Compensated Frequency vs Speed as a PSS input

Les Hajagos and Leo Lima
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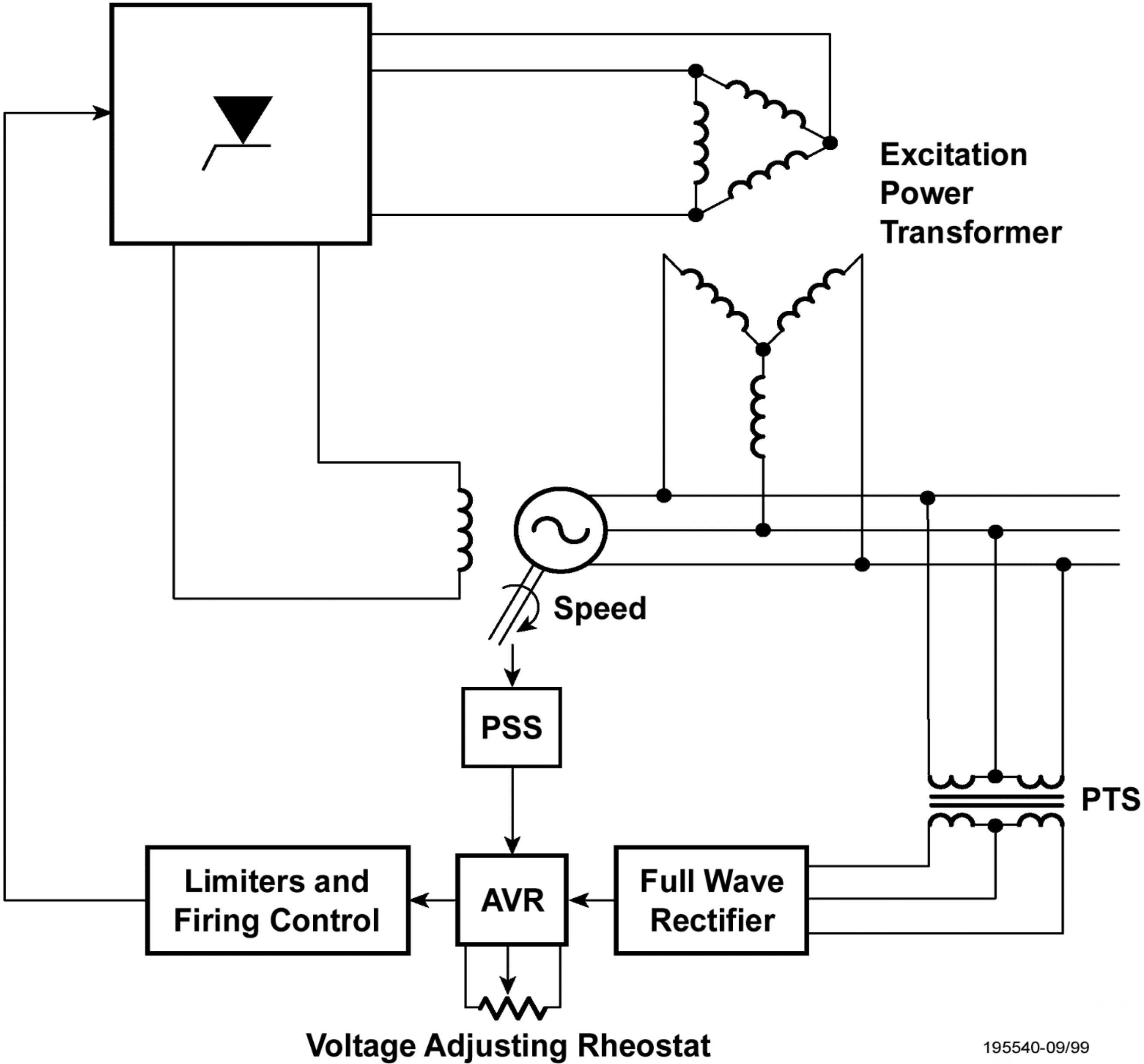
Power System Stabilizers

- Theory of PSS from 1960s to damp small signal oscillations from hydro plants with static exciters far from customer loads
- Classical tuning strategies based on generator rotor speed as a PSS input
- IEEE Tutorial Course Power System Stabilization via Excitation Control
  http://resourcecenter.ieee-pes.org/pes/product/tutorials/PES09TP250

Overview of PSS Connection



Power System Stabilizers

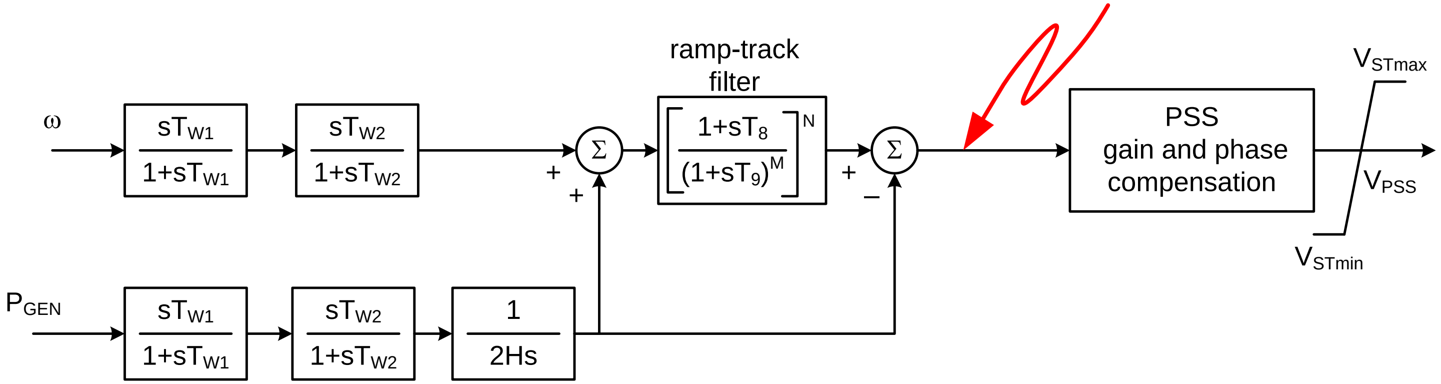
- PSS input signals
  - – Major research effort and lots of publications associated with the selection of the "best" input signal for the PSS
    - Shaft speed (beware of torsionals…)
    - Electrical power
    - Terminal bus (voltage) frequency

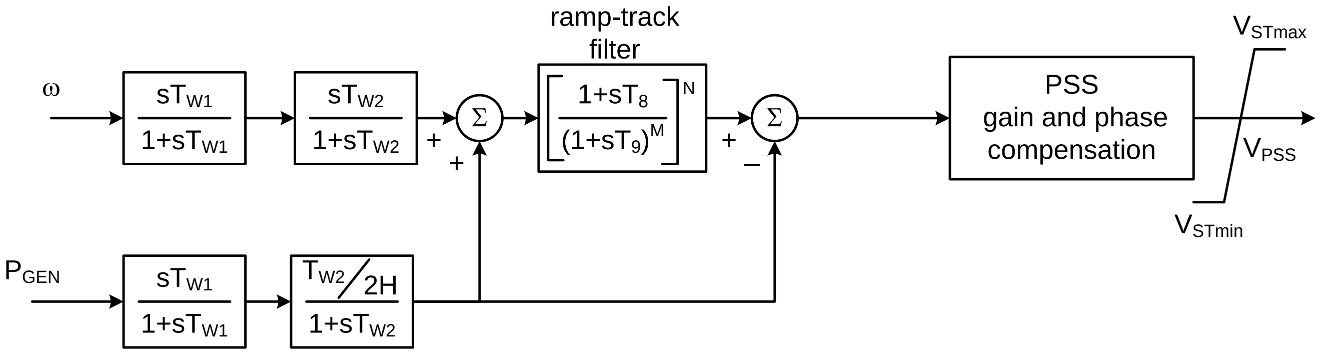
    - Integral of accelerating power (calculated speed)
    - Compensated frequency

Integral of Accelerating Power

- Most common modern PSS structure
  - The integral of the accelerating power is calculated from the speed and electrical power output of the generator
  - If correctly done, the calculated integral of accelerating power would match the shaft speed

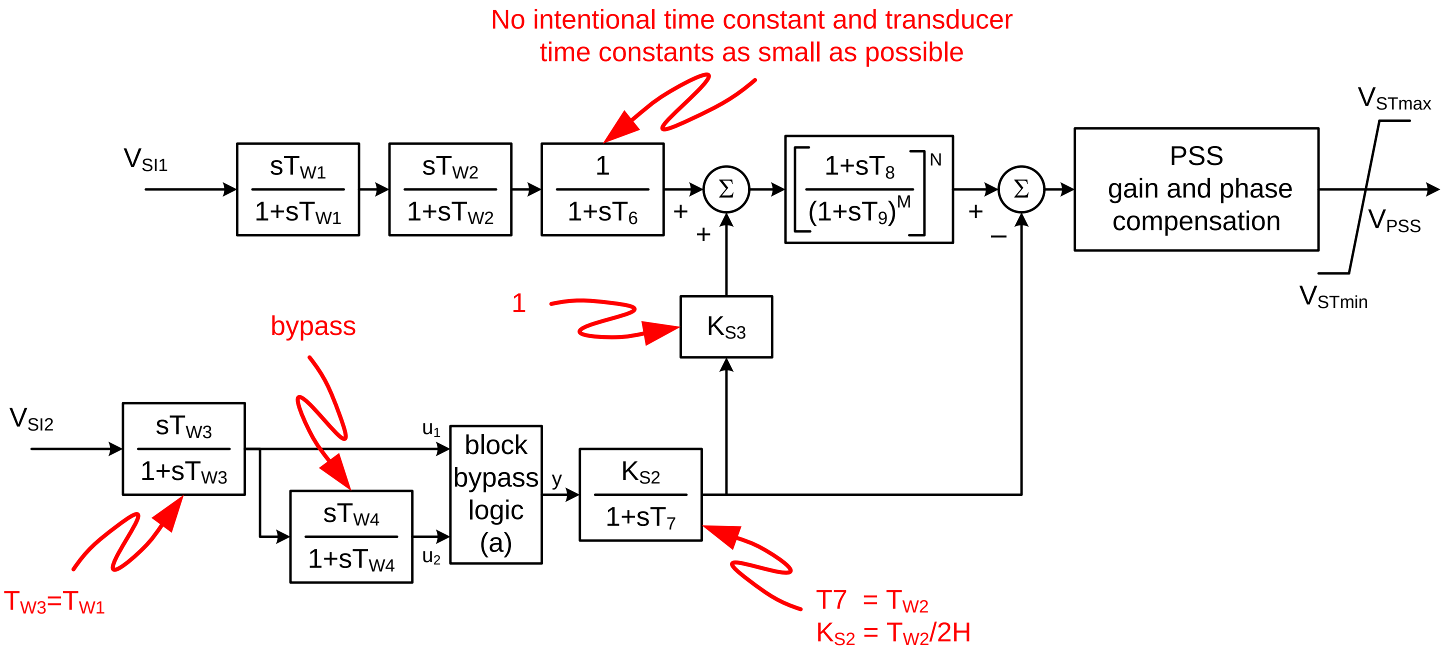
Integral of Accelerating Power


integral of accelerating power (calculated speed)



Integral of Accelerating Power

- IEEE Std. 421.5 (PSS2A, PSS2B, PSS2C models)
  - To represent the integral of accelerating power structure with these PSS models



No intentional time constant and transducer time constants as small as possible

1

bypass

$T_{W3}=T_{W1}$

$T7 = T_{W2}$
$K_{S2} = T_{W2}/2H$

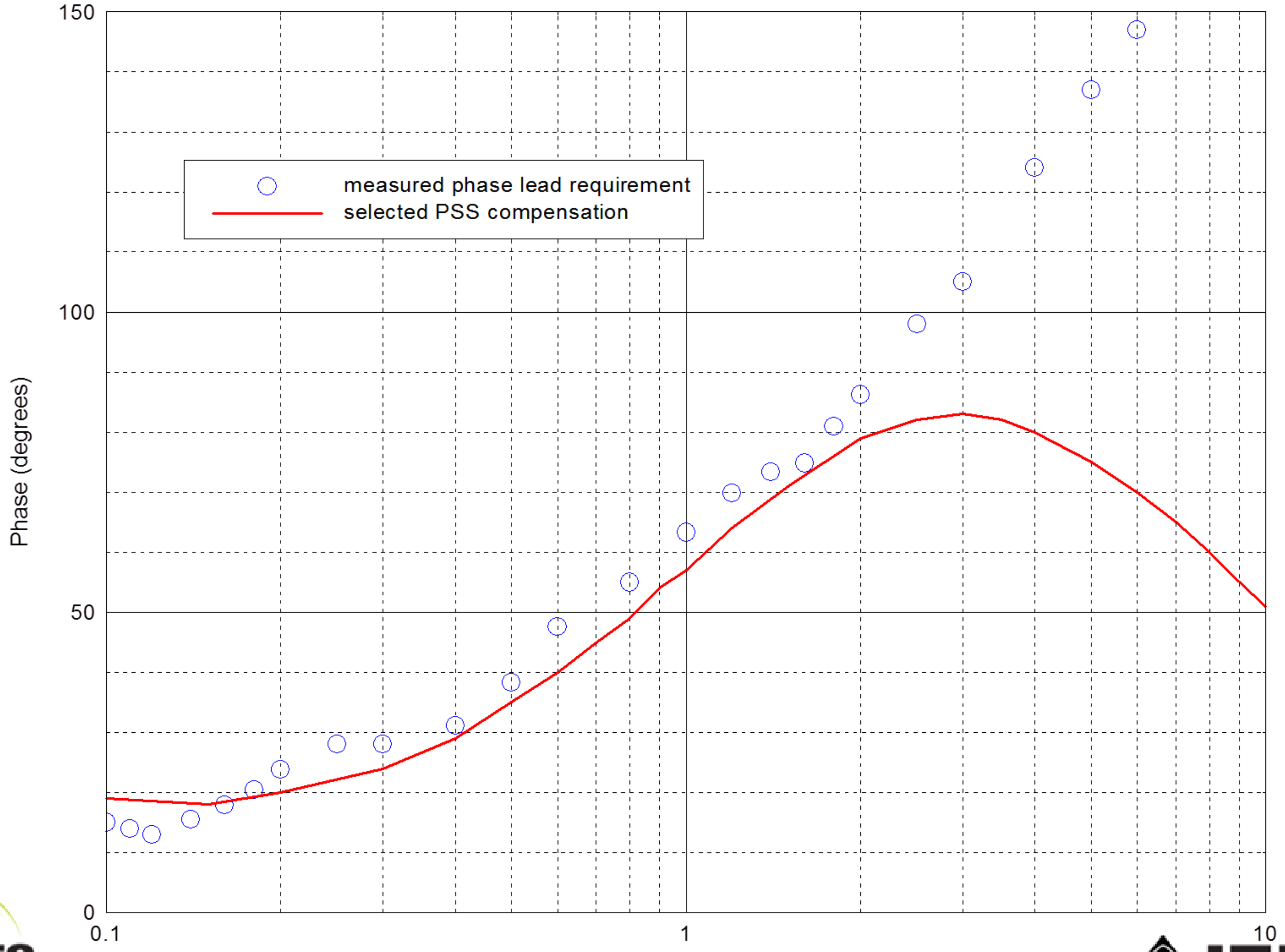
Integral of Accelerating Power

- Calculated speed (integral of accelerating power) is meant to match shaft speed
  - PSS tuning is done using the same approach of a speed-based PSS
  - Performance is affected if calculated speed is different from shaft speed
    - Setup of the washouts, bypass of the Tw4 block, setup of gains Ks2 and Ks3 are done incorrectly
    - First input signal is not shaft speed but compensated frequency

Stabilizer Tuning & Selection of Operating Settings

- Phase Lead Compensation
- Washout (High-Pass Filtering)
- Gain
- Output Limits

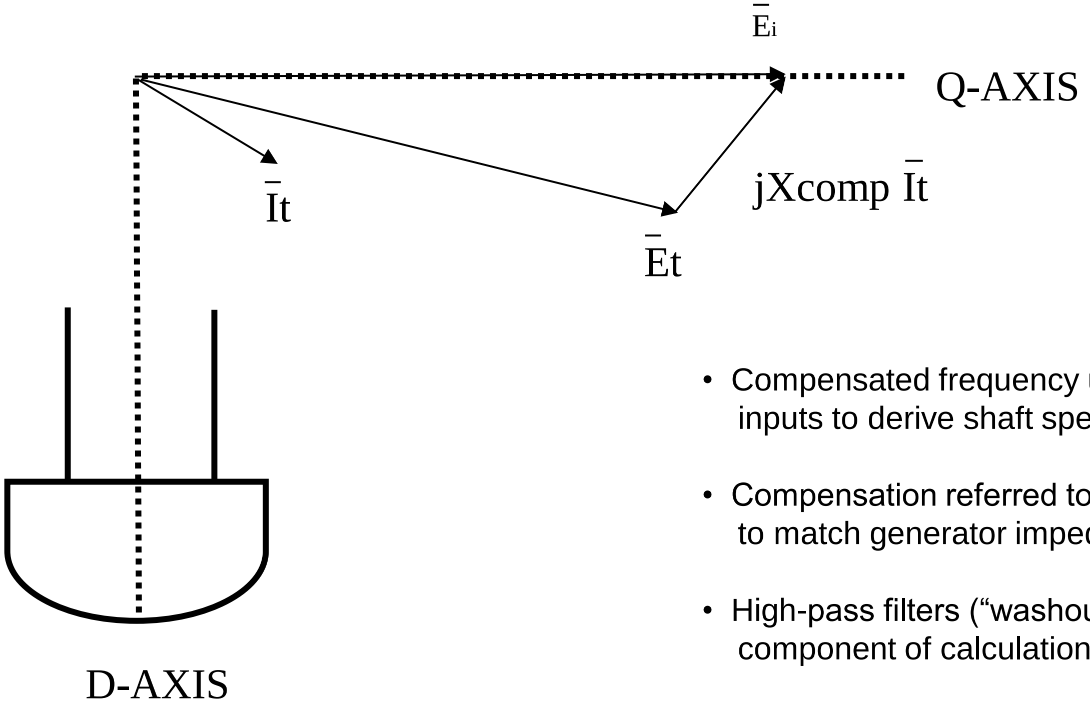
On-Line PSS Compensation



Compensated Frequency

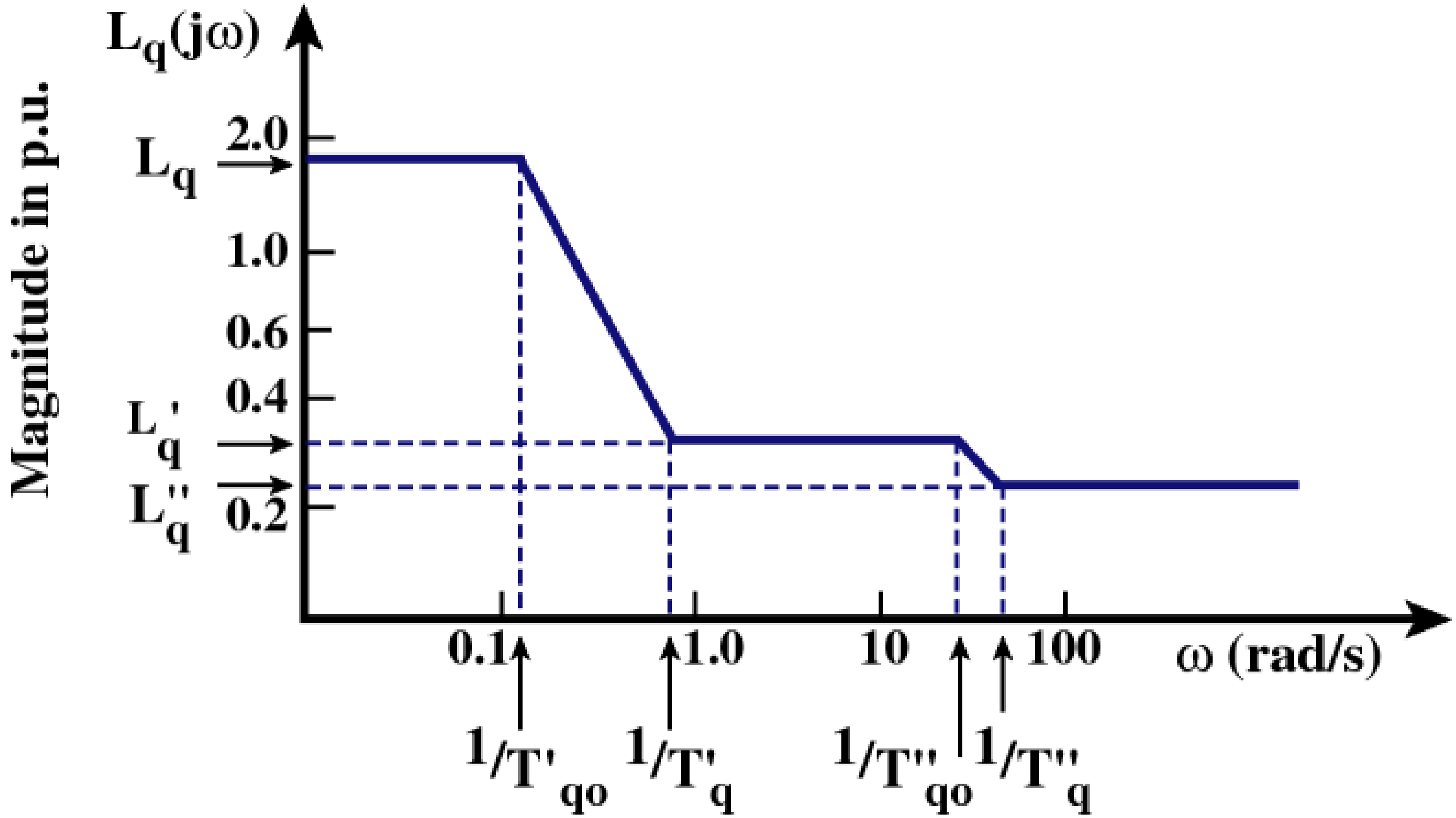
- Calculation based solely on PT and CT measurements
  - No feedback from shaft speed
  - Based on a simplified model for the synchronous machine, a voltage behind a reactance
  - If the reactance is properly selected/calculated, the calculated internal voltage is aligned with the q-axis and therefore the frequency of this internal voltage matches the shaft speed

Compensated Frequency

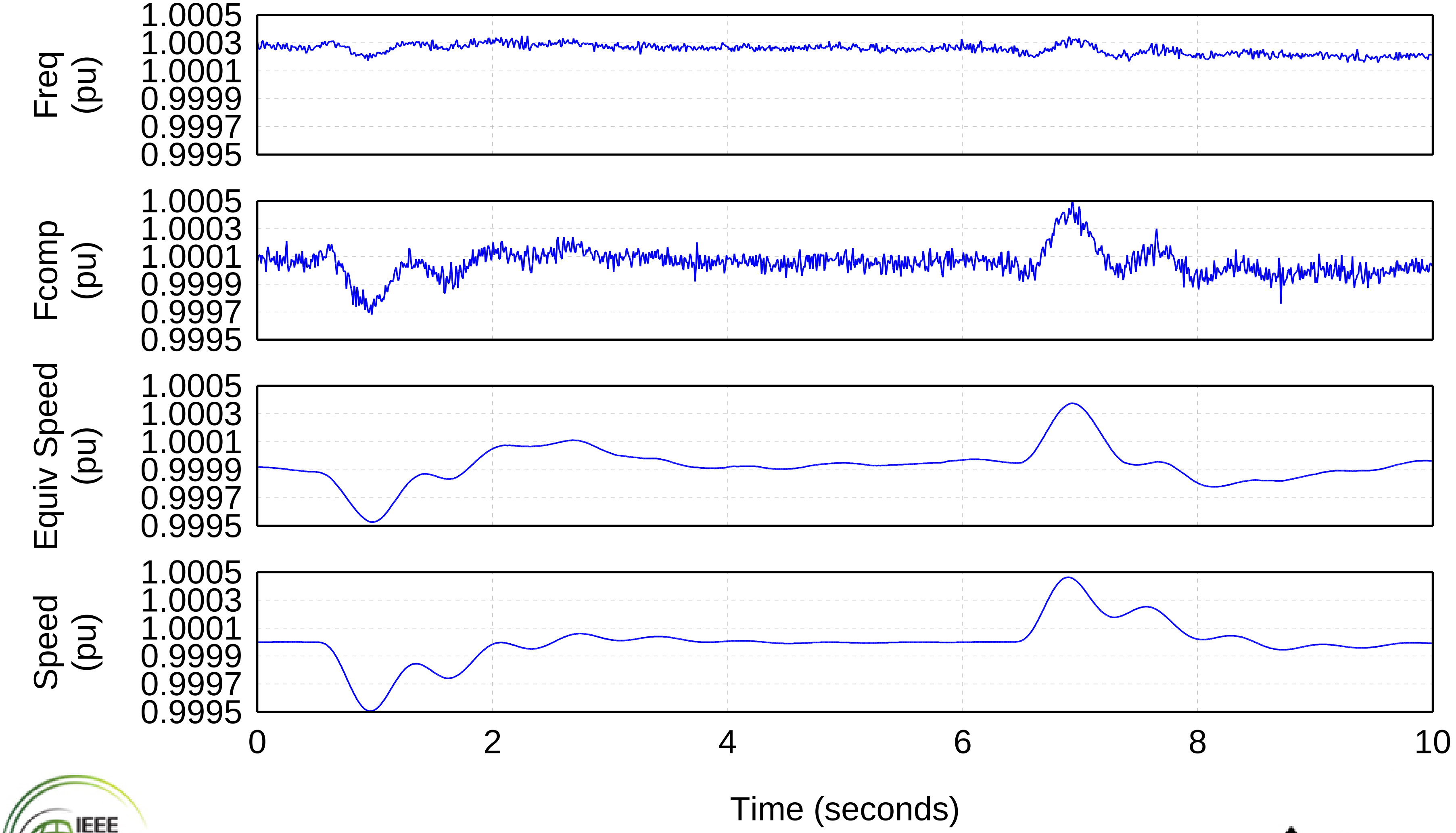


- Compensated frequency uses CT and PT inputs to derive shaft speed
- Compensation referred to as “Xcomp” selected to match generator impedance
- High-pass filters (“washouts”) remove dc component of calculation
- Washout time constants must pass electromechanical mode frequencies

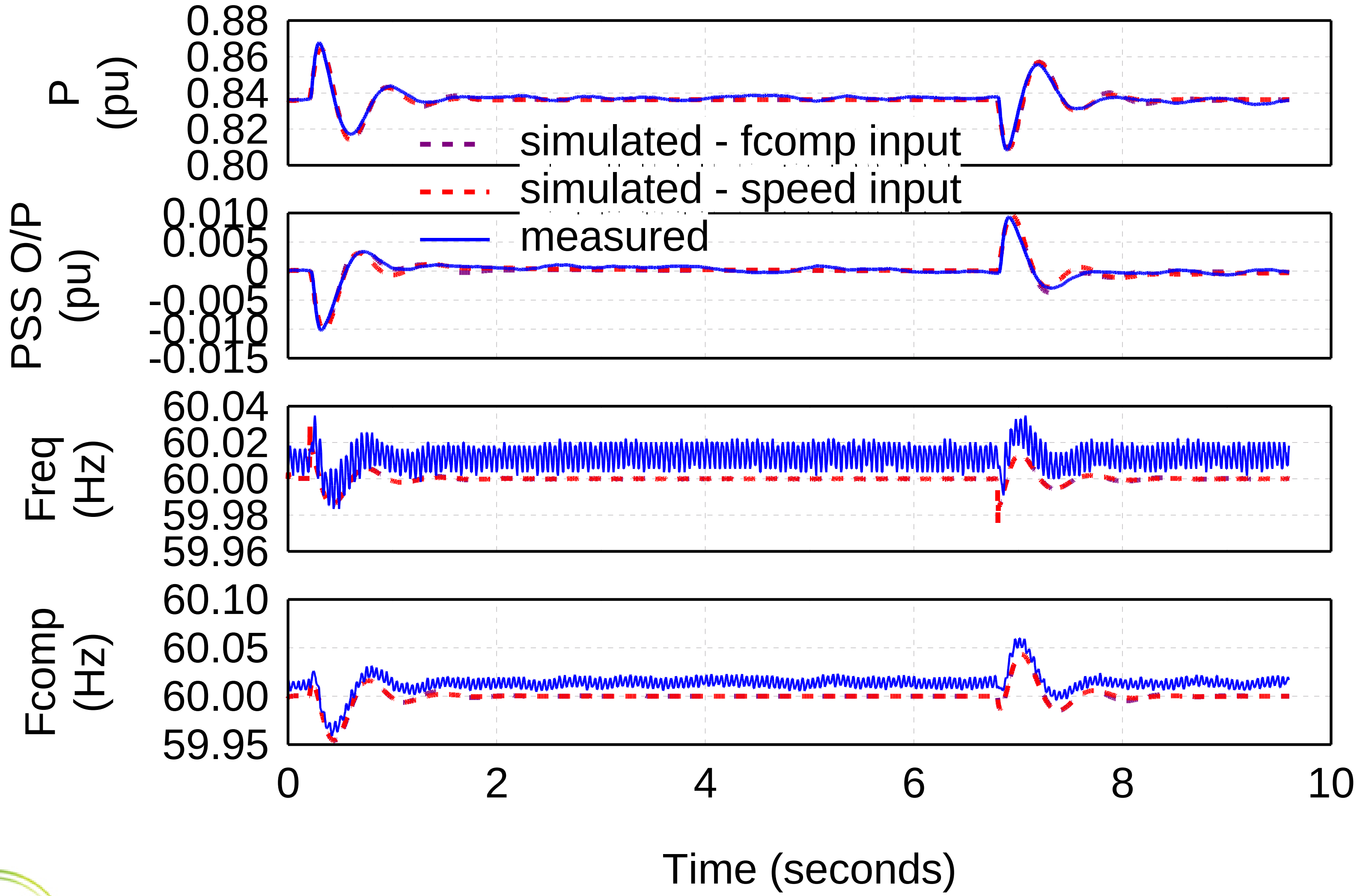
Variation of Magnitude of Lq(s) with Frequency



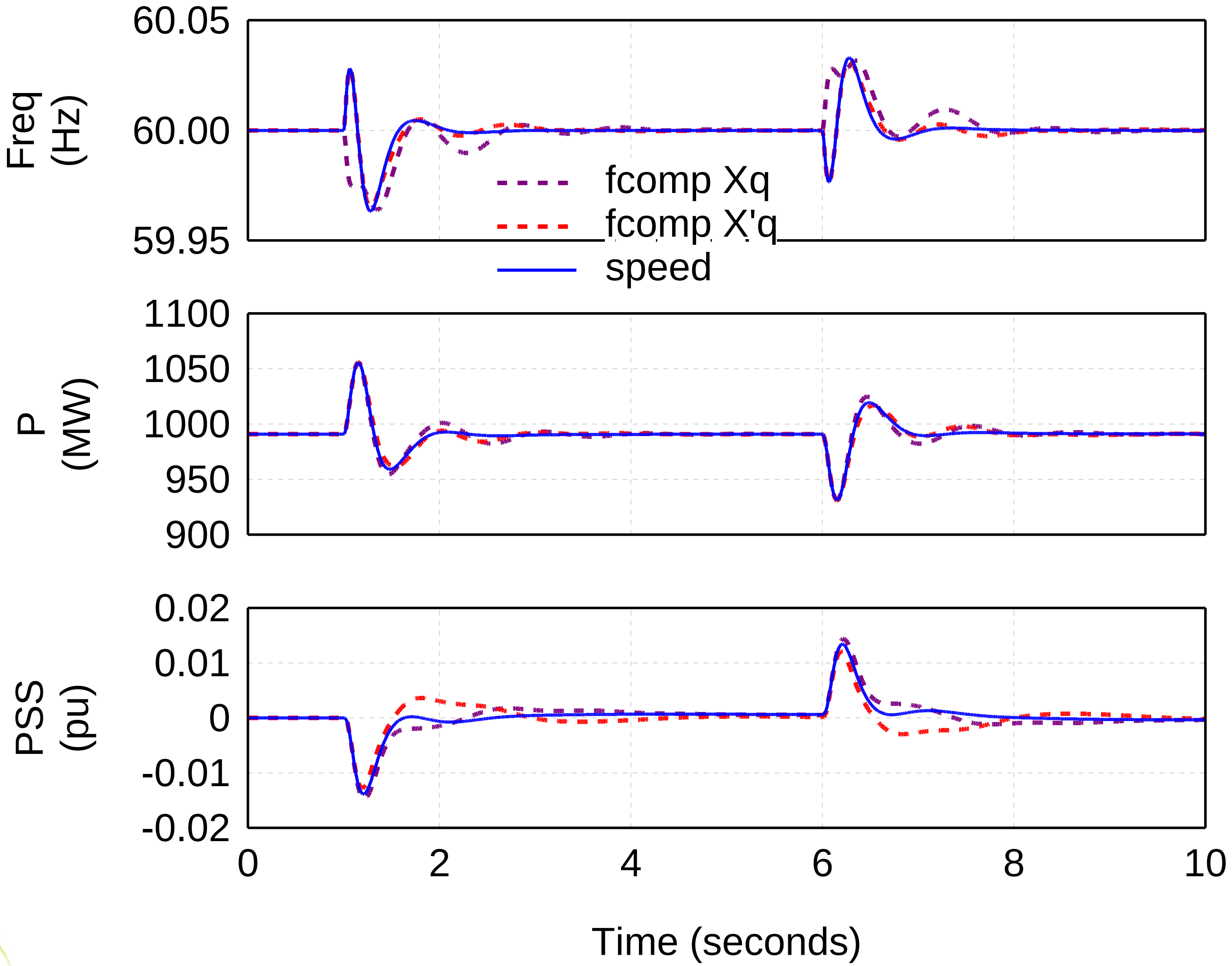
Comparison of Frequency Signals



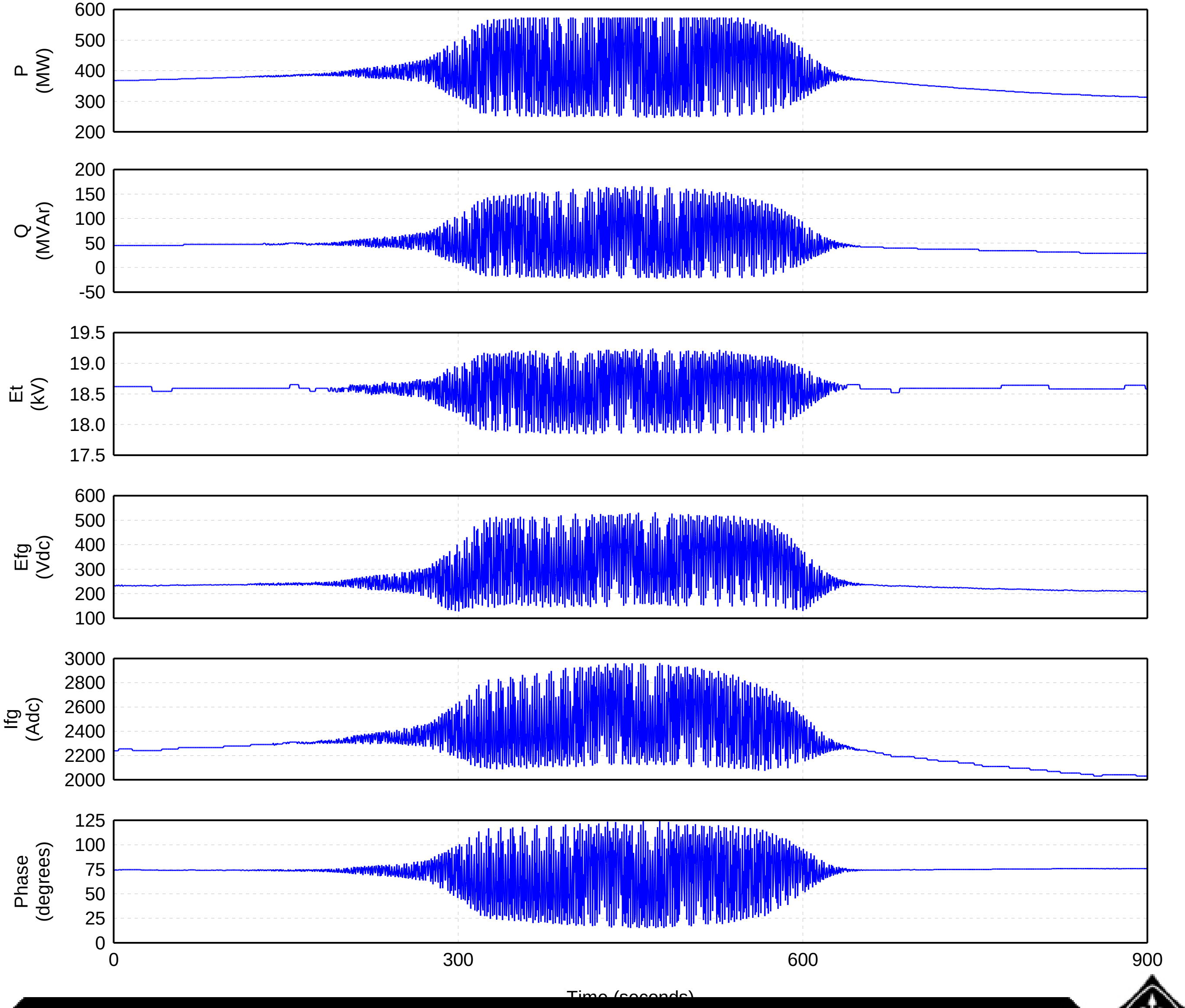
Job Well Done – Hydro unit Xqcomp=Xq



Round Rotor Unit



Improper Compensated Frequency Inputs



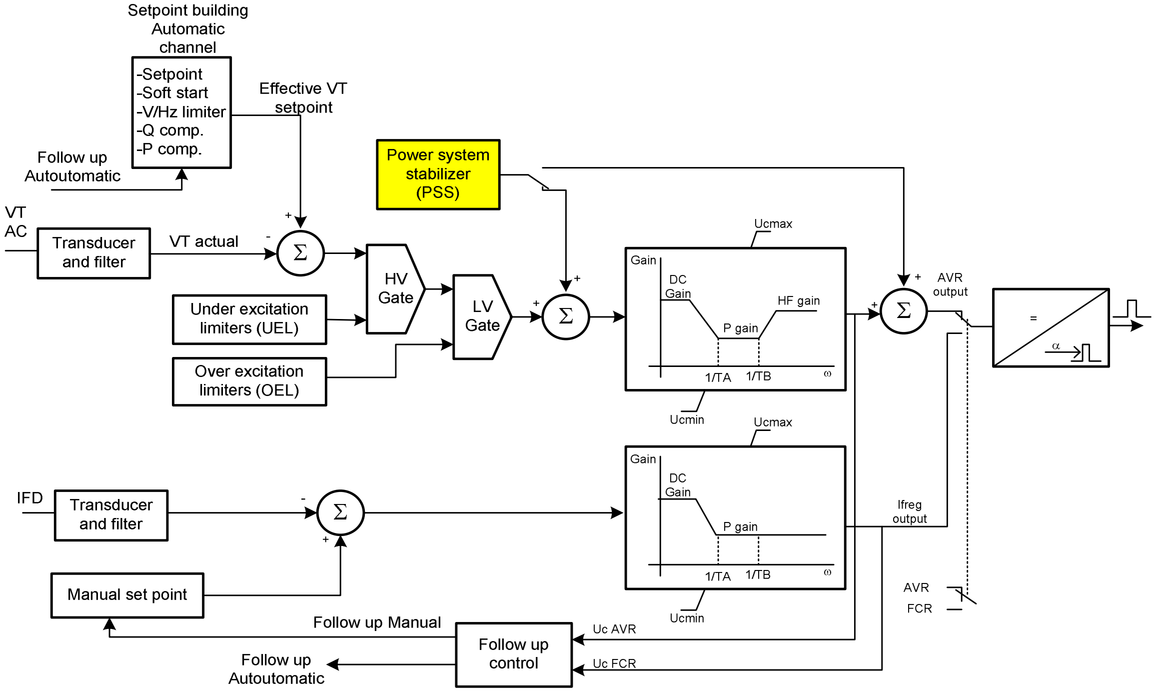
Influence of PSS in power systems subjected to high rate of change in frequency (ROCOF)

17PESGM2374

José Taborda – JT Systems Switzerland

Introduction

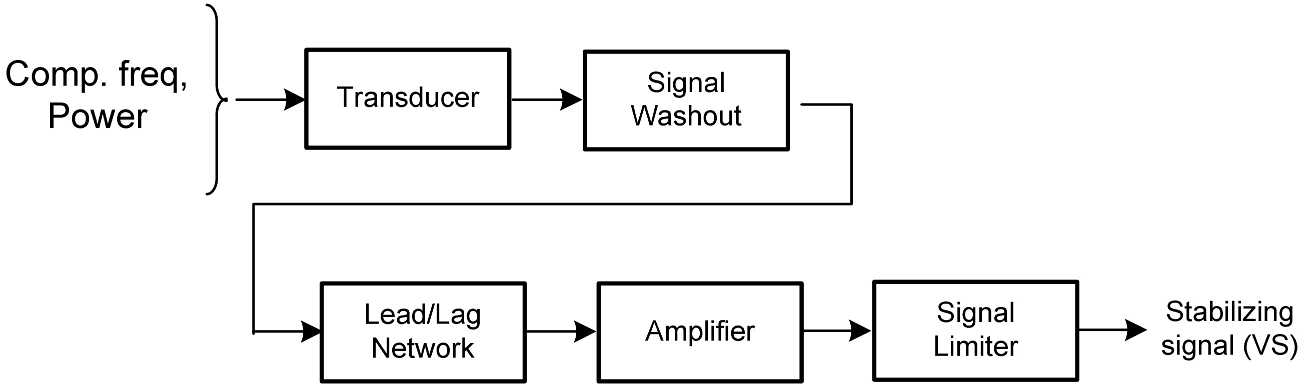
- Most of synchronous generators are equipped with excitation systems containing power system stabilizers PSS.
- PSS’s are mainly intended to improve the damping of electromechanical oscillations that may occur after power system perturbations (e.g. line switching, s.c. faults, loss of load, loss of generation etc.).



Introduction

- PSS's are typically tuned and tested to act in frequency band of electromechanical oscillations between 0.1 and 3.0 Hz covering local mode, inter-machine, inter-plant and inter-area oscillation modes.

- Most of PSS's use active power and/or compensated frequency as input signal(s) for the generation of stabilizing signal (PSS output).



Introduction

- Washout stages or filters are HP-filters used to block or reject the DC component of measured values (Power, comp. frequency).

- The time constants of wash out filters are mostly designed in order to:

  1. Allow passing of the desired lowest oscillation mode (e.g. inter area mode)

  2. Optimize compensation at low frequency range. (< 0.5 Hz)

- Washout filters are typically adjusted in the range of 2.0 s to 15.0s

- **The PSS parameters design and testing consider mostly the power system frequency constant**

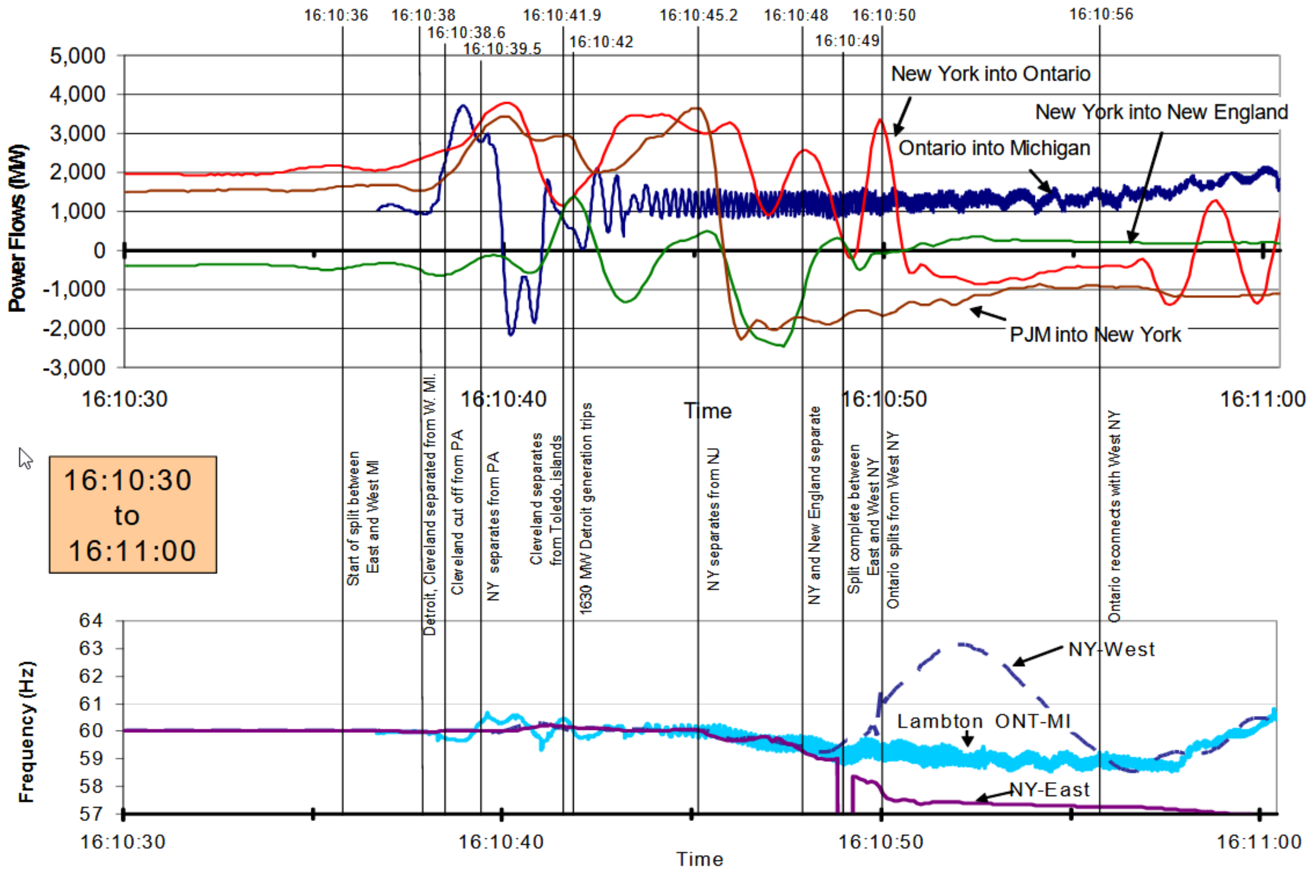
ROCOF cases

- Frequency changes happens normally after:
  - Severe loss of generation

  - Power system splitting after system fault like most of noticed blackouts e.g. Northeast blackout 2003, Southern Brazil 1999/2009, Indonesia 2005 etc.).

➡ Sudden unbalance between generation and consumption

Final NERC report – 2003 blackout



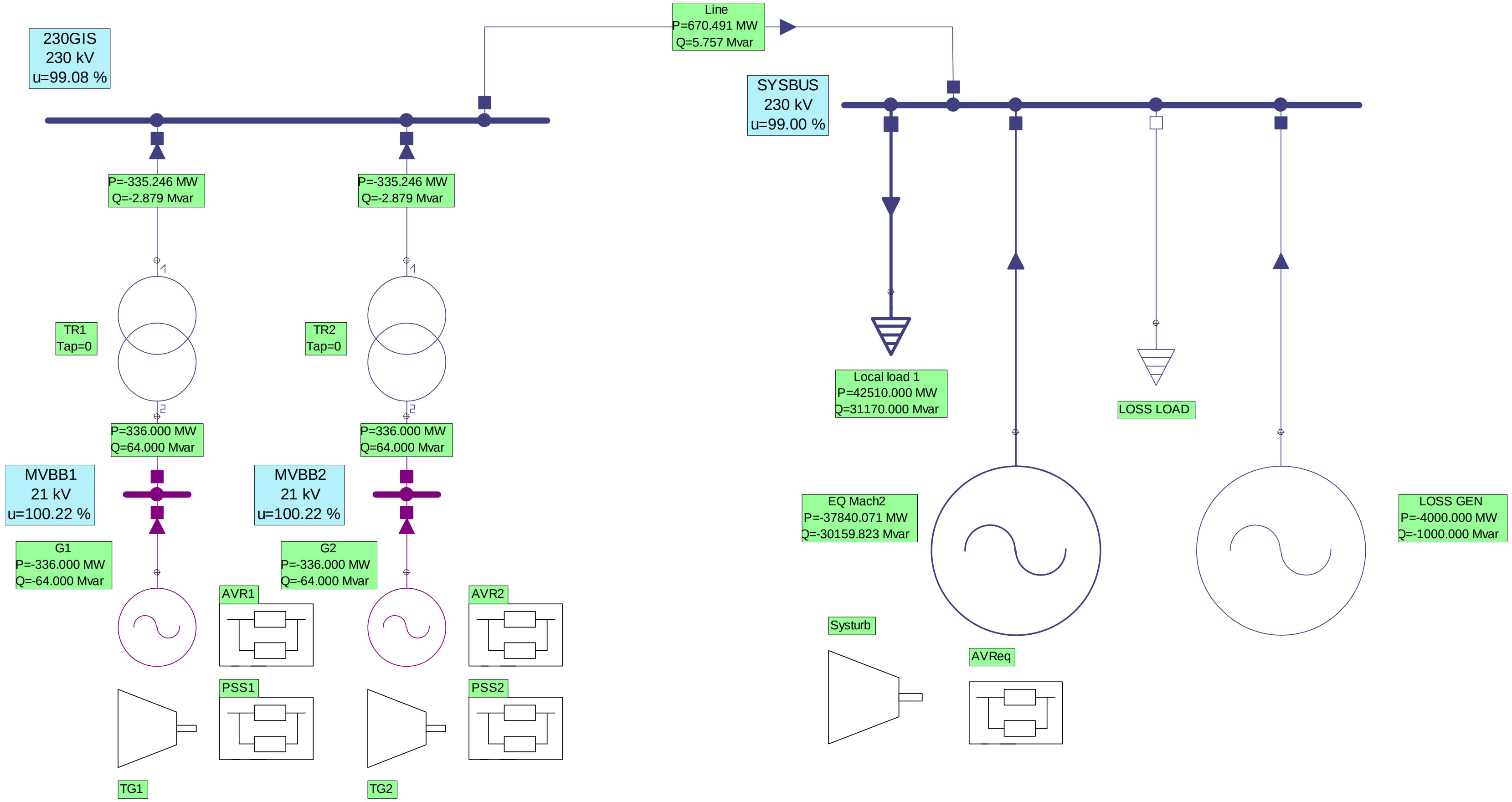
16:10:30
to
16:11:00

Grid code requirements

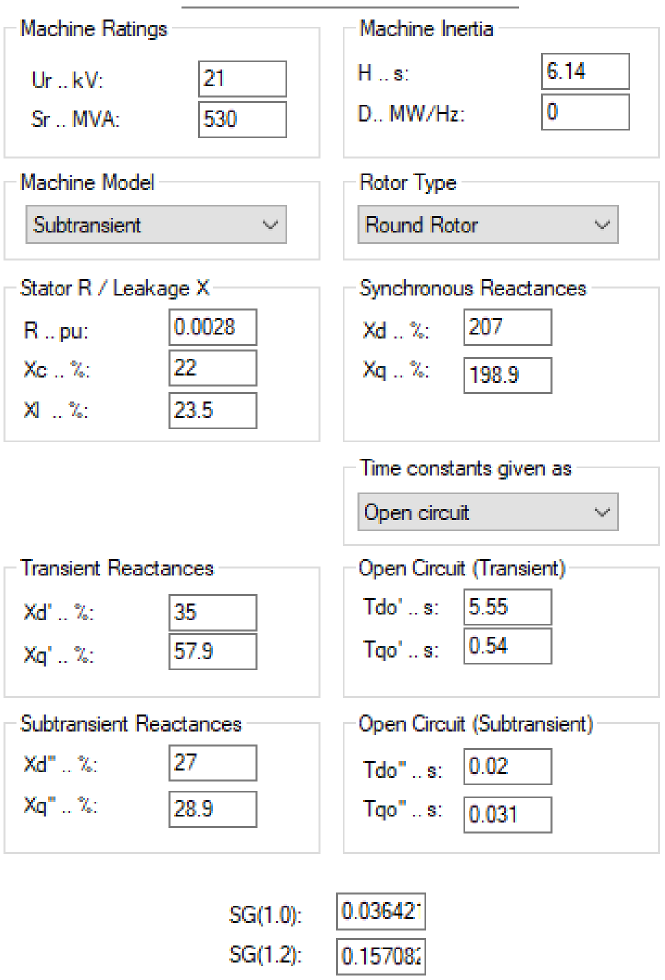
- Some grid codes consider that the generation units and associated equipment shall withstand a maximum ROCOF of 0.5 Hz/s

- Due to the integration of large of “renewables” and advanced power electronics in transmission (e.g. HVDC, Back-to-Back converter stations) few grid codes are increasing the ROCOF to 1 Hz/s for **new units**

Study case


Line
P=670.491 MW
Q=5.757 Mvar
230GIS
230 kV
u=99.08 %
SYSBUS
230 kV
u=99.00 %
P=-335.246 MW
Q=-2.879 Mvar
P=-335.246 MW
Q=-2.879 Mvar
TR1
Tap=0
TR2
Tap=0
P=336.000 MW
Q=64.000 Mvar
P=336.000 MW
Q=64.000 Mvar
MVBB1
21 kV
u=100.22 %
MVBB2
21 kV
u=100.22 %
G1
P=-336.000 MW
Q=-64.000 Mvar
G2
P=-336.000 MW
Q=-64.000 Mvar
AVR1
AVR2
PSS1
PSS2
TG1
TG2
Local load 1
P=42510.000 MW
Q=31170.000 Mvar
LOSS LOAD
EQ Mach2
P=-37840.071 MW
Q=-30159.823 Mvar
LOSS GEN
P=-4000.000 MW
Q=-1000.000 Mvar
Systurb
AVReq

Generator data



Machine Ratings
Ur .. kV: 21
Sr .. MVA: 530

Machine Inertia
H .. s: 6.14
D.. MW/Hz: 0

Machine Model
Subtransient

Rotor Type
Round Rotor

Stator R / Leakage X
R .. pu: 0.0028
Xc .. %: 22
Xl .. %: 23.5

Synchronous Reactances
Xd .. %: 207
Xq .. %: 198.9

Time constants given as
Open circuit

Transient Reactances
Xd' .. %: 35
Xq' .. %: 57.9

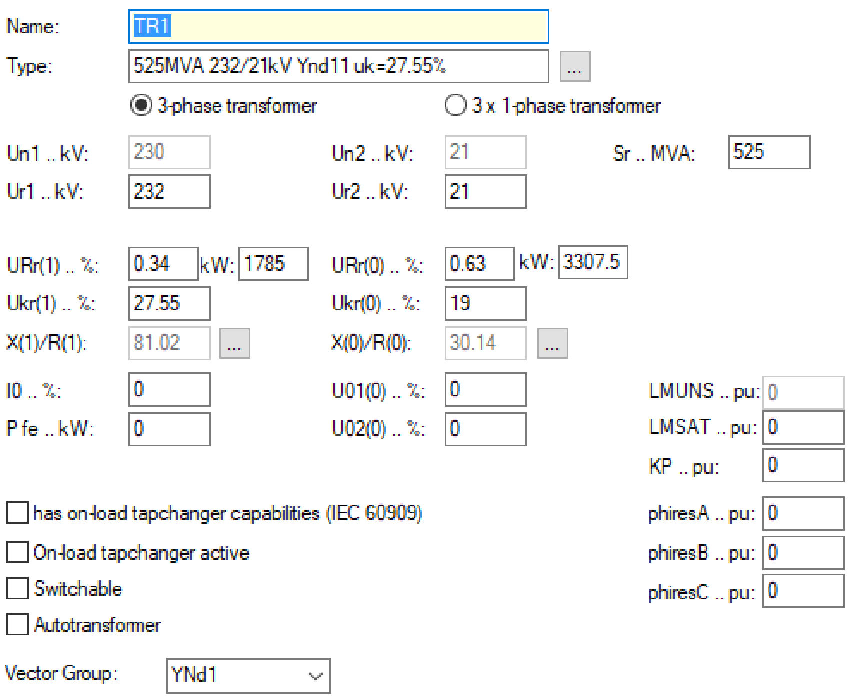
Open Circuit (Transient)
Tdo' .. s: 5.55
Tqo' .. s: 0.54

Subtransient Reactances
Xd" .. %: 27
Xq" .. %: 28.9

Open Circuit (Subtransient)
Tdo" .. s: 0.02
Tqo" .. s: 0.031

SG(1.0): 0.03642
SG(1.2): 0.15708

Transformer data



Name: TR1
Type: 525MVA 232/21kV Ynd11 uk=27.55%
● 3-phase transformer ○ 3 x 1-phase transformer

Un1 .. kV: 230
Ur1 .. kV: 232
Un2 .. kV: 21
Ur2 .. kV: 21
Sr .. MVA: 525

URr(1) .. %: 0.34 kW: 1785
Ukr(1) .. %: 27.55
X(1)/R(1): 81.02
URr(0) .. %: 0.63 kW: 3307.5
Ukr(0) .. %: 19
X(0)/R(0): 30.14

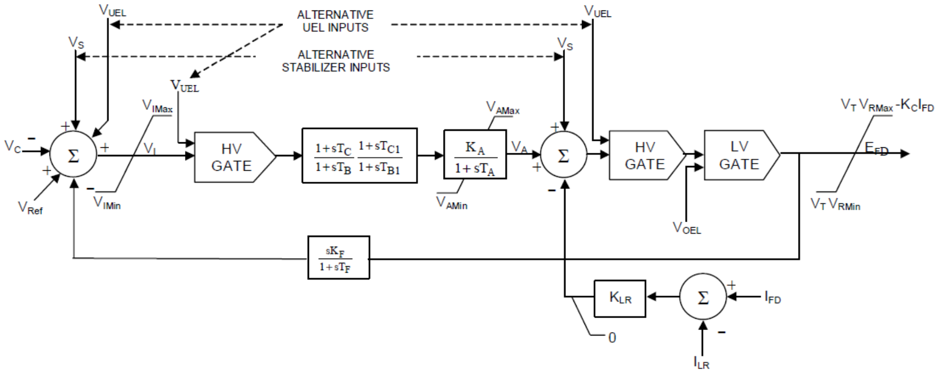
I0 .. %: 0
P fe .. kW: 0
U01(0) .. %: 0
U02(0) .. %: 0
LMUNS .. pu: 0
LMSAT .. pu: 0
KP .. pu: 0

☐ has on-load tapchanger capabilities (IEC 60909)
☐ On-load tapchanger active
☐ Switchable
☐ Autotransformer

phiresA .. pu: 0
phiresB .. pu: 0
phiresC .. pu: 0

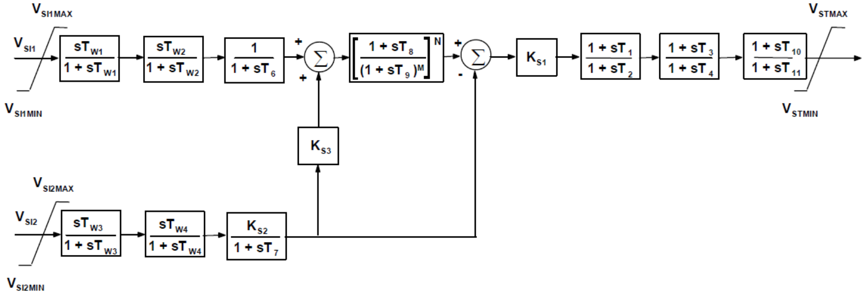
Vector Group: YNd1

AVR



UEL	0
TR	0.01 s
VIMAX	999 p.u.
VIMIN	-999 p.u
TB	11.75 s
TC	1.41 s
TC1	0.1 s
TB1	0.1 s
KA	500
TA	0.004 s
VAMAX	7.415 p.u.
VAMIN	-6.421 p.u.
KLR	0.0
ILR	0.0 p.u.
KF	0.0
TF	1.0 s
VRMAX	7.415 p.u.
VRMIN	-6.421 p.u.
KC	0.00

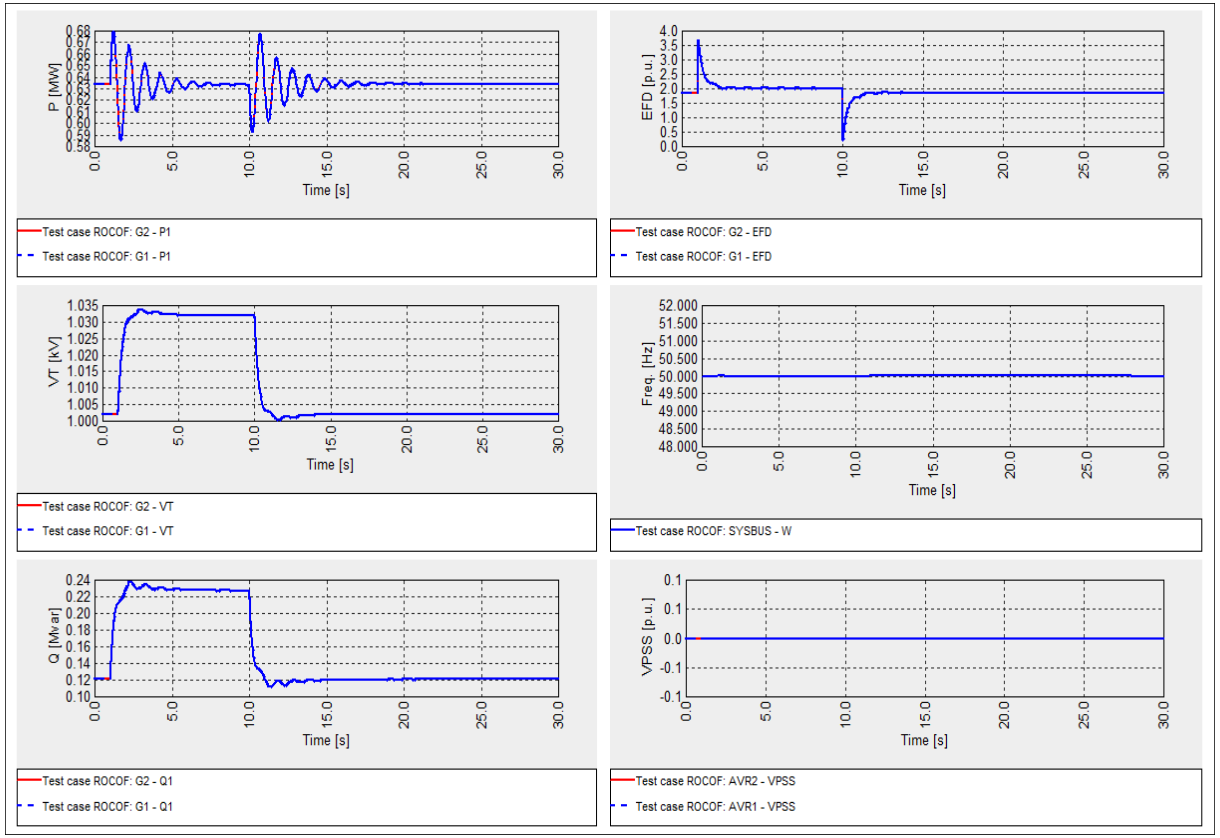
PSS



T5	0.012 s
T6	0.01 s
TW1	5 s
TW2	5 s
TW3	5 s
TW4	0 (by pass)
T7	5 s
T8	0.5 s
T9	0.1 s
T1	0.15 s
T2	0.012 s
T3	0.13 s
T4	0.012 s
T10	0.36 s
T11	0.88 s
KS1	20
KS2	0.407
KS3	1
VSMAX	0.05 p.u.
VSMIN	-0.05 p.u.
N	5
M	1

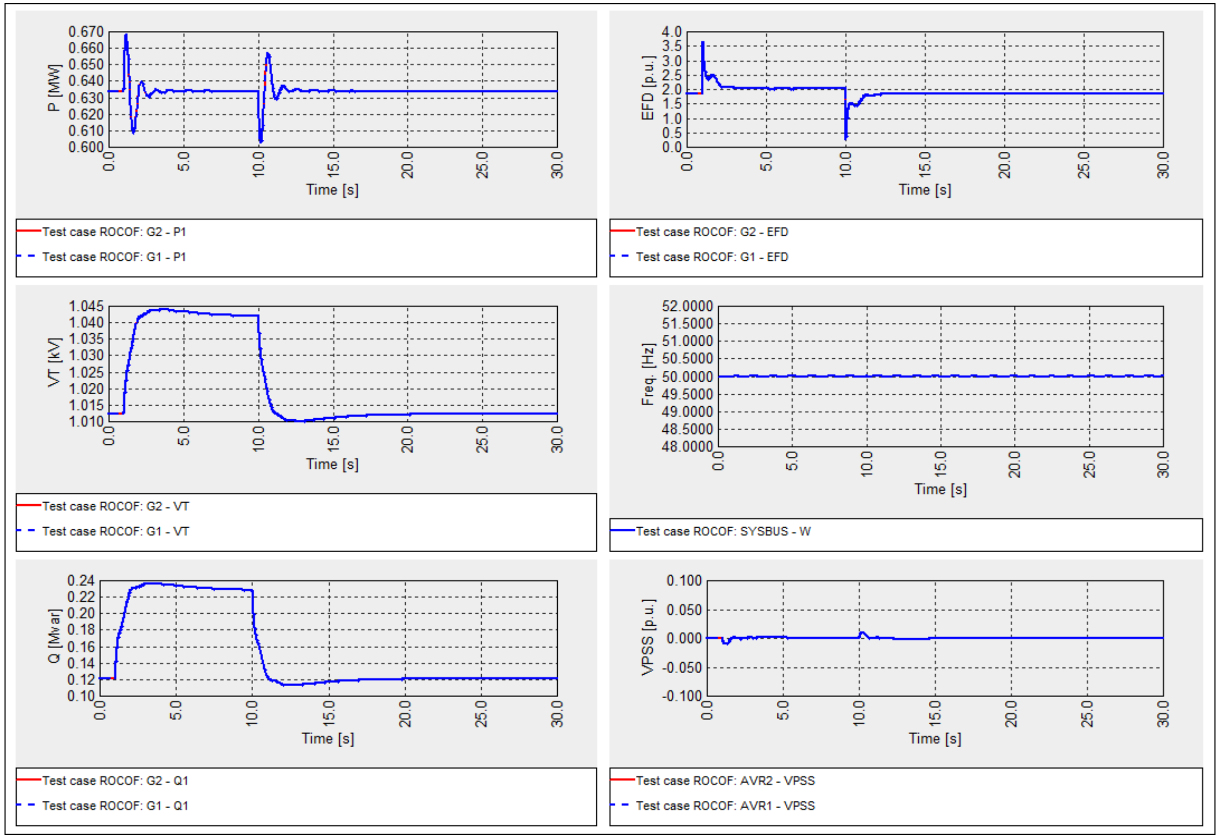
Small disturbance test

- Simultaneous AVR step response of 3% in both units with PSS off



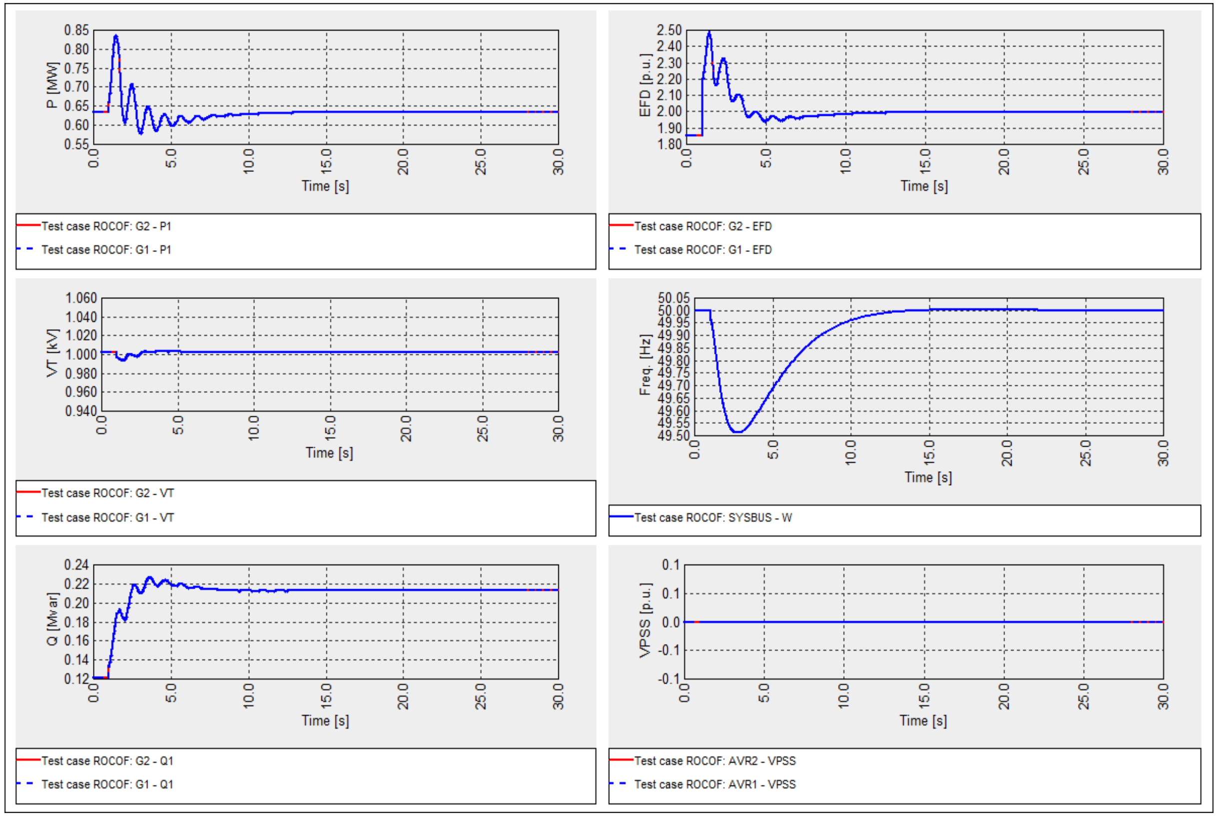
Small disturbance test

- Simultaneous AVR step response of 3% in both units with PSS on



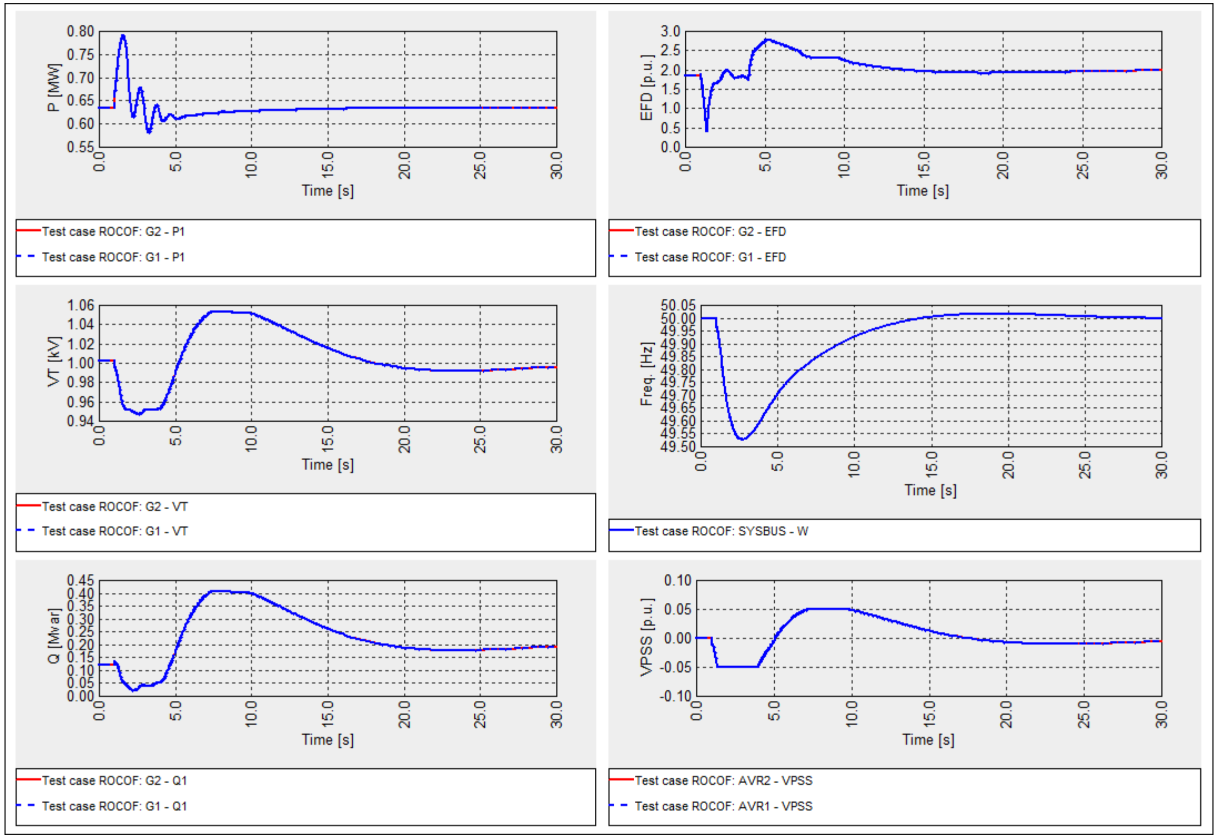
Loss of generation

- Both units with PSS off



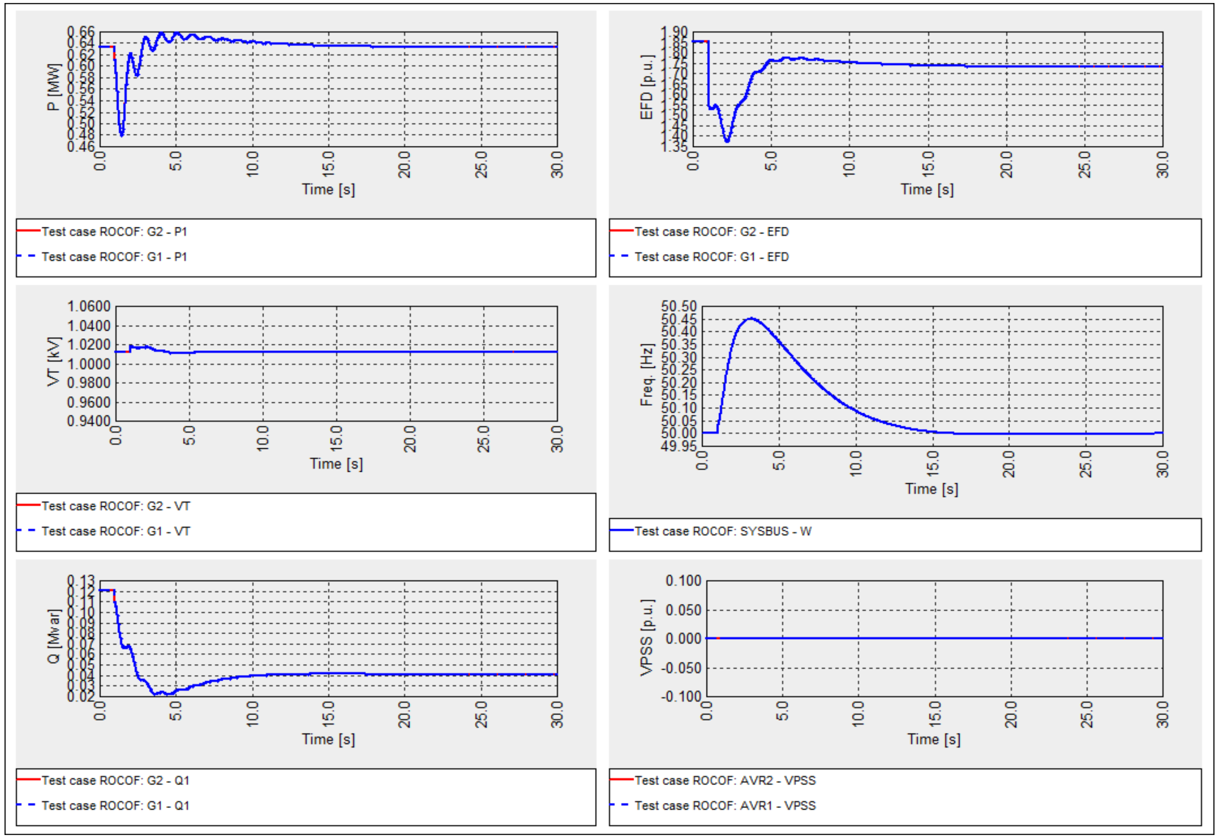
Loss of generation

- Both units with PSS on



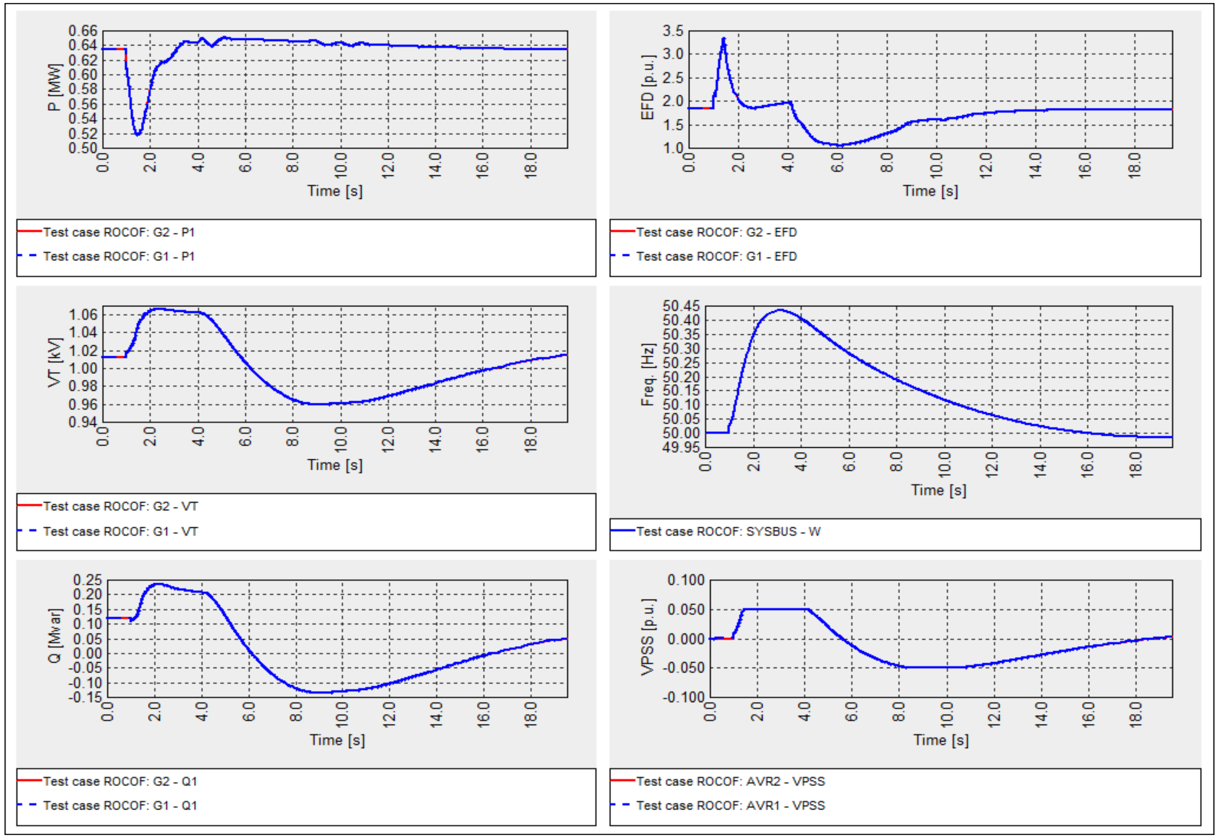
Loss of consumers

- Both units with PSS off



Loss of consumers

- Both units with PSS on



Possible PSS influences in case of ROCOF

- In case of under frequency, voltage of auxiliary services my drop to values that may cause to trip of loads (e.g. trip of variable speed drives feeding pumps)

- In case of over frequency, delayed overvoltage protection may trip the unit and auxiliary services as well

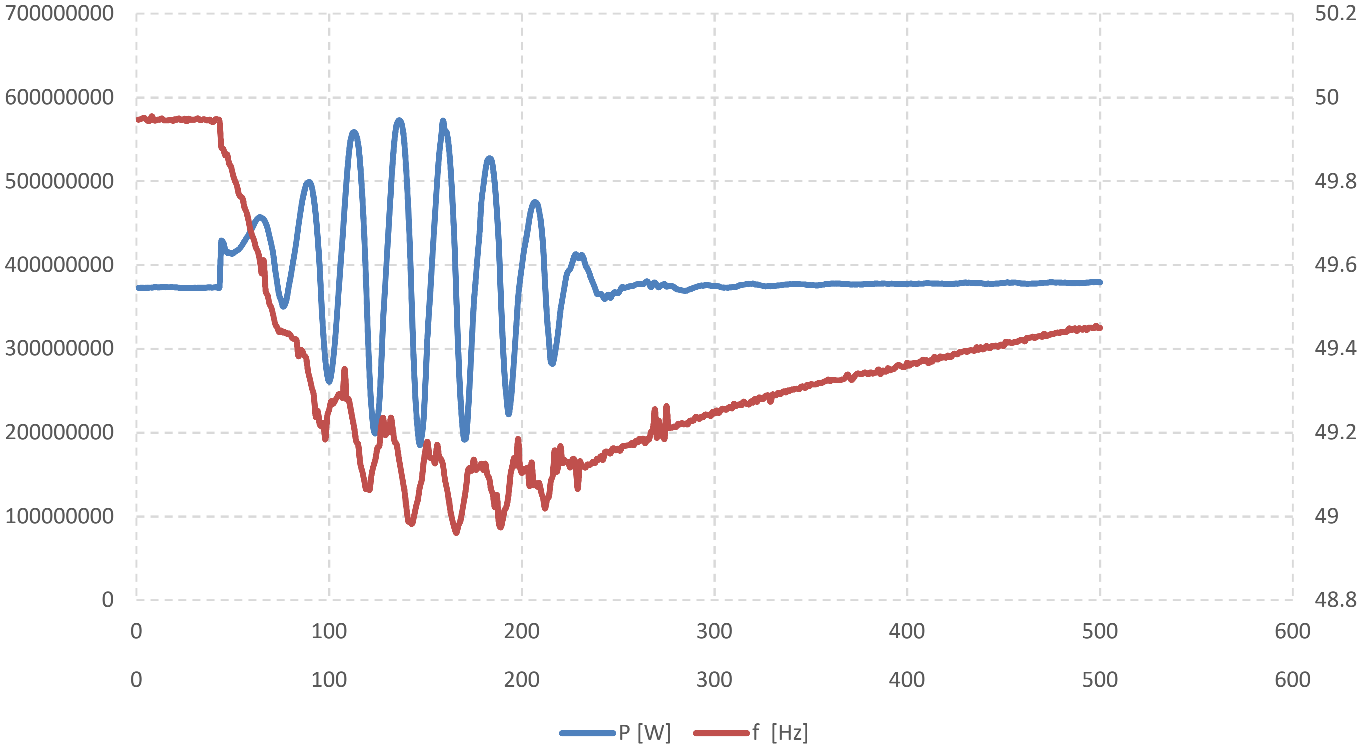
- Interactions with limiters and limitation logics leading to oscillatory behavior.

Possible measures to minimize effect of PSS for systems with high ROCOF (what is being done)

- Optimize tuning (washouts, overall PSS gain and signal limits)
- Switch PSS off on large frequency deviations
- Reduce PSS signal limits when frequency changes

Important: Implementation needs extensive testing in order to avoid any kind of undesired switching effects that may cause instability.

Real case – Frequency drop and power oscillations caused by iteration between PSS and limitation logic



New investigations of effect voltage dependent function for automatic and smooth PSS gain reduction in case of ROCOF

➡ Not based on frequency measurement!

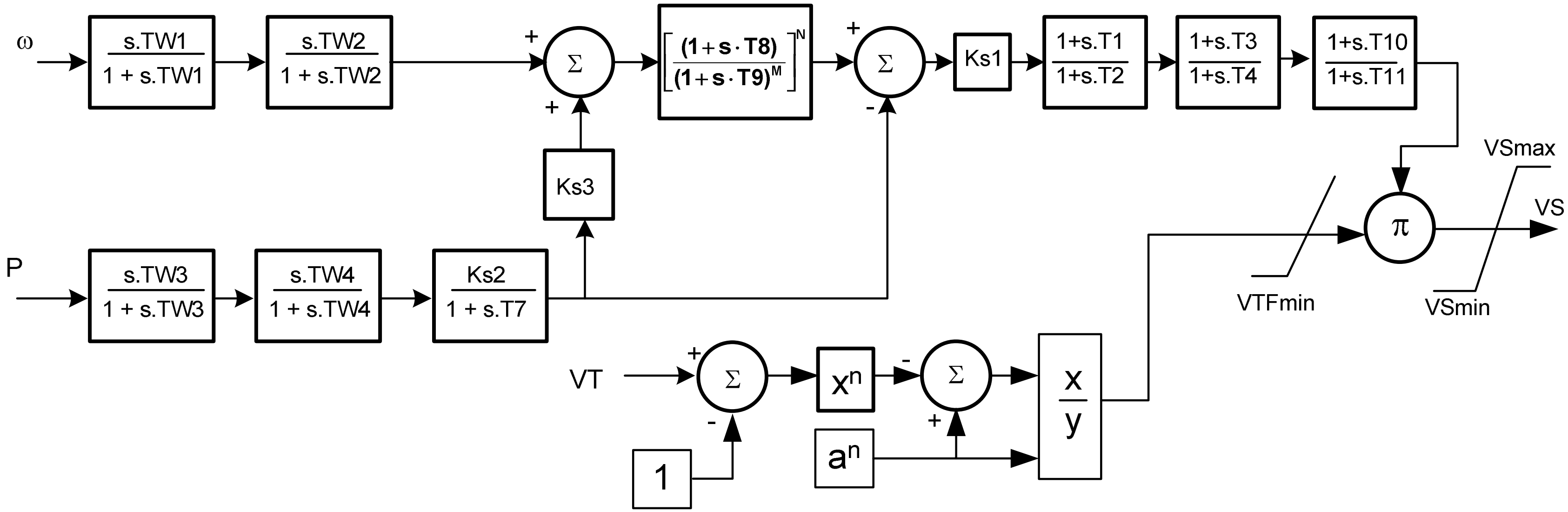
Key considerations

- The Primary control is the stator voltage
- The PSS is an additional feature provide in order to improve the damping of electromechanical oscillations

➡ If the PSS signal causes stator voltage changes that are beyond the allowed operation limits, the PSS influence shall be smoothly and quickly reduced.

➡ When the stator voltage is back to the operation limits, the PSS influence shall be smoothly and quickly restored.

Proposed function

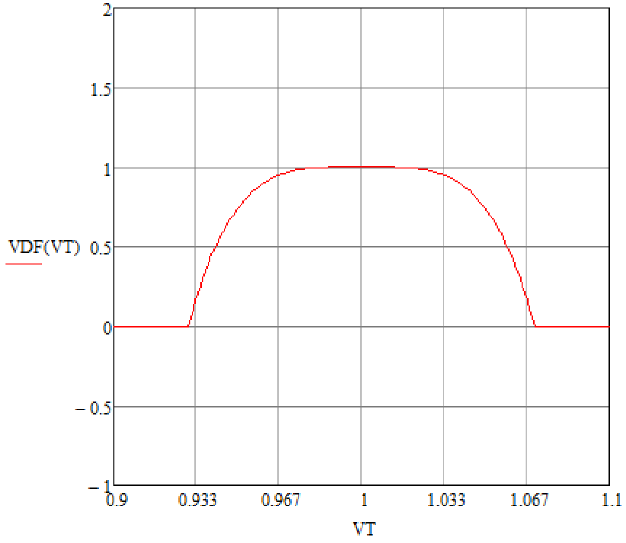


With

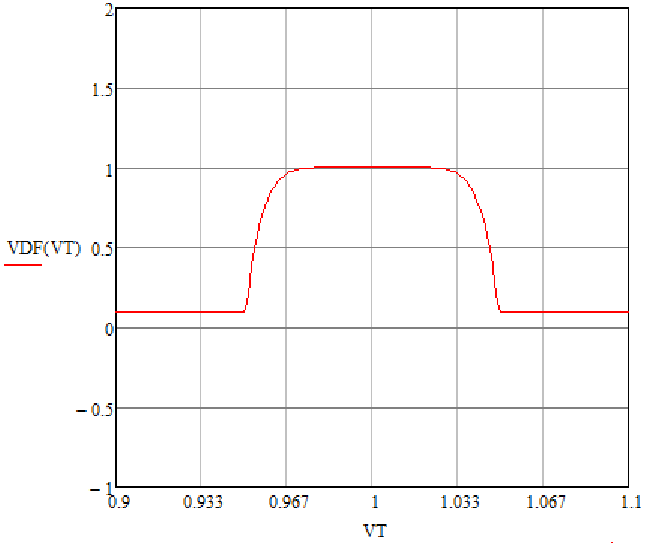
a=0.04…0.08 ; n=4,6 and 8; VDFmin=0.0 ... 0.80

Examples

a=0.07; n=4; VTFmin=0



a=0.05; n=8; VTFmin=0.1

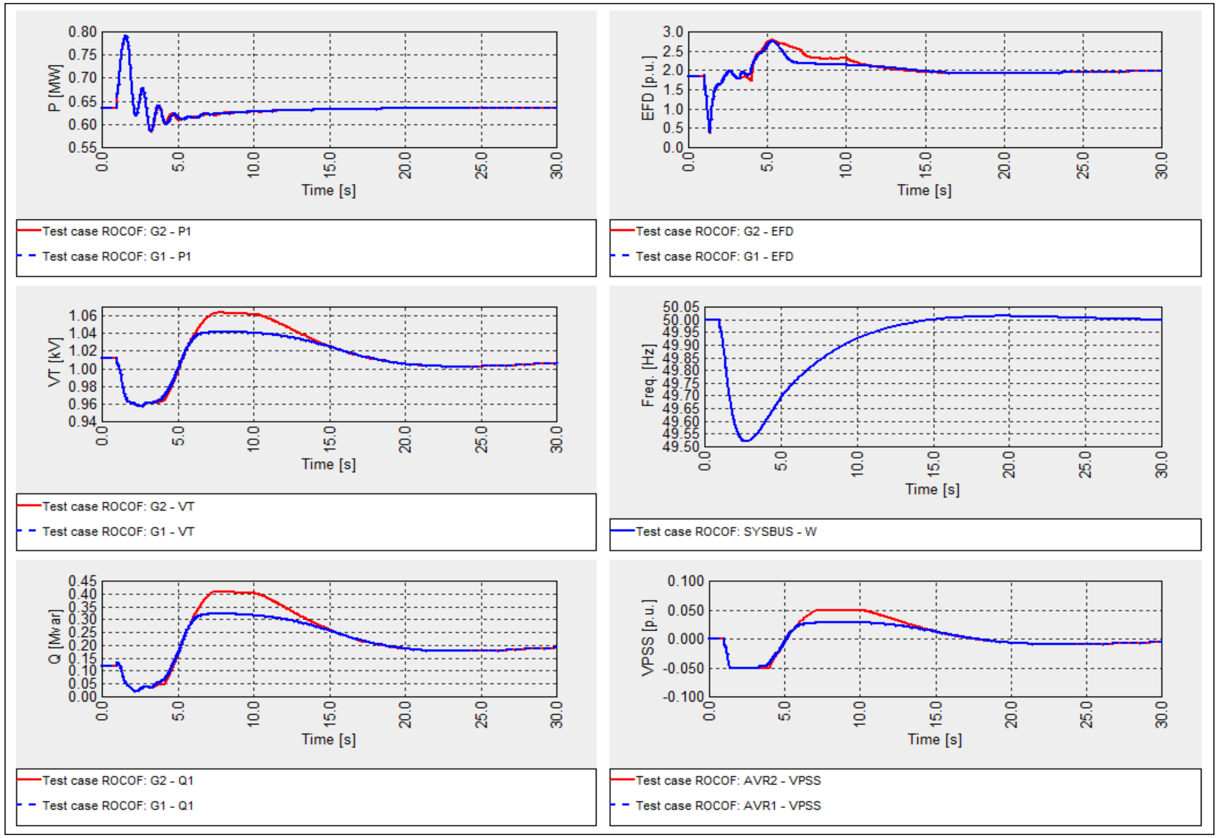


Proposed name : HAT function !

Test cases

loss of generation

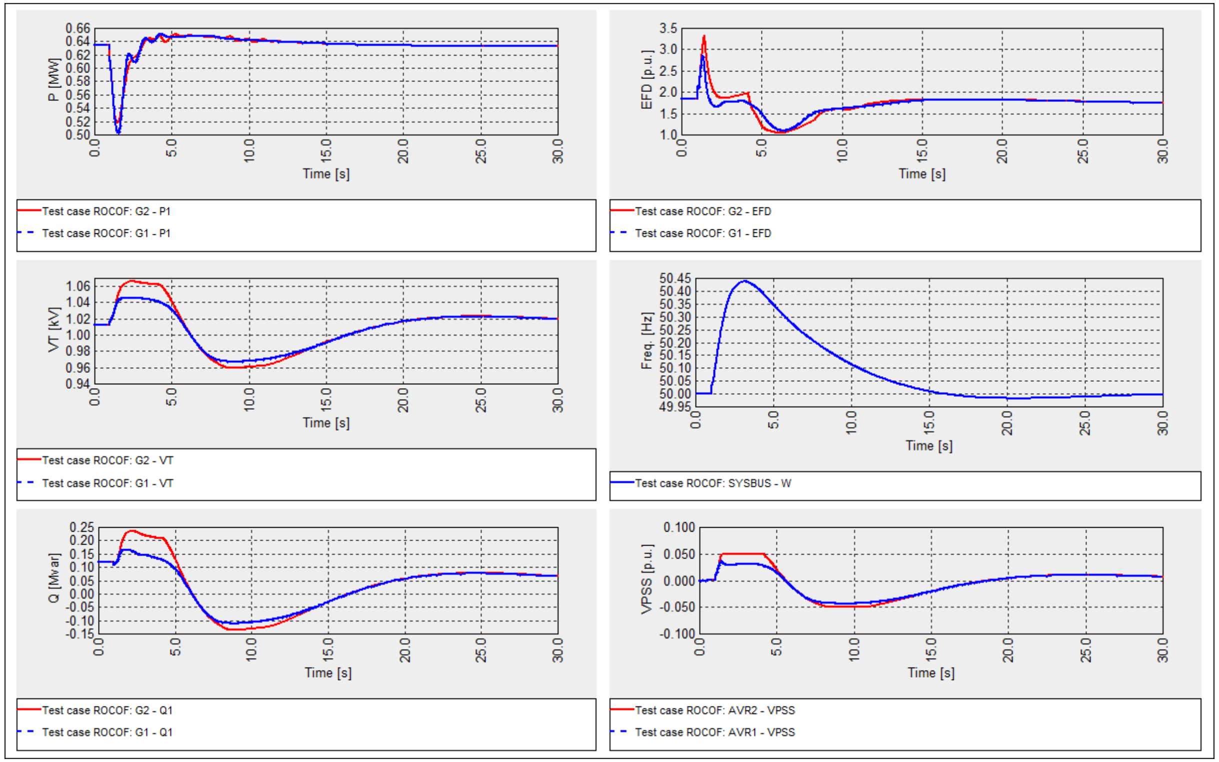
Only G1 with HAT function
a=0.05 n=4 VTFmin=0.0



Test cases

loss of consumers

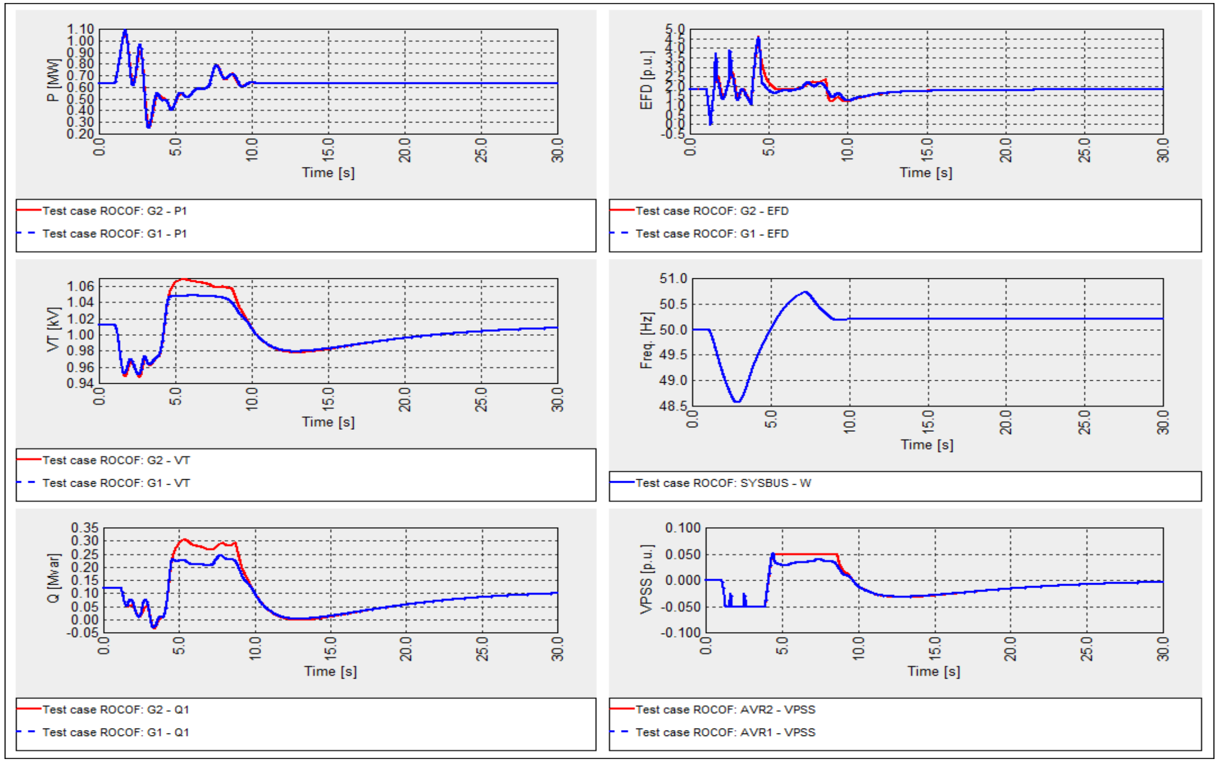
Only G1 with HAT function
a=0.05 n=4 VTFmin=0.0



Test cases

Only G1 with HAT function
a=0.05 n=4 VTFmin=0.0

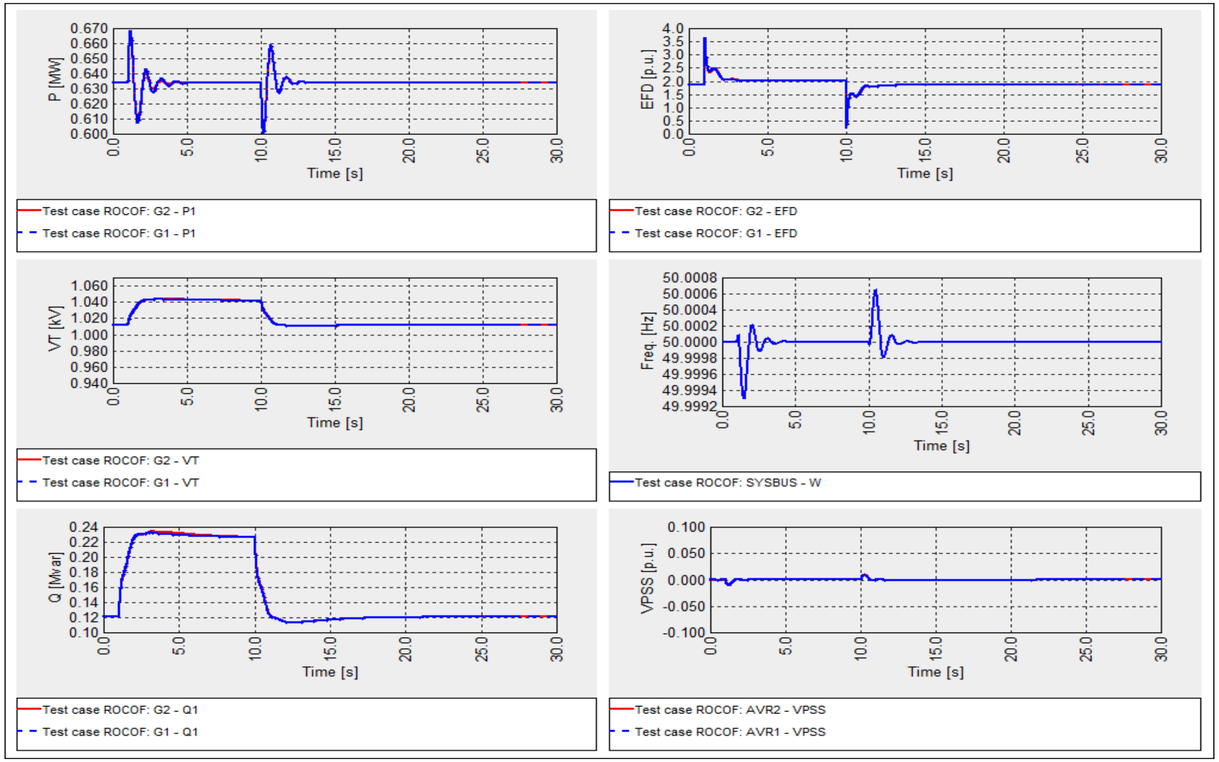
EIRGRID Fast drop and rise ROCOF profile



Test cases

3% AVR step step response

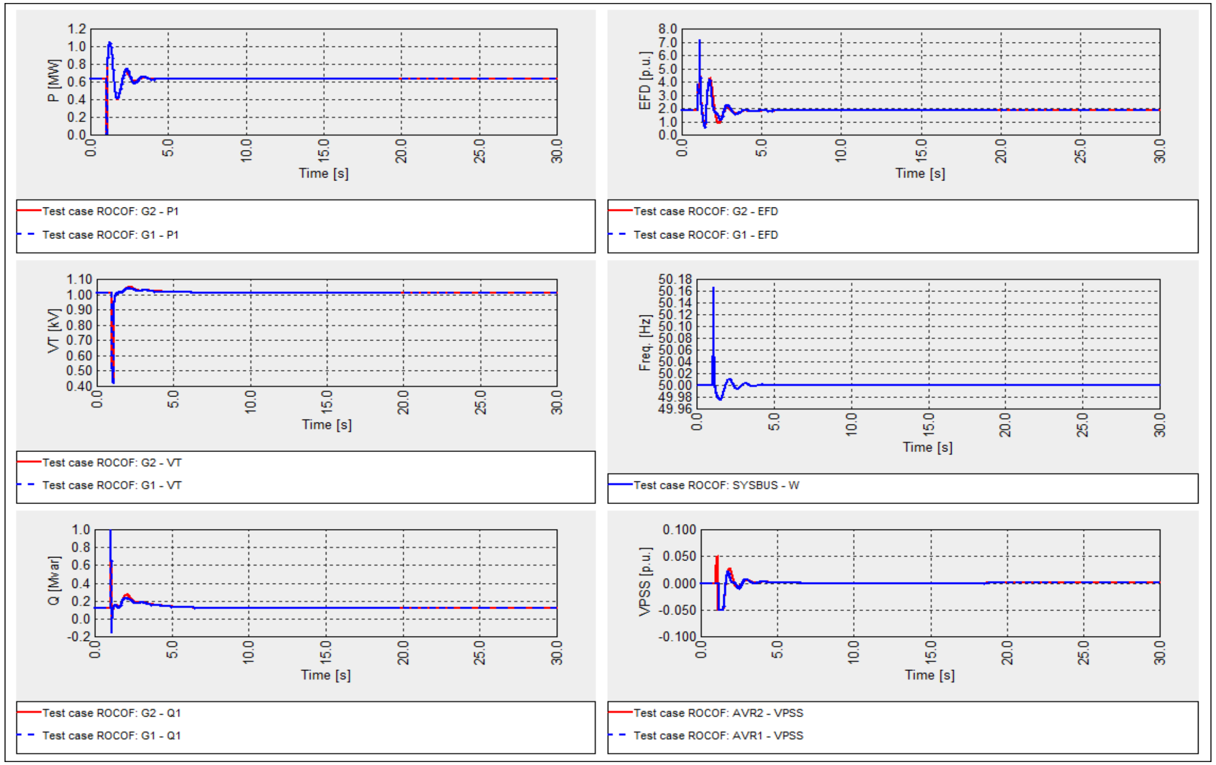
Only G1 with HAT function
a=0.05 n=4 VTFmin=0.0



Test cases

Only G1 with HAT function
a=0.05 n=4 VTFmin=0.0

3-phase fault 150ms at 230kV GIS



Final comments

- HAT function could be a suitable solution for to minimize the undesired PSS influence in case of high ROCOF!

Next steps:

- Further simulations for testing
- Implementation in equipment and testing on real time simulators
- Tests and observations on pilot plants of power systems with high ROCOF

Thank you!

PSS on Synchronous Condensers

Simon Lebeau
Hydro-Quebec TransEnergie

AGENDA

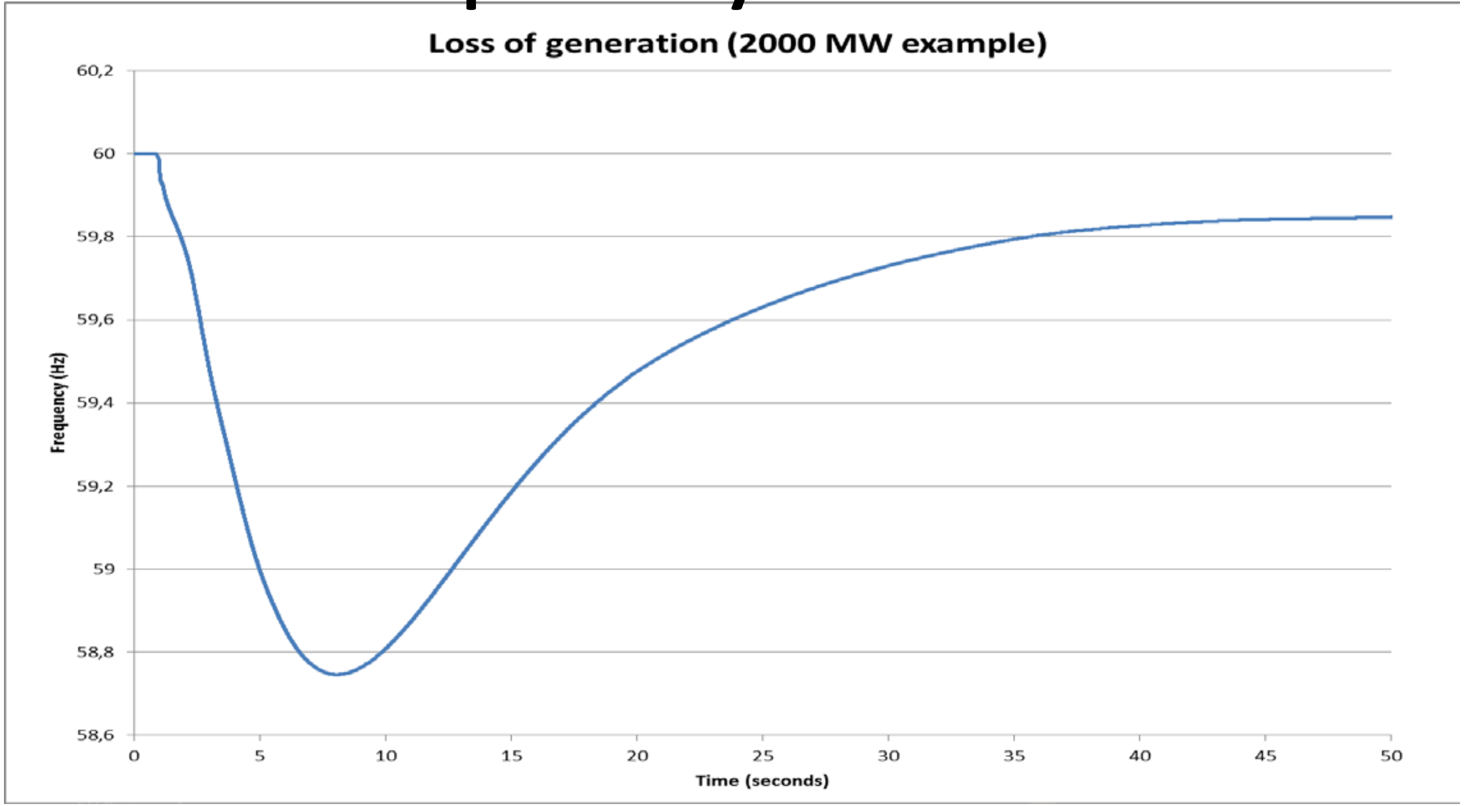
- Recap on load modeling and frequency deviation
- Impacts of PSS on synchronous condensers
- PSS on others dynamic reactive compensation device
- Conclusion

Load representation

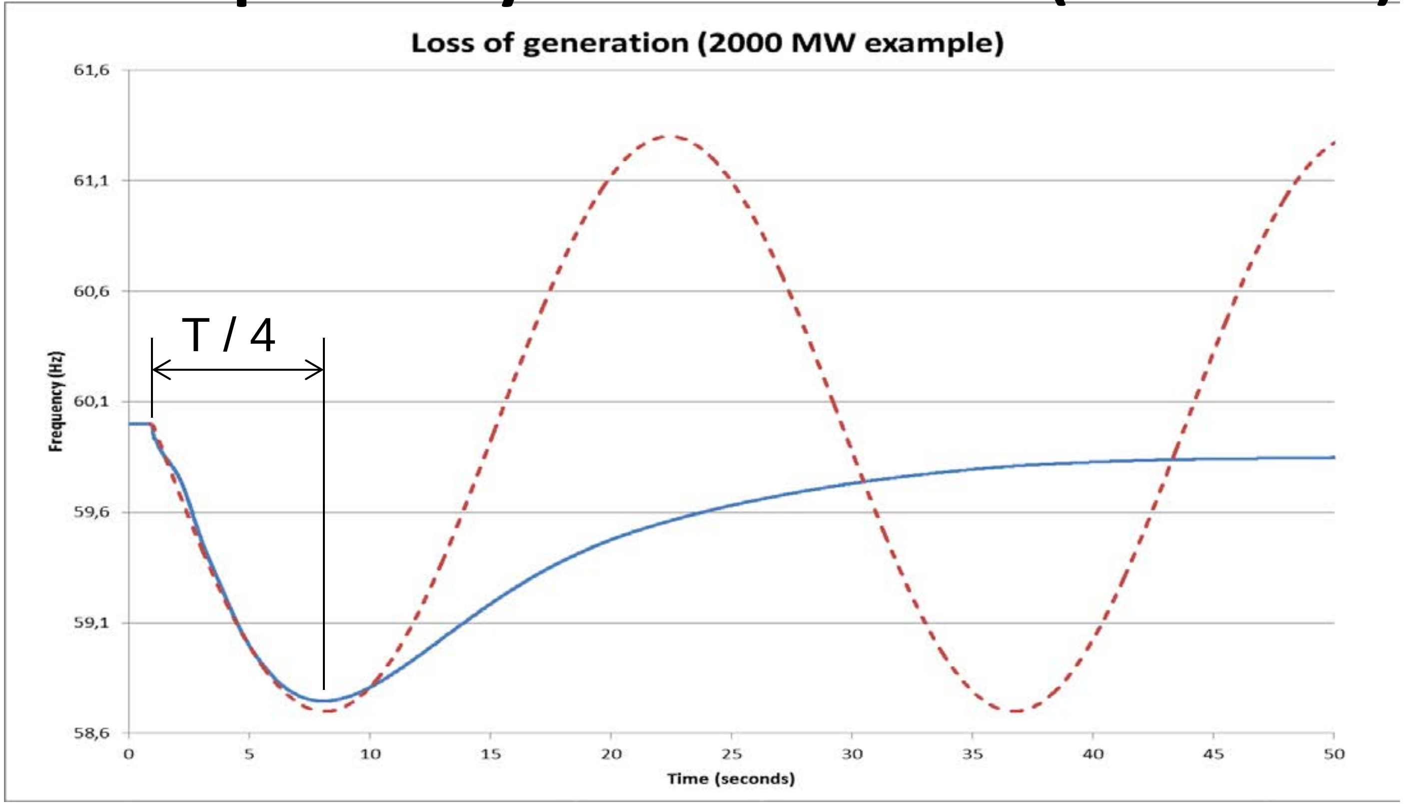
- Simple dynamic load model (static model):
  - $P = P_o * V^{n_1} * (1+ a_1 \Delta f)$
  - $Q = Q_o * V^{n_2} * (1+ a_2 \Delta f)$

It is possible to «control» the load if you control voltage and or frequency

Frequency deviation



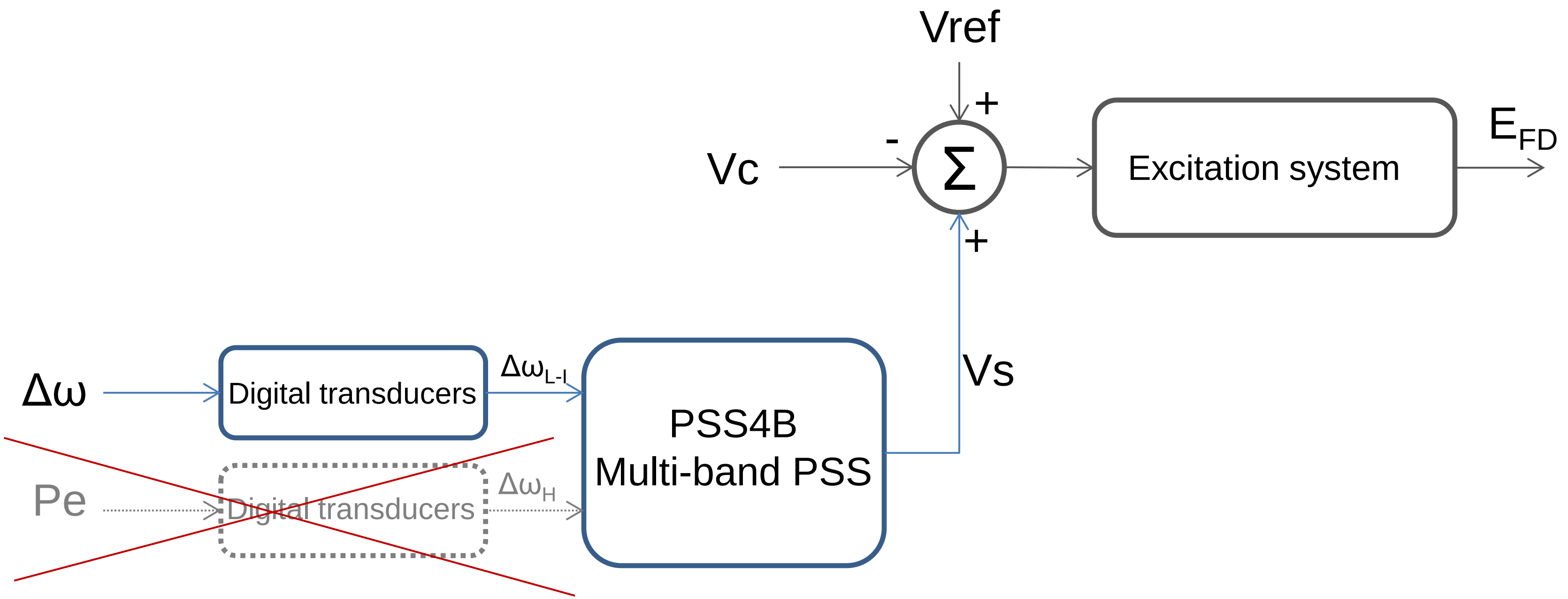
Frequency deviation (cont'd)



Improve Nadir frequency if

- Load is voltage dependant
- Load is frequency dependant
- Mvar facility near load center
- The period of frequency oscillation is known

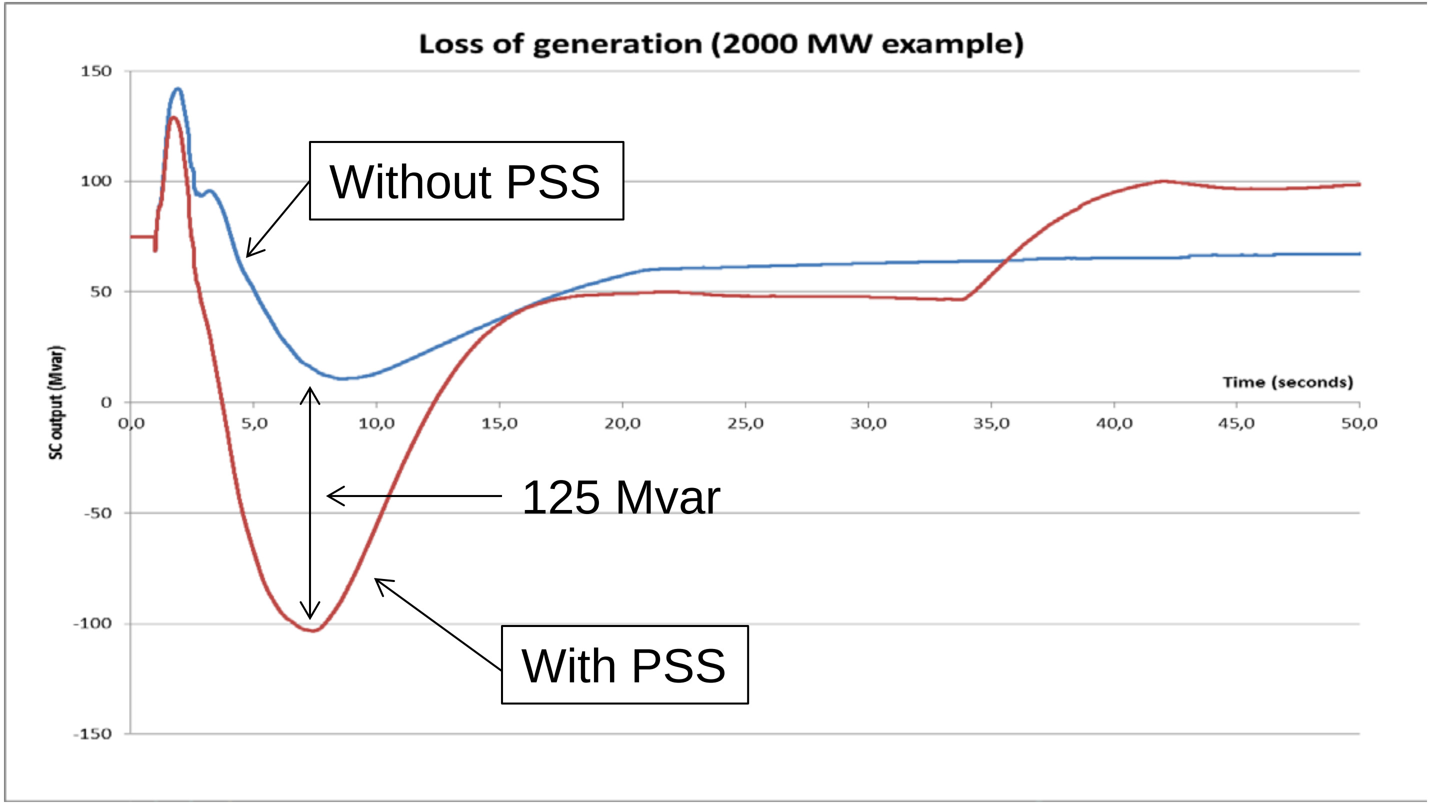
Diagram


Vref
+
Vc
-
Σ
+
Excitation system
E_{FD}
Vs
Δω
Digital transducers
$\Delta\omega_{L-I}$
PSS4B
Multi-band PSS
Pe
Digital transducers
$\Delta\omega_{H}$

At Hydro-Quebec:

- 5 Synchronous Condensers equipped with PSS
- PSS settings:
  - Center on 0.04 Hz frequency
  - Gain of 3.5 pu/pu
  - Output limiter : +0.02 pu and -0.04 pu

Effect of PSS on reactive power

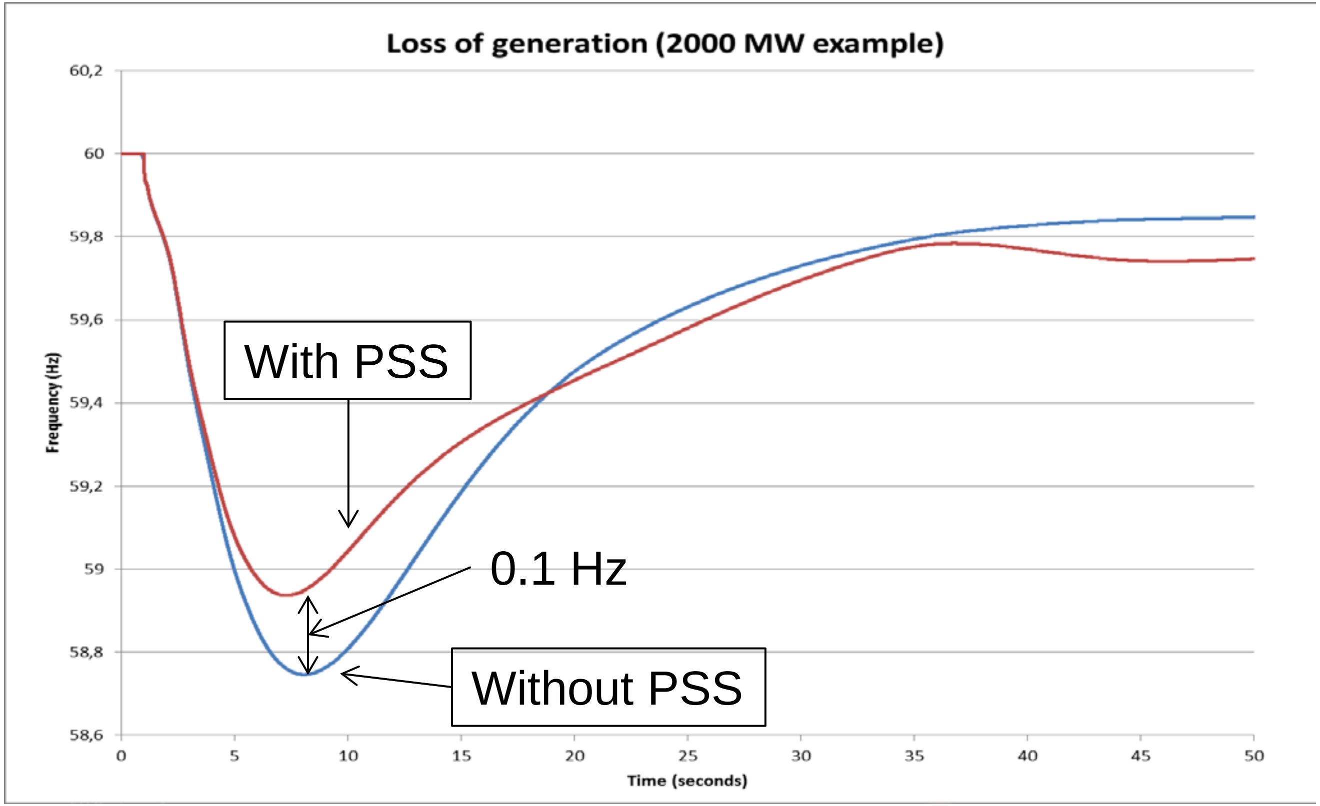


Without PSS

125 Mvar

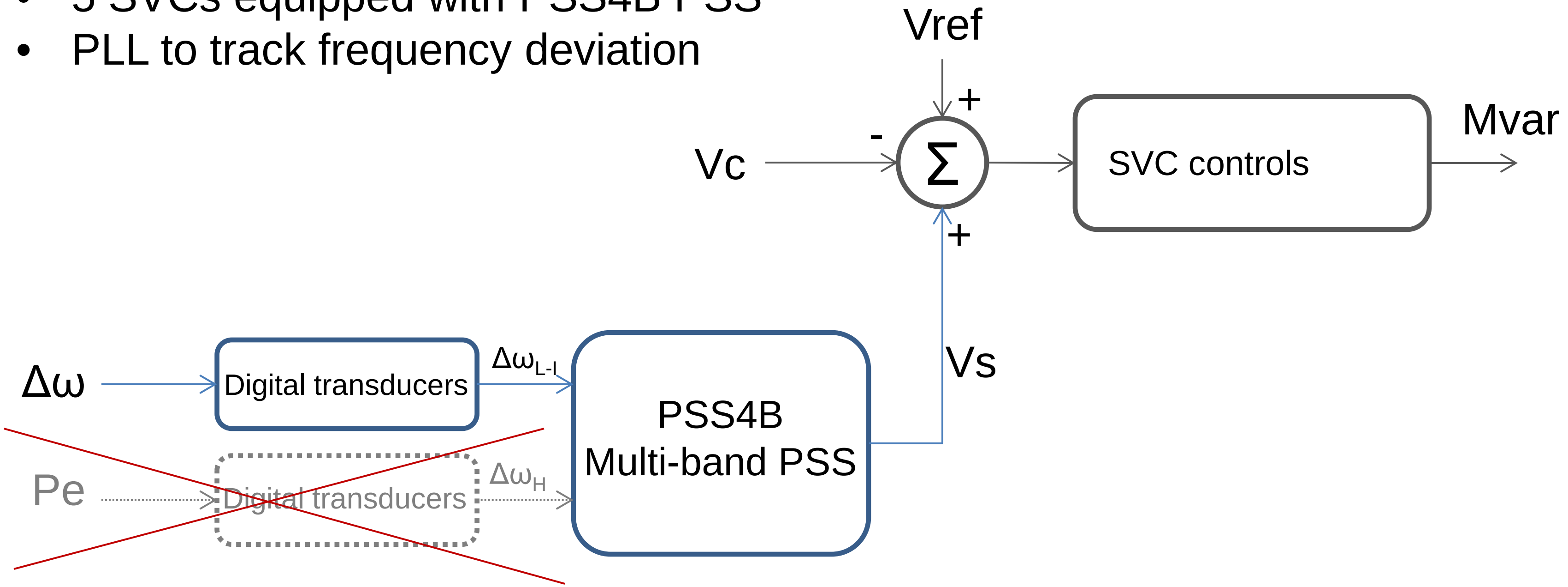
With PSS

Effect of PSS on frequency deviation



Also on SVCs

- 5 SVCs equipped with PSS4B PSS
- PLL to track frequency deviation



Conclusion

- Frequency deviation can be reduce by controlling voltage at the load.
- Simple PSS on any dynamic reactive device can do the work.
- Hydro-Quebec also reduce AGC oscillations (0.01 Hz) with PSS4B.

17PESGM2376

Practical challenges and limitations of generator- and exciter-models used for AVR, PSS and OEL/UEL tuning- and validation-studies, focusing on (exciter) field-current as active feedback in excitation control systems

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Overview

- Introduction
  - Application / Expectations «now and then»
- Practical challenges of generator modelling
  - Limitations of IEEE 1110 generator models in combination with OEL
- Practical challenges of exciter modelling
  - Limitations of IEEE 421.5 exciter models in combination with OEL and cascaded current controllers

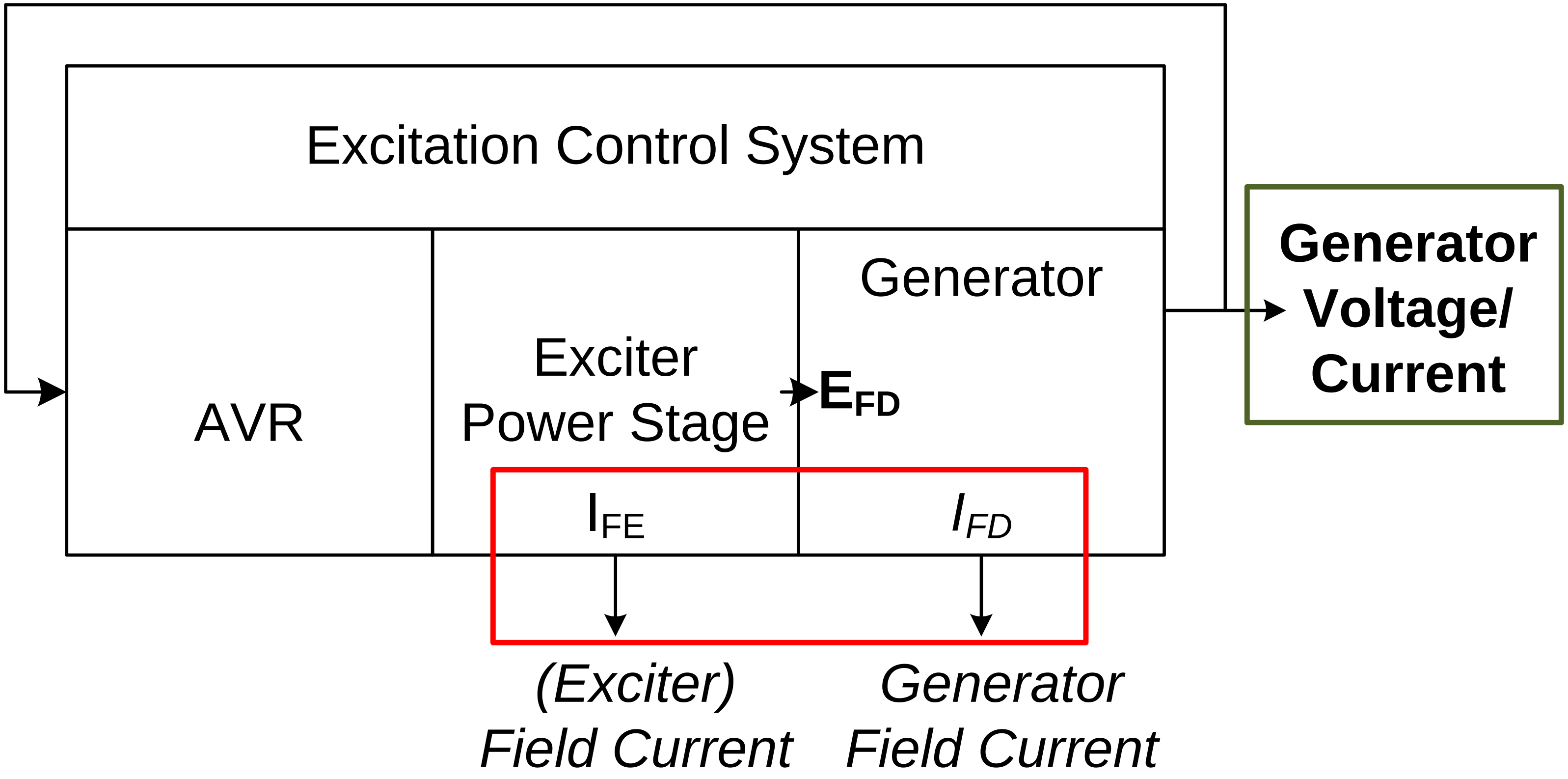
Application / Expectations «Now and then»

- Simulation scope was traditionally rather limited (eg. line faults)
  - Focus on dynamical response of AVR and PSS
  - Limited amount of state variables and simulation times in order to receive results within acceptable time frames
  - Excitation Limiters [OEL/(UEL)] etc. were not represented due to its delayed influence, which was beyond typical simulation times

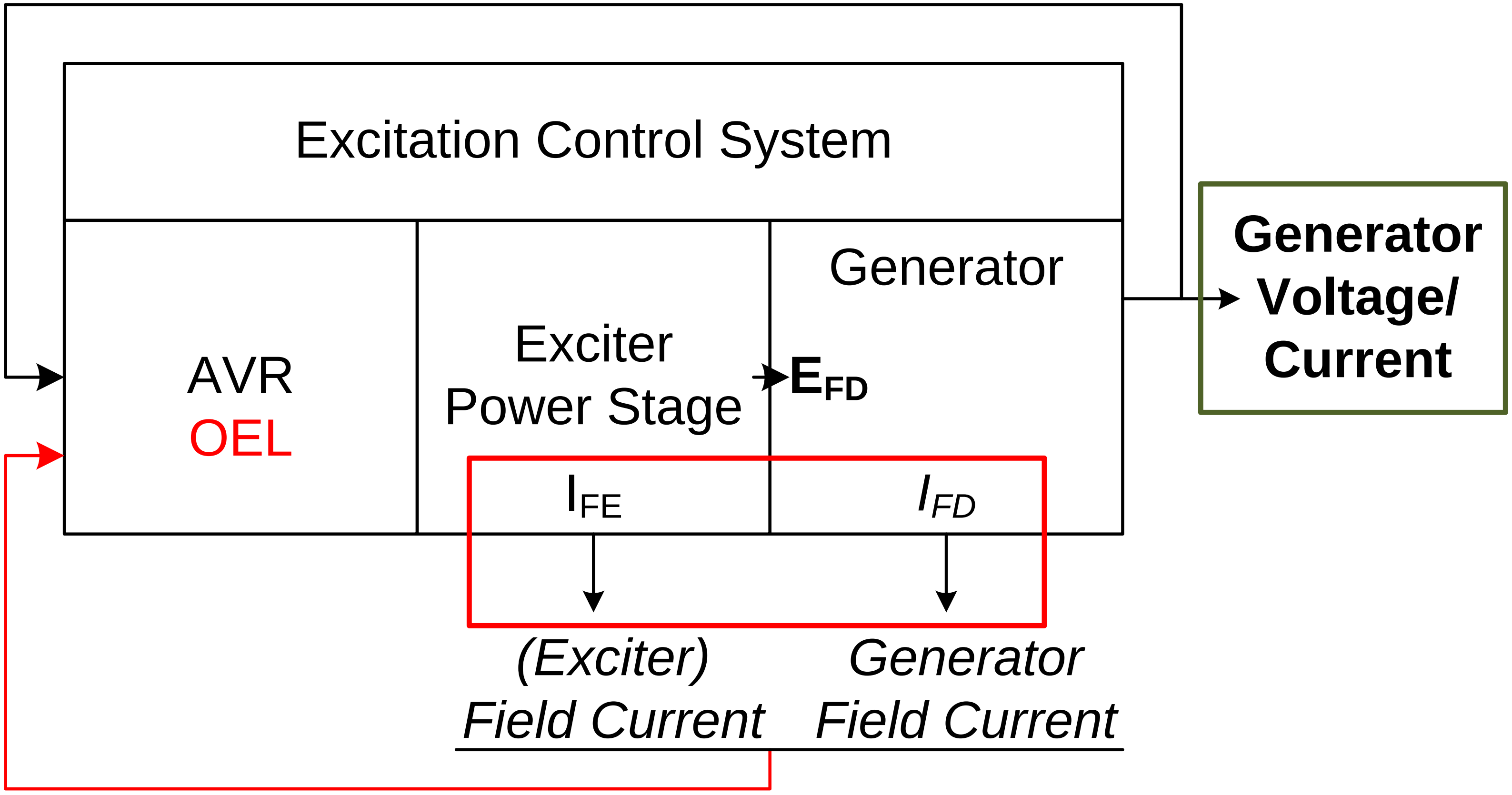
Application / Expectations «Now and then»

- State of the art computational power however allows to increase the amount of state variable and simulation times
- IEEE 421.5 therefore offers a variant of OEL models, which add new feedback signals to the exciter models

Practical challenges of generator and exciter modeling



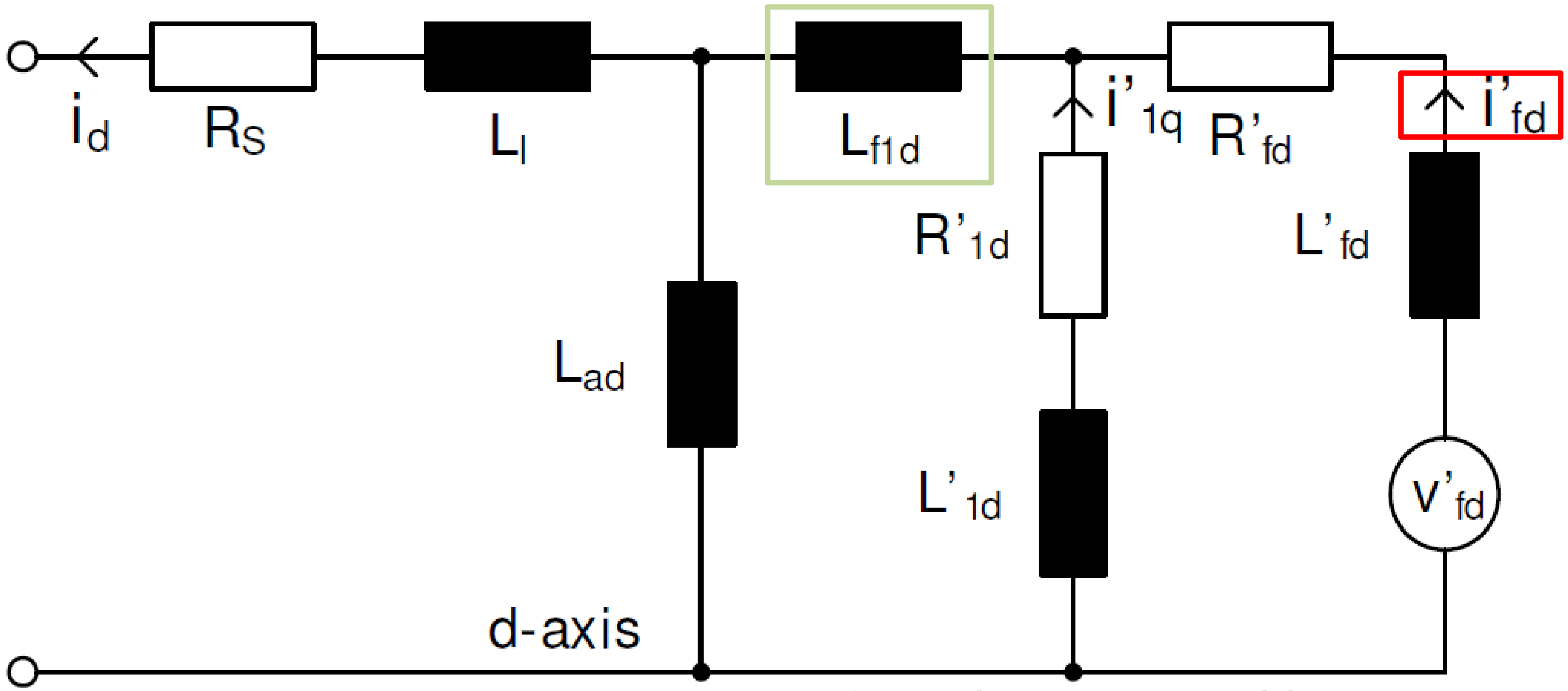
Practical challenges of generator and exciter modeling



Practical challenges of **generator** and exciter modeling

- [IEEE 1110] Model 2.(2); D-Axis eq. circuit]

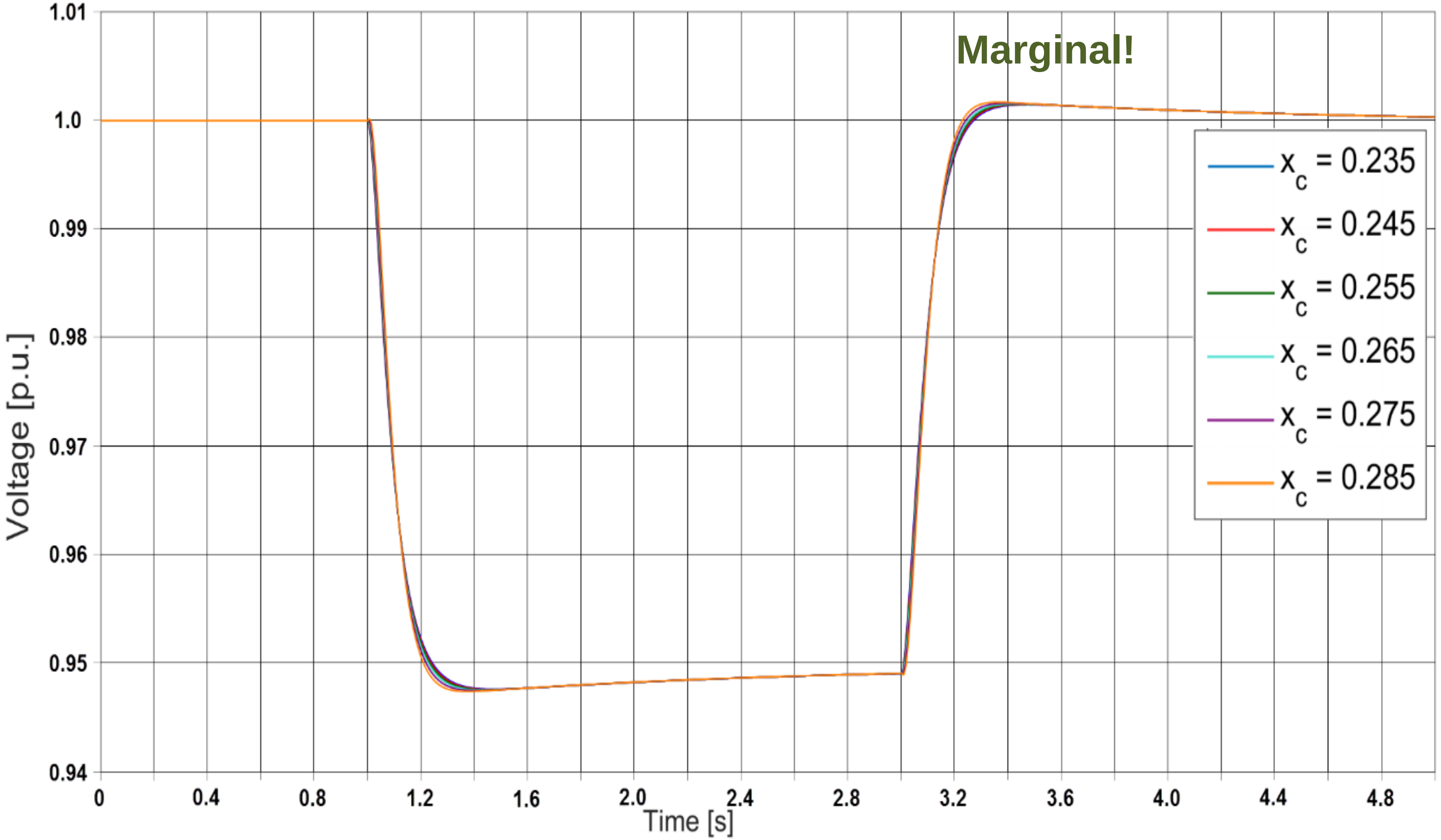
Most used Generator Model in industry. Lf1d mainly ignored == 0!



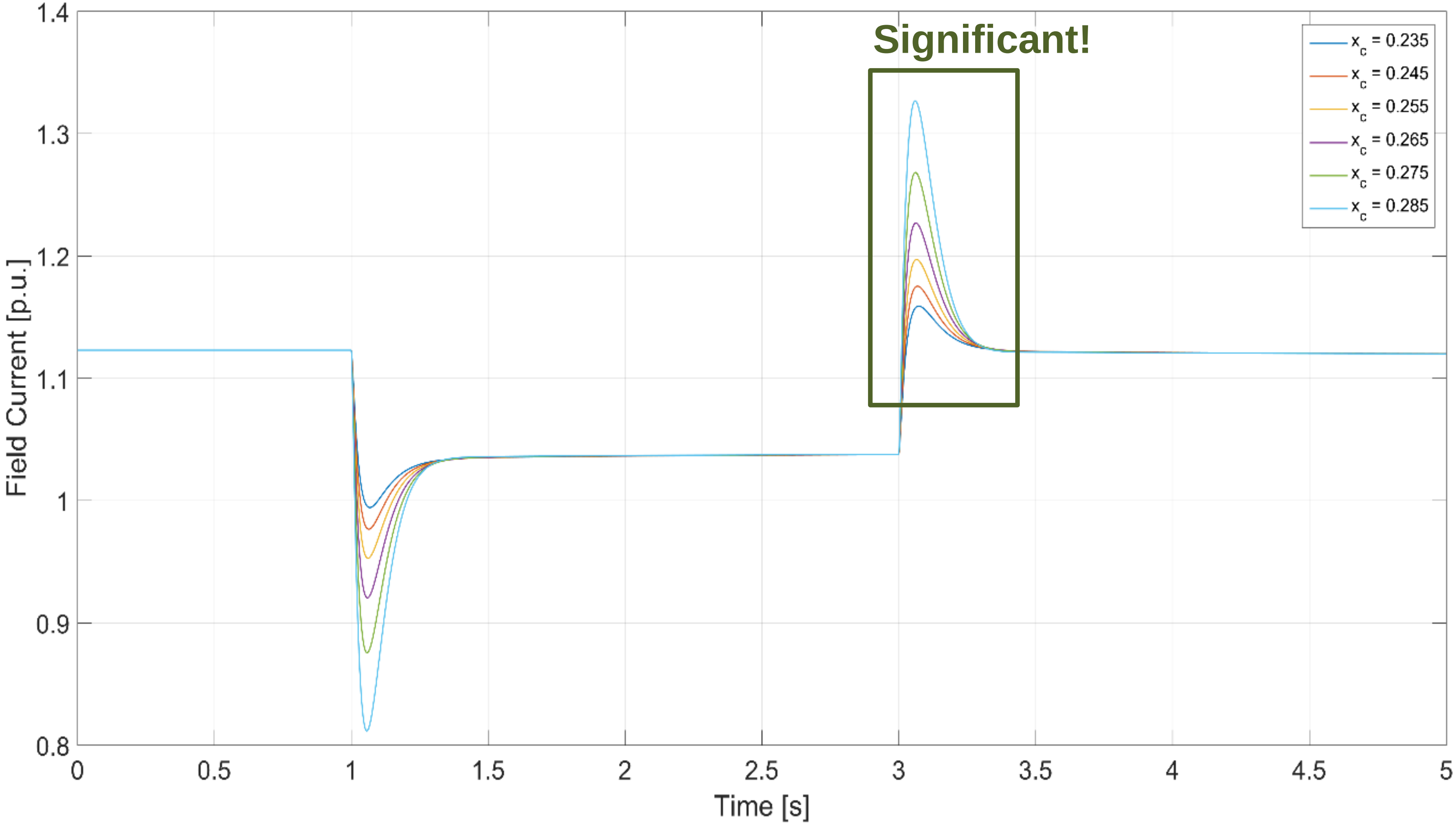
$x_c < x_l\ and\ x_{f1d} < 0$ for salient pole machine

$x_c > x_l\ and\ x_{f1d} > 0$ for turbomachines

Impact of Lf1d on stator Voltage



Impact of Lf1d on field current



Practical challenges of **generator** and exciter modelling

Summary:

- Lf1d is hardly used in system studies, since it isn’t available is 99% of the stations
- Expectations on model accuracy is gradually increasing, steering even into directions to match «internal variables», such as field current & voltage
- **Difficulties will raise, if generator field current become part of the control loop**

Practical challenges of generator and **exciter** modeling

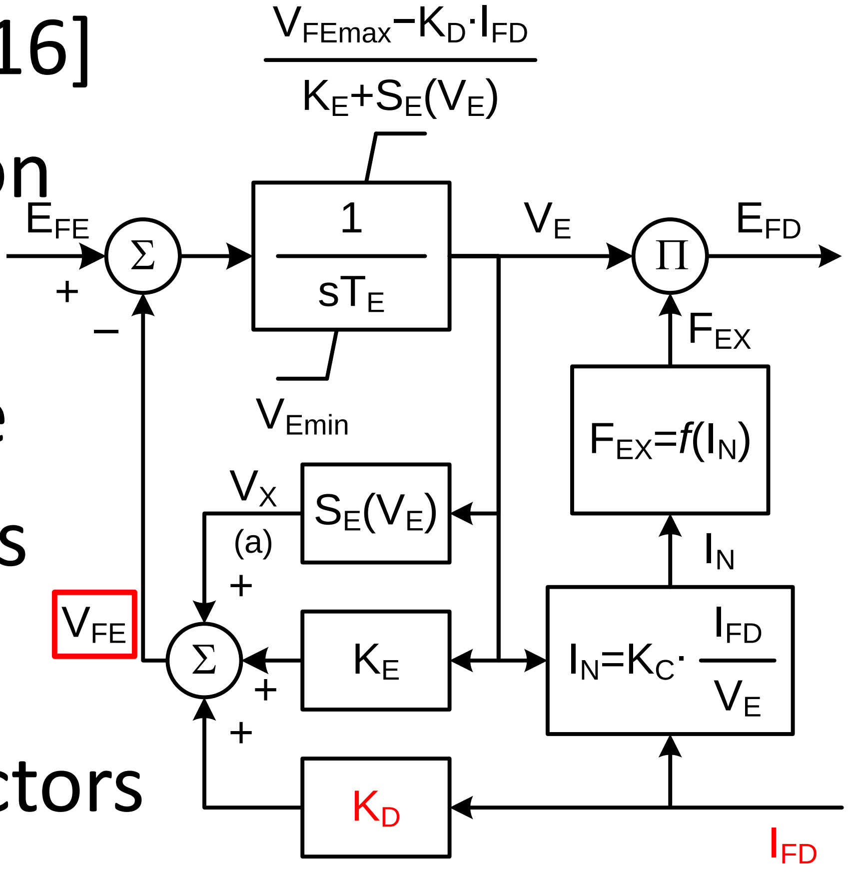
- Exciter Model [421.5-2016]

  Decent representation for steady state and small signal response

- Raising HIR requirements

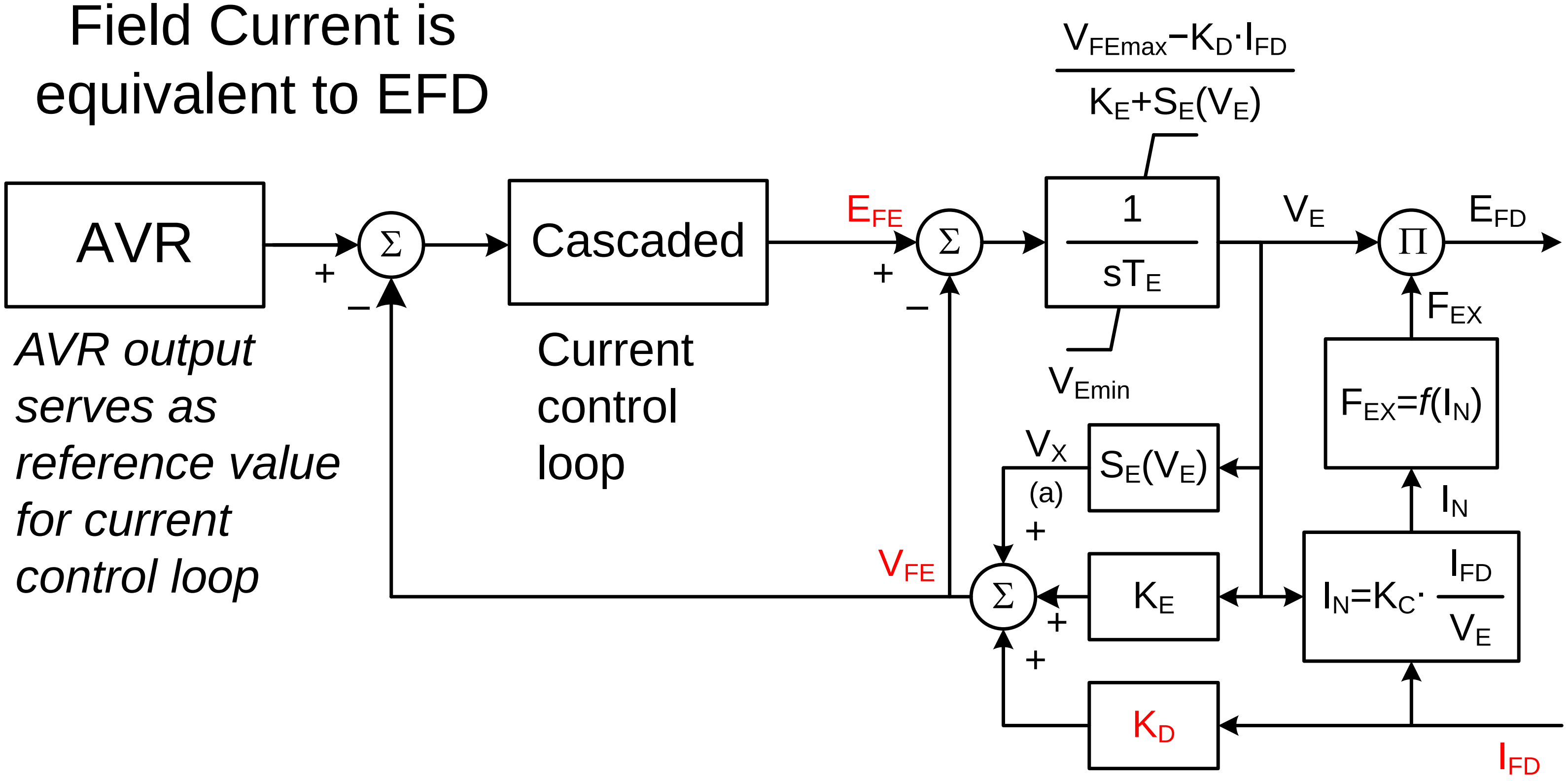
  May only be reached using huge ceiling factors

  → AVR with cascaded Current Controller



Practical challenges of generator and **exciter** modeling

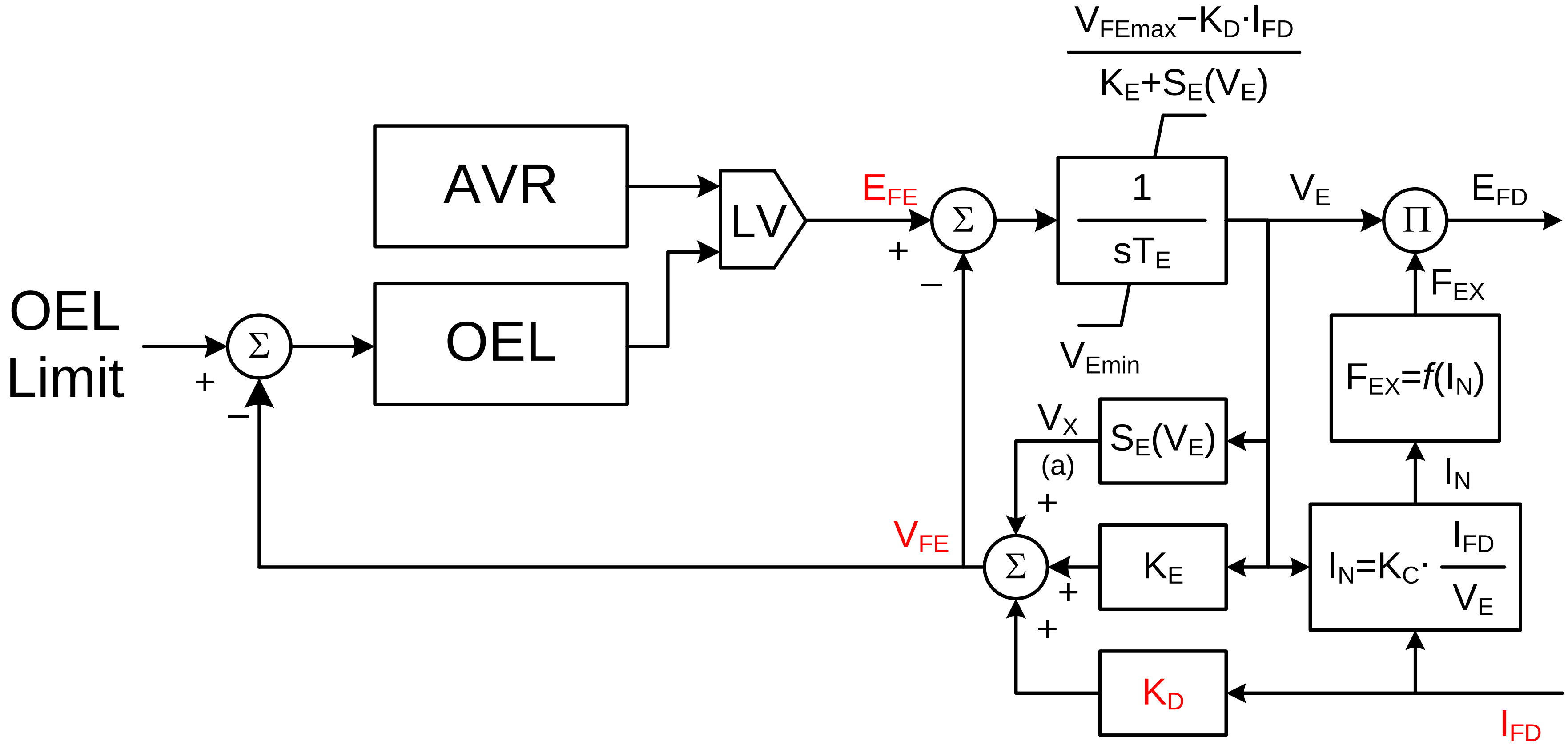
Assumption: Exciter Field Current is equivalent to EFD



AVR output serves as reference value for current control loop

Current control loop

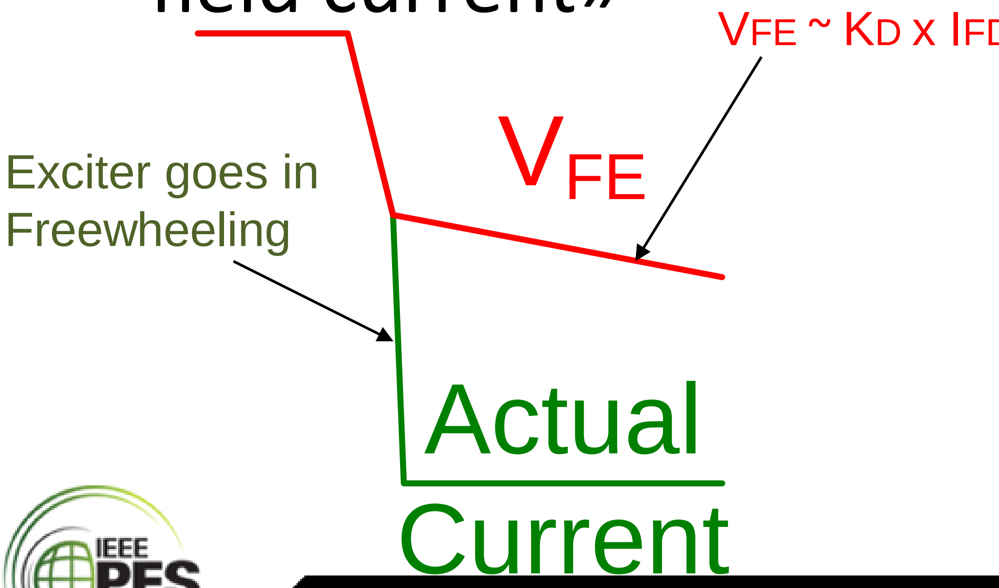
Practical challenges of generator and **exciter** modeling

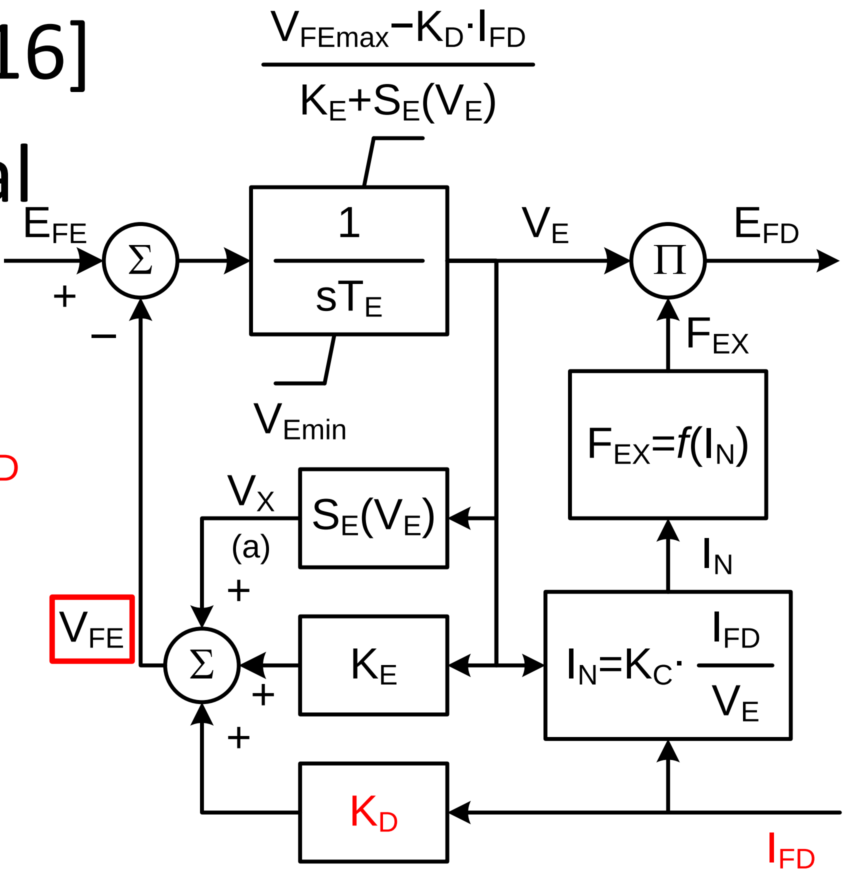


Practical challenges of generator and **exciter** modeling

- Exciter Model [421.5-2016]

  VFE is declared as «signal proportional to exciter field current»





Practical challenges of generator and **exciter** modeling

- Summary
  - VFE as feedback signal to controls may reach limits, in particular if «perfect» matching of exciter field current and exciter field voltage is desired (matching not limited to stator quantities)
  - «Logic-switch» to «force» VFE to zero may be an easy modification to the AC exciter model, if EFD or VE is zero → Brushless exciter is in «Free-wheeling» mode

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OEL and SCL Limiter Testing and PSS / Limiter Interaction

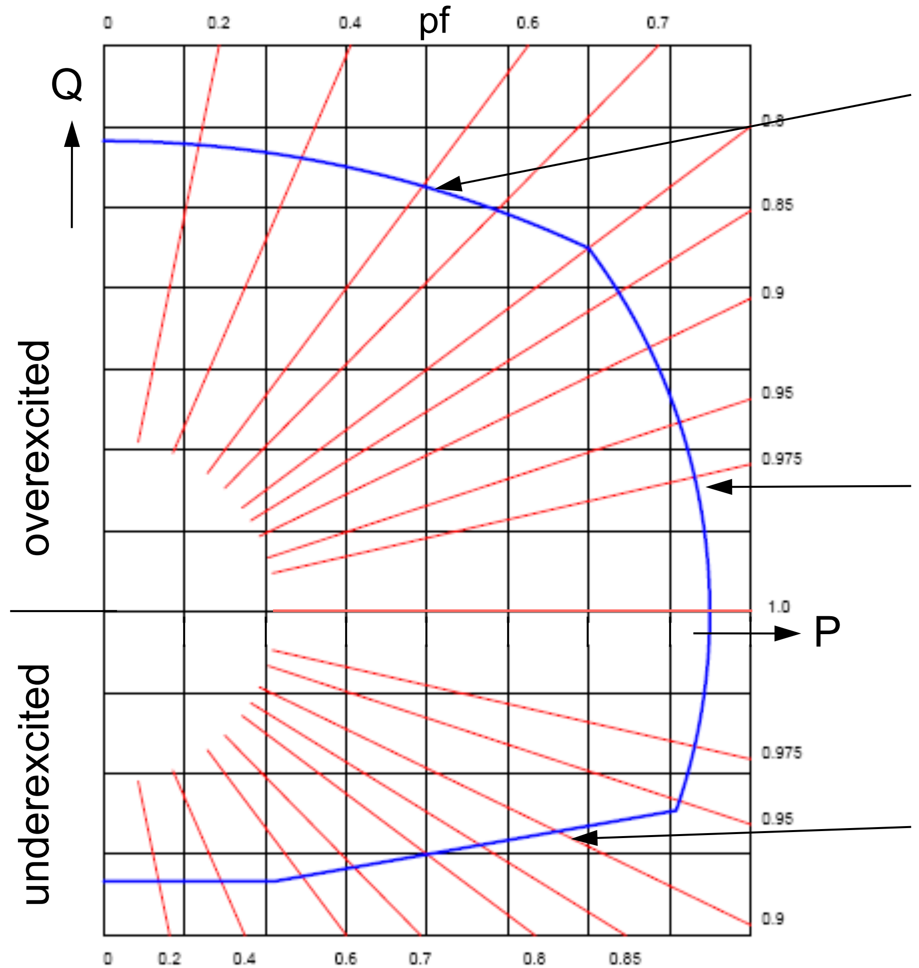
Ruediger Kutzner, Uwe Seeger

Presented by: Ruediger Kutzner,
Uwe Seeger

Overview

- Limitation – Reactive Capability
- New Models
- Test Methodology
- Test Results
- PSS / Limiter Interaction
- Conclusion

Generator Capability Curve



Source: Siemens AG

OEL – Overexcitation Limiter

Prevent overheating due to
high field current levels

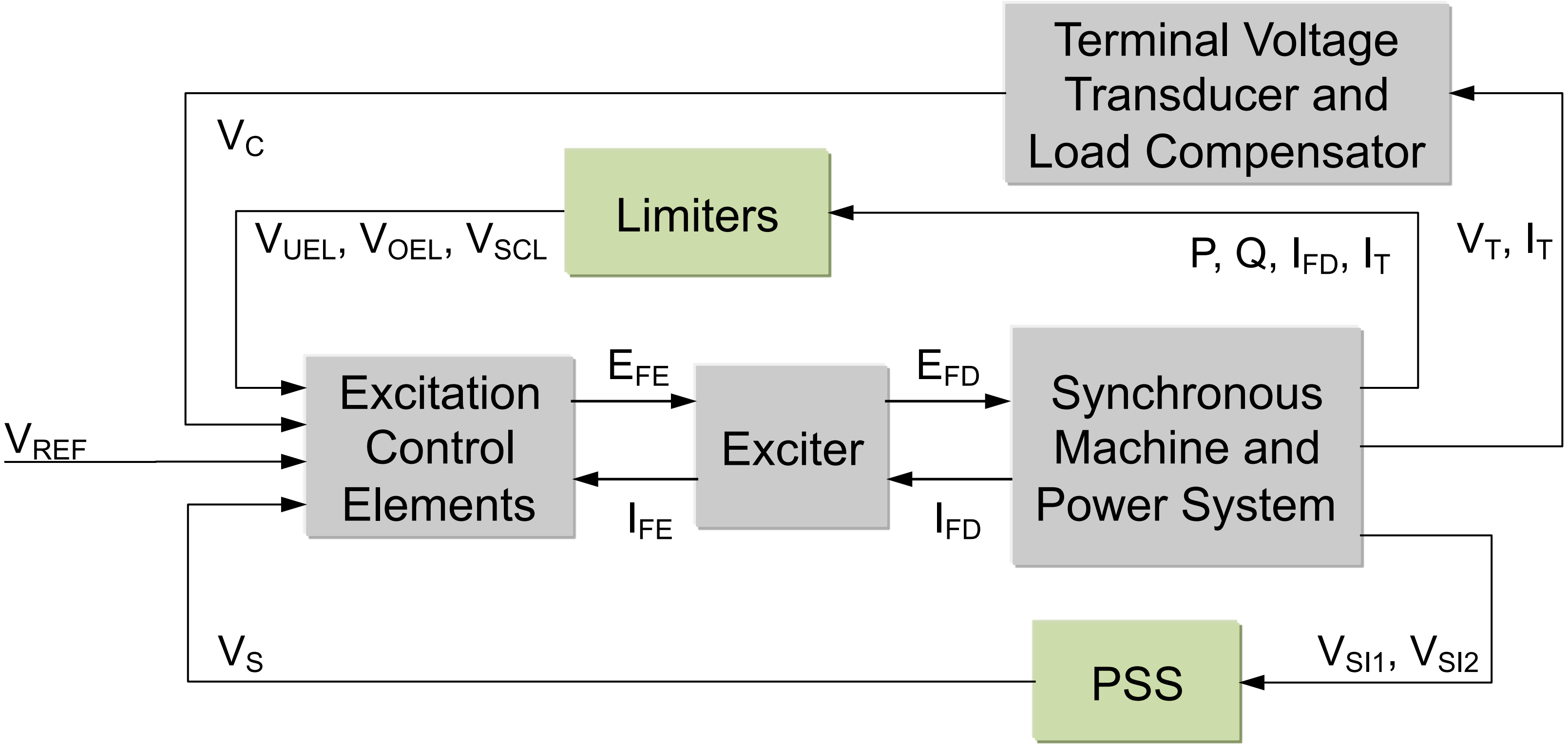
SCL – Stator Current Limiter

Prevent overheating due to
high stator current levels

UEL – Underexcitation Limiter

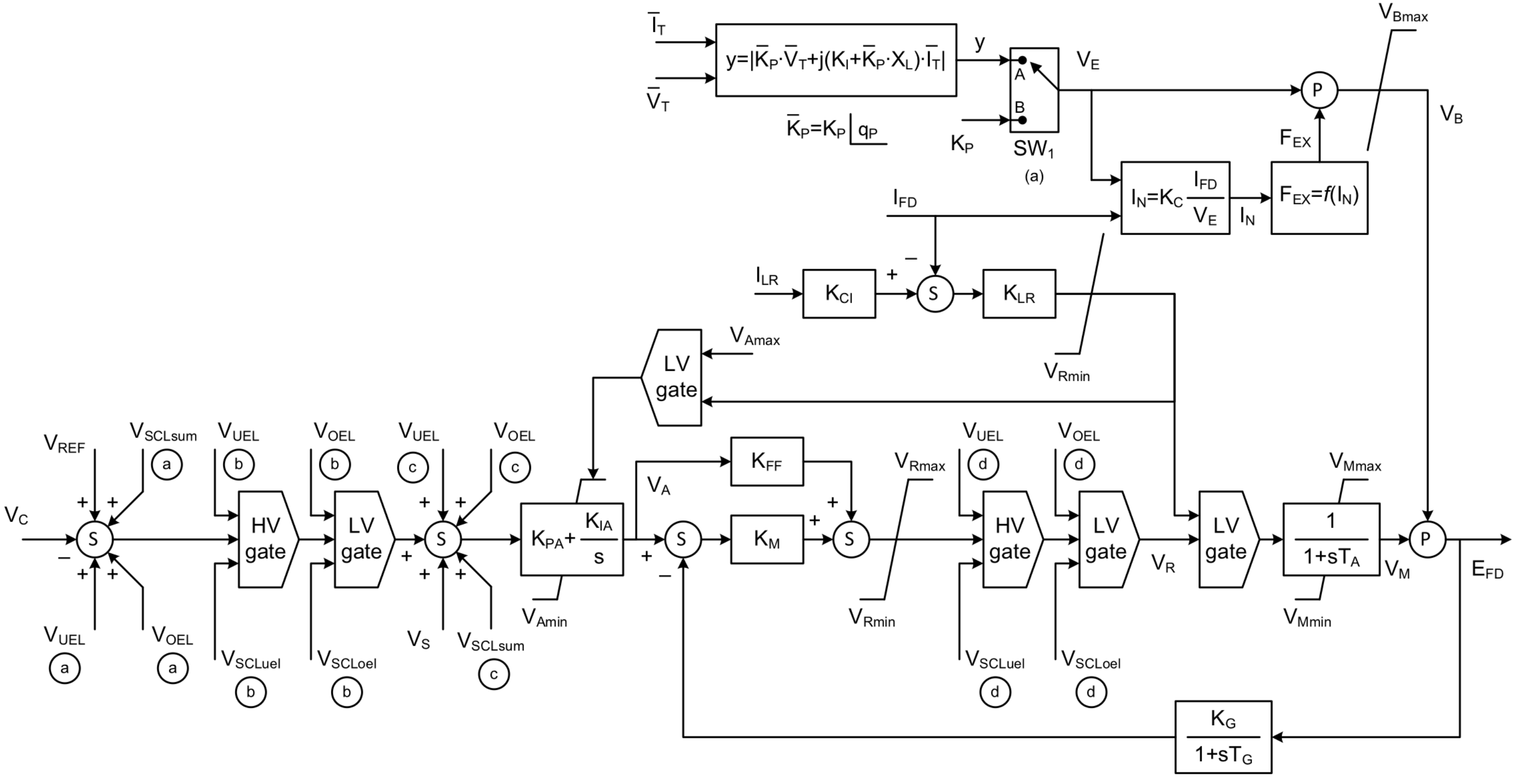
Prevent loss of synchronism,
prevent overheating in stator end region

Excitation Control System



New AVR models: ST6C

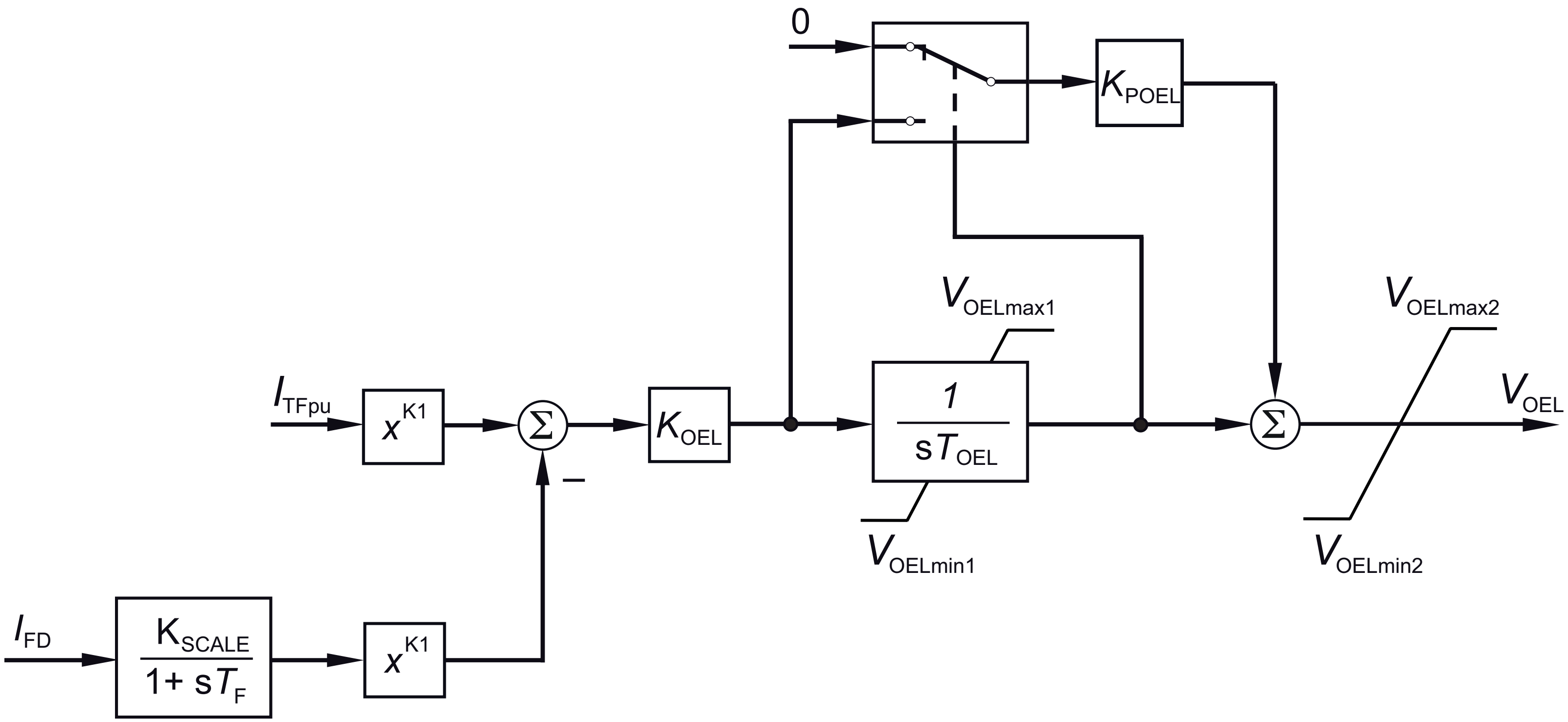
ST6C: static excitation system



Source: IEEE PES

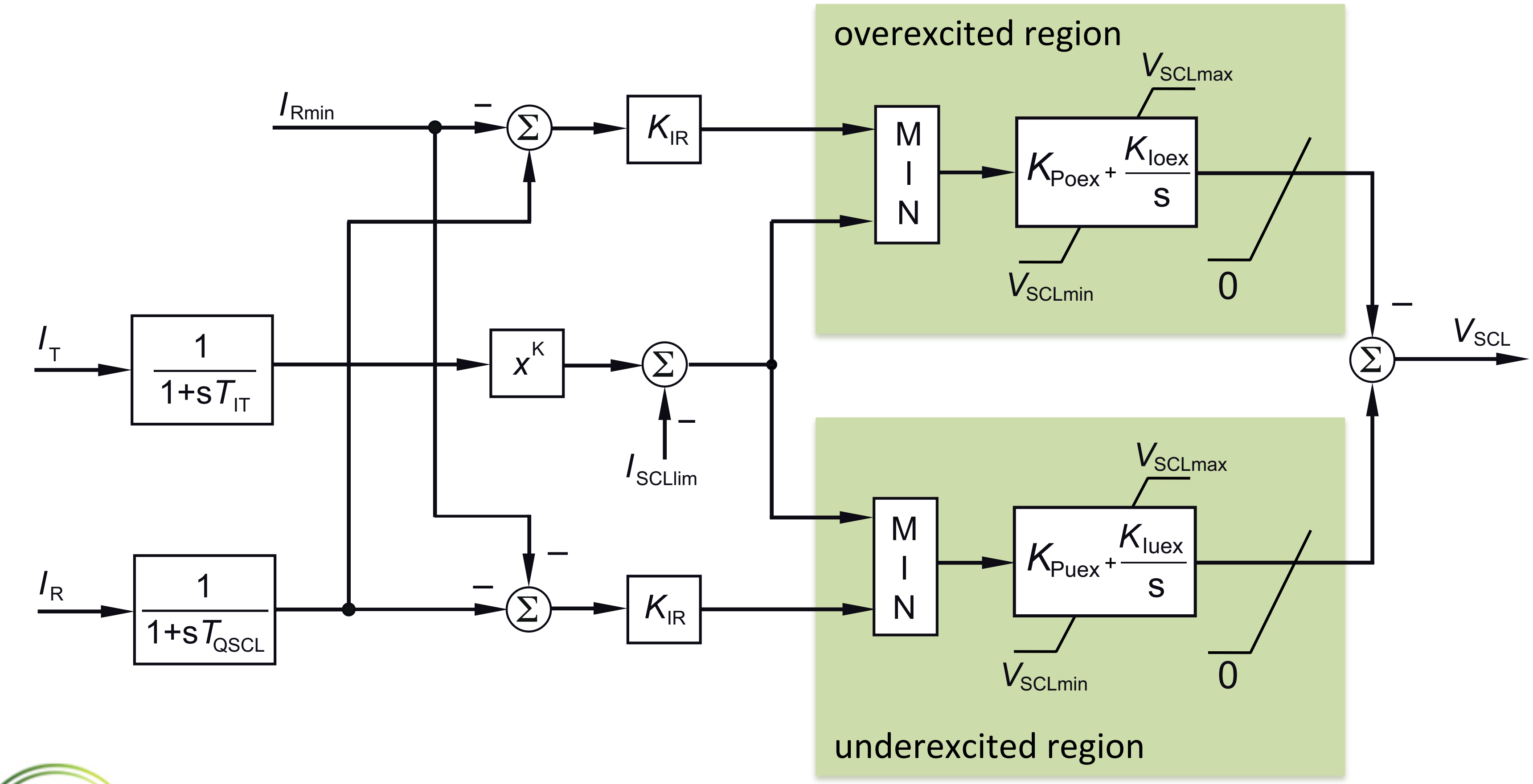
New OEL Models: OEL3C

OEL3C: summation point



New SCL Models: SCL1C

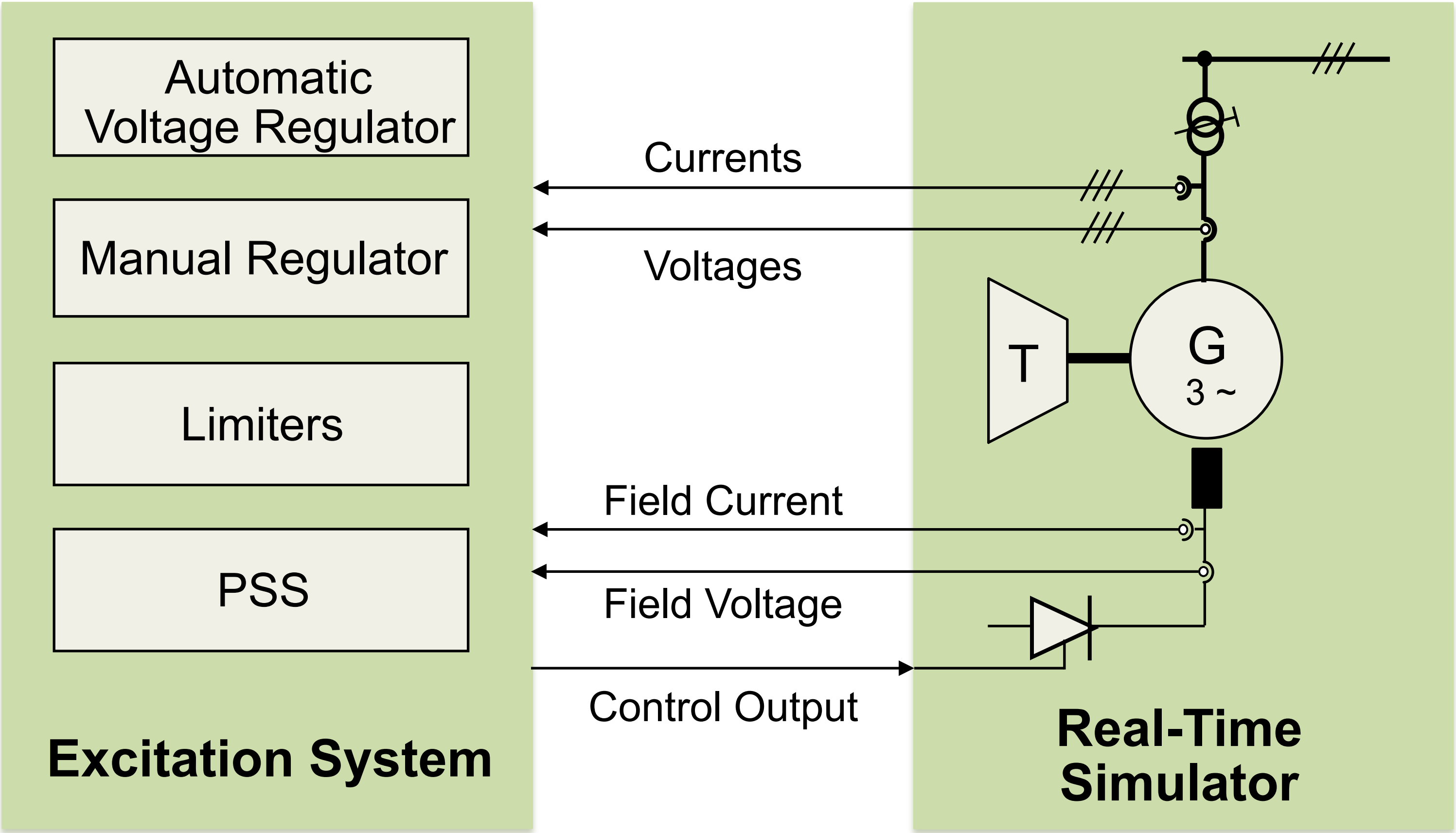
SCL1C: summation point



Test Methodology

- Offline simulation utilizing models
- On-site during commissioning (usually only with shifted characteristic)
- Test lab utilizing a real-time simulator
  - Closed-loop test of real system (HiL-Test)
  - No risk and no harm to plant
  - No restrictions of plant
  - Validate models

Hardware-in-the-Loop-Test



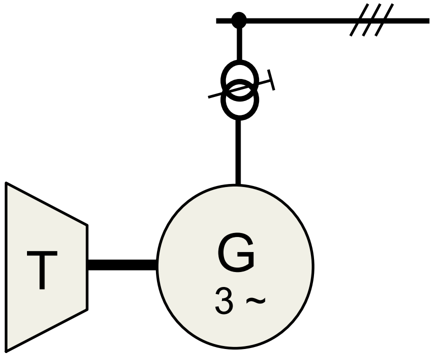
HiL Test Setup

Static Excitation System Thyripol®

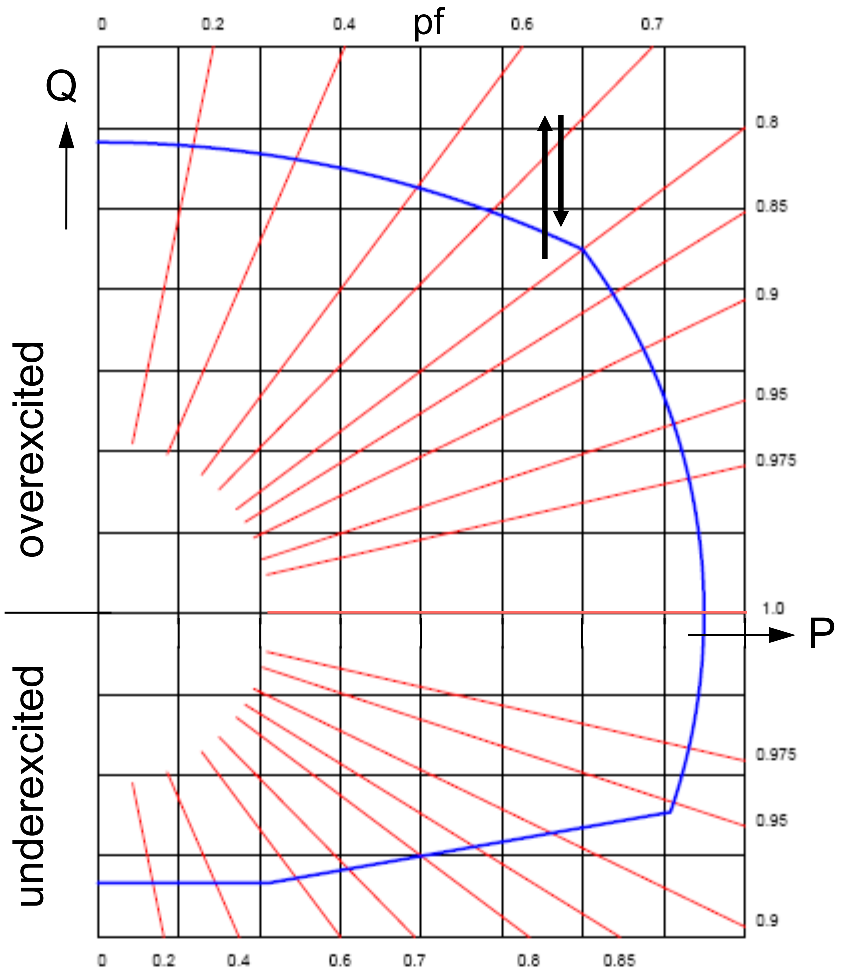
Real-Time Simulator

Source: Siemens AG

Test of OEL

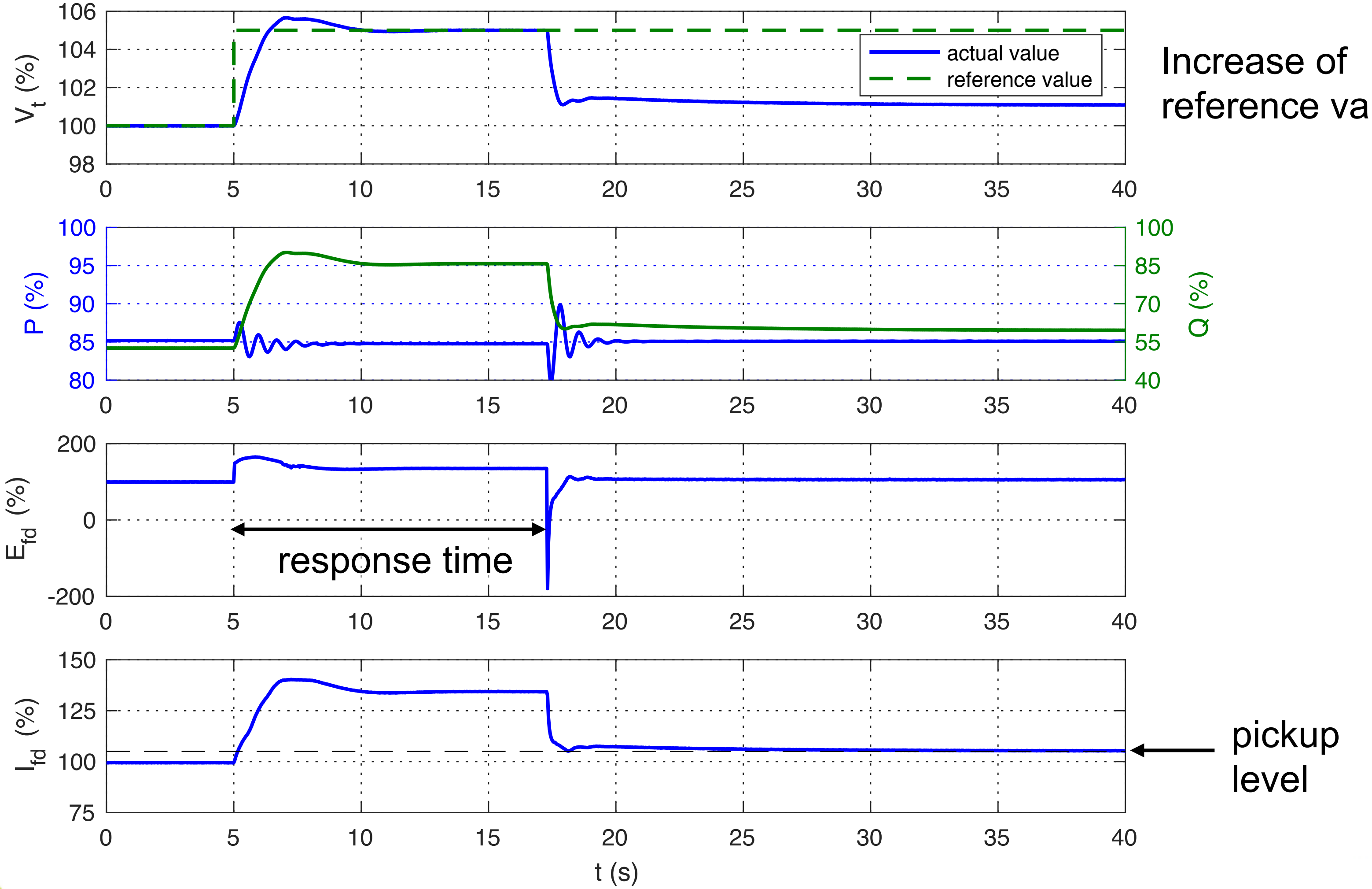


1. Reduce grid voltage or increase terminal voltage
   ➔ Increased field current
2. OEL reduces terminal voltage
   ➔ Reduction of field current



Source: Siemens AG

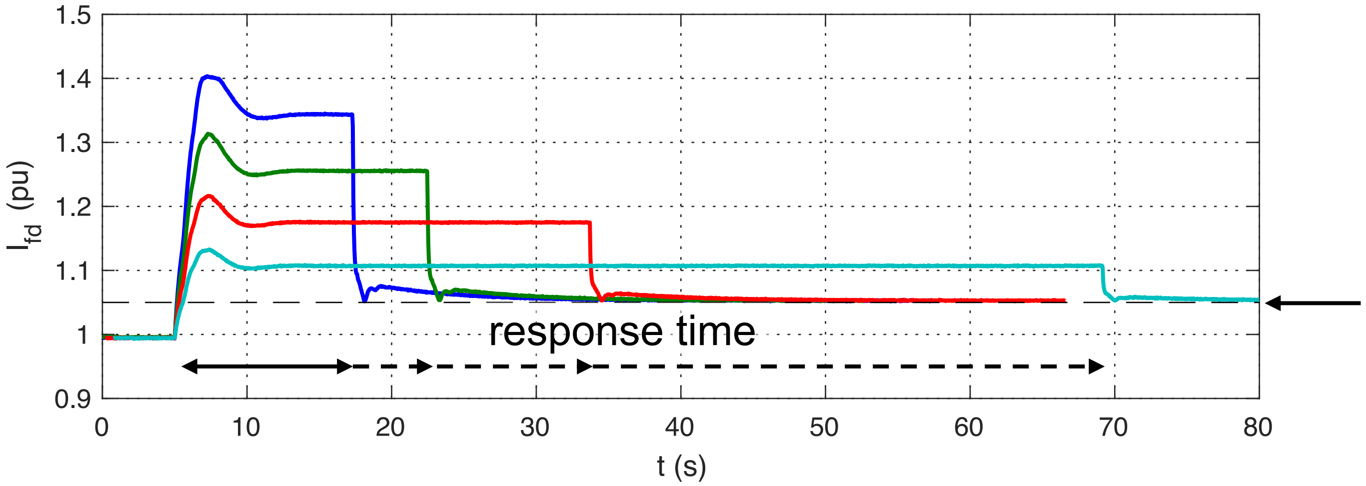
OEL3C HiL-Test Result



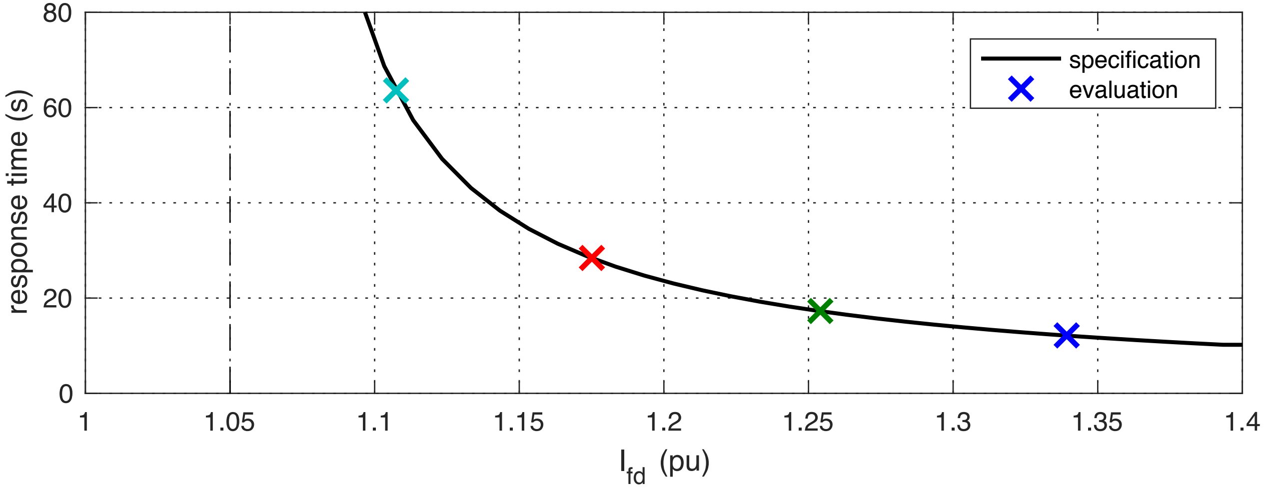
Increase of reference value

pickup level

OEL3C HiL-Test Result

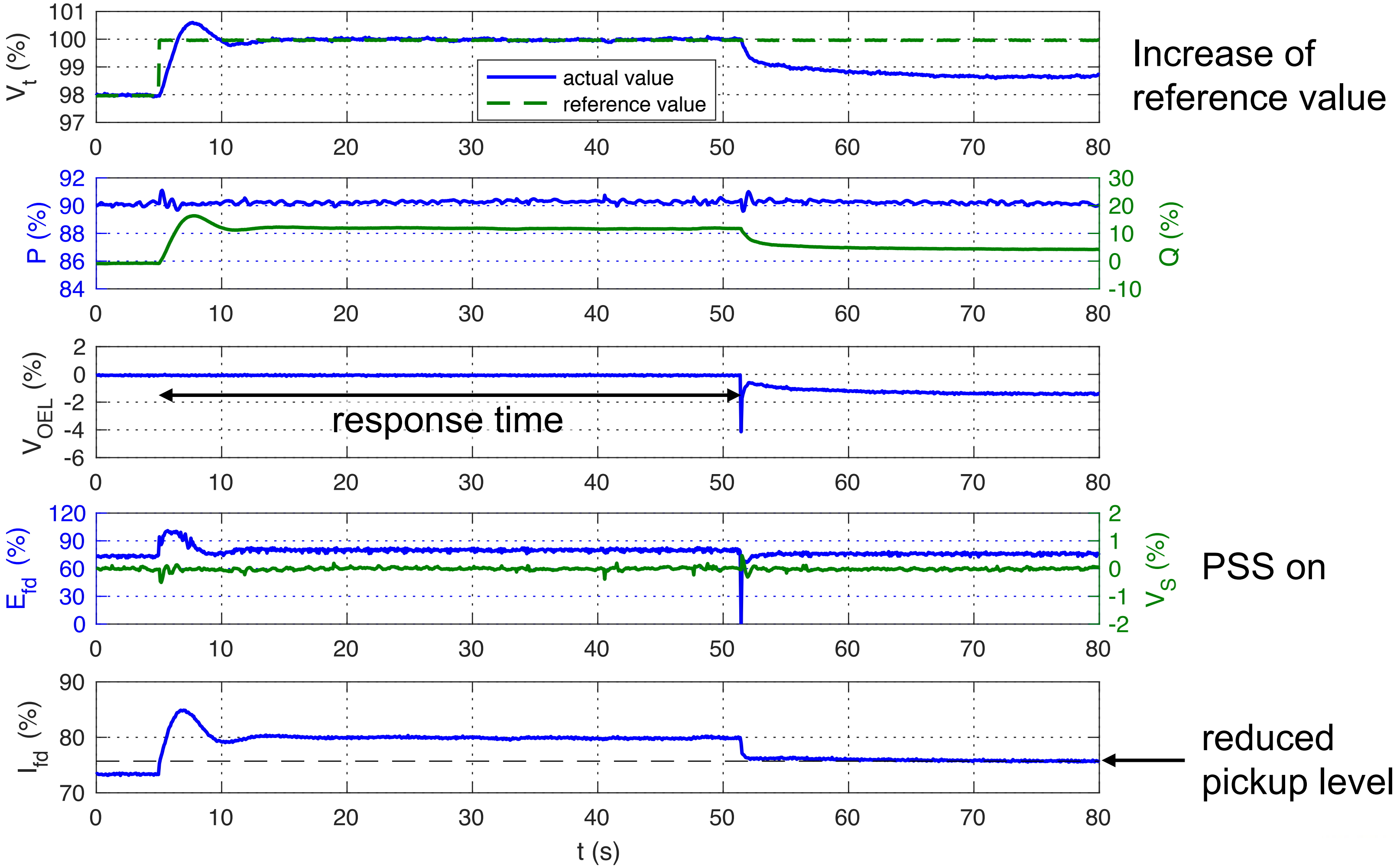


pickup level



linear characteristic

OEL3C Commissioning Result

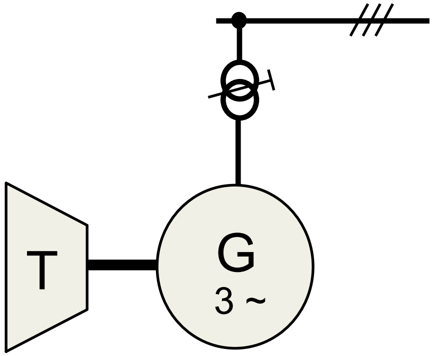


Increase of reference value

PSS on

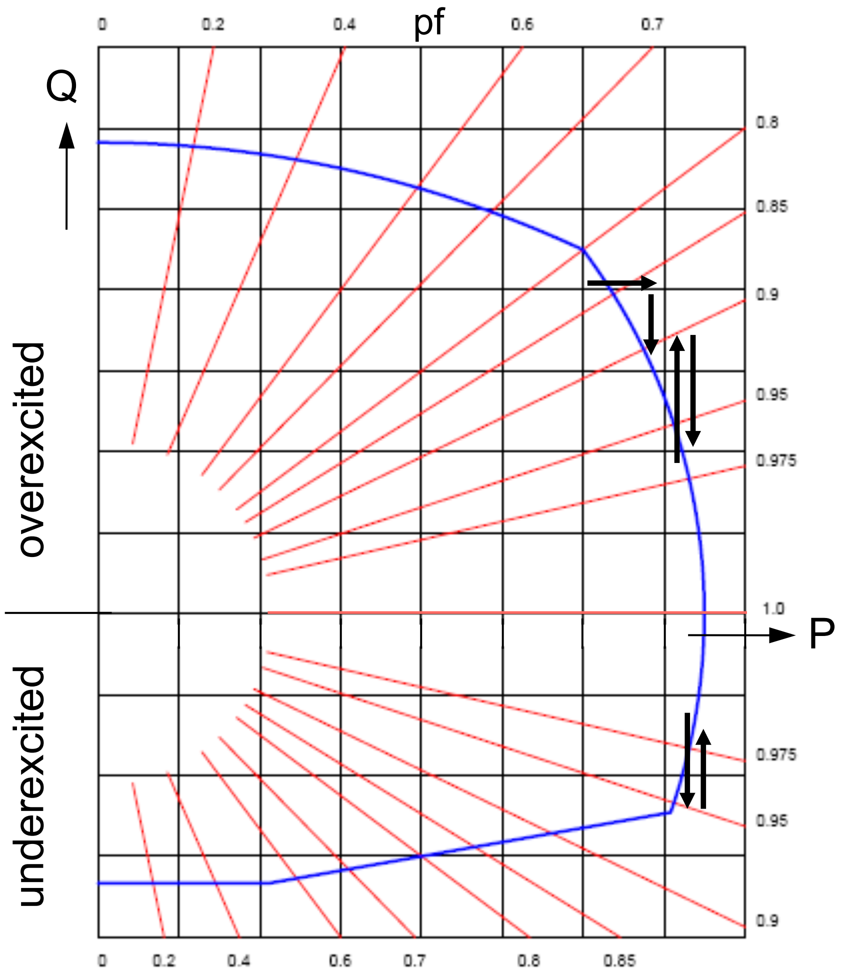
reduced pickup level

Test of SCL



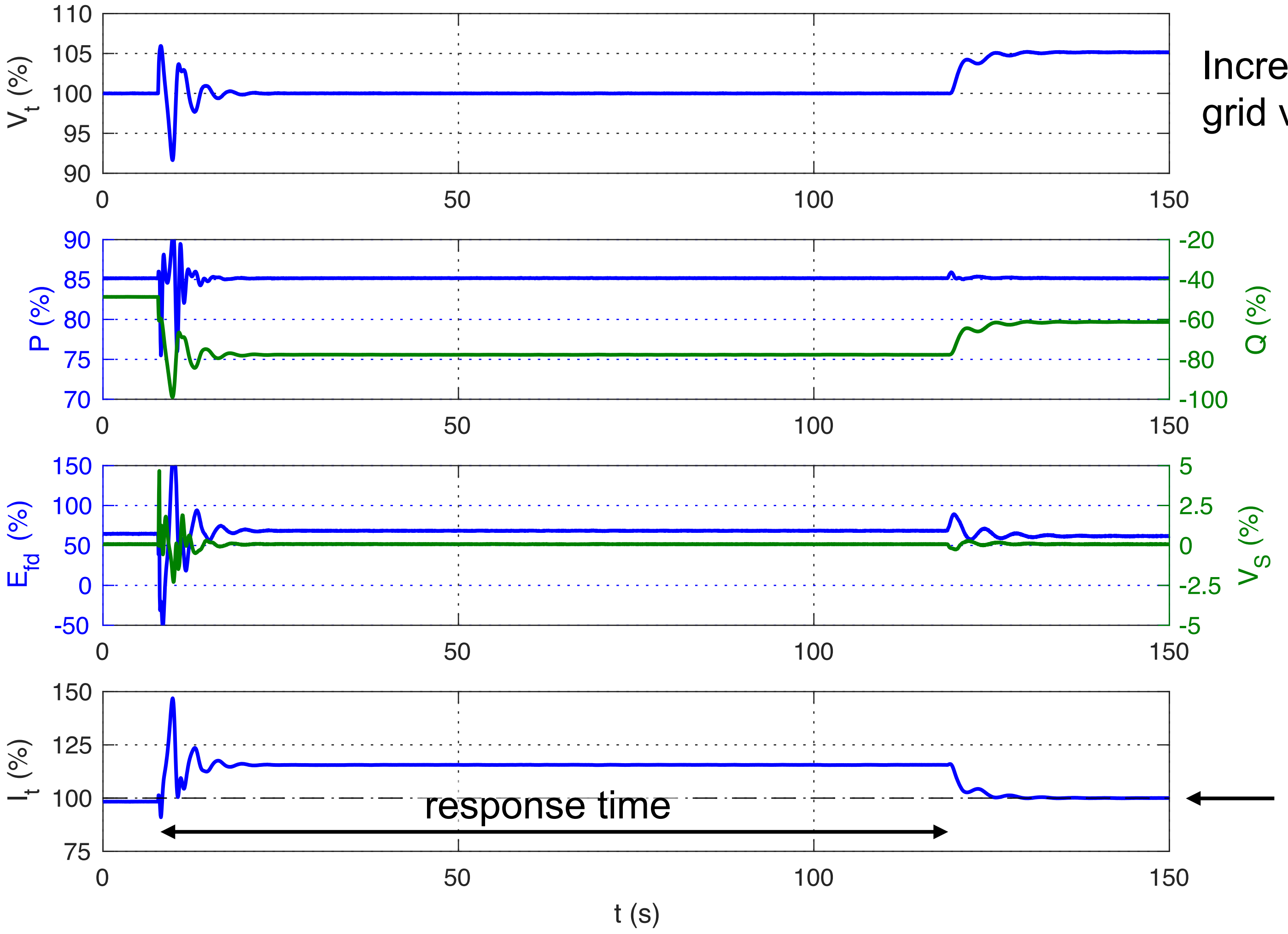
1. Change grid voltage or increase load
   ➔ Increased stator current

2. SCL changes terminal voltage
   ➔ Reduction of stator current



Source: Siemens AG

SCL1C HiL-Test Result

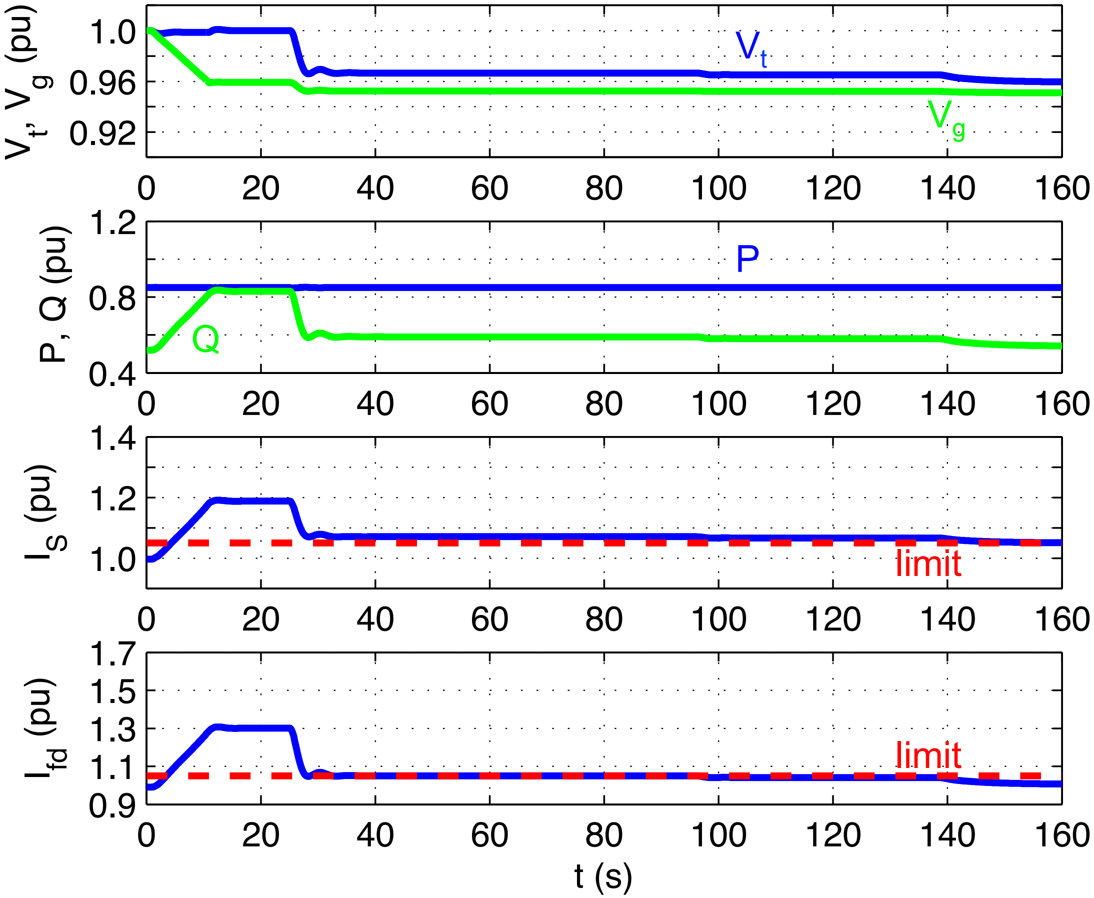


Increase of grid voltage

PSS on

pickup level

Coordination of OEL and SCL



Simulated decrease of system voltage by 4 %

Later SCL lowers stator current to admissible value

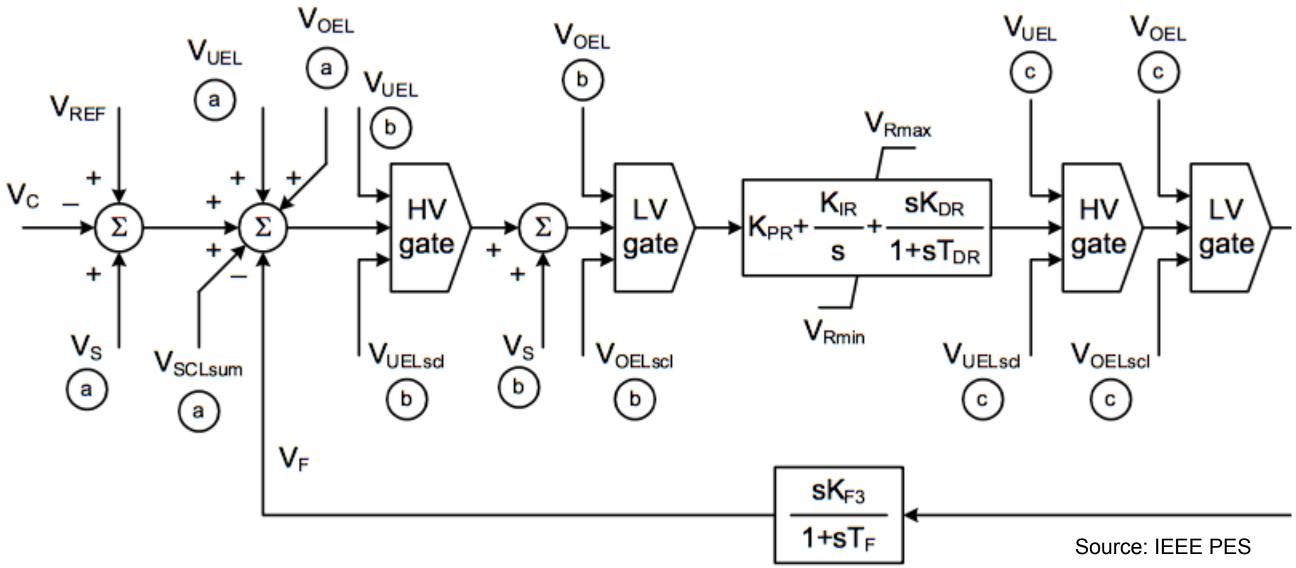
At first OEL lowers field current to admissible value

SCL Remarks

- OEL alone can not ensure that stator current does not exceeds the admissible value.
- SCL is additionally needed to keep stator current within the limit.
- OEL and SCL reduce terminal voltage.
- SCL can not help in the vicinity of a power factor of 1.
- SCL might cause instability in a weak systems if SCL settings are not appropriate.
- Additional measures, like a tap change or a reduced load, might be considered to keep terminal voltage inside the limits.

Interaction of Limiters and PSS

Voltage error calculation of AC7C:



add. take-over point d of V_{OEL} at regulator output

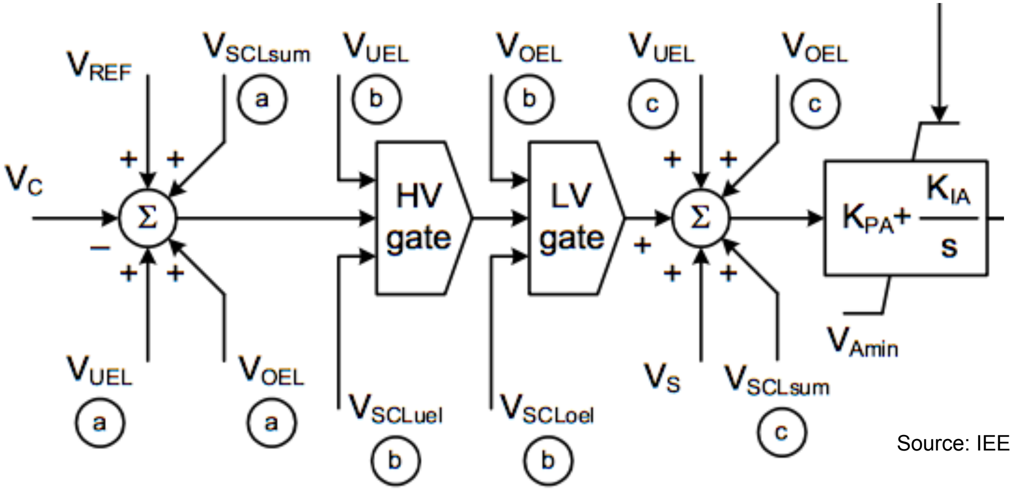
Source: IEEE PES

Summation point:	UEL – a	OEL – a	SCL – a
Take-over:	UEL – b, c	OEL – b, c, d	SCL – b, c

PSS: point a before take-over of UEL – b, c, OEL – b, c, d, SCL – b, c
point b before take-over of UEL – c, OEL – b, c, d, SCL – (b), c

Interaction of Limiters and PSS

Voltage error calculation of ST6C:



Add. take-over point d of V_{UEL}, V_{OEL}, V_{SCL} at regulator output

Source: IEEE PES

Summation point:	UEL – a	OEL – a, c	SCL – a, c
Take-over:	UEL – b, c, d	OEL – b, d	SCL – b, d

PSS: behind take-over of UEL – b, OEL – b, SCL – b
before take-over of UEL – d, OEL – d, SCL - d

Conclusion

- Different test methodologies for limiter testing.
- Usually limiters are tested with PSS on.
- Limiters needs to be tested individually and all together.
- Interaction of limiters and PSS depends on AVR models.

Thank you

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Challenges in the Synthesis of the Instantaneous Rotor Speed for PSS Applications

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Lucas Manso da Silva (*)
Henrique Augusto Menarim (*)
Nelson Martins (**)

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(*)

Eletrobras Cepel
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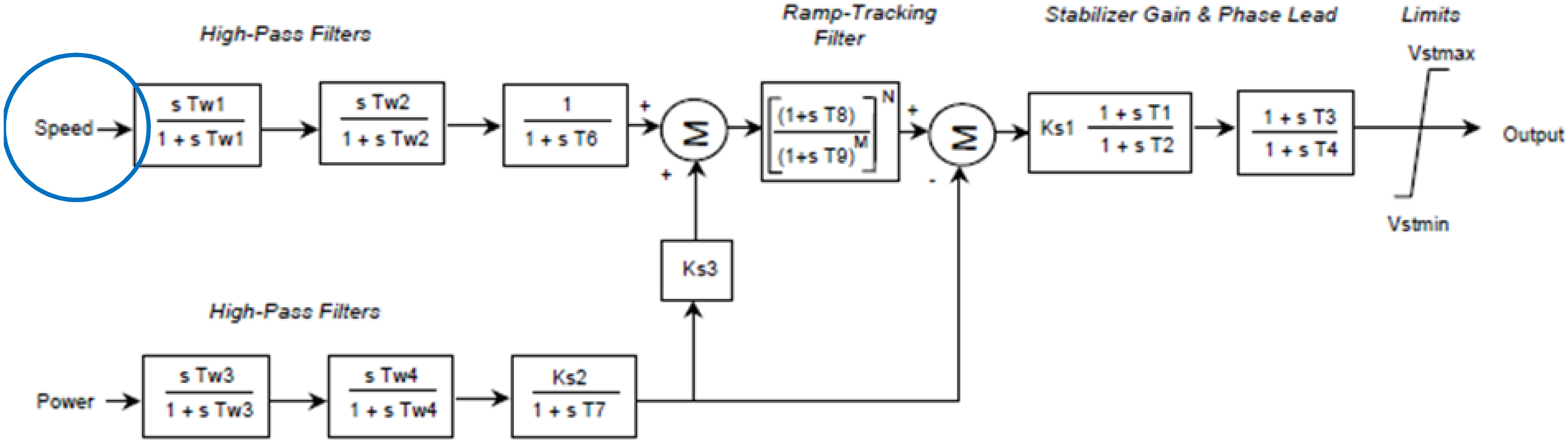
Motivation

Need of accurate rotor speed signal for PSS applications.



Accelerating Power PSS Model (PSS2A)

Current Practice for Rotor Speed Estimation

Rotor speed is estimated from measured electrical variables:

$$\Delta\omega = \Delta f + \frac{1}{\omega_o} * \frac{\partial}{\partial t}\left[tg^{-1}\left(\frac{P * x_q}{Vt^2 + Q * x_q}\right)\right]$$

Where:

- Δf = electrical frequency deviation measured at the generator terminals
- P = measured active power
- Q = measured reactive power
- Vt = measured terminal voltage
- xq = quadracture reactance parameter
- ω_o = nominal frequency

Current Results

Yields a signal that is a poor rotor speed estimate, mainly for round rotor machines

Power Plant: ARAUCÁRIA

Initial Conditions

Test 1:
Vo = 1pu
Po = 0.8pu
Qo = 0.3pu

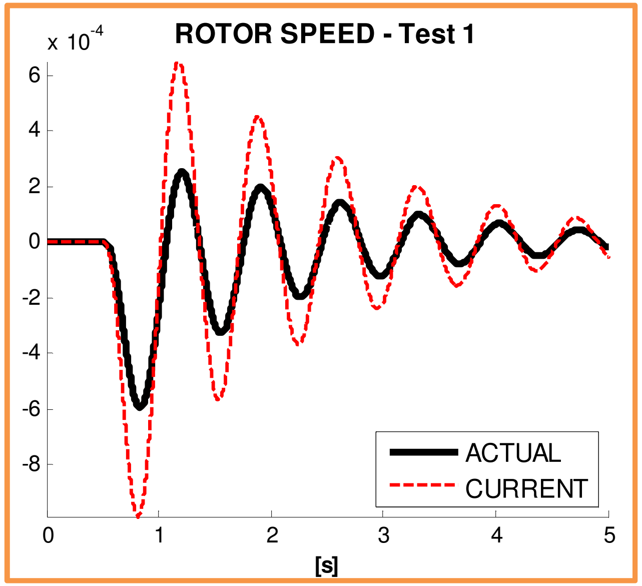
Test 2:
Vo = 1pu
Po = 0.3pu
Qo = −0.3pu

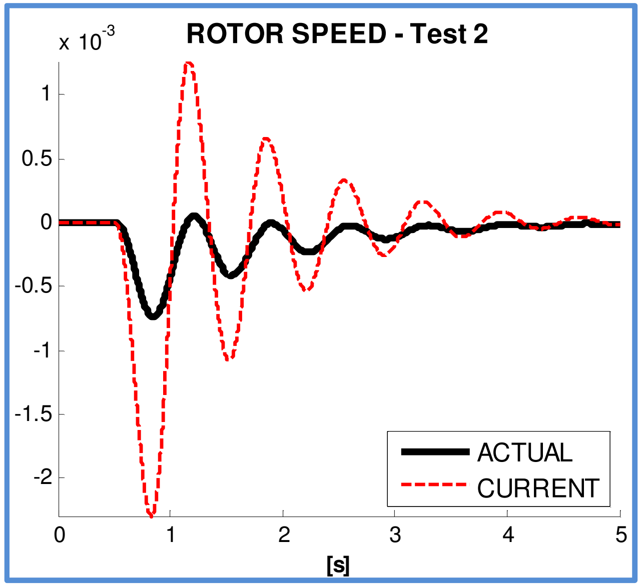
Equiv. System:
xe = 0.2pu

Test:
Response to Voltage Step

Synch. Machine Data:
Type = Round Rotor
Unity Rating: 198 MVA
xd = 2.04pu
x´d = 0.199pu
x´´d= 0.153pu
xl = 0.137pu
xq = 1.9pu
x´q = 0.327pu
x´´q= 0.153pu

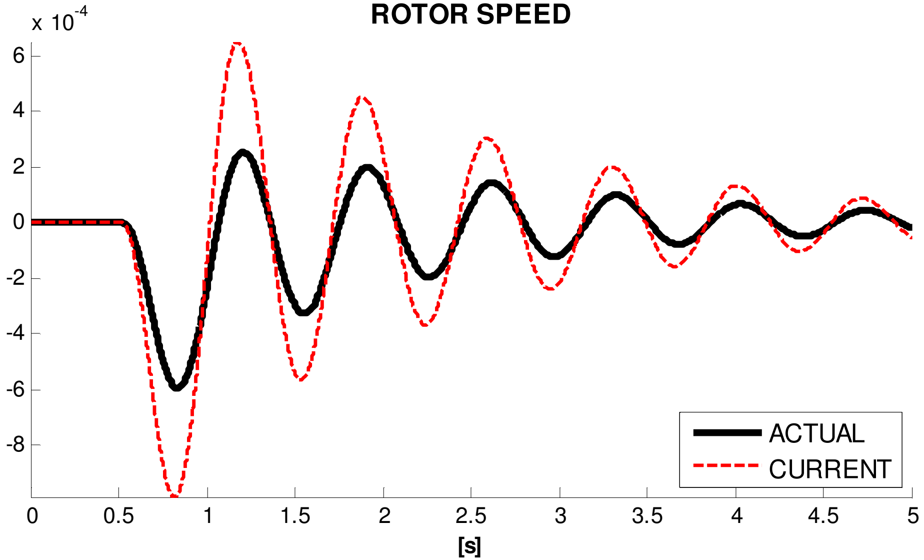
T´do = 9.8s
T´´do= 0.042s
T´qo = 0.96s
T´´qo= 0.064s
Ag = 0.043
Bg = 7.375
M = 11.92s
D = 0

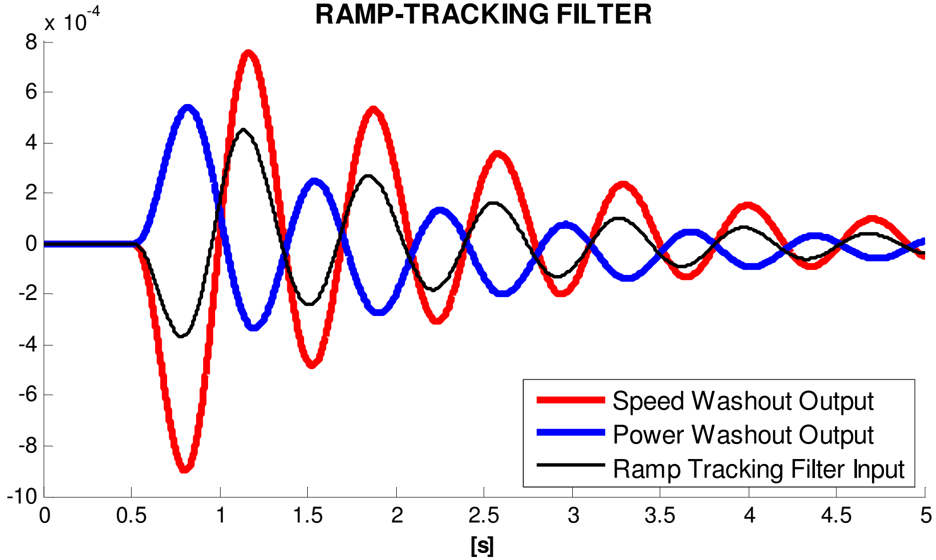




Current rotor speed estimation has a **larger amplitude** and more **phase advance** in respect to the actual rotor speed, these errors being also much **dependent on machine loading**

Current Impact on the PSS-2B Variables





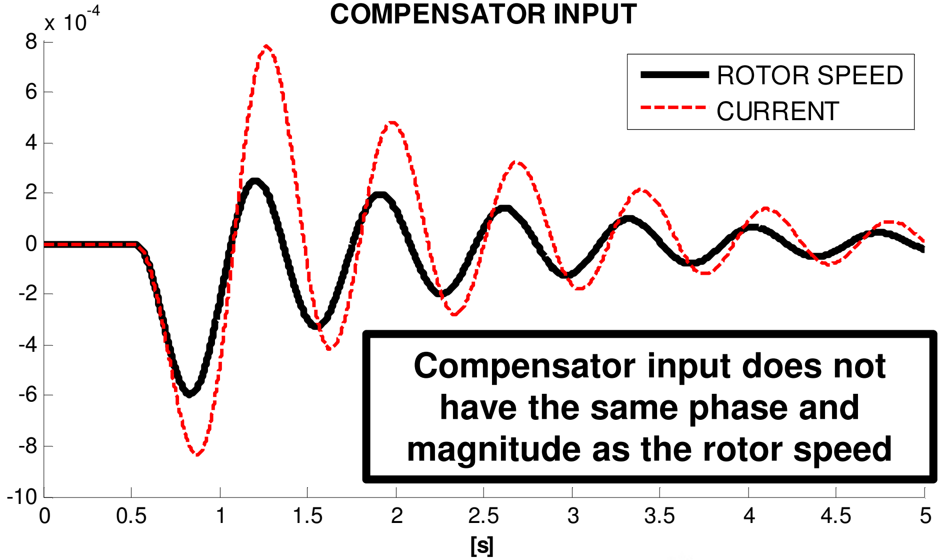
Power Plant: ARAUCÁRIA

Initial Conditions:
Vo = 1pu
Po = 0.8pu
Qo = 0.3pu

Equiv. System:
xe = 0.2pu

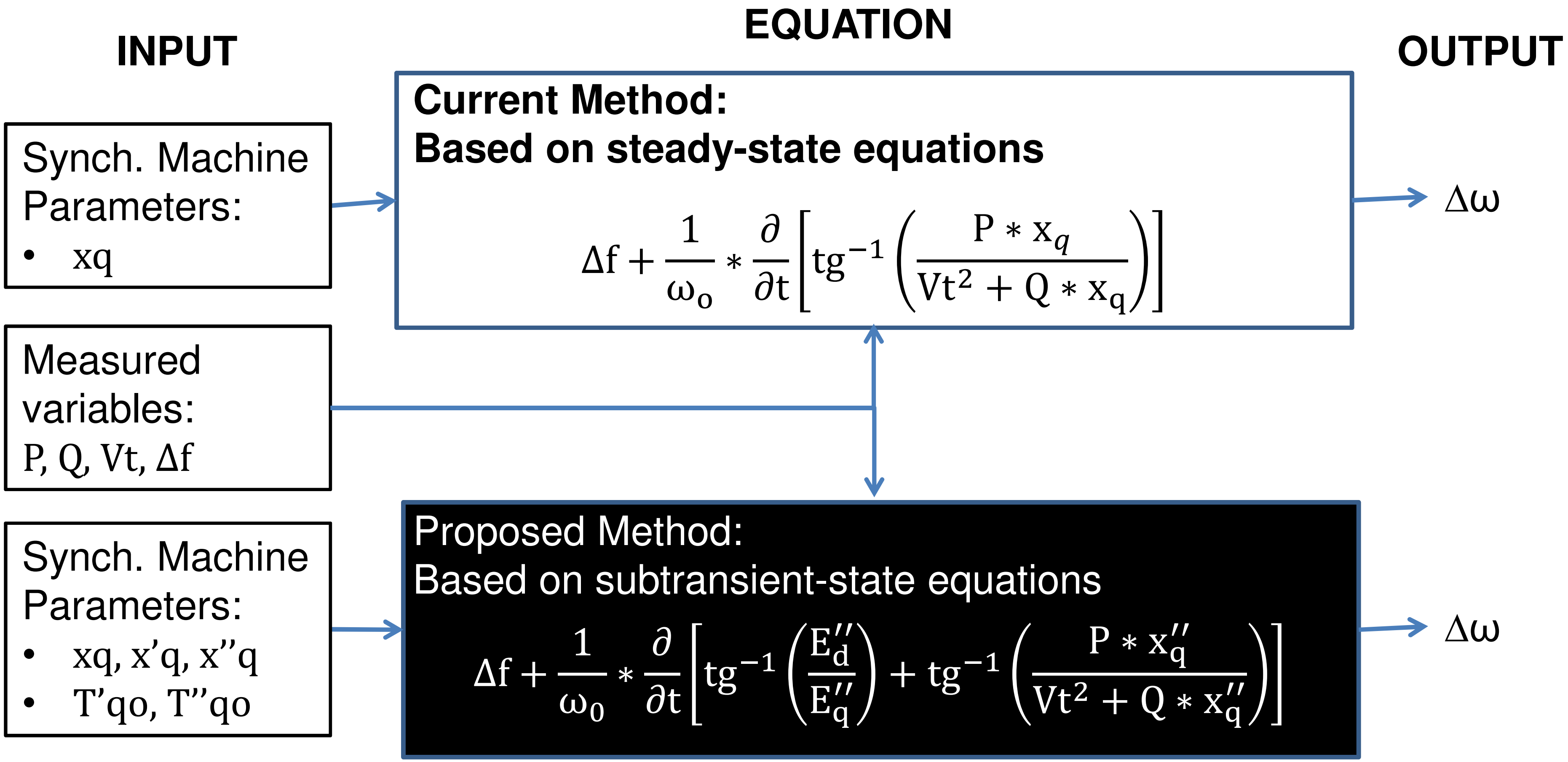
Test:
Voltage Step

Synch. Machine Data:
Type = Round Rotor
Unity Rating: 198 MVA
xd = 2.04pu   T´do = 9.8s
x´d = 0.199pu   T´´do= 0.042s
x´´d= 0.153pu   T´qo = 0.96s
xl = 0.137pu   T´´qo= 0.064s
xq = 1.9pu   Ag = 0.043
x´q = 0.327pu   Bg = 7.375
x´´q= 0.153pu   M = 11.92s
D = 0



Compensator input does not have the same phase and magnitude as the rotor speed

Proposed Method for Rotor Speed Signal



INPUT

EQUATION

OUTPUT

Synch. Machine Parameters:
- xq

Measured variables:
P, Q, Vt, Δf

Synch. Machine Parameters:
- xq, x’q, x”q
- T’qo, T”qo

Current Method:
Based on steady-state equations

$$\Delta f + \frac{1}{\omega_o} * \frac{\partial}{\partial t}\left[tg^{-1}\left(\frac{P * x_q}{Vt^2 + Q * x_q}\right)\right]$$

$\Delta\omega$

Proposed Method:
Based on subtransient-state equations

$$\Delta f + \frac{1}{\omega_0} * \frac{\partial}{\partial t}\left[tg^{-1}\left(\frac{E''_d}{E''_q}\right) + tg^{-1}\left(\frac{P * x''_q}{Vt^2 + Q * x''_q}\right)\right]$$

$\Delta\omega$

Performances of the Two Rotor Speed Estimation Methods Compared from Simulated Voltage Step Responses of Actual Machines of the Brazilian Grid

Round Rotor Machine

Power Plant: ARAUCÁRIA

Initial Conditions

Test 1:
Vo = 1pu
Po = 0.8pu
Qo = 0.3pu

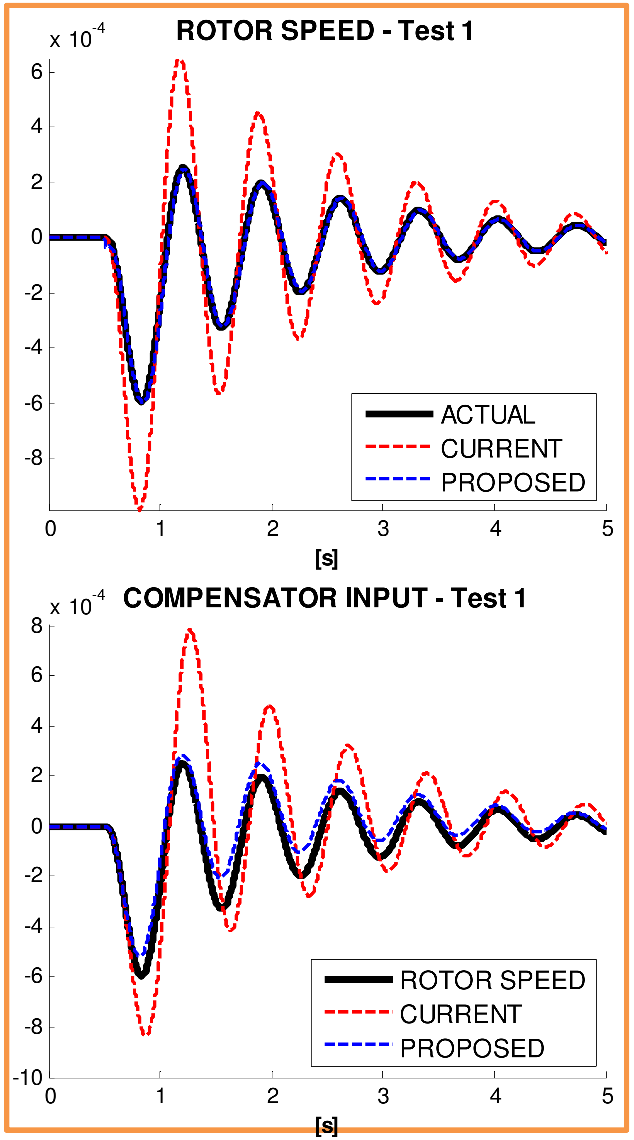
Test 2:
Vo = 1pu
Po = 0.3pu
Qo = −0.3pu

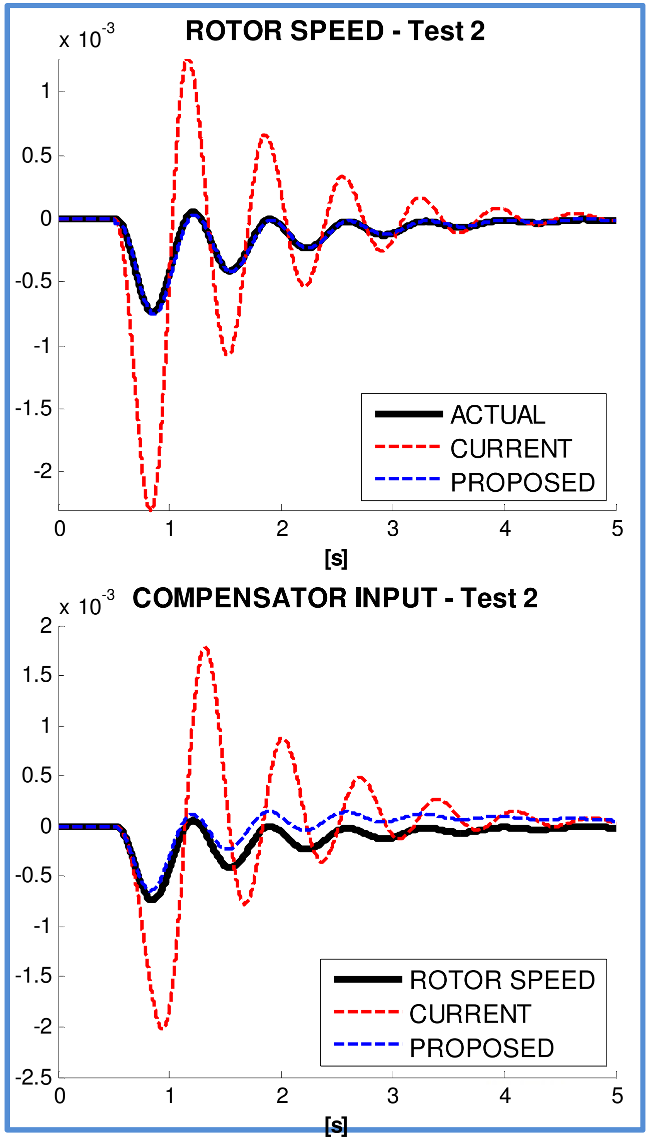
Equiv. System:
xe = 0.2pu

Test:
Response to Voltage Step

Synch. Machine Data:
Type = Round Rotor
Unity Rating: 198 MVA
xd = 2.04pu   T´do = 9.8s
x´d = 0.199pu   T´´do= 0.042s
x´´d= 0.153pu   T´qo = 0.96s
xl = 0.137pu   T´´qo= 0.064s
xq = 1.9pu   Ag = 0.043
x´q = 0.327pu   Bg = 7.375
x´´q= 0.153pu   M = 11.92s
D = 0

PSS Data:
TYPE = PSS-2B   T6 = 0.005s
TW1 = 3s   T7 = 0.005s
TW2 = 3s   T8 = 0.4s
TW3 = 3s   T9 = 0.1s
TW4 = BY-PASS   N = 1
KS2 = 0.25168   M = 4
KS3 = 1





Salient Pole Machine

Power Plant: ITAIPU

Initial Conditions

Test 1:
Vo = 1pu
Po = 0.8pu
Qo = 0.3pu

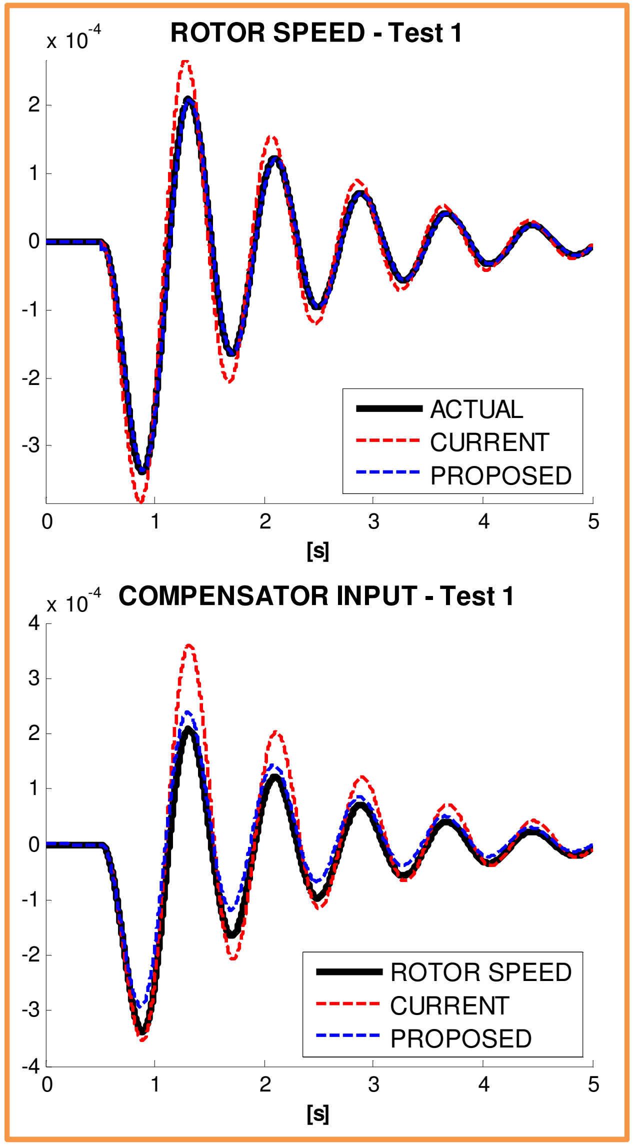
Test 2:
Vo = 1pu
Po = 0.3pu
Qo = -0.3pu

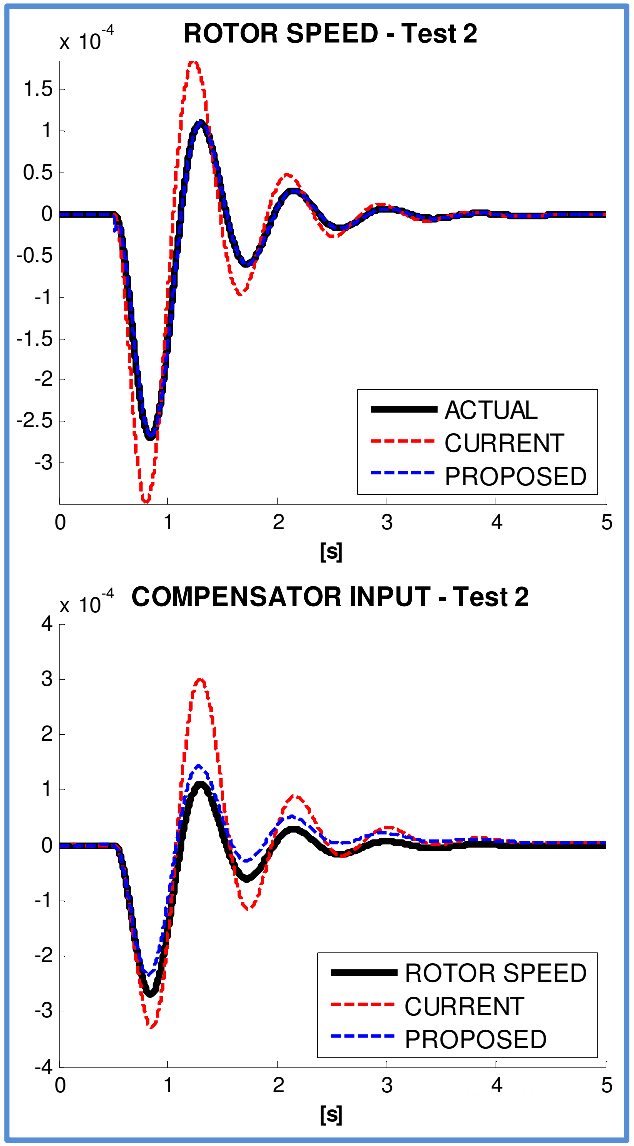
Equiv. System:
xe = 0.2pu

Test:
Response to Voltage Step

Synch. Machine Data:
Type = Salient Pole
Unity Rating: 737 MVA
xd = 0.949pu   T´do = 8.5s
x´d = 0.317pu   T´´do= 0.09s
x´´d= 0.252pu   T´qo = 0.5s
xl = 0.12pu   T´´qo= 0.19s
xq = 0.678pu   Ag = 0.6
x´q = 0.678pu   Bg = 5.84
x´´q= 0.252pu   M = 10.778s
D = 0

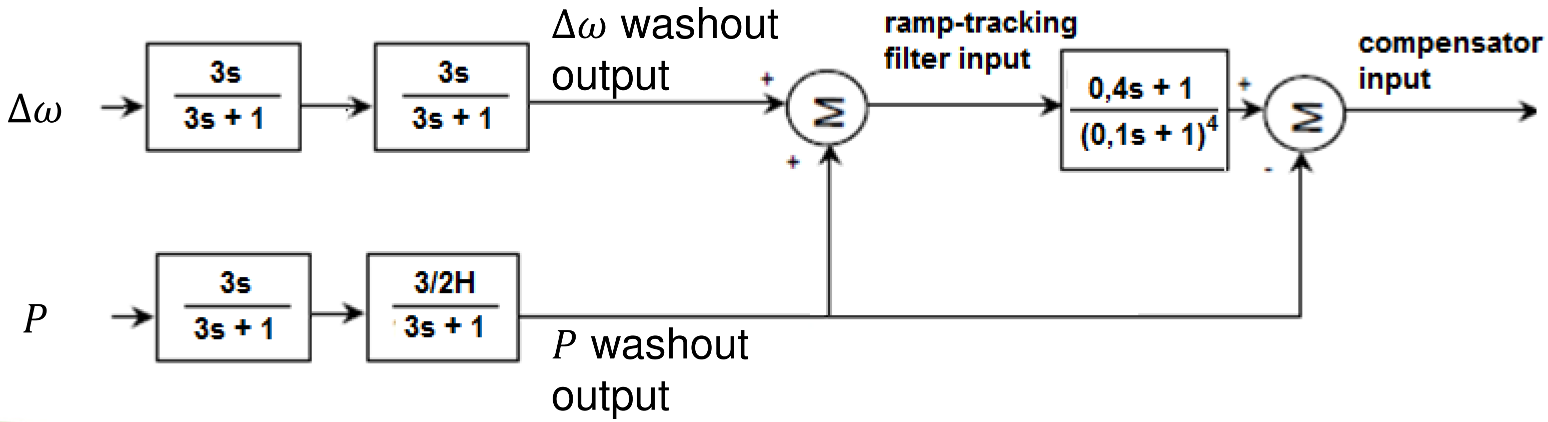
PSS Data:
TYPE = PSS-2B   T6 = 0.005s
TW1 = 3s   T7 = 0.005s
TW2 = 3s   T8 = 0.4s
TW3 = 3s   T9 = 0.1s
TW4 = BY-PASS   N = 1
KS2 = 0.27834   M = 4
KS3 = 1





Performances of the Two Rotor Speed Estimation Methods for Voltage Step Tests with Field Measurements and the Simulation of the PSS-2B Internal Variables

Internal variables from PSS-2B prototypes tested:



$\Delta\omega$

$\frac{3s}{3s+1}$

$\frac{3s}{3s+1}$

$\Delta\omega$ washout output

ramp-tracking filter input

$\frac{0{,}4s+1}{(0{,}1s+1)^4}$

compensator input

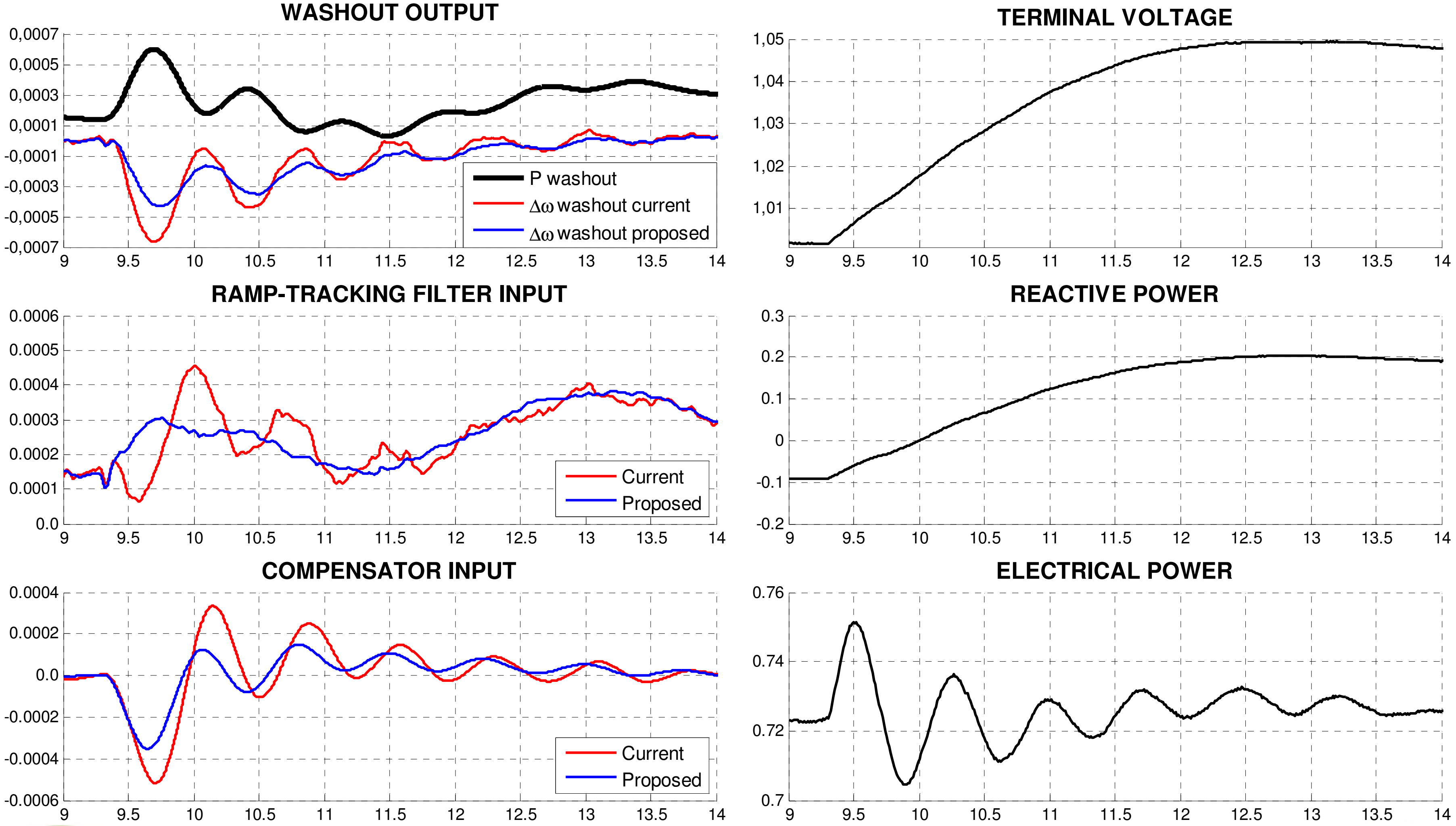
P

$\frac{3s}{3s+1}$

$\frac{3/2H}{3s+1}$

P washout output

Power Plant: Parnaíba – **Unity Rating**: 208 MVA
Type: Round Rotor – **Inertia (2H):** 10,28s


WASHOUT OUTPUT

TERMINAL VOLTAGE

RAMP-TRACKING FILTER INPUT

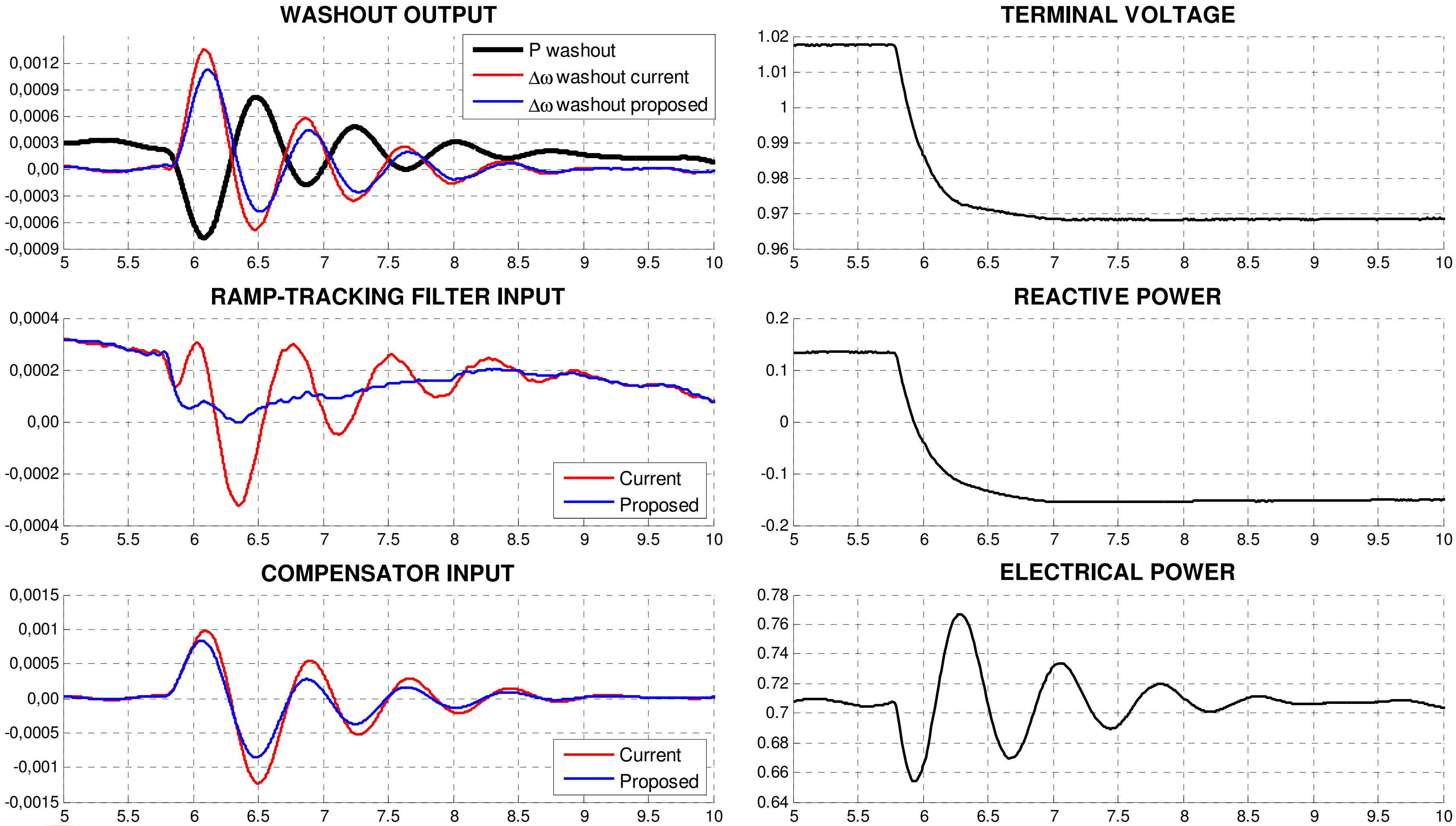
REACTIVE POWER

COMPENSATOR INPUT

ELECTRICAL POWER

Power Plant: Sogamoso – **Unity Rating**: 324 MVA

Type: Salient Pole – **Inertia (2H)**: 12,0s



Proposed Rotor Speed
Final Comments

PSS applications:

- Better quality and cleaner signal;
- Preliminary field tests have shown the superior performance of PSS-2B stabilizers.

Future work:

- Complete round of field tests for PSS-2B prototypes;
- Suitable signal for UEL structures that use Load Angle.

Use of integrated control systems:

- A higher quality rotor speed signal is available for speed-governor applications and to other excitation control functions.

Thank You!

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Verification and testing of new PSS model PSS6C by means of PRBS injection

Ruediger Kutzner, Uwe Seeger, Andree Wenzel

Presented by: Ruediger Kutzner, Uwe Seeger

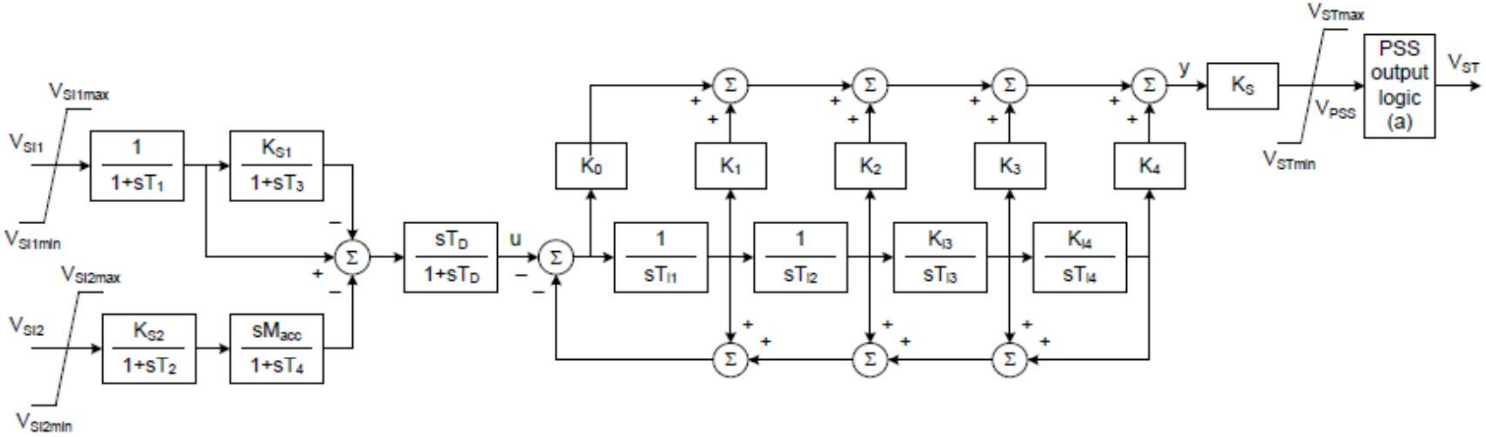
IEEE PES Power & Energy Society®

IEEE

Overview

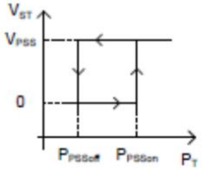
- Power System Stabilizer PSS6C acc. IEEE421.5(2016)
- Testsignal Pseudo Randon Binary Sequence (PRBS)
- Injection points of testsignal
- Measuring results
- Conclusion

Structure PSS6C according 421.5(2016)



footnotes:

(a) PSS output logic uses user-selected parameters P_{PSSon} and P_{PSSoff}. It also uses the signal V_{PSS}, shown in the block diagram, and the generator electrical power output P_T. The output logic implements the following hysteresis to define the output signal V_{ST}:



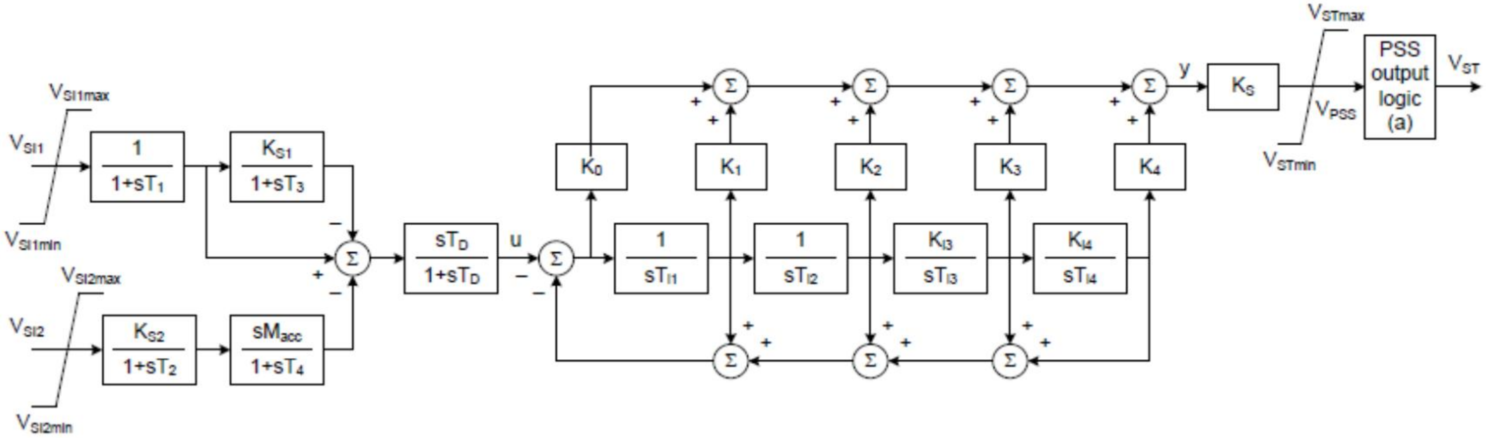
Power System Stabilizer PSS6C (1)

- IEEE 421.5 (2016)
- PSS with canonical form equation
- Dual input stabilizer: usually generator electrical power output ($V_{SI1} = P_T$) and rotor angular speed deviation ($V_{SI2} = \Delta\omega$)
- time constants T_1 and T_2 represent the transducer time constants, time constant T_D represents the main washout time constant

Power System Stabilizer PSS6C (2)

- Phase compensation is provided by adjustment of the time constants T_{i1} to T_{i4} and gains K_0 to K_4
- gain of the PSS is adjusted by K_S
- threshold values for the output logic P_{PSSon} and P_{PSSoff} for switching on / off depending on active power
- Parameter conversion to PSS3C is possible

Structure PSS6C according 421.5(2016)



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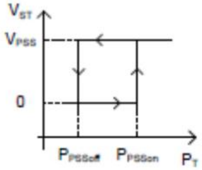
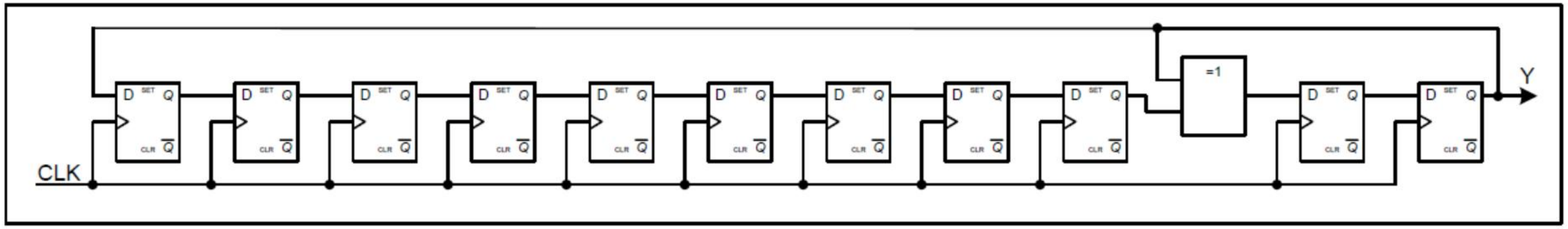


Testsignal Pseudo Random Binary Sequence (PRBS) (1)

- Realized with a linear feedback shift register – LFSR
- Recoupling by using XOR-functions
- Example shows LFSR with the Polynom

$$y^{11} + y^{9} + 1$$



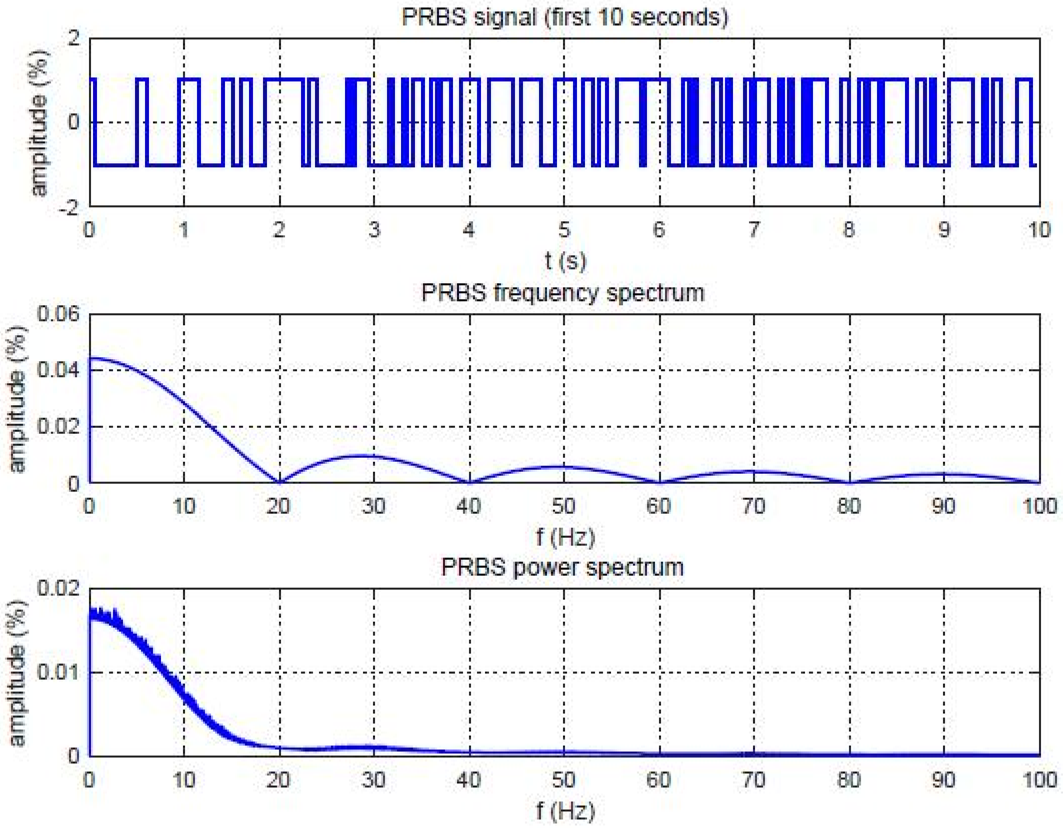
Testsignal Pseudo Random Binary Sequence (PRBS) (2)

- Signal Repetition of the cycle numbers

  $$p = 2^k – 1$$

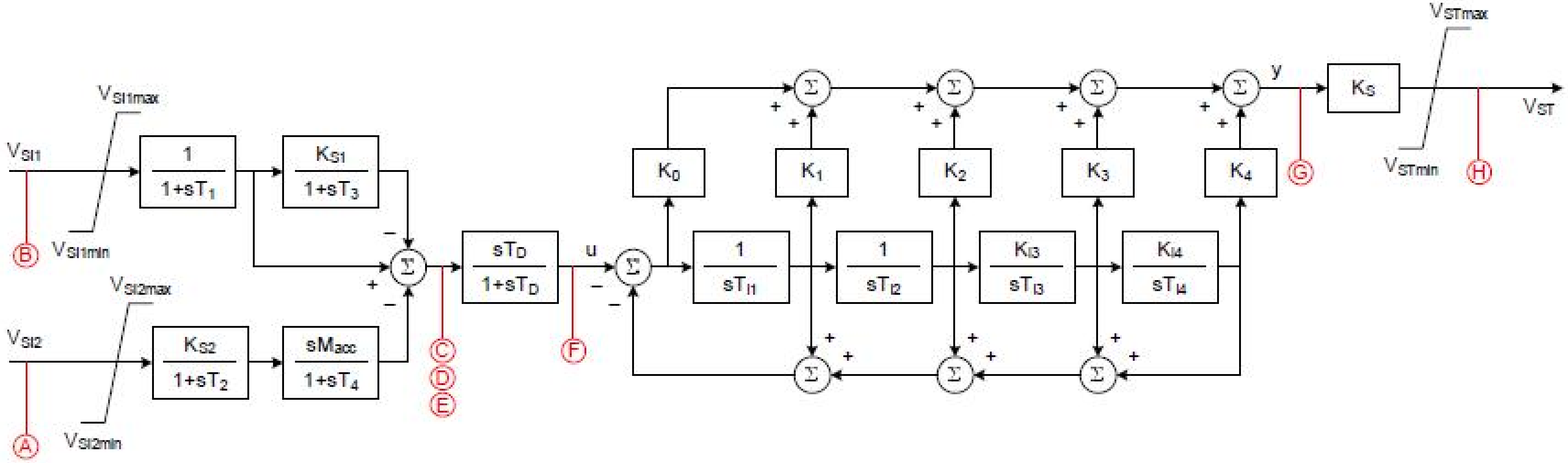
  K defines the highest order of the polynom
- Bandwith of the PRBS achieved by the pulse input CLK
- Duration of one sequence = p / bandwith
- Example of PRBS with order 11

Example of PRBS with order 11



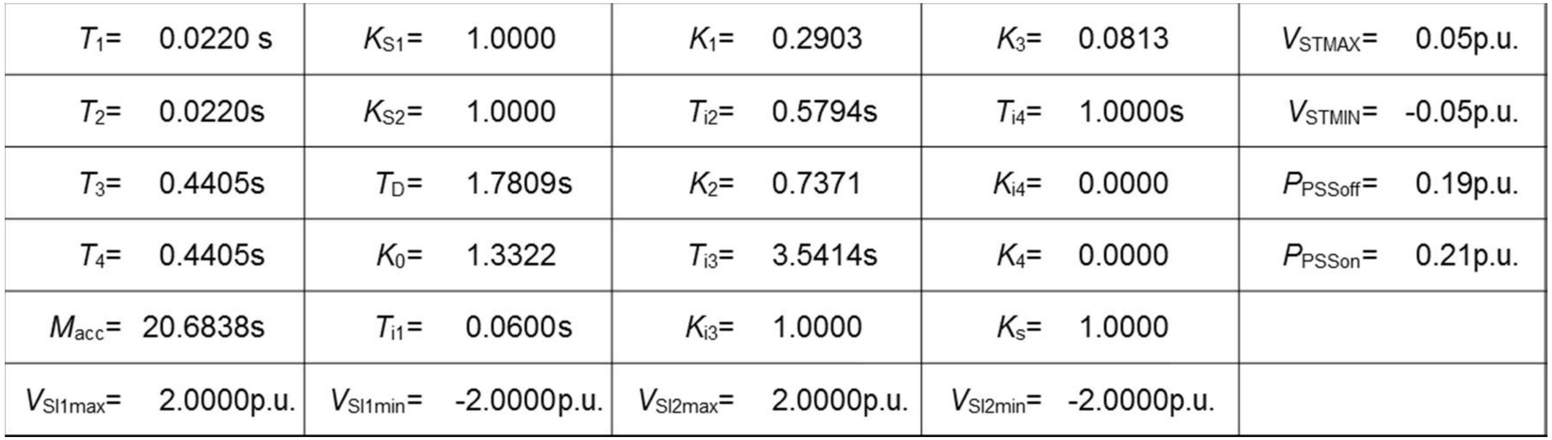
Injection of the testsignal PRBS

- PRBS testsignal is part of the AVR software, adjustable via parameters
- Testsignal injected to different points A – G



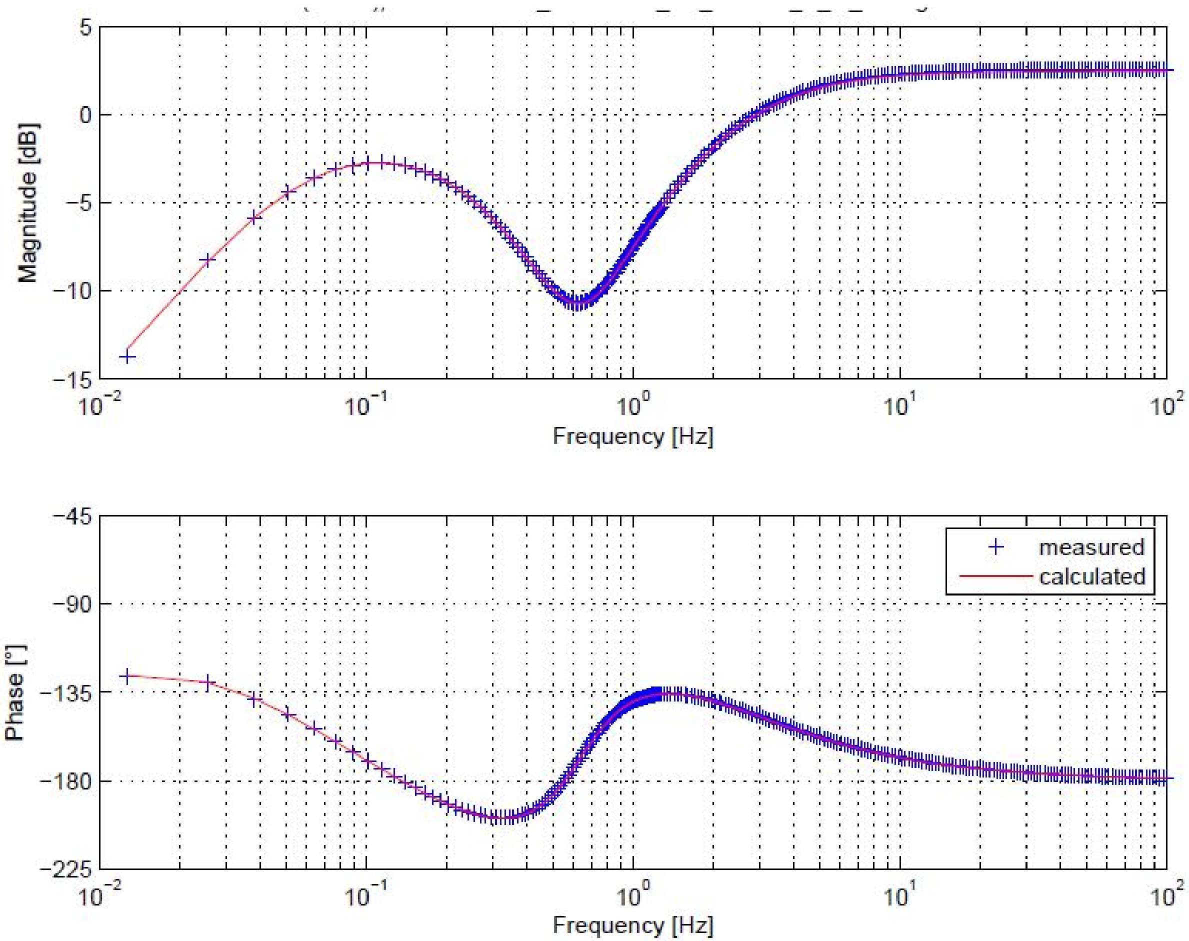
Parameter of tested PSS6C

- Testing was done with the following parameter set for PSS6C

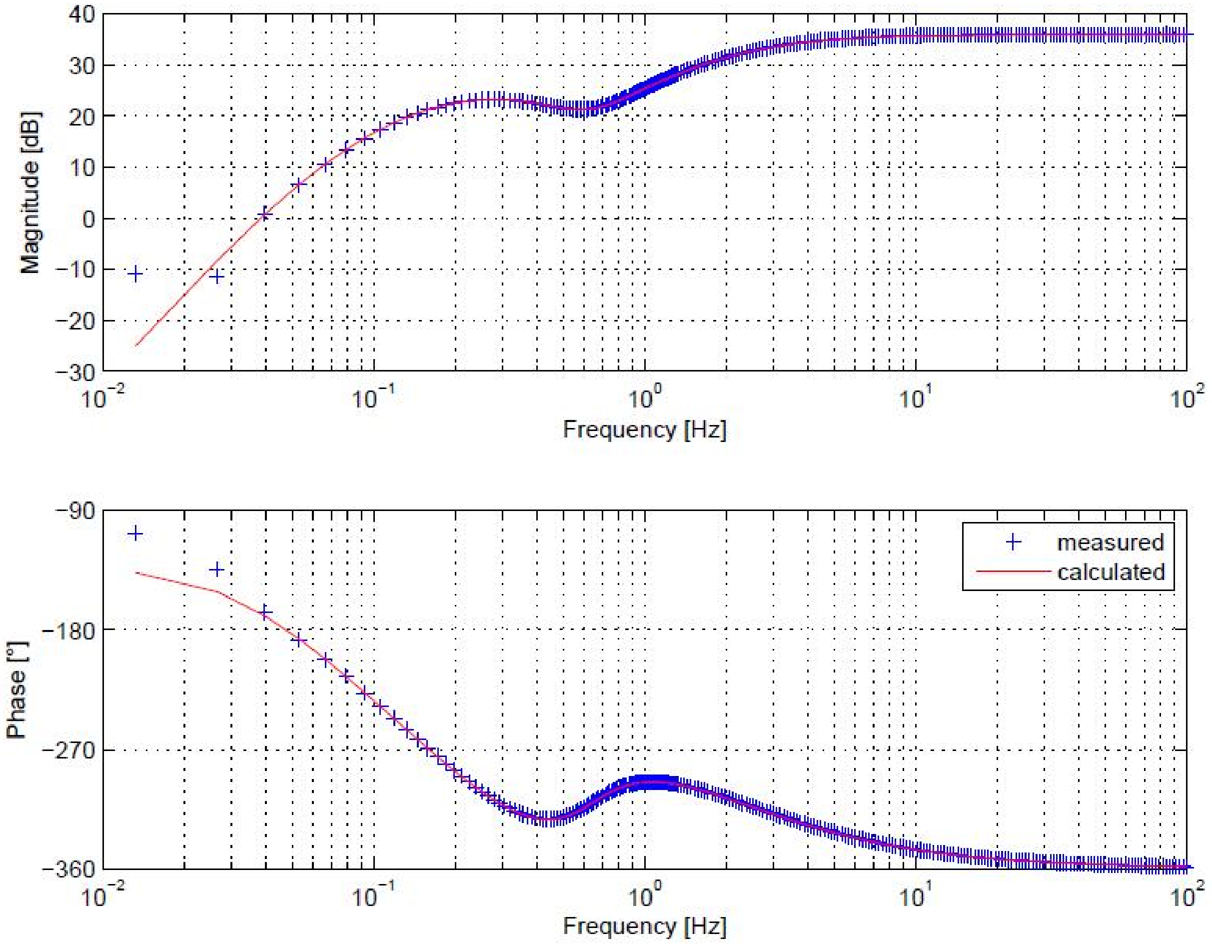


T_1=	0.0220 s	K_{S1}=	1.0000	K_1=	0.2903	K_3=	0.0813	V_{STMAX}=	0.05p.u.
T_2=	0.0220s	K_{S2}=	1.0000	T_{i2}=	0.5794s	T_{i4}=	1.0000s	V_{STMIN}=	-0.05p.u.
T_3=	0.4405s	T_D=	1.7809s	K_2=	0.7371	K_{i4}=	0.0000	P_{PSSoff}=	0.19p.u.
T_4=	0.4405s	K_0=	1.3322	T_{i3}=	3.5414s	K_4=	0.0000	P_{PSSon}=	0.21p.u.
M_{acc}=	20.6838s	T_{i1}=	0.0600s	K_{i3}=	1.0000	K_s=	1.0000		
V_{SI1max}=	2.0000p.u.	V_{SI1min}=	-2.0000p.u.	V_{SI2max}=	2.0000p.u.	V_{SI2min}=	-2.0000p.u.		

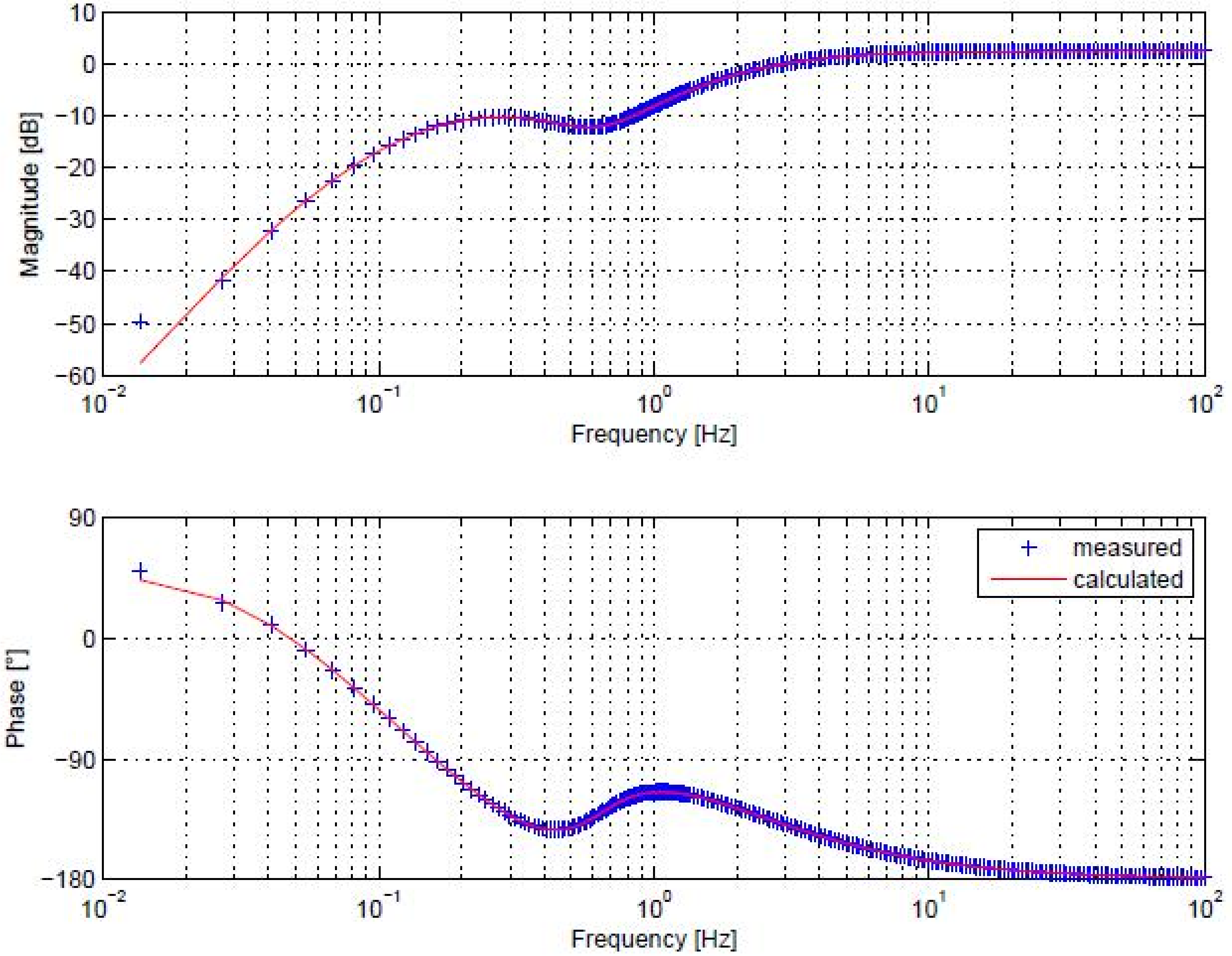
Measuring phase compensation F-G with Ki4 = 0



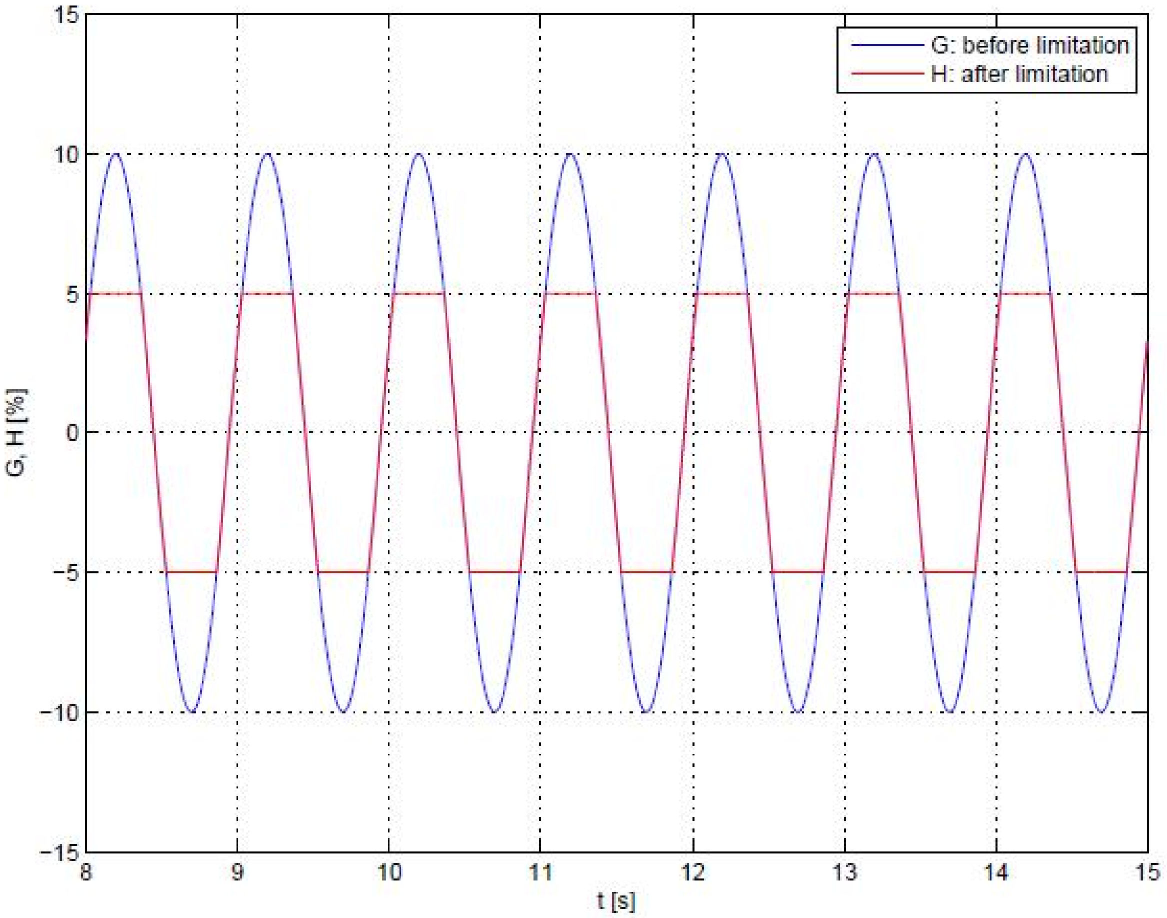
PSS6C Measurement Δω path A - G



PSS6C Measurement active power path B - G



PSS6C Measurement output limiter path G - H



Conclusion

- Validation shows a very good match of the Power System Stabilizer PSS6C implemented in the THYRIPOL software over a wide frequency range
  from 10^{-2} to 10^{2} Hz
- Testsignal PRBS can be used for validation and on site testing of PSS and AVR

Thank you

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