DELIVERING FLEXIBLE POWER AND ANCILLARY SERVICES WITH NUCLEAR POWER

Thomas Smed
Energiforsk Seminar April 2, 2019

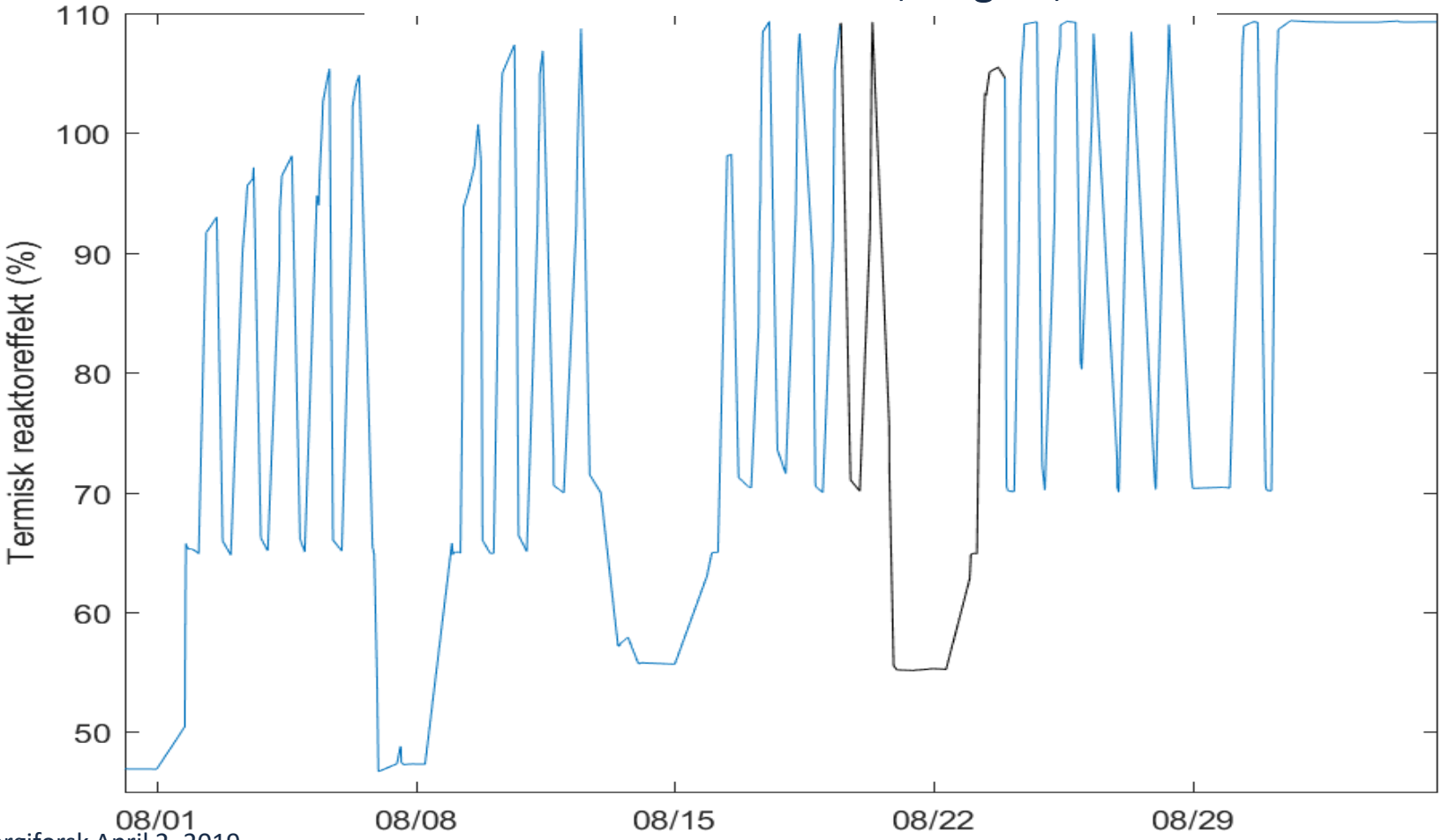
© Forsmarks Kraftgrupp AB

PART I: SLOW CONTROL, LOAD FOLLOWING

- Timescale: several hours to days

© Forsmarks Kraftgrupp AB

Thermal Power Forsmark 3, August, 1993

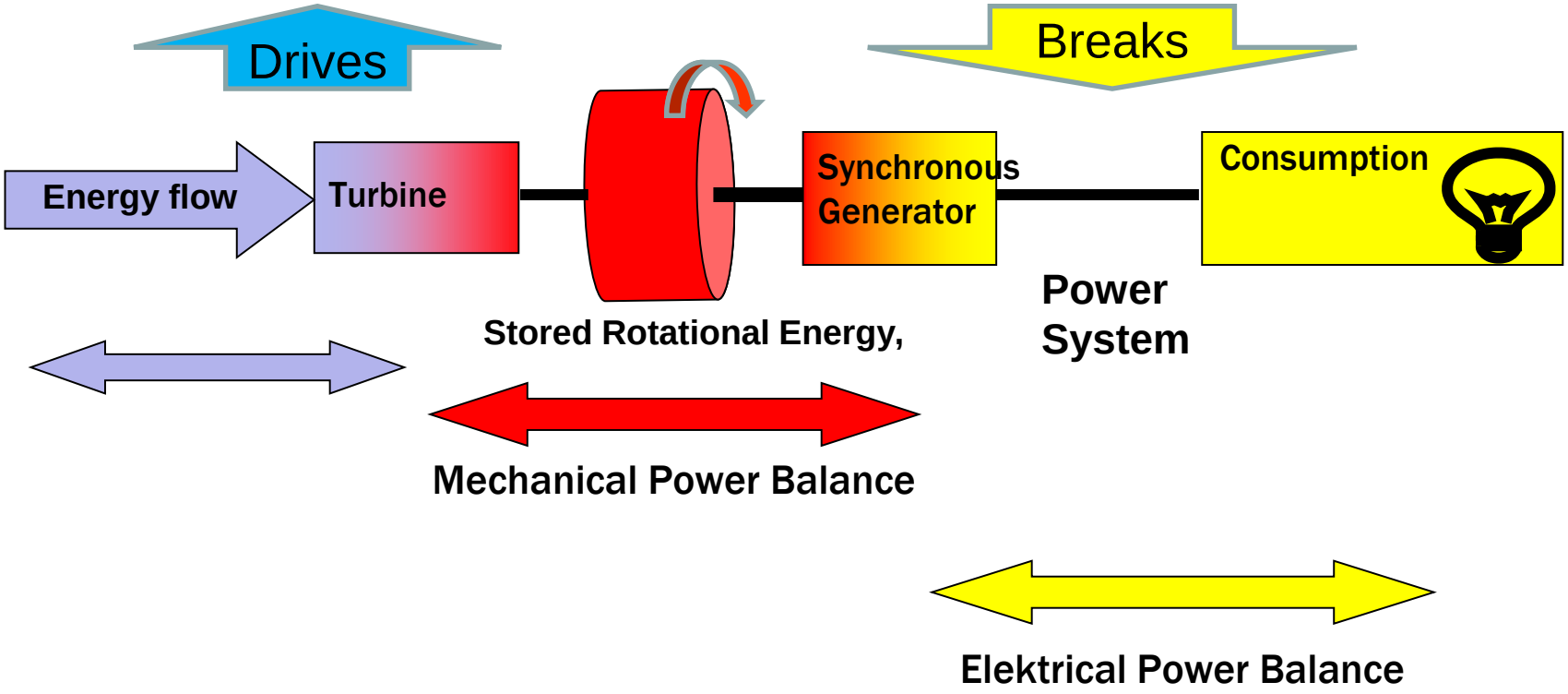


PART II: LARGE DISTURBANCE CONTROL

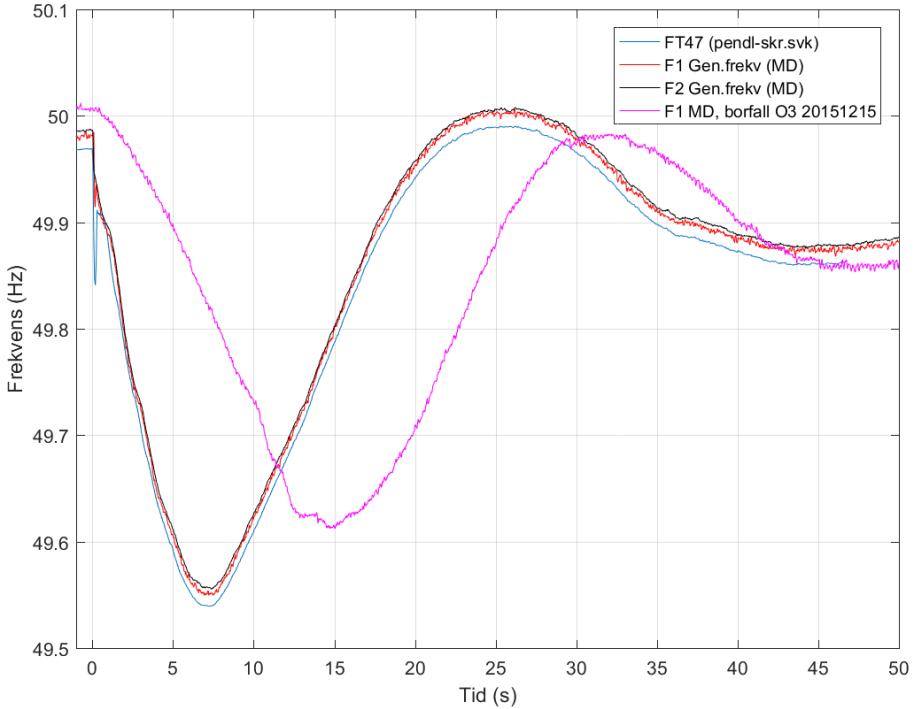
- Timescale: < 10 seconds
- Mitigate the frequency drop

© Forsmarks Kraftgrupp AB

BALANCE IN A SYNCHRONOUS POWER SYSTEM

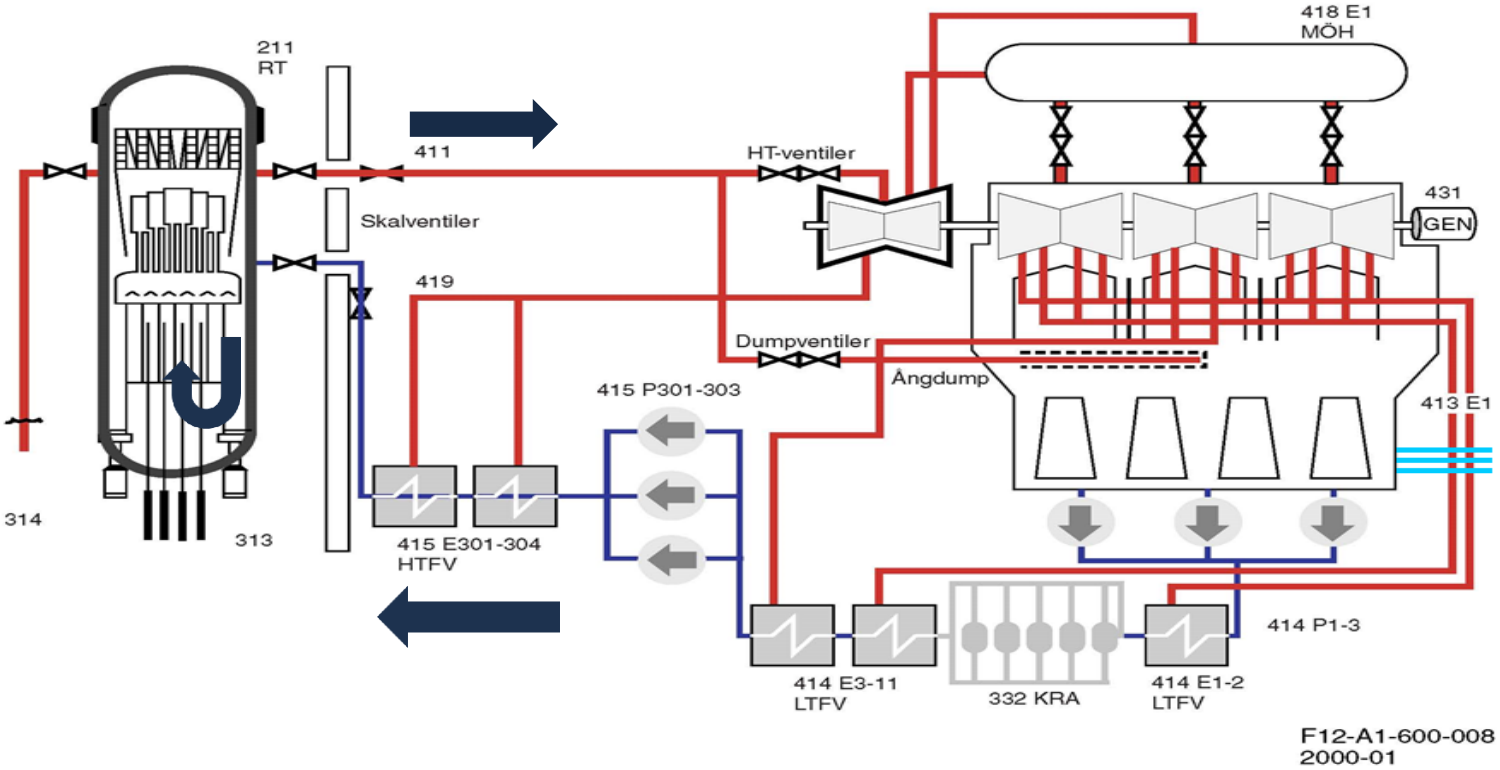


LOSS OF LARGE PRODUCTION UNIT

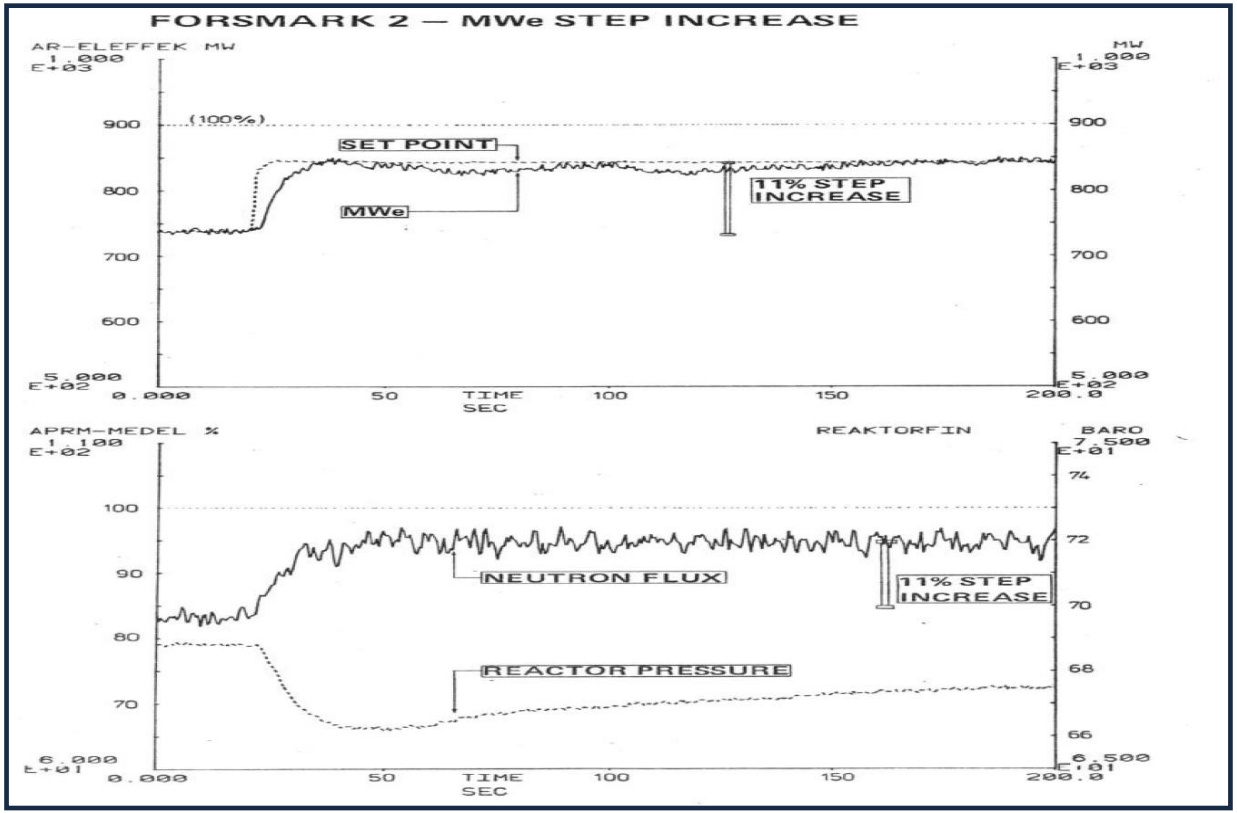


© Forsmarks Kraftgrupp AB

CONTROL SYSTEMS



ORIGINAL DESIGN? PSPA

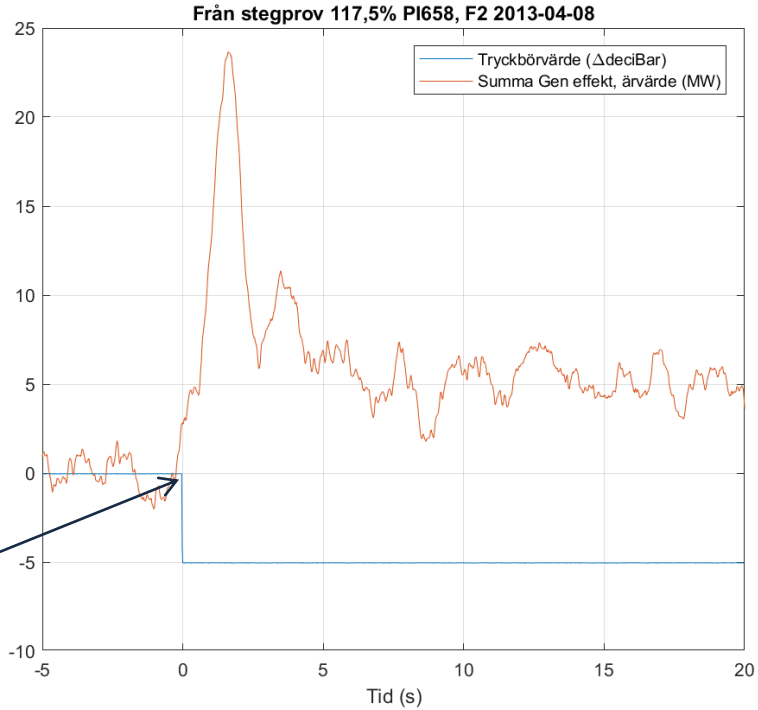


© Forsmarks Kraftgrupp AB

VATTENFALL

EXTRA BOOST WHEN LOOSING A LARGE UNIT

PSPA Light



$$\Delta P_{ref} = -0.5\ Bar$$

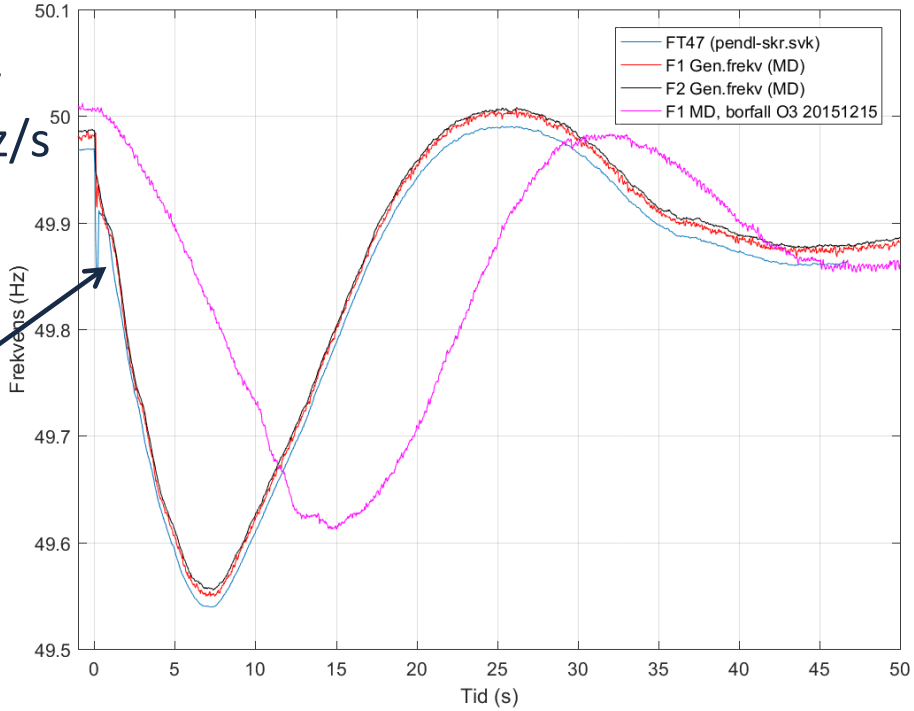
© Forsmarks Kraftgrupp AB

VATTENFALL

LOSS OF LARGE PRODUCTION UNIT

Confirm that f<49,85 Hz

AND that $\frac{df}{dt} < -0{,}04\text{Hz/s}$



Add -0,5 Bar step on Pressure set point

© Forsmarks Kraftgrupp AB

VATTENFALL

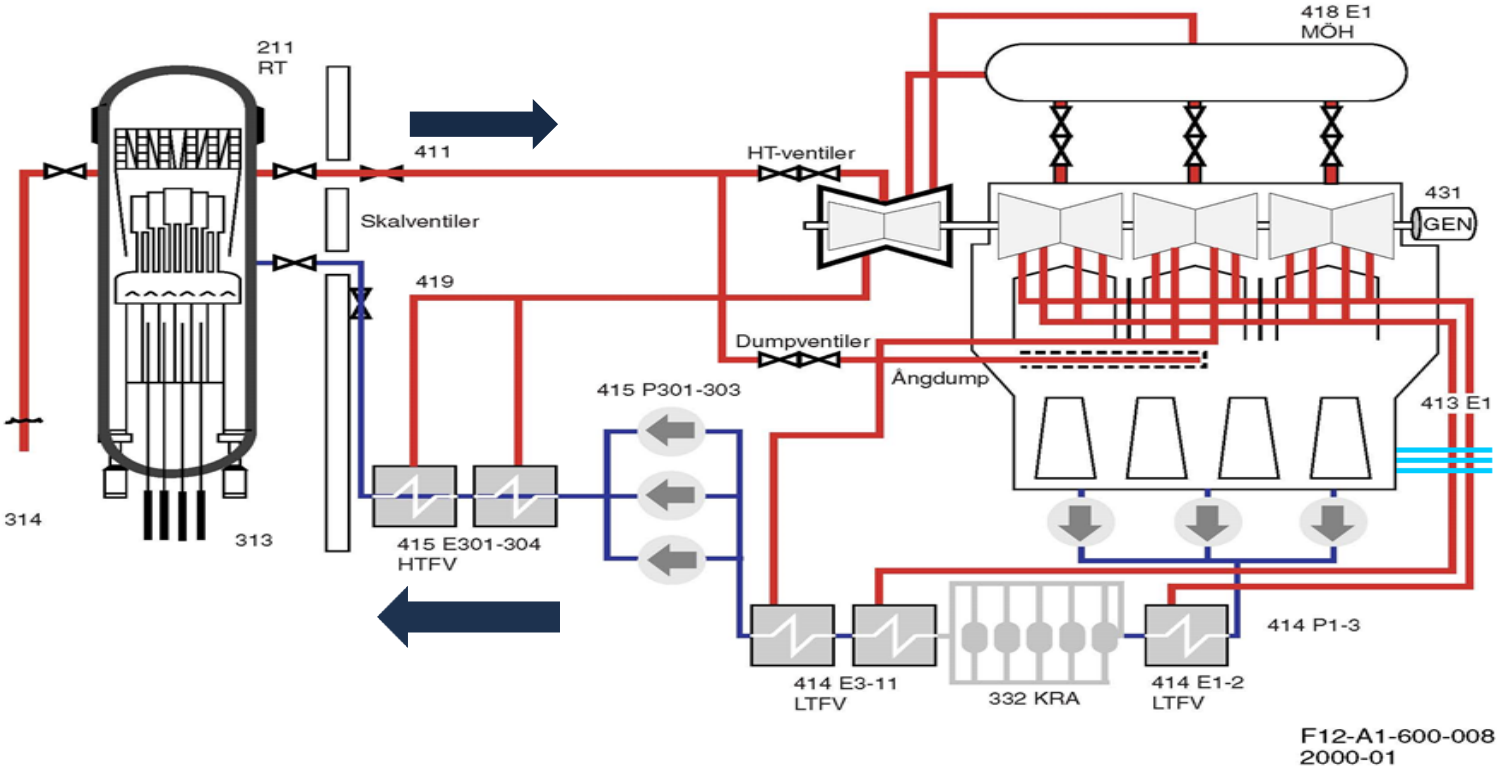
PART III: NORMAL FREQUENCY CONTROL - FCR

- Timescale: seconds ~ minutes
- Continuous control

- How can Nuclear Power contribute in the Nordic system?

© Forsmarks Kraftgrupp AB

THERMAL POWER

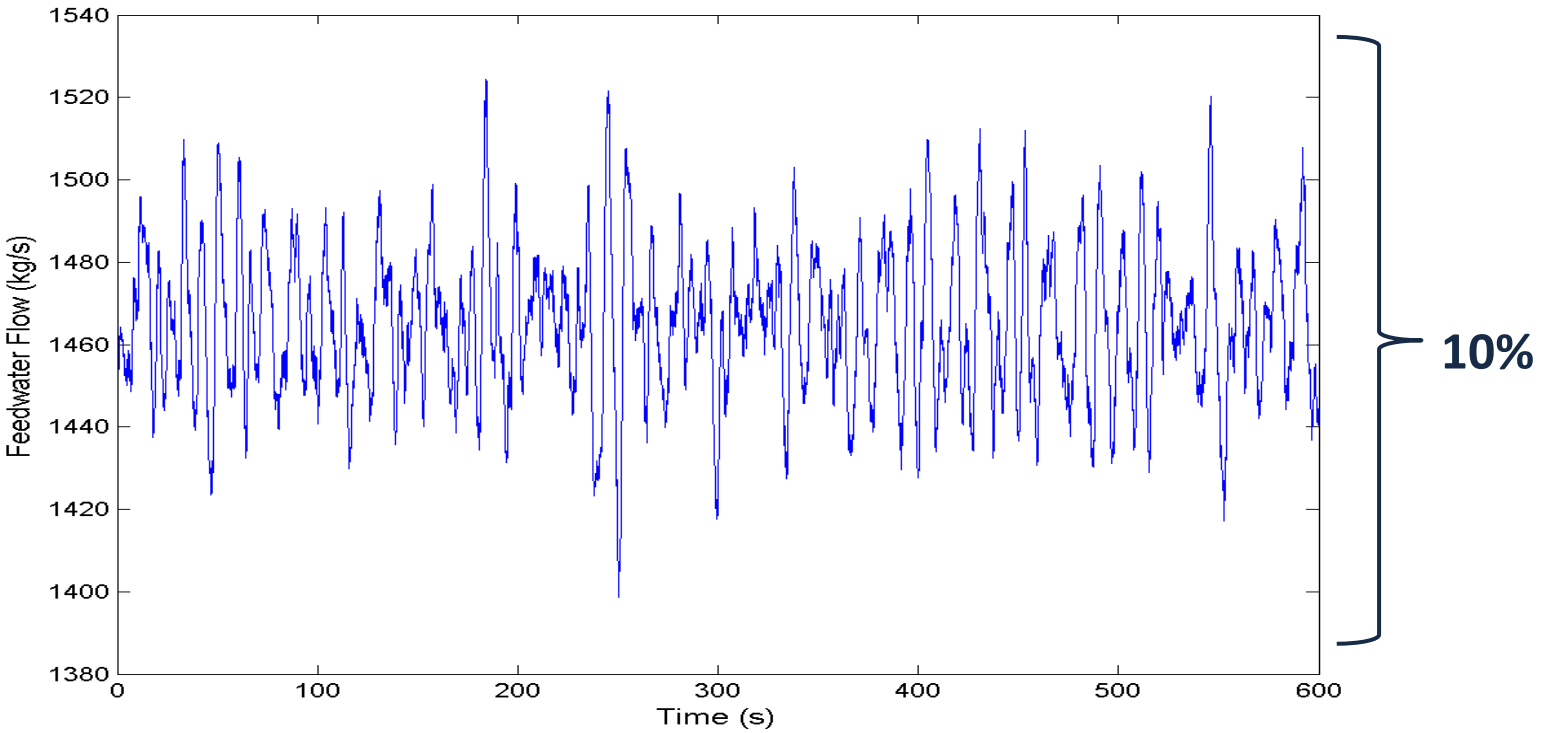


THERMAL POWER

Dominating uncertainty for thermal power is feed water flow

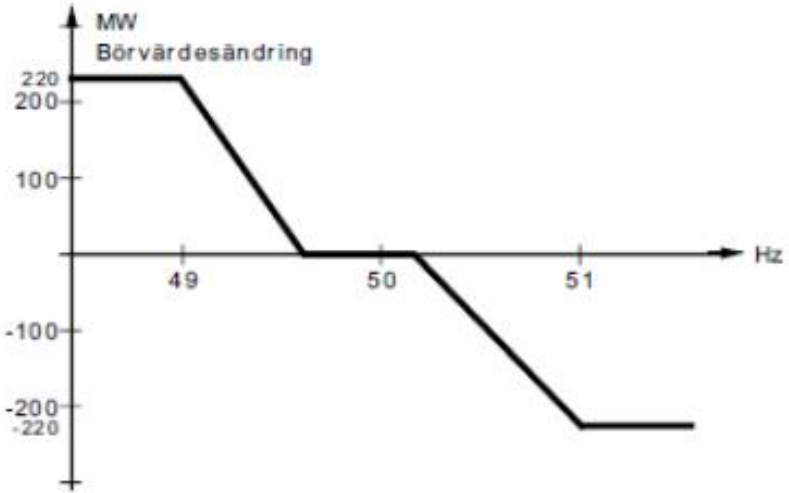
$$Q = \dot{m}_{FW}\left(h_{steam} - h_{FW}\right) + \delta$$

MEASURED FEED WATER FLOW F2 2012-02-14



ORIGINAL DESIGN? FREQUENCY CONTROL

Om nätfrekvensen är 49,4 Hz så kommer effektbörvärdet att ökas (49,6–49,4) x 220 MW)/0.6 = 73.3 MW om gällande effektbörvärdesbegräns-ningar tillåter.

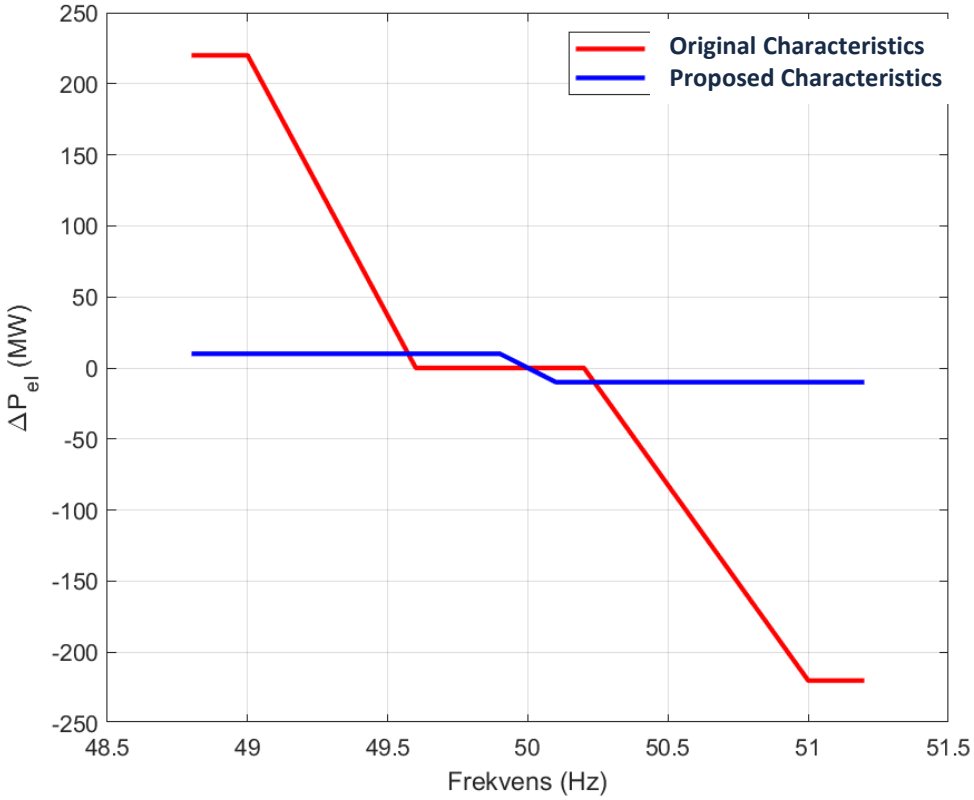


Figur 5.4 Effektbörvärdesenhet beroende av frekvensen.

Effektbörvärdesändringen från frekvensregulatorn begränsas i PIP-regulatorn till ± 220 MW (20 %).

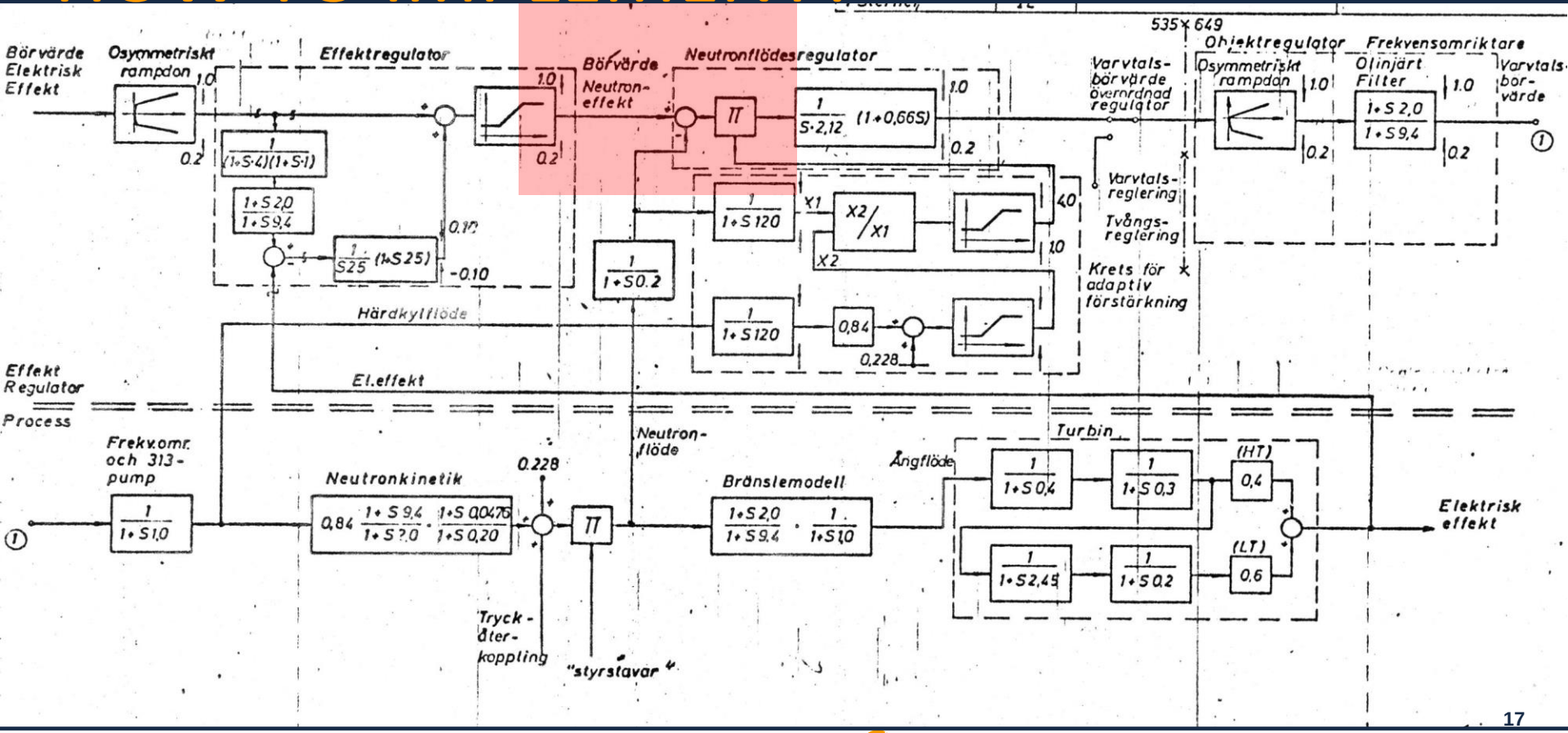
© Forsmarks Kraftgrupp AB

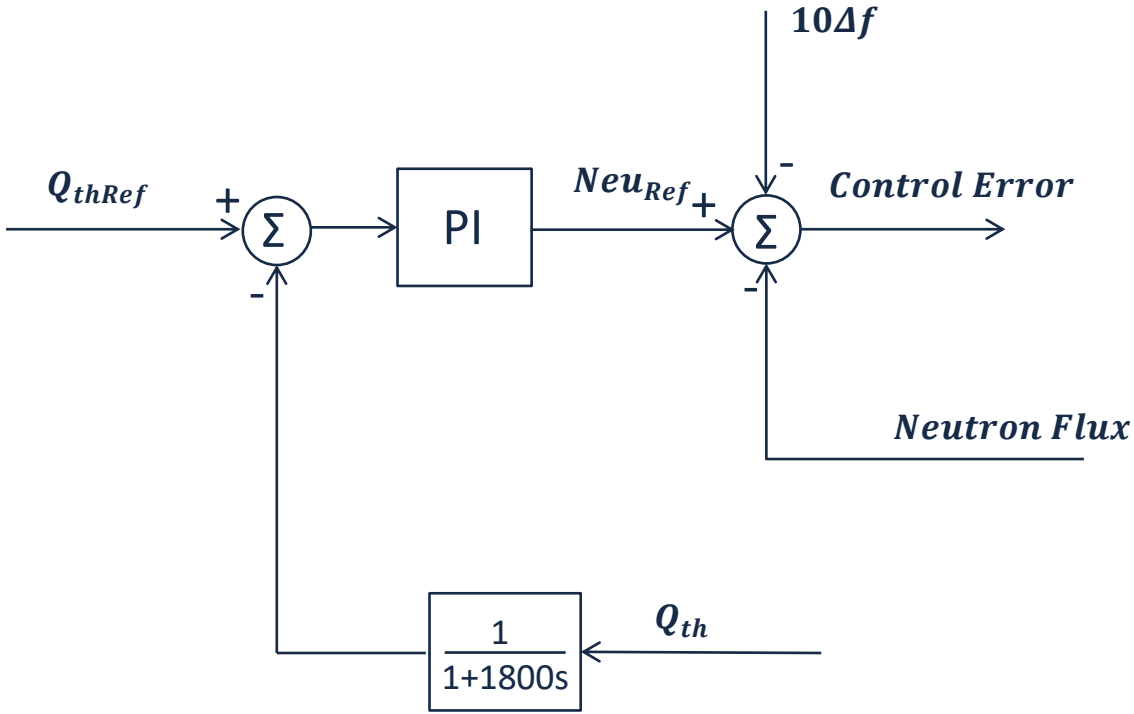
PROPOSED CHARATERISTICS



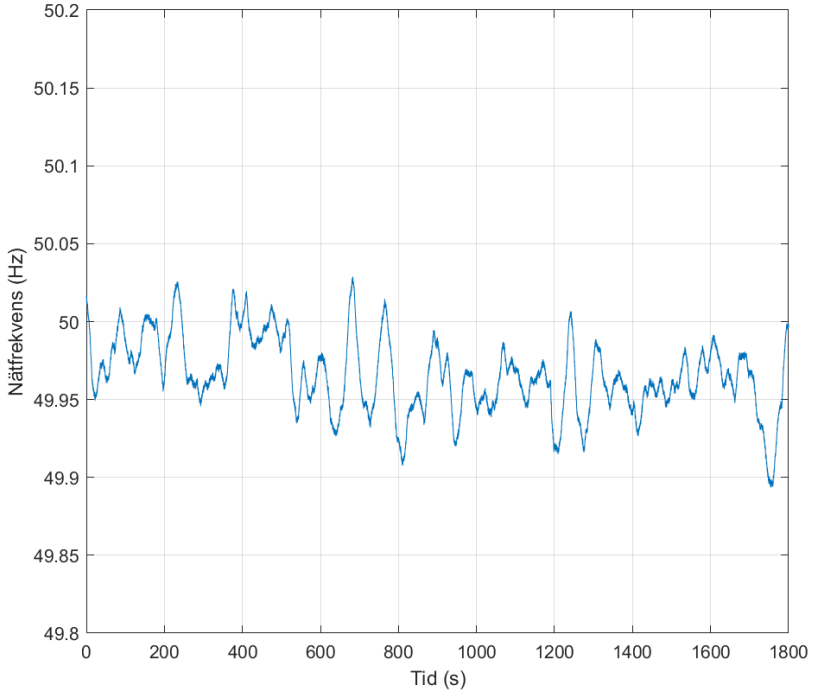
© Forsmarks Kraftgrupp AB
VATTENFALL

HOW TO IMPLEMENT?




$10\Delta f$
Q_{thRef}
+
Σ
-
PI
Neu_{Ref}
+
Σ
-
-
$Control\ Error$
$Neutron\ Flux$
1
1+1800s
Q_{th}

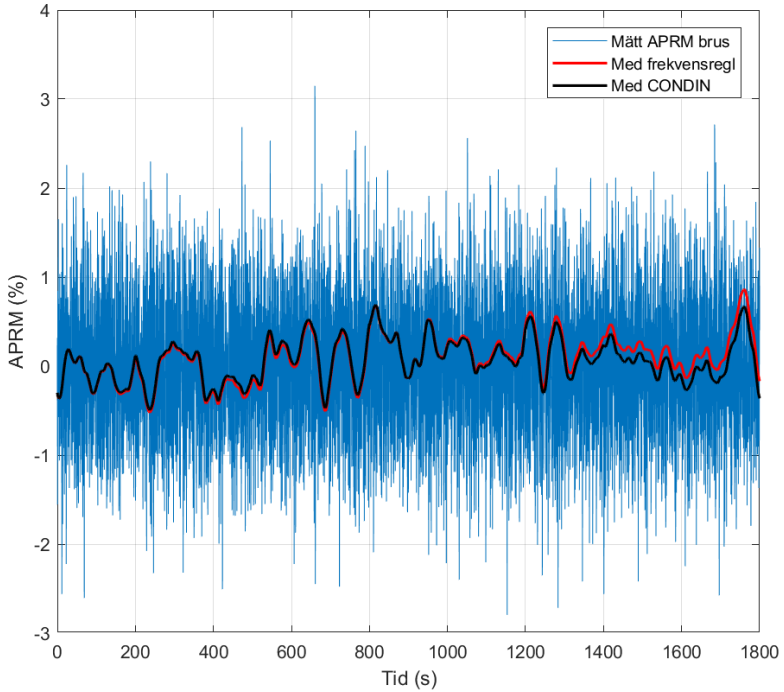
TRY THE ALGORITHM ON A DATA SET



© Forsmarks Kraftgrupp AB

VATTENFALL

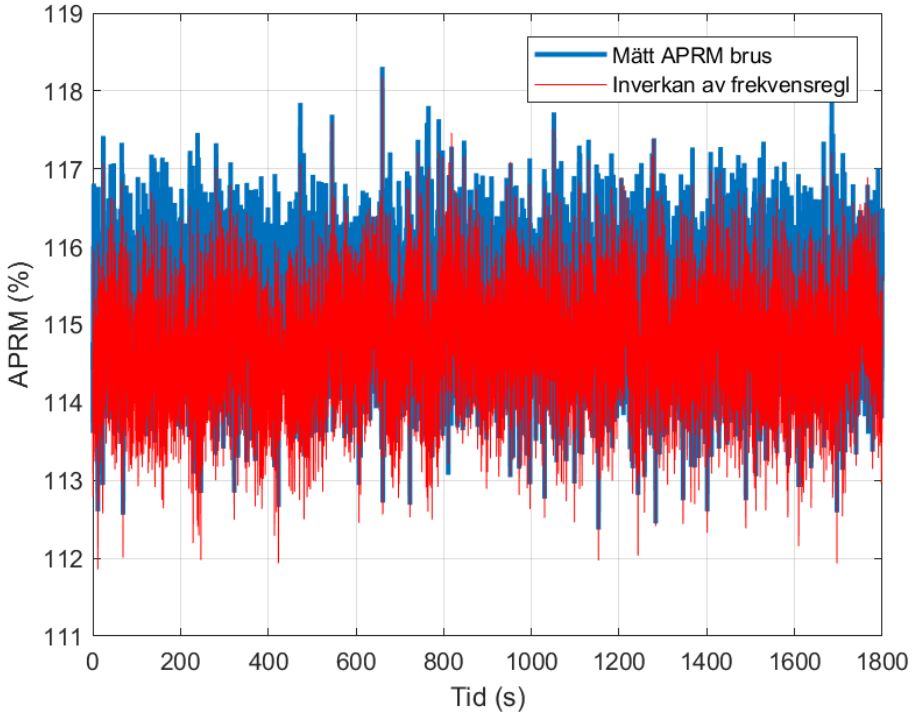
IMPACT ON FISSION POWER



© Forsmarks Kraftgrupp AB

VATTENFALL

IMPACT ON FISSION POWER

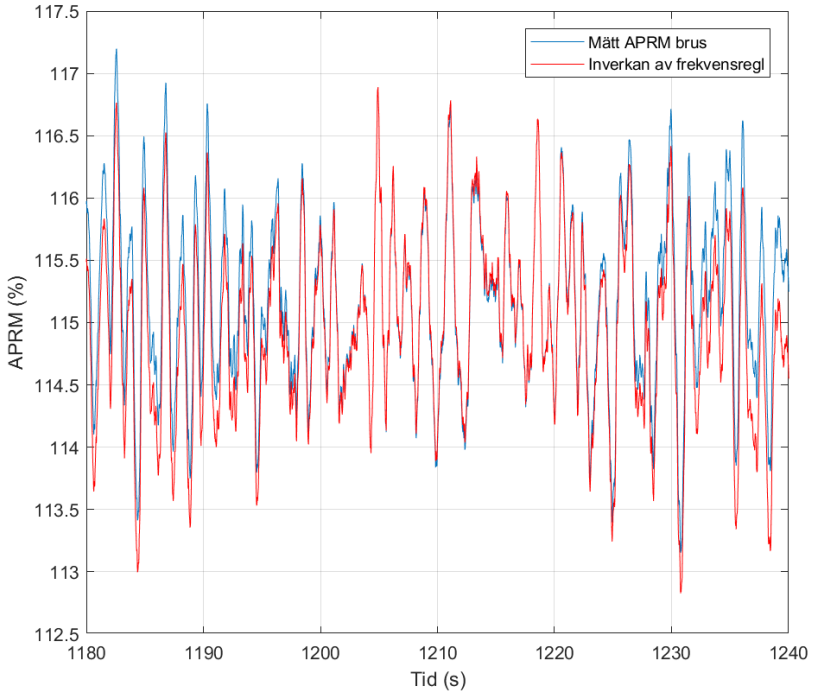


Power reduced 0,5%

© Forsmarks Kraftgrupp AB

VATTENFALL

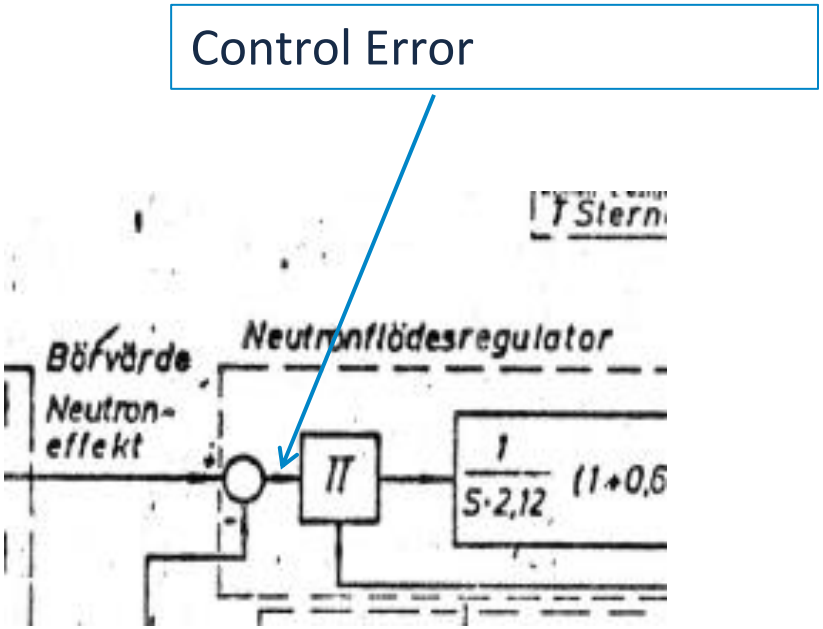
IMPACT ON FISSION POWER



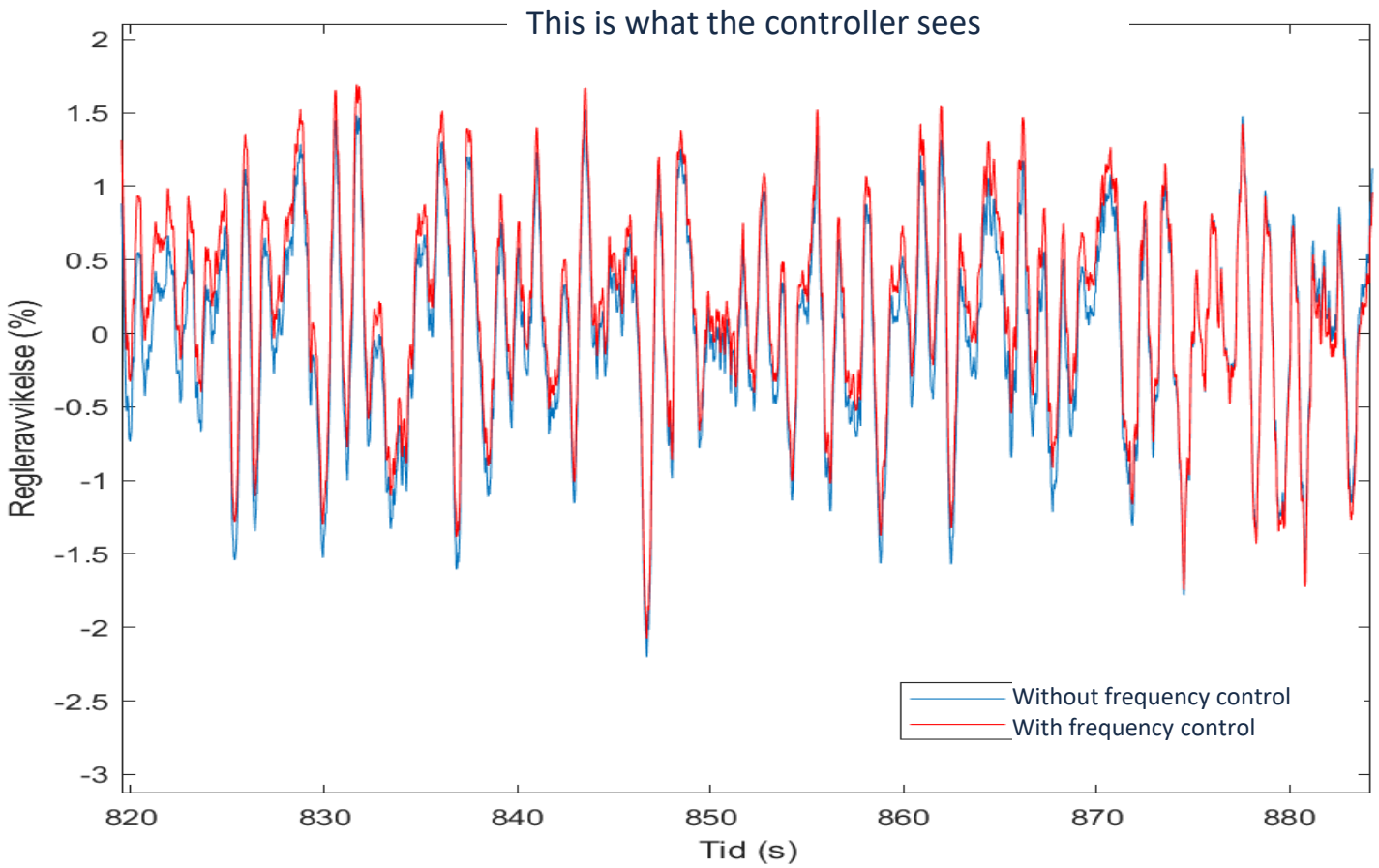
Power reduced 0,5%

© Forsmarks Kraftgrupp AB
VATTENFALL

WHAT DOES THE CONTROLLER SEE?

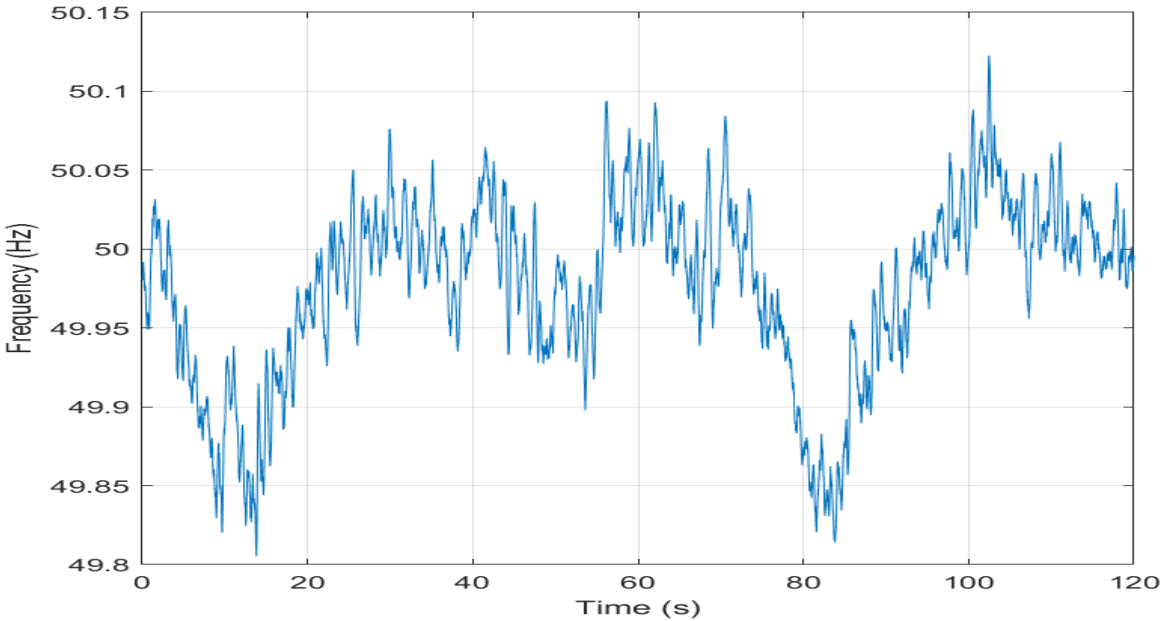


© Forsmarks Kraftgrupp AB



© Forsmarks Kraftgrupp AB

A MORNING WITH FREQUENCY DIPS



2019-01-14

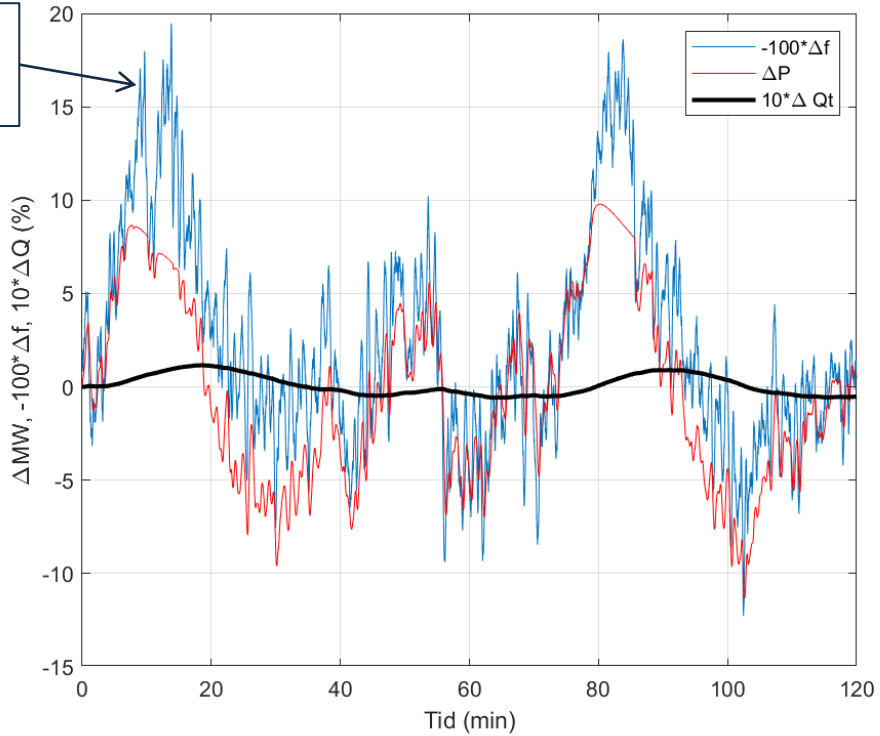
05:50-07:50

© Forsmarks Kraftgrupp AB

VATTENFALL

A MORNING WITH A FREQUENCY DIP

Here, the frequency is below 49.85 Hz



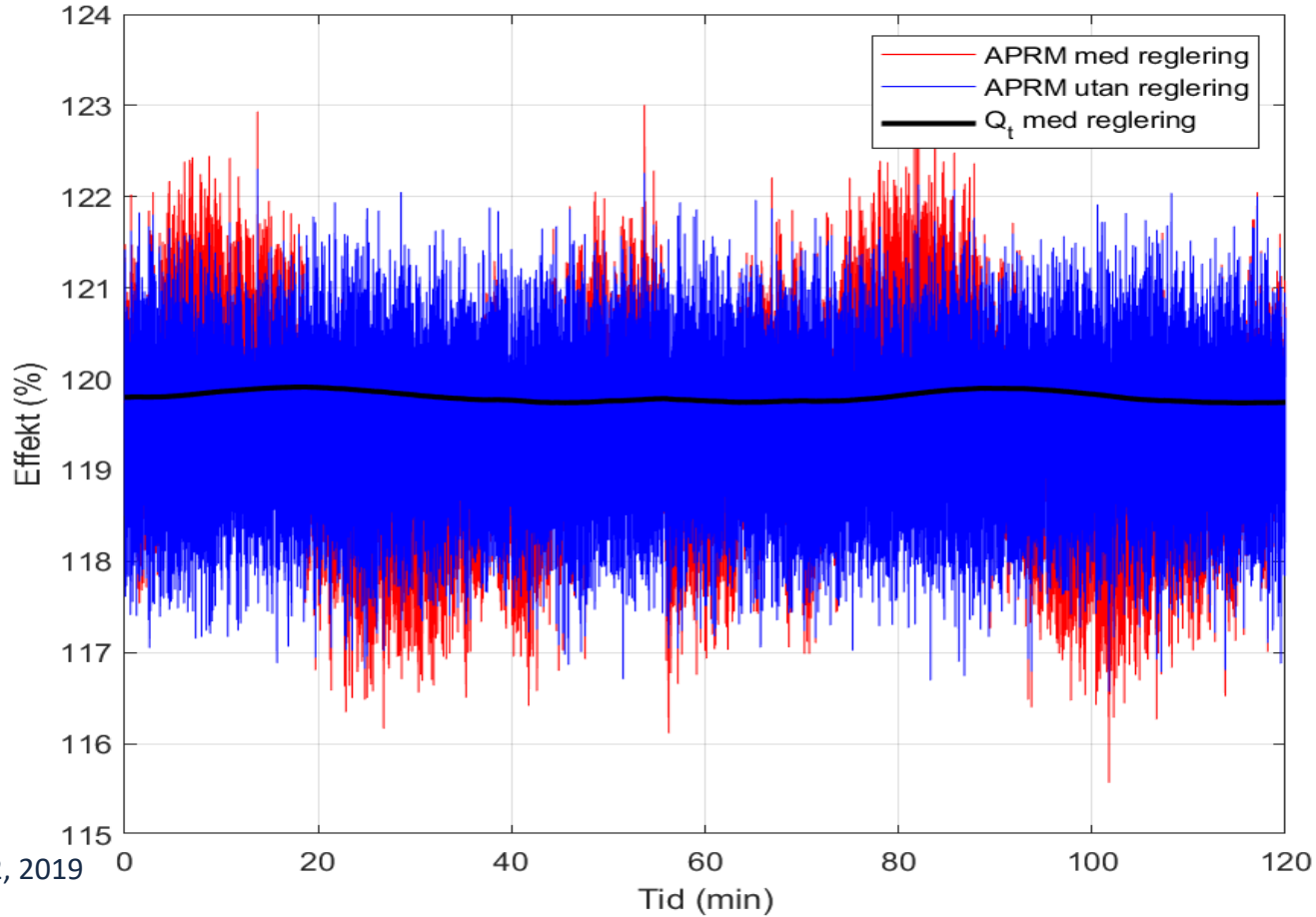
2019-01-14

05:50-07:50

© Forsmarks Kraftgrupp AB

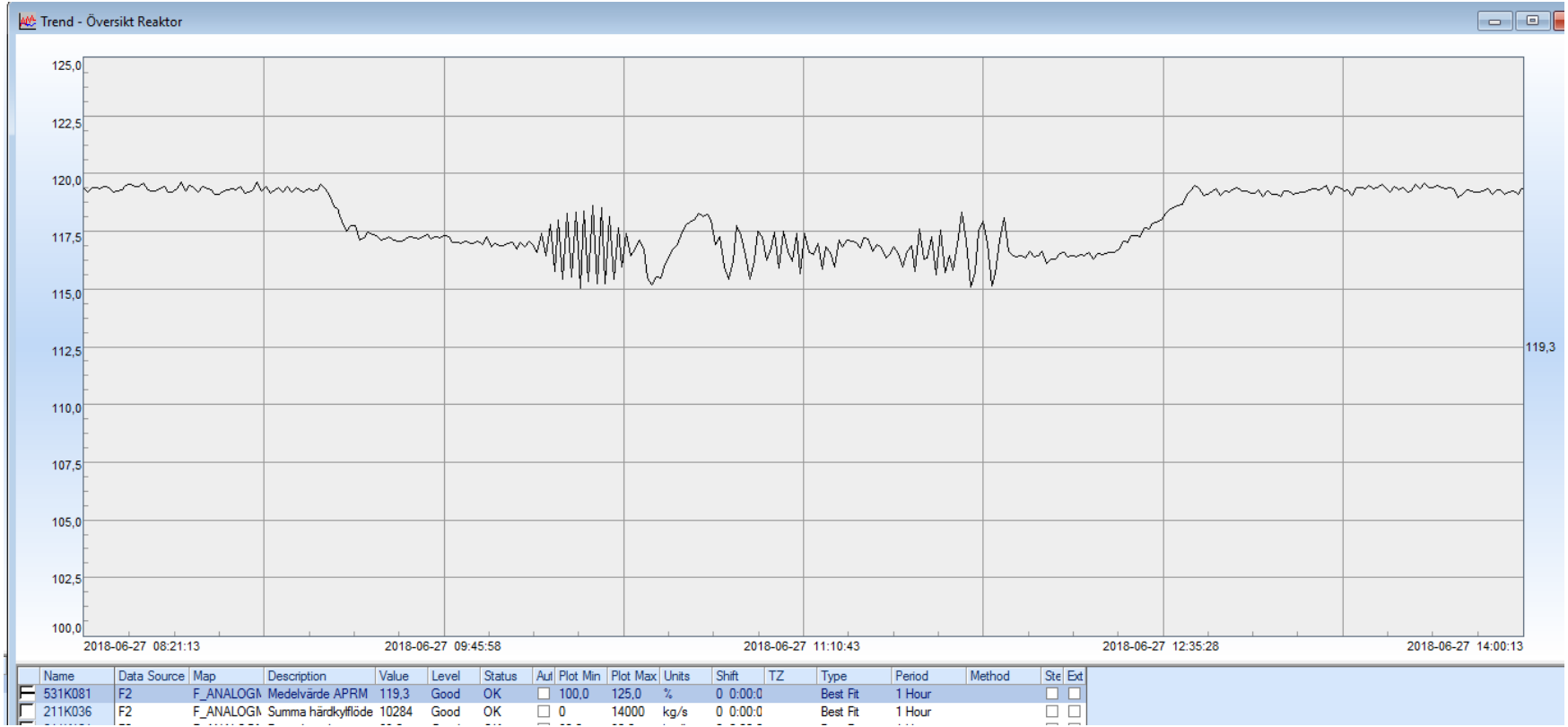
VATTENFALL

IMPACT ON APRM

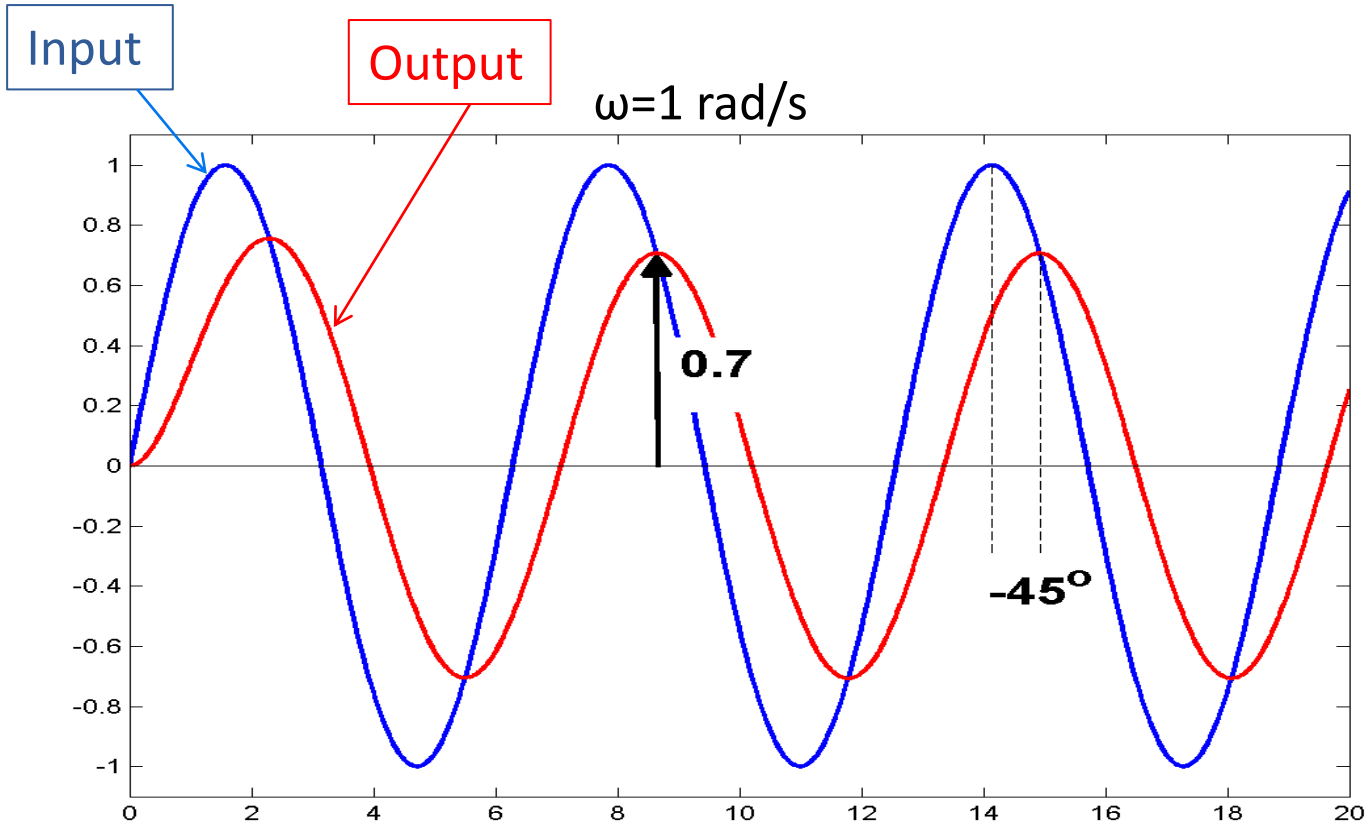


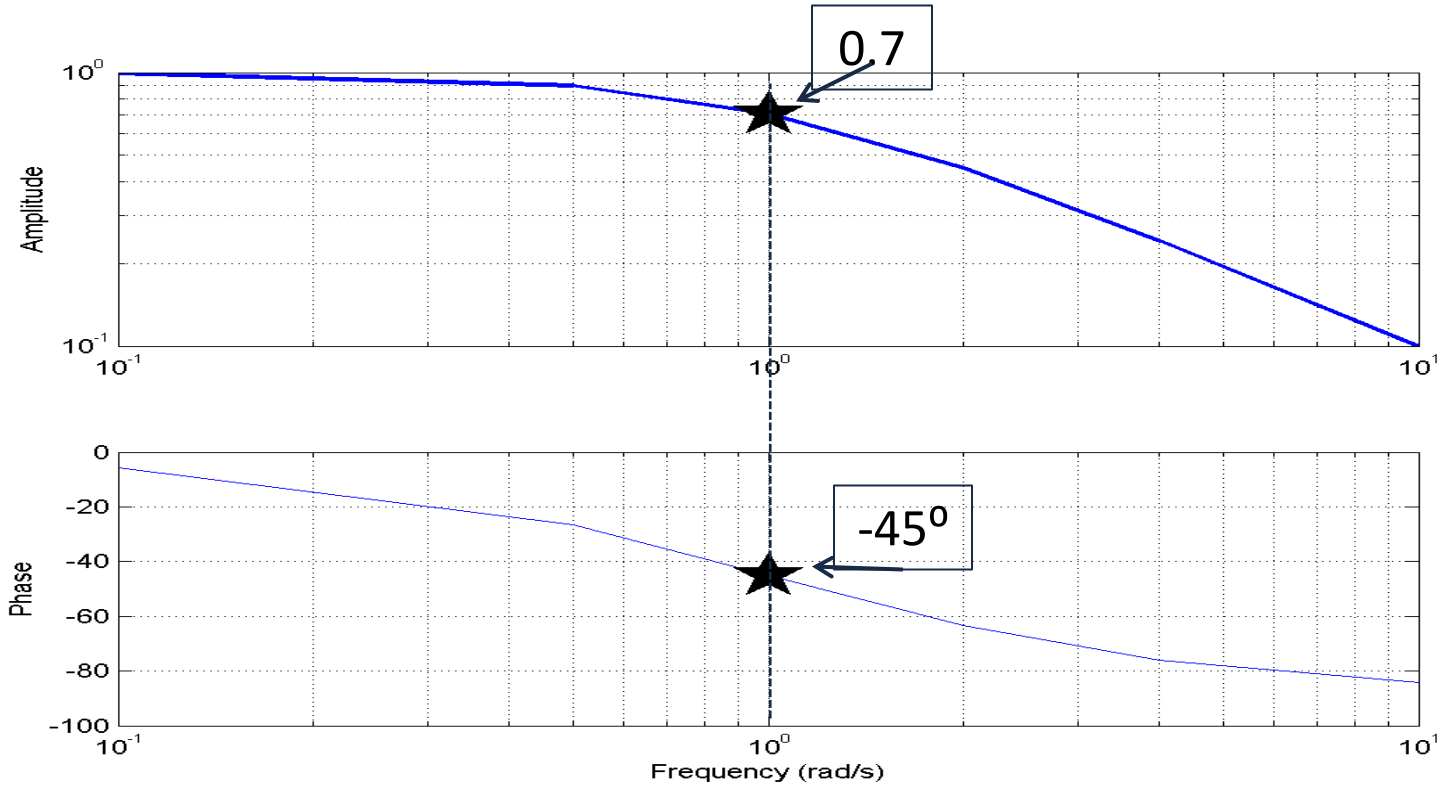
© Forsmarks Kraftg

BODE MEASUREMENT 2018-06-27

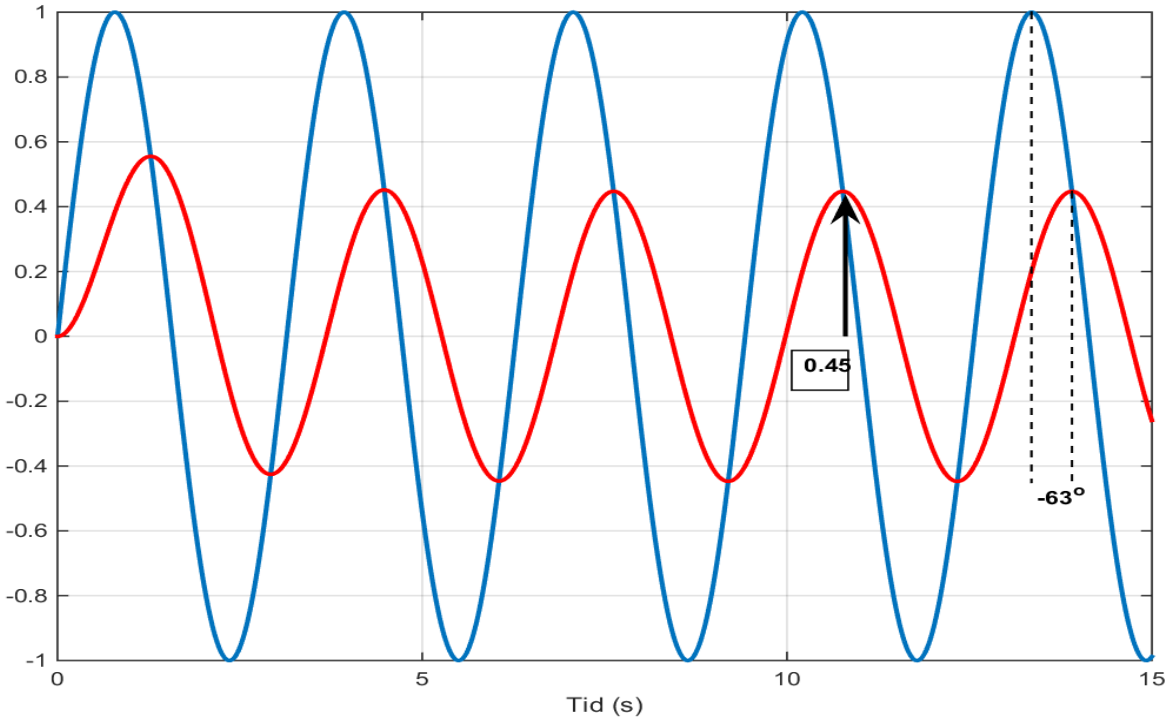


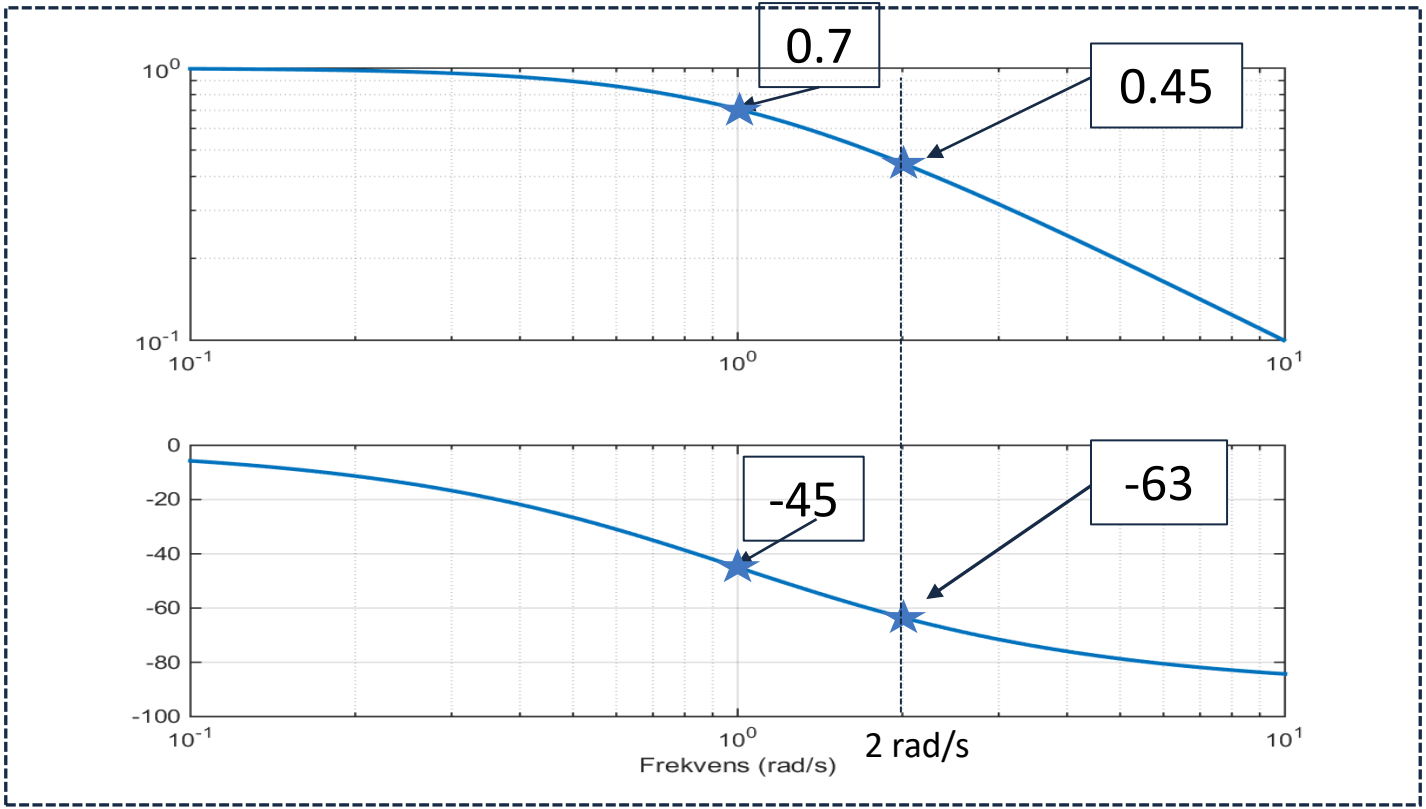
Name	Data Source	Map	Description	Value	Level	Status	Aut	Plot Min	Plot Max	Units	Shift	TZ	Type	Period	Method	Ste	Ext
531K081	F2	F_ANALOGM	Medelvärde APRM	119,3	Good	OK		100,0	125,0	%	0 0:00:0		Best Fit	1 Hour			
211K036	F2	F_ANALOGM	Summa härdkylflöde	10284	Good	OK		0	14000	kg/s	0 0:00:0		Best Fit	1 Hour			

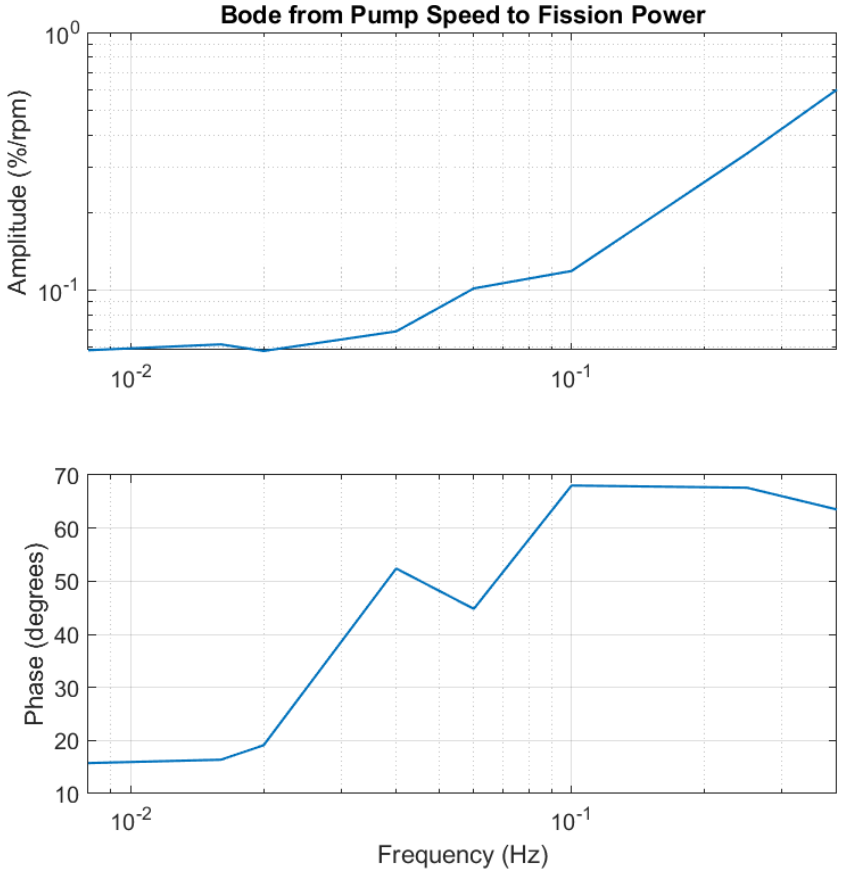

Input
Output
ω=1 rad/s
0.7
-45°
1
0.8
0.6
0.4
0.2
0
-0.2
-0.4
-0.6
-0.8
-1
0
2
4
6
8
10
12
14
16
18
20


0.7
Amplitude
10^0
10^{-1}
10^{-1}
10^0
10^1
-45º
Phase
0
-20
-40
-60
-80
-100
10^{-1}
10^0
10^1
Frequency (rad/s)

ω=2 rad/s



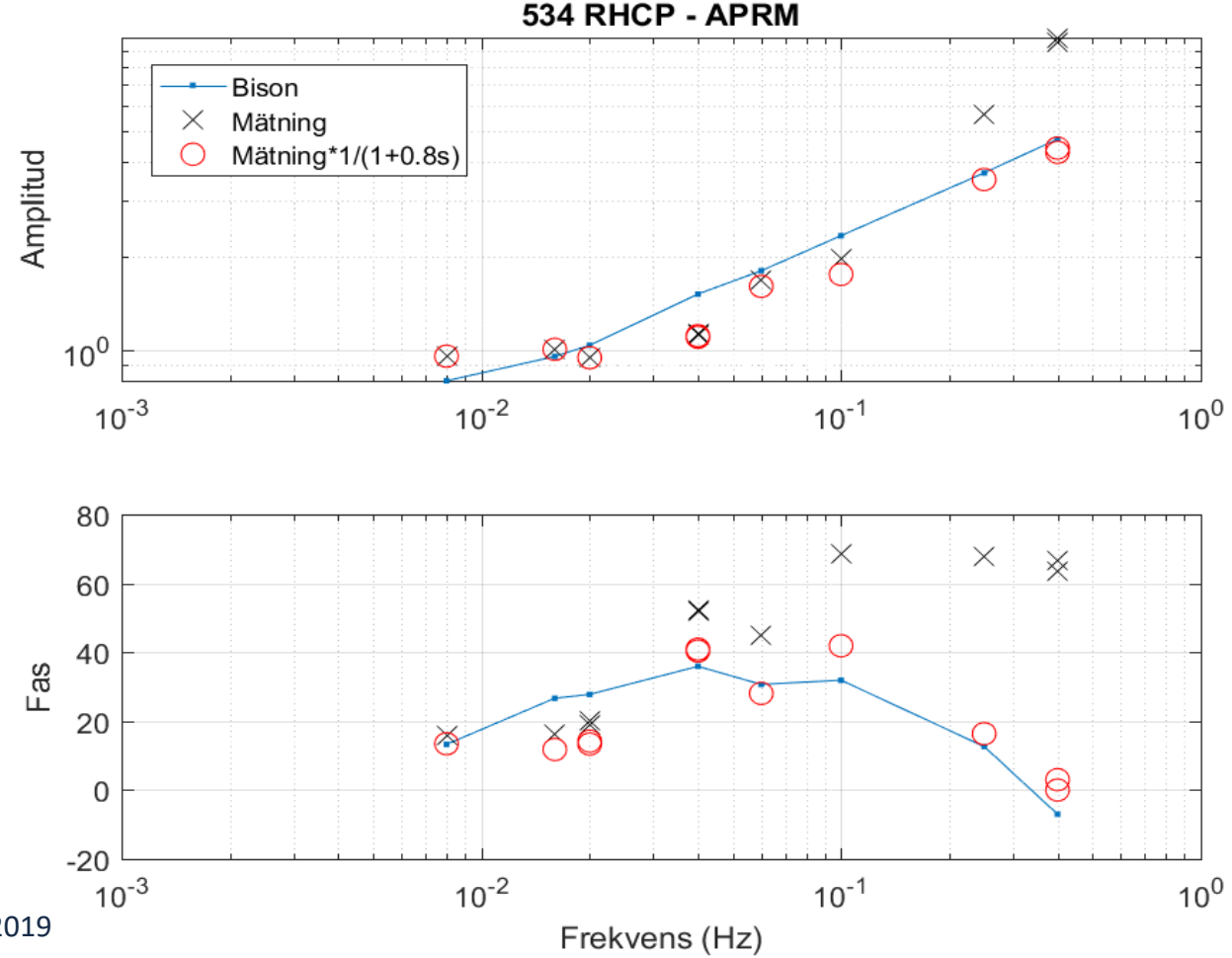

0.7
0.45
-45
-63
2 rad/s
Frekvens (rad/s)

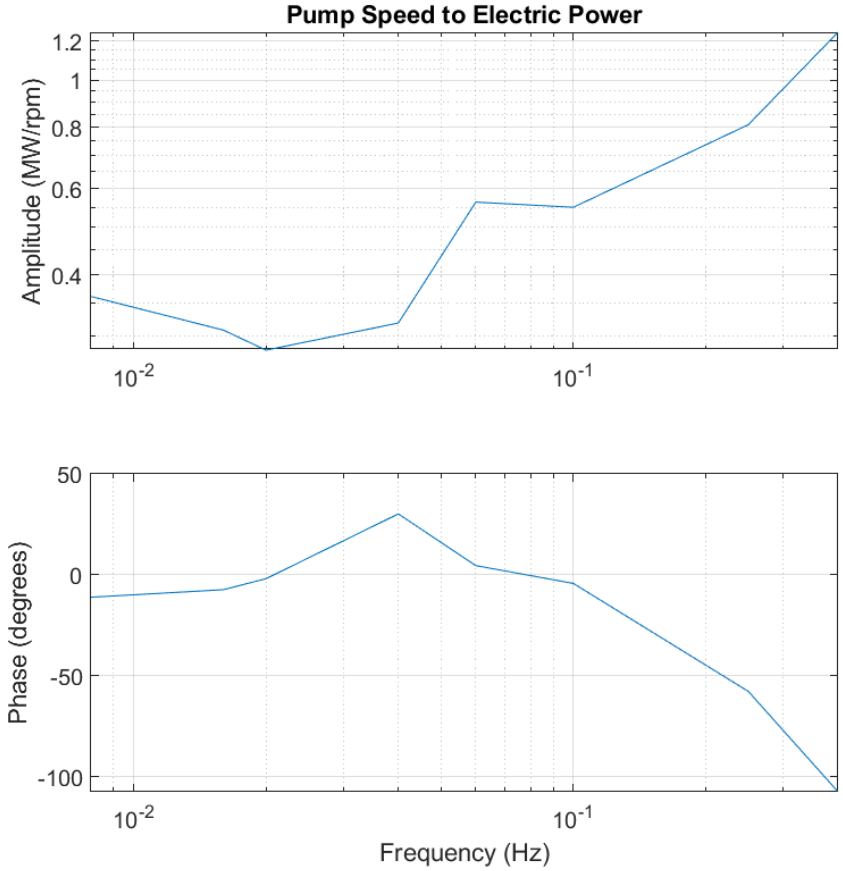


© Forsmarks Kraftgrupp AB

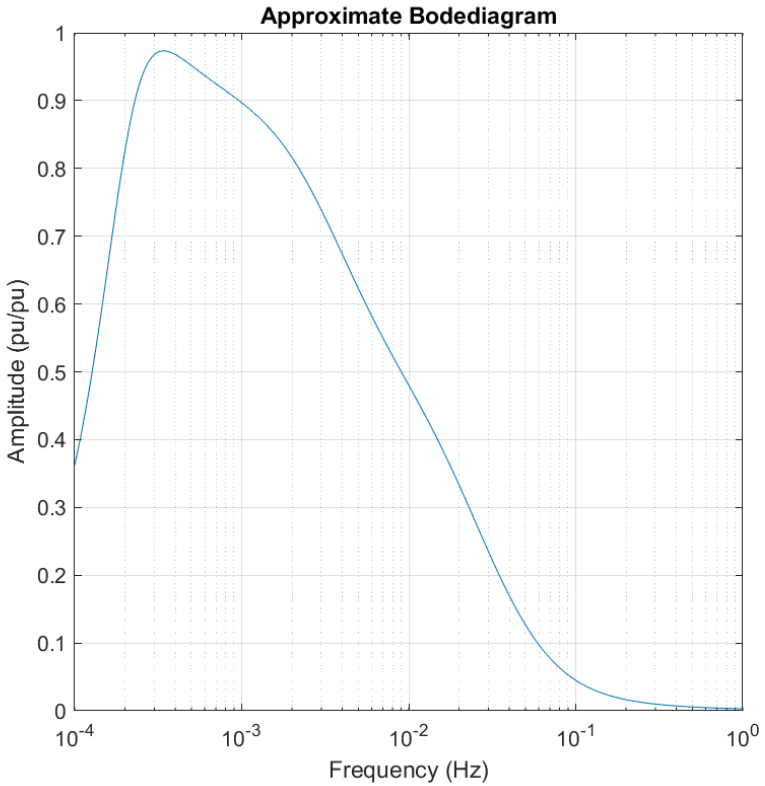
VATTENFALL

VALIDATION OF BISON VS MEASUREMENTS

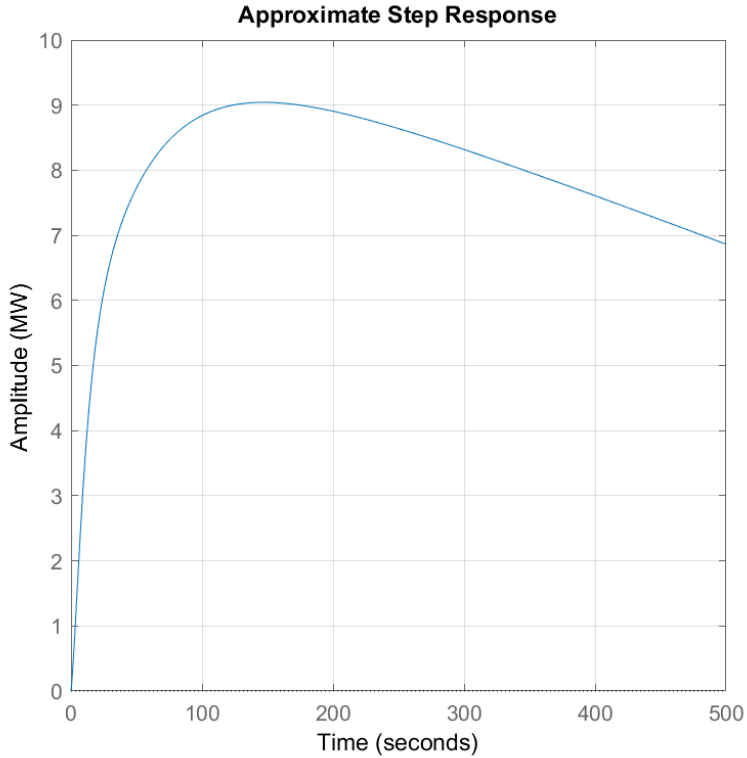




© Forsmarks Kraftgrupp AB



© Forsmarks Kraftgrupp AB



© Forsmarks Kraftgrupp AB

Q&A

- Will this be harmfull for the fuel?
  - Definitely not!
- Will there be more wear and tear on main circ pumps and valves?
  - Probably not. Note, however, that this is a production issue, not a safety issue.
- Will there be thermal transients on the feed water spurges?
  - No, nothing worse than we already have. Compare with the feed water flow on Ringhals 2-4.
- Exposure – fission product inventory?
  - The impact is not detectable. Time scale: weeks.
- Xenon?
  - Not detectable. Time scale: hours.
- Overpower deliberately?
  - We follow the rules. Historically, we have operated with more overpower due to cooling water temperature. Regard trip of other production unit as an AOO and incorporate in SAR.

© Forsmarks Kraftgrupp AB

Q&A

- Can there be an interaction between core instability and power system instability?
  - In principle yes, but this can be addressed by blocking frequency control when OPRM is active.
- No outer signal should impact the nuclear operation
  - The impact is small. Besides, we have had an impact from the cooling water temperature for 35 years.
- Will this impact the margins?
  - All relevant margins will be assessed according to SAR, e.g. pressure transient
- Is it worth while?
  - Yes, if it is accepted that we do not provide static amplification (droop), but we need an answer to this question before we can proceed

© Forsmarks Kraftgrupp AB

PROPOSED RESEARCH TOPICS

- Investigate the impact on the Power System Dynamics, in particular
  - Impact on 60-second oscillation
- Trigg condition for PSPA-light
- Confirm that dynamic stability is OK

© Forsmarks Kraftgrupp AB