A Grid Friendly™ Grid Monitor

Real-time grid information on your desktop screensaver

Are you interested in knowing more about the stability of the power grid by monitoring the electric power available at your wall socket? The Pacific Northwest National Laboratory (PNNL) Grid Friendly™ Grid Monitor provides detailed real-time graphs of the frequency and stability of the alternating current (AC) available at our wall sockets. The Grid Monitor software analyzes the AC signal of the power grid as measured from a normal 120-volt wall outlet. It easily can be set up as a screensaver on any computer and displays several graphs that, together, provide a real-time picture of the stability of the power grid in the Western Interconnect, which serves the entire western half of the United States.

Figure 1. The Grid Monitor screensaver displays five graphs of real-time analyses of the AC power signal.

This screensaver is a visual tool that bridges the gap between consumers, the energy research community, and related industry developers. For consumers, this high-tech tool opens a window onto the complexities of our national power grid. In the energy research community, this tool assists in monitoring the power grid signals, studying power signal dynamics and facilitating experiments on new energy technologies, such as Grid Friendly Appliances (visit http://gridwise.pnl.gov/technologies/transactive_controls.stm). Related industry developers can interpret signals such as these to better understand past grid disturbances and design tools and processes to increase the reliability of our electric power system.

The screensaver software was developed at PNNL as one of the many technologies needed to enable transformation of the nation's energy system. Industry leaders, along with the Department of Energy and PNNL, share the GridWise™ vision, a term they use to describe their concept of an advanced electric power grid for the 21st century.

The Grid Friendly Grid Monitor screensaver can be easily installed by anyone with Internet access who is interested in a glimpse of the intricacies of our complex power system in real time. Electricity users can view oscillations and disturbances as they occur in the Western Interconnect and peek into the world of power system engineers.

The Grid Monitor is one example of research and technology development under way at PNNL in support of the GridWise vision. Industry leaders, along with the Department of Energy and Pacific Northwest National Laboratory, use the term GridWise to represent the concept of an advanced electric power grid for the 21st century.

Pacific Northwest National Laboratory
Operated by Battelle for the U.S. Department of Energy

What is Grid Monitoring?

The grid frequency in each part of the nation's power system (the Eastern, Western, and Texas interconnects) is carefully controlled to maintain a normal frequency of 60 hertz (Hz). Deviations in this frequency indicate an imbalance in the grid between the supply and demand (load). A change in frequency can be a key indicator of major grid events, such as:

- a generator tripping off
- major loads switching on or off
- an unscheduled interruption of power flow through transmission lines

Left untreated, an imbalance between supply and demand can lead to a blackout.

The Grid Monitor screensaver displays key frequency-related characteristics of the power signal in real time. Grid monitoring, in general, is an evolving area of study toward understanding the dynamic behavior of complex power systems and improving their overall reliability.

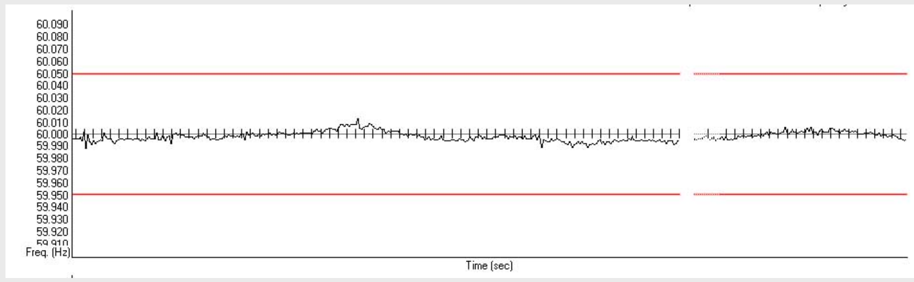

Figure 3. The Frequency Graph at the top of the screensaver plots the progression of the AC signal in real time, typically hovering in its tight, stable range.

About the Screensaver

The screensaver is an integrated collection of five dynamic graphs. The graphs give a picture of the stresses on the power grid, visibly showing frequency disturbances as they occur. Power system engineers can use these curves to judge the stability of the system and detect forewarnings of impending disturbances.

Frequency Graph

The top, most straightforward graph on the screen plots the frequency in hertz in real time. The vertical axis covers a very fine range, showing variations in thousandths of a hertz around the target line of 60 Hz. The curve is updated in real time, with a new reading plotted every tenth of a second.

Power grid operators are constantly at work, balancing the supply and demand of electricity and keeping the frequency hovering as close to 60 Hz as possible. Major disturbances in the system cause the frequency to drop or sometimes shoot up—moving beyond the "stable" zone delineated here by the red lines at 60.050 Hz and 59.950 Hz (for grid operations, a series of limiting thresholds apply). The screensaver can be set to make an audible alarm if these boundaries are crossed.

Oscillatory Graphs

In reality, the AC electric power signal is the sum of innumerable sub-signals. The 60 Hz AC signal is actually a complex accumulation of many elements such as random noise, mechanical vibratory dynamics of generators producing the power, damping effects, and even self-induced oscillatory dynamics of the transmission grid. It acts like a tremendous bed of interconnected springs and weights. Two other graphs of the Grid Monitor help show the oscillatory content of the most indicative low-frequency components of the AC signal.

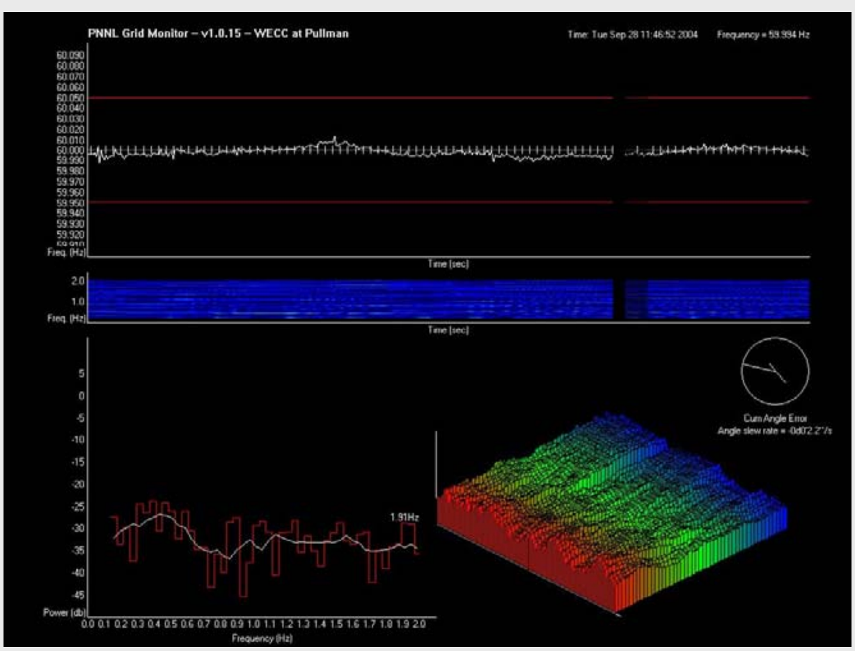

Figure 2. The screensaver's Frequency Graph and Oscillatory Mode Graphs provide insight on grid stability and dynamic interactions.

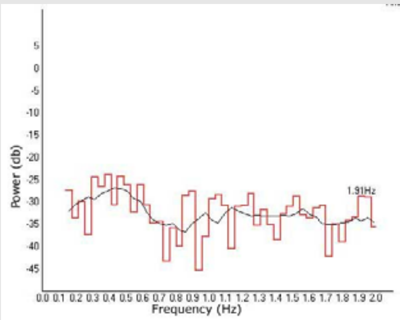

Figure 4. The Oscillatory Mode Graph reveals both inter-area and local modes.

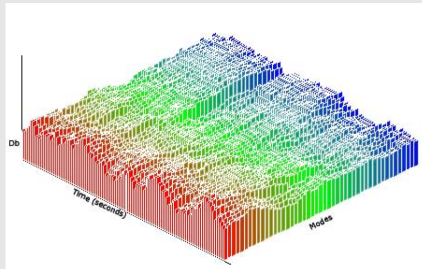

Figure 5. The 3-D Oscillatory Mode Graph can reveal significant recent trends in modes.

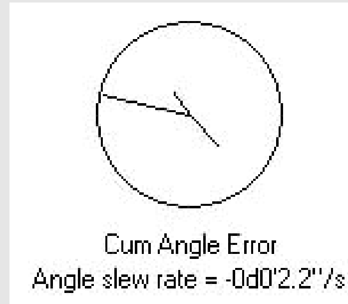

Figure 6. The Cumulative Error Angle complements the Frequency Graph.

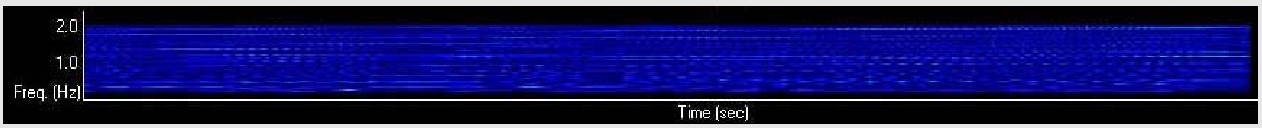

Figure 7. The Spectral Contour Graph reveals persisting peaks in the signature modes.

The spectrum of the grid frequency signal is analyzed using a Fast Fourier Transform. The magnitude of this spectrum from 0 to 2 Hz is presented in a variety of ways.

Oscillatory Mode Graph
The Oscillatory Mode Magnitude Graph plots the magnitude (in decibels) against the spectrum frequency from 0 to 2 Hz. The red curve shows the raw power level at each frequency and the white curve is its local average power.

Spectral Contour Graph
The Spectral Contour Graph along the center of the Grid Monitor provides a time-lapse visualization of the spectrum magnitudes. Sharp peaks in the Oscillatory Mode Graph are plotted here as hotter colors. As seconds progress, consistently significant oscillatory frequencies appear as bright lines on the contour graph.

3-D Oscillatory Mode Graph
The colorful 3-D graph also provides a time-lapse visualization of the spectrum magnitudes, adding each one second increment of the oscillatory mode magnitude curve as time progresses. The three colors represent high, middle and low frequencies from 0 to 2 Hz.

Sustained modes in a group of frequencies can signify that the grid is operating under stress. Overall high magnitudes indicate high oscillatory mode content in the grid frequency and may signal increased risk of a major disturbance.

Cumulative Angle Error Graph

The dial on the Grid Monitor screen shows the cumulative angle error, with hands showing degrees, minutes and seconds similar to hands on a clock. As the AC signal frequency hovers above and below 60 Hz, the cumulative deviation moves the hands clockwise for positive errors and counter-clockwise for negative errors. With absolutely no deviation from 60 Hz, the hands would all be pointing to 12:00; the larger a disturbance, the faster the hands turn.

Putting the Grid Monitor to Work

Experienced power system engineers can identify particular oscillatory modes by observing these graphs and recognizing the signatures of large inter-area power plant interactions in the 0.1 to 1.0 Hz range, as well as typical local, machine-generated modes in the 1.0 to 1.8 Hz range.

Frequency analysis software empowers Grid Friendly Appliances in the Grid Friendly Appliance Laboratory at PNNL.

The Washington State University GridStat program currently hosts a server for web streaming of Grid Monitor frequency data. The Grid Monitor screensaver was developed at PNNL.

For more information, contact:

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A Grid Friendly™ Grid Monitor
PNNL-SA-43551
Revision History: 10/21/04