Framework for synchrophasor measurements data processing and the case studies of the low-frequency oscillations

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WAMS development in Russia

Main Control Room

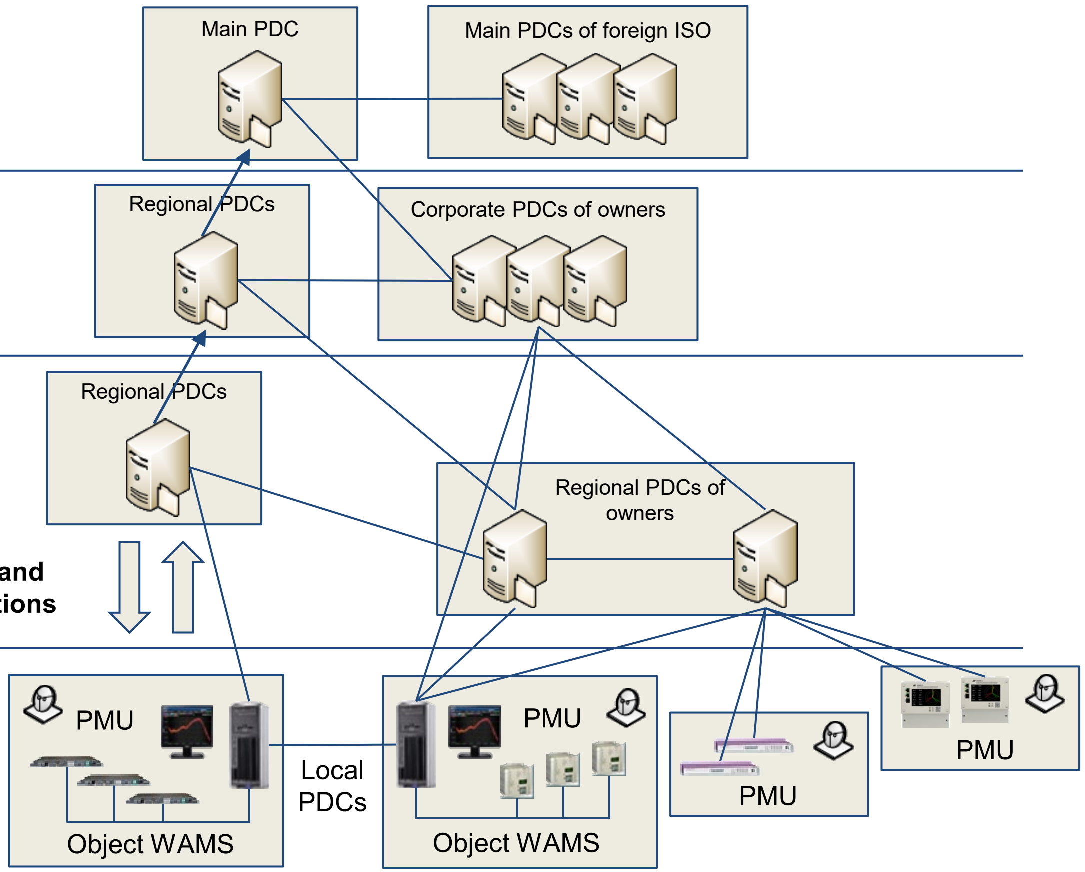
Regional level
7 branches -
United
Control Rooms

14 branches -
Regional
Dispatch Offices

Applications:

- PSS monitoring
- Advanced visualization
- Islanding
- Low frequency oscillation monitoring
- State estimation:
  - Stability Margin Monitoring System
  - Centralized power system Integrity Control Scheme
- Post event analysis
- Model verification
- PMU data quality monitoring

Monitoring and control functions



Object level
135 power stations &
substations
95 PDC & 900 PMU

- PSS monitoring
- PMU data quality monitoring
- Low frequency oscillation monitoring
  Generator operation monitoring

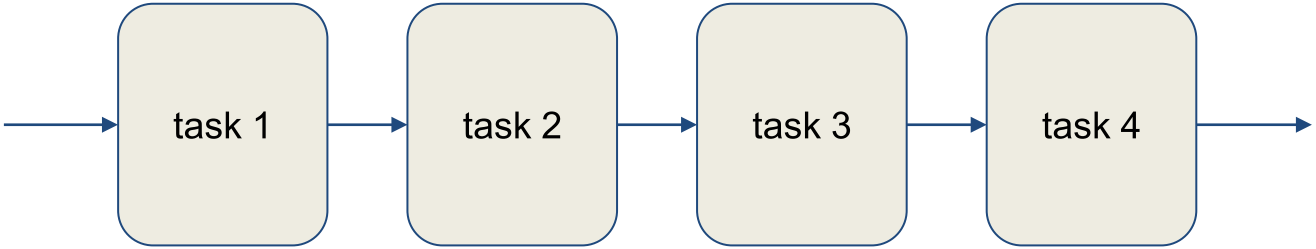
Low-frequency oscillations

- The experience shows that LFO occur more than **10 times a day** in the power system of Russia
- **Continuous online monitoring** of LFO and their **source detecting** in the dispatch center is required
- Challenges:
  - **low observability** of the power system
  - the source can be located in **neighboring countries**

Review 2015 – 2020

- **Focus of attention:** physics of oscillatory processes in big systems, detecting and identifying the low-frequency modes, developing new methods for locating the source of oscillations, real-time processing the large amounts of data, computational infrastructure.
- **Sequence of common subtasks:** data preprocessing, mode detection and selection, calculation the parameters of modes, source detection.

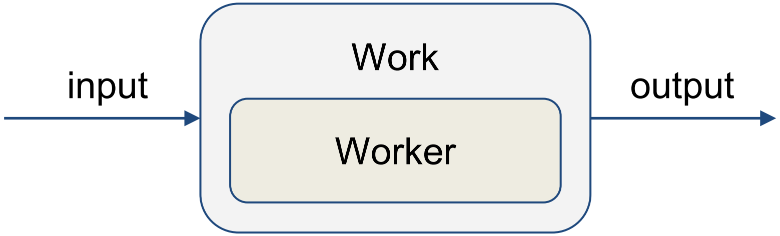
Set of solutions

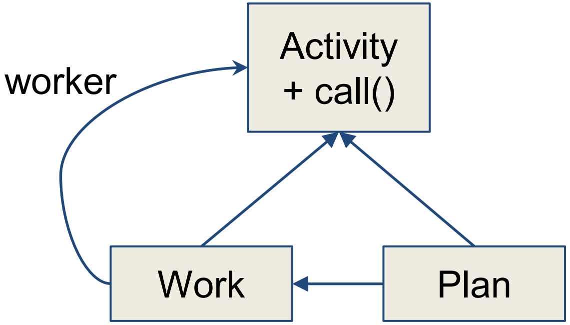


$$N = n_1 \times n_2 \times n_3 \times n_4$$

- Methods
- Parameters
- Implementations

Plan

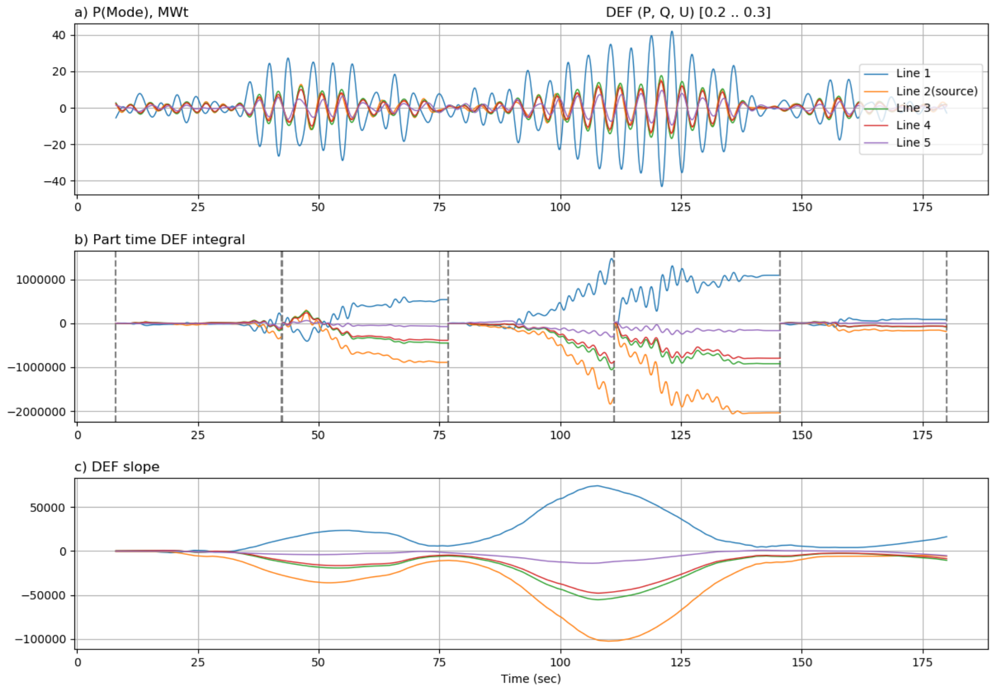




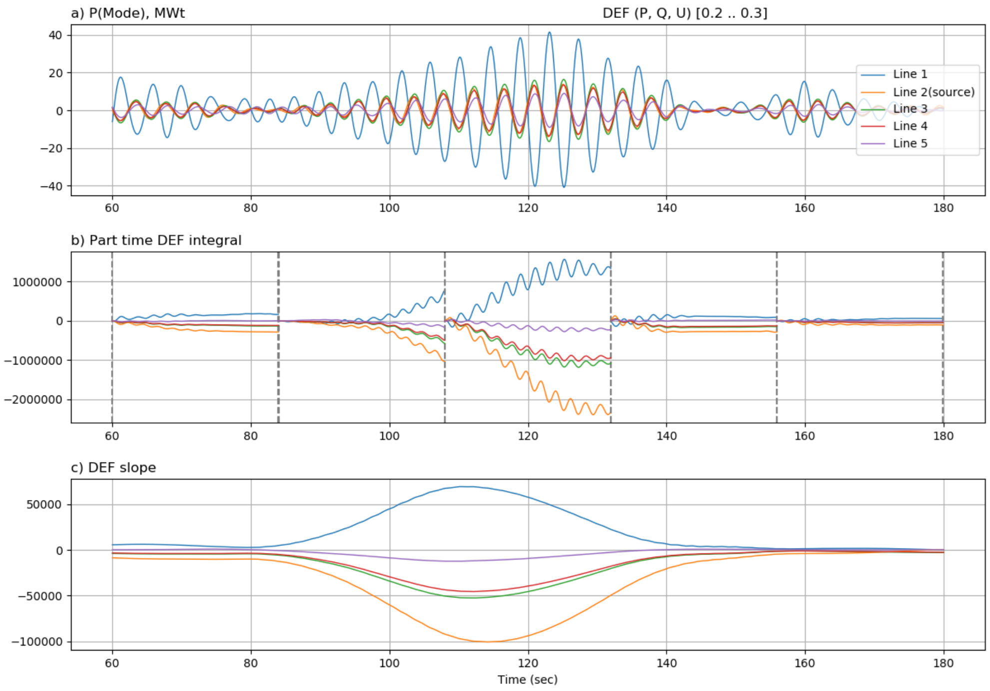
- worker is activity
- plan may be worker

```
{
    "class"   :  "WorkNode" ,
    "id"  :  "freq"    ,
    "inputs"    : [   "get_mode"   ],

    "work"  : {
        "descr"   :   "Get frequency of mode"          ,
        "worker"      : {
            "class"    :   "modulation.IqFreq"        ,
            "params"   : {...}
        }
    },

    "result"        : {
        "indep"   :   "Time"  ,
        "dep"  :   "Frequency [Hz]"
    }
}
```

Varying the worker: get mode

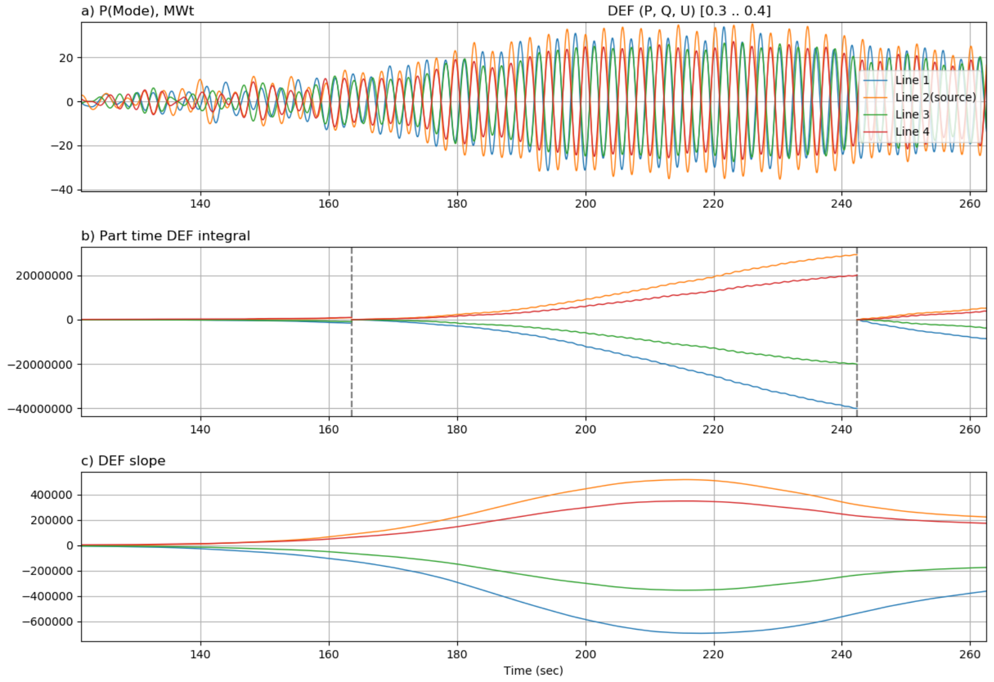


FIR-filter (401 taps)

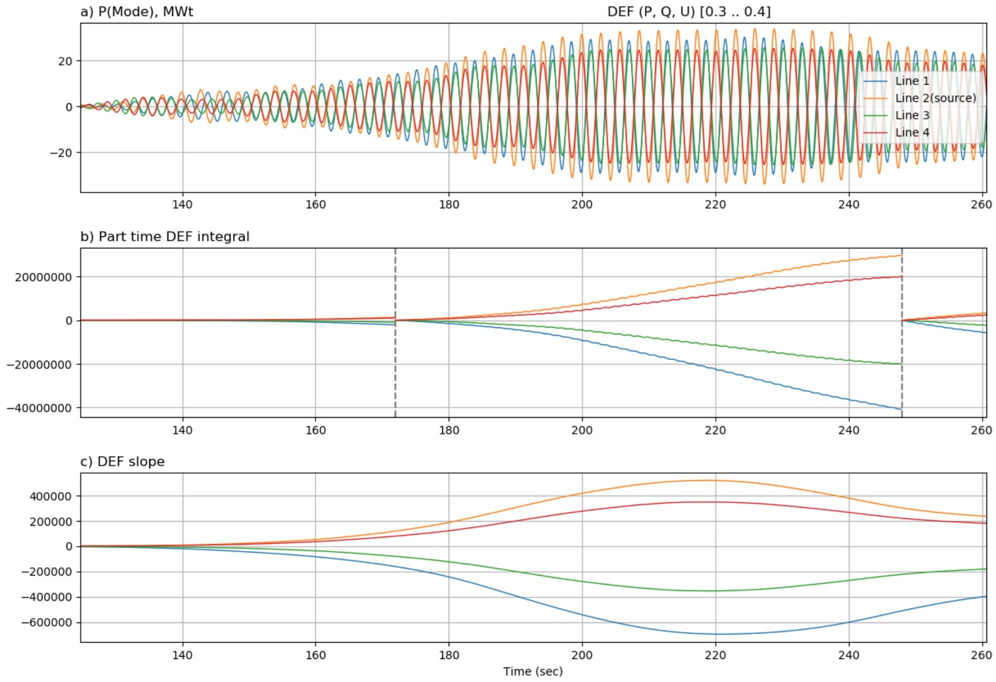


IIR-filter (Butterworth, 3 order, 14 taps)

Varying the worker: get mode



FIR-filter (301 taps)



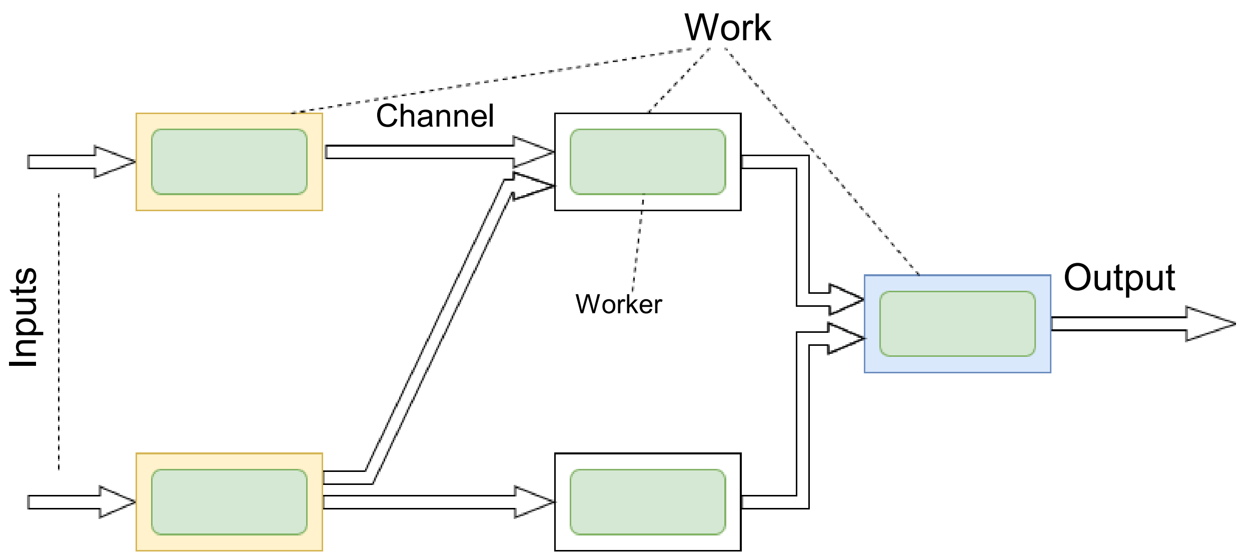
IIR-filter (Butterworth, 3 order, 14 taps)

Dsplab

- Field of application: Development of the DSP routines that require a flexible configuration of different stages of calculations on the user level; **investigation of variety of methods** solving the same DSP task.
- User can define the **plan of works** and then set the workers. The replacement of the worker does not destroy the workflow.
- Types of nodes: **Work**, **Map** (**Loop**), **Select** and **Pack**
- Licence: **LGPLv3**
- Programming language: **Python 3**

github.com/aleneus/dsplab

Parallel implementation

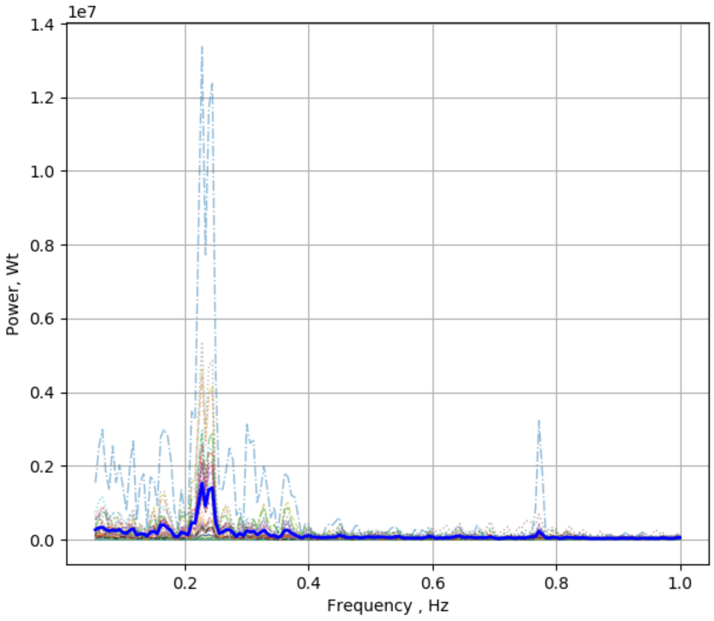


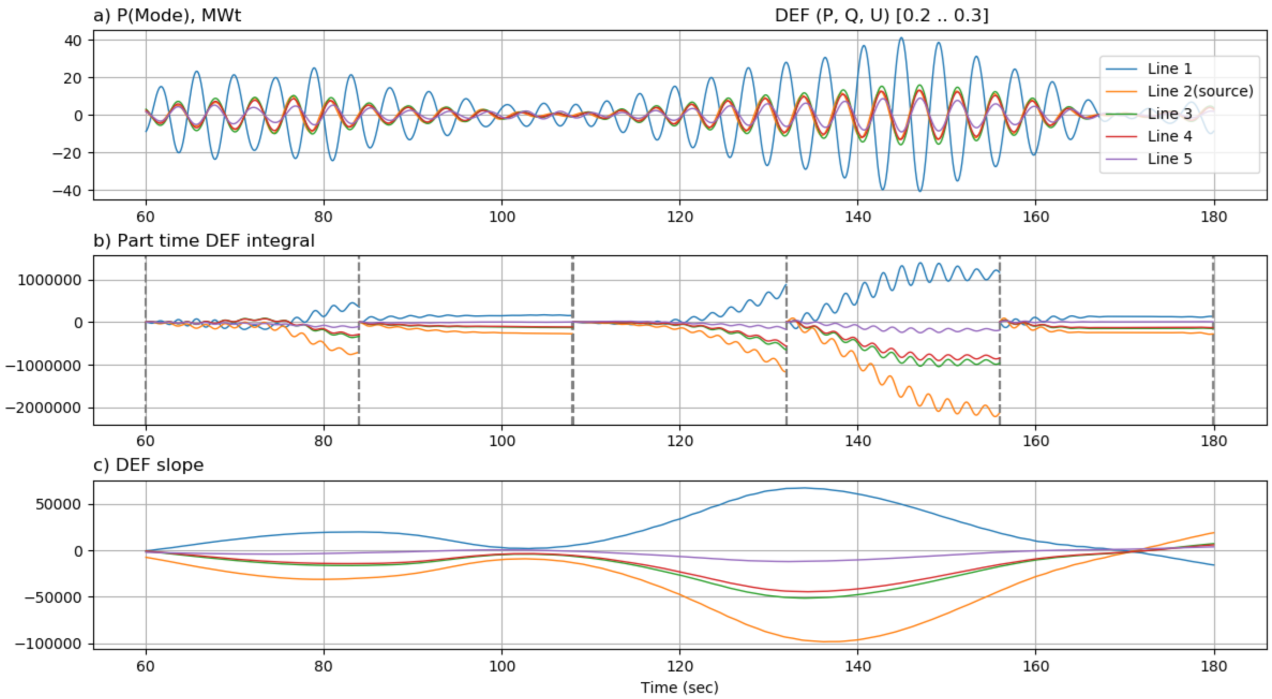
- There are different strategies for **splitting data** for parallel processing
- But the **functional nature of the plan** itself provides the automatic parallelism
- Suitable software development technologies: **“lightweight” threads**, **channels**

Real LFO cases

#	Date	Region	Number of data sources	Dataset	Record duration (min)	Mode (Hz)	Amplitude (P, MW), max	Duration of oscillations (min)
1	29.05.2018	North-central	83	f	5	0.5 - 0.7	-	1
2	07.03.2019	West	5	f, P, Q, U	4	0.7	12	3
3	02.05.2020	Central	114	P	2	0.13, 0.3	12	2
4	04.05.2020	Central	114	P	3	0.31	18	2
5	04.05.2020	Central	114	P	2	0.25 - 0.3	20	1
6	16.06.2020	West	116	f, P, Q, U	4	0.25 - 0.3, 0.11	22	1
7	02.09.2020	South	47	f, P, Q, U, I	3	0.25	40	2
8	24.09.2020	South	67	P, Q, U	5	0.2 - 0.3	55	0,5
9	25.11.2020	Syberia	202	f, P, Q, U	15	0.35	30	10

Case #7



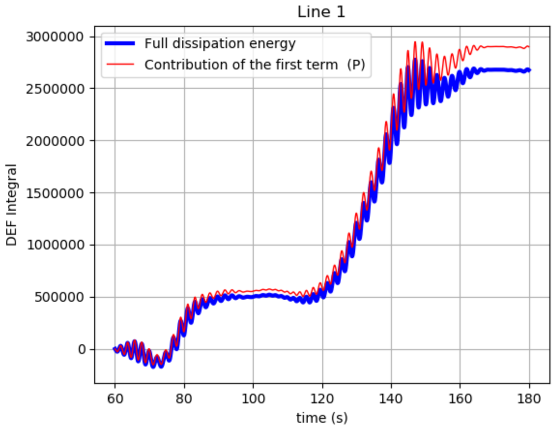


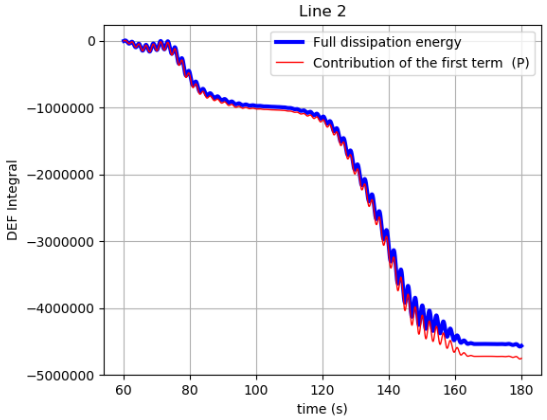
a) Amplitude power spectrum
Energy Flow method

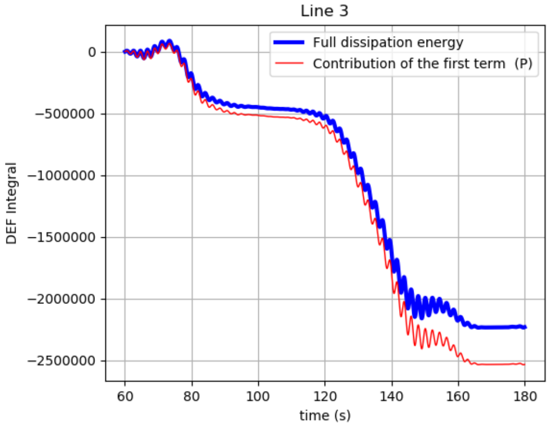
b) Dissipation

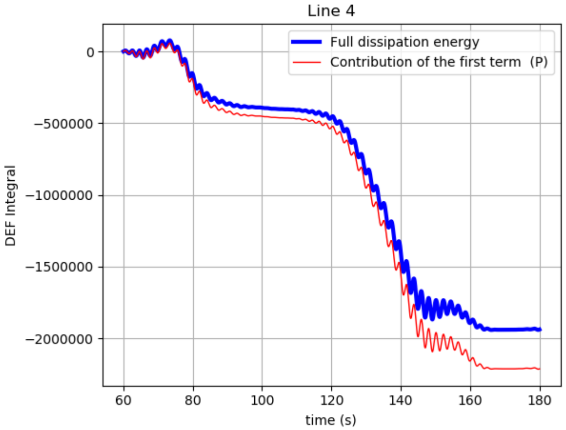
P and Q contribution

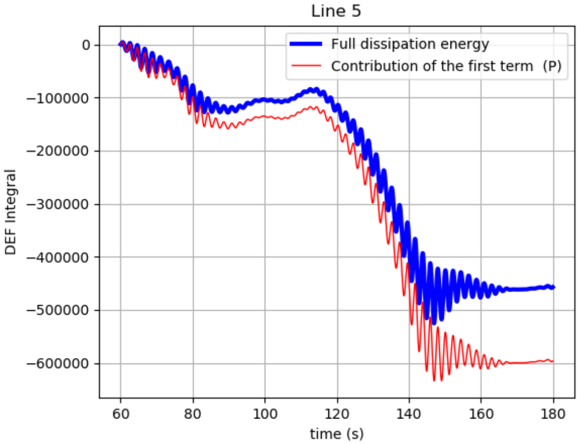
$$DEF_{ij}(t) = \int \left(\Delta P_{ij} d\Theta_i + \Delta Q_{ij} \frac{dV_i}{{V^*}_i} \right)$$











Conclusion

- Detection the source of LFO is one of the **many stages** of processing the synchrophasor measurements data.
- Due to the **growing variety of methods** for solving individual subtasks, program tools, allowing us to **explore** combinations of methods and **apply** the most successful ones are in demand.
- An approach to the representation of the data processing in the form of a generalized scheme (**plan**) with the possibility of variation of the used stage implementations is proposed.
- In the context of a generalized processing scheme, the **DEF method** has been successfully applied to analyze several real LFO cases in the power system of Russia.

Thank you for your attention!

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