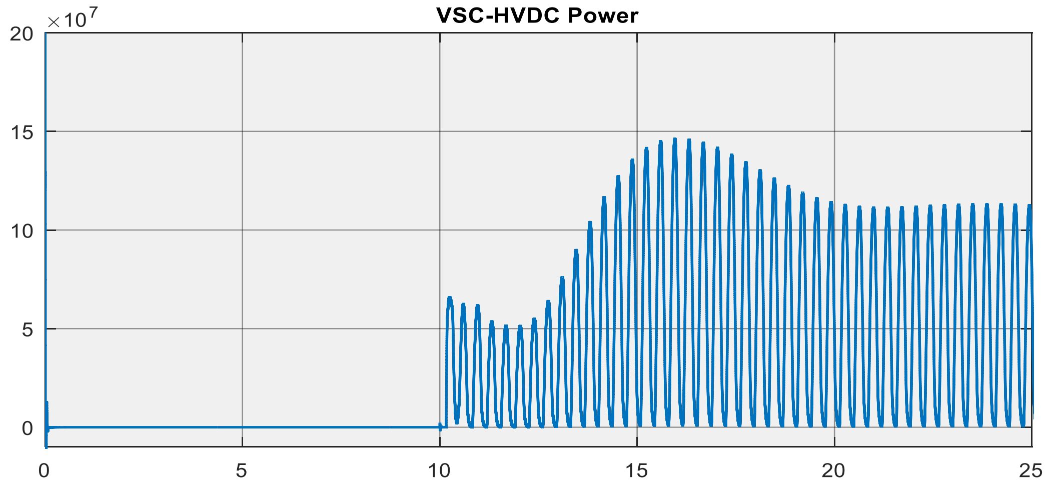


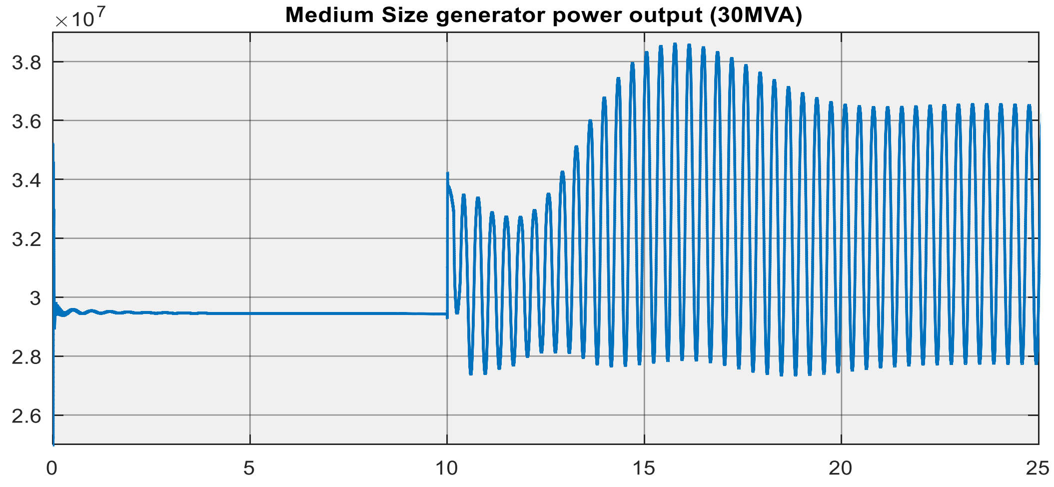
Results of GRF considering no communication delay

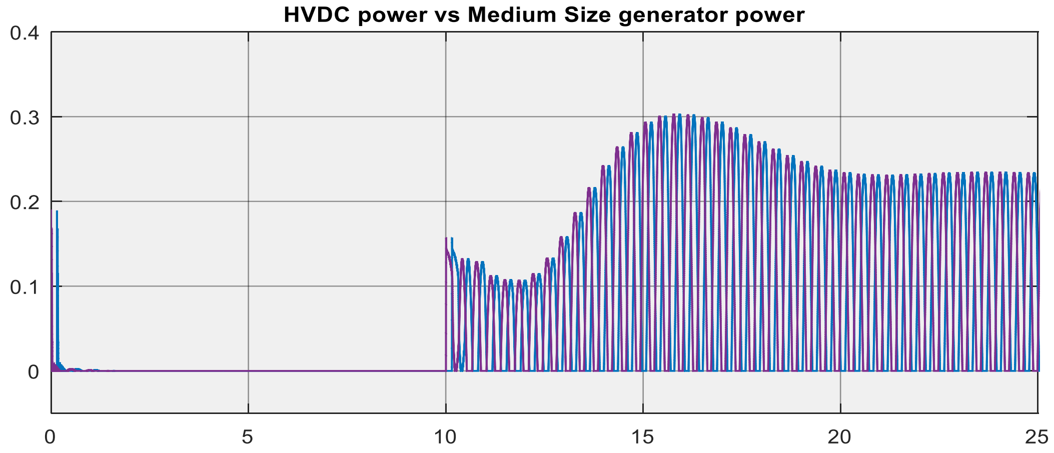


Results of GRF Considering communication delay of 150ms



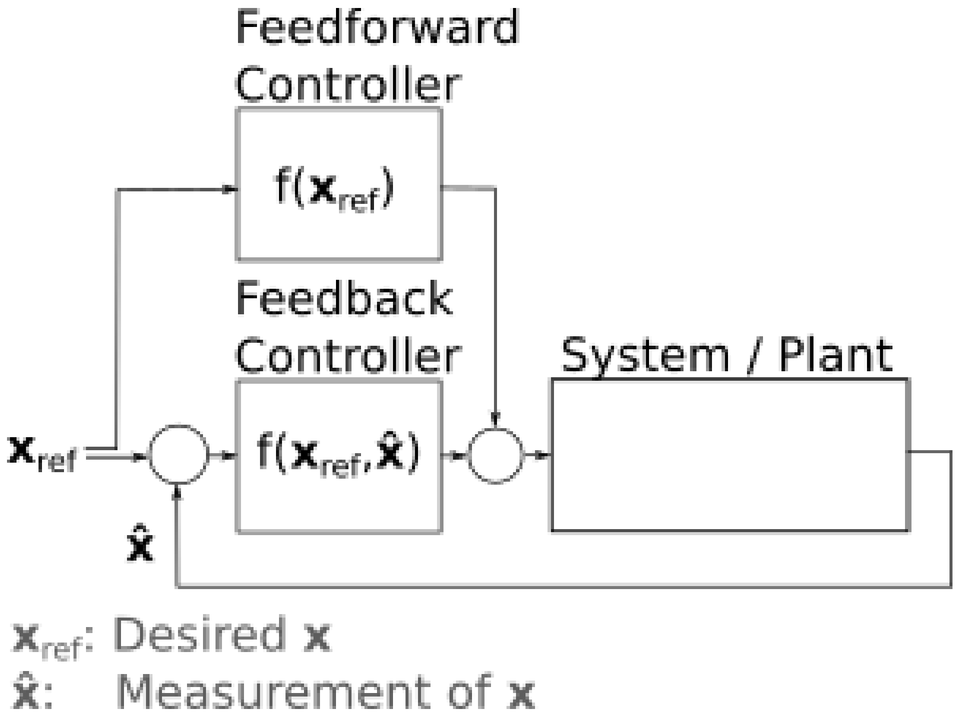




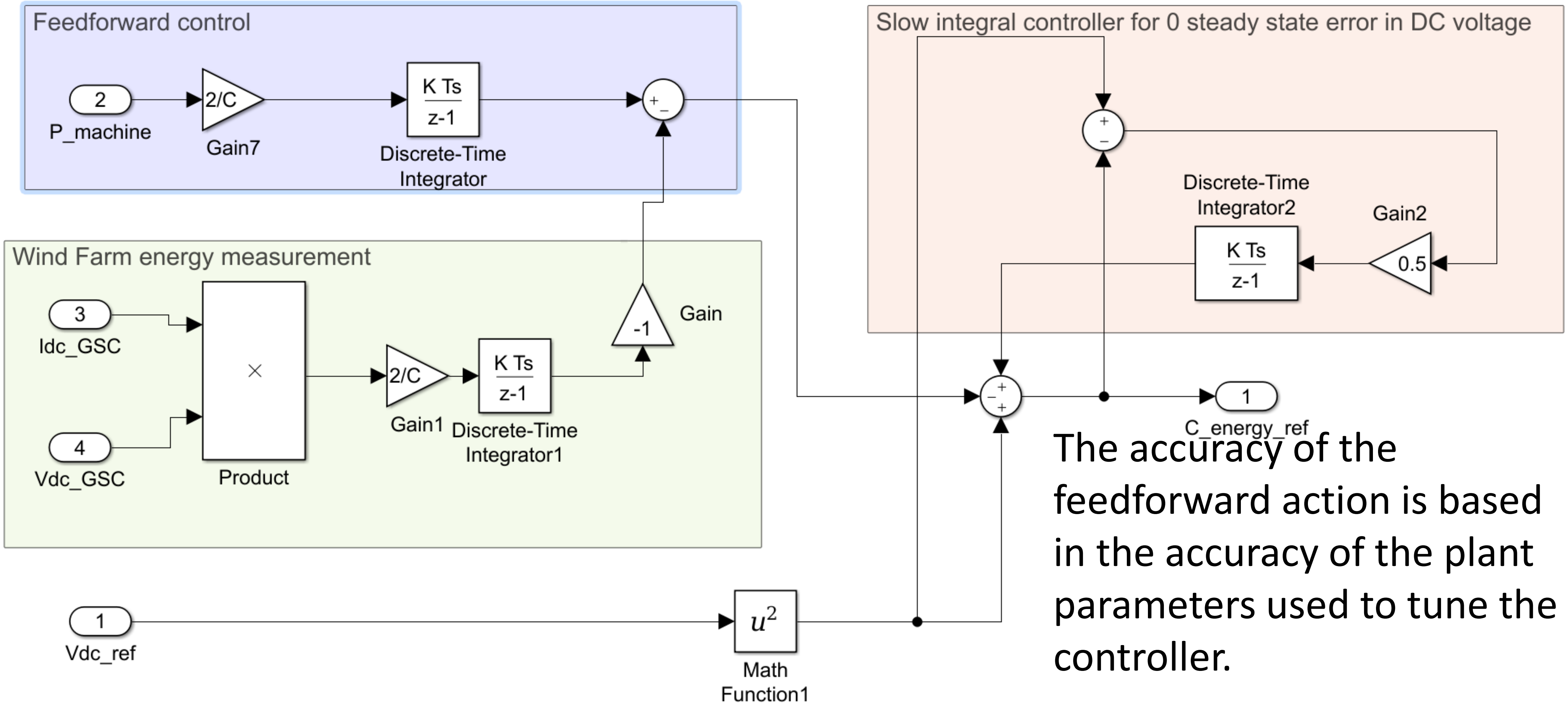


Feedforward Controller for GRF

- Requirements:
  - The HVDC converter station must use the energy stored in the capacitor to provide immediate GRF.
  - Once the energy from the offshore wind farm arrives to the onshore HVDC station, it must replenish the lost energy in the capacitor without affecting the GRF profile.
  - HVDC voltage must not decrease beyond a safety level.



Feedforward Controller for GRF



The accuracy of the feedforward action is based in the accuracy of the plant parameters used to tune the controller.

DC voltage plant disturbance rejection

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Variable to control
Capacitor Energy

$$W = \frac{1}{2} C v_{dc}^2$$

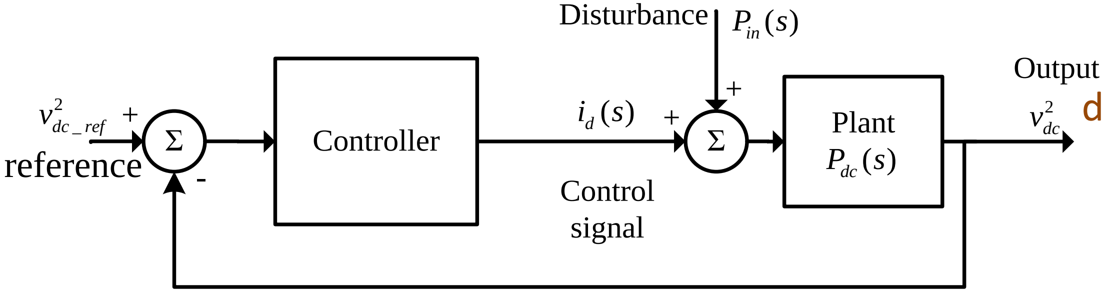
Plant

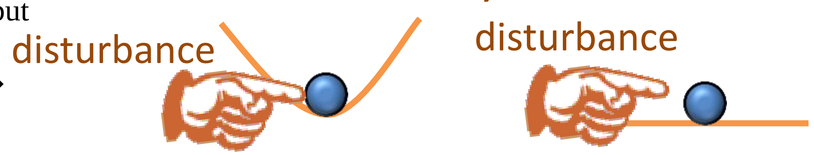
$$\frac{dW}{dt} = \frac{1}{2} C \frac{dv_{dc}^2}{dt} = P_{in} - {}^3\!/_2\, v_d i_d$$

Transfer Function

$$\frac{v_{dc}^2(s)}{i_d(s)} = P_{dc}(s) = -\frac{3v_d}{Cs}$$

The transfer function has a pole in the origin, making it very susceptible to disturbances

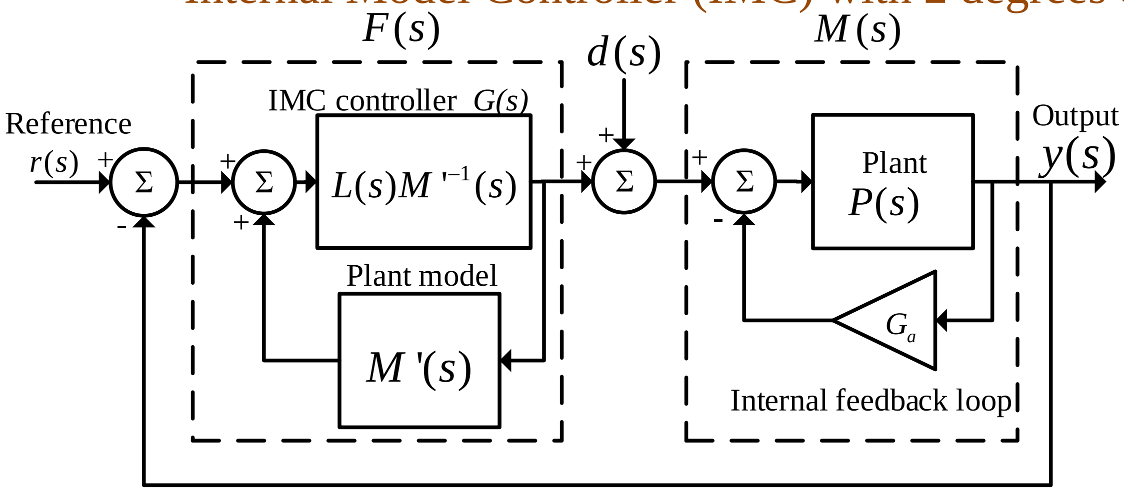




Poorly damped system

Naturally damped system

- Robust control of the dc voltage
- Internal Model Controller (IMC) with 2 degrees of freedom



Active damping

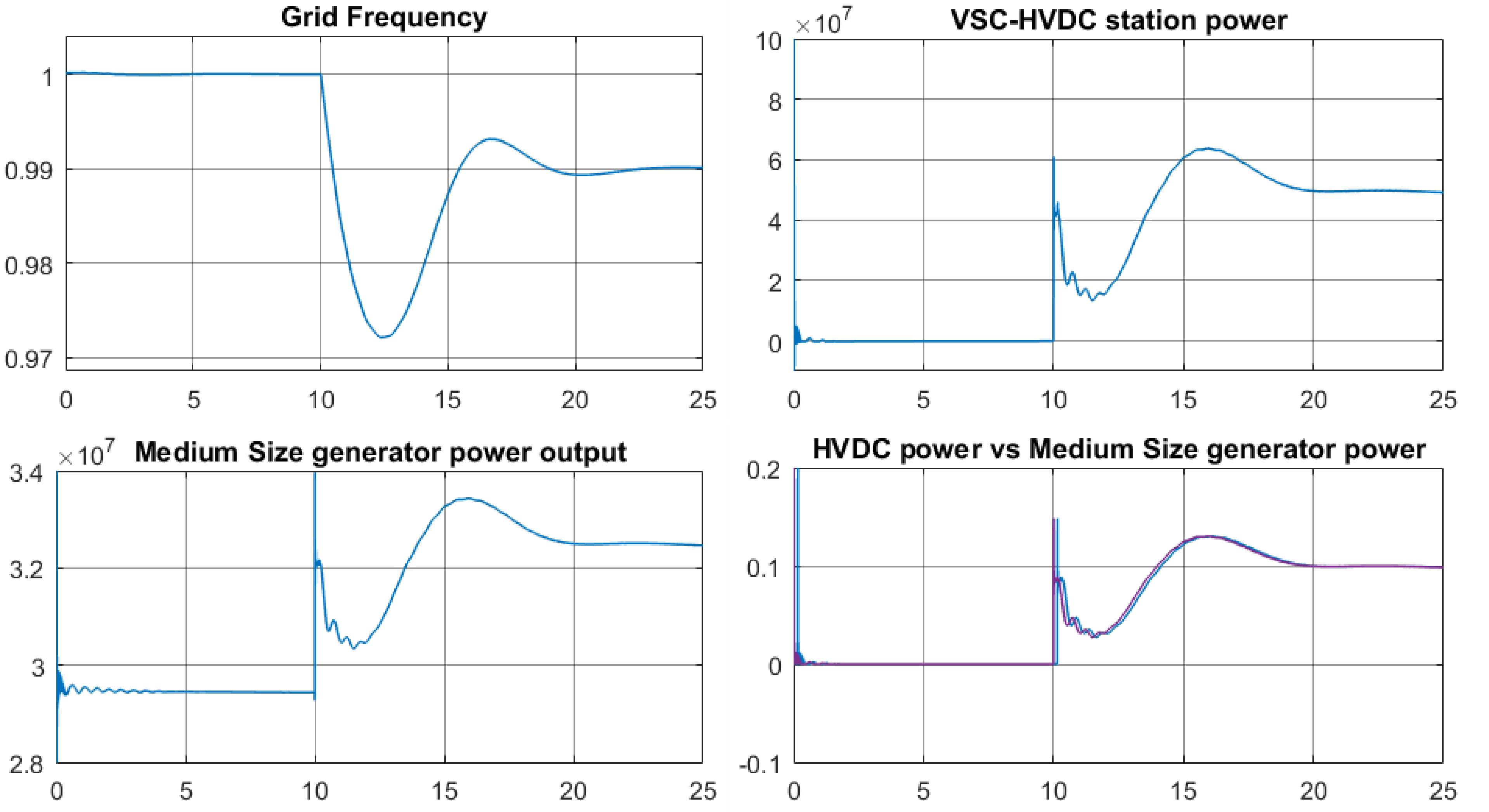
IMC constant for robust control of dc voltage

$$Kp_{dc} = -\frac{\alpha_{dc} C}{3 v_d}$$

$$Ki_{dc} = \alpha_{dc} G_{dc}$$

$$G_{dc} = -\frac{1}{3}\frac{\alpha_{dc} C}{v_d}$$

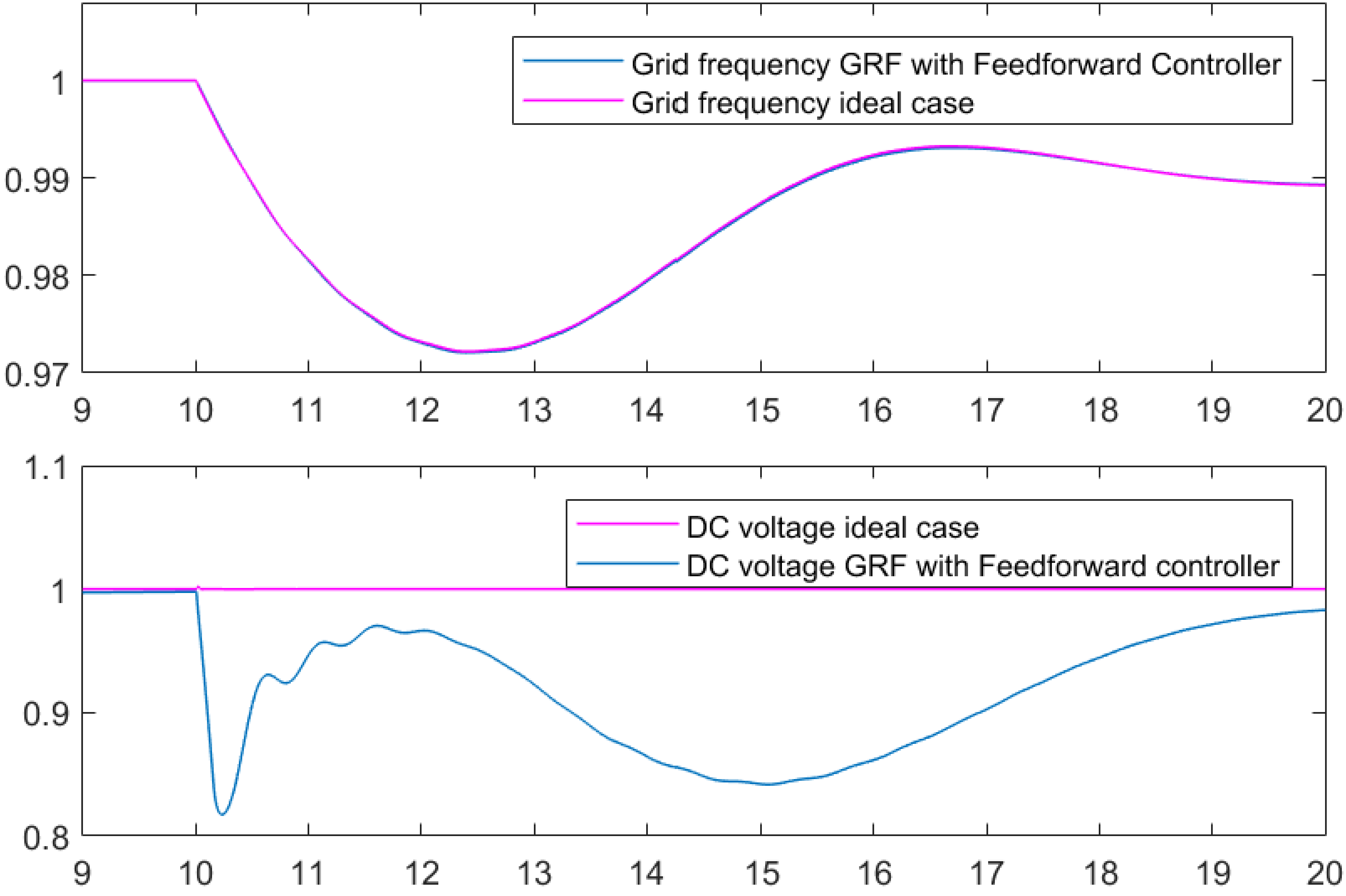
Enhanced feedforward controller simulation results for a 150ms delay



Feedforward controller enables using GFR with delay in communications

The stability of the grid is not compromised

Ideal results vs Feedforward controller results

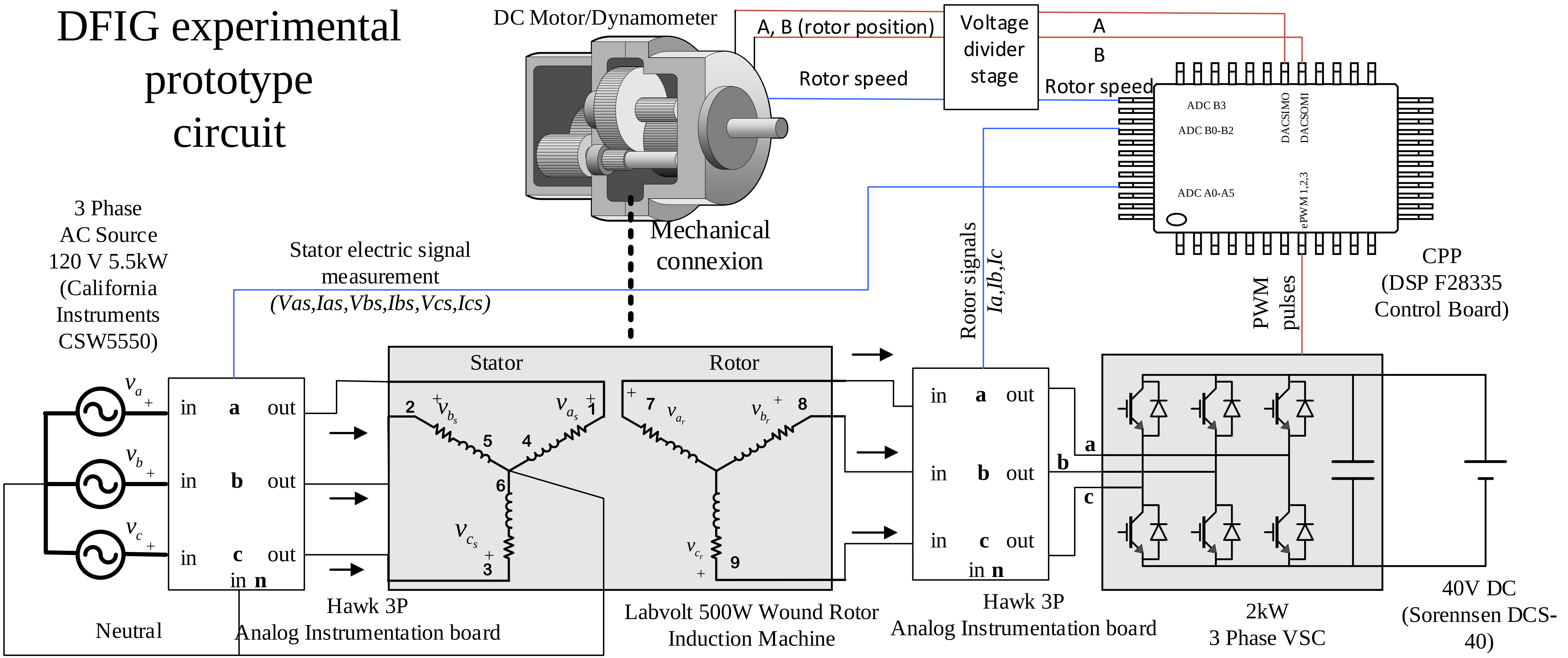


Feedforward controller results follow very closely the ideal results

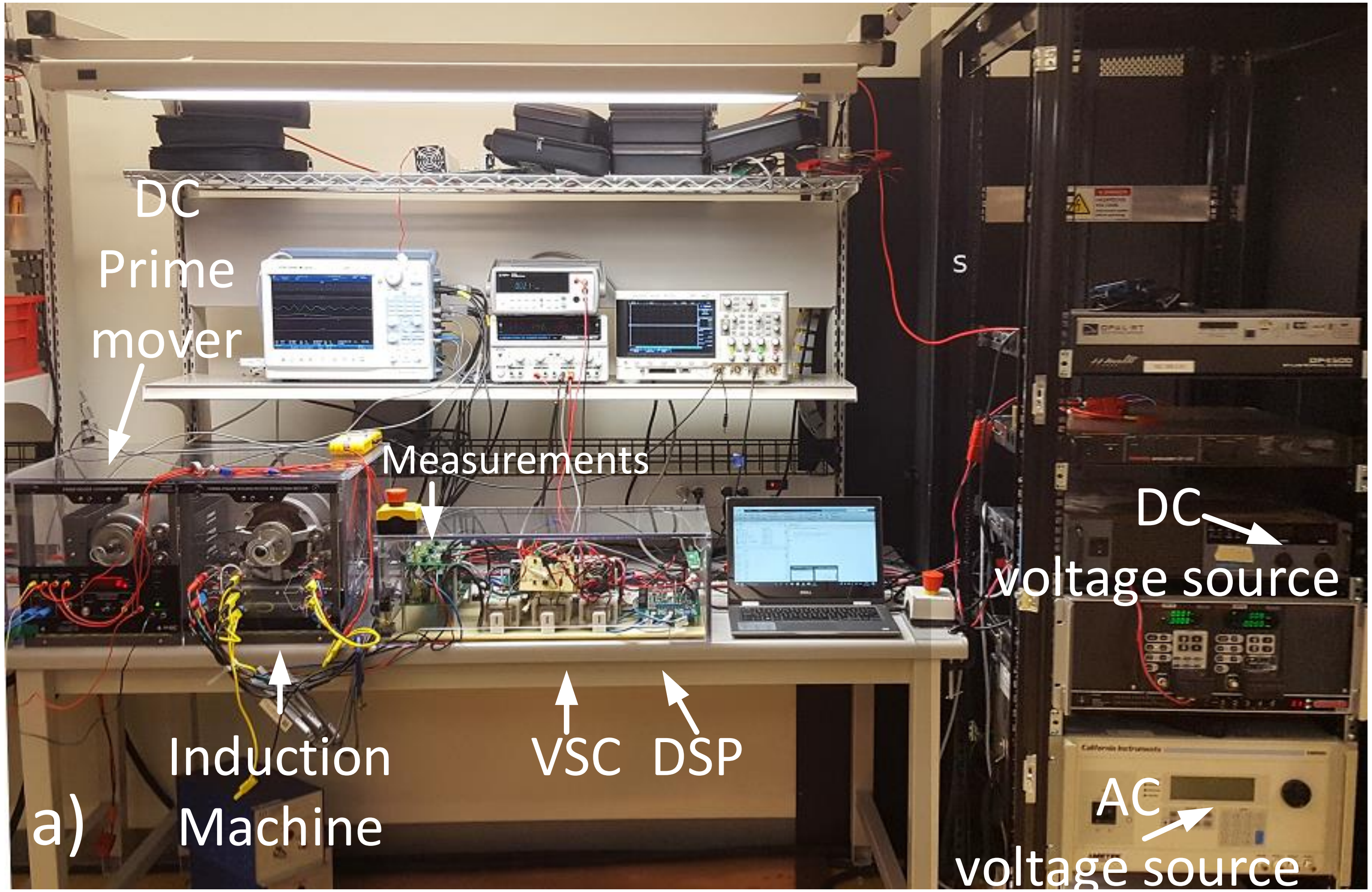
The extraction of energy from the DC capacitor produces variation on the DC voltage, but it is adjusted by the enhanced feedforward controller to match the set-point value

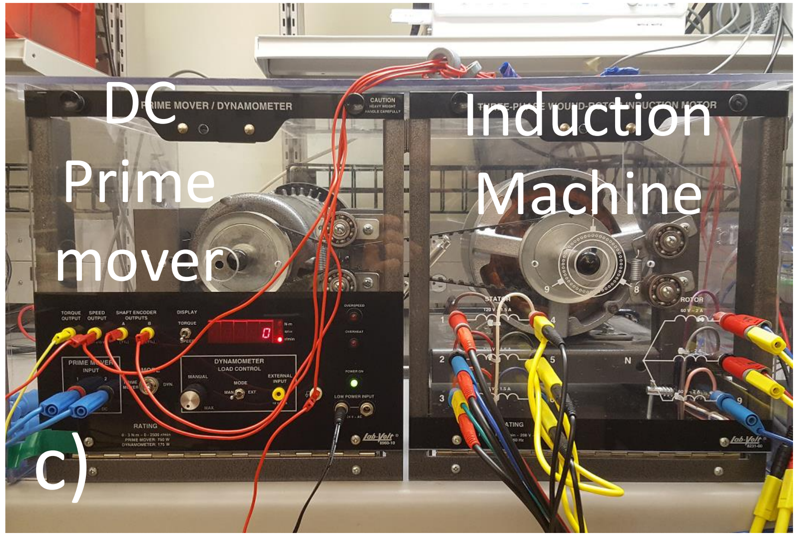
Second part of research: DFIG prototype development

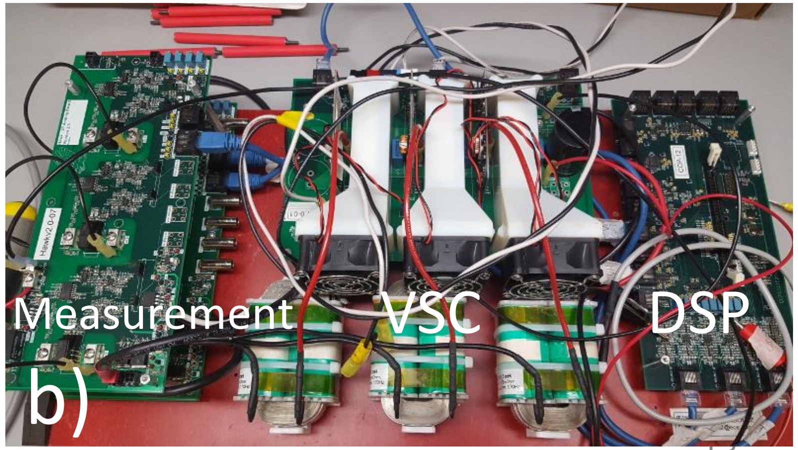
DFIG experimental prototype circuit



DFIG Experimental prototype





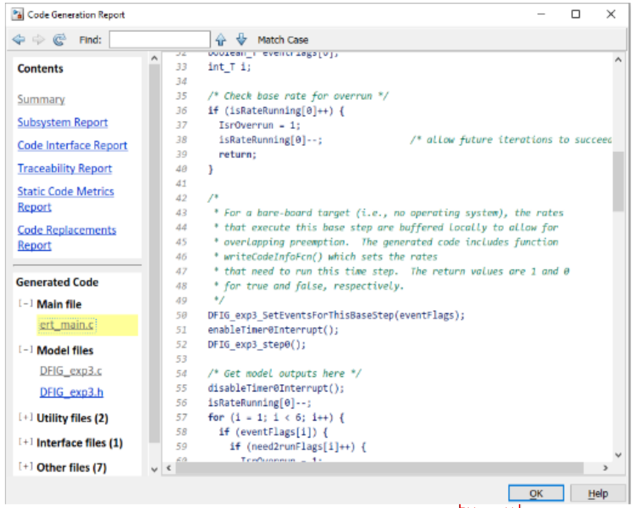


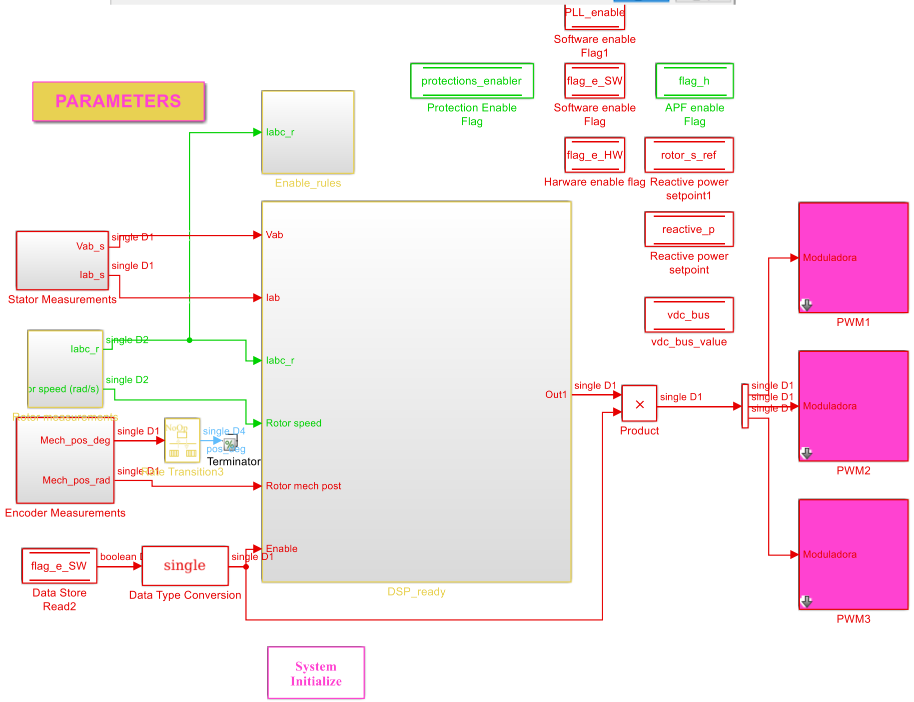
Digital Controller development

A program that

- reads 10 analog inputs using analog-to-digital converters,
- reads 2 digital inputs of a rotor position encoder,
- executes 4 closed-loop D2F-IMC controllers,
- executes a PLL,
- executes 2 abc-to-dq0 transformation
- generates switching pulses for the 6 IGBTs of the VSC

was designed in floating point architecture with a sampling frequency of 12kHz (i.e. 83.3 microsecond step program execution) using **automatic code generation**

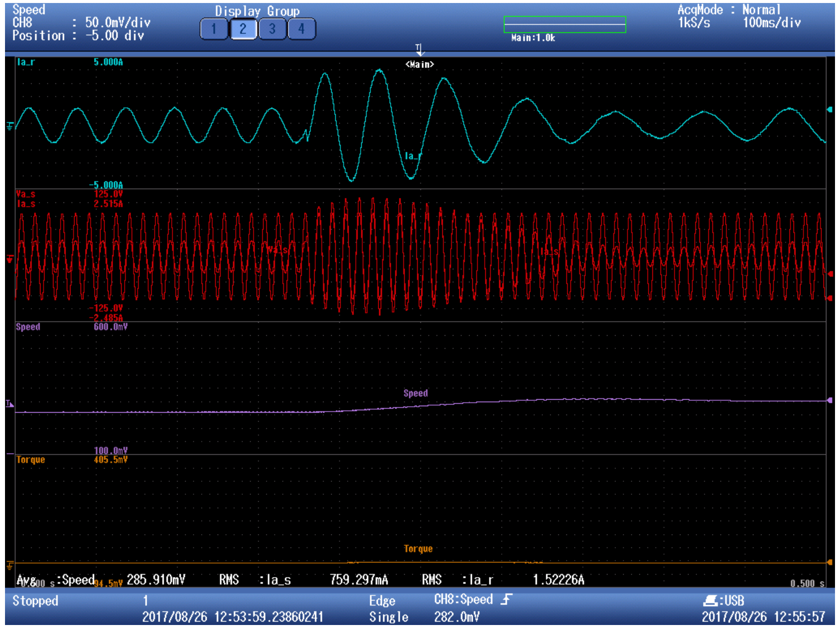




Experimental results: Rotor Speed Controller

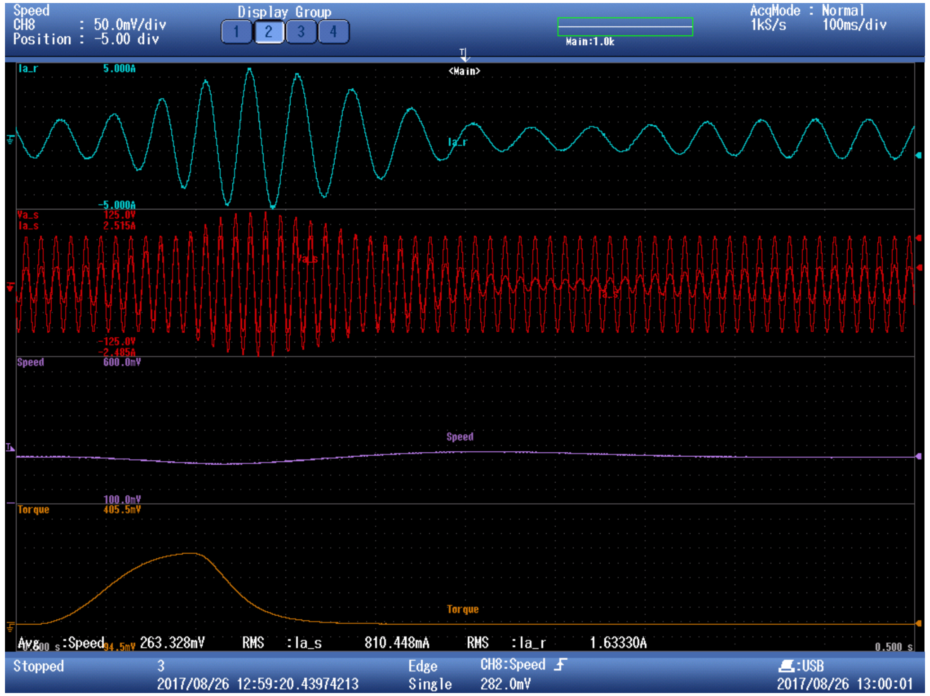
Reactive power consumption at machine terminals is 0

Rotor speed control is attained



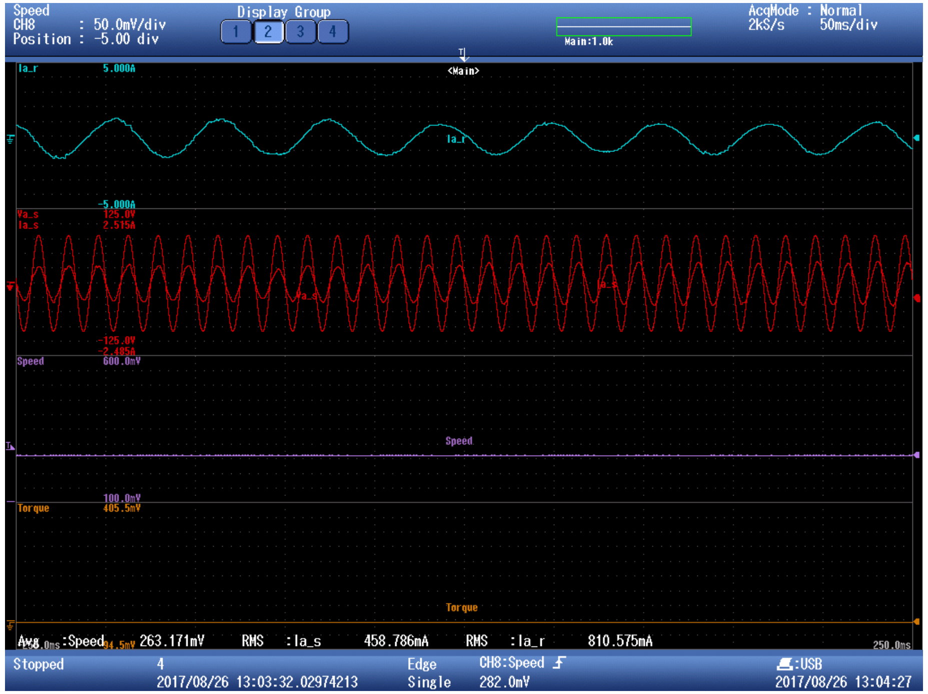
Experimental results: Speed Control

Rotor speed is kept constant for changes in mechanical torque inputs



Experimental results: Reactive power control

Reactive power can be controlled without affecting the machine speed.



Experimental Results: Advanced control

Harmonic distortion in Voltage Signal produce highly distorted Rotor and Stator Currents

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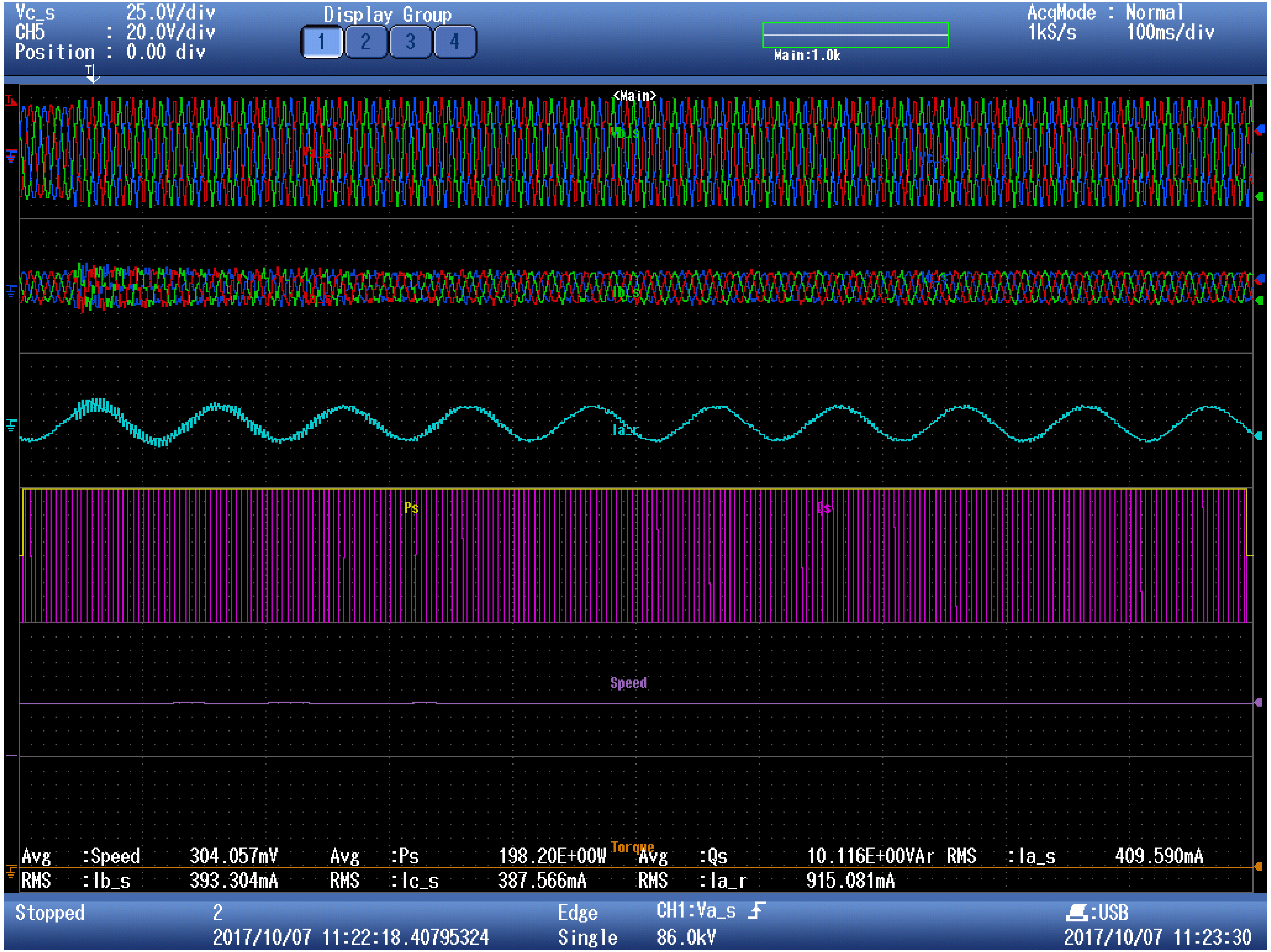
Experimental Results: Advanced control



The Stator and Rotor Current Harmonic distortion is eliminated using our proposed advanced controller technique

Experimental Results: Advanced control

Same result presented with shorter time division.

Questions?

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