ESIG
ENERGY SYSTEMS
INTEGRATION GROUP

ESIG REPORT

Diagnosis and Mitigation of Observed Oscillations in IBR-Dominant Power Systems: A Practical Guide

EXECUTIVE SUMMARY

Oscillations in power systems have always been of concern. The increasing use of inverter-based resources (IBRs)—such as solar photovoltaics, wind, and battery systems and inverter-based transmission, distribution, and load technologies—has led to oscillations with a wider range of characteristics and root causes. These raise new issues and risks for power system operation and planning, since oscillations can lead to unwanted equipment disconnections, supply interruptions, equipment damage, and other violations of reliability criteria.

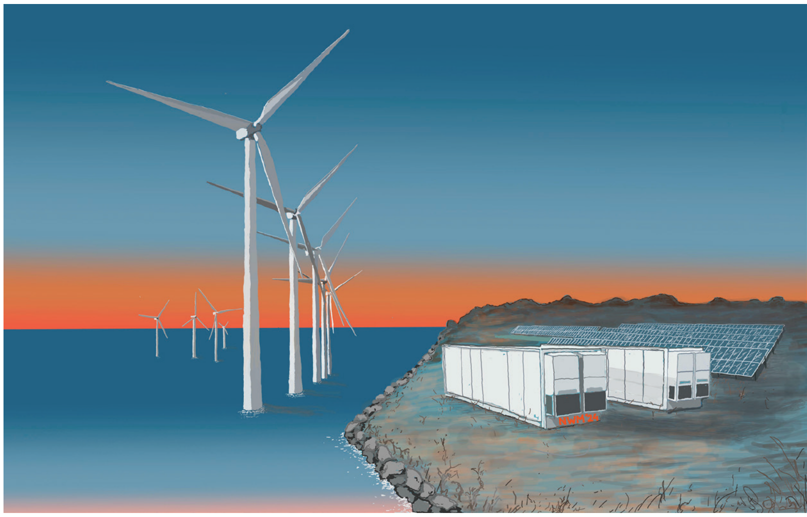
This practical guide is a starting point for practitioners who encounter oscillatory behavior, a sort of field guide or diagnostician's assistant. Consulting the guide is the first step that follows "I see an oscillation. What is it? What do I do about it?"

The document is primarily intended to provide help for practitioners when the oscillations observed are "real"—that is, they have been detected or measured in the field (say, by a relay or phasor-measurement unit). But, since much of the diagnostic approach applies to oscillations observed in time simulations, they are included as well. Users will find the guide an aid to understanding and mitigating simulated oscillations.

Causes of Oscillatory Behavior

While this topic is complex, some practical simplifications cover most oscillatory behaviors:

- Something is broken: some aspect of the installation is not what you thought it was.
- Controls are too aggressive for the condition: gains too high, time constants too short, delays too long.



- The simulation is bad: wrong or inadequate models or the wrong tool was used.

The experienced practitioner will recognize these points and immediately observe that each one has a world of detail behind it. This guide will help the user find out which applies, what to do about it, and where to go for more help. A causality screening matrix is included that introduces a compact synopsis of attributes and causality, and the detailed table of contents will help the more experienced user to zero in on the topic of their choosing.

Something is broken.

Some practitioners will be inclined to immediately reach toward simulation tools to get to the bottom of observed oscillations. However, poor behavior is often the result of physical or software problems outside of normal modeling. Practical examples include:

- Switched polarity or phase rolling on signals
- Parameters like gains or ratios improperly implemented, documented, or per-unitized

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- Equipment in improper operating paradigm, such as stuck in start-up, standby, or island mode, or just shut down
- Equipment that is physically broken, such as stuck actuators, shorted wires, or failed circuitry

A key to diagnosing these types of problems is knowing where to look. Operational monitoring that is aided with identification tools can be a key to finding "bad actors." A growing arsenal of visualization and mapping tools have often proven to be effective, with their ability to track locations of high-amplitude oscillations, detect the direction of oscillatory energy flow, and distill mode shapes or other information about the potential participation of generators in oscillatory behavior. After-the-fact forensic measurements and simulations can confirm causality and often point to simple fixes.

The control is too aggressive.

The practical reality of closed-loop controls is that the desire or even requirement for rapid response often drives unstable behavior. This has always been true, but the advent of IBRs places equipment physically capable of astonishingly fast changes into the complex power system. As conventional high-inertia synchronous units are retired, it becomes increasingly possible for fast controllers to push the system into instability.

Anecdotal experience suggests that the majority of oscillations originate with a single "bad actor." An ensuing debate as to whether the control of that single resource is too aggressive, too slow, or too dumb, the grid is too weak, or the bad actor is just the straw-on-the-back of a systemic problem, may be more a matter of semantics than practical utility. The simple expedient of calming the control or avoiding the problematic operating condition may have other unacceptable consequences (including poor regulation, non-compliance with requirements, constrained operation of the plant, or subeconomic operation). This drives the practical reality, recognized in this guide, that such short-term fixes to avoid oscillations may need to be replaced or supplemented with more extensive (and expensive) long-term mitigation. All mitigation options may have some negative consequences, ranging from significant capital costs, to reduced economy or flexibility of operation, to degradation of other aspects of dynamic performance.

A possible synopsis of mitigations, roughly in order of speed of implementation, includes:

- Control setpoint adjustment
- Operation or dispatch adjustment (within plant)
- Operation adjustment on host network (dispatch, topology switching)
- Control parameter modification (tuning)
- Reduction of series (or shunt) compensation levels
- Control structure modification (e.g., added signal filtering, damping control, reduced latency, altered phase-locked loop, change of inverter control mode from grid-following to grid-forming)
- Addition of passive elements within plant (e.g., compensation, filtering, detuning of resonances)
- Addition of active elements within plant (e.g., static synchronous compensator (STATCOM), active filters, storage with grid-forming inverters)
- Host grid reinforcement, improvement of system strength, or addition of dynamic reactive compensation and active damping devices

Simulation is bad.

The art of simulating IBRs has been evolving and occasionally problematic for a couple decades. Practice has not reached equilibrium. Potential for misleading or meaningless simulations of a range of IBR behaviors abound—including those that cause oscillations. This guide provides some help recognizing bad simulations and avoiding some of the more common mistakes, which include:

- The use of poor input data, i.e., bad parameterization for properly structured models
- The use of IBR models with structures that are inappropriate or missing details, such as latency or phase-locked loop, that are important to the phenomenon being observed
- The use of grid models that are overly simplified, poorly coded, or missing key attributes
- Inappropriate choice of simulation platform, such as phasor analysis when electromagnetic transient study is required

- Poorly controlled or processed simulations, with pathologies like aliasing or numerical instability

And beyond.

These basics do not always cover more complex causality. Interactions can occur between many resources that may have multiple owners or cross jurisdictions. The resultant oscillations may be without identifiable individual bad actors. Experience supports the investigation of such possibilities but generally only after the single bad actor possibility has been dismissed. This guide can help the diagnostician understand when the behavior is more complex and can help with the initial steps to resolution. But some complex phenomena are beyond the scope of this guide, and oscillations are one face of a complex and overlapping problem space. Concerns about other dynamic behaviors, notably fault ride-through issues, urgently need attention as well, but are outside this scope.

Components of This Guide

This guide is organized to provide the diagnostician with background and processes to quickly address most types of oscillatory behaviors in power systems, especially those associated with high levels of IBRs. The information presented becomes progressively more detailed. The reader interested in the topic, but not charged with solving a specific problem, will find earlier sections the most illuminating. The introduction and the section "Oscillations and System Stability" provide the technical background necessary as a foundation for forensics. An overall diagnostic process is then presented with a high-level flow chart and supporting sections on measurements and analytical tools.

The steps for the actual diagnostic process begin in the "Initial Assessment" section. There we introduce a novel causality screening matrix that distills correlation between observed behaviors and possible causes into an extremely compact diagnostic aid. The diagnostician will emerge from the initial diagnostic assessment with a candidate causality for more detailed diagnosis. The balance of the guide provides detailed guidance for assessment and countermeasures for specific phenomena. Guidance is provided on the use of simulations, including ways to avoid common simulation errors, along with extensive references aimed at helping the user find more detailed and advanced help.

Beyond consulting this guide, diagnosticians must also recognize the need for collaboration with equipment manufacturers, researchers, organizations (like ESIG), and other practitioners in understanding and mitigating the more complex problems.

The industry is on a steep learning curve, with new tools and understanding constantly emerging. Most of the material in this guide will remain foundational, even as new understanding and tools are developed. Beyond consulting this guide, diagnosticians must also recognize the need for collaboration with equipment manufacturers, researchers, organizations (like ESIG), and other practitioners in understanding and mitigating the more complex problems.

Diagnosis and Mitigation of Observed Oscillations in IBR-Dominant Power Systems: A Practical Guide by the Energy Systems Integration Group's Stability Task Force is available at https://www.esig.energy/oscillations-guide/.

To learn more about the topics discussed here, please send an email to info@esig.energy.

The Energy Systems Integration Group is a nonprofit organization that marshals the expertise of the electricity industry's technical community to support grid transformation and energy systems integration and operation. https://www.esig.energy.