Frequency and Voltage Control in systems with high DER penetration

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New York State Reliability Council
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DER is Electronically Coupled Generation and Load

A solar development is electronically coupled generation

A battery is electronically coupled generation while it is discharging

A battery is electronically coupled load while it is charging

An induction motor connected by a contactor is a friend of the grid with regard to frequency control

A motor connected through an electronic drive may, or may not, be a friend of the grid

Electronically coupled equipment is evolving faster than understanding

Much of the discussion to date regarding electronically coupled equipment has

either

Considered that DER will not contribute to control of frequency and voltage

or

Claimed 'unique' capabilities related to particular situations

These are extremes of a spectrum of capabilities, most of which are useful when properly applied

Inertia and Primary Frequency Control

Reduction of system inertia has received a lot of attention

It is an issue - but it is far from the only issue

Inertia

Why is inertia an issue ?

Because

$$2H\frac{d\omega(t_{initial})}{dt} = \frac{\Delta P_{turbine} - \Delta P_{load}}{\omega}$$

tells only the initial part of the story

and

$$\Delta\omega(t_{final}) = \frac{\Delta P_{turbine} - \Delta P_{load}}{D + \frac{K_t}{R}}$$

approximates the end of the story
but doesn't tell how it comes about

Power system operation

A generator trips

No person has time to do anything - $2H\frac{d\omega(t_{initial})}{dt} = \frac{\Delta P_{turbine} - \Delta P_{load}}{\omega}$

frequency starts to fall immediately

Turbine governors do the right thing - $\Delta\omega(t_{final}) = \frac{\Delta P_{turbine} - \Delta P_{load}}{D + \frac{K_t}{R}}$

frequency settles at a reduced value

(System-level controls restore frequency and transmission flows after governor action has stabilized frequency)

Power system operation

Turbine governors do the right thing -

They don't have to wait for instructions

They know what to do

They do it - immediately

- autonomously

Managing reserve for primary control

Essentially every rotating machine has a governor

The governor is primary control

The governor can be supervised by other controllers
- temperature controller of a gas turbine
- pressure controller of a steam turbine
- plant load controller

Supervising controller may be primary and act as a limiter
- temperature / pressure / acceleration

Supervising controller may be secondary and act on the setpoint of a primary controller
- plant load controller
- balancing area automatic generation controller

Primary control points

The governor may, or may not, be in command of the machine.

Overall experience is that 25-35 percent of connected capacity operates with governor in command

Secondary controls must be properly coordinated with primary controls

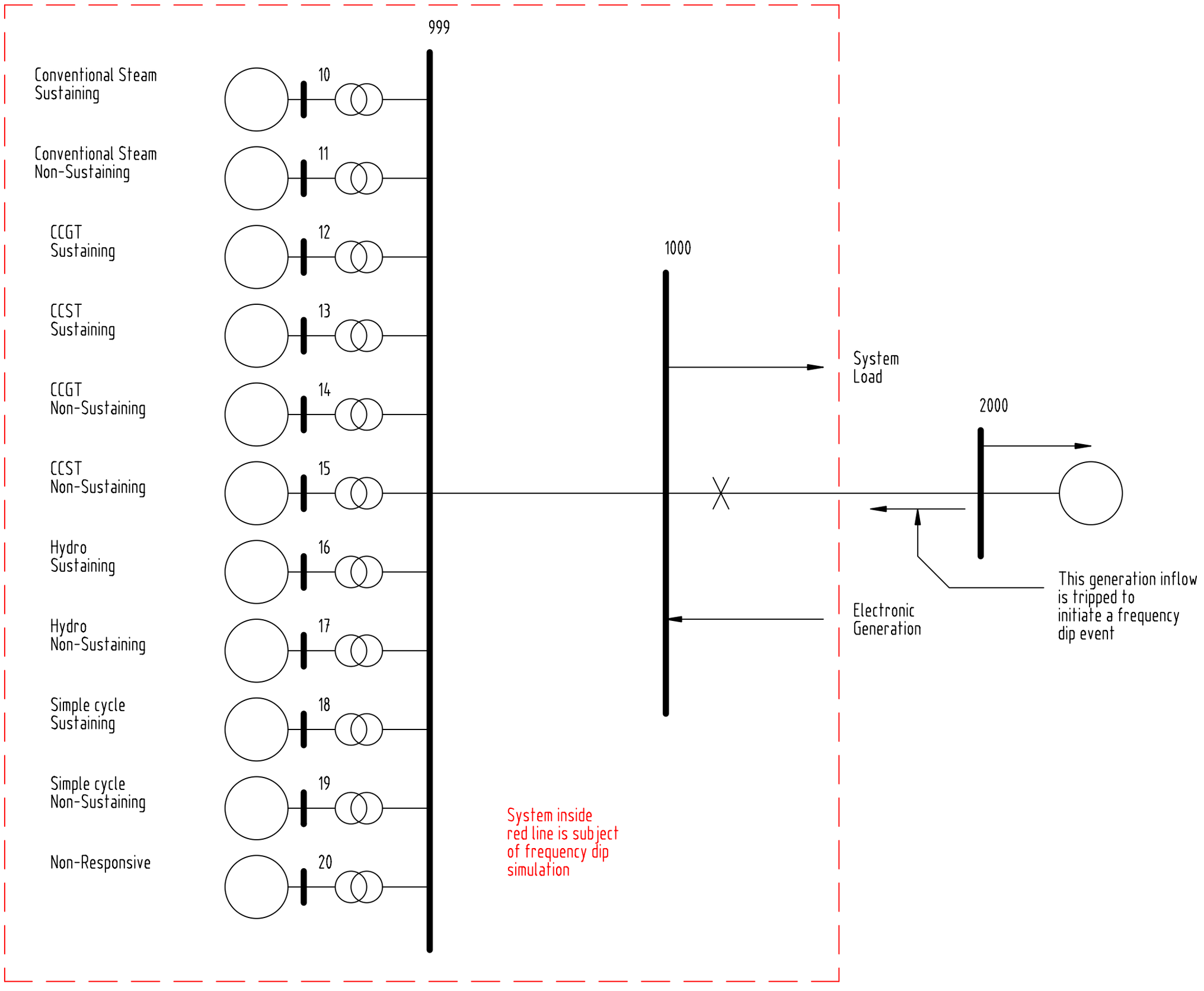
Must understand what the governor controls

Steam/gas turbine - governor controls the turbine
Hydro turbine - governor controls the turbine

Electronic generation can have a governor

Photo-voltaic - governor controls electronic inverter
Battery - governor controls electronic inverter
Wind turbine - governor must control the turbine

Microcosm generation fleet model



Primary control response

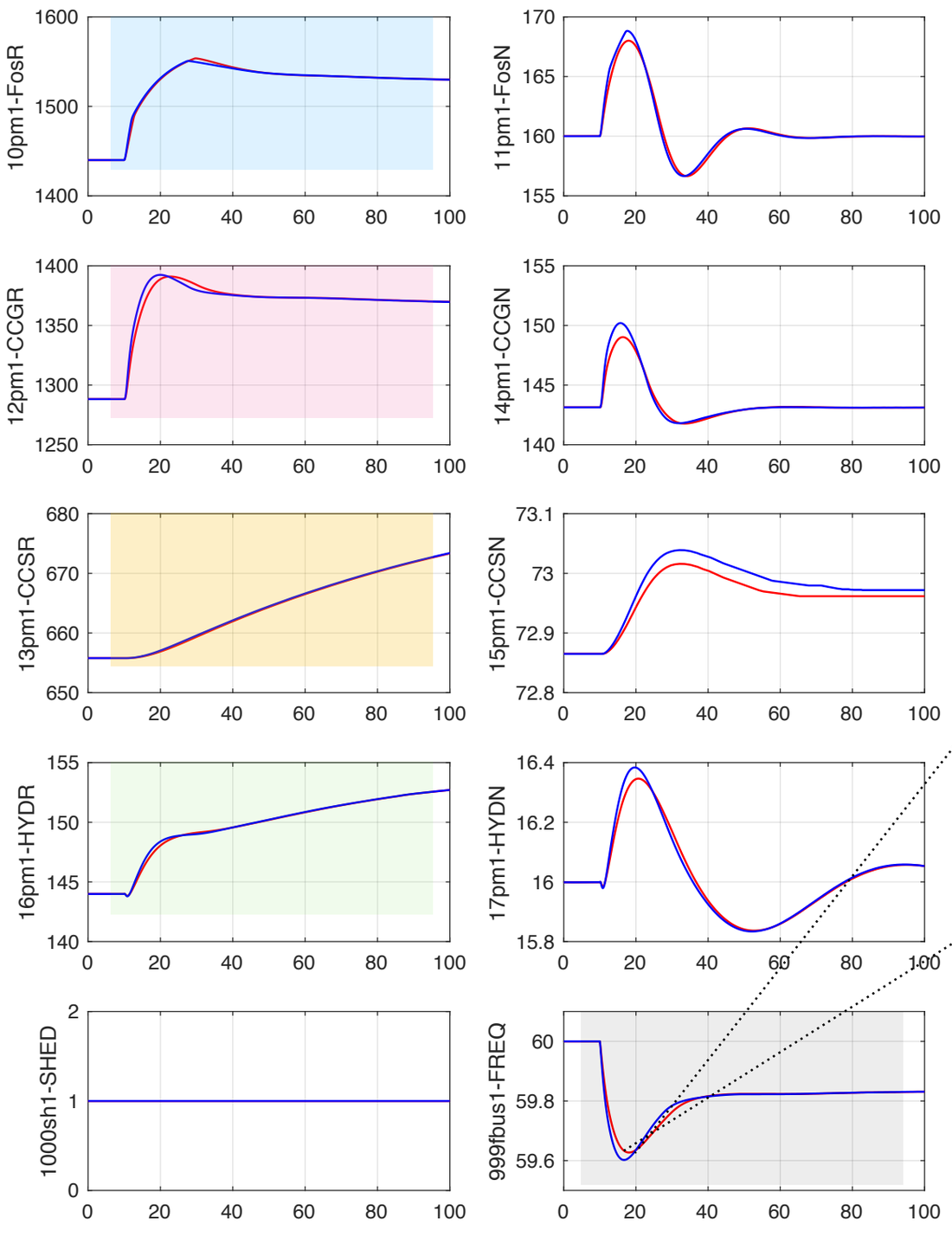
Electronic fraction 0.0

Steam

CCGT

CCST

Hydro



Responsive fraction 0.4
Sustaining fraction 0.9*0.4

H of rotating generation = 4.0
Stored energy 48000 MW-sec
H of system = 4.0
Nadir frequency 59.63

H of rotating generation = 3.0
Stored energy 36000 MW-sec
H of system = 3.0
Nadir frequency 59.60

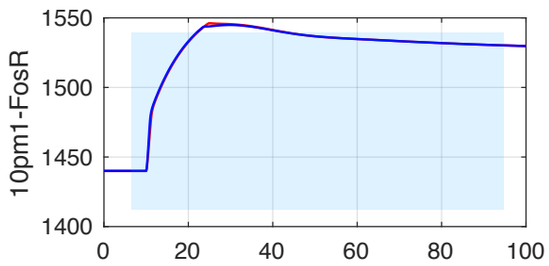
p2500June/q-0-0.cha p2500June/q3-0-0.cha qq3-0-0.pdf

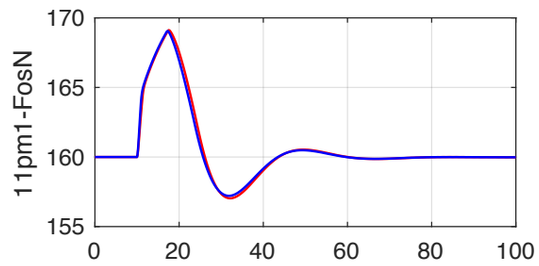
Primary control response

Electronic fraction 0.5

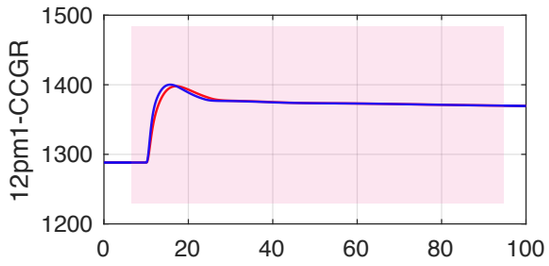
Responsive fraction 0.4
Sustaining fraction 0.9*0.4

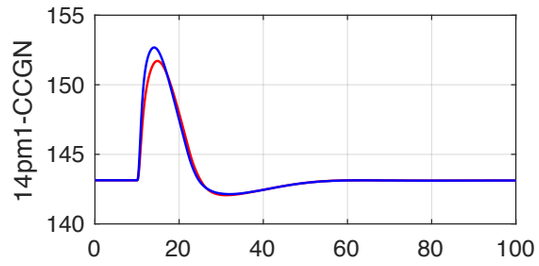
Steam





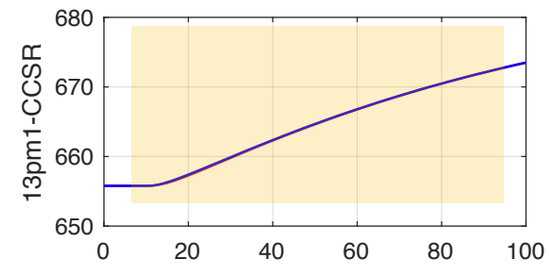
CCGT

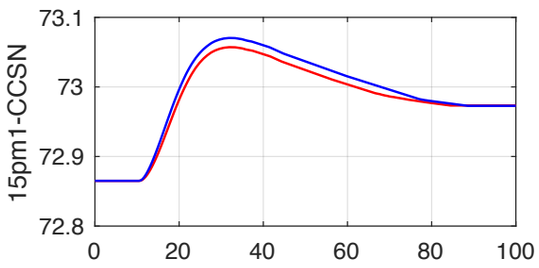




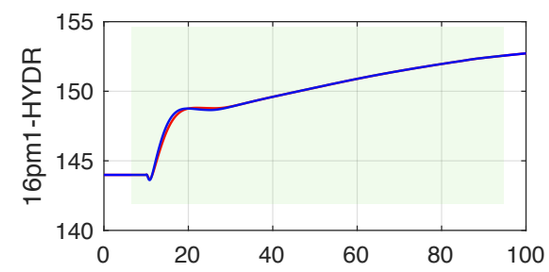
H of rotating generation = 4.0
Stored energy 24000 MW-sec
H of system = 2.0
Nadir frequency 59.55

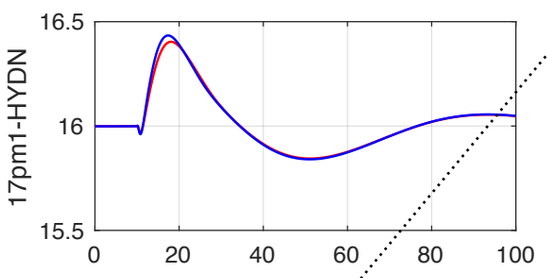
CCST



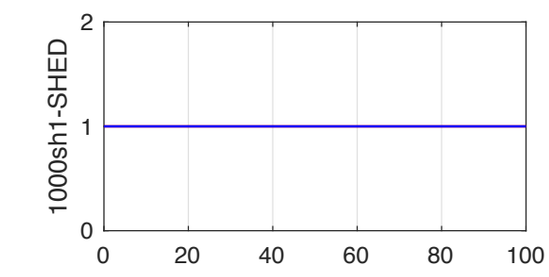


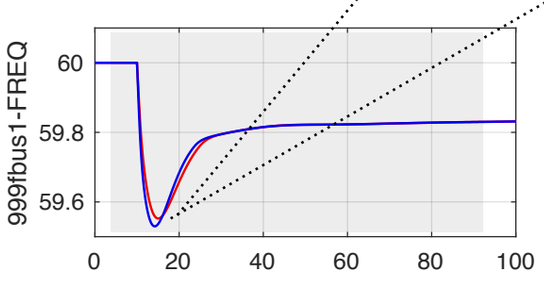
Hydro





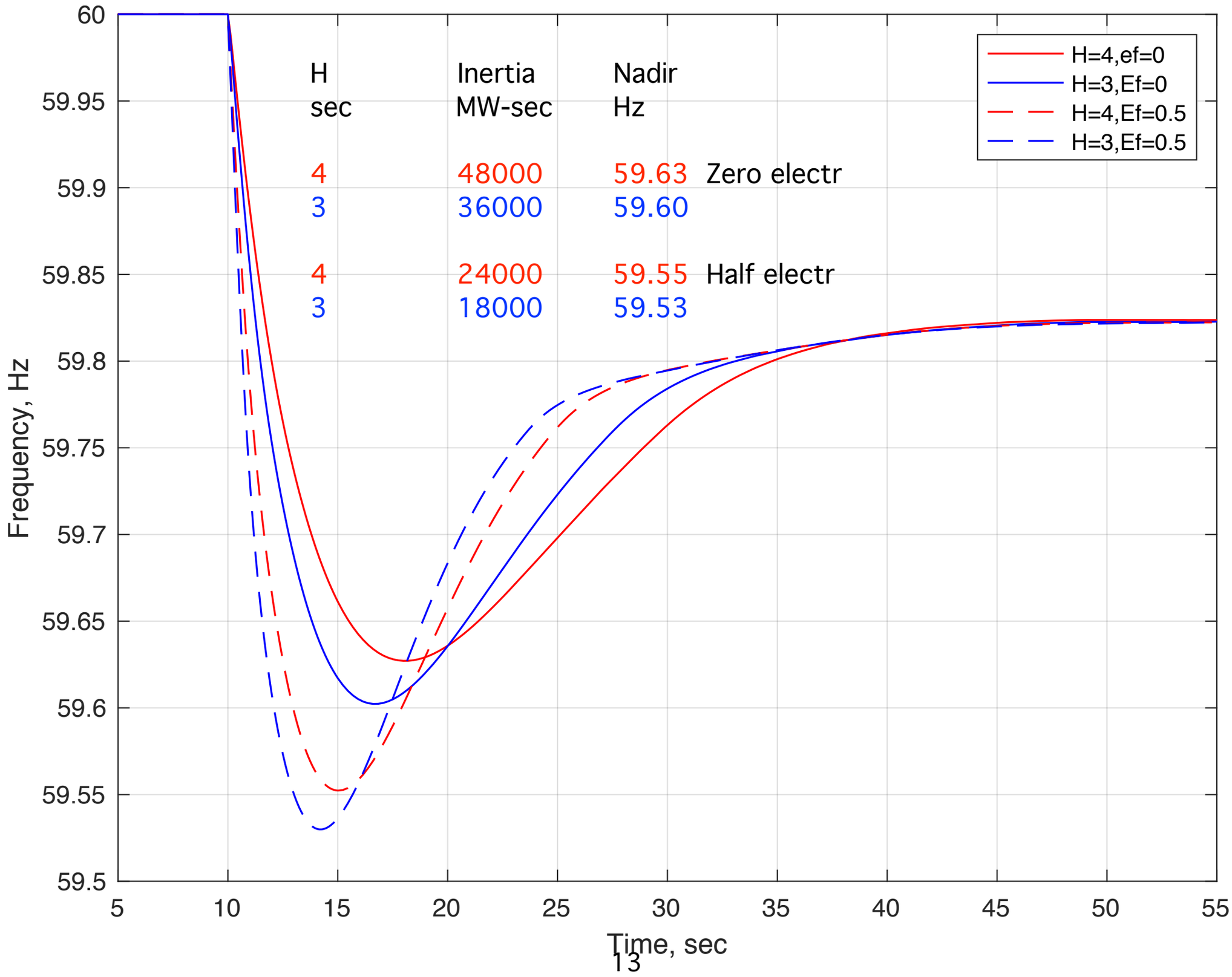
H of rotating generation = 3.0
Stored energy 18000 MW-sec
H of system = 1.5
Nadir frequency 59.53



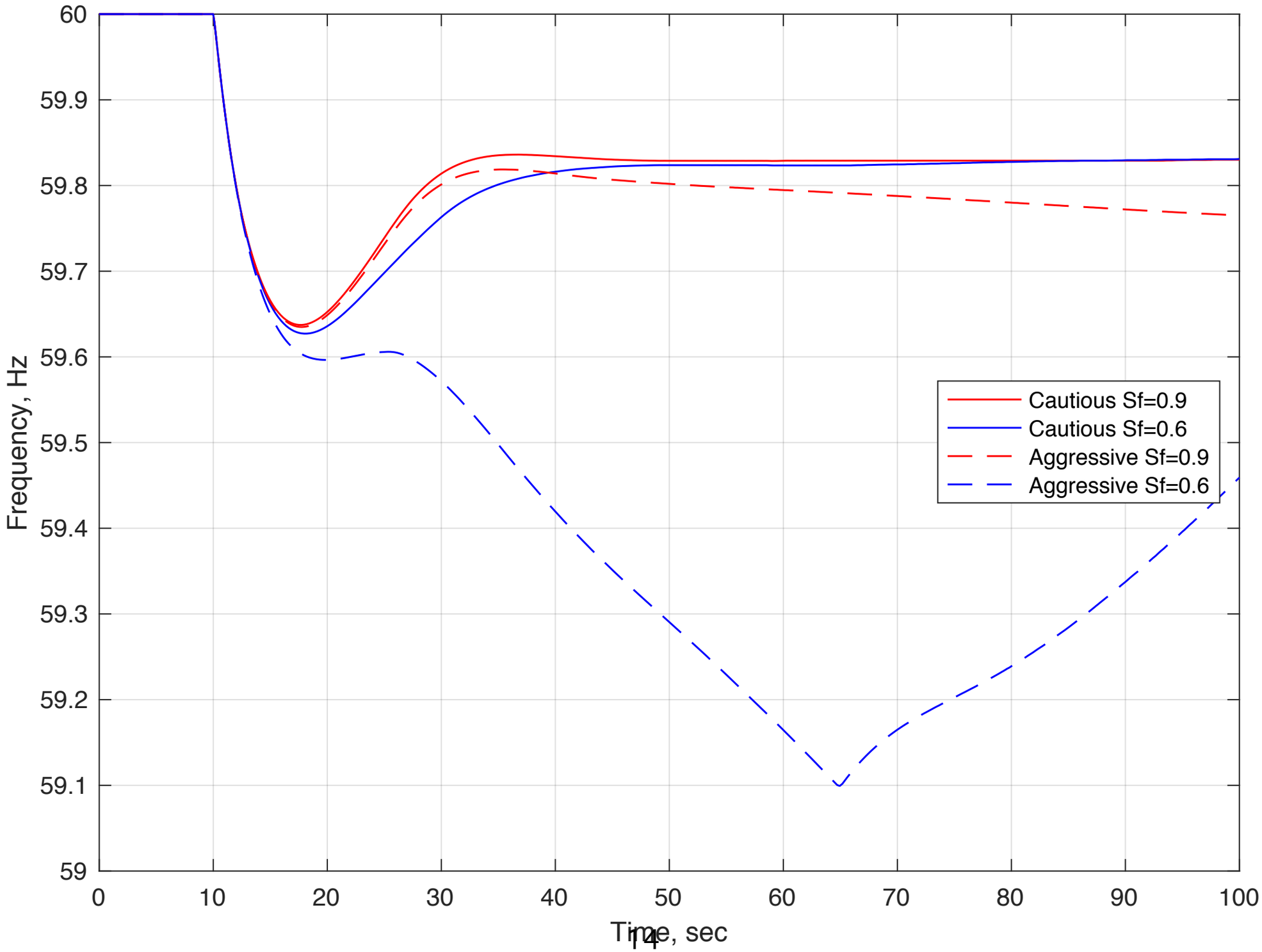


p2500June/q-10-0.cha p2500June/q3-10-0.cha qq3-10-0.pdf

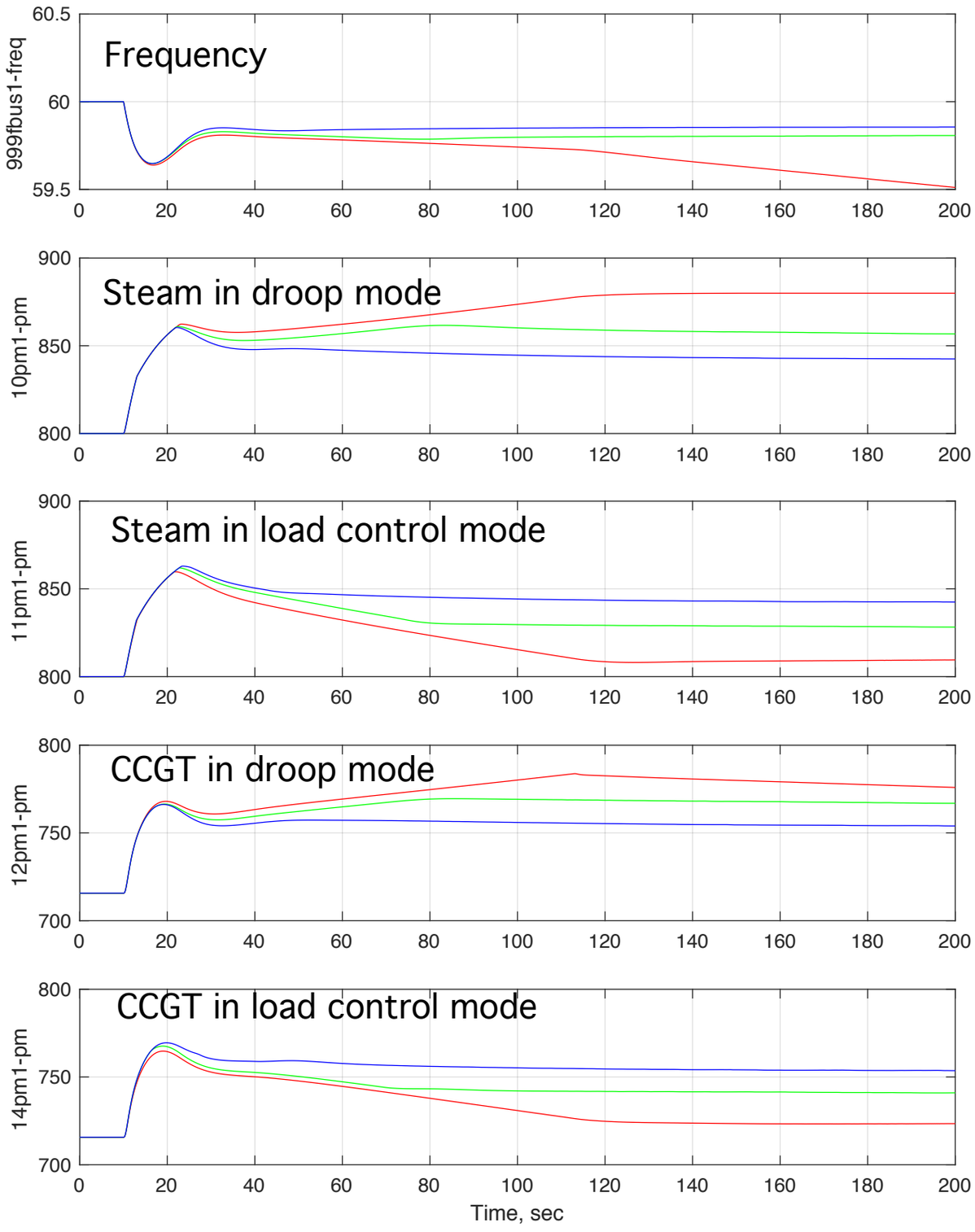
Sensitivity to inertia constant



Effect of aggressive withdrawal of initial response



Use of frequency bias in plant (DCS) load controllers



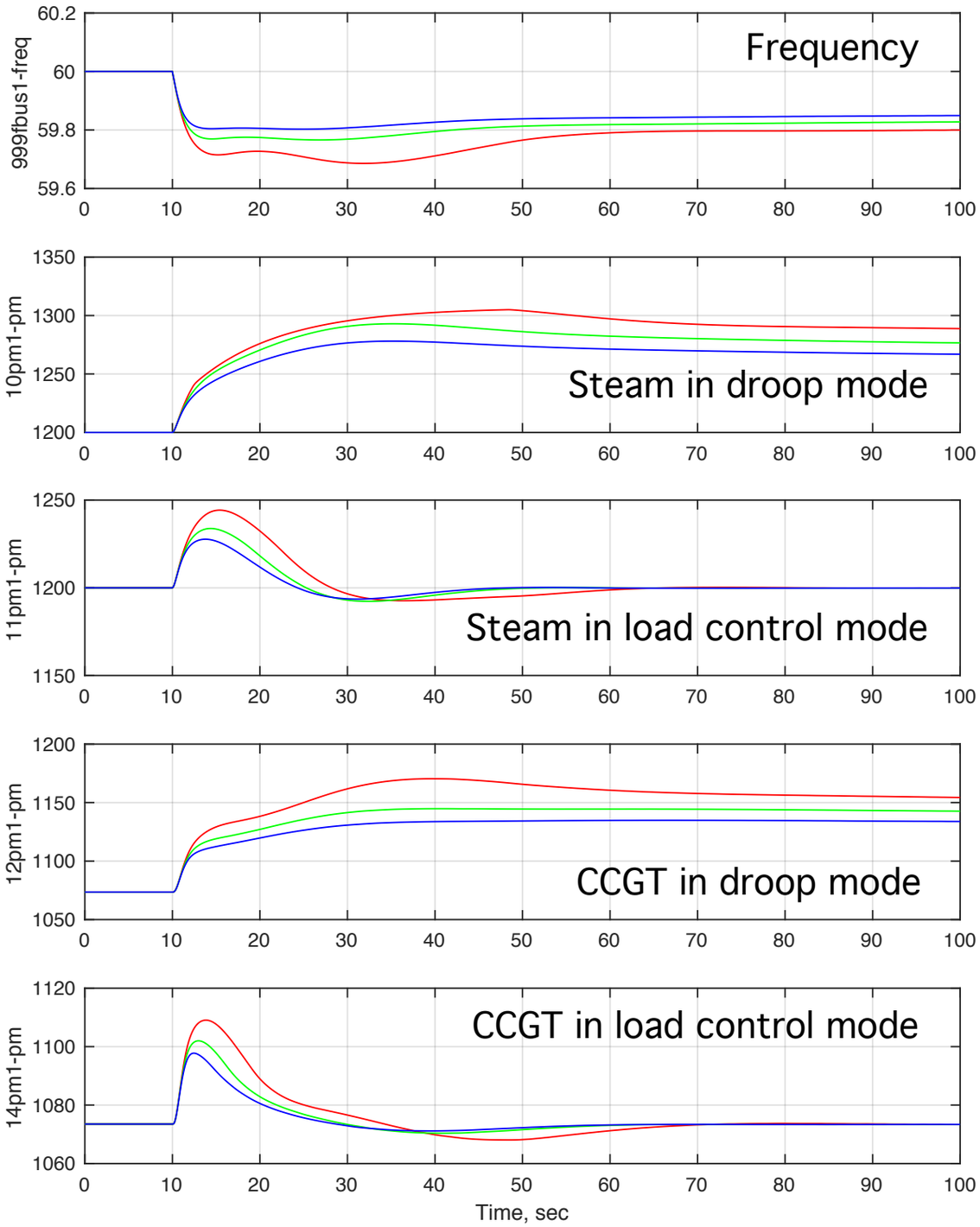
No frequency bias

Bias corresponds to half of governor droop

Bias corresponds to governor droop

p2500June/w-2-0.cha / p2500June/w-2-1.cha / p2500June/w-2-2.cha
w20-21-22.pdf

Effect of load frequency sensitivity



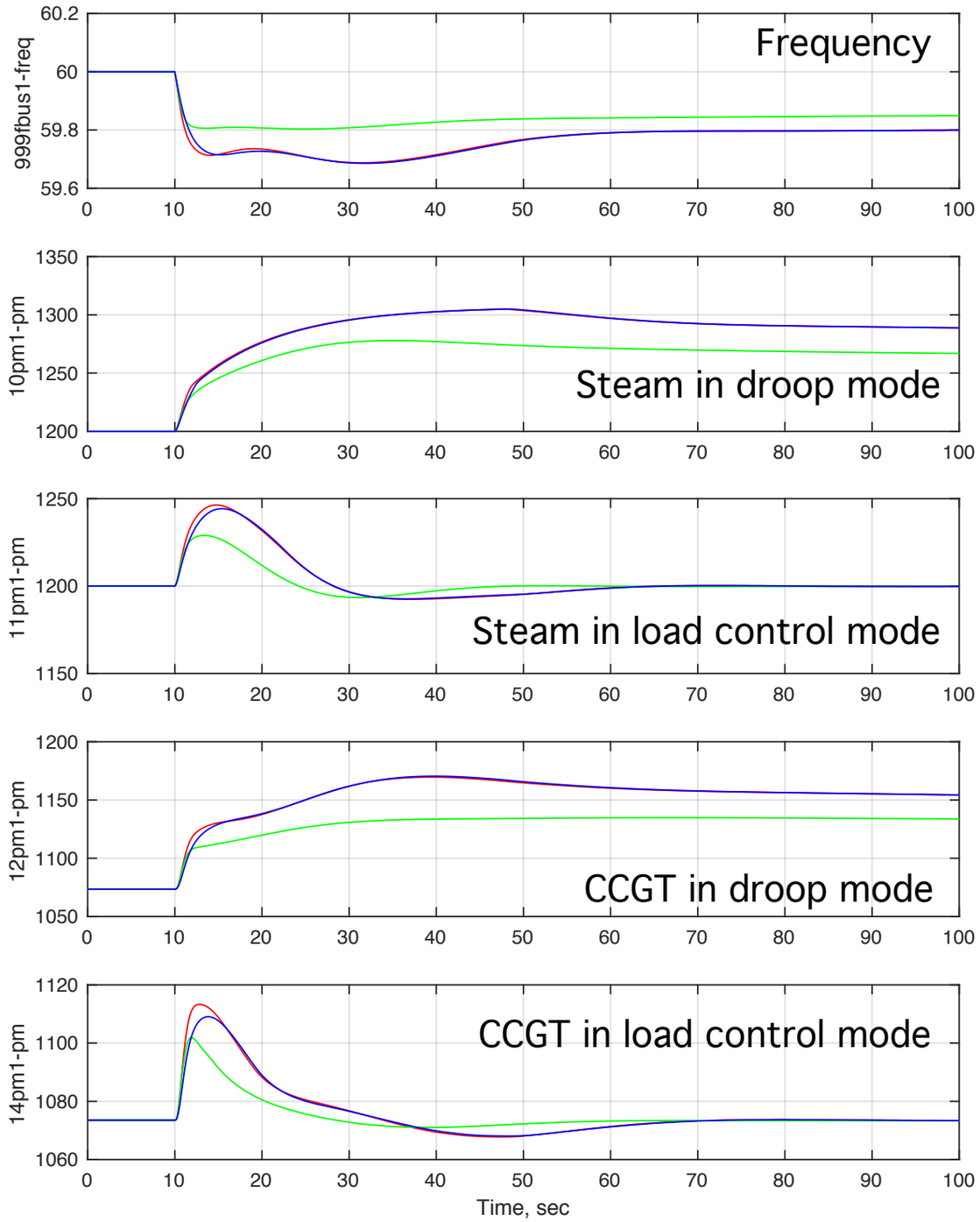
D = 0

D = 1

D = 2

a2500load/a2500fload-0-1.cha / a2500load/a2500fload-2-1.cha / a2500load/a2500fload-4-1.cha
a2500fload-012-1.pdf

Relative sensitivity to inertia and load damping



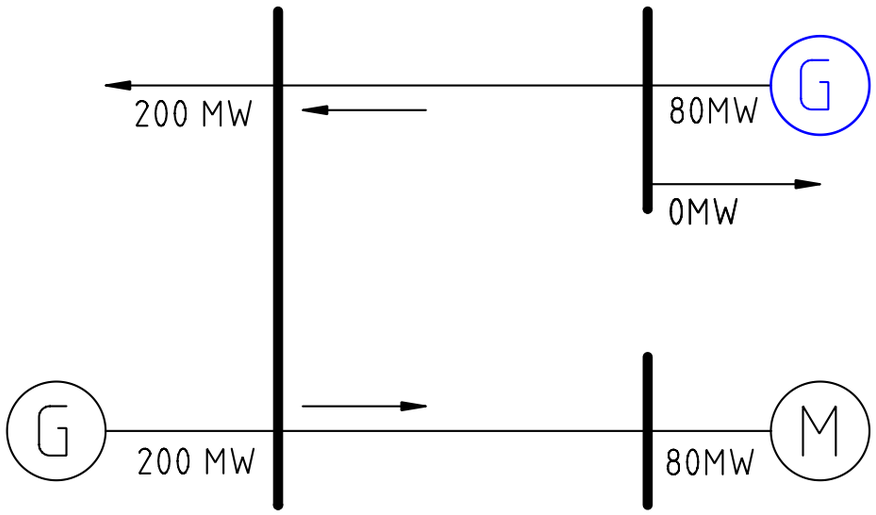
D = 0 H = 3

D = 2 H = 3

D = 0 H = 4

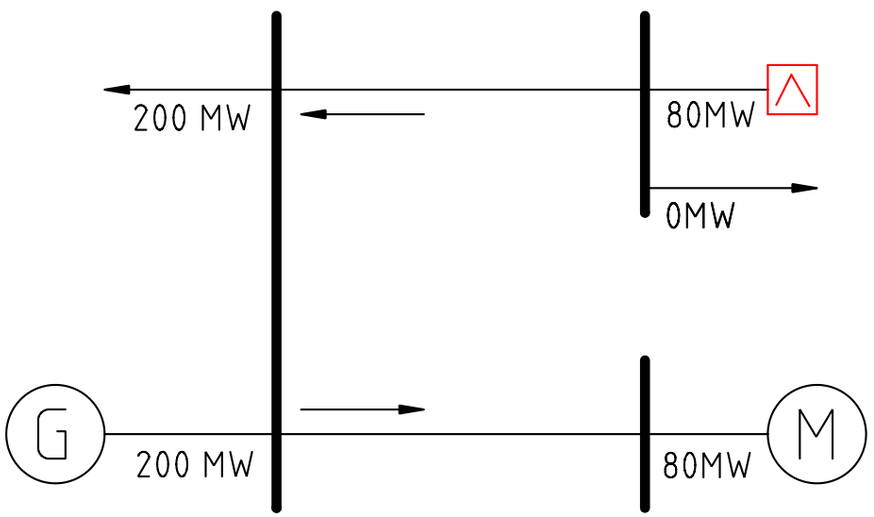
a2500load/a2500fload-0-0.cha / a2500load/a2500fload-4-0.cha / a2500load/a2500fload-0-1.cha
a2500fload-020-001.pdf

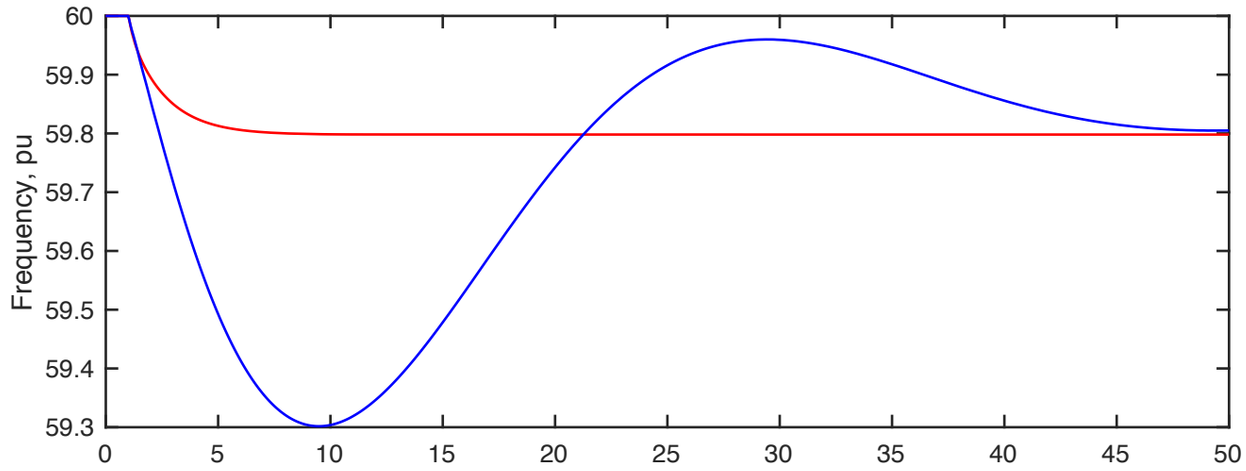
Rotating and electronic primary control (feedback control)

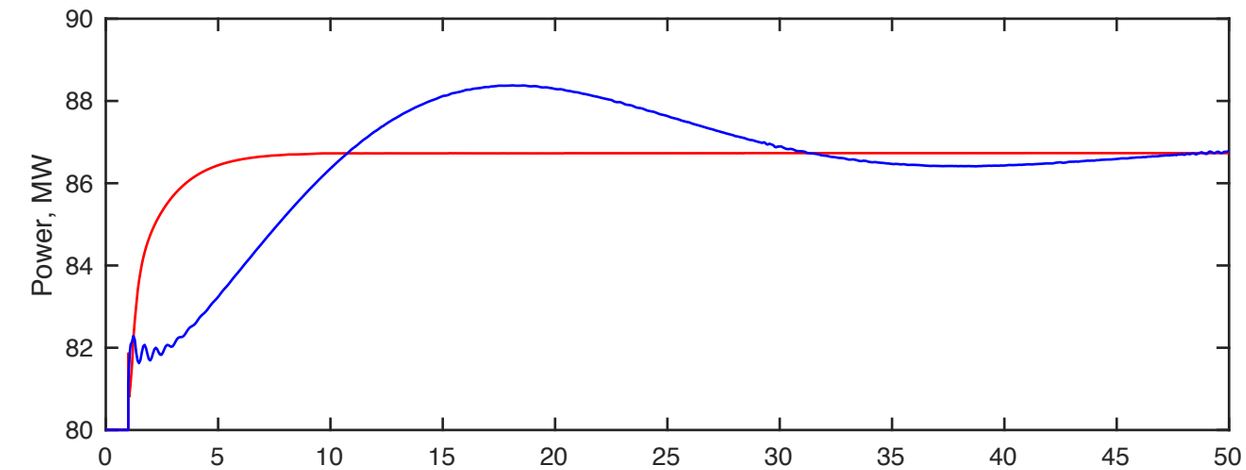


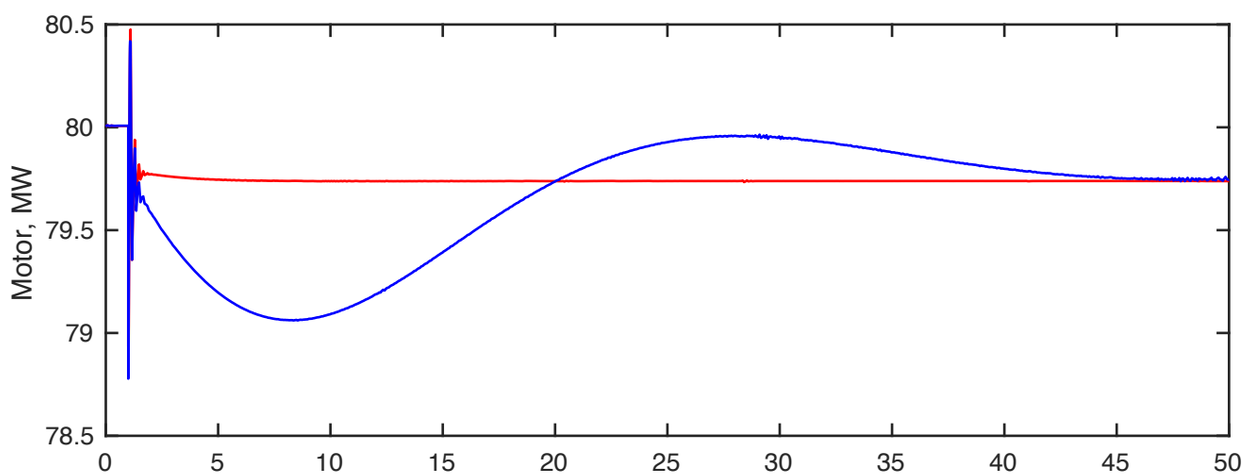
Rotating local generation
hydro governor

Electronic local generation
electronic primary control

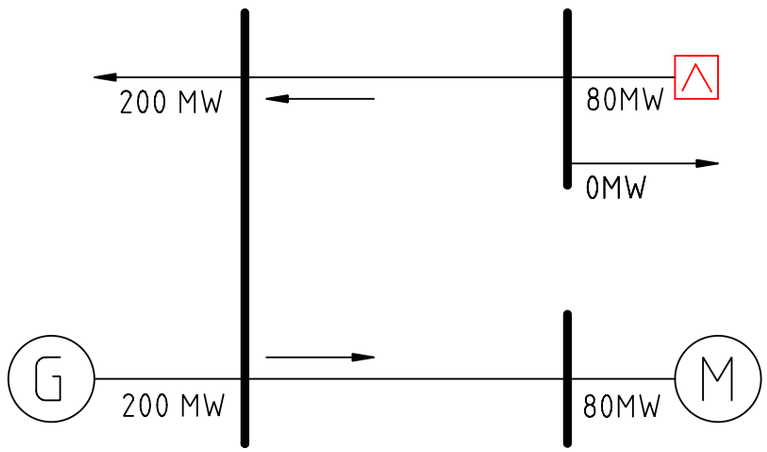








Triggered response by electronic local generation

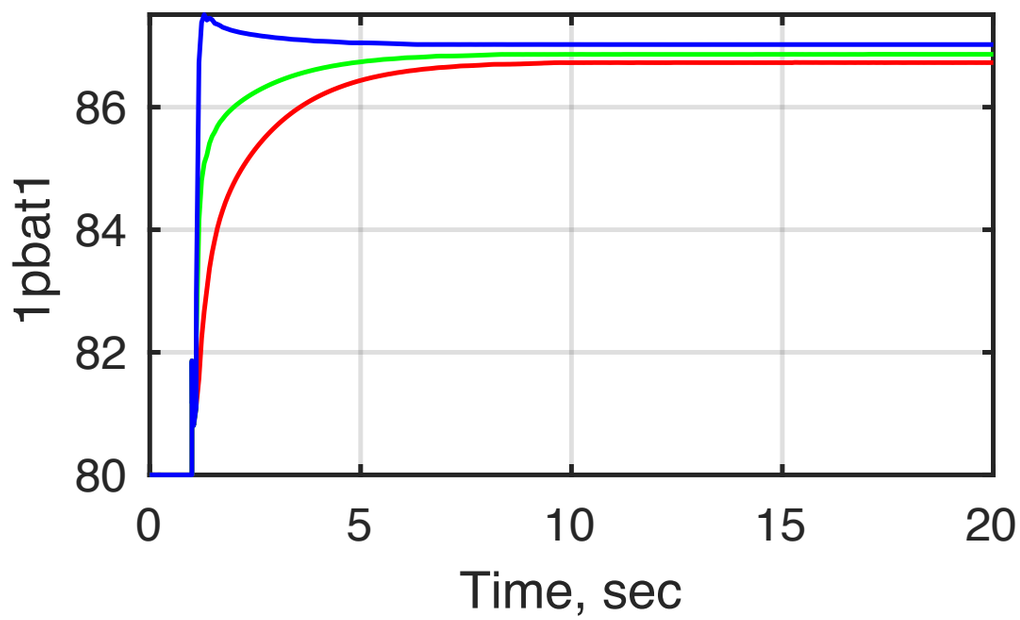


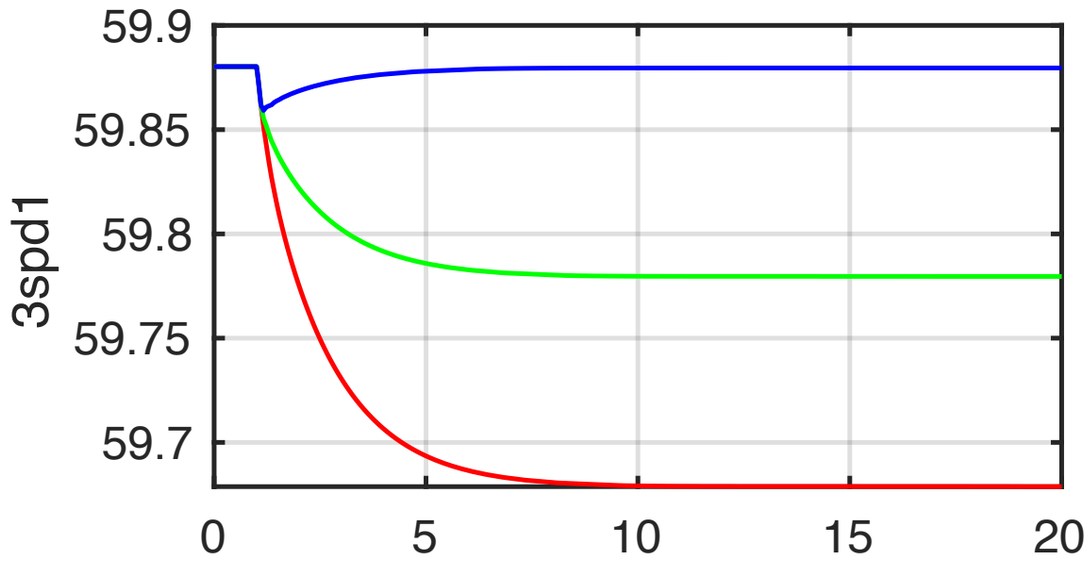
Increase in electronic generation triggered after delay of 100 msec

Red no triggered response

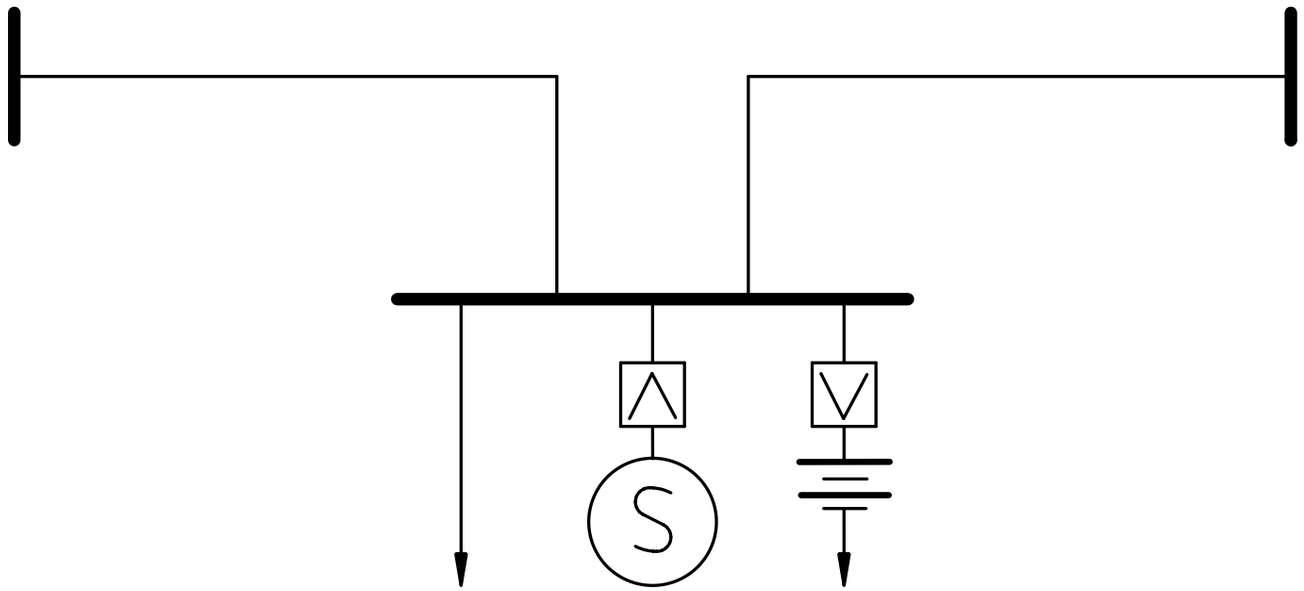
Green 50% triggered response

Blue 100% triggered response





A Reactive Power Example



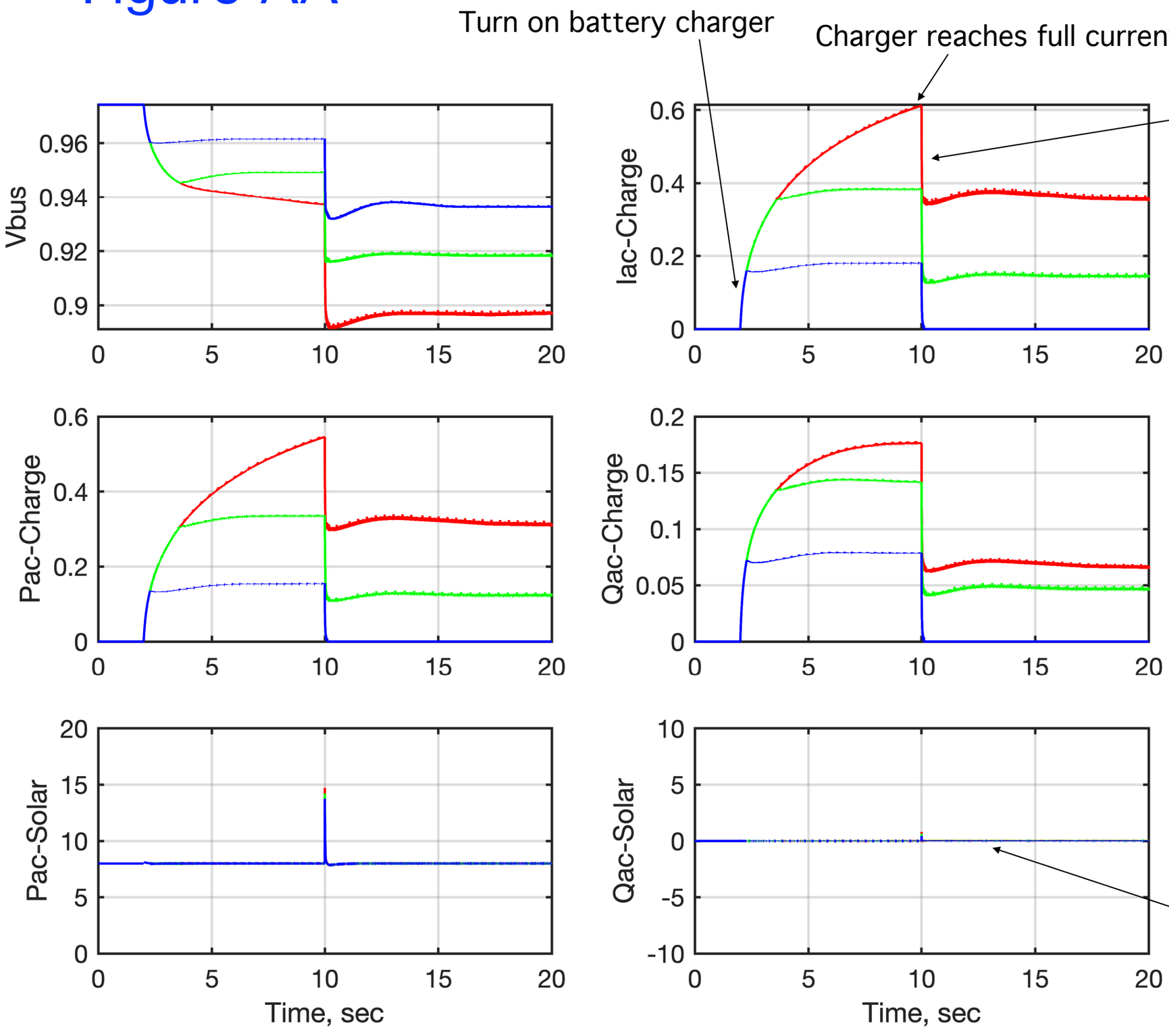
Load 'pocket'
Old thermal plant has been retired
Solar development has made up some of the loss of local power production
Battery is used to handle early-evening load

Sunny day all over
Grid power at favorable price
Turn on battery charging
Bus voltage dips

One of the incoming lines opens

Voltage dips further

Figure AA



Red - AC current limit not applied

Green - AC current limit applied reduces charging real power

Blue - AC current limit applied stops charging

Form of charger AC current limit

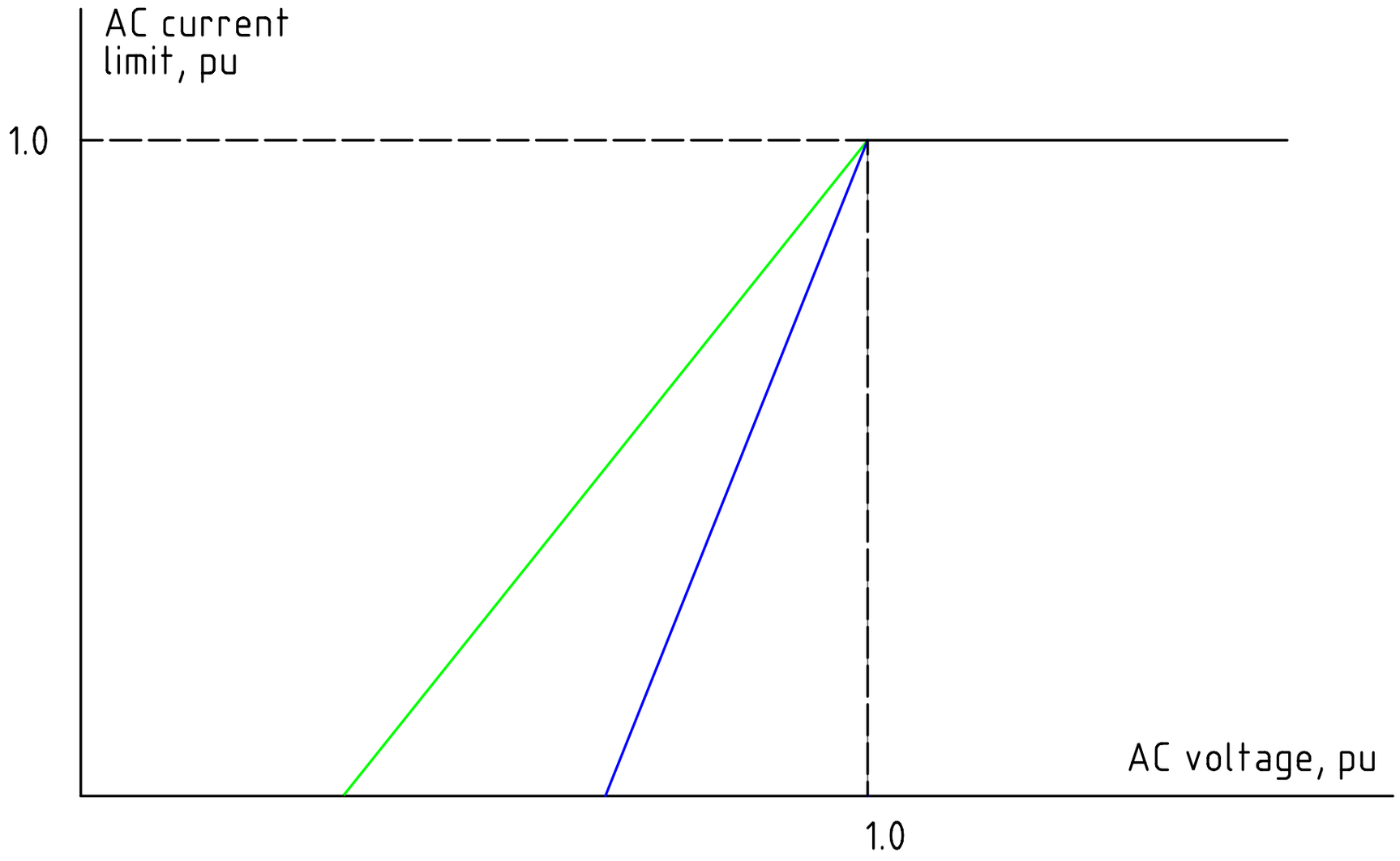
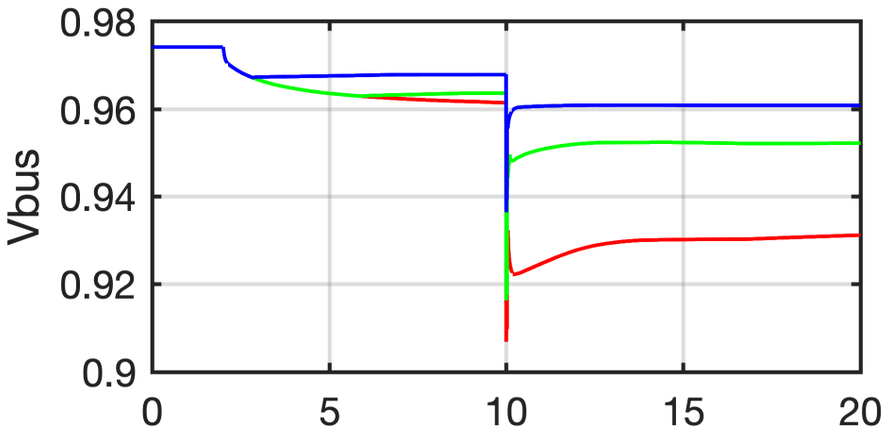
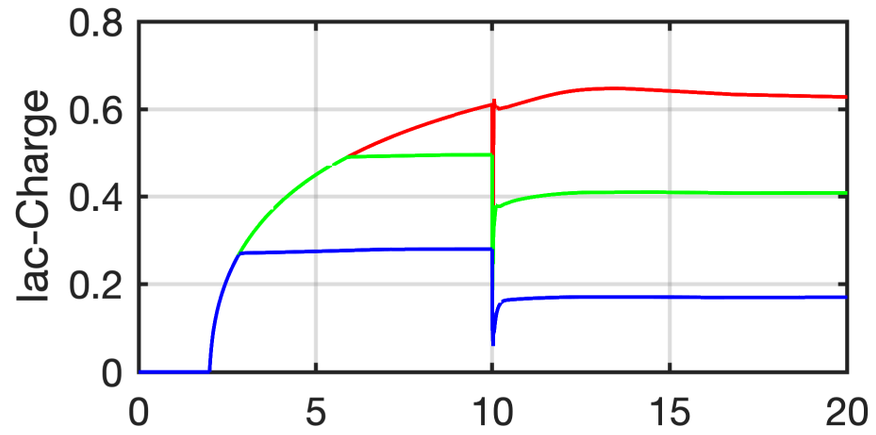
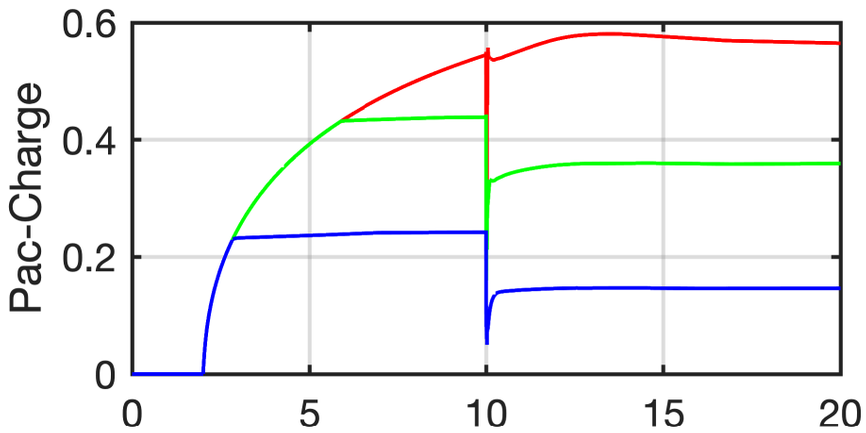
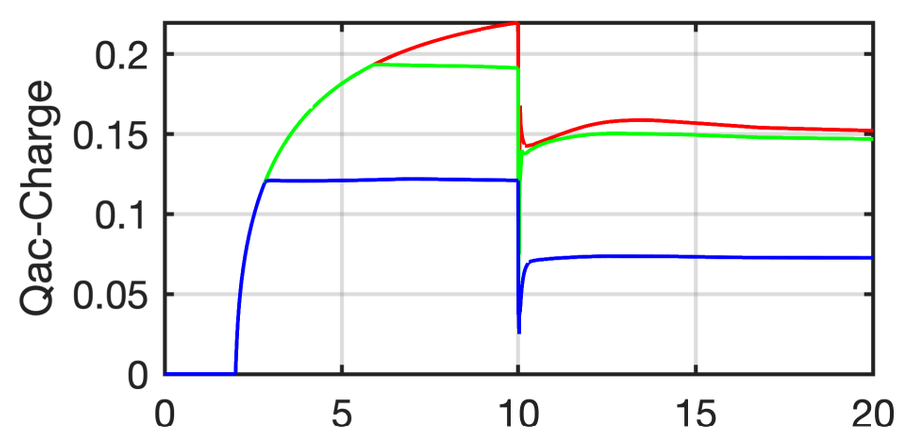


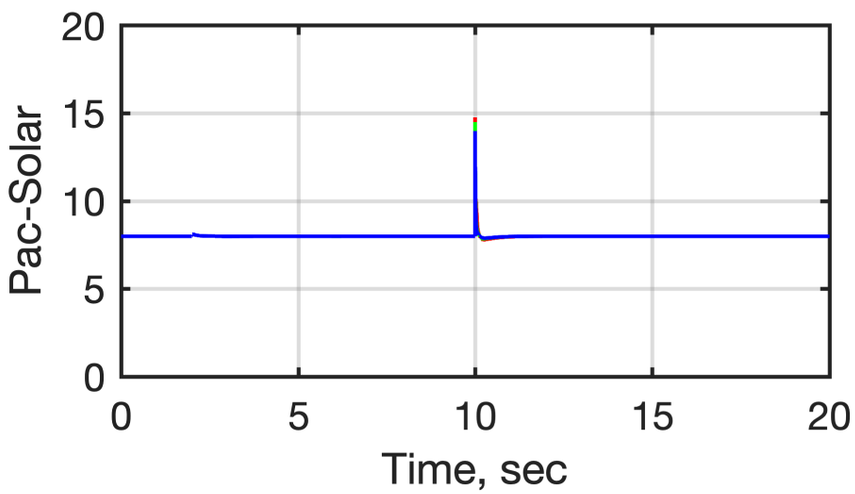
Figure CC

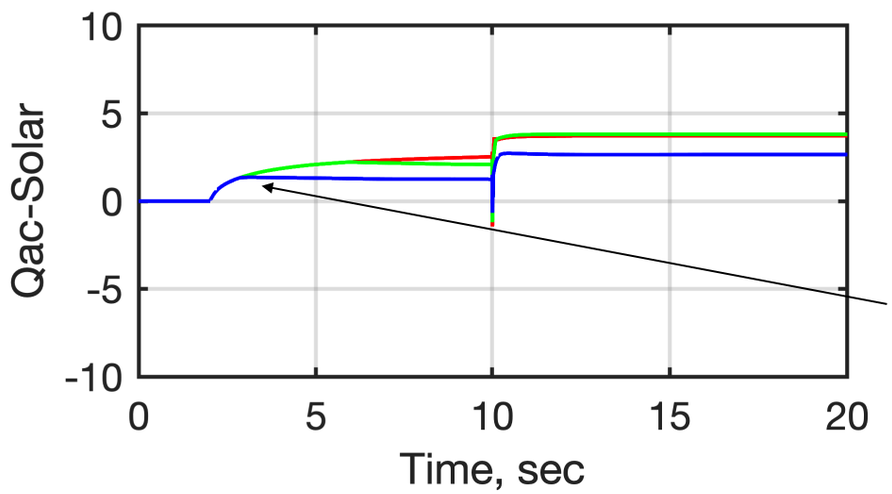












Red - AC current limit not applied

Green - AC current limit applied reduces charging real power

Blue - AC current limit applied stops charging

Solar inverter regulates AC terminal voltage

Summary - real power control

The availability and prompt delivery of primary frequency response is critical today

The timing of delivery will need to be quicker as the fraction of electronically coupled equipment increases

The frequency sensitivity and voltage sensitivity of loads are as important as the characteristics of generation

Summary - General

It will be necessary for electronically coupled generation to contribute primary frequency response

The effects on frequency control of replacing rotating generation with electronically coupled DER are systemwide

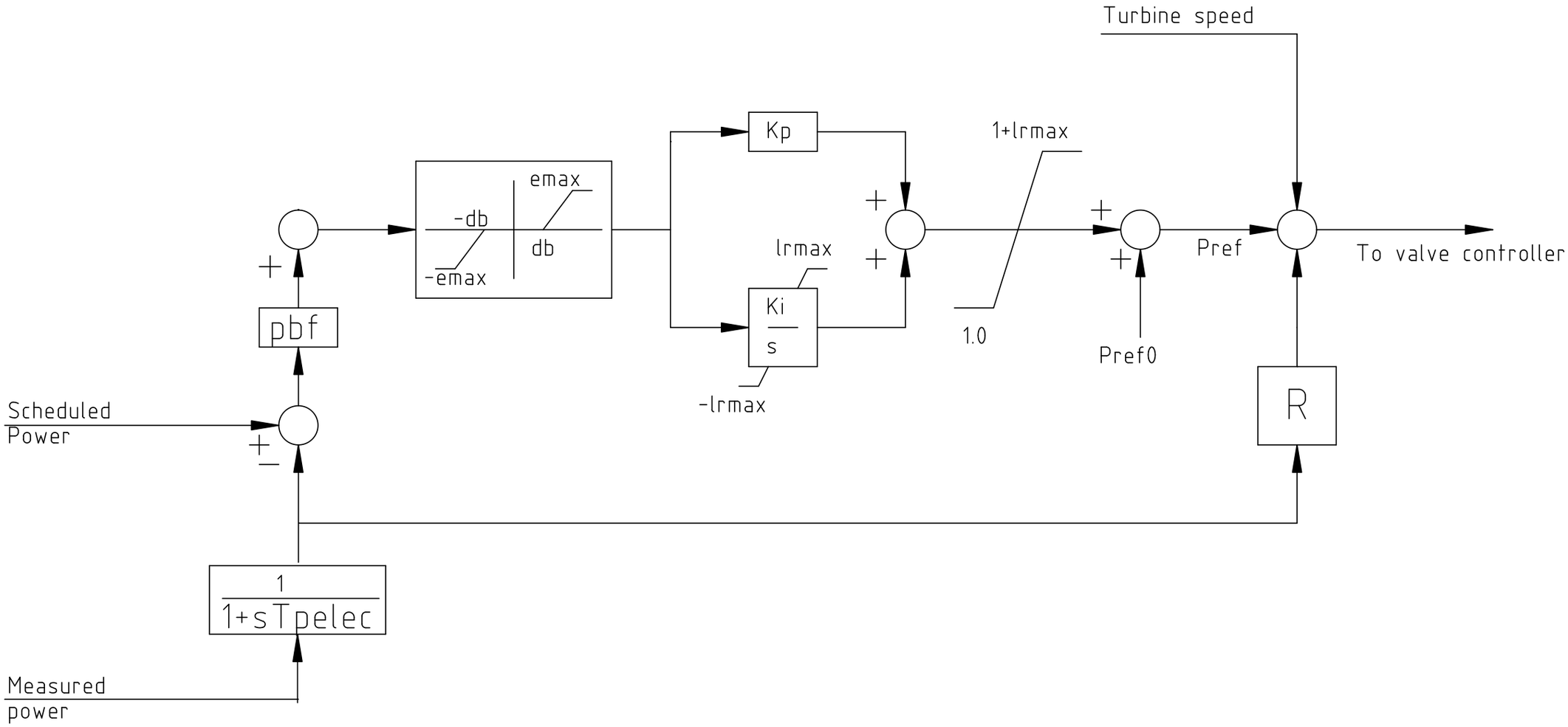
The effects on voltage control of replacing direct-connected equipment with electronically coupled equipment may be mainly local (but not always so)

Proper use of primary response of electronically coupled generation can be expected to improve quality of frequency and voltage control

Thankyou

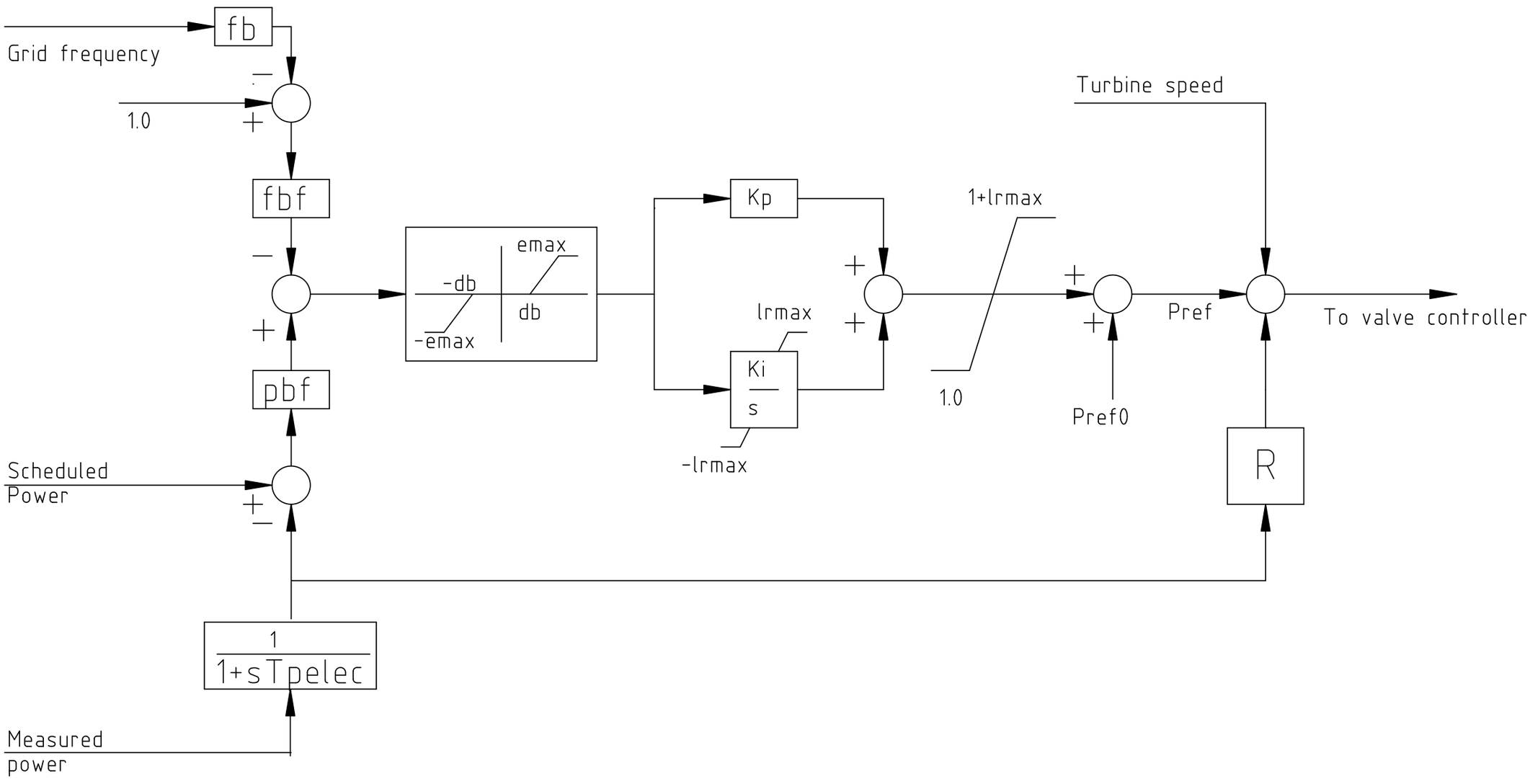
Use of frequency bias in plant (DCS) load controllers

$$P_{set}(f) = P_{sched}$$



Use of frequency bias in plant (DCS) load controllers

$$P_{set}(f) = P_{sched} + B_{fp}(f_{sched} - f)$$



batt electronic controller model