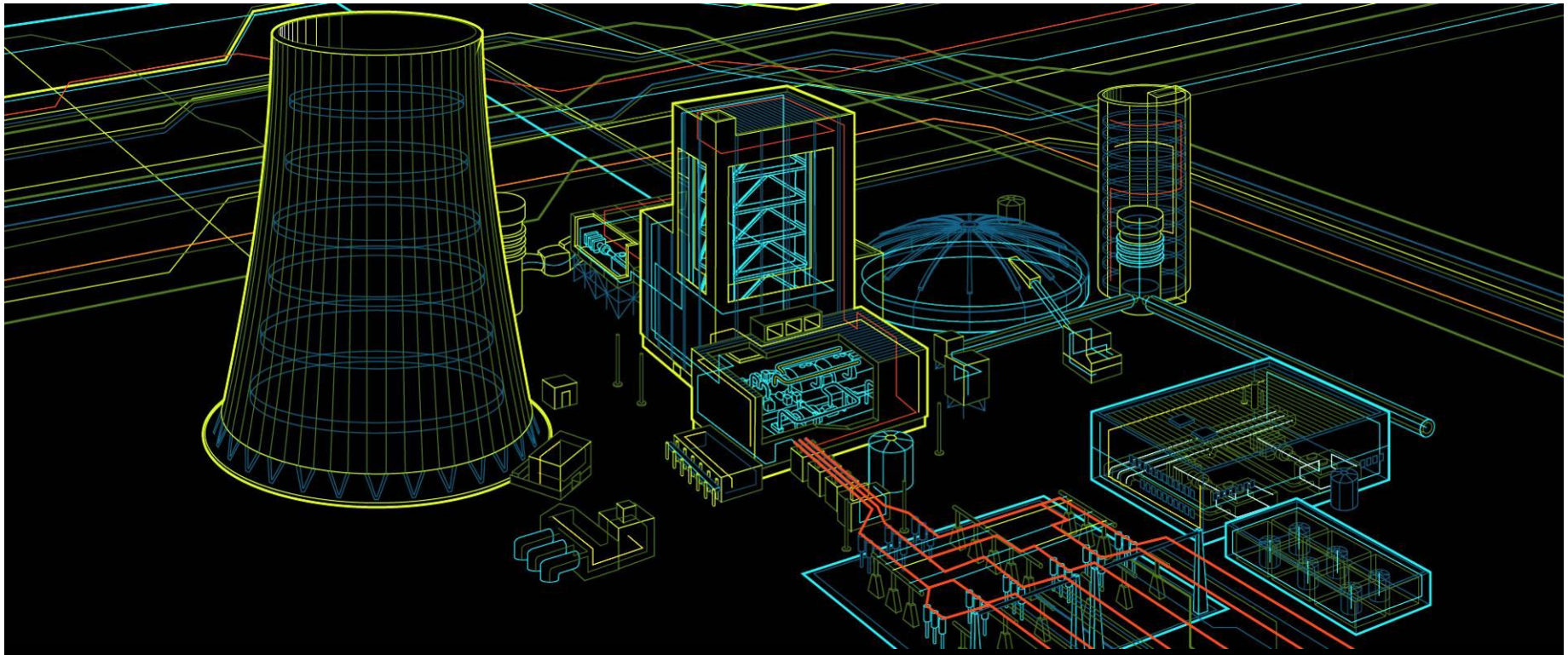
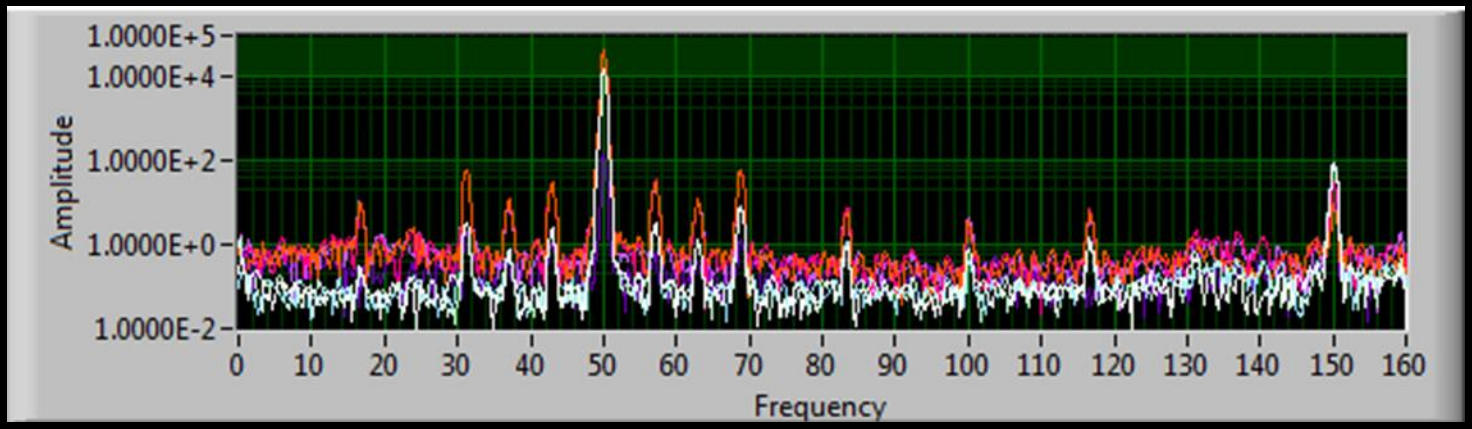


prof. tord bengtsson, ABB Corporate Research, 2016-11-24

# Sub Synchronous Resonance
# Field observations and SSR filter

# Content

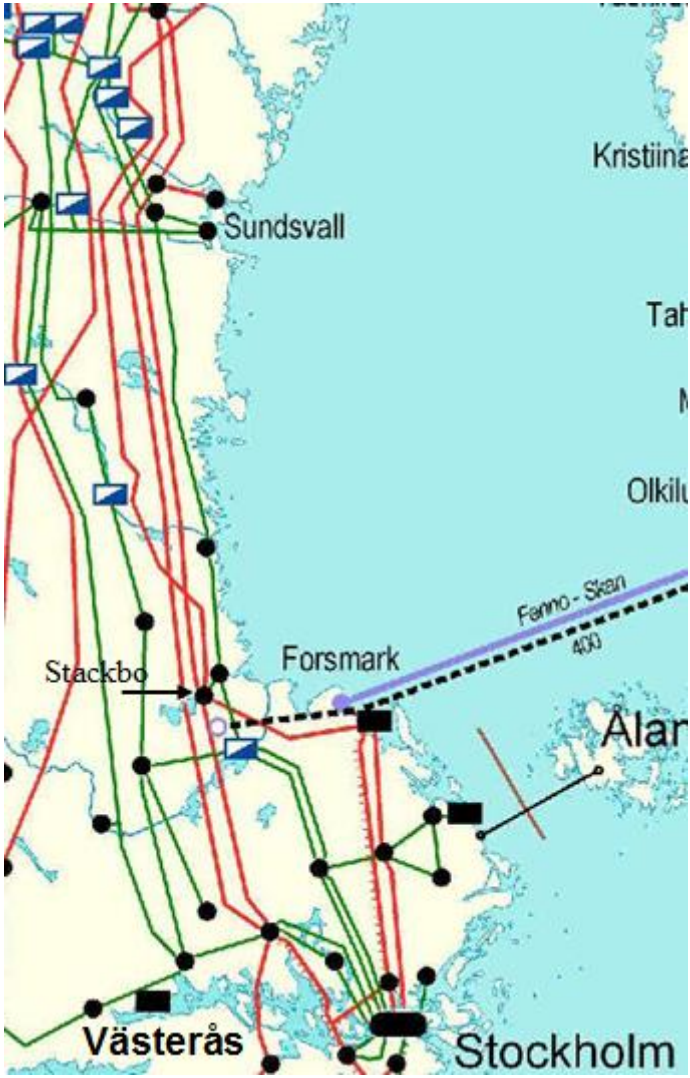
- Field SSR observations:
  - Field data acquisition overview
  - Transient initiated SSR example
  - Persistent SSR example
  - Comparison substation – generator terminal
- Filter function:
  - Enabler for SSR detection
  - Some details on the algorithm
  - Some relevant properties




# Field SSR observations

# SSR pilot installations in Sweden

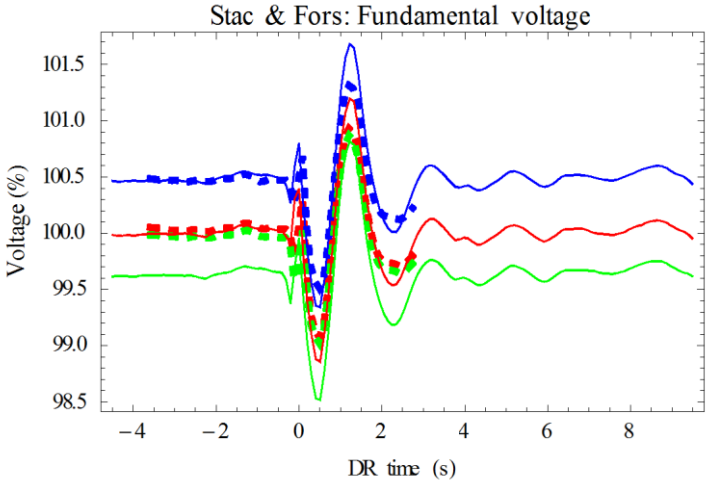
- During development of the SSR protection functionality in the 670 Series:
  - Two 670 Series IEDs were installed which first just recorded Comtrade files when triggered from existing SSR protection
    - One at 400 kV OHL (SS Stackbo) going north
      - Operative since May 2012
    - One in NPP Forsmark 3, on 1170MW generator
      - Operative since July 2012
  - No interaction/communication between the two IEDs
  - Analysis off-line

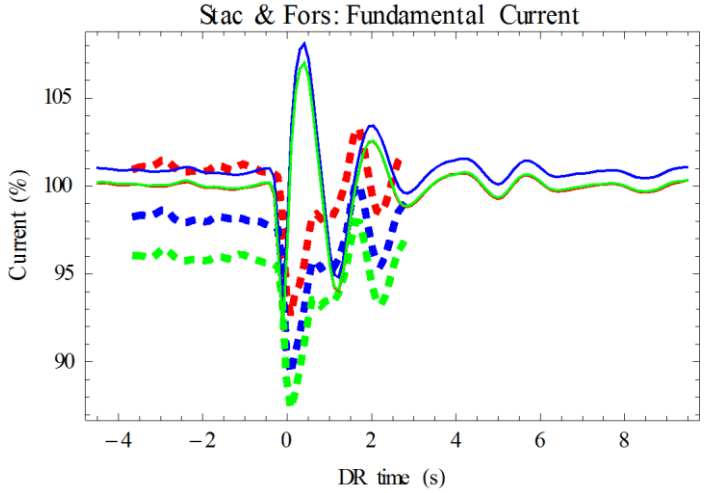


# Prominent SSR example
## Event August 7 2012, 09:58

- Event caused by a quick 300 MW ramp down of Fennoskan link
- Seen by both Forsmark and Stackbo

At fundamental frequency:



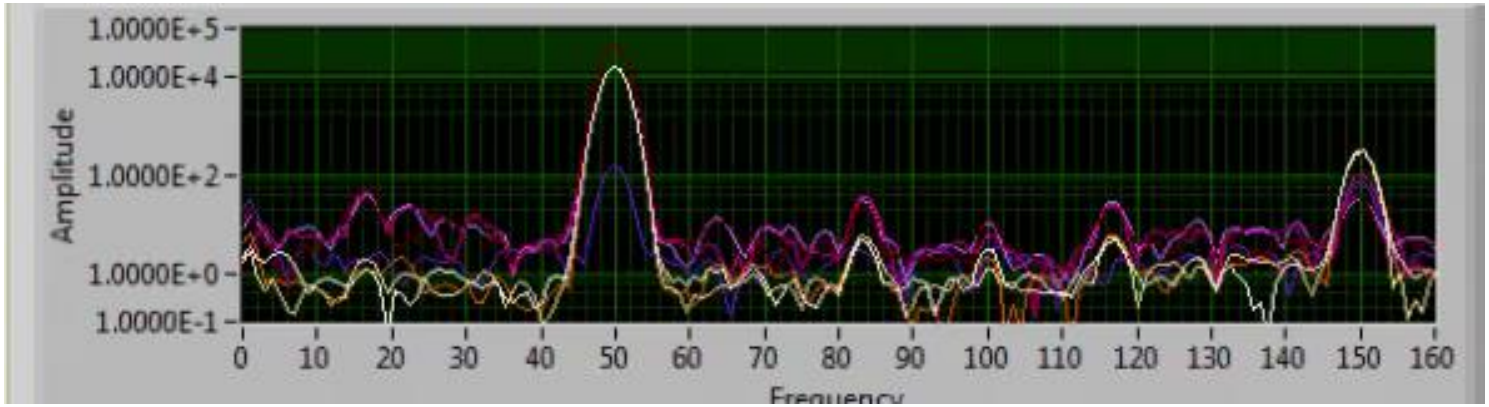




- Forsmark – full lines
- Stackbo – dashed
- 100% = Mean of phase 1

# SSR event 2012-August-07
## Spectral movies from captured DRs

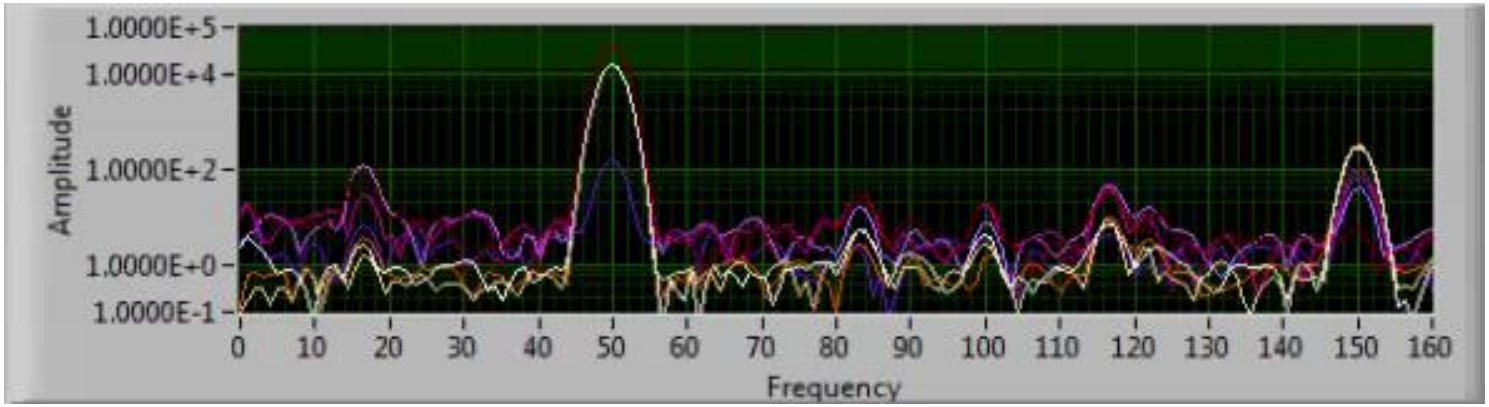
3-Ph Current spectra's with red color

Forsmark

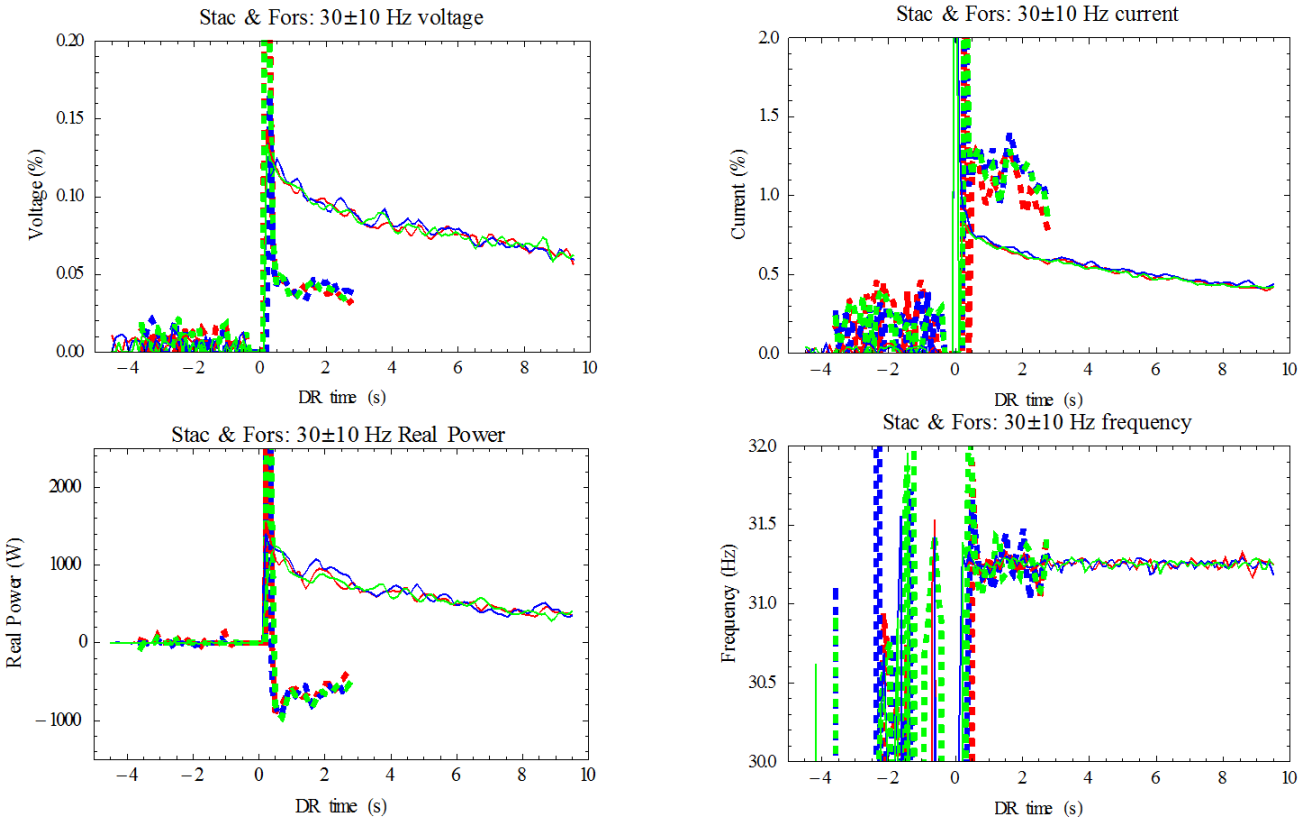



Voltage spectra's with white/gray color

Stackbo



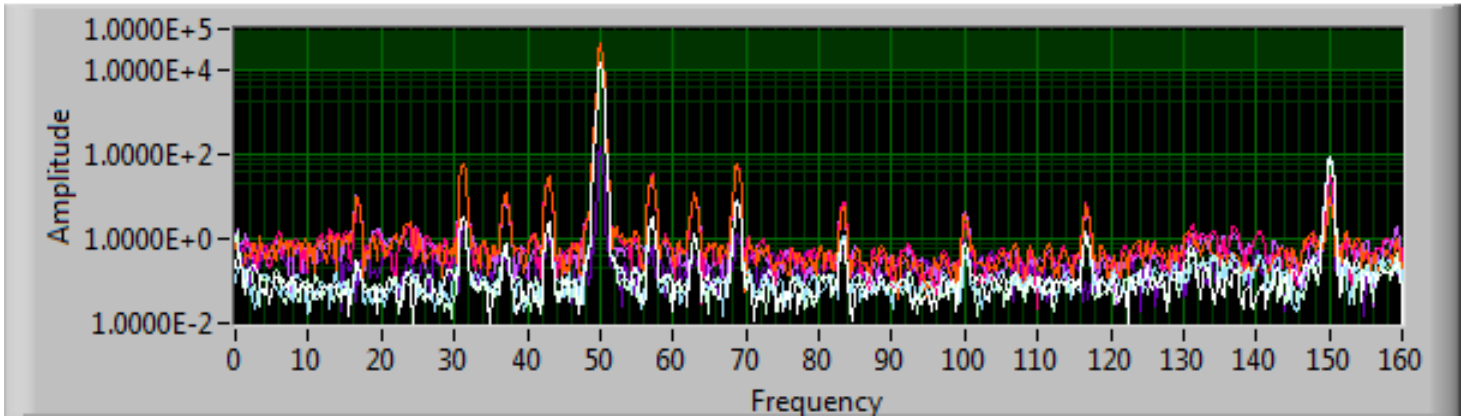
# Example event August 7, 2012
## At subsynchronous frequency




- Voltage relatively lower at Stackbo, currents slightly higher
- Power direction opposite to fundamental in Stackbo

# SSR event 2012-August-07
## Three resonance frequencies observed

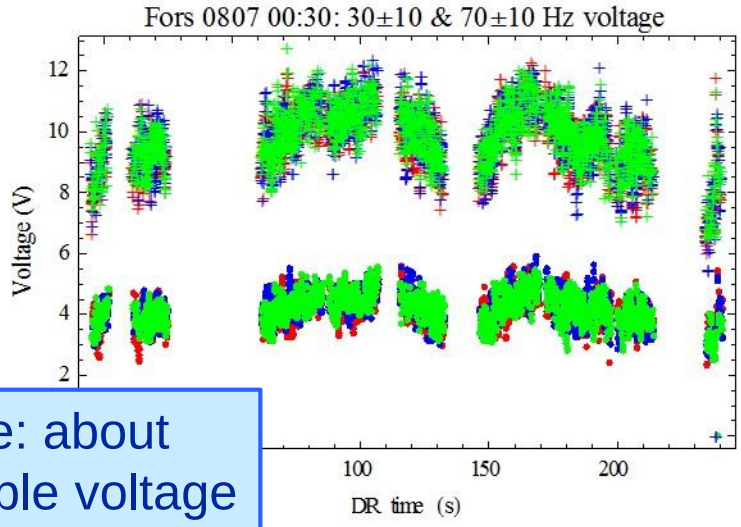
- An 8 s analysis reveal three frequency pairs:
  - 32 & 68 Hz, shaft mechanical frequency 18 Hz
  - 38 & 62 Hz, shaft mechanical frequency 12 Hz
  - 42 & 58 Hz, shaft mechanical frequency  8 Hz

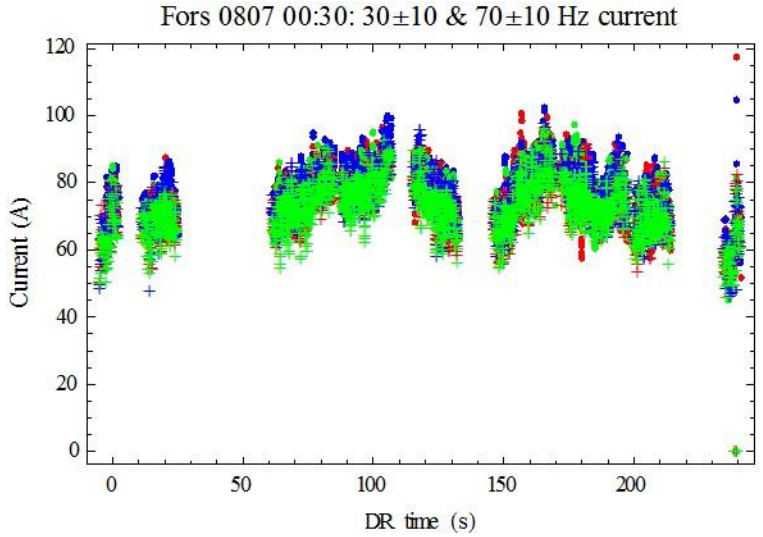


# Persistent SSR observed from DRs
## Forsmark, August 7, 2012 00:28:32 – 00:32:31

- One example only, more seen
- 29 records trigged within 5 min
- One trig at Stackbo
  - Very slight indications of SSR here.
  - No trig at Stackbo for the other events

- At 50 Hz:
- Voltage: 12 kV
- Current: 33 kA




Note: about double voltage at 70 Hz

Need to log SSR activity continuously!

# SSR pilot installation development

- From summer 2012 several SSR events were captured at both locations

- The pilot installations had the following “upgrades”:
  - 400kV IED was moved in April 2013 from Stackbo substation to Ängsberg substation (better SSR location)
  - During Spring 2013 both IEDs were upgraded with new prototype software containing the new filter. From then the captured DRs contained SSR quantities and SSR frequencies estimated by the new filter. However DRs are limited to 11s length. Therefore
  - At the same time logging PC was added in both installations to log every 5s the SSR quantities from the filters in a PC. At the same time this PC as well collects all DR files captured by the IED.

# Persistent SSR events at Forsmark
# > 100 A in July – September 2013

- Events longer than 1 min shaded.
- Long events are mainly 31 Hz
- Long events seems to occur once a month

| date | time | peak31 (A) | peak37 (A) | duration | DR # |
|---|---|---|---|---|---|
| 0701 | 08:48 | 145 | 31 | 20s | 856? |
| 0702 | 21:40 | 180 | 0 | 5 min | 893 – 907. |
| 0705 | 21:11 | 105 | 0 | 5s | 974 |
| 0710 | 14:37 | 50 | 270 | 15s | 217 |
| 0722 | 09:48 | 100 | 60 | 5s | no DR??? |
| 0724 | 22:42 | 260 | 80 | 5s | 396 |
| 0725 | 17:30 | 20 | 130 | 5s | 399 |
| 0725 | 19:21 | 40 | 190 | 5s | 400 |
| 0726 | 09:57 | 30 | 175 | 10s | 409 |
| 0727 | 16:27 | 25 | 130 | 5s | 420 |
| 0727 | 20:47 | 20 | 175 | 5s | 422 |
| 0730 | 14:38 | 100 | 0 | 20 min | 426 – 429 |
| 0802 | 03:53 | 10 | 115 | 10s | 454 |
| 0802 | 08:09 | 105 | 0 | 3 min | 456 -460 |
| 0804 | 23:39 | 60 | 245 | 15s | no DR |
| 0902 | 06:40 | 130 | 0 | 30 min | 703 – 759 |
| 0914 | 09:15 | 20 | 170 | 10s | 794 |
| 0917 | 08:40 | 5 | 600 | 5s | 807 |

# SSR event captured on 2013-July-02
## Current Values from PC txt log file during whole event

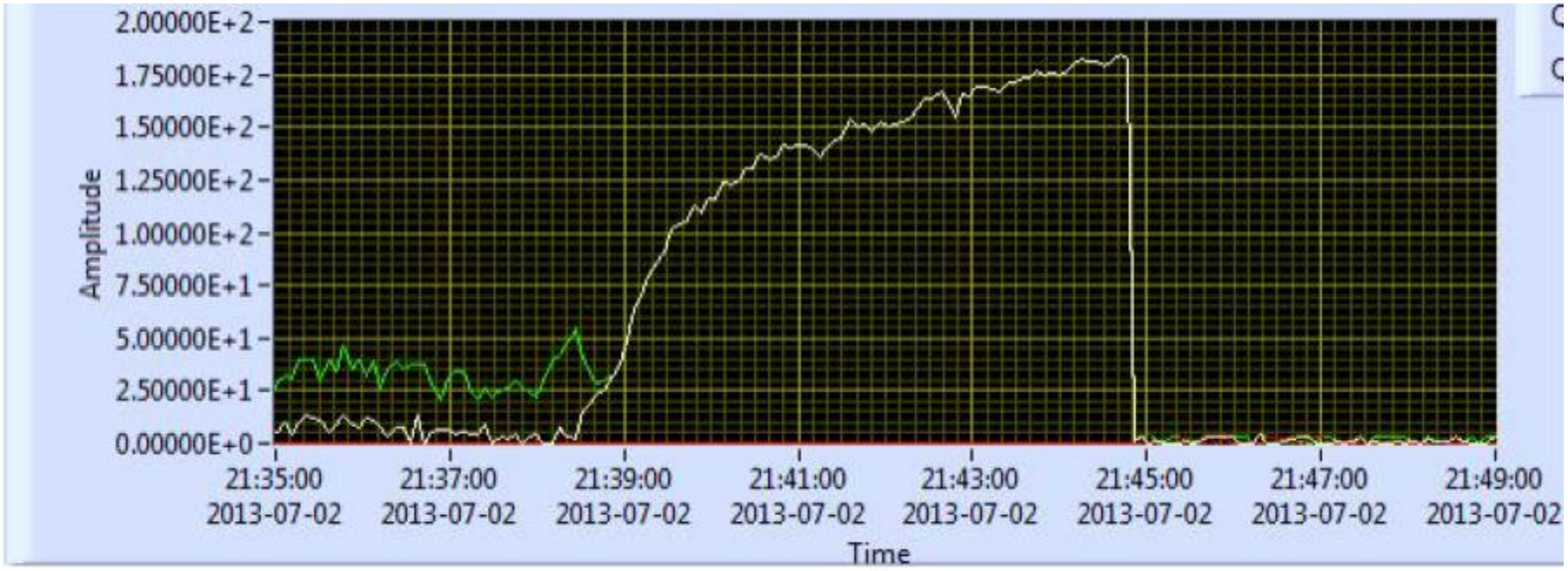



*Figure 10: The event at 21:40, June 02 which caused Forsmark 3 to trip. White is 31 Hz SSR current, green is broadband SSR current and red is 37 Hz SSR current. From log file IEDlog7.*

- No evidence of initiating cause – no transient
- Three filters used in the 670 IED
  - 31Hz, 37Hz and Broad-Band (15-45Hz)

# SSR event captured on 2013-July-02
## Frequency Values from PC txt log file during this event

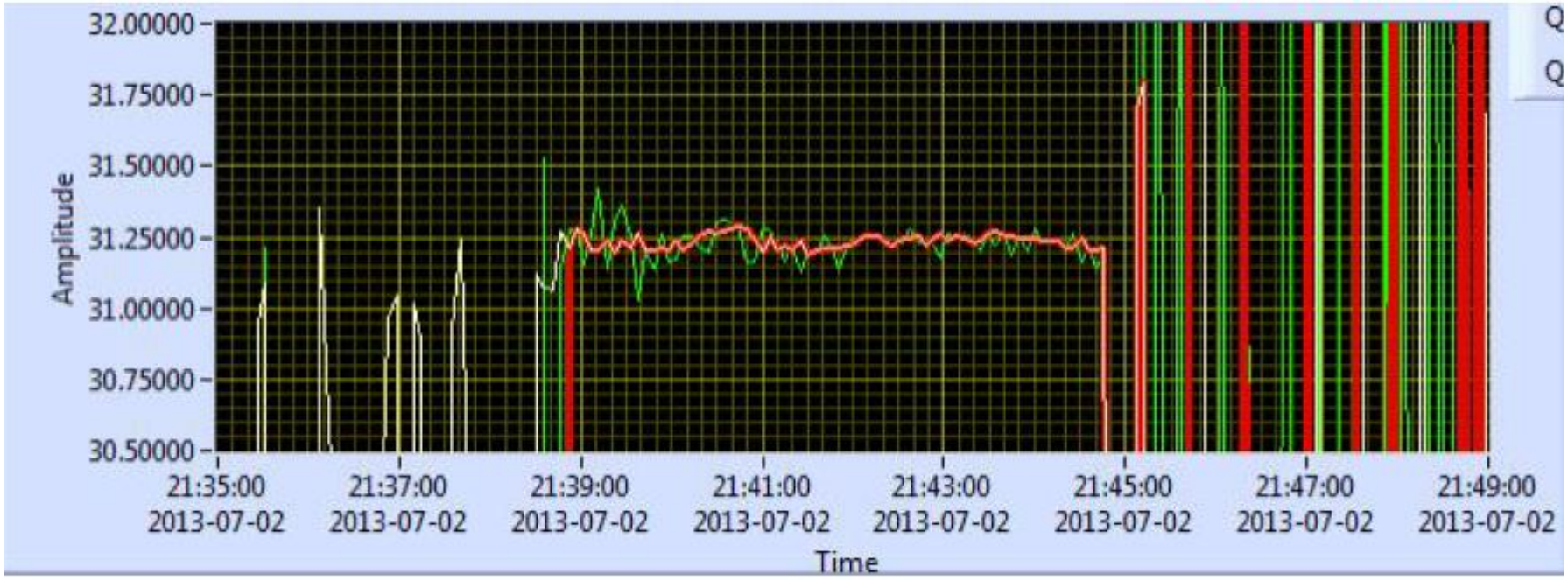
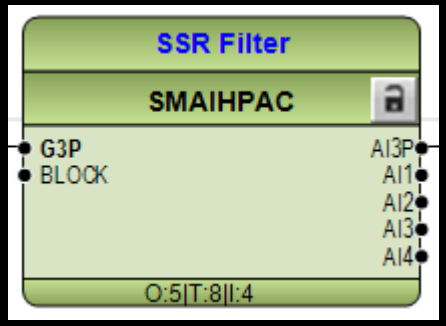



*Figure 12: Frequencies observed at the June 02 event. White is 31 Hz current frequency, red is broadband current frequency and green is broadband voltage frequency. Current at 37 Hz finds no signal.*




# Filter function

# Many protection functions are available in 670 Series

- 87G, 87T, 87O, 87W — Various Differential Protections
- 87HZ — High Impedance Differential
- 21 — Line Distance Protection, Under-impedance Protection
- 87L — Line differential protection
- 51V, 50/51, 67, 50N/51N, 67N — Backup protections
- 64S, 64R — 100% Stator ground fault, Injection based, Rotor Injection
- 59THD — Stator ground fault 100% (3rd harmonic based)
- 59N — Stator ground fault 95%
- 78, 40 — Pole slip function, Loss and under excitation
- 32 and/or 37 — Reverse or low forward power function
- 46, 47, 67Q — Negative phase sequence functions
- 50AE — Accidental energizing
- 49, 49S, 49R — Thermal overload standard/stator/rotor
- 24 — Overfluxing (V/Hz)
- 81U, 81O, 81R — Various Frequency Protections (f>, f<, etc.)
- 50(N)/51(N)/27/59(N) — Basic Protection Functions (I>, I<, U>, U<, etc.)
- ***SMAI HPAC filter for SSR protection (available only in customized version)***
- AND, OR, Timers, Flip-Flop — Programmable Logic
- Metering, Disturbance recording, Event Recording
- Etc.

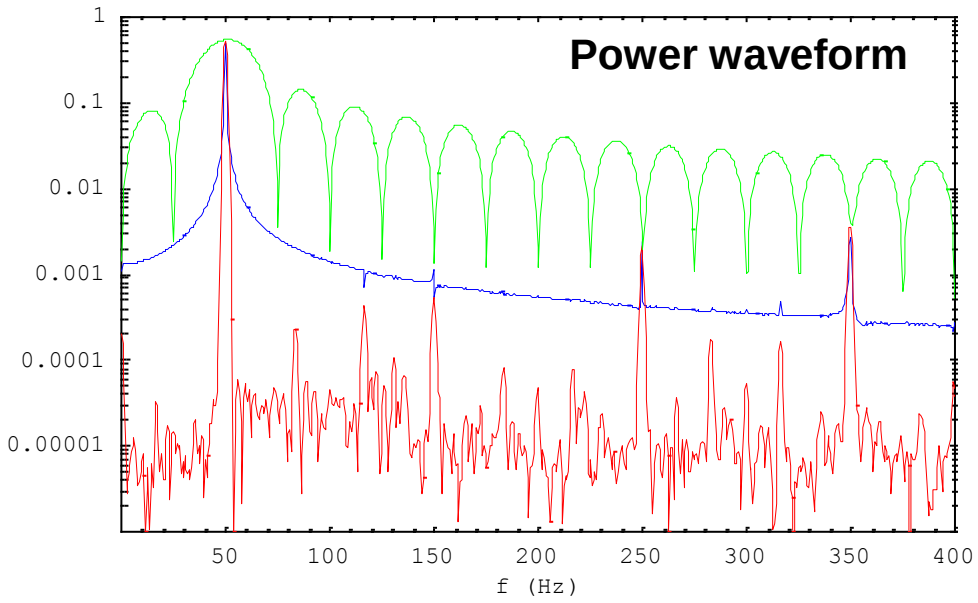
# High Precision AC filter- HPAC
## What is it?

- An algorithm for extracting phasors from an AC waveform
- Similar to traditional DFT but:
  - Substantially higher precision
  - Any frequency and any number of frequency components
    - Not only harmonics
  - Does not require sampling rate adjustment
- Based on interpolated spectral analysis
  - First developed around 2000 for dielectric measurements
  - Used in numerous research applications
    - Basis for two PhD theses
  - Analysis kernel in 64S & 64R protection functions

# HPAC
## Precision enablers

- Long records reduce noise ~ √length
  - Same as long averaging times for DC measurements
- Spectral analysis technique eliminates FFT spill level
- Interpolation eliminates synchronized sampling requirement

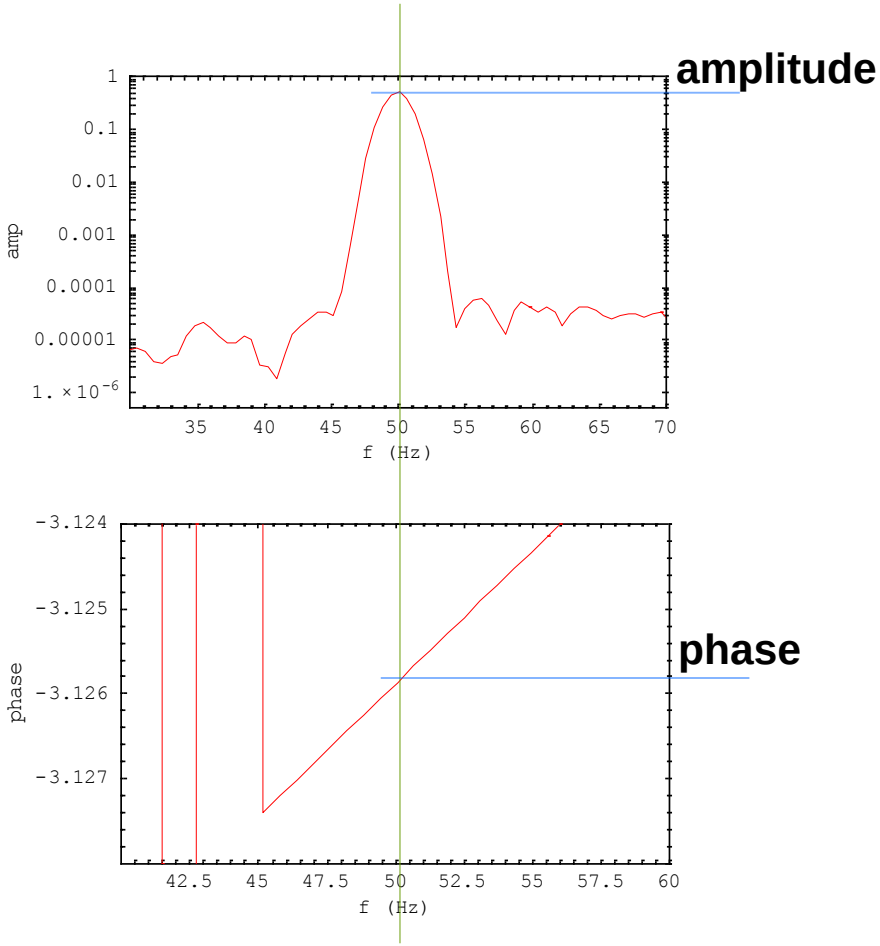
- No magic: High precision need long time
  - Quantum-mechanical Heisenberg relation applied to AC analysis




- 2 period DFT
- 1s FFT
- 1s HPAC

# HPAC
## Extracting phasor

- Magnitude of phasor is maximal absolute value of peak
- Frequency defined at peak maximal amplitude
- Phase found by phase value at frequency
- Curve fitting techniques essential

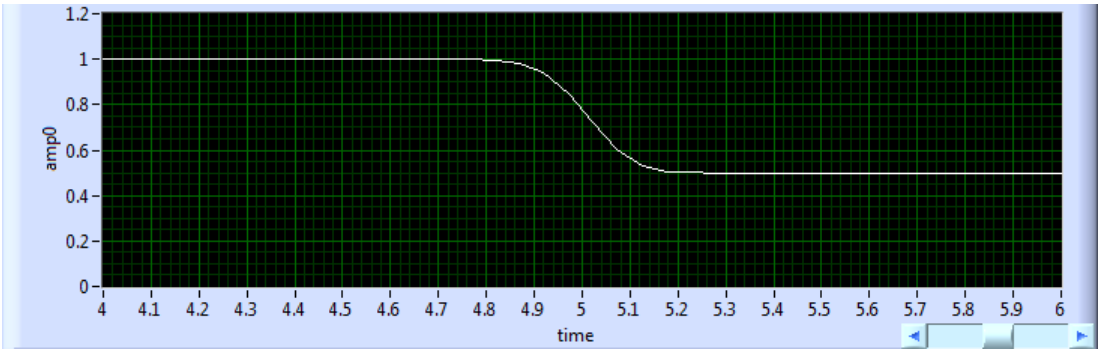


# SMAI HPAC filter – Important settings

- ***SetFrequency***: Required frequency to be extracted from the input signals
- ***FreqBandWith***: Allows to increase the natural pass frequency band of the filter (i.e. to make it more broad)
- ***FilterLength***: Specifies the length of the filtering window
  - Longer window gives better frequency precision and less noise
- ***OverLap***: Specify how much data in % from the previous filter calculation is re-used for the next successive filter calculation

# *FilterLength* – Defines Speed of Response

- Set value for parameter *FilterLength* also defines the response time of the filter after a step change of the measured signal.
- The filter will correctly estimate the new signal magnitude once about 75% of the filter length has been filled with the new signal value.

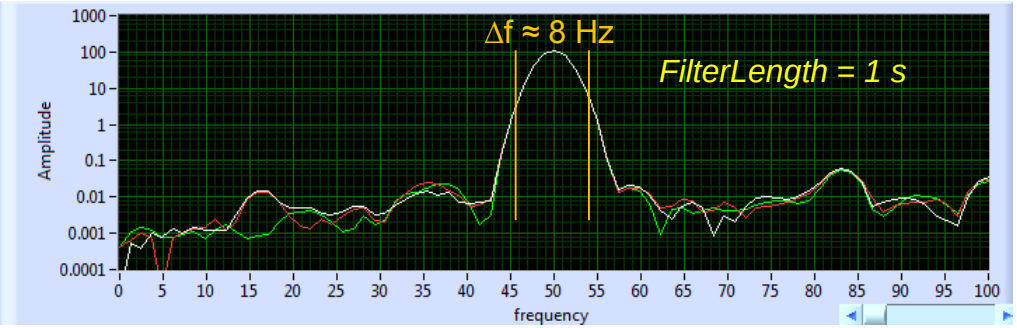



*Amplitude response of a step change from 1 to 0.5 at t=5 s with 1 s filter length. Small changes visible from roughly 4.7 s to 5.3 s. Generated with 99.5 % overlap.*

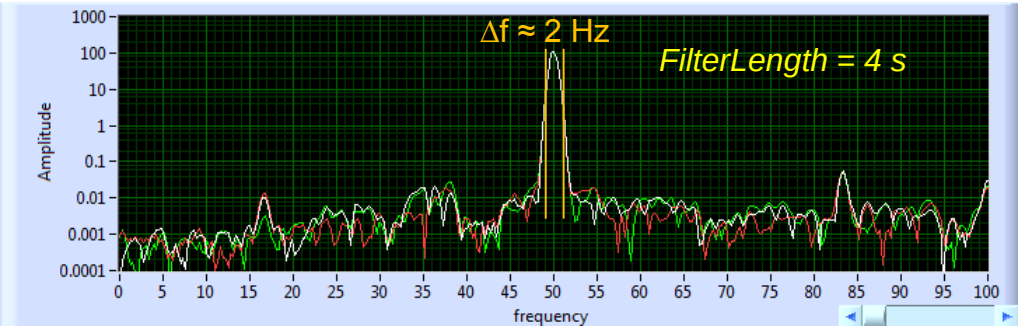
Thus 50% overlap is a good compromise between resolution and CPU demand

# *FilterLength* - Defines Natural Pass Band

- Longer *FilterLength* gives proportionally narrower pass band = basic search range.



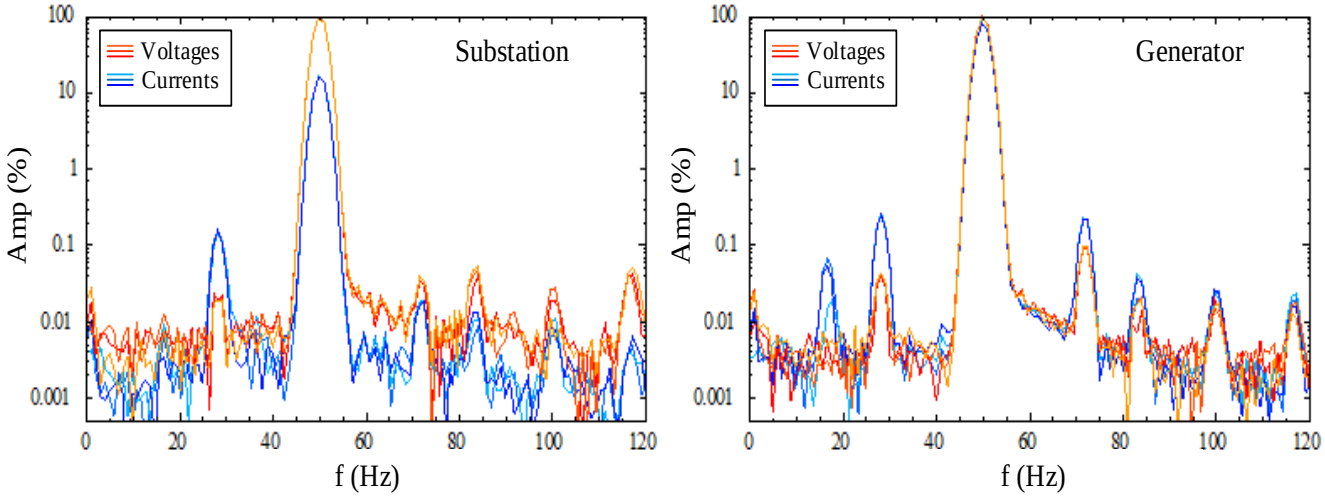

- Search range can be extended with *FreqBandWidth*
  - Adds to range on both sides
  - Limits not sharp, can vary a pass band and depend on amplitude.




*PC analysis with same code file as in IED*

# Conclusions

- SSR may be triggered by transients
  - These usually decay in seconds
- SSR may also appear without recorded trigger
  - These may persist for minutes or even hours
  - indications of >10 h seen in DR sequences
- SSR seen at generator more informative
- With the HPAC filter algorithm it is possible to detect SSR activity by software analysis only.
  - Delicate analog filters not needed
  - Sensitive: < 0.1 % of fundamental
  - Versatile: broad-band or narrow band



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