June 24, 2020
Webinar Questions and Answers

"Real-Time Oscillation Analysis: Technology Readiness, and a Vision for Future Needs and Applications" with Jim Follum

Dan/Evan

Igor Ivanov: Hello, what do you exactly mean by, say, "5% damping"?

Natural oscillations are related to the system's modes of oscillation. Mathematically, the modes correspond to the eigenvalues of the linearized system and are therefore expressed as the complex number $\sigma + j\omega$. The frequency of the mode is given by

$$f = \frac{\omega}{2\pi}$$

in Hz, and the damping ratio is defined as

$$\zeta = -\frac{\sigma}{\sqrt{\sigma^2 + \omega^2}}$$

The damping ratio is often expressed in percent and indicates how quickly the oscillation with frequency f will decay. If a mode has a damping ratio below 0%, the system is unstable because the oscillations will increase in amplitude. For damping ratios greater than 5%, the system is stable and corresponding oscillations will decay more quickly over time.

SasiKala Ramachandran: What is the frequency limit on natural and forced oscillations?

Inter-area natural oscillations, which are of interest for system stability, typically fall in the frequency range between 0.1 and 1.2 Hz. There are other types of natural oscillations, such as from local plant controllers, but the presentation focused on the inter-area modes of oscillation. Forced oscillations can occur at any frequency because their frequency is determined by the forcing input.

Raj Kumar: Can we Build a Jacobian type of Matrix (something similar) for entire Grid (say HV level) for a typical mode?

Modal modeling comes from the linearized system about some power flow. The eigenvalues then represent the modes. There are two basic approaches. The first is based on actually linearizing the transient stability differential and algebraic equations. The second uses curve fitting (e.g., Prony analysis) of a system's free response to a disturbance. There are many papers in the literature on this subject. There are also software tools that have been developed to do this.

Ryan Lott: Dan, are there ever transient ringdowns in PMU data with a particular frequency and damping ratio that do not pertain to a particular system mode after a disturbance such as a line trip?

> No. The response is always driven by the natural modes in the frequency range of interest. This assumes no significant inverter-based generation which is a research area of interest.

SasiKala Ramachandran: is it a postmortem analysis or at real time events

> The plots of mode meter results from the presentation were done offline, but commercial mode meters are available that continuously update the mode estimates for real time tracking.

Guohui Yuan: Dan, can you comment on the impact to system stability from wind and solar in WECC, and how PMU data can help?

> High-penetration of inverter-based generation (IBG) certainly impacts modes. The controls used for the IGB have significant impact on the nature of the impact. This is an important area of current research.
>
> Solar and Wind plants are interconnected through interconnection processes that ensure system stability for various single and multiple contingencies under various conditions. PMU data can help with monitoring the plants, validating the dynamic model for planning and real-time assessments and monitoring oscillations.
>
> There have also been examples where forced oscillations in PMU data were traced to wind turbine controllers. When the data was provided to the generation vendor's attention, the problem was mitigated.

SasiKala Ramachandran: Suggest some PMU Data Analytics tool

> In the interest of fairness, we're going to avoid suggesting particular tools, but we encourage you to check with the vendors that participate in NASPI meetings.

G P: Hello Dan, what's the current practice on probing tests in the WECC. How about EI and Texas?

> The WECC is continuing probing tests via BPA. I don't know about other systems.

Lin Zhu: Thanks for the presentation! The oscillation frequency and damping are varying from time to time. Unit commitment or system contingency (N-1, or N-2) which could cause larger oscillation frequency and damping ratio variation?

> Correct; the modes drift throughout the day as operating conditions vary. When plotted over the course of several days, daily trends can be observed. Contingencies have the potential to dramatically change the frequencies and damping ratios of the modes. A good example is when Alberta disconnects from the rest of the western North American power system. When this happens, the two-dominant north-south modes in the system merge into a single mode with a different frequency and damping ratio.

Slava

SasiKala Ramachandran: On what criteria the source can be identified?
&
Priya Singh: How to identify and locate the source of oscillation?
&
Aman Gautam: please elaborate more on oscillation source identification.

> At ISO-NE, we use the Dissipating Energy Flow method (which is an upgraded version of energy-based method for actual PMU) for the source identification. Dissipating Energy (DE) is proportional to damping and the source of DE is the source of oscillations. DE can be calculated for a transmission element by using PMU measurement for frequency, voltage and current. DE can be viewed exactly the same way as traditional MW flow – it flows from the source to consumers. Plotting DE values on oneline diagram as arrows (similarly to plotting MW where direction of arrow reflects the sign of MW) allows to trace the source of oscillations. Use of DE pattern to locate the source works for majority of natural oscillations and for all forced oscillations including the case of resonance conditions.
>
> In many cases, the largest magnitude of oscillations also indicates the source location. However, this approach is unreliable because it can fail in the case of resonance conditions, when the frequency of forced signal is close to the frequency of natural mode.

Raj Kumar: Slava, Thanks for insight, As per our experience Phasorpoint Oscillation engine normally damping is high for interarea modes damping reduces when mode frequency increase like local modes, appears specific to Phasor point oscillation engine, what are your thoughts on this?

> I am not aware on such phenomena and I do not have substantial reasons to expect that the damping estimation for local modes in Phasorpoint is performed underestimated comparing to inter-area modes. At least, that was never a concern for us. I would recommend to ask GE that question. GE team and their partners at Psymetrics (original developer of Phasorpoint) should be able to answer.

Igor Ivanov: Could you please shine light (in a few words) on how to identify the source of oscillation if a large multiGW power system?

> Reliable way is to use the Dissipating Energy flow in the grid. You can find more details in the answers above. This publication could be a good starting point to learn details: S. Maslennikov, B. Wang, E. Litvinov. “Dissipating energy flow method for locating the source of sustained oscillations,” International Journal of Electrical Power & Energy Systems, vol.88, pp.55-62, June 2017.
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> ISO-NE can share free of charge the offline version of the Oscillation Source Locating application, called OSLp, see details here: https://www.iso-ne.com/participate/support/request-software/

SasiKala Ramachandran: In a connected network too many nodes all be there then which algorithm is apt to find it?

> The energy flow methodology is appropriate even for large networks. For a large power system, monitoring the tie lines between control areas and applying the energy flow method would point to the region where the oscillation’s source is located. Once the control area is identified,

the local system operators can use the energy flow method with PMUs internal to their system to identify the source.

Ryan Lott: Slava, does increasing the number of PMU monitored tie lines between areas have a substantial, if any, effect on the efficacy of OSL-like tool to determine source area of forced oscillation? Or is one tie-line good enough?

In ideal situation, all tie-lines should be monitored by PMUs. Reasonable also is monitoring major tie-lines. If your Control Area is connected to more than one external Areas, then having only one tie-line monitored by PMU is insufficient. It should be at least one line with each of external Areas. Redundancy would be preferable because some of PMU could be unavailable and that may happen during the oscillatory event. In fact, it should not be necessary a tie-line, but a line allowing to clearly trace the direction from/to of your control area.

SasiKala Ramachandran: for an 50/60 Hz system what is the alarm threshold is to be maintained?

Frequency of the network does not define the threshold values. For practical reasons of ISO-NE system, we use thresholds in the range 3-15 MW peak-to-peak.

Tabia Ahmad: What PMU based applications are expected to be affected with low quality PMU data? Esp. effect on oscillation identification

Oscillation identification and the source location can be impacted by the low-quality PMU data. “Low quality” is a broad term. The impact of a specific feature of “low quality” significantly depends on the type of algorithm in the application. For example, for OSL application extensively using spectral analysis, harmful could be outliers, missed samples, all types of artificial spikes in PMU data.

Ryan Lott: Slava, why should we expect the number of modes to reduce with the increase of Inverter based resources?

The number of modes is a type of proportional function of the number of traditional generators online. Replacement of traditional generators by inverter-based should reduce the number of modes. Different story is the frequency spectra of oscillations. That will depend significantly on the locations of traditional generators. I would recommend reading the following paper, where there are analytical solutions for the frequency spectra of an idealized system providing a principal understanding of the phenomena of modes and the relation to the system size.
S.M.Ustinov, J.V.Milanović, V.A.Maslennikov, “Inherent dynamic properties of interconnected power systems”, International Journal of Electrical Power & Energy Systems, Volume 24, Issue 5, June 2002, pp. 371-378

SasiKala Ramachandran: how or what parameters from the PMU Data are to be analyzed? Provide some insights about data analytics tool for PMU data

These are the standard PMU measurements: frequency, voltage and current phasors.

Guohui Yuan: To Slava, have you observed, or do you anticipate any damping trends with respect to the increase of inverter-based generation in the ISO NE area?

Not any trends so far. The penetration of inverter-based generation in ISO-NE is about 10% so far and that does not affect significantly the damping.

YI ZHAO: Could you give more details about how to distinguish the forced oscillation and natural oscillation? Since the natural oscillation is one natural mode of the system, many generators participate the mode, how to find the source of the natural oscillation?

> Simple example: let the sign of PSS gain of one of generators is inverted by some reason. Such a generator will be a source of negative damping and thus be a source of oscillations. The most efficient mitigation of such undamped oscillation is to identify that such a generator is the source of oscillations and mitigate the source (disconnect from network as a quick fix; investigate what is the actual reason within generator creating negative damping). Used at ISO-NE process efficiently identifies the source of such oscillations.

NK: How can poorly damped natural oscillations be mitigated by using "finding the source" approach? We can't usually figure out the actual source of natural oscillations in real-time measurement. Does it mean that "finding the source" approach can just tell us where the large magnitude of natural oscillation come from?

> Most poorly damped natural oscillations are related to problems at a particular plant, very similar to forced oscillations. Thus, in most cases there is not a need to distinguish between natural and forced oscillations to initiate the proper response. The exception is inter-area natural oscillations, which as you say involve many generators in the mode. In this case, the appropriate mitigation is typically to reduce power flows along the oscillation's path.
>
> The largest magnitude of oscillations in the network can be often used as an indication of the source location. However, that approach is unreliable and can fail for the resonance conditions, when the frequency of forced signal is close to the frequency of natural mode. At ISO-NE we use much more reliable approach by calculating the flow of dissipating energy in the network. I would recommend looking at the responses to other questions, which provide more information.

DMITRII DUBININ: to Slava: could you please tell about the actions of ISO in cases when you find out that any power plant is the source of LFO?

> Typically, after the detection of a specific power plant or generator as the source, ISO operations contact that power plant to investigate the actual reasons for oscillations with the objective to eliminate it from happening in the future. If the magnitude of oscillations is not "critical", the communication process is shifted offline and conducted by operations engineers. If the magnitude of oscillations is "large" and the Control Room can see it as a threat to the system, then Control Room personnel can implement emergency actions to disconnect the source-generator from network, or implement a range of other online actions by communicating with the source-power plant. This range can include the reduction/change the MW output, change of control mode for AVR or governor, reverse the recently implemented actions leading the appearance of oscillations, etc.

Guohui Yuan: @Slava, when you use Power Quality module to weed not bad data, is it possible to unintentionally miss some system dynamics that might not be known traditionally? I would argue not to discount bad data too easily.

> As a general approach, I would agree with you. At the same time, that depends on how to define "bad data" in the relation with the specific type of algorithms used in an application. Based on few years of working with actual PMU data, I have identified a number of specific deficiencies of

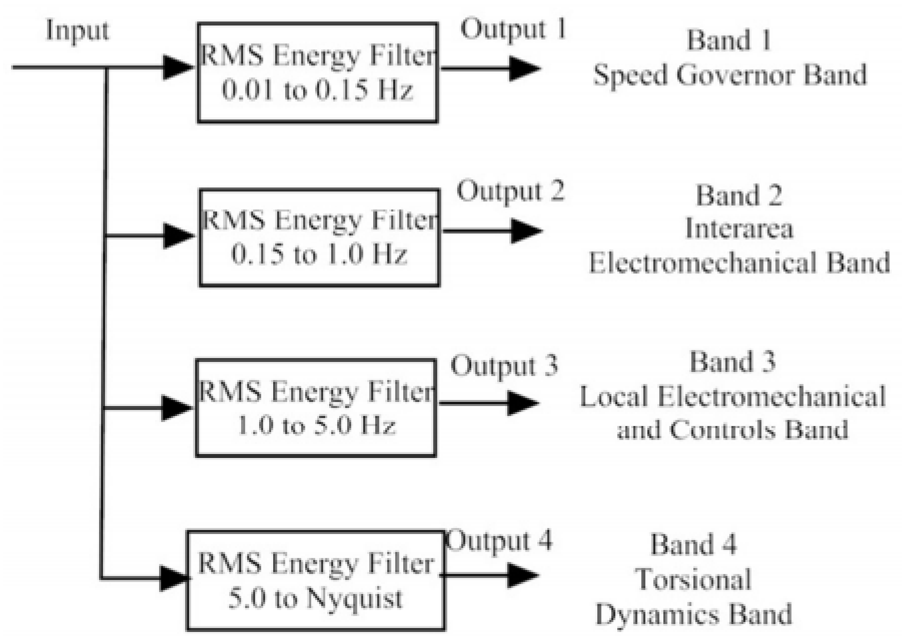
PMU data, which can negatively impact the performance of the Oscillation Source Locating (OSL) application. A data quality module handling all these cases was implemented inside of OSL.

The proposed generic data quality module should have two outputs: corrected data and flagged suspicious data. That is up to downstream application which output to use. This approach does not blindly remove “bad data” but only indicates “bad” data and the final decision is up to a downstream application.

Aftab

SasiKala Ramachandran: what do Band 3 oscillation meant to be?
&
SasiKala Ramachandran: What is your Band limit for each Band?

The bands refer to frequency ranges that generally correspond to different types of oscillations. Custom and commercial oscillation analysis software use these bands. Here’s a figure providing an overview of the bands from (M. Donnelly, D. Trudnowski, J. Colwell, J. Pierre and L. Dosiek, "RMS-energy filter design for real-time oscillation detection," 2015 IEEE Power & Energy Society General Meeting, Denver, CO, 2015, pp. 1-5).



SasiKala Ramachandran: does any open source tools are available for Oscillation monitoring?

Aftab Alam: I have not heard of open source tools for real-time oscillation monitoring

Rodolfo Bialecki: When trying to identify a specific known interarea mode it's interesting to use certain signals (active power flows, angular differences etc.) in which the mode is more observable and drop signals that just bring more useless data into the analysis. Could you share some insights on your practical approach for that (if you have this signal selection step)?

The NERC SMS is developing a white paper on recommended oscillation analyses to support the monitoring. One of the questions that we are aiming to understand better is what signals should be selected monitoring inter-area modes. You are welcome to join the effort.

Shaun/Subbarao

SasiKala Ramachandran: do i get support for installing FNET?

FNET event reports and videos are centrally hosted by CURENT at UTK: http://fnetpublic.utk.edu/

Sean Murphy: In what cases do we need wide-area vs. local measurement data to characterize events? What types of events can be addressed using local measurements? What types of events warrant more data sharing?

Natural oscillations require wide monitoring and forced oscillations can be detected with local monitoring. However, a wide-area monitoring system is needed to first determine whether it is a natural or forced oscillation. ESAMS will be part of a hierarchical system with lower resolution, but larger geographic coverage. Both natural and forced oscillations affect the entire interconnection (you can't stop an oscillation from crossing utility boundaries), so some form of data exchange is needed on the interconnection level. EIDSN supports this data exchange.