Locating the Source of Forced Oscillations

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assuring the wide area view

WSU Damping Monitor Offline was the Tool Used to Detect the Oscillations

- WSU Damping Monitor Approach
  - The DMO uses ALL PMU channels to determine if a high energy oscillation exists.
    - Does not continuously monitor modes
    - Measurement Based

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Forced Oscillation Indication

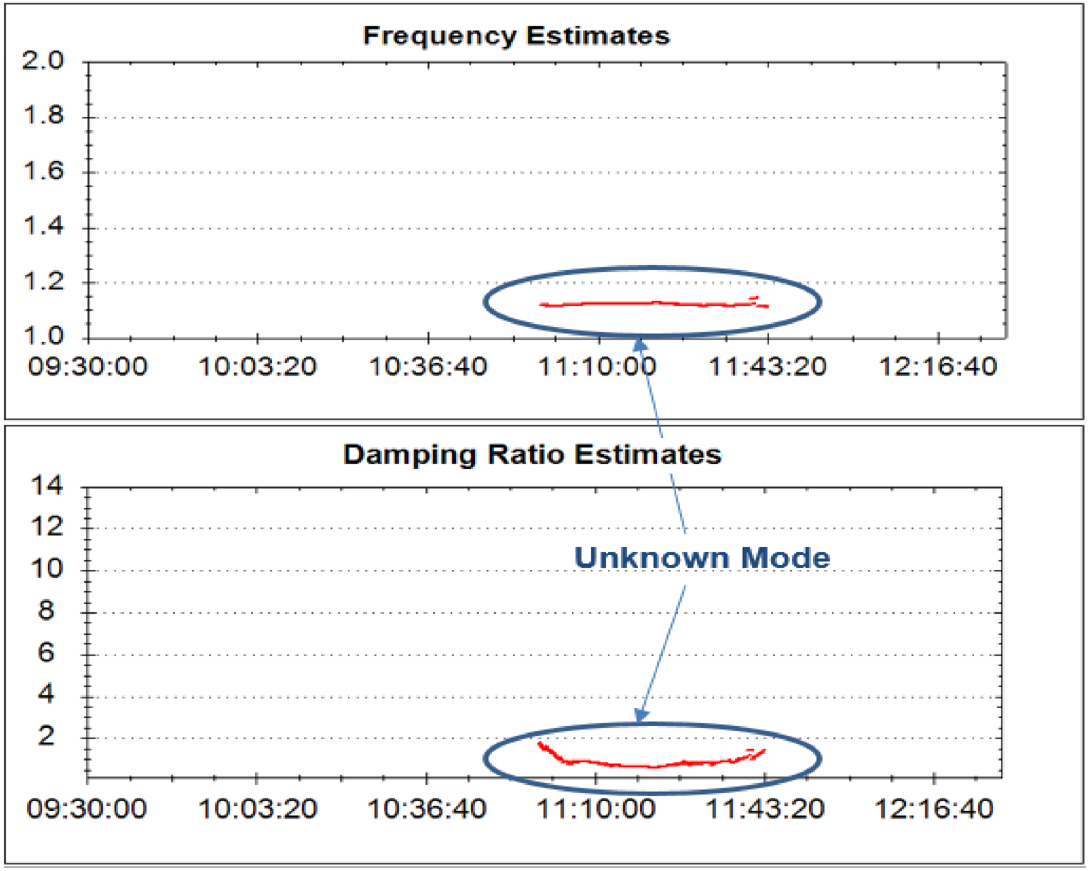
- A forced oscillation is *usually* indicated by the following characteristics:
  - High Energy (relative to the frequency spectrum)
  - Low Damping
  - The introduction of a previously unknown Mode
  - Abrupt Appearance

An Example of Events

- Peak and WSU were examining the system response to a generation loss that occurred at a given time.
- The WSU DMO was run during the time period and the 1 – 7 Hz frequency range was analyzed.

Finding a Forced Oscillation

- An unknown mode that appeared for about 45 minutes
  - Distinctive with a defined start and end time.
  - No correlation with the generation loss.



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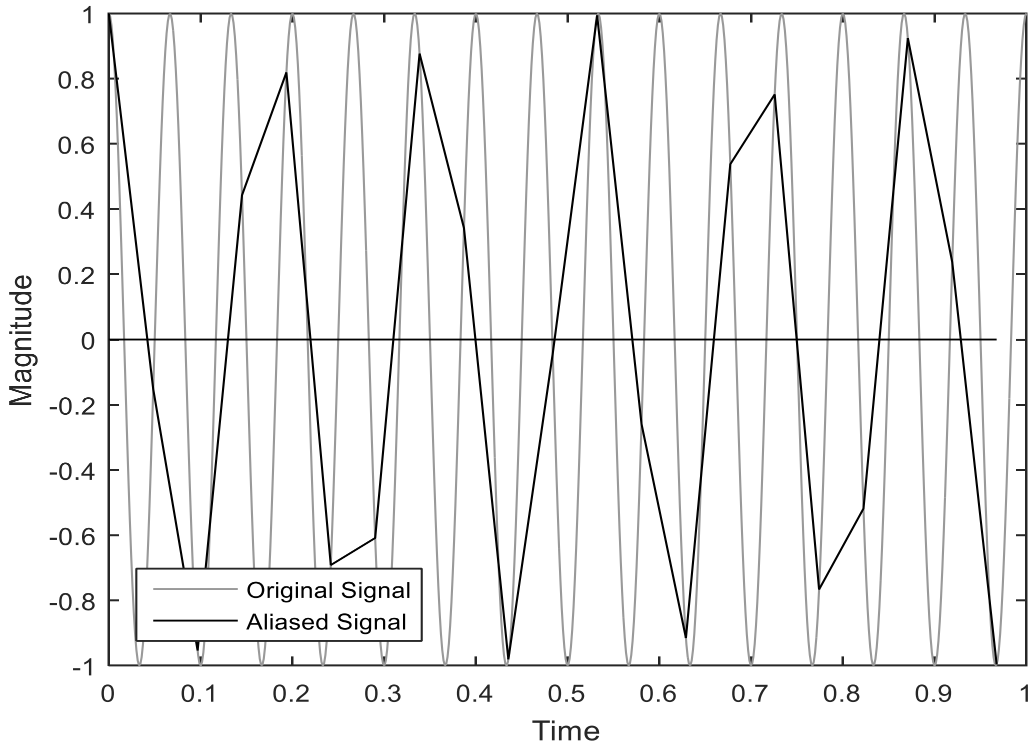
Problems with SCADA Data

- Low sample rate makes aliasing a problem



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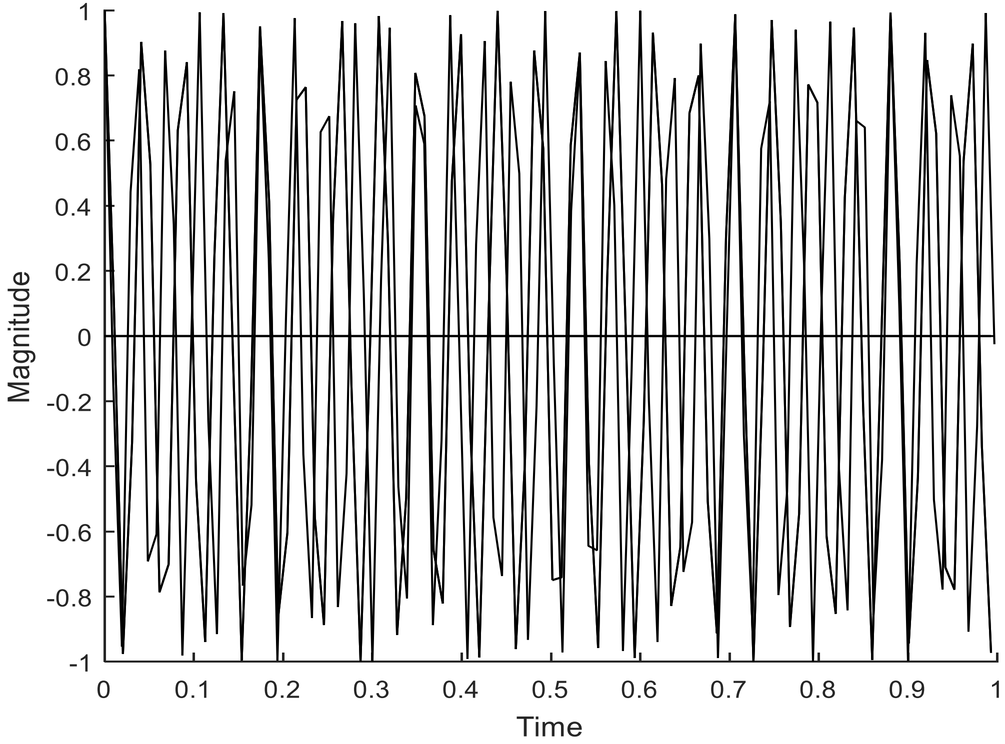
Problems with SCADA Data (cont.)

- On a larger sample, this begins to look like “noise”



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How to find the Source?

- Not all generators are visible by PMU data
- SCADA data is much more readily available
  - ~10 second sample rate
- Peak developed a tool to process this SCADA data to find the likely cause of oscillations. (working title: **P**attern **M**ining **A**lgorithm)
  - Mani (WSU) helped identify what an oscillating generator may look like.
    - Key in detecting these patterns

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Assumptions

- Due to the low sample rate of PMU data compared to the oscillation frequency, aliasing occurs
- If the assumption is made that the sample rate and the oscillation frequency are mutually exclusive of one another, there exists the notion that an oscillation can still be detected.
- The inflection points of these raw values are examined and considered to be an occurrence of an oscillation. ($\frac{\partial^2 X}{\partial t^2} = 0$)

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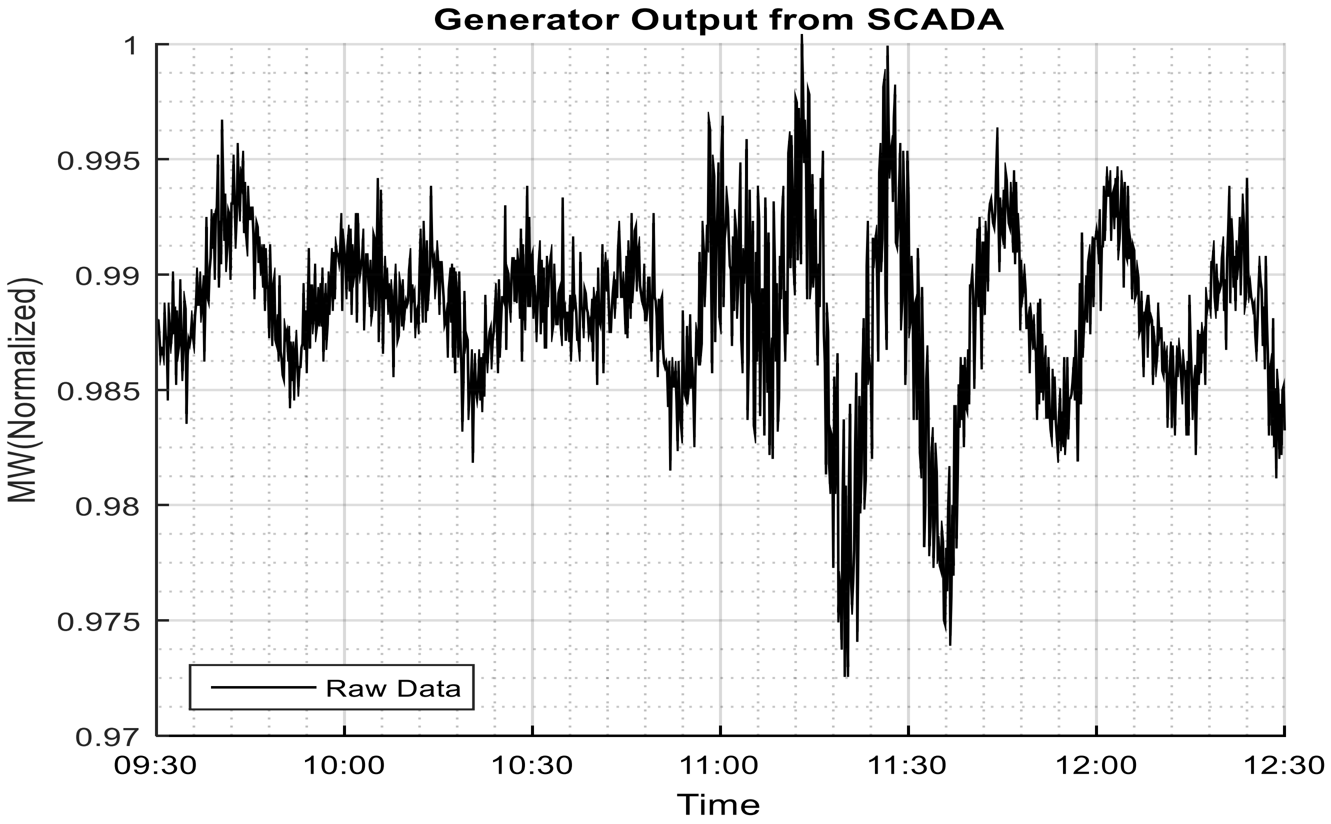
Find the Oscillation….

- For the following generator, an oscillation exists for ~45 minutes:



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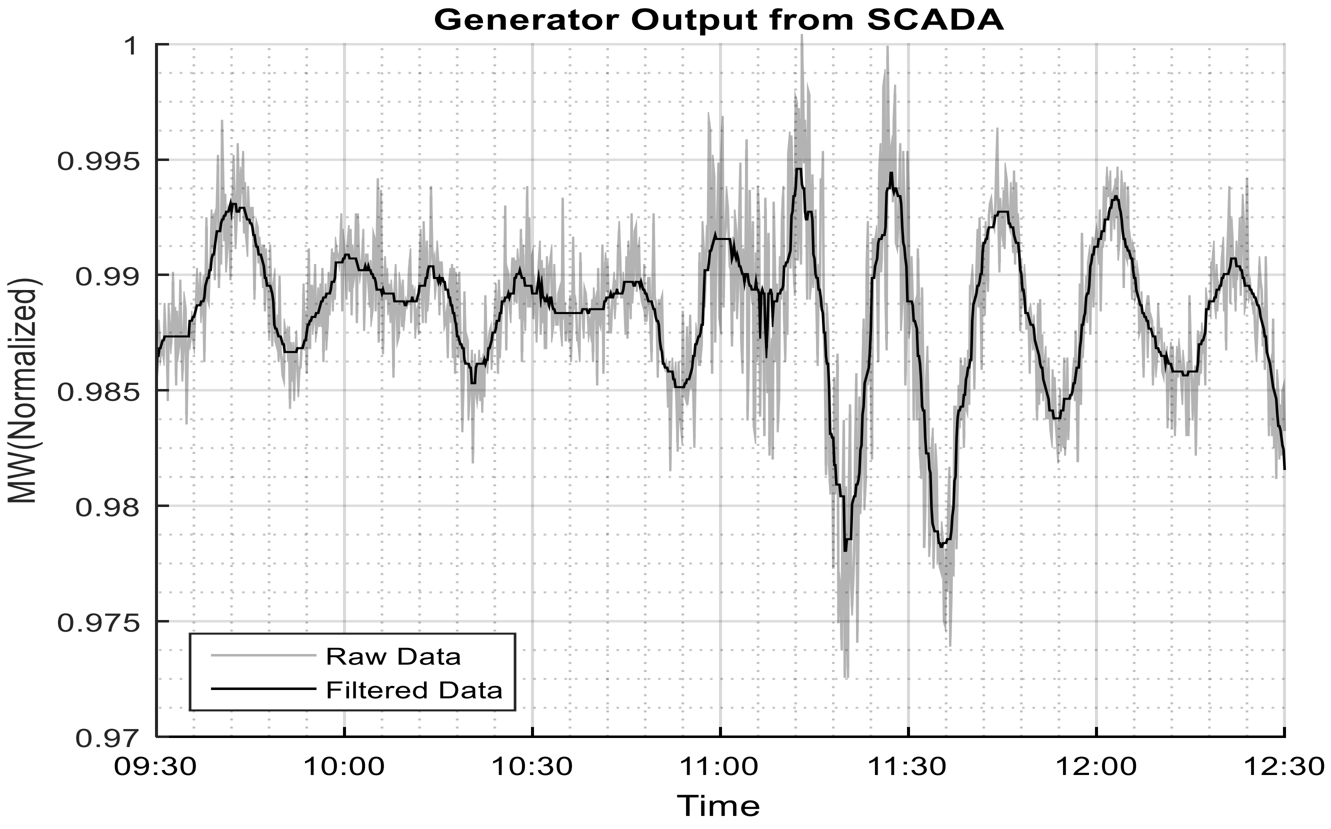
Adding a Filter..

- A simple n-point median filter is used as a “reference”



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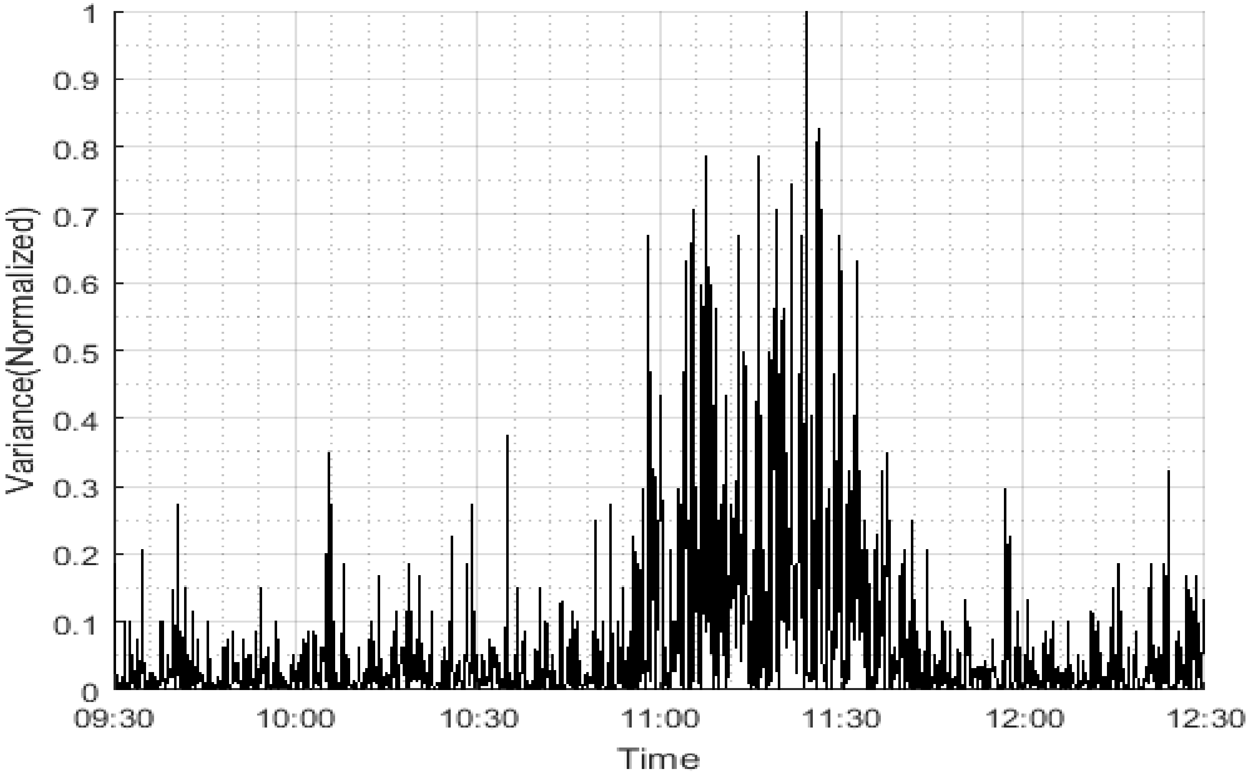
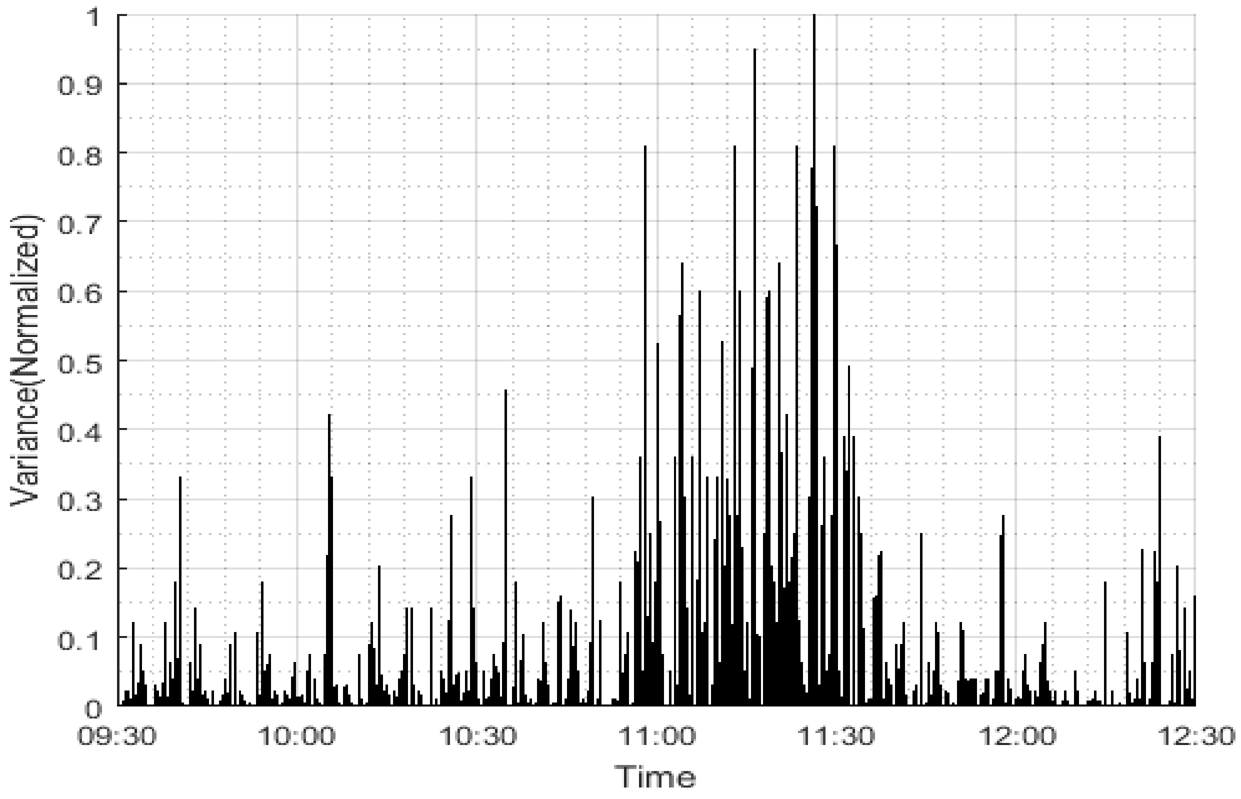
Using the Variance of the Two (Δ^2)

- Now the picture starts to become clearer…



Variance with Inflection-Point Filter



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Removal of Noise

- Differentiating between a generator that is “noisy” all the time, and a generator that is only “noisy” during the oscillation requires the use of two data sets:
  - When the oscillation was seen to have occurred
  - And when it didn’t.
    - **Knowing the behavior of the generator outside of the oscillation becomes key to baselining it.**

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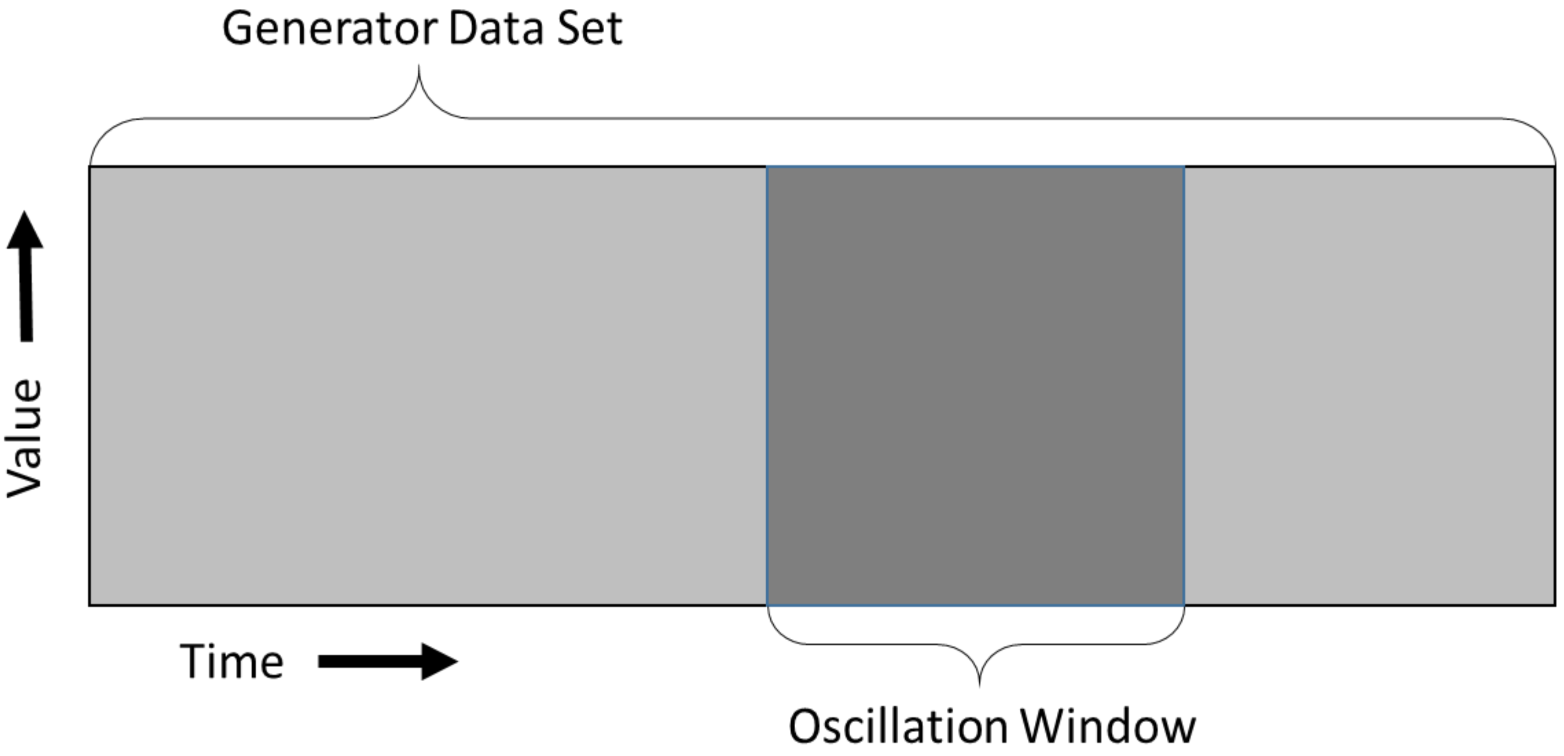
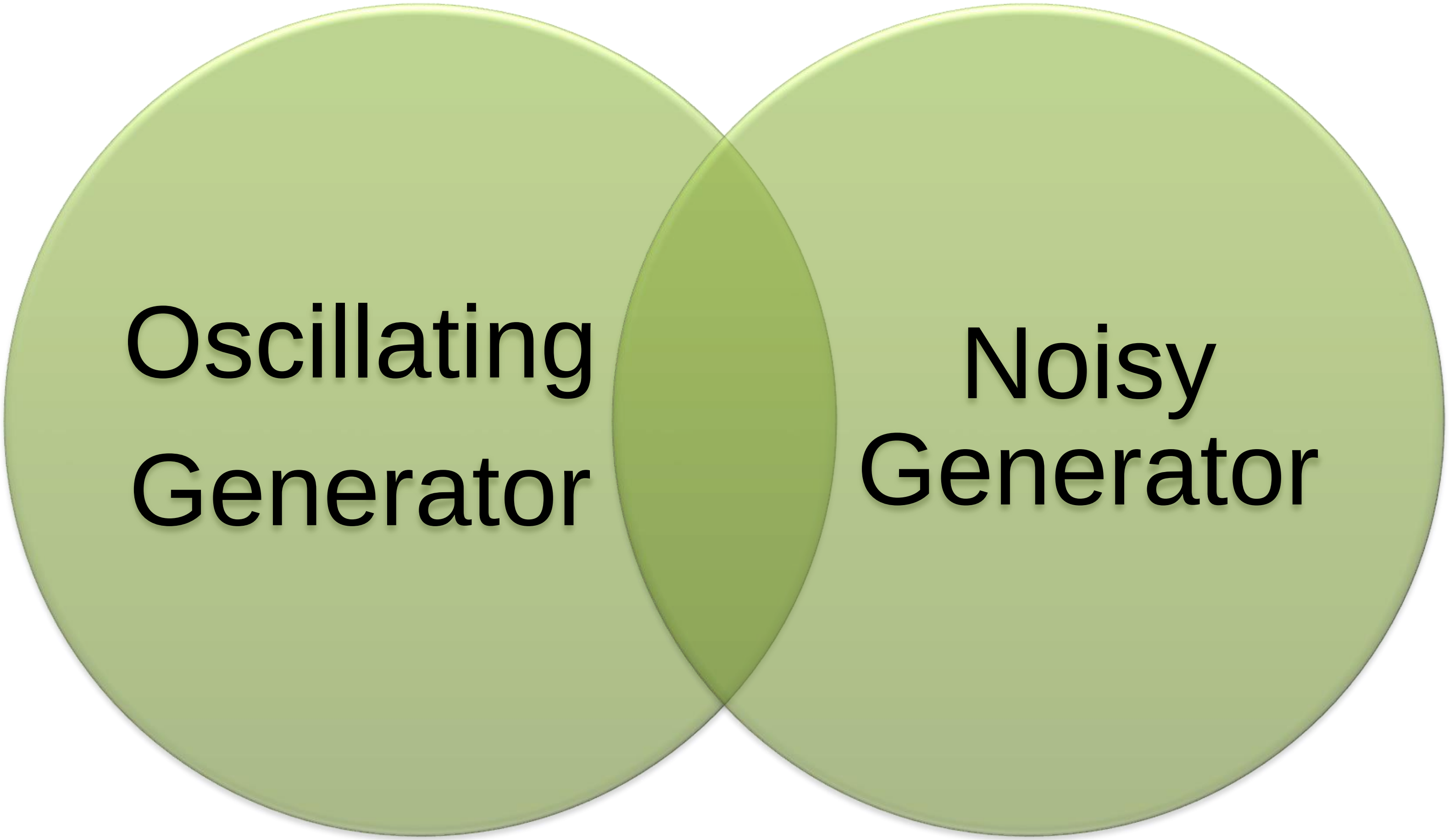
Graphical Illustration of the Data Set



Sometimes a "Noisy" Generator Can Be the Source of Oscillation



Baselining for Noise Removal

- Knowing the "typical" behavior of each generator is considered.
- In order to do this, the baseline is set to 3σ (standard deviations) of the data is used.
  - Anything over this threshold will then be considered outside the norm, and thus, an oscillation.

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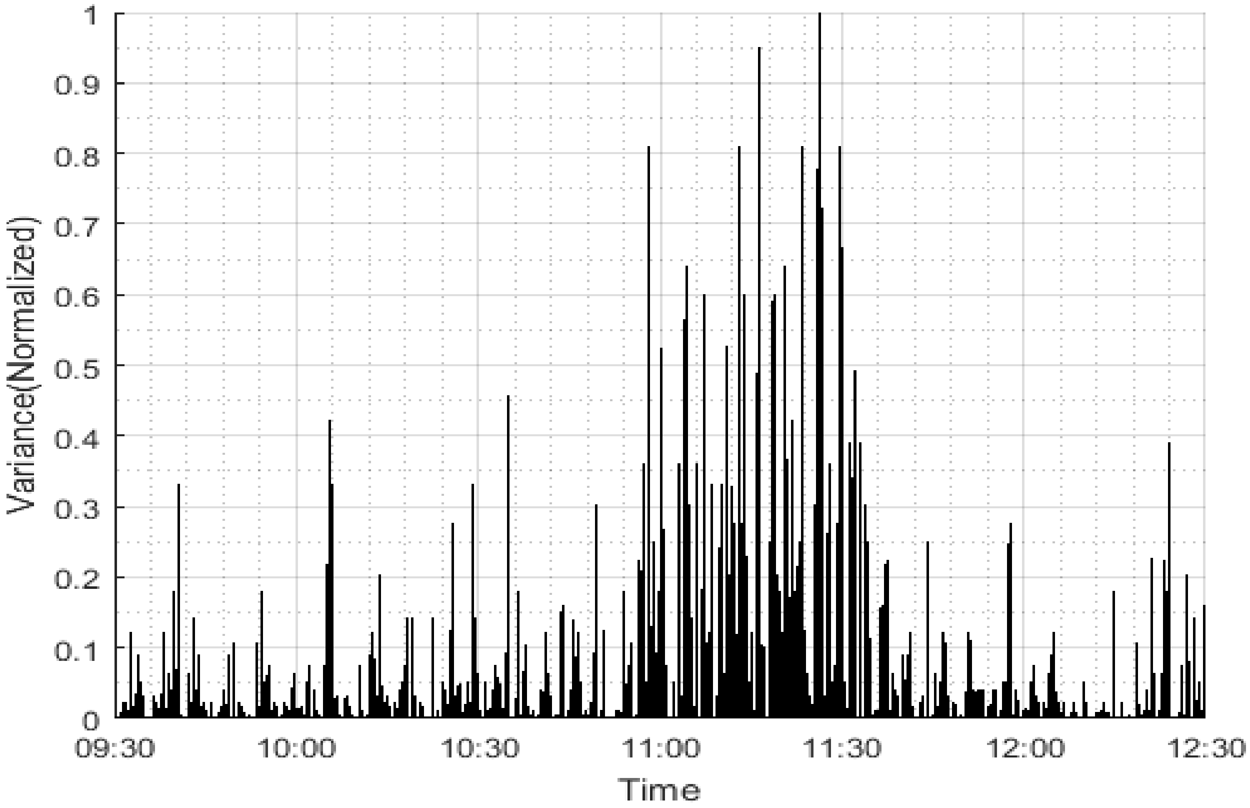
Back to the Variance with Inflection-Point Filter



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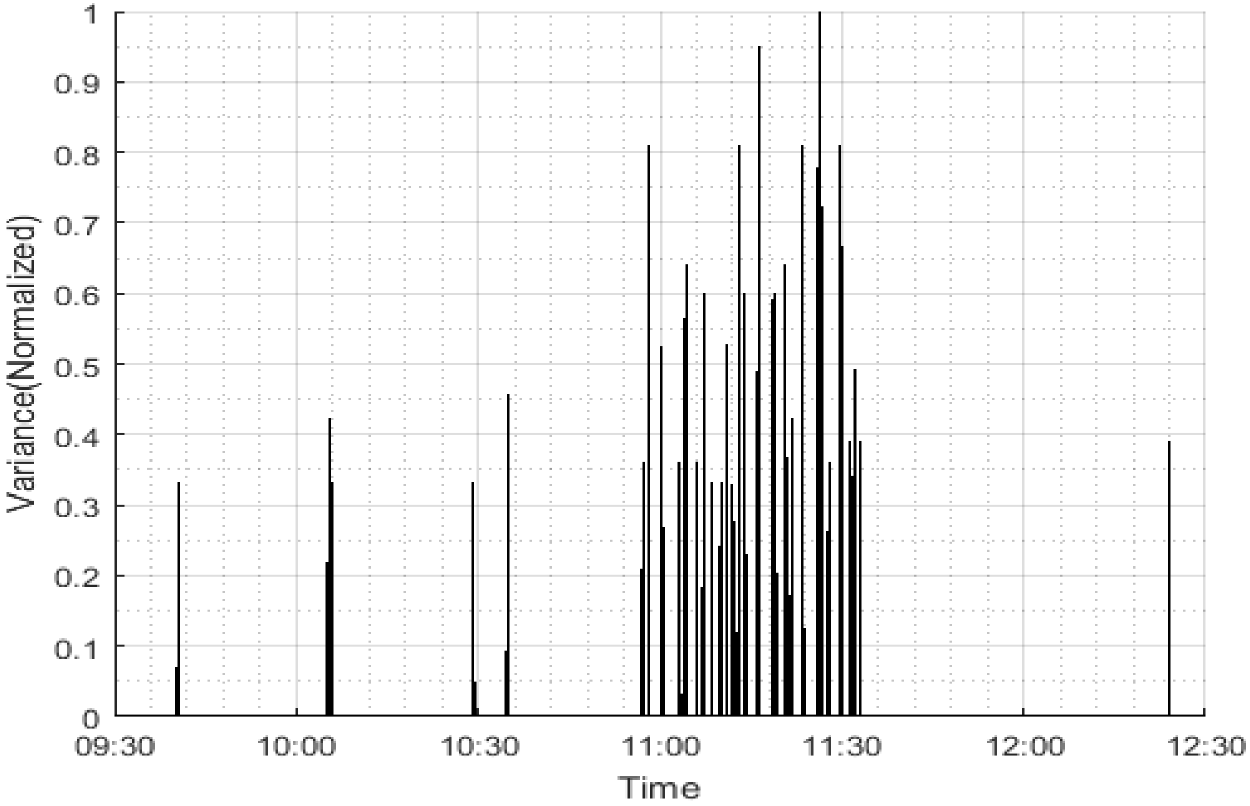
Variance with additional 3σ Filter



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Now to find it..

- The inputs needed are:
  - The generator SCADA data set
  - The known start and end time of oscillation (window to be provided by an oscillation detection tool)
- With a given time-stamped (n x m) generator matrix, each generator is ranked by looking at the prevalence of the oscillation inside the window in respect to the prevalence to that outside the window.

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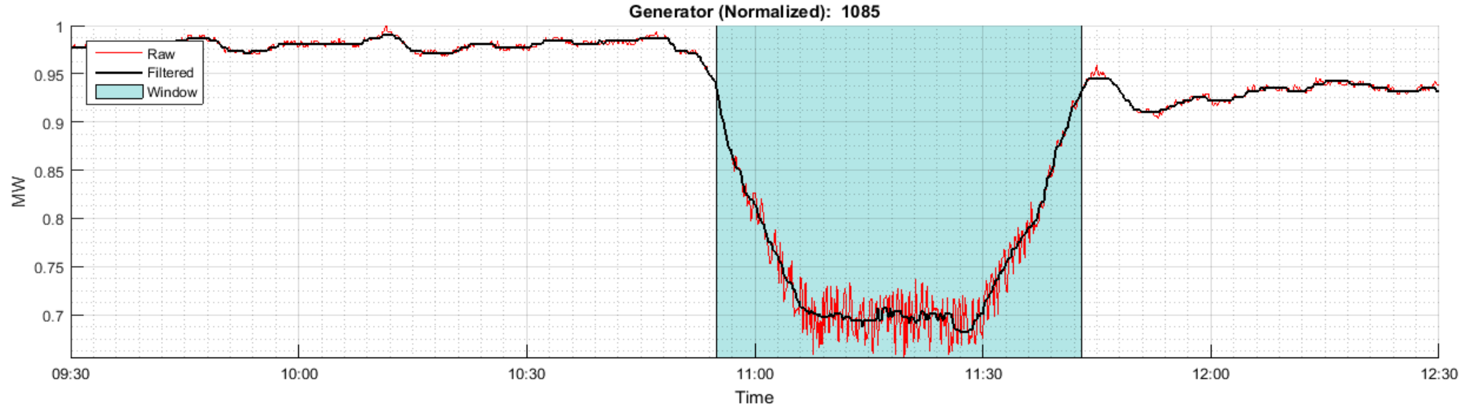
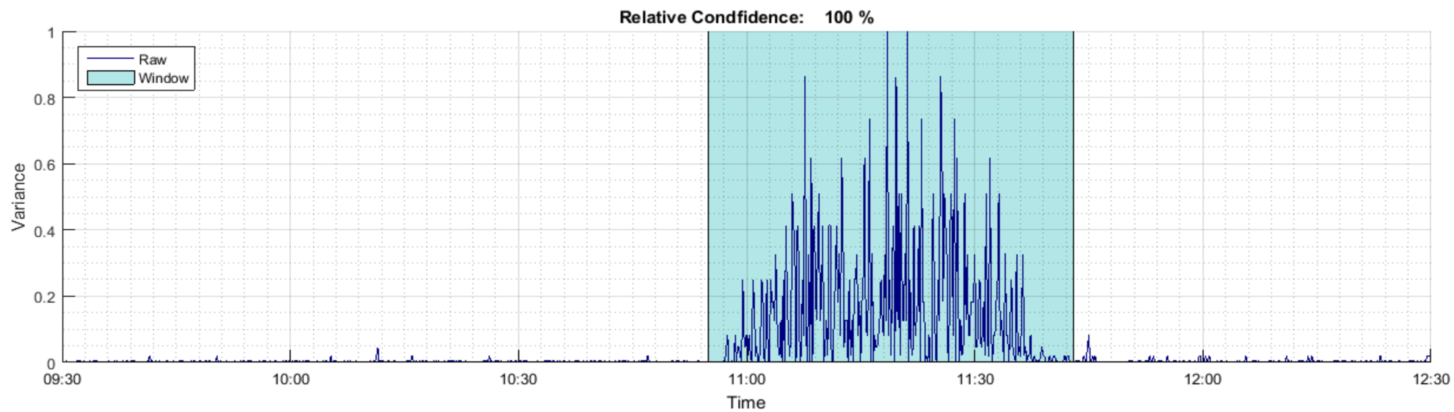
The Actual Source of the Oscillation





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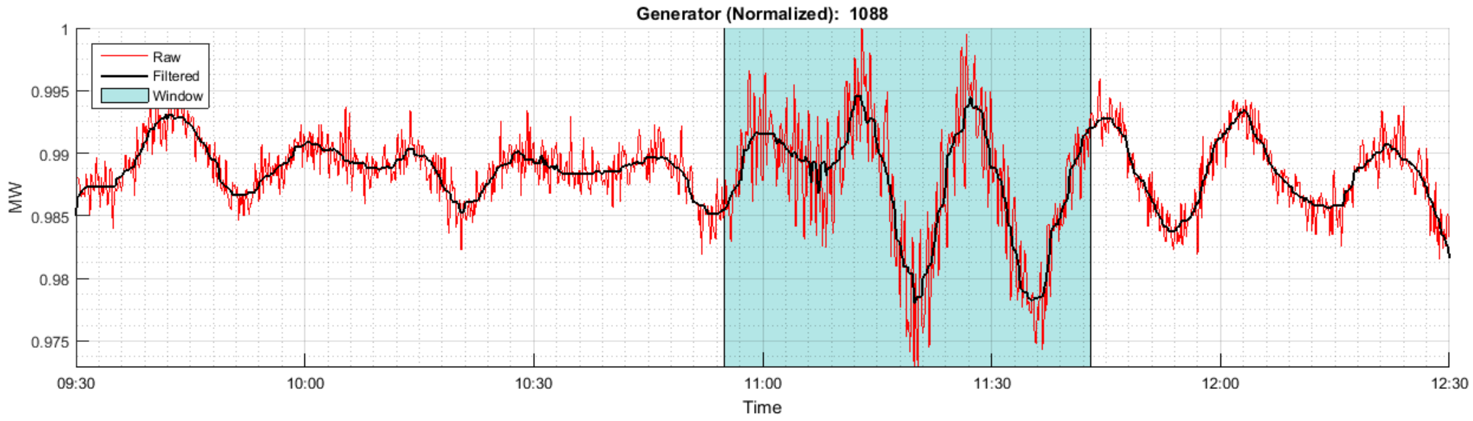
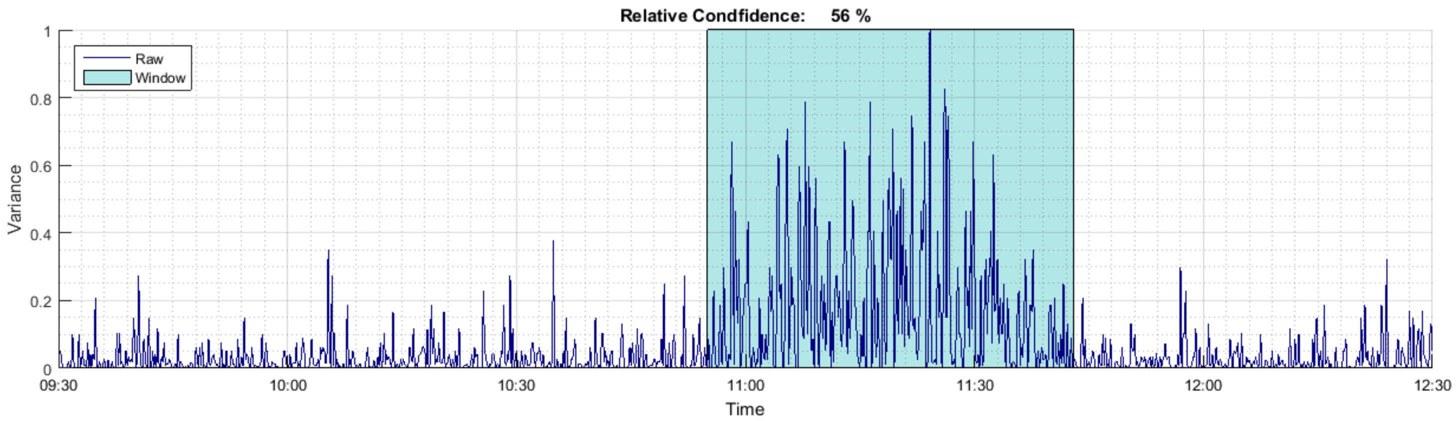
Validation

- The generator operator for this plant was contacted, and that there was a mechanical governor failure which caused the oscillation.
- **The correct generator was identified through this process.**

Generator Reacting to the Oscillation





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Why?

- In this case, the previously discussed generator happened to be part of the same generating plant as the oscillating generator.
- This gives a clear indication, that while there was an oscillation that did in fact occur on the a generator, it was due to it reacting to the other.
  - "Electrically adjacent" generators are often shown to exhibit this phenomena.

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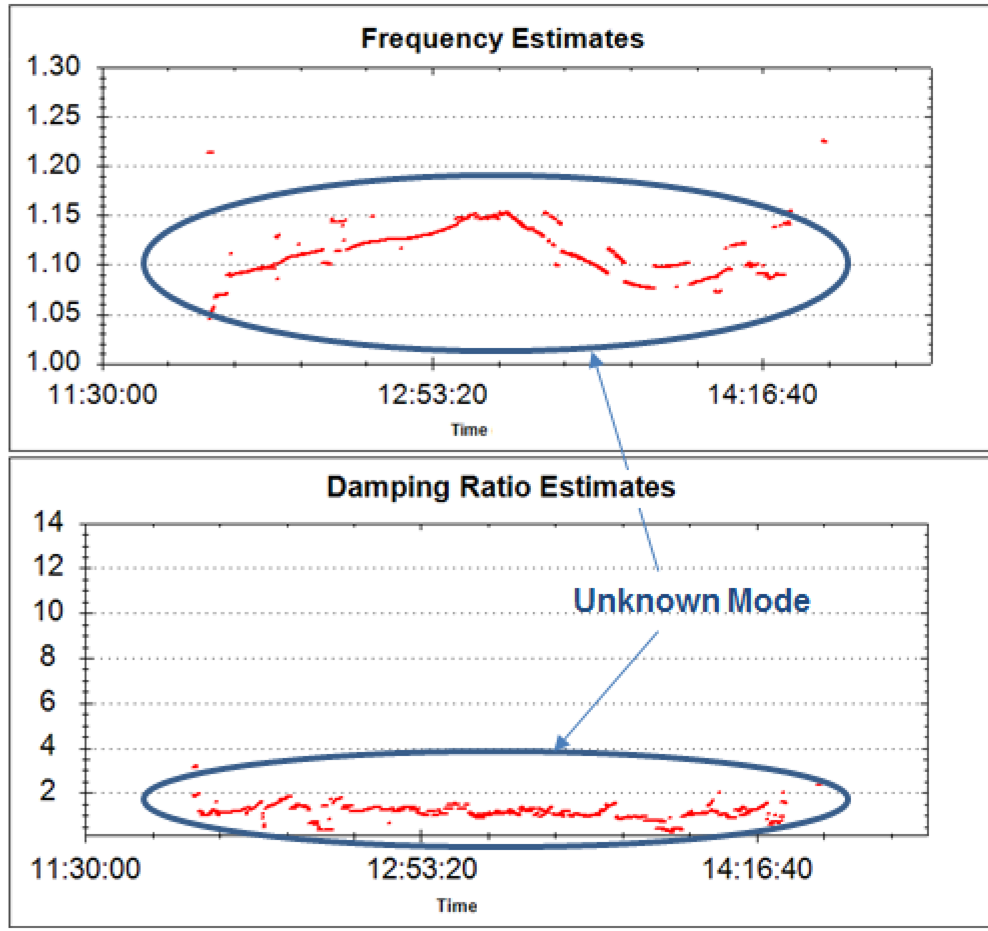
The Oscillation Returning

- The unknown mode re-appeared for about 150 minutes
    - Distinctive with a defined start and end time.



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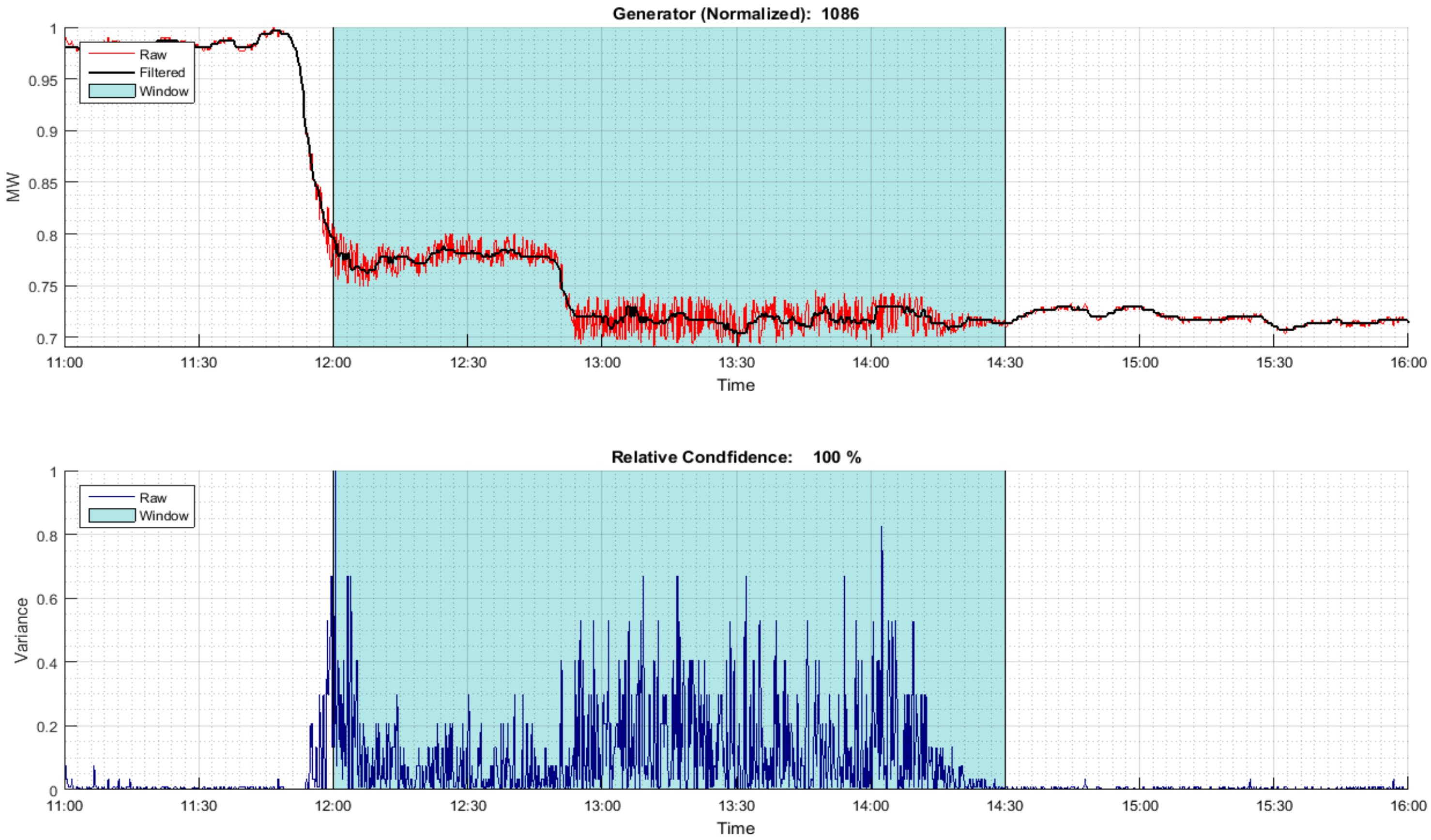
The Actual Source of the Oscillation



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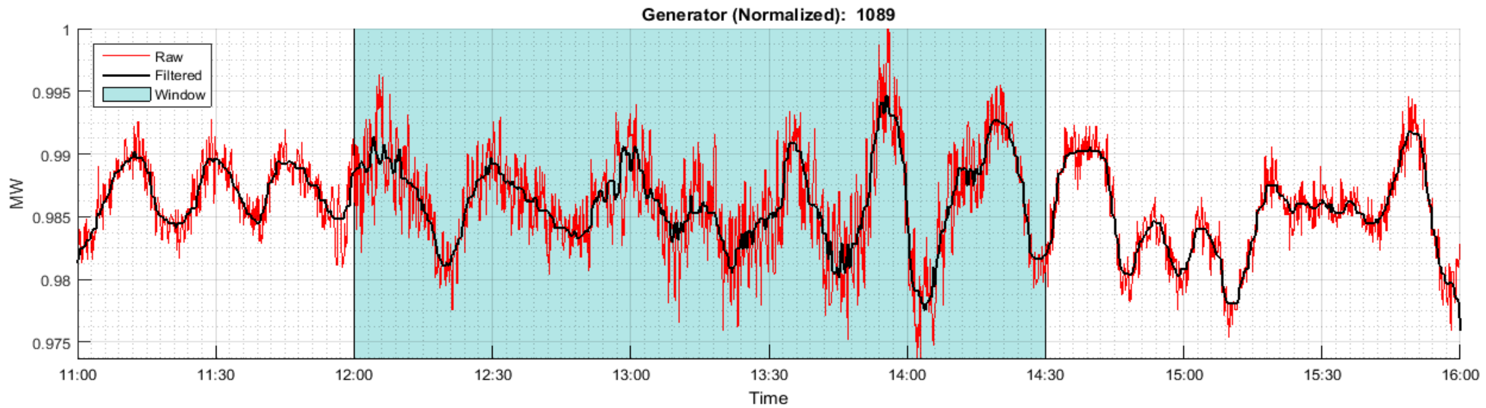
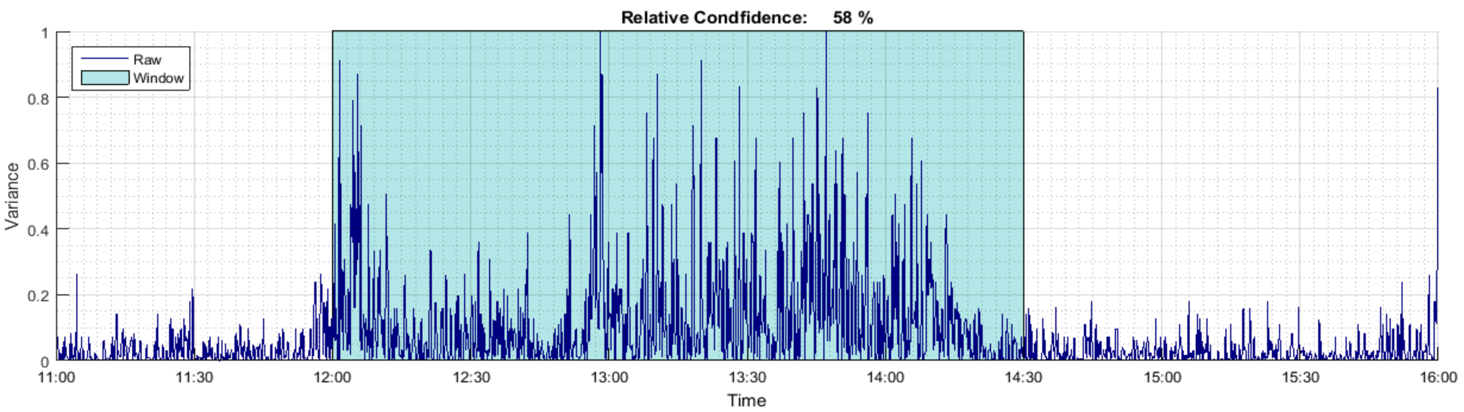
Generator Reacting to the Oscillation





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Validation

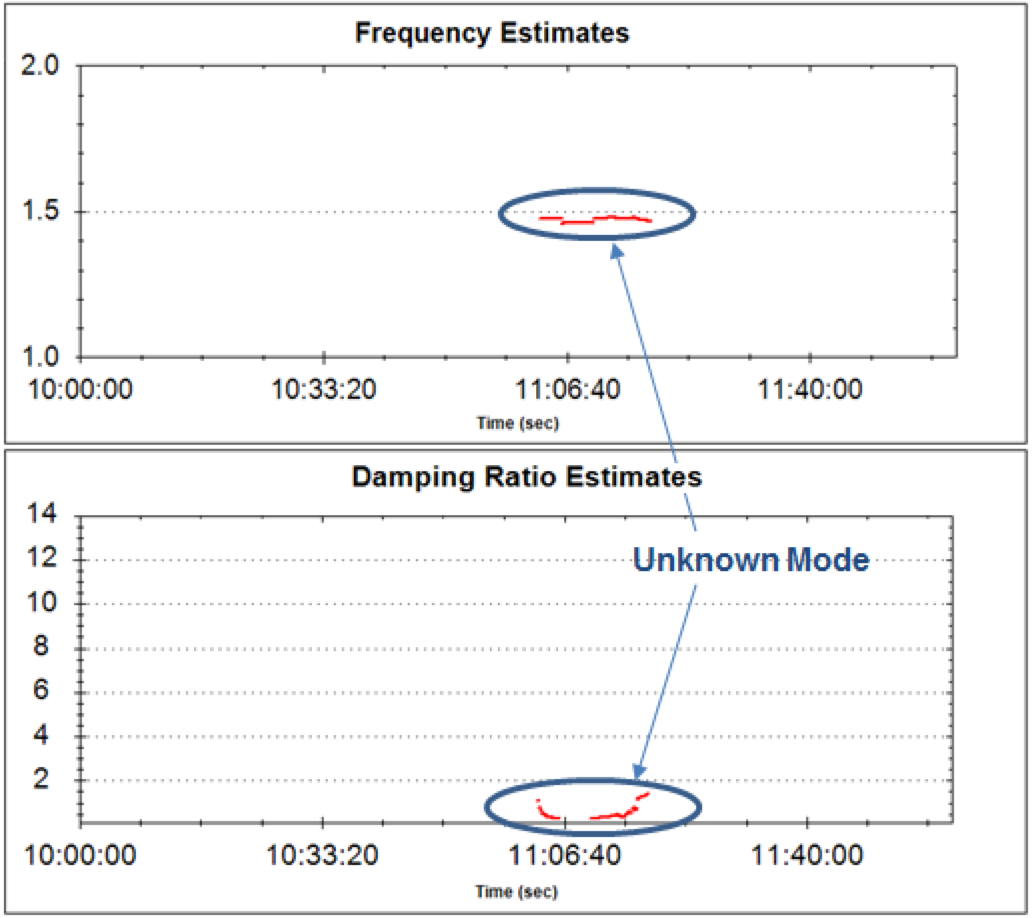
- This was the previous plant having another mechanical failure. (same generator)
- **The correct generator was again identified through this process.**

Example Case (from BPA)

- BPA had found a relatively large oscillation that propagated through a major part of the system
- Low PMU coverage made it difficult to find

The Unknown Mode

- The unknown mode appeared for about 10 minutes
  - Distinctive with a defined start and end time.



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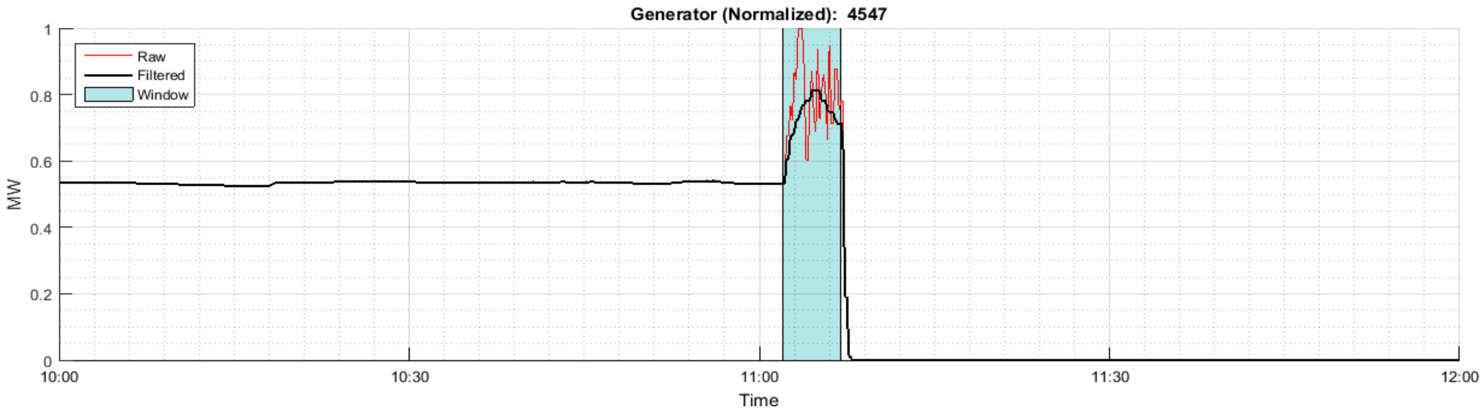
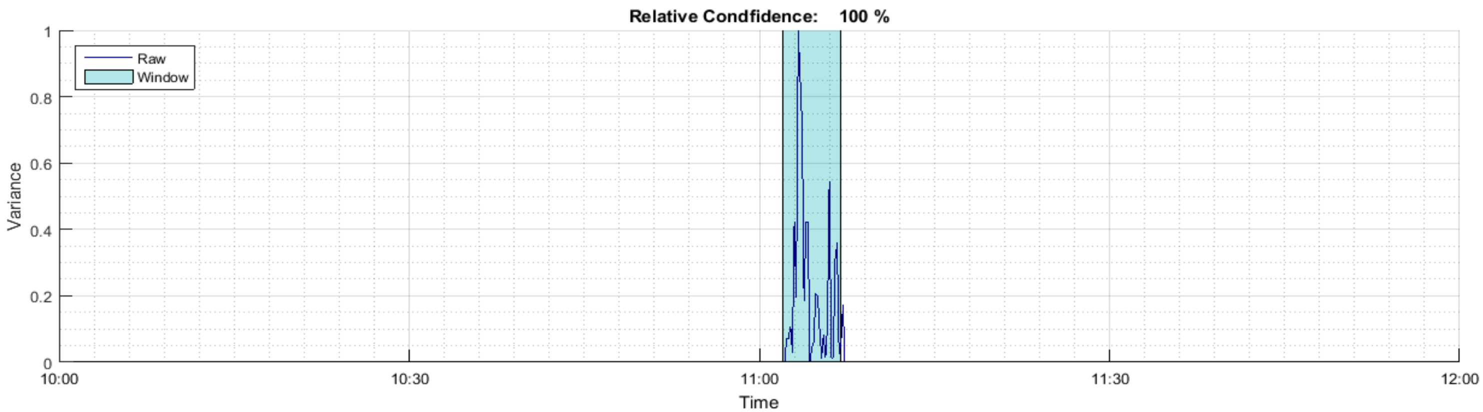
The Actual Source of the Oscillation





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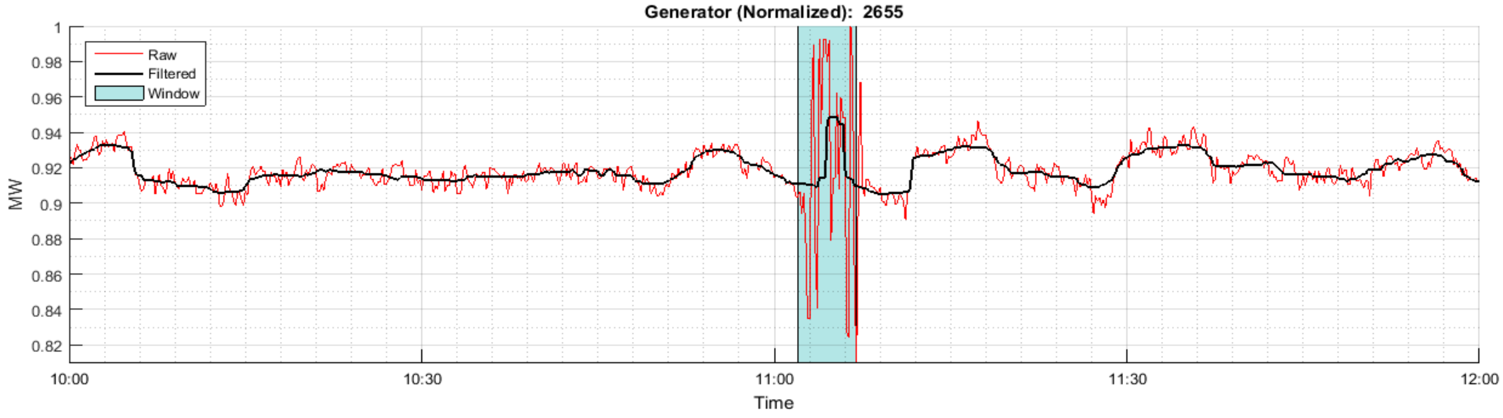
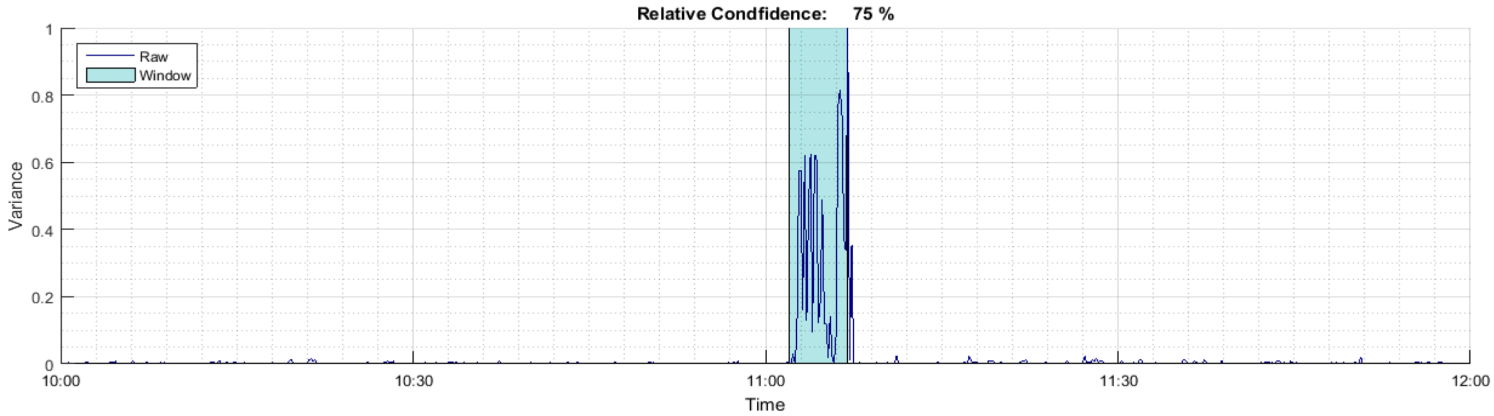
Generator Reacting to the Oscillation





Conclusion

- Peak has developed a self-baselining tool which is able to detect the source of forced oscillations using SCADA Data.
  - This has been verified against 4 known oscillations.
  - It is in the process of being used to find other unknown oscillations. (findings in progress)
- An IEEE paper is being published in collaboration with WSU.

Acknowledgments

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- Tianying (Lily) Wu – Summer Intern

Thank You!

Questions?

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assuring the wide area view