NASPI North American SynchroPhasor Initiative

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Webinar Questions and Answers

"Impacts of Forced Oscillations on Power Systems"

with Aftab Alam and Urmila Agrawal

Question: Can you confirm that microPMU granularity is only 120 Hz or 2 samples per cycle in a 60 Hz US frequency. Or is it 120 samples per cycle?

Answer: *The data used in the analysis for forced oscillations shown in Slide-10 is archived at 15 samples/second.*

Question: According to your nomenclature in which category you see the so-called ambient oscillations? Most probably forced oscillations?

Answer: Ambient oscillations are the natural response of systems to the random load disturbances continuously exciting the system modes and therefore fall under the category of natural oscillations. One thing to note is that the forced oscillations are the response of a system to the periodic disturbances (such as a cyclic load) and not random disturbances.

Question: Can these be also causes for FO?

Answer: FOs are caused when a source introduces a periodic disturbances to a system, for example cyclic load. Any random disturbances that are not periodic will not cause FOs.

Question: On slide 4, if I understood correctly, you remarked that localized forced oscillations are kept local due to "inductive nature of grid". But later you mention that localized forced oscillations could be in the 1Hz-5 Hz range. Are you sure the inductive nature of the grid plays a significant role at a frequency of 1 Hz?

Answer: In slide 5, the example was only to show the local nature of forced oscillations that was detected in the 1-5 Hz frequency band. It does not mean that all oscillations detected in this band will be local specifically in the 1-2 Hz frequency range. The inductive nature of the grid will play a major role in the frequency range above system modes, likely to be above 2 Hz.

Question: How PMUs are helpful for detection of forced oscillations and at what PMU reporting rate will helpful? 25 PFS or 50 FPS or 100 FPS. Hope M class PMU can be used.

Answer: The natural oscillations occurring in power systems are in the frequency range of 0.1 Hz to 2 Hz and the forced oscillations can be of higher frequency depending on the frequency of the disturbance. To study these oscillations, specifically in the frequency range of system modes, the PMU rating rate should at least be 5 samples/second (folding frequency = 2.5Hz). If forced oscillations occurring are at higher frequency range, the PMU reporting rate should at least be twice that of the frequency of the FOs. Using these phasor measurements, the forced oscillation detection and other algorithms can be implemented to detect and further analyze these oscillations.

Question: How accurate is to be the design of your model (control systems and impedances) to study these oscillations in simulation? How much approximation is warranted?

Answer: For studying oscillations using simulated data, full system model with higher order generator model should be used and as accurate as possible.

Question: What is your time interval used to compute the rate of change of frequency oscillation before your red alarm notification starts logging the event duration?

Answer: Most applications are detecting forced oscillations every 1-2 seconds.

Question: What are the impacts of resonance at wider range?

Answer: The impacts of resonance at wider range depends on the amplitude of the power swings observed across wide-area. For power swings having high amplitude that can cause equipment trip, control action or triggering of protection scheme can have severe consequence if it results in cascading trip actions.

Question: Page 10 : How was this oscillation detected or located?

Answer: This oscillation event was detected by energy-band based detector in RTDMS tool used in the control center. As the energy of the measurements in the 0.15 to 1 Hz frequency band exceeded the threshold because of the presence of FOs, the alerts were seen. Once the oscillations were detected, the RC West operators started communicating with other operators and also checked the power output display for the inverter-based resources. Since the source was a battery system, the display helped locate the source of these oscillations.

Question: How big was the Battery storage system to have caused such a disturbance?

Answer: Each of the two battery storage units causing these oscillations was of 50 MW rating.

Question: What was determined to be the cause of battery forced oscillations?

Answer: The battery forced oscillations was caused by the interruption of the network connectivity in the battery facility.

Question: Do you think Regional Reliability Standard VAR-501-WECC3.1 (Power System Stabilizer (PSS) is sufficient to take care of Oscillations in the Western Interconnection.

Answer: Regional Reliability Standard VAR-501-WECC3.1 (Power System Stabilizer (PSS) may not be sufficient to take care of Oscillations in the Western Interconnection, specifically forced oscillations.

Question: What was the capacity of the battery (in examples slide of southern California disturbance) and what was the impact (viz: equipment failures etc.)? What tools system operators used to identify oscillation?

Answer: Each of the two battery units in which these oscillations originated were of close to 50 MW. Since the damping ratio of the mode having close to that of the forced oscillation was high, ~ 200 MW power swings were observed in the COI flow and no further impact was observed. However, if the damping ratio of the mode was low and if the source would not have been identified in time (likely to happen), then this situation could have been much more severe. The answer on tools for identifying the oscilaltions has been already answered in the previous question.

Question: The WECC forced oscillation event happened on what day and what time? How was it finally mitigated?

Answer: The WECC forced oscillation event occurred on 27th and 28th January around 5 pm. On 27th Jan, the oscillations went away on their own. However, operators were able to do some investigation and locate the source of these oscillations. When these oscillations showed up again the next day, as the operators already were aware of the cause of the forced oscillations, the units were shutdown to mitigate forced oscillations.

Question: How did the oscillation die down in the first case?

Answer: The units causing these oscillations were shutdown to mitigate these oscillations.

Question: What is NS-A mode?

Answer: North-South A mode is a dominant inter-area mode in the Western Interconnection having a frequency of 0.18 – 0.25 Hz. In this mode, the entire North of the U.S. Western Interconnection oscillates against the entire South.

Question: For example #2 when that oscillations happened? And for Example #3, same question, when that happened?

Answer: These are examples of old events, not sure of the date and time of the event.

Question: Is the CA utility owner of battery storage have knowledge and visibility that there battery creating force oscillation to CAISO grid? Is there an automated notification coming from CAISO to flag the responsible battery owner?

Answer: Yes, the CA utility owner have the knowledge of the issue and since then the issue has been resolved. For the second question, no, we do not have any automated process to notify the responsible entity.

Question: In the spectra of example wide-area forced oscillation, .e.g. slide 11, we can see the peak at the oscillation frequency - good! But we also see frequencies that are remarkably low. What is the interpretation of those "negative" peaks?

Answer: They negative peaks are the artifacts of the periodogram spectrum estimate caused by the spectrum leakage in the side lobes.

Question: What is the nominal damping ratio?

Answer: The exact nominal damping ratio would be system dependent depending on how much small-signal stability margin you think would be sufficient following a credible critical contingency that can severely reduce the damping ratio of a system mode. In the Western Interconnection, the alert are set for 3% damping ratio. If the damping ratio of a mode goes below this threshold, then the alert is triggered.

Question: It would be really useful to understand what analysis you have conducted following these non-classical electromechanical mode forced oscillation events- to both classify what good damping by frequency should look like and demonstrate in simulation that effect on a comparable scenario. further- have you looked for the presence of the oscillation frequency and its associated damping prior to the event? Is there a link to embedded harmonic emissions present at certain modes?

Answer: Based on the current practice, the single damping ratio threshold is used for all frequency level. The oscillation frequency and the damping ratio of the NS-A mode, frequency for which was close to the forced oscillations, are shown in slide-10. The harmonic emissions depend on the type of periodic disturbance introduced by the source in the system. If the disturbance is a sinusoidal signal then only single harmonic component will be present, if it is square then odd harmonic components will be present and so on.

Question: Which is the best mode assessment technique for real time synchophasor data under forced oscillation? as per your experience

Answer: There are some modemeter algorithms that can be found in research papers. One of such algorithms include the enhanced version of the traditional modemeter algorithms currently deployed in CAISO. This algorithm can be found in Agrawal, Urmila, et al. "Electromechanical mode estimation in the presence of periodic forced oscillations." *IEEE transactions on power systems* 34.2 (2018): 1579-1588. The other algorithm based on frequency domain decomposition that can estimate system modes in the presence of forced oscillations can be found in H. Zhang, J. Ning, H. Yuan and V. Venkatasubramanian, "Implementing Online Oscillation Monitoring and Forced Oscillation Source Locating at Peak

Reliability," *2019 North American Power Symposium (NAPS)*, 2019, pp. 1-6, doi: 10.1109/NAPS46351.2019.9000376. The performance of these algorithms can depend on how close the system mode frequency is to that of forced oscillations.

Question: Please, could the panelists offer some comments on how this discussion about transmission grids might be applied to distribution grids, especially distribution grids with high penetration of Inverter Based Resources?

Answer: We have not looked into this yet.

Question: Do you know what the damping ratio were during those events?

Answer: The damping ratio of the NS-A mode before the event shown in slide 10 was ~15%.

Question: How is the source of disturbance identified?

Answer: Similar wide-area forced oscillations were also observed on a day prior to the event shown in slide-11. On that day, the forced oscillations went away on their own. However, the operators did some investigation and were able to identify possible source of the FOs in the Southern California. The display of the power output of the inverter-based resources in the control center helped locate this source. The next day, when the oscillations appeared again, the operators were able to take mitigation action based on the analysis done the previous day by asking the unit owner to take down the unit offline.

Question: How do you improve damping of source which have no inertia?

Answer: Electromechanical modes are due to the inherent electromechanical nature of power systems consisting of rotating masses having inertia. With no inertia, the whole dynamics of the system would be different and move from electromechanical to control-based dynamics. We will be looking at control oscillations at that point.

Question: Are forced oscillations becoming more common due to renewable energy, energy storage, etc?

Answer: With increased inverter-based resources, the equipment that can cause forced oscillations have also increased. Therefore, we are likely to see more forced oscillation events in the system.

Question: What caused the solar plant to oscillate?

Answer: Response provided in the previous question.

Question: The source of the forced oscillations identification takes in average how much time?

Answer: It can take from few minutes to few days depending on how much information you have readily available on the source and time taken to process the information. For the example shown in slide-11, the operators checked the inverter output of the inverter resources in the control center and

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were able to identify the location within 10-15 minutes. Without those display, it could have taken more time.

Question: How to distinguish measurement noises and forced oscillations?

Answer: Measurement noises are random in nature (not periodic), so the periodgram spectrum will be similar to that of the white noise. Forced oscillations are periodic in nature (a square, sinusoidal or other periodic signal) and therefore the periodogram spectrum of these oscillations will have a peak at the frequency of the forced oscillations.

Question: It seems that so far operators act on a corrective fashion by identifying the source of oscillations and turning them off. Would operators be interested in a preventive action, such as changing the OPF dispatch point to improve the frequency response of an interconnection, especially at the low frequency band? Thanks for the great talk!

Answer: The forced oscillations are indicator of malfunctioning equipment or the control mis-operations. It would be difficult to identify this until it actually happens. The only "preventive" action that can be taken will be to improve the damping ratio of system modes, for example by generation re-dispatch, so that the amplitude of the forced oscillations will not be high when these oscillations occur and have frequency close to that of a system mode. Another thing to note here is that these frequency oscillations are different from the interconnection frequency response.

Question: Dr. Venkatsubramian group at WSU pointed out that in resonance it is hard to localize the sources. Do you have comments on why this would be the case?

Answer: Identifying the source of the forced oscillations is a challenging task not only during resonance condition (when the frequency of forced oscillation is close to that of a system mode having close to zero damping ratio. This is in fact the case when the frequency of forced oscillations is in the frequency range of system modes. In this situation, the amplitude of forced oscillations can be higher at location far from the source. This is due to the overall dynamics of the system and the transfer function from the input location to the measurement location.

Question: In conclusion slide, what measures can be immediately taken to lower the magnitude of the oscillations while the source of oscillation is being identified?

Answer: The actions to improve the damping ratio of a mode should be identified from offline studies for each specific mode and could involve generation re-dispatching and reducing flows across major critical lines.

Question: How to identify and analyze source of oscillation from mode assessment?

Answer: The identifications and the analysis of the source of oscillation cannot be done using mode assessment tools. There are several algorithms developed to detect the forced oscillations in a system and identify their locations.

Question: Do we have damping ratio threshold number that we can use for our red flag notification for localized and wide area oscillation?

Answer: The damping ratio thresholds depend on how much small-signal stability margin is needed such that the system is secure against credible contingencies. In the case of wide-area forced oscillations, the damping ratio should be high enough such that the power swings does not affect system reliable operations. This damping ratio value would be dependent on the frequency and the location of forced oscillations.

Question: On page 4 about local oscillation, can you elaborate why the inductive nature of power system prevented propagation of local oscillation, but not inter-area oscillation?

Answer: The frequency of the forced oscillations determines if these oscillations will be observed across wide-area or will be localized at the source. Due to the grid's inductive nature, power systems act as a low-pass filter (impedance is proportional to the frequency). In the frequency range of the system modes, the impedance of the system is low and allows the propagation of the oscillations across wide-area. However, in the frequency range above that of system modes, the impedance of the grid comes into play and does not allow oscillations to propagate to other areas and thereby resulting in localized oscillations.

Question: Thanks for great presentation. I would like to ask a question as follows: as you conclude that we need to identify the oscillation sources. With a large scale power system with high penetration of RES, it is hard to create model-based analysis, how can we identify the oscillation sources based on measurement-based approach? Any methods or suggestions on it? Thanks

Answer: Several ISOs have implemented dissipating energy-based algorithm to locate the source of forced oscillations.

Question: Has CAISO started to see new/changing oscillation modes as the interconnected generation fleet moves from larger steam plants to inverter based resources? Are dynamics models for these new IBR facilities "good enough" to identify issues before they happen? Any issues getting good models for these plants and/or integrating these models into your EMS tools?

Answer: We have not seen any significant changes in the system modes in the Western Interconnection so far with increasing inverter based resources. Since the analysis is performed using real PMU measurements, dynamic model quality is not an issue for the oscillation assessment.

Question: Do you think PMUs at distribution system would help detect and localize forced oscillations in the system?

Answer: If the source of the forced oscillations is located in a distribution system, then possibly.

Question: Why was the damping ratio underestimated?

Answer: The damping ratio of the mode got underestimated because of the presence of forced oscillations. It is a limitation of the algorithm as it does not take into consideration the presence of forced oscillation in the signal being analyzed.

Question: Are there any efforts from NERC to come up with any standards with regards to monitoring and mitigation of oscillations?

Answer: NERC Standard IRO 002-6 provides some guidance on monitoring and mitigation of oscillations.

Question: Is there a transmission system operator TSO which monitor oscillation at real time??

Answer: Yes, various RC and TOP operators across various interconnections monitor oscillations in real time using different tools.

Question: Can you point to specific algorithm or paper that RTDMS uses to locate the source of FO?

Answer: Many RCs and TOPs are using dissipating-energy based algorithm to locate the source of FOs. The algorithm might have some limitations as well when the forced oscillations' frequency matches a mode having low damping ratio.

Question: What threshold you fix? Point out some reference sources to study about oscillations and its analysis? Can you mention some guidelines for managing oscillations? Especially in to MATLAB how to work with COMTRADE FILES.

Answer: The damping ratio threshold is 3%. You can refer to a recently published white paper by Synchrophasor Measurement Working Group under NERC that has various references related to oscillations analysis. The report can be found at: Oscillation Analysis Monitoring and Mitigation (nerc.com).

Question: Have you looked at whether Grid forming inverters would significantly damp the mode- may not be an inertia against frequency but inertial against voltage angle behaviour that helps?

Answer: Grid forming inverters do not have any inherent nature to damp out oscillations. A thorough investigation needs to done for any controller designed in inverter-based resources, irrespective of being grid-forming and grid-following, to damp out the oscillations to understand its efficacy.

Question: Where are you getting your power quality data to compute the dominant harmonics frequency injected in oscillation? Do you get it from your PMU or separate power quality meter?

Answer: We use PMU measurements data to do any analysis related to oscillations including that for harmonic components. We do not use any separate power quality meter.