Examples of processing low-frequency oscillations in Russia and ways to improve the analysis

Aleksandr Popov[1], Kirill Butin[2], Dmitry Dubinin[3],

Andrey Rodionov[1], Alexey Mokeev[2], Sergey Piskunov[2]

[1]Engineering center "Energoservice", Russia
[2]Northern (Arctic) Federal University, Russia
[3]System Operator of the United Power System, Russia

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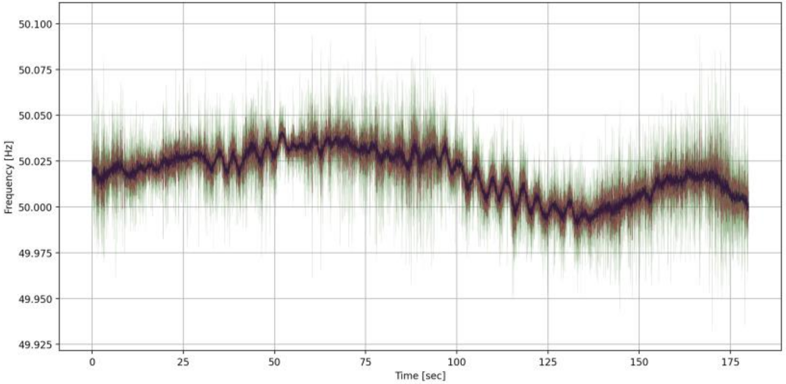
Low-frequency oscillations



Focus of attention: understanding the **physics** of oscillatory processes in complex power systems, detecting and identifying the low-frequency **modes**, developing new methods for detecting the **source** of oscillations, **real-time** processing the large amounts of data, building the computational **infrastructure**, automation of **research**.

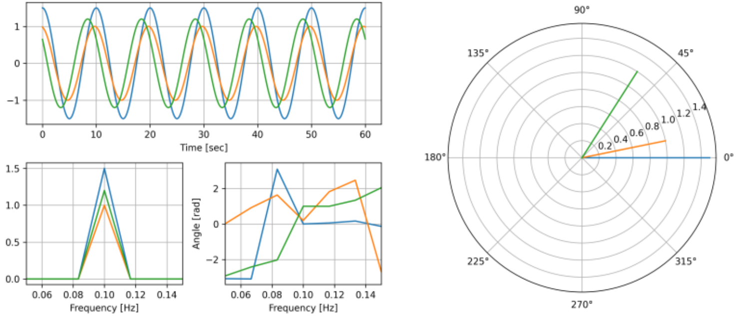
Detecting the source of LFO: damping torque of the generator, wave propagation, **phases of modes**, **oscillation energy**, comparison with the model, machine learning, and others.

DEF

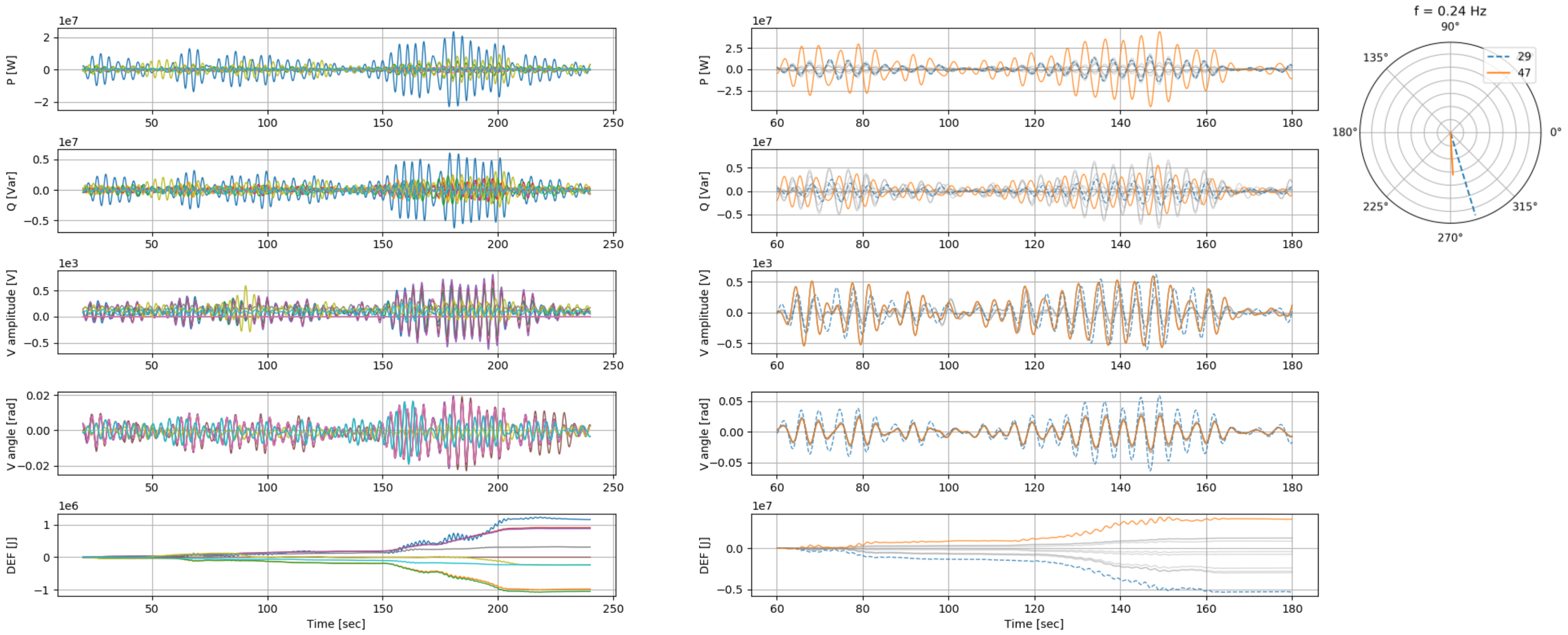
$$W_{ij}^{D} \approx \int (2\pi \Delta P_{ij} \Delta f_i dt + \Delta Q_{ij} \frac{d(\Delta V_i)}{\tilde{V}_i + \Delta V_i})$$

$$W_{ij}^{D}(t) = DE_{ij} * t + b_{ij}$$

MSE



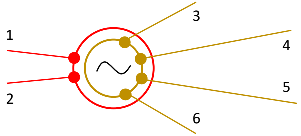
Examples of analysis

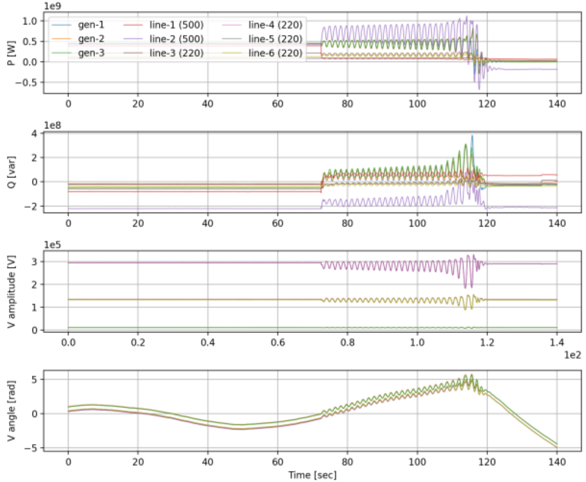


Near the power plant

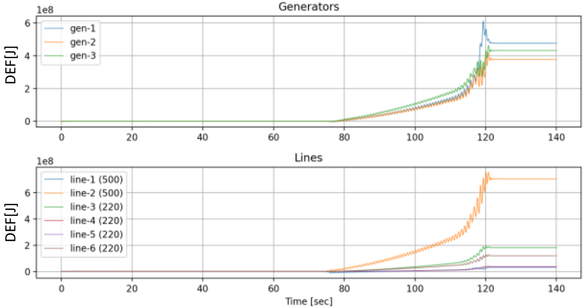
Stage 1. Detecting the direction of the source by power **lines** PMU data.

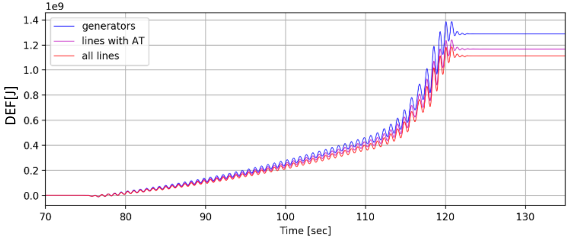
Stage 2. Analysis the PMU data from **power plant** and **outgoing lines**.





Comparing the oscillatory energy on generators and outgoing lines provides an important **feature** when detecting and verifying the source of LFO.





$$\dot{I}_1(t) = L^{-1} \int_0^t \Delta\dot{U}(\tau) e^{-p_1(t-\tau)} d\tau$$

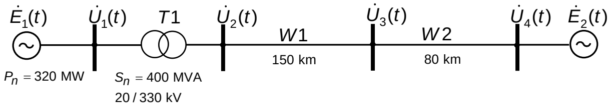
$$\Delta\dot{U}(t) = \dot{U}_{500}(t) - \dot{U}'_{220}(t)$$
$$p_1 = \beta_1 + j\omega_0$$
$$\beta_1 = RL^{-1}$$

$$\dot{I}(n) \approx \Delta\dot{U}(n) Y(j\omega n)$$

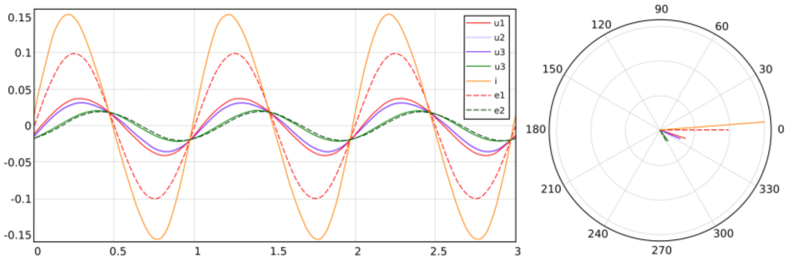
Instantaneous current frequency

The **instantaneous current frequency** is determined through values of difference of EMF synchrophasors of the power plant and power system and parameters of lines and transformer and affects voltages on substation buses.

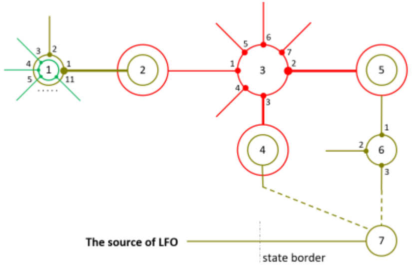
Model (LFO of 1 Hz from station 1):



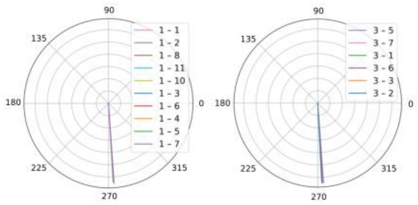
Instantaneous frequencies (from U, I, and EMF):



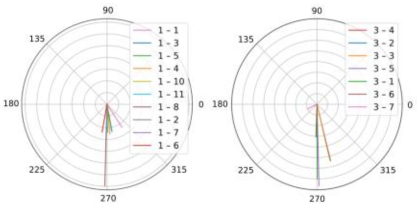
When calculating instantaneous frequencies from current synchrophasors, the direction to the LFO source can be obtained from the data of **single node.**



F by voltage (mode)



F by current (mode)



Scalable MSE: comparing the phases of oscillations on lines outgoing from stations gives a picture of the propagation of oscillations throughout the power system.

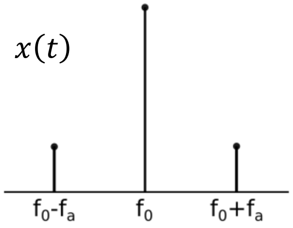
Signal decomposition

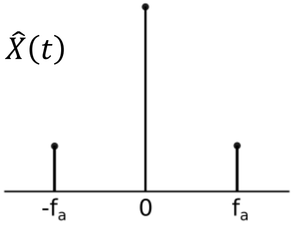
Electromechanical transients are characterized by **amplitude** and **phase** modulation of current and voltage.

In both cases the signal can be presented as the sum of a **central** component with a frequency of 50 (60) Hz and **side** sinusoidal components.

$$x(t) = X_m \cos\big(2\pi f_0 + \varphi(t)\big)$$

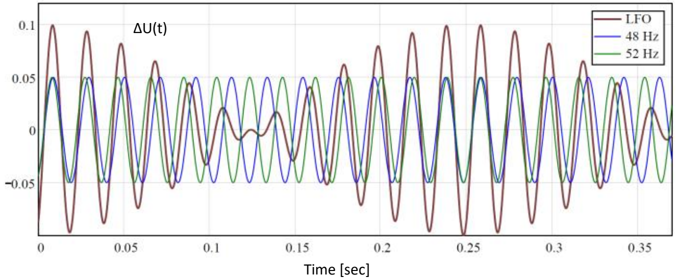
$$\varphi(t) = K_a \cos(2\pi f_a t) + \psi$$





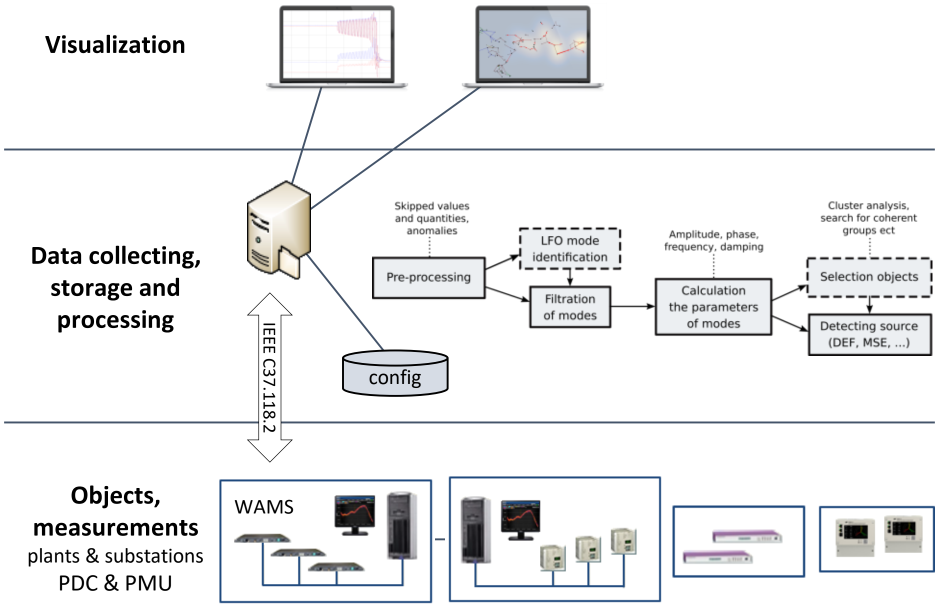
Signal with **variable** parameters can be replaced by the **constant** parameter signals in analysis.

$$\varphi(t) = 0.1 \cos 2\pi 2t$$

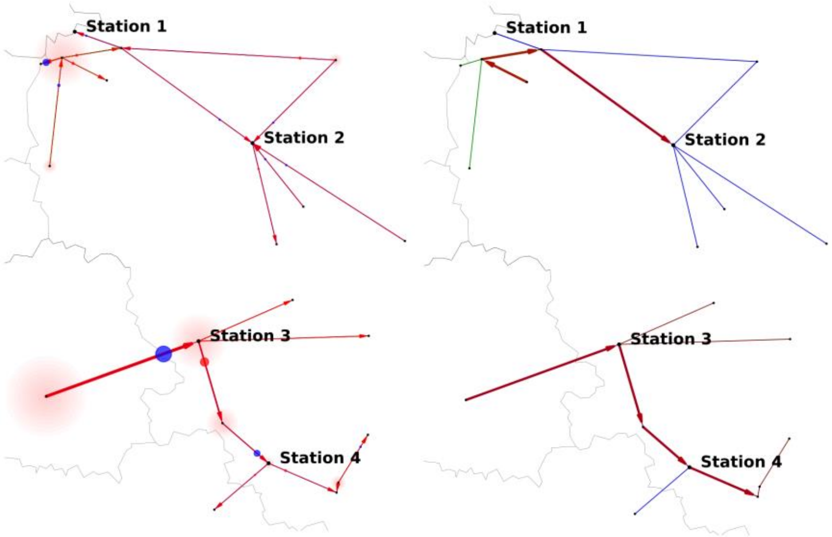


Such a decomposition will allow to obtain those components of active and reactive power that directly affect the amount of oscillation energy.

ES Phasor



Visualization
Data collecting, storage and processing
Objects, measurements
plants & substations
PDC & PMU
IEEE C37.118.2
config
Skipped values and quantities, anomalies
Pre-processing
LFO mode identification
Filtration of modes
Amplitude, phase, frequency, damping
Calculation the parameters of modes
Cluster analysis, search for coherent groups ect
Selection objects
Detecting source (DEF, MSE, ...)
WAMS



Station 1
Station 2
Station 3
Station 4
Station 1
Station 2
Station 3
Station 4

Thank you for your attention!

Aleksandr Popov	a.popov@ens.ru
Kirill Butin	k.butin@narfu.ru
Dmitry Dubinin	dubinin@so-ups.ru
Andrey Rodionov	a.rodionov@ens.ru
Alexey Mokeev	a.mokeev@narfu.ru
Sergey Piskunov	piskunov.s@edu.narfu.ru