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
- Applications:
  - PSS monitoring
  - Advanced visualization
  - Islanding
  - Low frequency oscillation monitoring
  - State estimation:
    - Stability Margin Monitoring System
    - Centralized power system Integrity Control Scheme

Regional level
- 7 branches - United Control Rooms
- 14 branches - Regional Dispatch Offices
- Object level
  - 135 power stations & substations
  - 95 PDC & 900 PMU
  - PSS monitoring
  - PMU data quality monitoring
  - Low frequency oscillation monitoring
  - Generator operation monitoring

Monitoring and control functions

Applications:
- PSS monitoring
- Advanced visualization
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  - Centralized power system Integrity Control Scheme
- Post event analysis
- Model verification
- PMU data quality monitoring

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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

\[ N = n \times n \times n \times n \]

1 2 3 4

- Methods
- Parameters
- Implementations
Plan

- worker is activity
- plan may be worker

```json
{
    "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]
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

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