Power System Oscillation Source Analysis Using OSLp Tool

November 16, 2022
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• There is a short survey that will launch at the end of the webinar. Your survey responses help us tailor training content, improve your webinar experience, and gain support to host future events.
Today’s Speakers

Mohit Joshi
Energy Systems Modeler and Analyst
National Renewable Energy Laboratory

Bin Wang
Asst. Professor, Dept. of Electrical & Computer Engineering
University of Texas at San Antonio

Shri. Abishek RS
Deputy Manager (SRLDC) POSOCO

MVD Raghava
Assistant Manager POSOCO
Global Power System Transformation (G-PST) Consortium

**What?**
A global consortium focused on support to power system operators with advanced, low-emission solutions

**Who?**
- **Founding System Operators**
- **G-PST Core Team**
  - Technical Institutes
- **Emerging Economy System Operators**
  - Indonesia, Ukraine, Vietnam, India, South Africa, Tanzania, Morocco, Peru, Colombia, and others

**How?**
1. System Operator Research and Peer Learning
2. System Operator Technical Assistance
3. Workforce Development
4. Localized Technology Adoption Support
5. Open Tools and Data
Partner Country System Operator Modes of Support

- Peer learning with other system operators
- Direct technical assistance and training
- Internship and fellowship programs
- Embedded expert assistance
- Learning on research innovations
- Conducting joint applied research
Dissipating Energy Flow (DEF) for Locating the Source of Oscillation

Bin Wang, PhD, PE
University of Texas at San Antonio

Nov. 16, 2022
Power System Oscillations

- A marginal state between stable and unstable
- 0.1-3Hz oscillations for traditional power grids
- 0.2Hz-8Hz-20Hz-100x Hz oscillations for low-inertia grids

Wide-spread 8Hz voltage oscillations in Scotland in Aug. 2021

0.29Hz oscillations involving PV
IRPWG Meeting on Aug. 19, 2021
Source: TVA
Existing Research on Oscillation Analysis

- Detection
- Estimation of oscillation parameters
  - Amplitude
  - Frequency
  - Damping ratio
  - Mode shape
- Classification: forced vs. natural mode
- Source location: identifying the destabilizing component(s)

\[ y(t) = \sum_{i=1}^{n} A_i e^{\sigma_i t} \cos(\omega_i t + \theta_i) \]
Oscillation Source Location (OSL) Methods

- Some existing methods by 2015 [2]
- New developments through 2022 [3]
  - Model inference-based methods
  - Purely data-driven methods
  - Other methods

<table>
<thead>
<tr>
<th>Category</th>
<th>Key Idea</th>
<th>Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>Damping torque</td>
<td>The generator with a negative damping torque coefficient is the source</td>
<td>Possible unavailability of rotor angle and speed data. Possible failures under forced oscillation cases.</td>
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<tr>
<td>Mode shape</td>
<td>Largest magnitude, most leading phase of the mode shape or their combinations may indicate the source</td>
<td>Lack of a theoretical foundation. Possible failures for cases having weakly damped/undamped oscillation together with forced oscillation.</td>
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<tr>
<td>Energy</td>
<td>The device producing dissipation energy is the source</td>
<td>Strong assumption in modeling loads and network. Lack of theoretical proofs for multi-mode cases.</td>
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<tr>
<td>Equivalent circuit</td>
<td>The source of the equivalent circuit is the source of the oscillation</td>
<td>Possible failures when the phasor concept cannot be applied, e.g. non-sinusoidal oscillations. Lack of theoretical proofs for multi-mode oscillation cases.</td>
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<td>Hybrid</td>
<td>A larger difference between simulations and measurements indicates the source</td>
<td>Possible unavailability of the accurate model of the entire system.</td>
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<td>Traveling wave</td>
<td>The closer to the source, the earlier the location will exhibit oscillation</td>
<td>Inaccurate and unreliable detection of the oscillation arrival time. Unavailability of the wave speed map in real-time. Lack of investigations on multi-mode cases.</td>
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<td>Machine learning</td>
<td>An offline trained decision tree from model-based simulations to locate the source using online measurements</td>
<td>Possible unavailability of the accurate model of the entire system. Can be only applied to forced oscillation cases.</td>
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</table>

Dissipating Energy Flow (DEF) Method

- Inputs required for calculation
  - PQVθ measured by PMU
- Physical meaning

<table>
<thead>
<tr>
<th>DE_{ij}</th>
<th>Implication</th>
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<tbody>
<tr>
<td>DE_{ij} = 0</td>
<td>System is under steady state</td>
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<tr>
<td>DE_{ij} ≠ 0</td>
<td>System is experiencing transients/oscillations</td>
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<tr>
<td>DE_{ij} &gt; 0</td>
<td>Oscillation source is behind bus i</td>
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<tr>
<td>DE_{ij} &lt; 0</td>
<td>Oscillation source is behind bus j</td>
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\[ W_{ij}(t) = \int \left( \Delta P_{ij} d\Delta \theta_i + \Delta Q_{ij} \frac{d(\Delta V_i)}{V_i^*} \right) \]
\[ = \int \left( \Delta P_{ij} \cdot 2\pi f_i dt + \Delta Q_{ij} \frac{d(\Delta V_i)}{V_i^*} \right) \]
\[ = DE_{ij} \cdot t + b_{ij} \]

Illustration of DEF for OSL

- DEF analysis of two real events [5]

DEF’s Effectiveness

- Oscillation management at ISO-NE [6]
  - Since 2017, online OSL has automatically processed 1200+ oscillation events. Alerts and Alarms automatically generated by the PhasorPoint application by GE.
  - Correctly identified the source (generator and area) for all instances of oscillations with known sources inside and outside of ISO-NE.

2021 IEEE-NASPI OSL Contest

- Co-hosted by IEEE and NASPI [7-8]
- Objective: evaluating the efficiency of OSL methods and their practical implementation.
- Contest highlights:
  - 13 challenging simulated events [9]
  - 60 teams from 11 countries signed up
  - 21 submissions

### Summary of 2021 IEEE-NASPI OSL Contest [10]

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<th>Team</th>
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**Energy-based methods are most efficient**

**Details of implementation could be critical**

**Machine Learning and Model-based method are less efficient**

Methods
1: Energy-based
2: Oscillation shape and magnitude
3: Machine Learning and Model-based analytic
4: Cross Power Spectra Density

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How to Get DEF Tool?

- DSATools/DSAOA since Release 20.0 [12].

<table>
<thead>
<tr>
<th>DEF Implementation</th>
<th>Notes</th>
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<tbody>
<tr>
<td>OSLp V1.3</td>
<td>This is the latest version of OSLp by ISO New England as of September 2022 that can be shared upon request at [11]. Several pre- and post-processing techniques are integrated for better performance when dealing with real PMU data, including automatic data window selection, band pass filtering, spectral analysis, and spikes analysis.</td>
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<tr>
<td>OSLp V2.0</td>
<td>This is a beta version of OSLp that is being developed internally within ISO-NE and will be sharable later. This version contains all features in V1.3, and has the following new features: (1) implementation of the Complex DEF [43], (2) implementation of a Cross Power Spectral Density (CPSD) approach [88], (3) classification of oscillation source in terms of active power-frequency control or reactive power-voltage control, (4) enhanced capability for noise filtering, and (5) enhanced data processing to handle PMU data from low-voltage distribution systems potentially containing high-frequency oscillations involving inverter-based resources.</td>
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Source:

Final Remarks

• DEF is a measurement-based tool for locating the source of oscillation, i.e., the component(s) destabilizing the system.
• DEF is not perfect in theory. It may fail in case of complex control interactions [13].
• DEF is among the most effective tools so far.

For Further Information


https://ieeexplore.ieee.org/document/8946821


https://ieeexplore.ieee.org/document/6296740


https://ieeexplore.ieee.org/document/9132669


https://www.nrel.gov/docs/fy22osti/81394.pdf


Thank you!

Bin Wang, PhD, PE
IEEE Senior Member
Assistant Professor
bin.wang2@utsa.edu
University of Texas at San Antonio
Power System Oscillation Source Analysis Using OSLp Tool

November 16, 2022
Outline

• Introduction & overview of Southern Regional (SR) grid
• OSLp journey so far
• Overview of the Dissipating Energy Flow (DEF) method
• Case Studies
• Implementation of OSLp
• Demo of the web dashboard
Major causes for oscillations

- Loss of major evacuating lines for generating stations
- Maloperation of generator control systems (mostly the Turbine-Governor system)

315 PMUs spread across 95 substations (600+ signals)
OSLp journey so far

• NREL & ISO New England provided OSLp source code in Matlab
• Converted to Python and validated using offline PMU data
• Parallel processing techniques to improve speed
• Deployed in Real Time
• Triggered by an already existing PMU Event Detection Engine (Zscore based)
• Real Time results viewed by the operator in a web dashboard
• Matrix Pencil method to supplement DEF method
Overview of the Dissipating Energy Flow (DEF) method

- Data cleaning (removing outliers and stalled signals)
- Identification of the dominant mode using FFT
- Filtering the Real Power (MW) signal for the dominant mode
- Identify the line with maximum amplitude of filtered mode (study line)
- Identify the time window wherein the oscillation is predominant (study window)
- Compute the dissipating energy flow for each branch
- Visualize the dissipating energy directions in a map to identify the source of oscillation
Case Studies
April 27, 2022
few lines tripped in Sharavathi hydro complex triggering oscillations
220 kV Sharavathi – Shimoga T/C trips
Plant operator reduces generation by 500 MW
DEF Analysis (FFT, Study Line & Study window)

Frequency spectrum

0.74 Hz

MaxLine : Sub:HASAN_PG:Ln:400TLGPA_KA1_

Line Flow (MW)

Time (s)

0 50 100 150 200 250 300

BV

MW

0 20 40 60 80 100 120 140

Scans
DEF Analysis (Source identification)

Source correctly identified Hasan PMU
Case Study 2

Sept 28, 2021 Idamalayar hydro unit tripped triggering small amplitude oscillations
DEF Analysis (FFT, Study Line & Study window)

Frequency spectrum

Normalized Amplitude

0.0 0.2 0.4 0.6 0.8 1.0 1.2 1.4

Frequency [Hz]

1.15 Hz

MaxLine: Sub: UMPET_PG: Ln: 400PLKAD_PG2_

Line Flow (MW)

Time (s)

0 50 100 150 200 250 300

-100

-80

-60

-40

-20

0

100

80

60

40

20

0

MW

Scans

0 20 40 60 80 100 120 140

5.0

7.5

10.0

2.5

5.0

0.0
DEF Analysis (Source identification)

Source correctly identified Kalamassery PMU
Case Study 3

May 20, 2022 small amplitude oscillations observed on the Inter Regional lines
DEF Analysis (FFT, Study Line & Study window)

Frequency spectrum

0.63 Hz

Longest time window selected
DEF Analysis (Source identification)

Source correctly identified Solapur PMU
Implementation of OSLp
Leverage of Open Source Technologies

OSLp Engine

Used Modin Dataframes to scale the program for this huge volume of data

Store Results

Postgres Database to store the results

Visualize Results

Grafana & Apache e-charts

HTML Canvas for DEF Visualization on Grid Geo-Map
Oscillation Source Detection

- **Trigger from the Event Detection Engine (In House using Z score)**

- **Data Cleaning and Process for selection of Oscillation time and spike analysis**

- **Get MW, MVAR and Positive sequence Voltage Magnitude of all Lines only for identified Oscillation Time**

- **Clean the data and calculate DEF**

- **Matrix Pencil Analysis for the top 5 DEF Lines**

- **Store the results to Database (Postgres) and Visualize (Grafana) in Dashboard**
Dashboard
OSLp Real Time Dashboard
Demo of the Dashboard – Real Time Events
Q&A and Discussion

Please use the Q&A function in your Zoom toolbar to ask questions to our presenters.
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**Nov. 17 2022** - Learning from Vietnam’s Experience on High Fluctuations of Variable Renewable Energy in the Grid System


**Dec. 15 2022** – Planning for Peru’s Power System – The Control Center of the Future
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