Vorlesungen Mechatronik im Wintersemester

Energiforsk – Vibration Seminar
Stockholm, November 9th 2023

TECHNISCHE
UNIVERSITÄT
DARMSTADT

Sub Synchronous Resonance (SSR) – A Serious Electromechanical Interaction in Turbogenerators

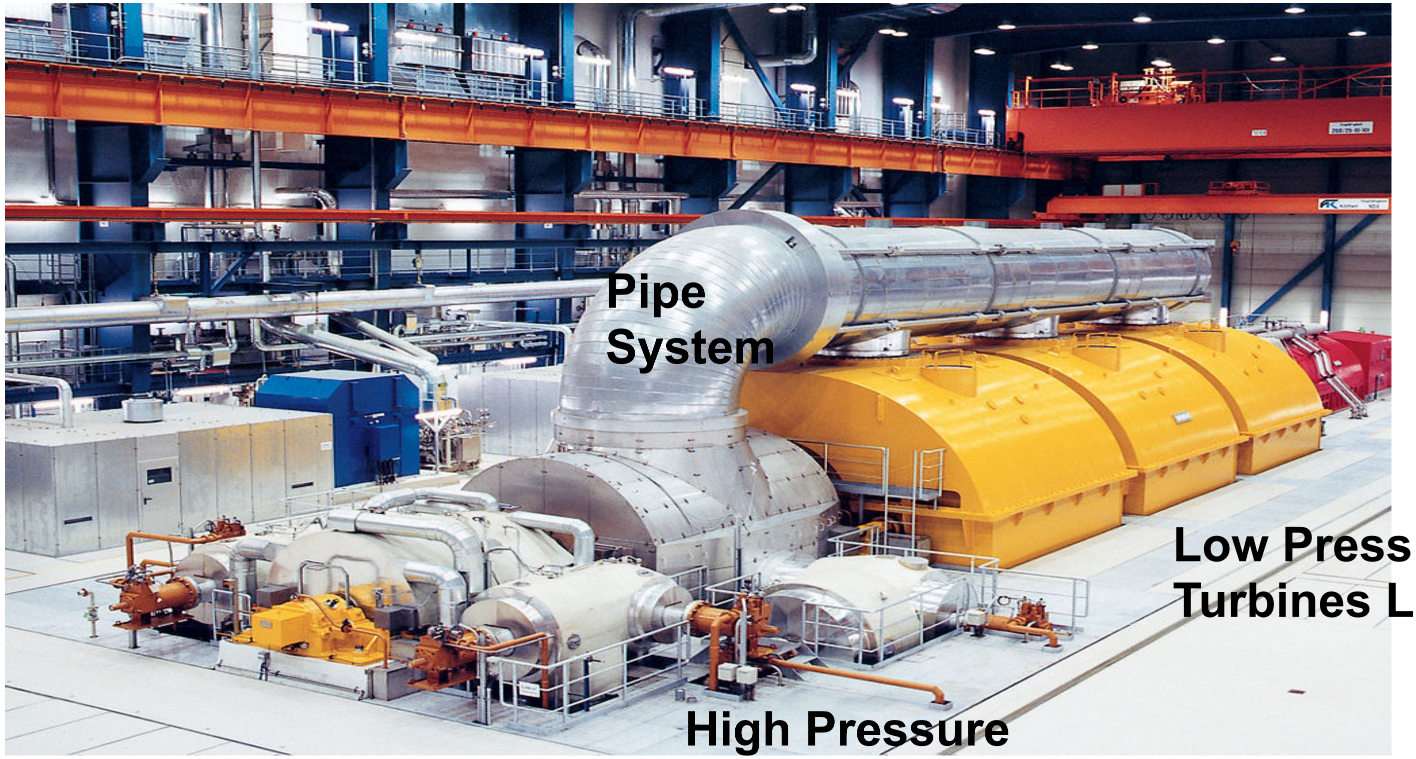
Rainer Nordmann, Sven Herold
Technische Universität Darmstadt and Fraunhofer Institute LBF

Sub Synchronous Resonance (SSR) –
A Serious Electromechanical Interaction in Turbogenerators

- Definition of Sub Synchronous Resonance (SSR)
- Torsional Vibrations of a Turbogenerator due to Air Gap Torques
- A simple Electrical Model with Series Compensation
- Electrical Natural Frequency and Impedance Function
- Mechanical Model for Torsional Vibrations of a Turbogenerator
- Torsional Natural Frequencies and Mode Shapes
- Sub Synchronous Resonance in the Turbogenerator OL3

Definition of Sub Syncronous Resonance (SSR)

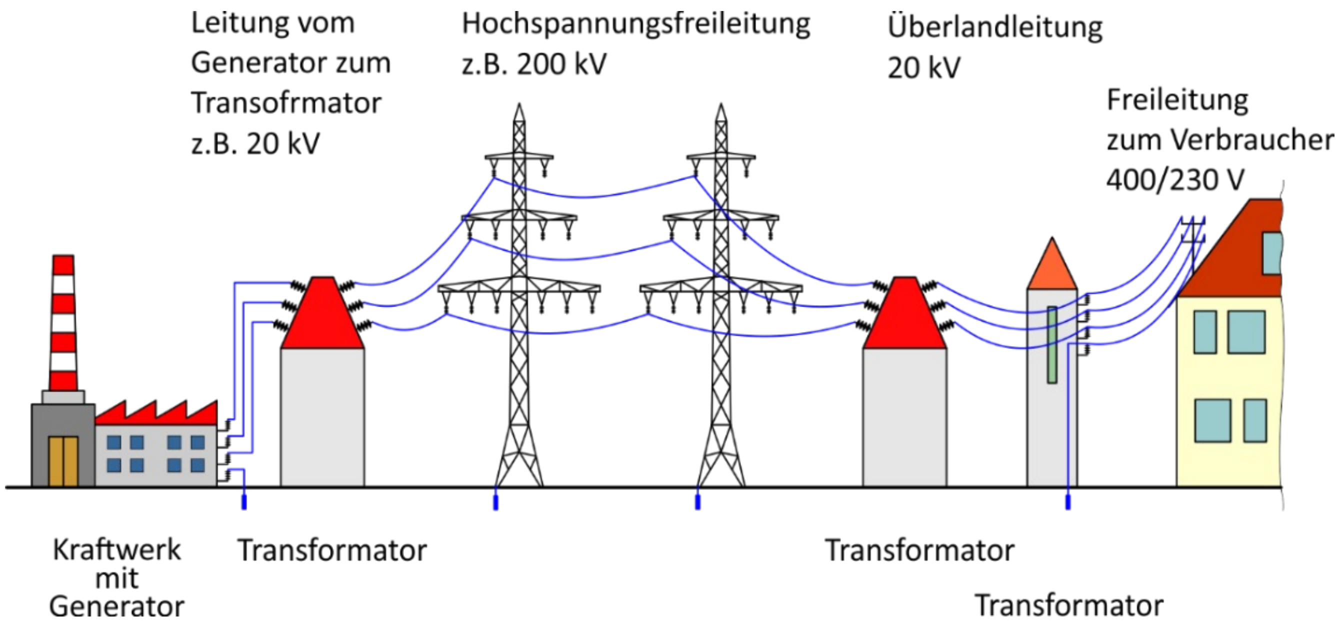
Turbogenerator System with Mechanical Components

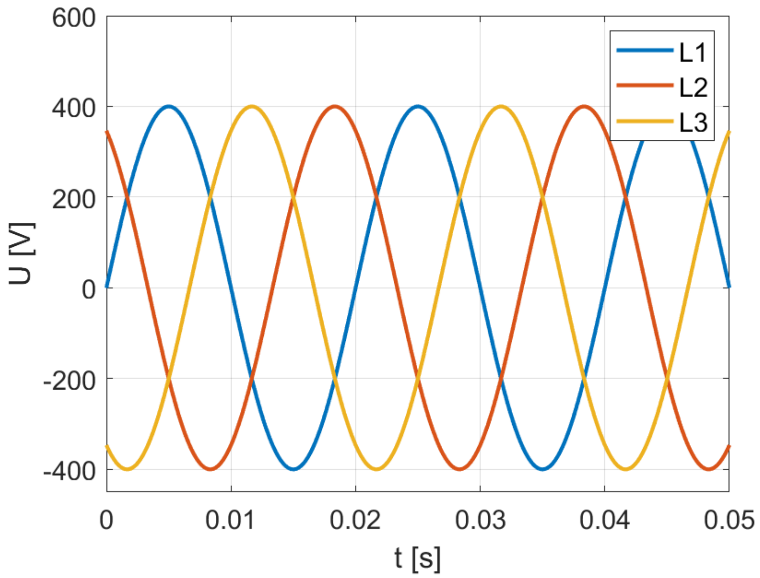


Turbogenerator System with **Mechanical Components**

Definition of Sub Syncronous Resonance (SSR)

Turbogenerator System (Mech. + Electr.) and the Electrical Grid

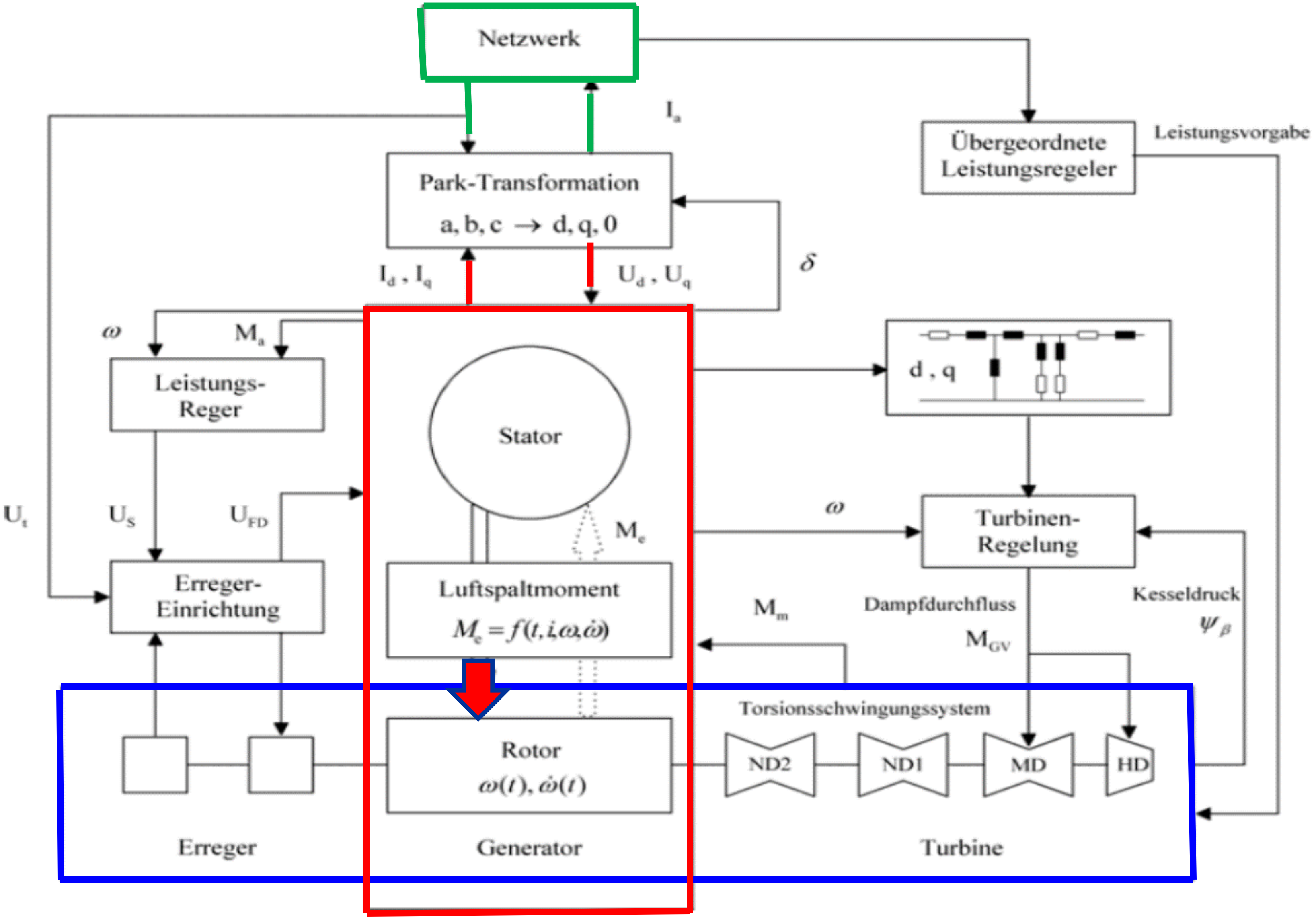




The Turbogenerator System with **Mechanical** and **Electrical** Components and the **Electrical Grid** System

Definition of Sub Syncronous Resonance (SSR)

Block-Diagram: Turbogenerator System (Mech. + Electr.) and Electrical Grid



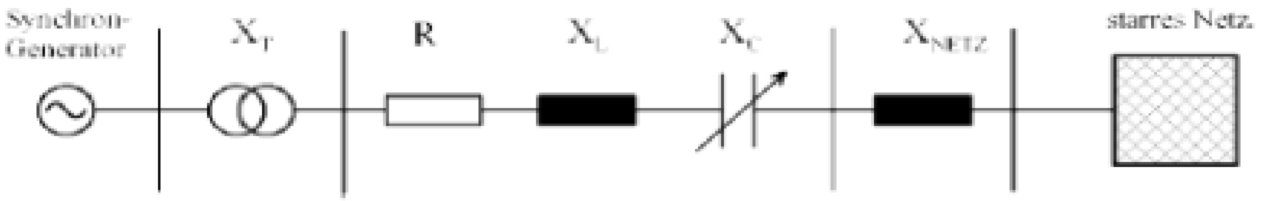
Electrical Grid

Electrical Components of Turbogenerator

Mechanical Components of Turbogenerator

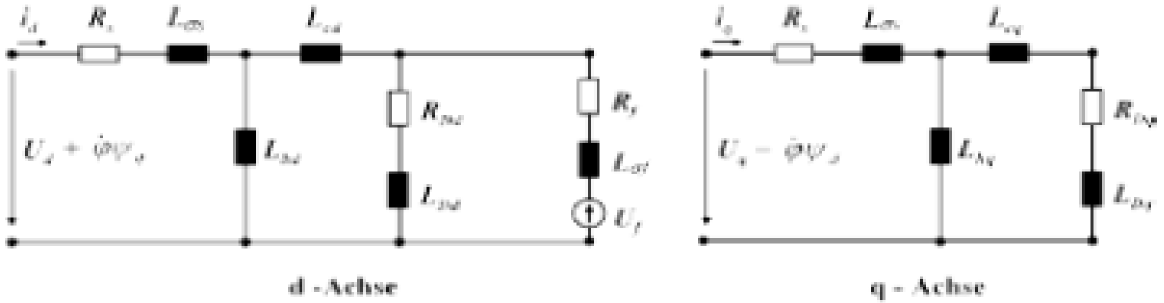
Definition of Sub Syncronous Resonance (SSR)

Model of the Turbogenerator System and the Electrical Grid



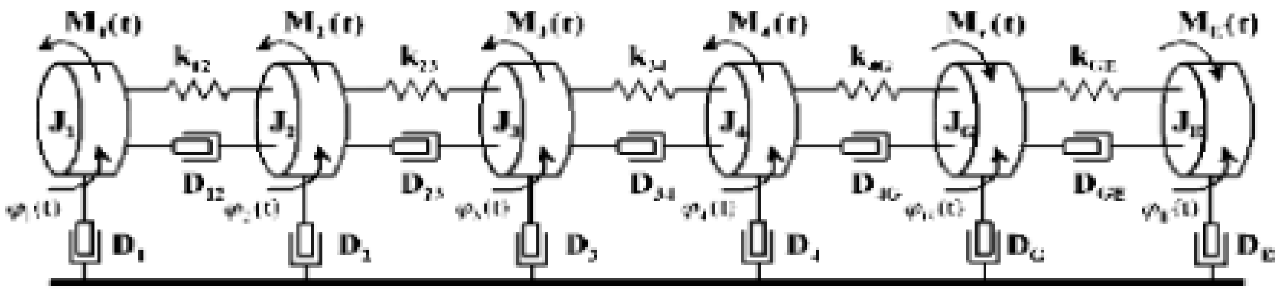
Model for the **Electrical Grid**

Park`sches Ersatzschaltbild



Model for the **Electrical Components of Turbogenerator**

Feder-Masse-Modell



Model for the **Mechanical Components of Turbogenerator**

Definition of Sub Synchronous Resonance (SSR)

Energy Exchange between the Mechanical and the Electrical System

---

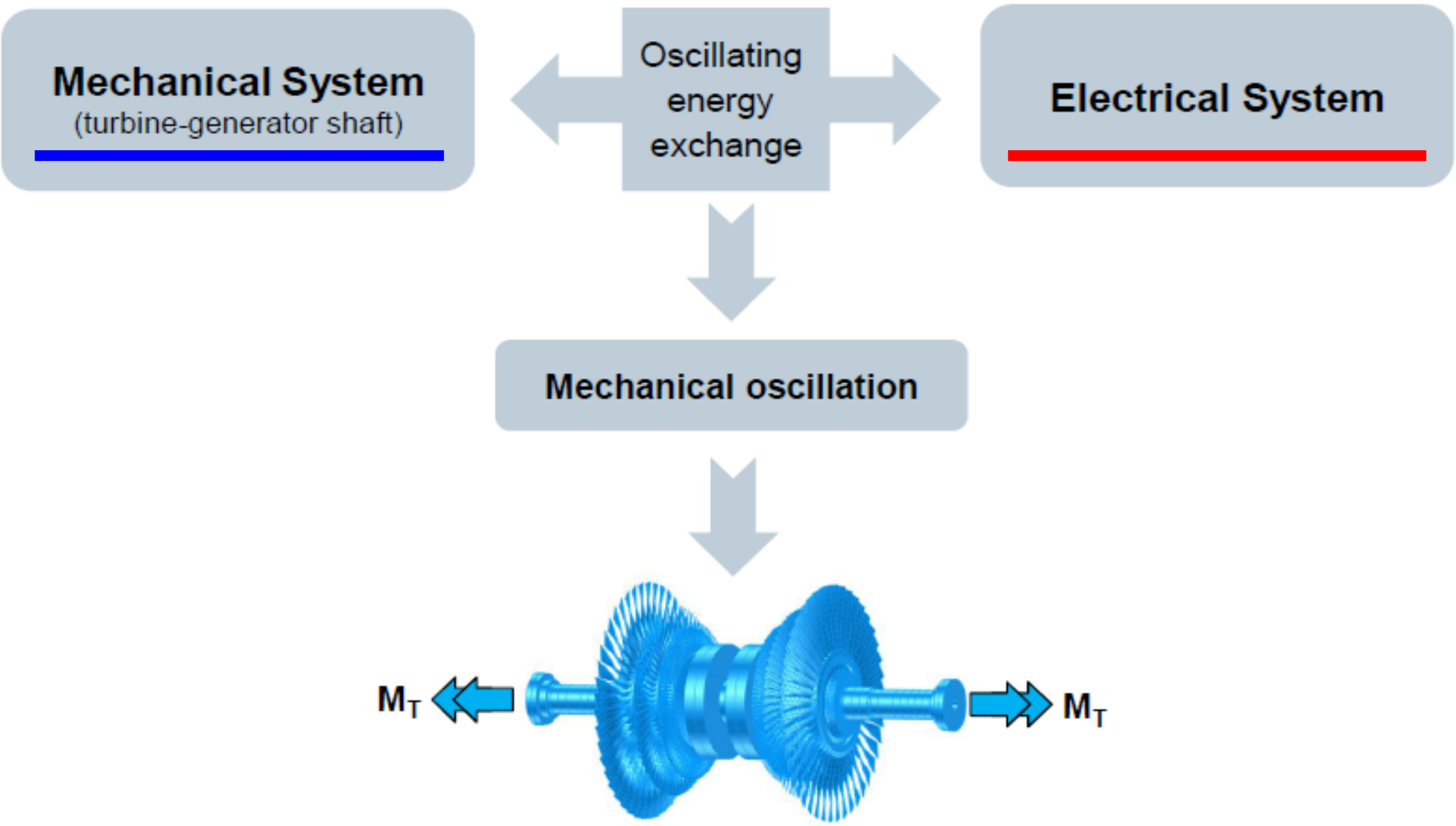
Sub Synchronous Resonances are oscillations in the **electrical** and **mechanical** systems, which can occur when turbine generator units feed into a network, where long lines are compensated by **series capacitors**.

Triggered by a **fault** or by **switching operations** in the **electrical system,** which represents an electrical resonant circuit, an **exchange of energy** between **the mechanical shaft** and the inductive and capacitive elements of the **electrical circuit** will occur.

The resulting currents generate **low frequency electrical torques** in the generator **air gap**. If the frequencies of these torques are in the vicinity of one of the lowest torsional natural frequencies, the shaft assembly will be excited to **strong resonant torsional vibrations (SSR).**

Definition of Sub Synchronous Resonance (SSR)

Energy Exchange between the Mechanical and the Electrical System



Mechanical System
(turbine-generator shaft)

Oscillating energy exchange

Electrical System

Mechanical oscillation

Definition of Sub Synchronous Resonance (SSR)

Energy Exchange between the Mechanical and the Electrical System

---

In order to predict **Sub Synchronous Resonances** it is necessary to model the system with the greatest possible accuracy, both for the **entire network** with series and parallel capacitances as well as for the **electrical part** of the **generator** and the **mecanical shaft assembly**.

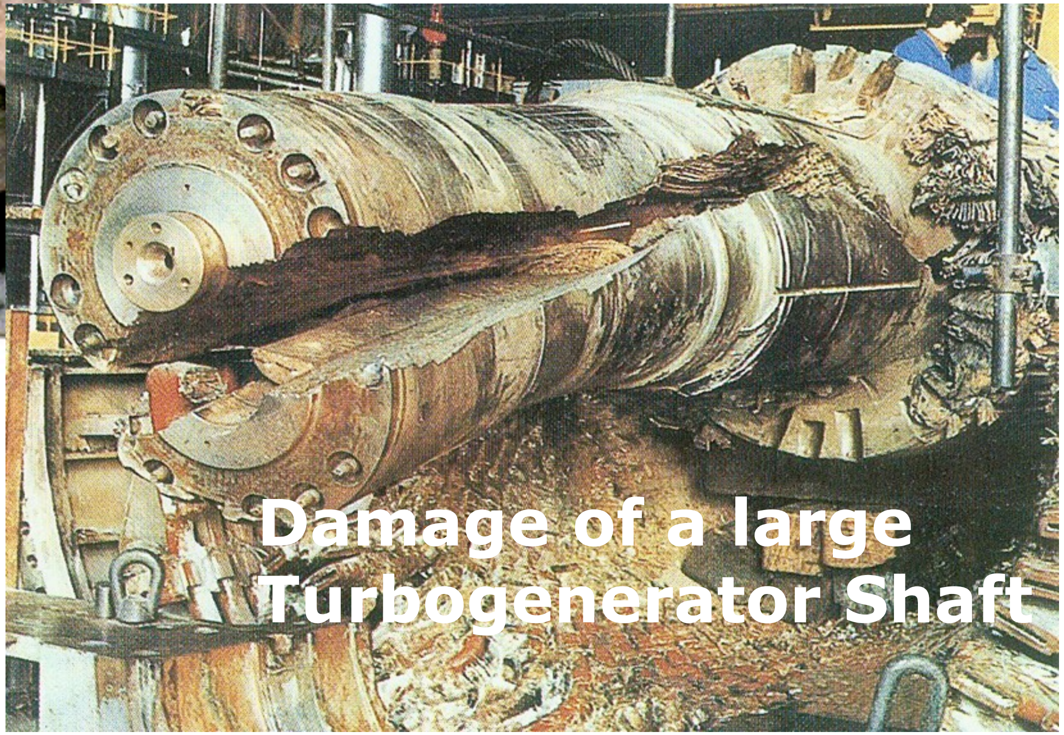
The „electro-mechanical damping“ is generally low or even negative. In case of a **negative damping** the torsional vibrations will increase (instability!), which may lead to impermissibly **high stresses** and even to **damages**.

Definition of Sub Synchronous Resonance (SSR)

Damages due to Energy Exchange between Mechanical and Electrical System

Coupling Damage

Bild 1 Bohrungen 4-6



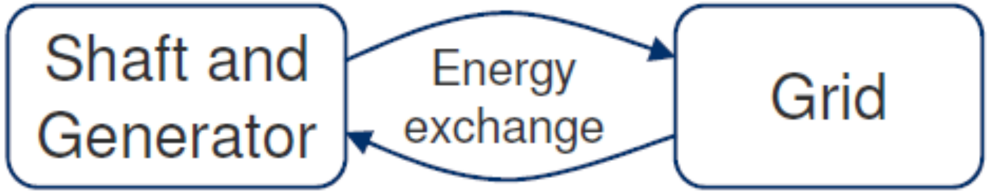
Damage of a large Turbogenerator Shaft

Definition of Sub Synchronous Resonance (SSR)

IEEE (**I**nst. of **E**lectrical & **E**lectronical **E**ngineers): Terms and Definition for SSR

Sub-synchronous resonance is an electric power system condition where the electric network exchanges energy with a turbine generator at one or more of the natural frequencies of the combined system below the synchronous frequency of the system.

(IEEE SSR Working Group, "Proposed Terms and Definitions for Subsynchronous Resonance," IEEE Symposium on Countermeasures for Subsynchronous Resonance, IEEE Pub. 81TH0086-9-PWR, 1981,p 92-97.)



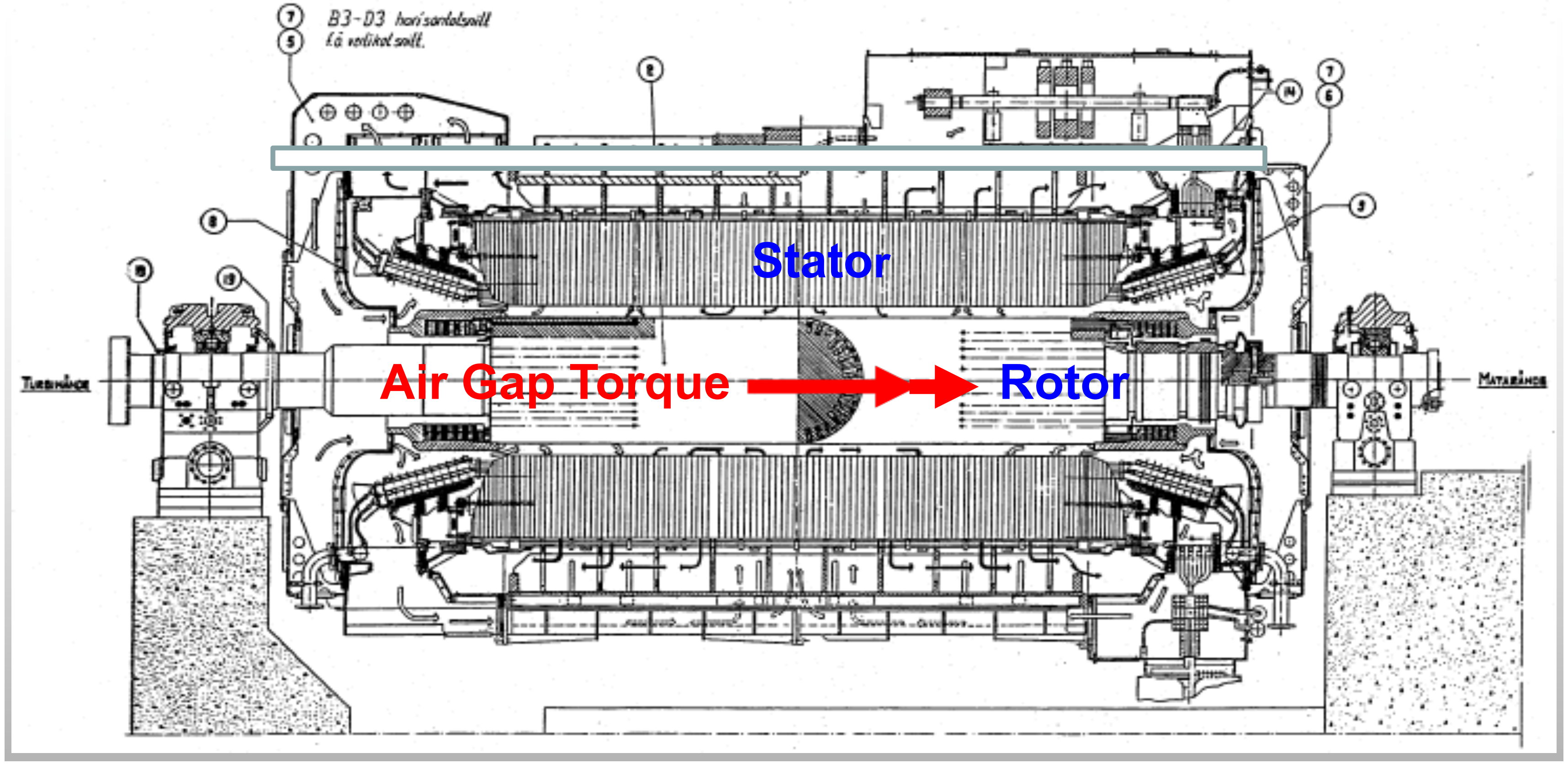
Natural frequencies
below the synchronous frequency

Sub Synchronous Resonance (SSR) – A Serious Electromechanical Interaction in Turbogenerators

- Definition of Sub Synchronous Resonance (SSR)
- Torsional Vibrations of a Turbogenerator due to Air Gap Torques
- A simple Electrical Model with Series Compensation
- Electrical Natural Frequency and Impedance Function
- Mechanical Model for Torsional Vibrations of a Turbogenerator
- Torsional Natural Frequencies and Mode Shapes
- Sub Synchronous Resonance in the Turbogenerator OL3

Torsional Vibrations of a Turbogenerator due to Air Gap Torques

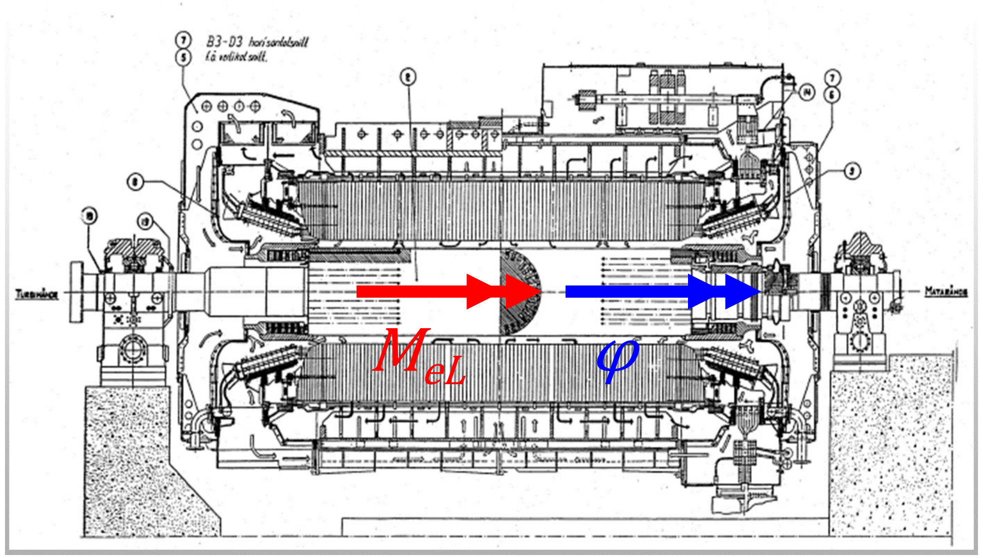
Generator Cross Section with Rotor and Stator



Torsional Vibrations of a Turbogenerator Shaft Train can be excited by **Air Gap Torques,** generated due to **Electro-Mechanical** Interaction

Torsional Vibrations of a Turbogenerator due to Air Gap Torques

Air Gap Torque due to Electro-Mechanical Interaction



$$M_{eL} = \frac{d}{d\varphi} \sum_{j=1}^{n} \sum_{k=1}^{m} L_{j,k}^{S,L}(\varphi) \cdot i_j^S(t) \cdot i_k^L(t)$$

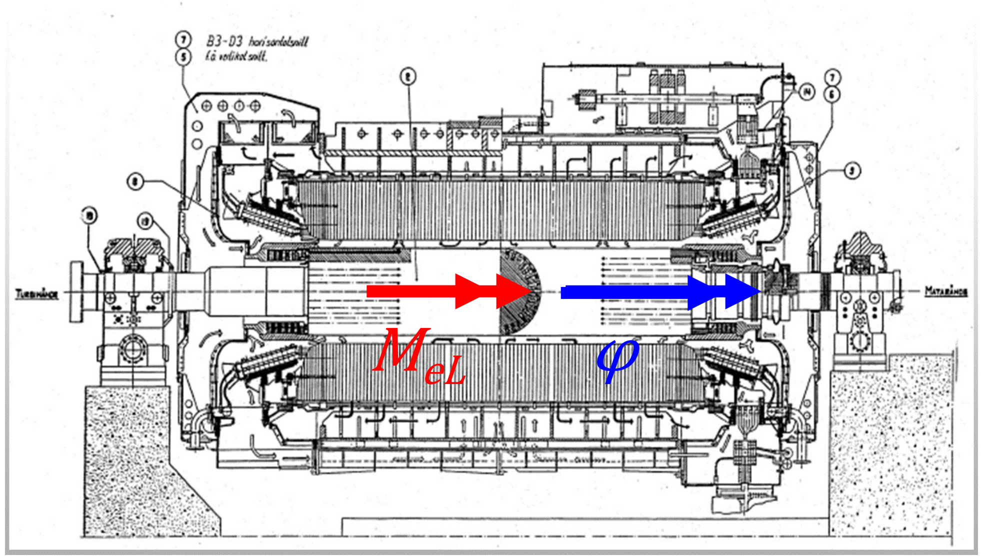
Kulig,S.: „Simulation Models for Calculating The Tosional Vibrations ...“ Springer 1981

Due to **electrical disturbances** or **switcing operations** in the generator-grid system transient **Air gap torques** M_{eL} will be generated, which excite the shaft train to **Torsional vibrations**.

The time dependent **Air gap torque** M_{eL} depends on **electrical quantities - currents** in the rotor- and stator-windings and the **coupling Inductances -** and on **mechanical quantities**.

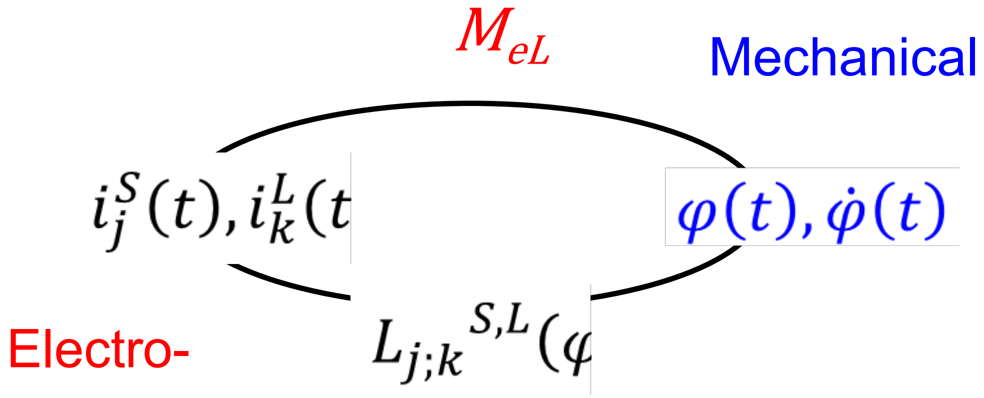
Torsional Vibrations of a Turbogenerator due to Air Gap Torques

Air Gap Torque due to Electro-Mechanical Interaction



Air Gap Torque:

$$M_{eL} = \frac{d}{d\varphi} \sum_{j=1}^{n} \sum_{k=1}^{m} L_{j,k}^{S,L}(\varphi) \cdot i_j^S(t) \cdot i_k^L(t)$$



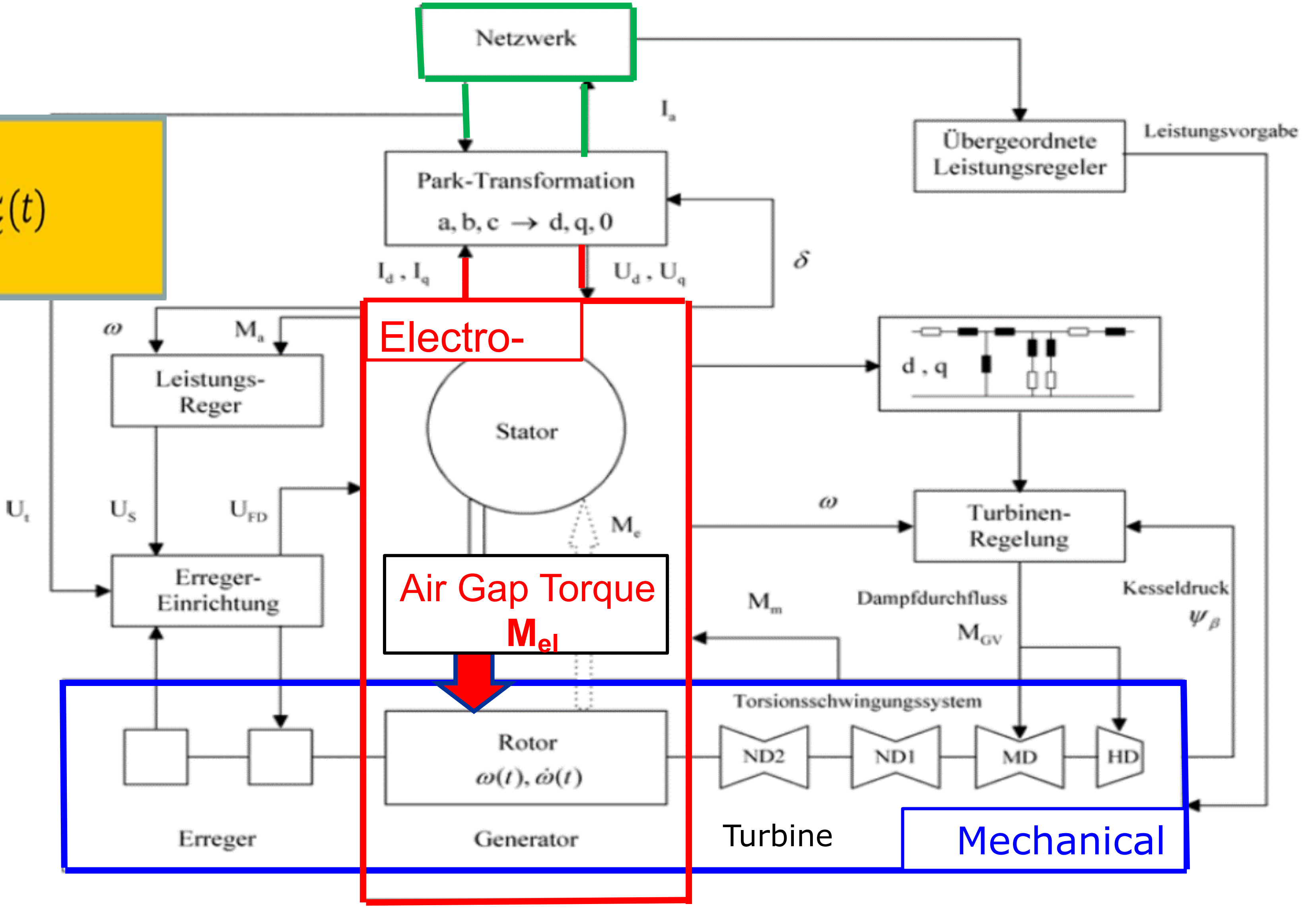
Electro-Mechanical Interaction in the **Air Gap**.

Torsional Vibratios of a Turbogenerator due to Air Gap Torques

Air Gap Torque due to Electro-Mechanical Interaction

$$M_{eL} = \frac{d}{d\varphi} \sum_{j=1}^{n} \sum_{k=1}^{m} L_{j,k}^{S,L}(\varphi) \cdot i_j^S(t) \cdot i_k^L(t)$$

The **Air Gap Torque M_{el}** is a function on several parameters of the overall system. They influence the **currents** i_j^S, i_k^L in the rotor and stator windings and the **inductances** $L_{j,k}$ in the formula of the **Air Gap Torque**

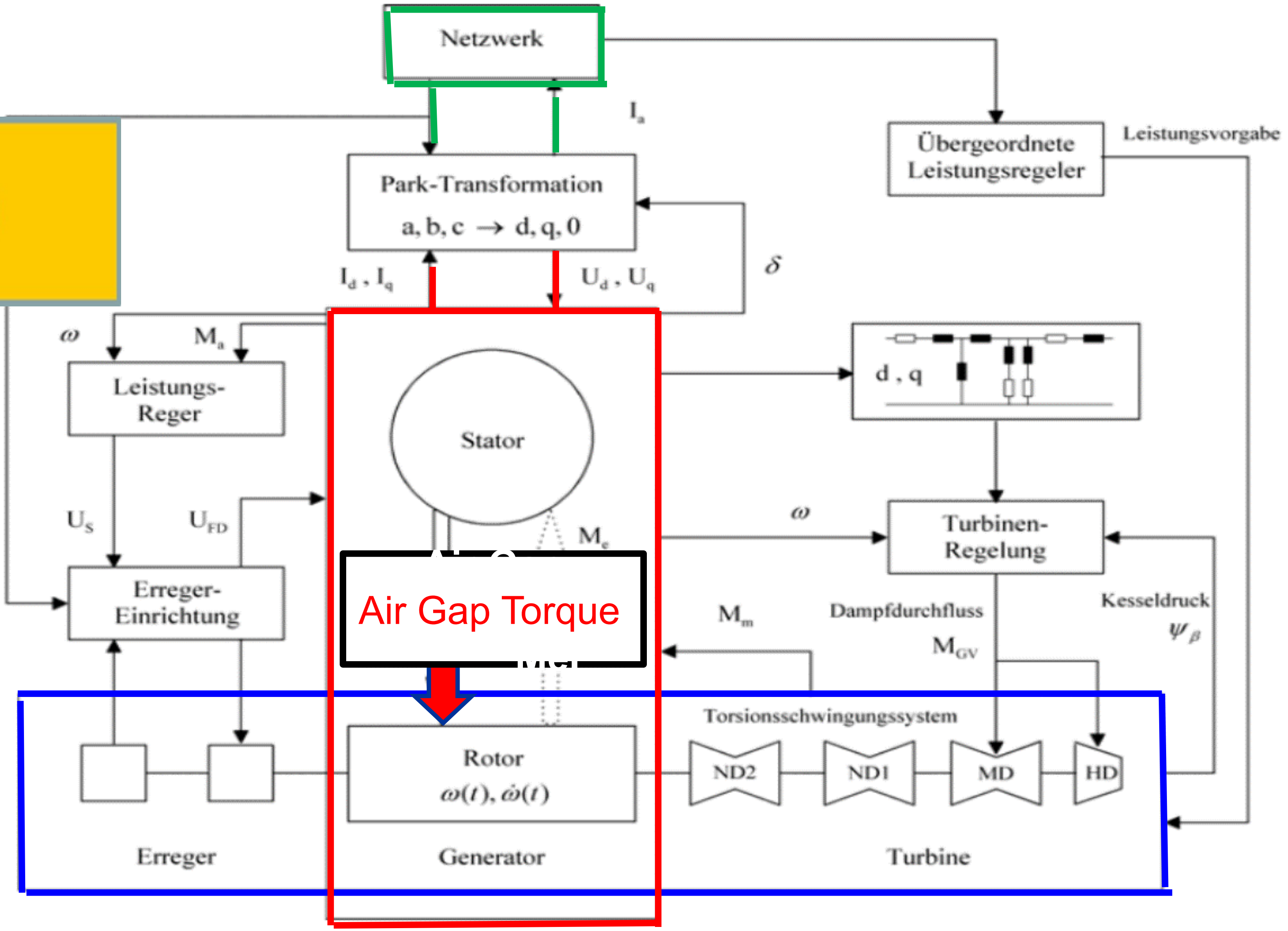


Torsional Vibrations of a Turbogenerator due to Air Gap Torques

Air Gap Torque due to Electro-Mechanical Interaction

$$M_{eL} = \frac{d}{d\varphi} \sum_{j=1}^{n} \sum_{k=1}^{m} L_{j,k}^{S,L}(\varphi) \cdot i_j^S(t) \cdot i_k^L(t)$$

Important questions are, which **frequencies** are included in the **Air Gap Torque M_{el}** and which of these frequencies can excite **torsional vibrations** of the shaft train of the **Turbogenerator ?**



Torsional Vibrations of a Turbogenerator due to Air gap Torques

Frequency content in the Air Gap Torque in an SSR event

For the further discussion we define the following **frequencies**:

- The **grid synchronous frequency** : $f_S = \omega_S / 2\pi = 50$ Hz
- The **electrical natural frequencies** of the electrical system (generator and grid). i = 1, 2,..I : $f_E^{\,i} = \omega_E^{\,i} / 2\pi$ Hz
- The **mechanical torsional natural frequencies** of the Turbogenerator shaft train. j = 1,2,..J : $f_M^{\,j} = \omega_M^{\,j} / 2\pi$ Hz

Torsional Vibrations of a Turbogenerator due to Air gap Torques

Frequency content in the Air Gap Torque in an SSR event

After an occurence of a **fault in the electrical system** oscillating currents with **electrical natural frequencies** f_E^i are produced in the power system. Due to these **additional** electrical resonant currents the **Air Gap Torque** consists now of the frequencies:

- the rated **grid synchronous frequency** $f_S = 50$ Hz and
- the **electrical natural frequencies** f_E^i sub sychronous

Example: In case of one dominant electrical Natural frequency f_E^i the frequency content of the **Air Gap Torque** will be equal to the **difference**: $f_{AGT} = (f_S - f_E^i)$

Torsional Vibrations of a Turbogenerator due to Air gap Torques

Conditions for **S**ub **S**ynchronous **R**esonance (**SSR)**

If one of the frequencies $(f_S - f_E^i)$ is in the vicinity of one of the lowest **mechanical torsional natural frequencies** f_M^j, the shaft assembly will be excited to **strong resonant torsional vibrations.**

The conditions for **Sub Synchronous Resonance** are:

$$\boxed{f_M^j = (f_S - f_E^i) = f_{AGT} = f_{SSR}^i}$$

f_M^j	Torsional natural frequency of the Shaft
f_E^i	Electrical natural frequency
f_S	Synchronous frequency of the Grid

Sub Synchronous Resonance (SSR) – A Serious Electromechanical Interaction in Turbogenerators

- Definition of Sub Synchronous Resonance (SSR)
- Torsional Vibrations of a Turbogenerator due to Air Gap Torques
- A simple Electrical Model with Series Compensation
- Electrical Natural Frequency and Impedance Function
- Mechanical Model for Torsional Vibrations of a Turbogenerator
- Torsional Natural Frequencies and Mode Shapes
- Sub Synchronous Resonance in the Turbogenerator OL3

A simple Electical Model with Series Compensation

Complement of the electrical natural frequencies

- In order to evaluate the **SSR-Sensitivity** of a Turbogenerator-System with its mechanical and electrical components and the Electrical Grid, the conditions for a Sub Synchronous Resonance have to be studied.

- As shown before, the probability for an **SSR event** is high, if one of the **torsional natural frequencies** f_M^j is close to the **complement** of the **electical natural frequencies**: (f_S - f_E^i).

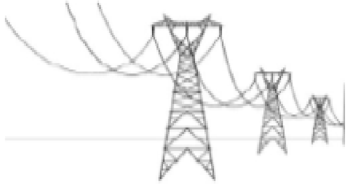
- The key for the evaluation of an SSR event is therefore the knowledge of the **electrical natural frequencies** f_E^i and the **natural frequencies** f_M^j

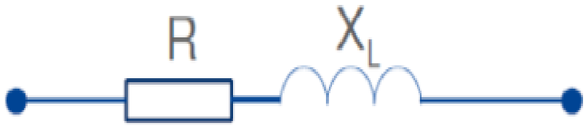
- In the following explanation we start with a very **simple Model** of an **Electrical System** (Generator plus Grid) with series compensation.

A simple Electrical Model with Series Compensation

Transmission Lines with Series Compensation

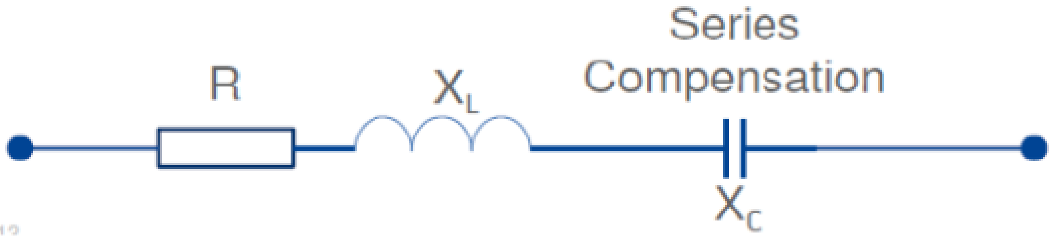
- Transmission Lines are mainly characterized by series Inductive Reactance $X_L = L\,\omega_S$ and by a Resistance R





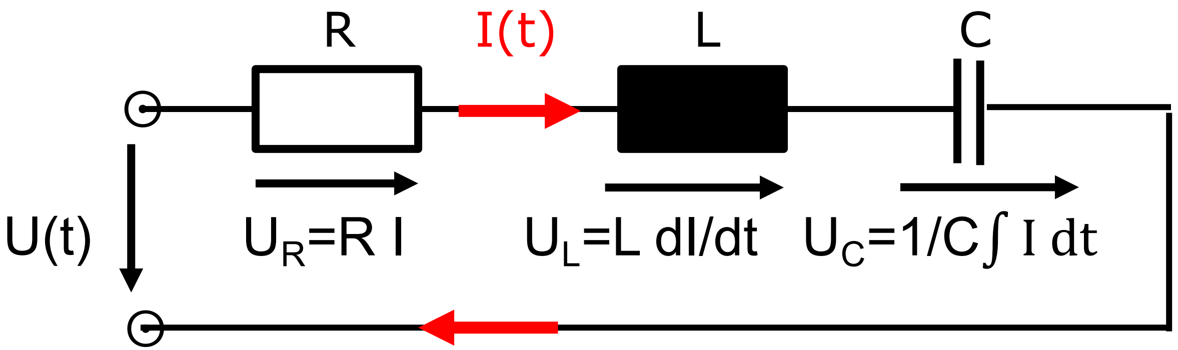
- The X_L value can limit the maximum allowable transfer, especially across long lines

- Additional in **series-connected capacitors** $X_C = 1/\,(C\,\omega_S)$ reduce the total reactance and increase the maximum transfer across the line.



A simple Electrical Model with Series Compensation

Simple Electrical Circuit Model (Grid plus Generator)



Diff. Equation for the **Electrical Circuit**:

$$R\,I + L\,dI/dt + 1/C \int I\,dt = U(t)$$

U(t) Voltage, I(t) Current, R Resistance, L Inductance, C Capacity

This very **simple Electric Circuit Model** shows the basic components of an electric circuit. A real Electrical Model contains much more electrical components of the Grid and in addition also components of the electrical part of the Generator.

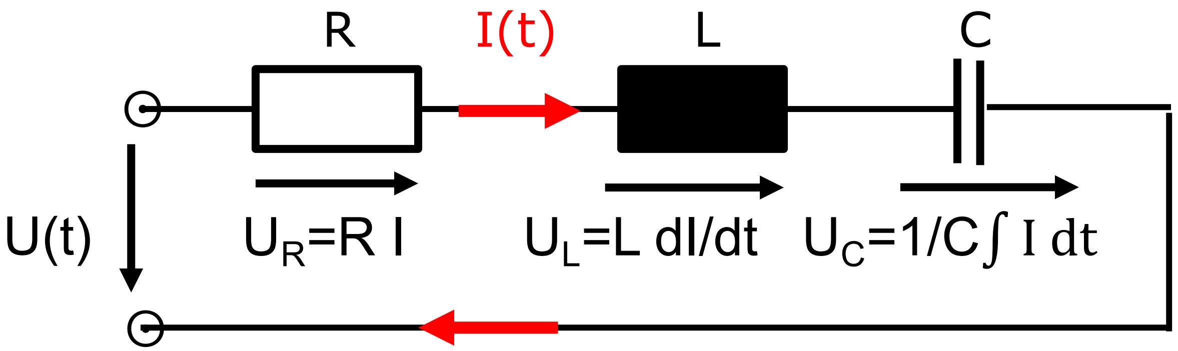
However, with this simple model we can explain in an easy way the basic relations for an **Sub Synchronous Resonance (SSR)** event and how the electrical natural frequencies and the Impedance function can be determined and used for an evaluation of SSR.

Sub-Synchronous Resonance in Turbogenerators – A Serious Torsional Vibration Problem

- **Definition of Sub Synchronous Resonance (SSR)**
- **Torsional Vibrations of a Turbogenerator due to Air Gap Torques**
- **A simple Electrical Model with Series Compensation**
- **Electrical Natural Frequency and Impedance Function**
- **Mechanical Model for Torsional Vibrations of a Turbogenerator**
- **Torsional Natural Frequencies and Mode Shapes**
- **Sub Synchronous Resonance in the Turbogenerator OL3**

Electrical Natural Frequency and Impedance Function

Diff. Equations and Eigenvalues of the Electrical Model **with Resistance** R



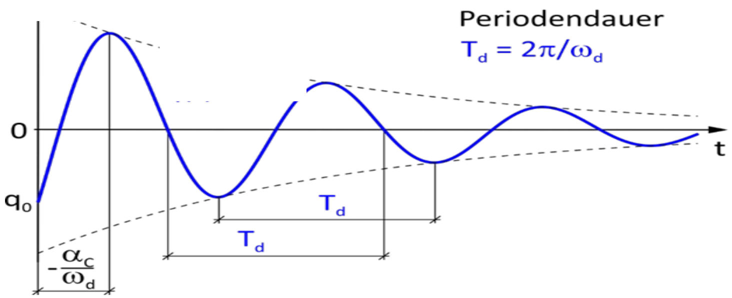
Diff. Equation for the **Electrical Circuit**:

$$R\,I + L\,dI/dt + 1/C \int I\,dt = U(t)$$

U(t) Voltage, I(t) Current, R Resistance, L Inductance, C Capacity

The electrical circuit has the following complex **Eigenvalues**

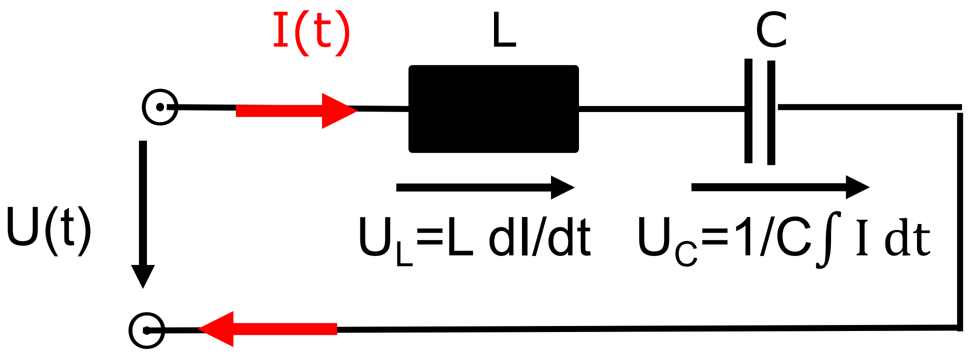
$$\lambda_{1,2} = \lambda_{real} \;+/-\; j\,\lambda_{imag} = -(R/2L) \;+/-\; j\sqrt{(1/CL) - (R/2L)^2}$$



They express: **Electrical Damping** **Electrical Natural Circular frequency $\omega_E = 2\pi f_E$**

Electrical Natural Frequency and Impedance Function

Diff. Equations and Eigenvalues of the Electrical Model **without Resistance** R



Diff. Equation for the **Electrical Circuit**:

$$\boxed{L\, dI/dt + 1/C \int I\, dt = U(t)}$$

$$\boxed{\lambda_{1,2} = +/- \; j\, \lambda_{imag} = +/- \; j \sqrt{(1/CL} \quad = +/- \; j\, \omega_E}$$

Electrical Natural Circular Frequency without Resistance: $\omega_E = \sqrt{1/CL}$

If we introduce the **Reactances** $X_L = L\, \omega_S$ and $X_C = 1/(C\, \omega_S)$ we obtain

$$\boxed{\omega_E = \omega_S \sqrt{(X_C / X_L)}}$$

ω_S Synchronous frequency of the Grid

Electrical Natural Frequency and Impedance Function

Electrical Natural Frequency of the Model **without Resistance**

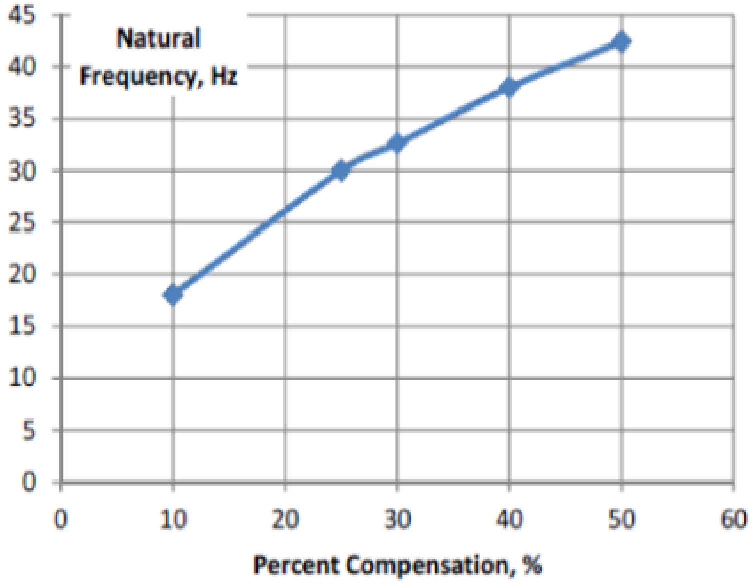
The Electrical Natural Circular Frequency ω_E of the circuit can be influenced by the Inductive and Capacitive Reactances X_L, X_C

$$\boxed{\omega_E = \omega_s \sqrt{(1\ X_C / X_L}}$$

ω_E - Electrical natural circular frequency

ω_s - Synchronous frequency of the Grid

X_L ,X_C - Inductice and Capacitive Reactances



Electrical Natural Frequency and Impedance Function

Impedance Function of the simple Electrical Circuit Model

The **Impedance Function** Imp is defined as the ratio **Voltage/Current** for the case of a **Harmonic** Excitation I(t) with a **circular frequency** ω

In complex notation $\underline{I}(t) = \underline{\hat{I}}\, e^{j \omega t}$, $\underline{U}(t) = \underline{\hat{U}}\, e^{j \omega t}$ (j = imaginary unit)
we obtain the Impedance Function Imp(j ω) for the simple Electrical Model

$$\mathrm{Imp}\,(j\omega) = \hat{U} / \hat{I} = \{ R + j\,\omega L + 1 / (j\,\omega C \} = \mathrm{Re}\,(\mathrm{Imp}) + j\,\mathrm{Im}\,(\mathrm{Imp})$$

$$\mathrm{Imp}\,(j\omega) = \hat{U} / \hat{I} = R + j\,(\omega L - 1 / \omega C) = R + j\,(X_L - X_C)$$

Electrical Natural Frequency and Impedance Function

Impedance Function of the simple Model of the Electrical Circuit

The following information can be obtained from the **Impedance Function**

- Re (Imp (jω)) : R expresses the **Resistance (damping)** of the simple Electrical circuit. In general if Re (Imp (j ω)) is negative, the Electrical system is unstable!
- Im (Imp (jω)) : If $(X_L - X_C) = 0$, then $\omega^2 = 1 / (L C) = \omega_E^2$
  Im (Imp (j ω) = 0 means, that the electrical grid is in a **Resonance Condition**.
  ω_E is the **Resonance Frequency** of the **Electrical Circuit**

Electrical Natural Frequency and Impedance Function

Example of an Impedance Function Imp (j ω)

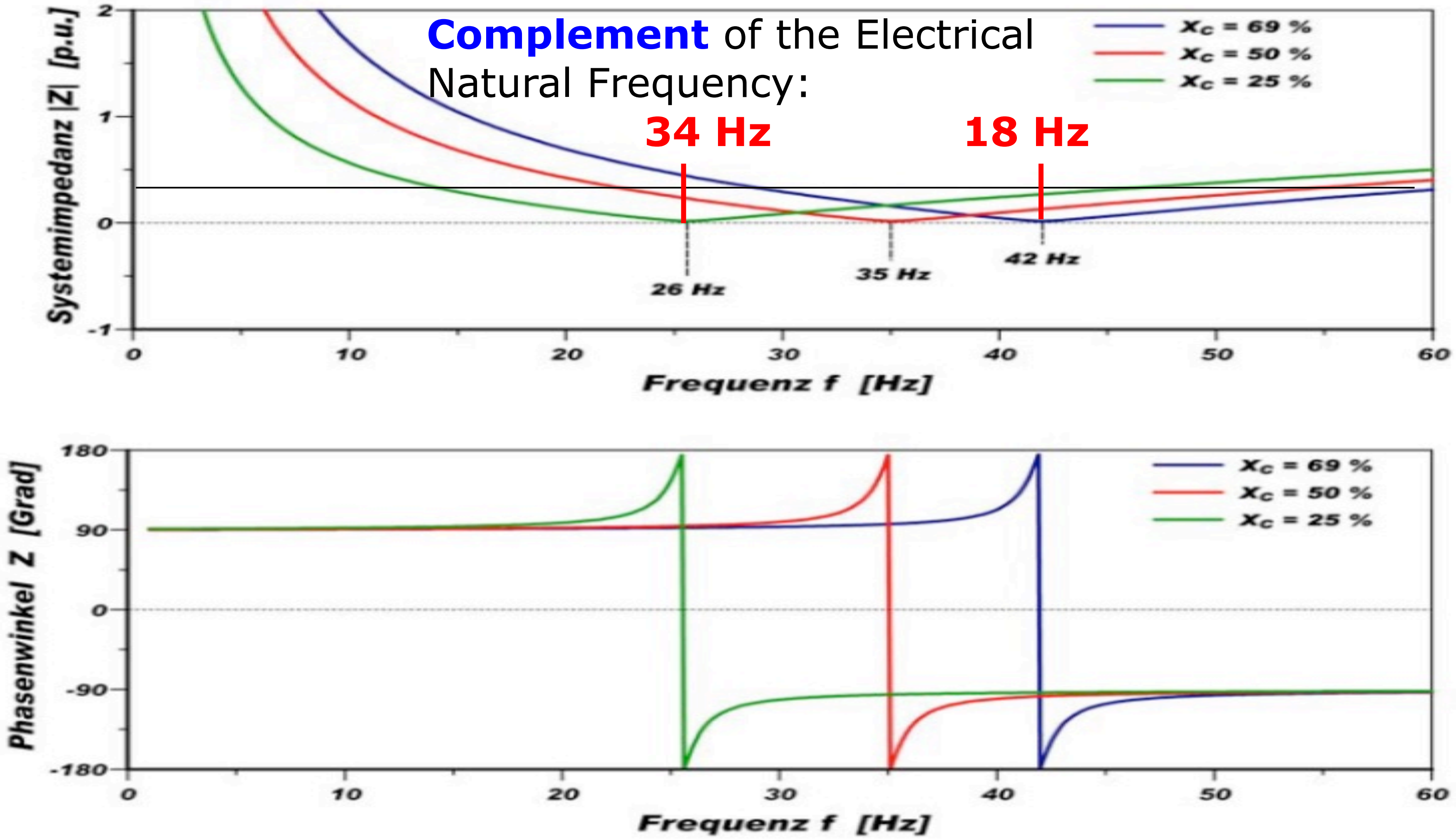
- The investigation of the **Impedance Function** of the Electrical System (Electrical part of the Generator and the Grid) is a suited method to predict the possible occurence of an SSR event.

- The following diagram shows an example of an **Impedance Function** in **Amplitude and Phase** presentation. Three cases of different compensation rates X_C are shown in the frequency range from 0 to 60 Hz.

- The **Electrical Resonance Frequencies** for the different compensations can be determined at frequencies, where the Amplitude of the Impedance Function is Zero (26 Hz, 35 Hz and 42 Hz). If in this 60Hz (synchr. frequency) application the **Mechanical Natural Frequencies** are at the **complement frequences** 18 Hz and/or 34 Hz, the conditions of an SSR event are most likely.

Electrical Natural Frequency and Impedance Function

Amplitude and Phase of an Impedance Function for different compensations



Complement of the Electrical Natural Frequency:

34 Hz

18 Hz

Electrical Natural Frequency and Impedance Function

Example of Impedance Functions of the Finish Grid close to OL3

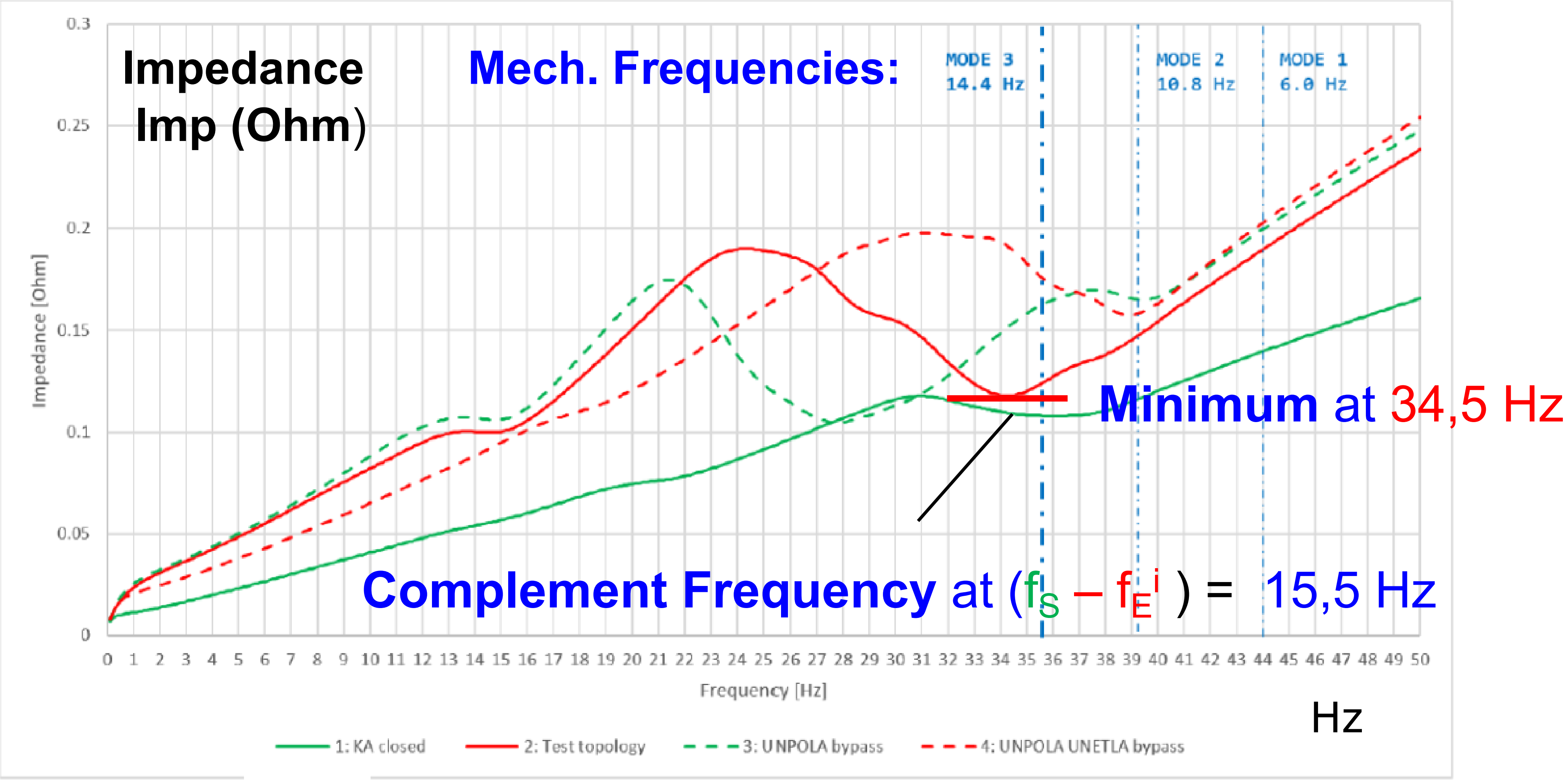
- The following diagram shows calculated frequency-dependent amplitudes of four **Impedance Functions** for different topologies of the **Finish Grid** close to the **OL3 Turbogenerator** System. The Impedance scans present the network plus the integrated Generator as seen from the Generator terminals.

- The solid red curve presents the Impedance Function of one topology, in which an **SSR event** occured in reality at the **OL3 Turbogenerator**. The calculated Impedance Function did not reach a value of zero, however a **minimum** has been predicted at a **frequency of** 34,5 Hz.

- If the frequency at this Minimum can be interpreted as one of the **electrical natural frequencies** $f_E^i = 34{,}5$ Hz of the Grid plus Generator, an occurence of **SSR** can be expected at the frequency of $(f_S - f_E^i) = 15.5$ Hz. This value fits quite well to one of the **torsional natural frequencies of** 14,4 Hz.

Electrical Natiural frequency and Impedance Function

Impedance Function of the Finish Grid close to the OL3 Turbogenerator



. Impedance from generator terminals as a function of frequency

Sub Synchronous Resonance (SSR) –
A Serious Electromechanical Interaction in Turbogenerators

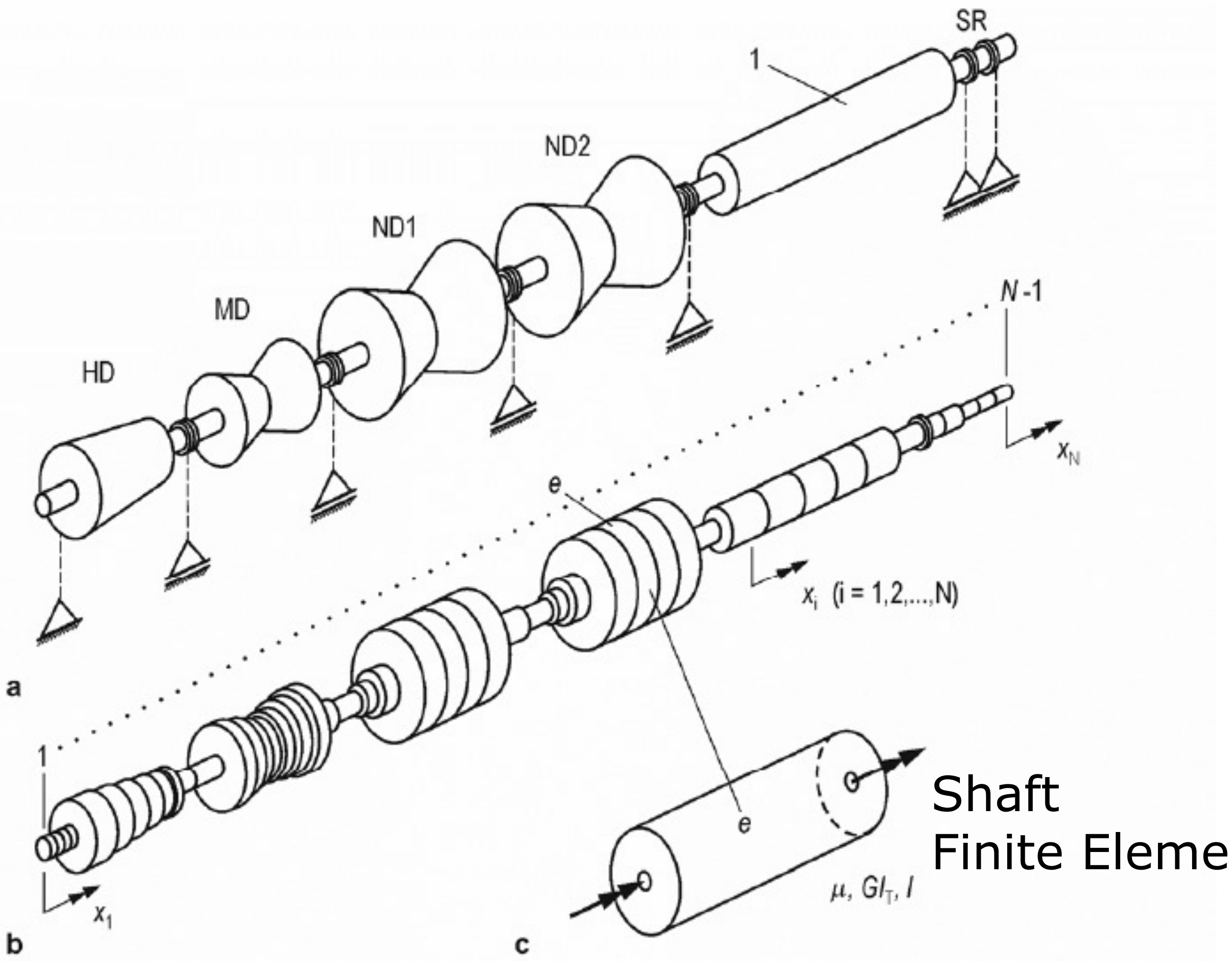
- Definition of Sub Synchronous Resonance (SSR)
- Torsional Vibrations of a Turbogenerator due to Air Gap Torques
- A simple Electrical Model with Series Compensation
- Electrical Natural Frequency and Impedance Function
- Mechanical Model for Torsional Vibrations of a Turbogenerator
- Torsional Natural Frequencies and Mode Shapes
- Sub Synchronous Resonance in the Turbogenerator OL3

Mechanical Model for Torsional Vibrations of a Turbogenerator

Mass and Stiffness Distribution along the Shaft Train (Finite Elements)

The **Mechanical Model** of a general **Turbogenerator Shaft Train** can be built up by means of the **Finite Element Method.**

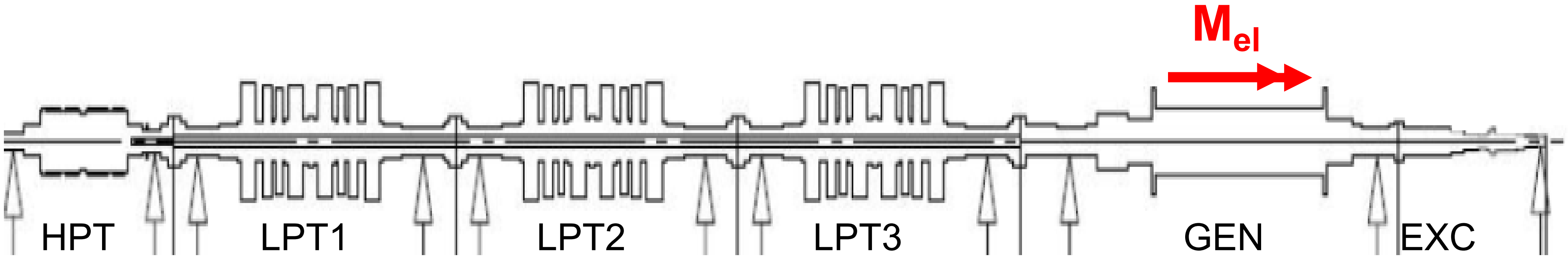
Each Finite Element will be described by its **length**, the **moment of inertia** and the **torsional stiffness.**



Shaft
Finite Element

Mechanical Model for Torsional Vibrations of a Turbogenerator

FE-Model and Equations of Motion for Torsional Vibrations



$$\boxed{\mathbf{M}\,\ddot{\mathbf{q}}\,(t) + \mathbf{D}\,\dot{\mathbf{q}}\,(t) + \mathbf{K}\,\mathbf{q}\,(t) = \mathbf{M}_{el}\,(t)}$$

The linear Equations of the Torsional Motion are built up of mass, damping and stiffness matrices of the shaft train and the torque vector $\mathbf{M}_{eL}(t)$ due to the **Electro-Mechanical Interaction** in the **Air Gap**.

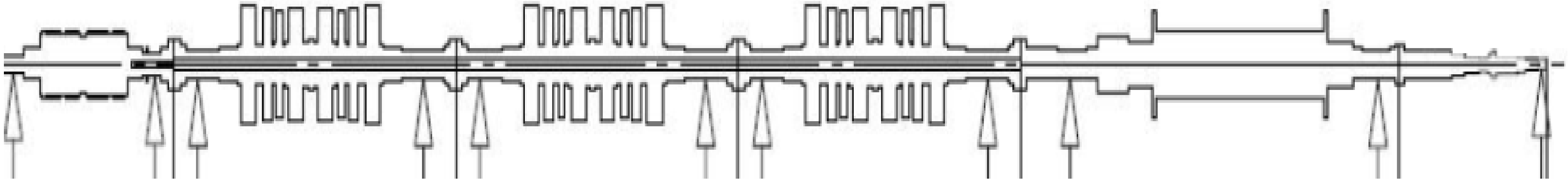
q (t) is the vector of the angular displacements.

Sub Synchronous Resonance (SSR) –
A Serious Electromechanical Interaction in Turbogenerators

- Definition of Sub Synchronous Resonance (SSR)
- Torsional Vibrations of a Turbogenerator due to Air Gap Torques
- A simple Electrical Model with Series Compensation
- Electrical Natural Frequency and Impedance Function
- Mechanical Model for Torsional Vibrations of a Turbogenerator
- Torsional Natural Frequencies and Mode Shapes
- Sub Synchronous Resonance in the Turbogenerator OL3

Torsional Natural Frequencies and Mode Shapes

Assessment of Torsional Vibrations in the Design – Eigenvalue Analysis



An Eigenvalue Analysis leads to the **Torsional Natural Frequencies** ω_M^j and to the corresponding **Mode Shapes $\boldsymbol{\varphi}_M^j$** .The **damping** in the shaft train is **low.** Therefore the natural frequencies are not influenced by the damping: **D** ~ 0.

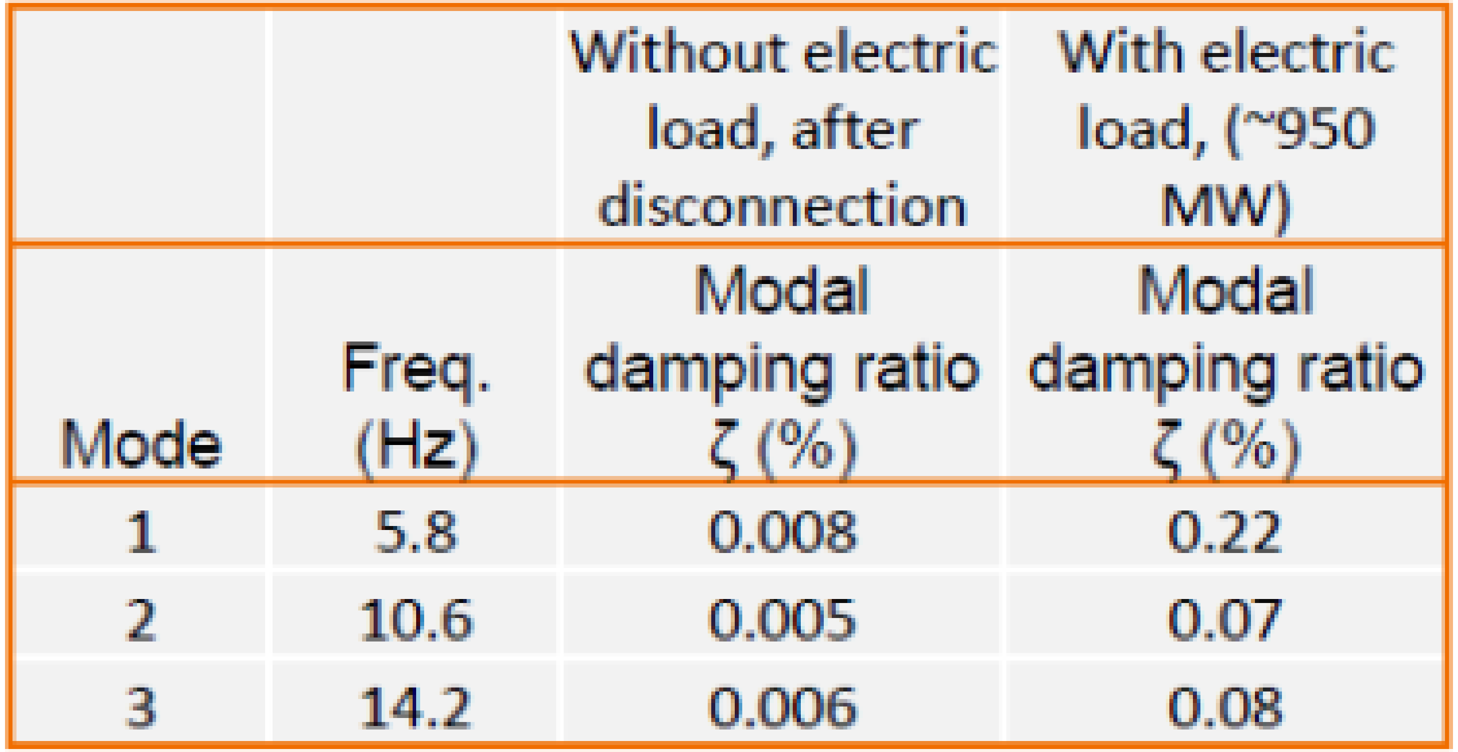
$$(\mathbf{K} - \omega^2 \cdot \mathbf{M}) \cdot \boldsymbol{\varphi} = 0$$

Torsional Natural frequencies ω_M^j

Torsional Mode shapes $\boldsymbol{\varphi}_M^j$

Modal Damping in % with and without Electrical Load

Estimation of Mechanical and Electrical Damping at OL3 Turbogenerator



		Without electric load, after disconnection	With electric load, (~950 MW)
Mode	Freq. (Hz)	Modal damping ratio ζ (%)	Modal damping ratio ζ (%)
1	5.8	0.008	0.22
2	10.6	0.005	0.07
3	14.2	0.006	0.08

Modal Damping in % with and without Electrical Load

Torsional Natural Frequencies and Mode Shapes

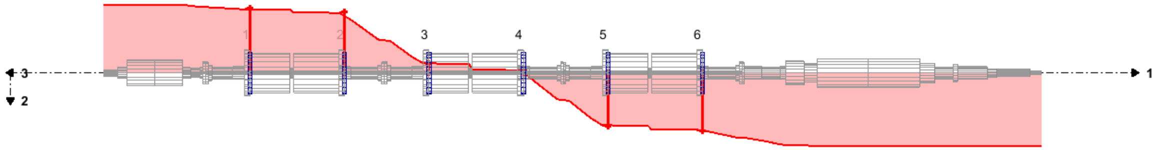
Example: Lowest Torsional Natural Frequencies and Mode Shapes of OL3

- The four lowest **Torsional Natural Frequencies** $f_M^j = \omega_M^j / 2\pi$ Hz of the **OL3 Turbogenerator** Shaft Train are presented in the next diagram together with the corresponding **Mode Shapes** $\boldsymbol{\varphi}_M^j$. They are in the range between 5,9 Hz to 24,0 Hz and are relevant for a **Sub Synchronous Resonance (SSR)** event.
- The first **three Modes** can be well excited by an **Air Gap Torque**, due to the fact, that these Modes have dominant angular displacements in the Generator part. This is particularly the case for the **3rd mode at 14,6 Hz**. Therefore this frequency is very sensitive regarding **SSR.**
- The Blade-Rotor-Coupling is not relevant for these lower Modes and can be neglected. The blades are only considered by their moments of inertia.

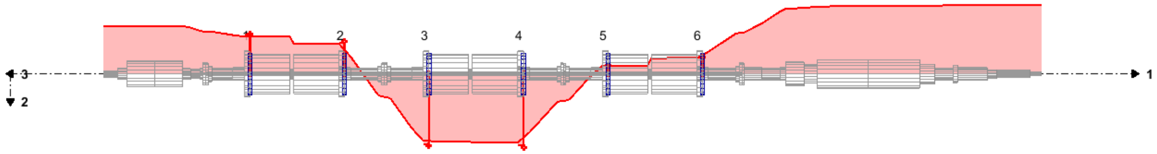
Torsional Natural Frequencies and Mode Shapes

Example: Lowest Torsional Natural Frequencies and Mode Shapes of OL3

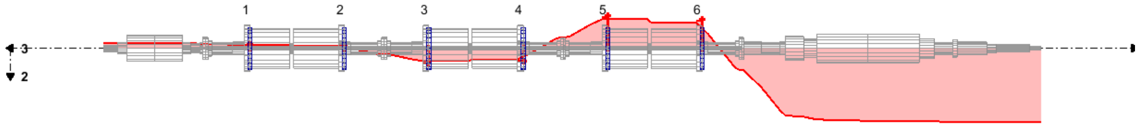
5.9 Hz



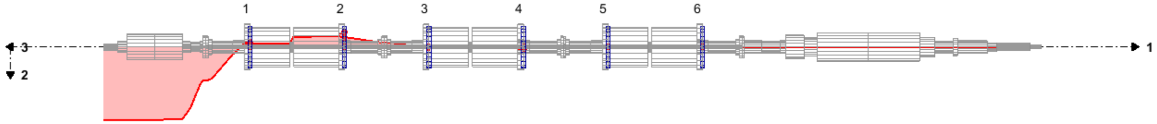
10.9 Hz



14.6 Hz



24.0 Hz



Torsional Natural Frequencies: $f_M^j = \omega_M^j / 2\pi$ Hz (j = 1, 2…4)

Mode Shapes of the **Shaft Train:** $\boldsymbol{\varphi}_M^j$

Torsional Natural Frequencies and Mode Shapes

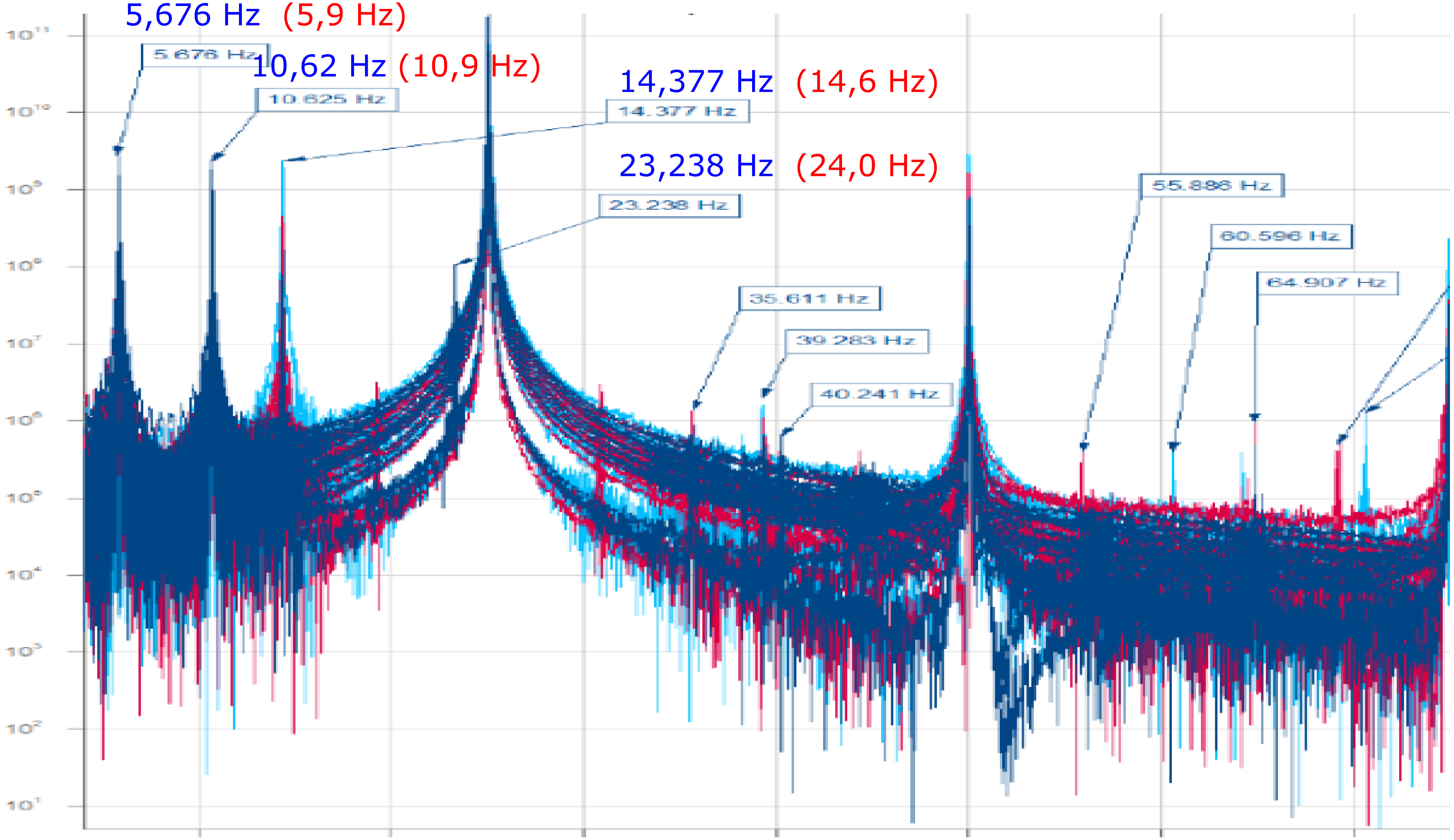
Example: Measurement of Torsional Natural Frequencies of OL3

- The before mentioned four **Torsional Natural Frequencies** f_M^j [Hz] have also been measured **during operation** of the **OL3 Turbogenerator Shaft Train.** They have been detected besides other frequencies in the lower range of the **Frequency Spectrum** (next diagram). As can be seen the measured frequencies fit quite well to the calculated values:

	Measured Torsional Frequency	**Calculated** Torsional Frequency
1.	5,67 Hz	5,9 Hz
2.	10,63 Hz	10,9 Hz
3.	14,37 Hz	14,6 Hz
4.	23,23 Hz	24,0 Hz

Torsional Natural Frequencies and Mode Shapes

Example: Measurement of Torsional Natural Frequencies of OL3



5,676 Hz (5,9 Hz)

10,62 Hz (10,9 Hz)

14,377 Hz (14,6 Hz)

23,238 Hz (24,0 Hz)

Sub Synchronous Resonance (SSR) – A Serious Electromechanical Interaction in Turbogenerators

- Definition of Sub Synchronous Resonance (SSR)
- Torsional Vibrations of a Turbogenerator due to Air Gap Torques
- A simple Electrical Model with Series Compensation
- Electrical Natural Frequency and Impedance Function
- Mechanical Model for Torsional Vibrations of a Turbogenerator
- Torsional Natural Frequencies and Mode Shapes
- Sub Synchronous Resonance in the Turbogenerator OL3

Sub Synchronous Resonance in the Turboenerator OL3

Conditions for **S**ub **S**ynchronous **R**esonance **SSR**

Repetition:

If one of the frequencies (f_S - f_E^i) is in the vicinity of one of the lowest **mechanical torsional natural frequencies** f_M^j, then the shaft assembly will be excited to **strong resonant torsional vibrations.**

The conditions for **Sub Synchronous Resonance** are therefore:

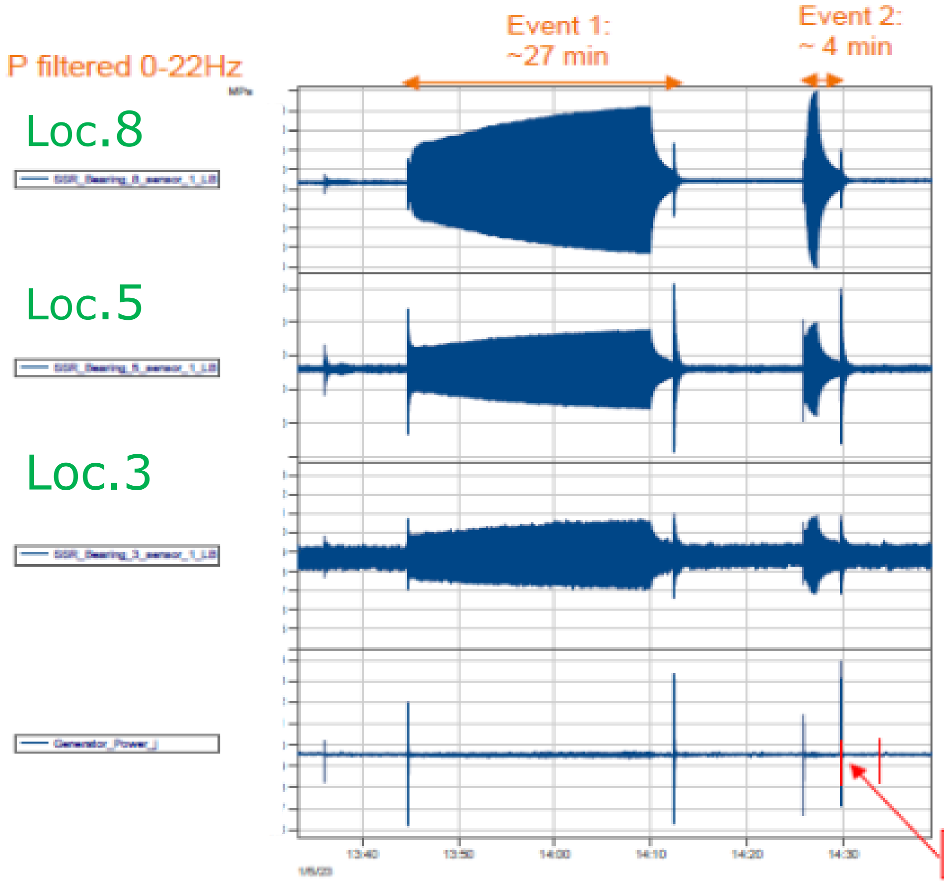
$$\boxed{f_M^j = (f_S - f_E^i) = f_{SSR}^i}$$

f_M^j	Torsional natural frequency of the Shaft
f_E^i	Electrical natural frequency of the Grid
f_S	Synchronous frequency of the Grid (50 Hz)

Sub Synchronous Resonance in the Turbogenerator OL3

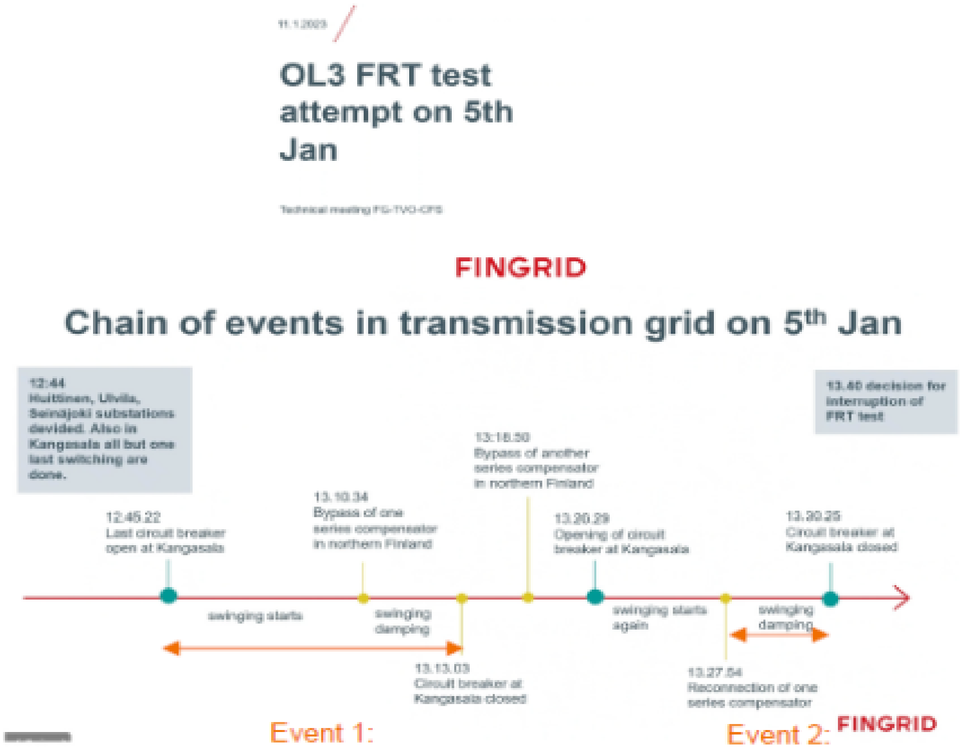
Monitoring of the SSR event on 5.1.23 by SSR sensors (loc. 3, 5, 8)

Maximum stress at loc.8



Damping estimation

Test description by FINGRID:


11.1.2023

OL3 FRT test attempt on 5th Jan

Technical meeting FG-TVO-CFS

FINGRID

Chain of events in transmission grid on 5th Jan

12:44 Huittinen, Ulvila, Seinäjoki substations devided. Also in Kangasala all but one last switching are done.

12.45.22 Last circuit breaker open at Kangasala

13.10.34 Bypass of one series compensator in northern Finland

13.13.03 Circuit breaker at Kangasala closed

13:18.50 Bypass of another series compensator in northern Finland

13.20.29 Opening of circuit breaker at Kangasala

13.27.54 Reconnection of one series compensator

13.30.25 Circuit breaker at Kangasala closed

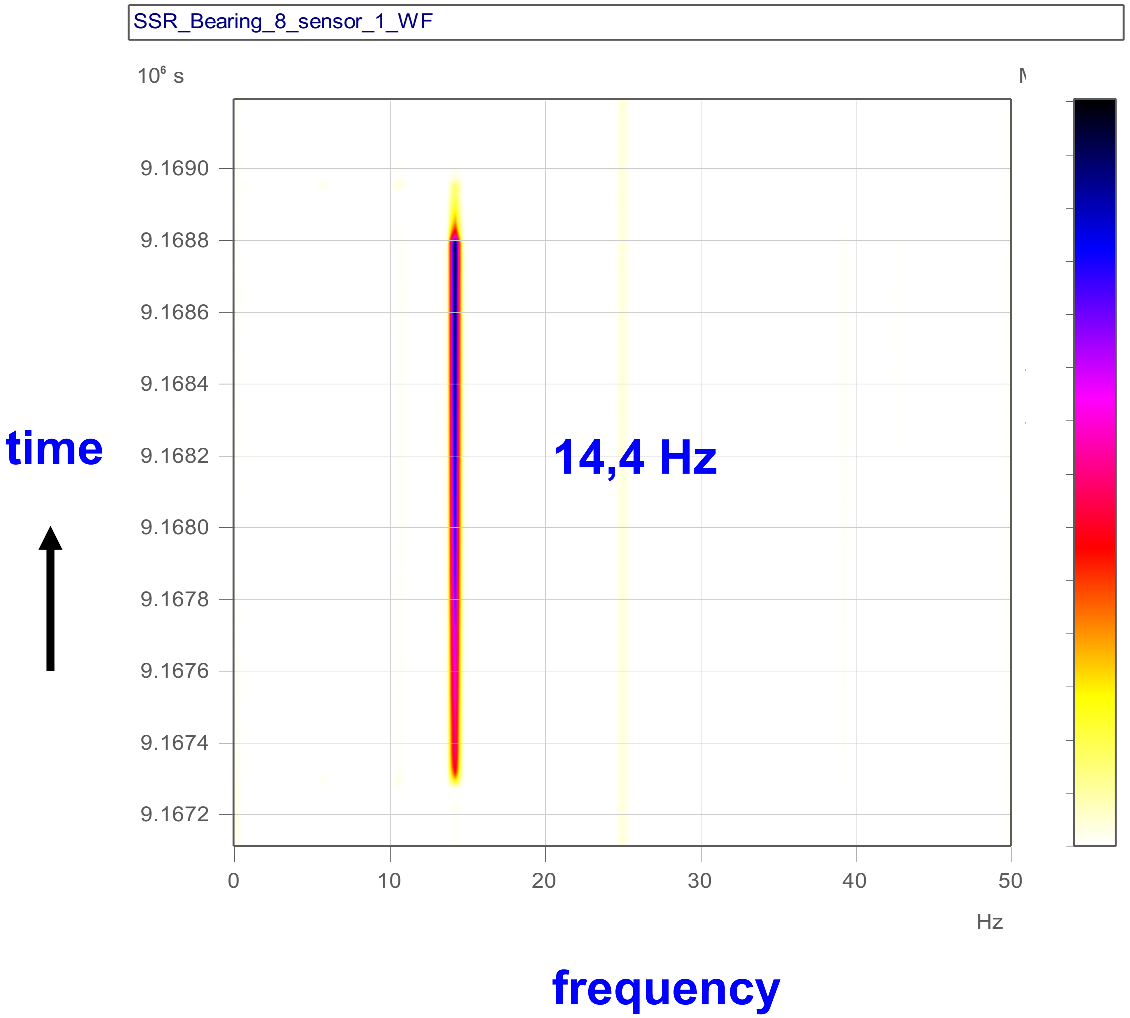
13.40 decision for interruption of FRT test

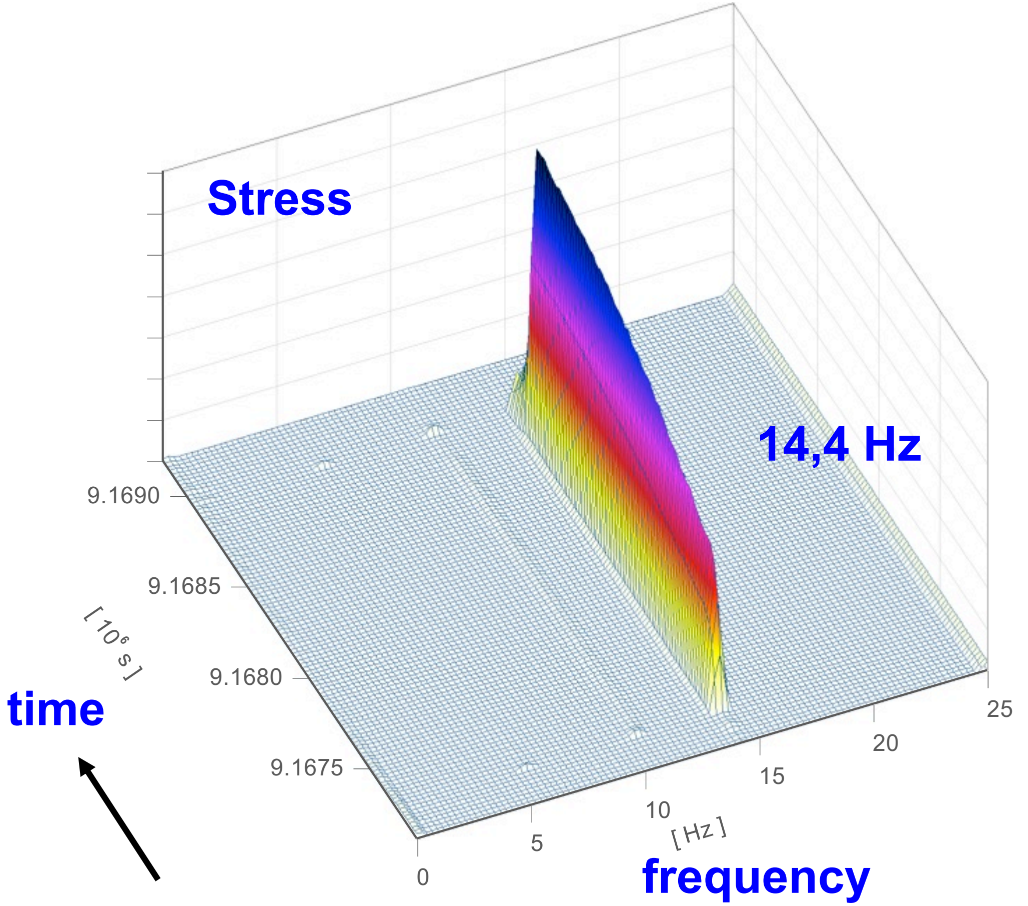
Event 1:
~ 27 min

Event 2:
~ 4 min

Sub Synchronous Resonance in The Turbogenerator OL3

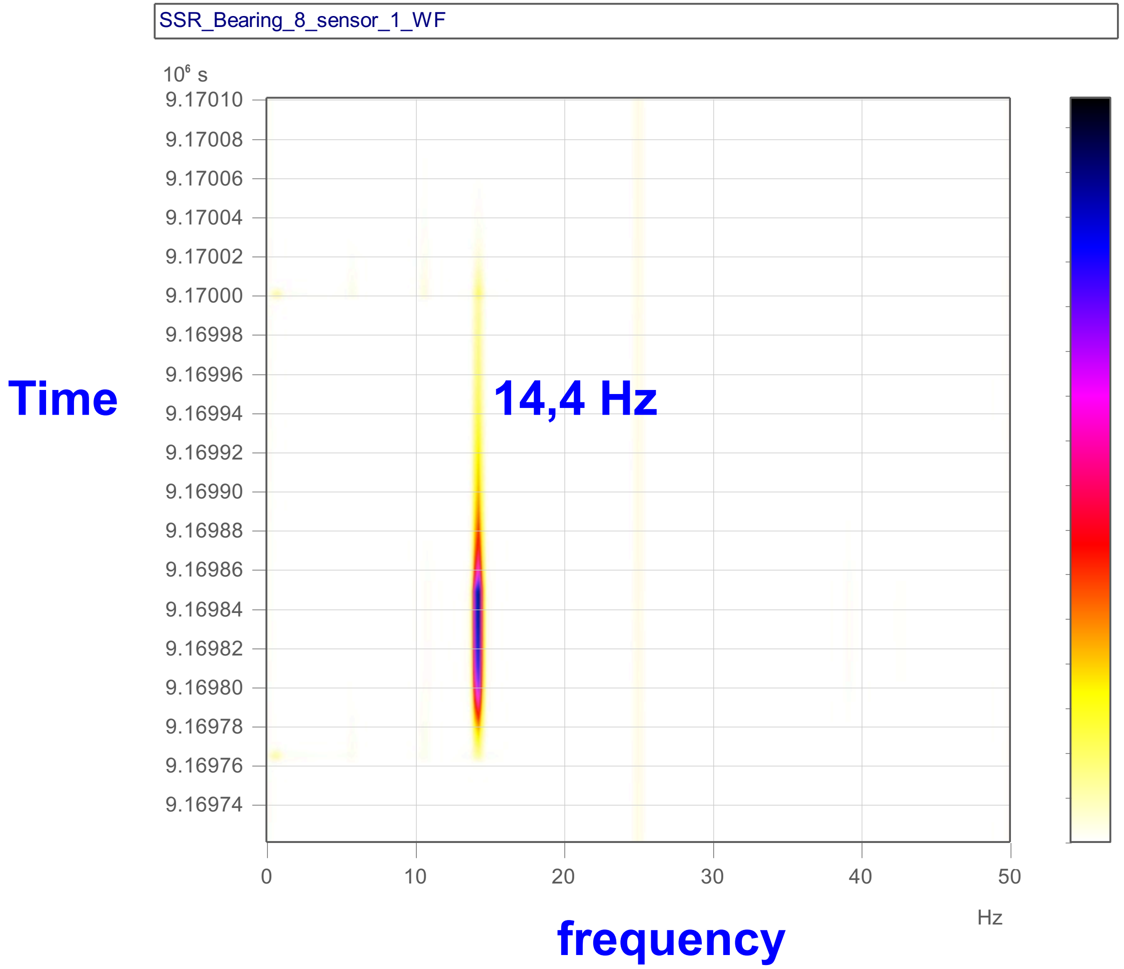
Monitoring of the OL3-SSR **event 1** on 5.1.23 by SSR1 sensor at loc.8

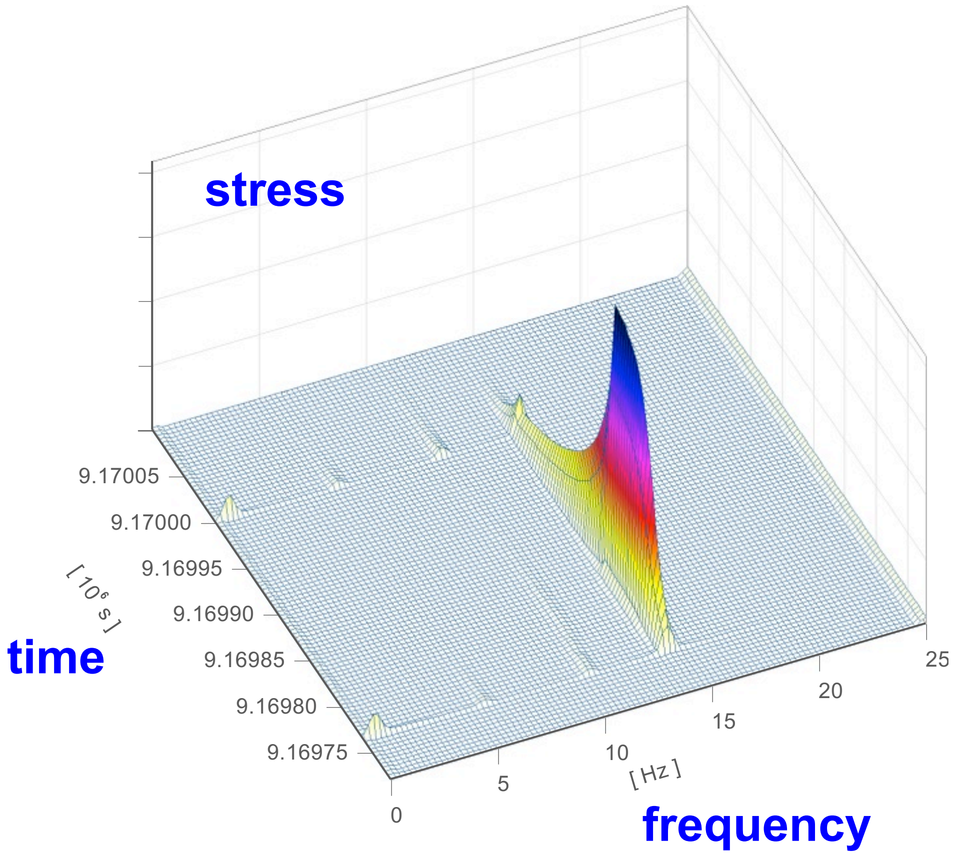




Sub Synchronous Resonance in the Turbogenerator OL3

Monitoring of the OL3-SSR **event 2** on 5.1.23 by SSR1 sensor at loc.8





Vorlesungen Mechatronik im Wintersemester

Energiforsk – Vibration Seminar
Stockholm, November 9th 2023

TECHNISCHE
UNIVERSITÄT
DARMSTADT

Sub Synchronous Resonance (SSR) – A Serious Electromechanical Interaction in Turbogenerators

Rainer Nordmann, Sven Herold
Technische Universität Darmstadt and Fraunhofer Institute LBF