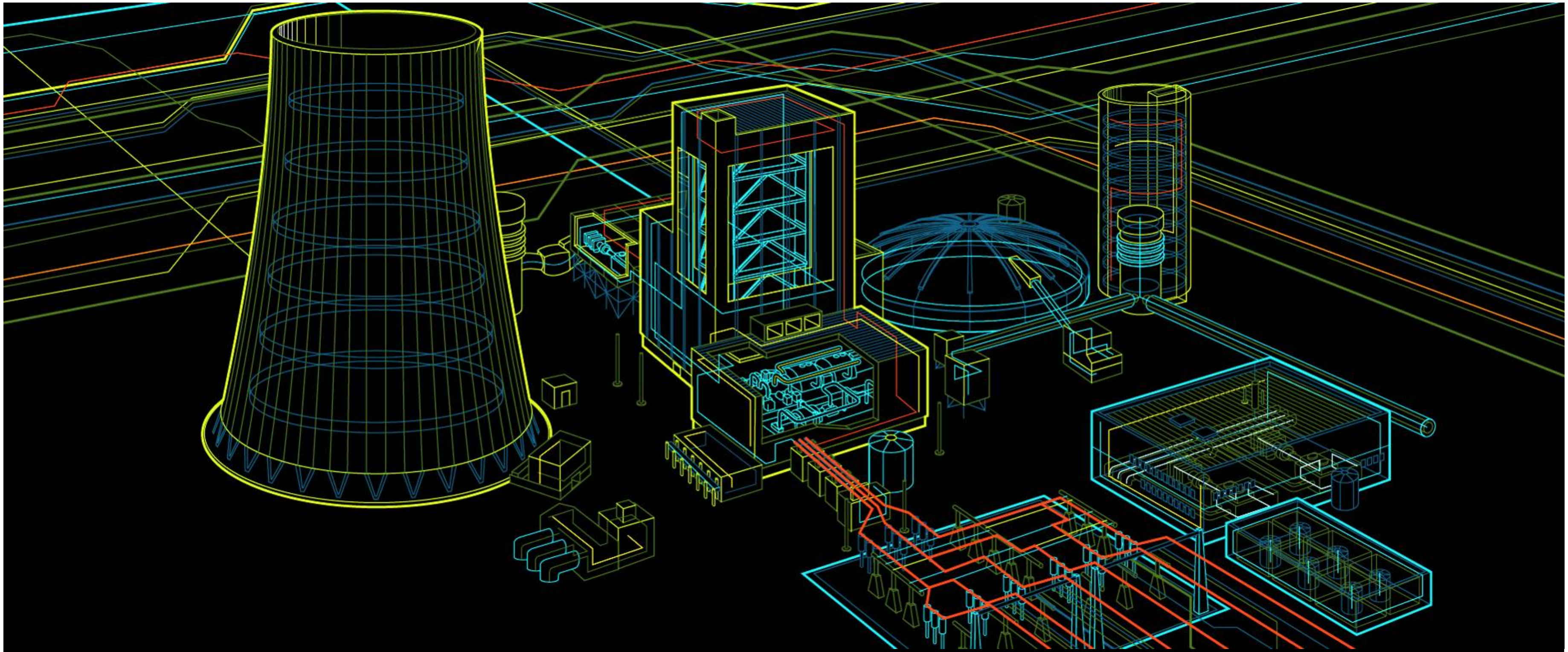


Stefan Roxenborg, ABB Grid Automation Products, 2016-11-24

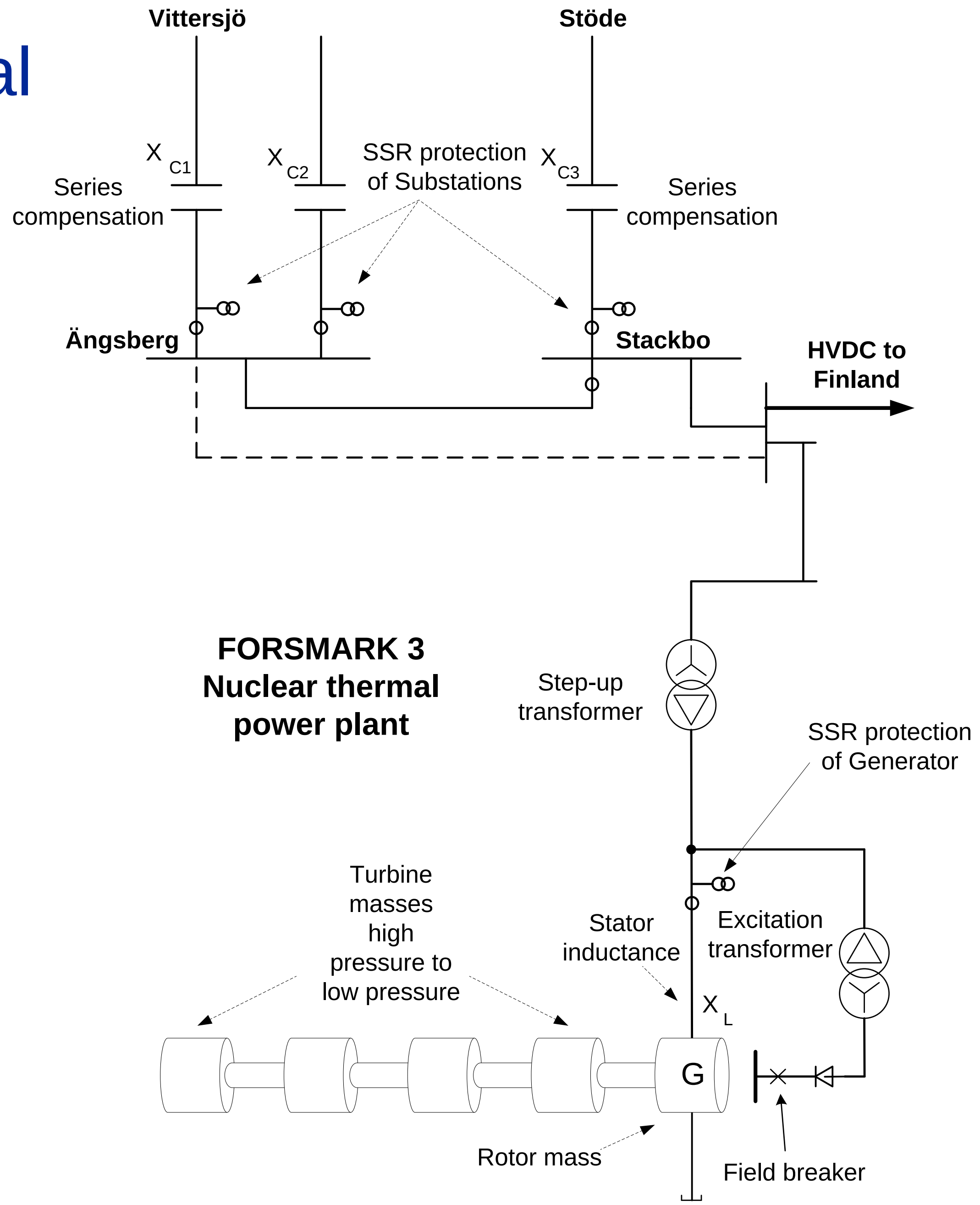
Sub Synchronous Resonance
SSR Introduction and Theoretical SSR amplitudes

Introduction

- **We started a SSR project 2012, together with Forsmark/Vattenfall and SVK, for capturing SSR events at:**
  - Forsmark F3, at generator terminals.
  - Ängsberg/Stackbo, one of the 400kV substations connected to a series compensation of powerlines.

- **The idea was to replace an old analogue Westinghouse SSR relay with a new SSR digital relay:**
  - This due to an upgrade of the F3 generator.
  - In turn also meant that the expected SSR modes would change.
  - And the old analogue relay would not be synchronized for this purpose.

Electro-Mechanical System



U and I - SSR measurements:

- Generator terminal F3
- Stackbo/Ängsberg

SSR causes:

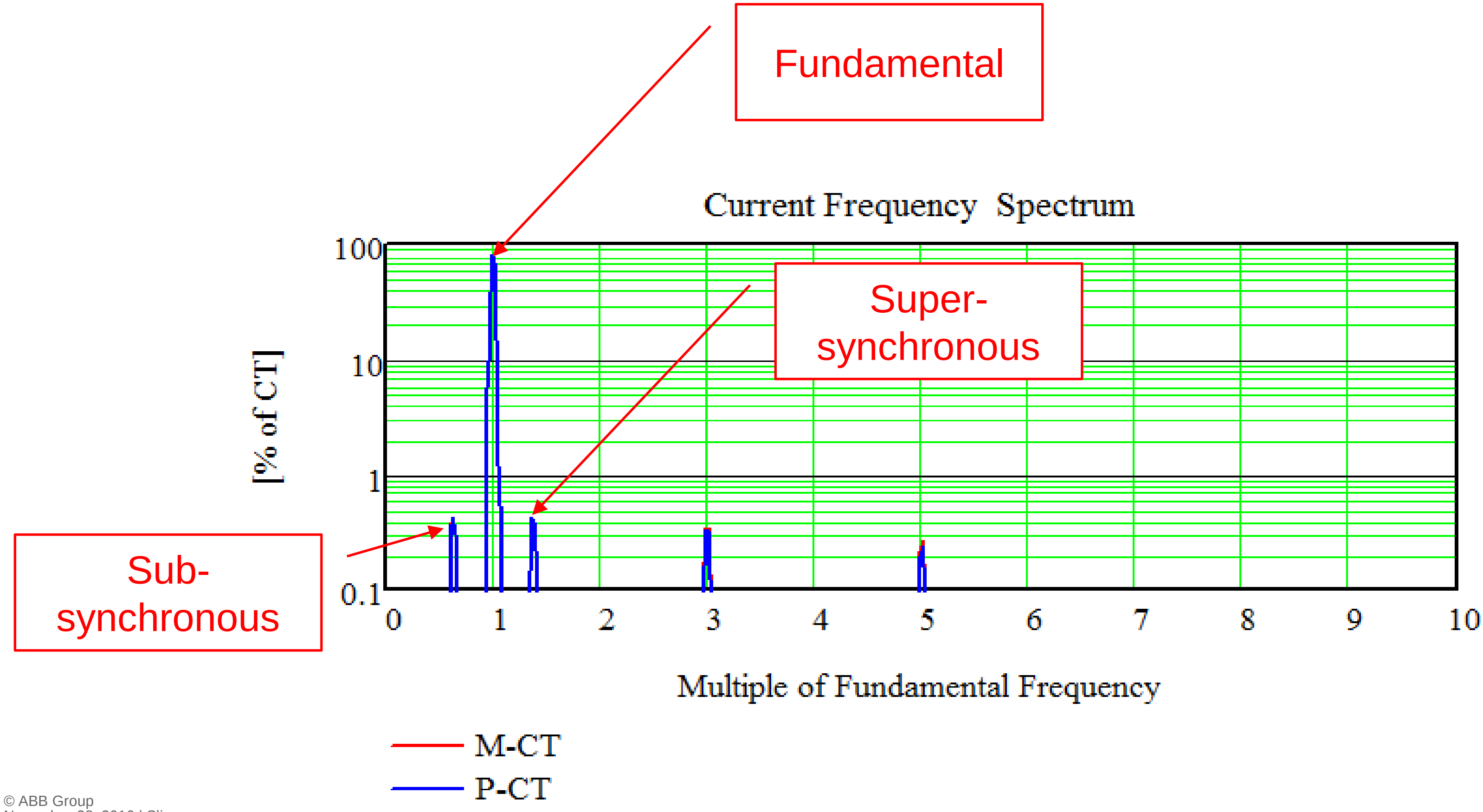
- Turbine regulation
- Excitation regulation
- Series compensated Power-system

$$\omega L = \frac{1}{\omega C}$$

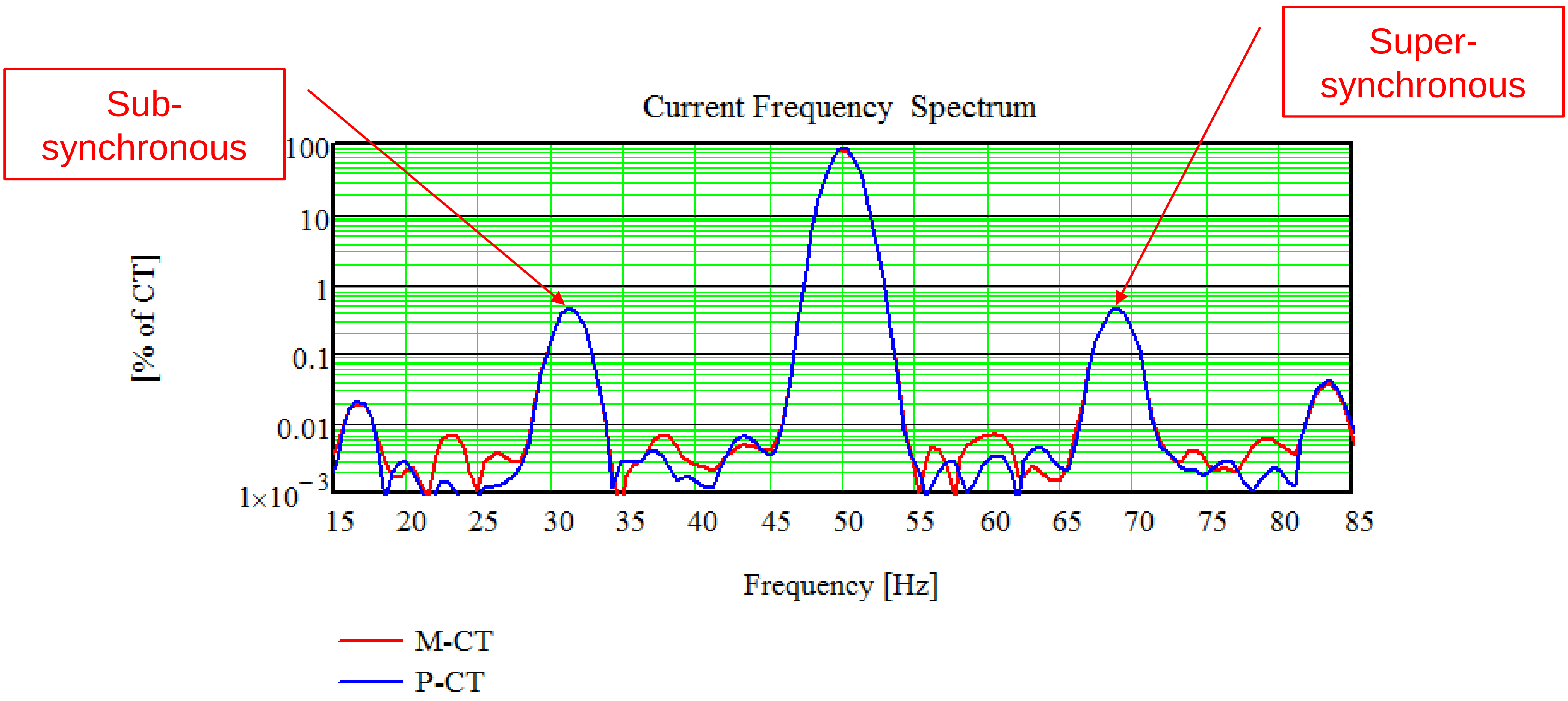
Frequency of induced I and U due to SSR

- The mechanical frequency is modulated on the fundamental power system frequency:

$$f_{SSR} = f_{FUNDAMENTAL} \pm f_{MECHANICAL}$$

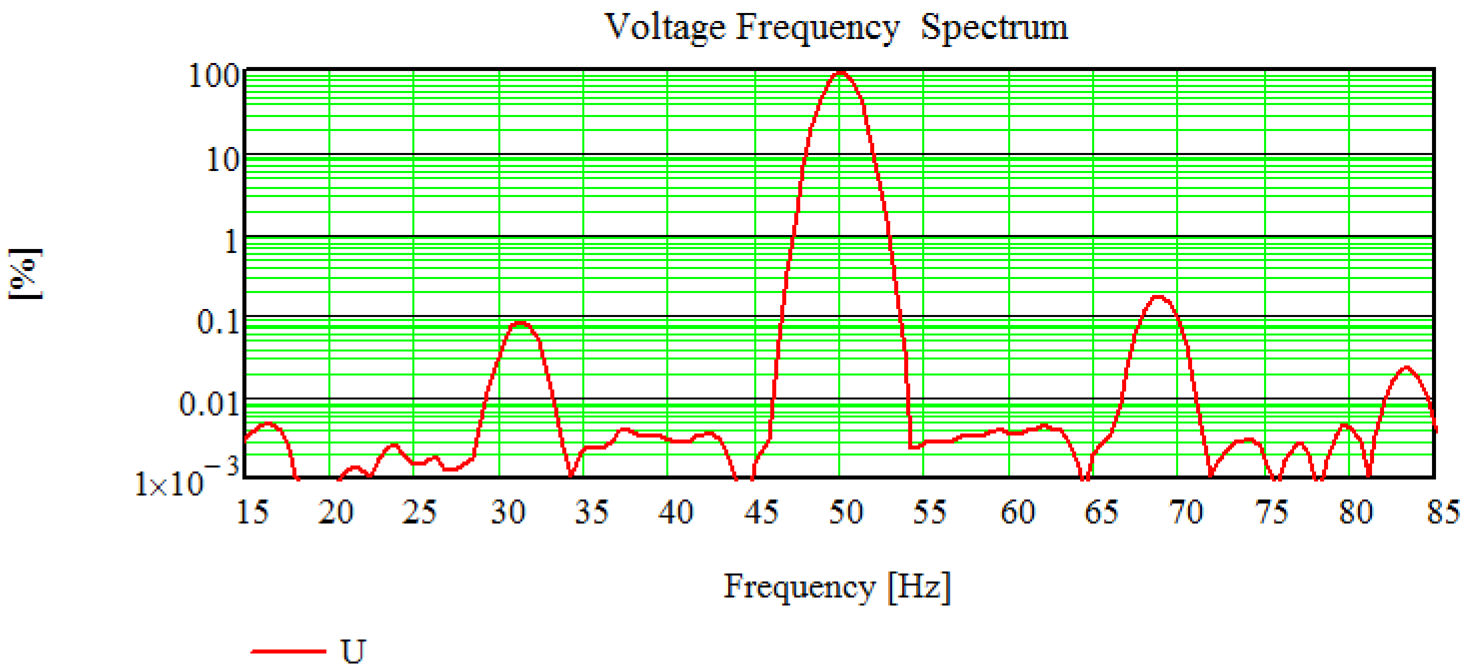


SSR Current Detection Challenge



- Existing SSR equipment only look at Sub-Synchronous currents.
- SSR Current from 0,1% up to several percent of fundamental component.
- Extremely good filtering is required.
- SSR currents depends on the power system impedance at SSR frequencies.

SSR Voltage Detection Challenge



- SSR voltages even smaller than the currents, but detectable.
- Theoretical studies gives:
  - SSR voltages are proportional to the torsional amplitude of the axis.
  - SSR voltages are proportional to SSR frequency, while currents are not.

Theoretical SSR voltage amplitudes

- The instantaneous angular velocity of single phase synchronous machine:

$$\omega(t) = \omega_n + \Delta\Omega \cos(\omega_p t)$$

$\omega_n =$ *Average angular velocity*

$\omega_p =$ *Torsional mechanial resonance*

$\Delta\Omega =$ *Angular velocity deviation*

- The induced voltage in the stator:

$$u(t) = \frac{d}{dt}\left\{A \cdot B_m \sin\left[\omega_n t + \frac{\Delta\Omega}{\omega_p}\sin(\omega_p t)\right]\right\}$$

$A =$ *Number of turns and area of stator winding*

$B_m =$ *Magnetic air-gap field*

$$u(t) = \omega_n A \cdot B_m \left\{\cos(\omega_n t) + \frac{\Delta\Omega}{2\omega_n\omega_p}(\omega_n + \omega_p)\cos\left[(\omega_n + \omega_p)t\right] - \right.$$

$$\left. - \frac{\Delta\Omega}{2\omega_n\omega_p}(\omega_n - \omega_p)\cos\left[(\omega_n - \omega_p)t\right]\right\}$$

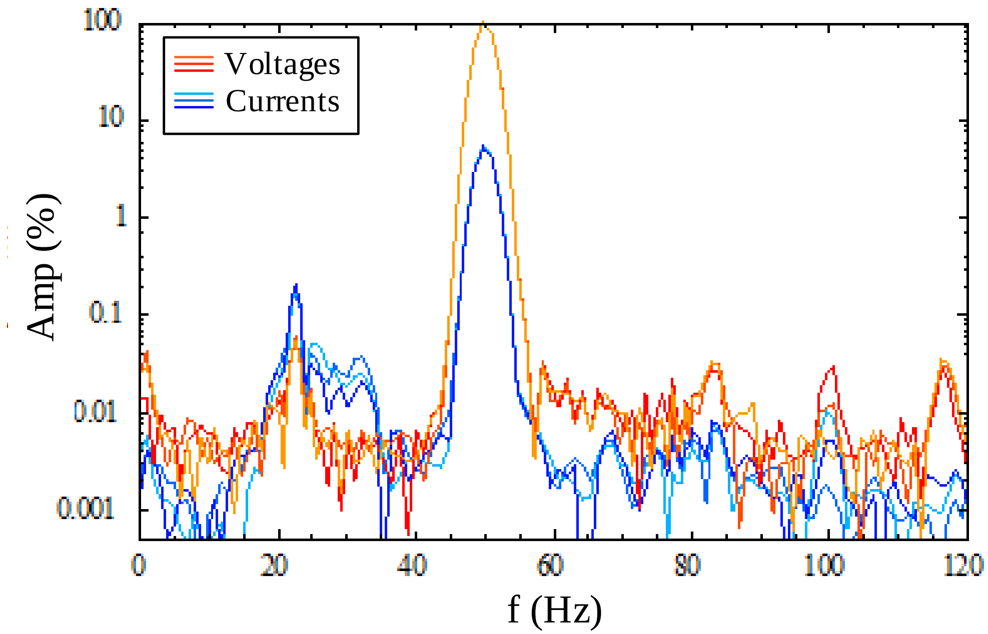
- From this expression we note an amplitude dependence of super and sub synchronous voltages, connected to frequency modes

$$\frac{|U|_{super}}{|U|_{sub}} = \frac{\omega_n + \omega_p}{\omega_n - \omega_p} = \frac{f_{super}}{f_{sub}}$$

Consequences of the amplitude relation

The relation between the SSR voltages can be used to reject non SSR disturbances.

- If not both sub and super frequencies observed => No SSR
- If amplitudes are not approximate agreement with the relation => No SSR.
- The previous SSR protection has sometimes reacted on non-SSR disturbances, possibly like the one shown.



This story continues with

- Tord Bengtsson presents more results from the field studies and some information on the filter function.
- Zoran Gajic presents the overall design of the SSR protection.

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