Application Note | AN101

Applying RingDown™ Prognostics to Power Drive Systems

Purpose

The purpose of this Application Note is to cover the extraction of signals for use with RingDown™. RingDown is a prognostic method that analyzes the state of health (SoH) of a power supply or power drive system by examining the output current or voltage "signature." For accurate prognostic and advanced diagnostic analysis, signature analysis provides a sound method of observing the level of aging and/or degradation. From this, the remaining useful life (RUL) can also be derived.

To accommodate the large number of power system topologies, power levels, and loads, Ridgetop has taken care to provide modularity in its hardware, software, and libraries. Some amount of system engineering is required to determine which modules should be monitored, as is some amount of small circuit design of a waveform capture board. Ridgetop can provide this signal conditioning as part of a non-recurring engineering (NRE) arrangement with the customer.

Overview

RingDown employs a method of assessing power supply degradation through analysis of the eigenvalues. Eigenvalues are the set of unique response time constants and frequencies that represent the characteristics of the system under test. A second-order system will have a characteristic step or impulse response that carries the natural frequencies that show the power systems' characteristics, as shown in Figure 1.

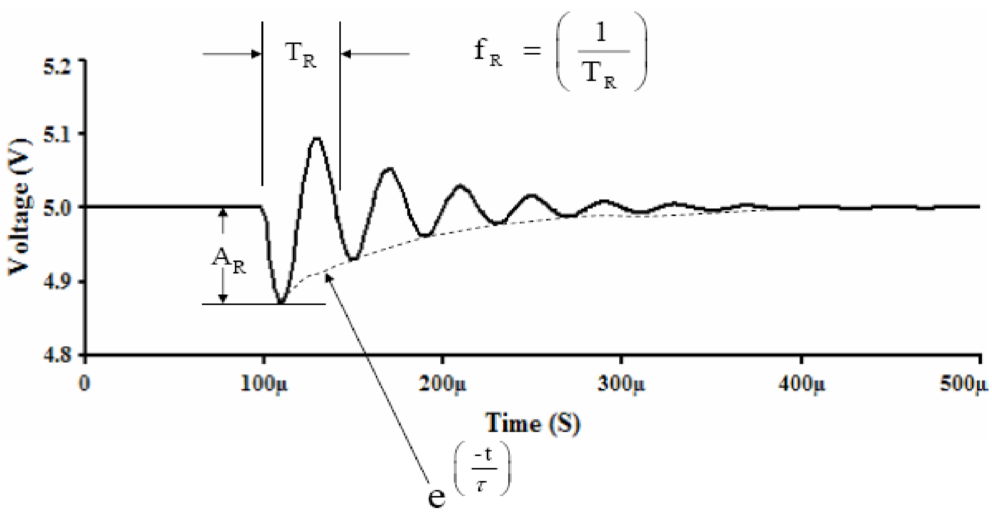

Figure 1: Power system transient response profile

Damped Ringing Response

A damped ringing response from a second-order system can be characterized by the following set of equations:

Equation 1: $V_O = V_{DC} + A_R \left\{ \exp\left({-t}/{\tau} \right) \right\} \left\{ \cos\left(\omega t + \phi \right) \right\}$

V_{DC} = the direct voltage output of the switched-mode power supply (SMPS); A_R is the peak amplitude of the dampened ringing response; t is time; and τ is the dampening time constant.

Equation 2: $\omega = 2\pi f_R$

f_R = the resonant frequency of the dampened ringing response; and ϕ is the phase shift of the resonant frequency.

The terms A_R, τ and ω are complex expressions dependent primarily upon the exact topology of the SMPS, especially the feedback loop; the current mode of the SMPS (continuous current flow or discontinuous current flow); and the type of the abrupt current change (impulse or step).

For continuous current mode and an impulse type of current change, the terms become the following:

Equation 3: $A_R = -Z_{out} \Delta I \frac{A}{A+1} \left(\frac{1}{\omega_0 \sqrt{1 - {1}/{4Q^2}}} \right)$

Equation 4: $\tau = \left(\frac{2Q}{\omega_0} \right)$

Equation 5: $\omega = \omega_0 \sqrt{1 - {1}/{4Q^2}}$

Equation 6: $\omega_0 = \sqrt{A+1} \left(\frac{1}{\sqrt{LC}} \right)$

Equation 7: $Q = \sqrt{A+1} \left(\frac{1}{R} \sqrt{\frac{C}{L}} \right)$

These expressions show how the amplitude, the duration of the ringing, and the frequency of the ringing response are related to and dependent upon the gain (A), resistance (R), capacitance (C) and inductance (L) of the feedback loop of the switched-mode power supply (SMPS) or power supply to actuator. Of the three variables that change in response to an abrupt stimulus, such as an abrupt change in load current, the dampening time and the ring frequency are particularly amenable to prognostic analysis methods as Ridgetop provides.

Determination of Good vs. Degraded Power Systems

As shown in Figure 2, a power supply can still be fully functional, yet the aging of its internal components (e.g., MOSFETs, capacitors, PWM IC) can cause the characteristic response to vary. The variance from normal can be used to determine the root cause, as well as the RUL.

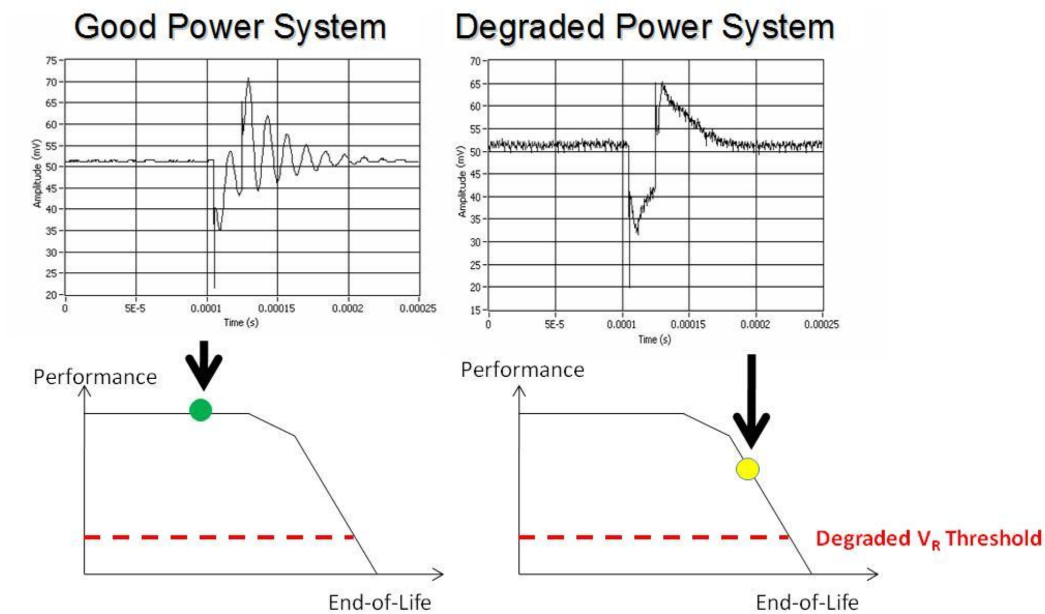

Figure 2: Characteristic step response from a high-efficiency DC-to-DC power converter; this could occur during “power-up” tests or could be invoked at any time

Generating the Step Response

The response can be taken upon power-up, or as invoked through a built-in test (BIT) command to the system. A synchronized range gate will provide the limits between the rise of the voltage, the ringing transient, and steady-state, as shown in Figure 3**.**

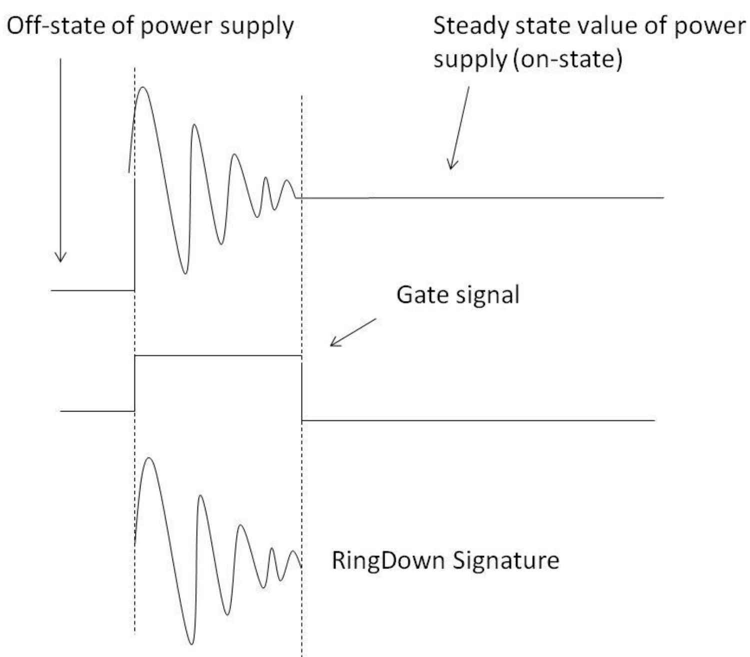

Figure 3: Extracting the ring signature

Considerations on Extracting the Waveform Signature

There are three aspects to be considered when capturing the signal: the highest frequency component of the waveform, the amplitude of the signal, and the method of using either current or voltage. Figure 4 shows a block diagram of a current-probe based system.

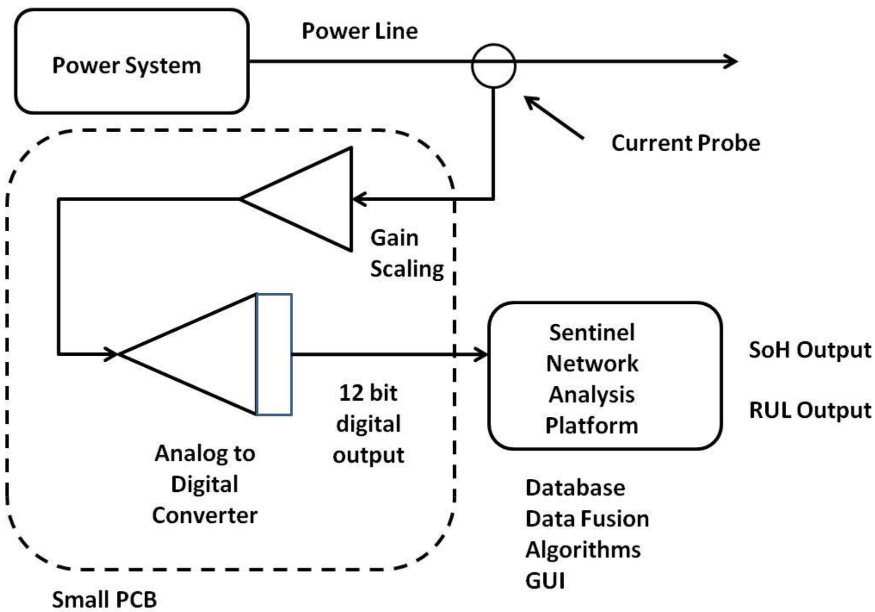

Figure 4: Block diagram of a Signal Extraction and processing for a power rail

1. Highest Frequency Component

   To capture the response profile the frequency response of the probe used needs to be at least 10x the highest frequency component in the waveform signature. For example, if the switching power supply operates at 250 KHz switching rate, then the response of the probe must have at least a flat passband of 2.5 MHz in its response.

   Since there is also a direct relationship of rise time and frequency, given by:

   $T_R = 0.35$ / Bandwidth

   The parameters can be also examined in the time domain.

2. Signal Amplitude

   A second issue is the output amplitude of the step response waveform. The amplitude of the signal must not saturate or exceed the maximum rating of the probe, whether it is current or voltage based. The probe must also be sensitive to the signal levels as well. It is possible to size the probe to handle a variety of signal levels too numerous to mention. For best results, the signal must be conditioned to a level of 1 volt peak-to-peak.

3. Current or Voltage Probes

   The intent of a non-intrusive sensor is to capture the relevant waveform information, and not damage or otherwise have an impact on normal operation. Current probes can inductively couple the output signal and capture the signal for subsequent conditioning and processing. Voltage problems make direct contact with the output, so care must be taken to avoid fault conditions that may affect robustness of operation.

Special Cases

The RingDown method has been applied to a variety of different switched-mode power supplies that have feedback loops, including buck, boost, H-Bridges and others. If the supply does not "ring" due to its being a stiff system or a linear supply, then there are other methods to extract the waveforms using Resonant Probe technologies, such as SMRTProbe™ from Ridgetop.

Determining Degradation Factor From Waveforms

The location of the power supply's life on the Degradation Aging Curve is found through highly accelerated life testing (HALT) methods. In this process, the observation point is the signature waveform. As the power supply is subjected to environmental effects, the waveform will change shape over the course of the testing regime, prior to outright failure. The sequential progression of waveform changes will define where the power supply lies on its Degradation Profile. The amount of time necessary to reveal the aging progression will depend on the specific supply itself, and how well the component derating, and design centering steps were considered during its design.

Display of Results

Ridgetop provides a tool, Sentinel Network™, as a platform for processing and displaying the state of health and remaining useful life (RUL) for the power system. Sentinel Network is a web-enabled application, and supports remote monitoring of the condition of the power system. A representative display is shown in Figure 5.

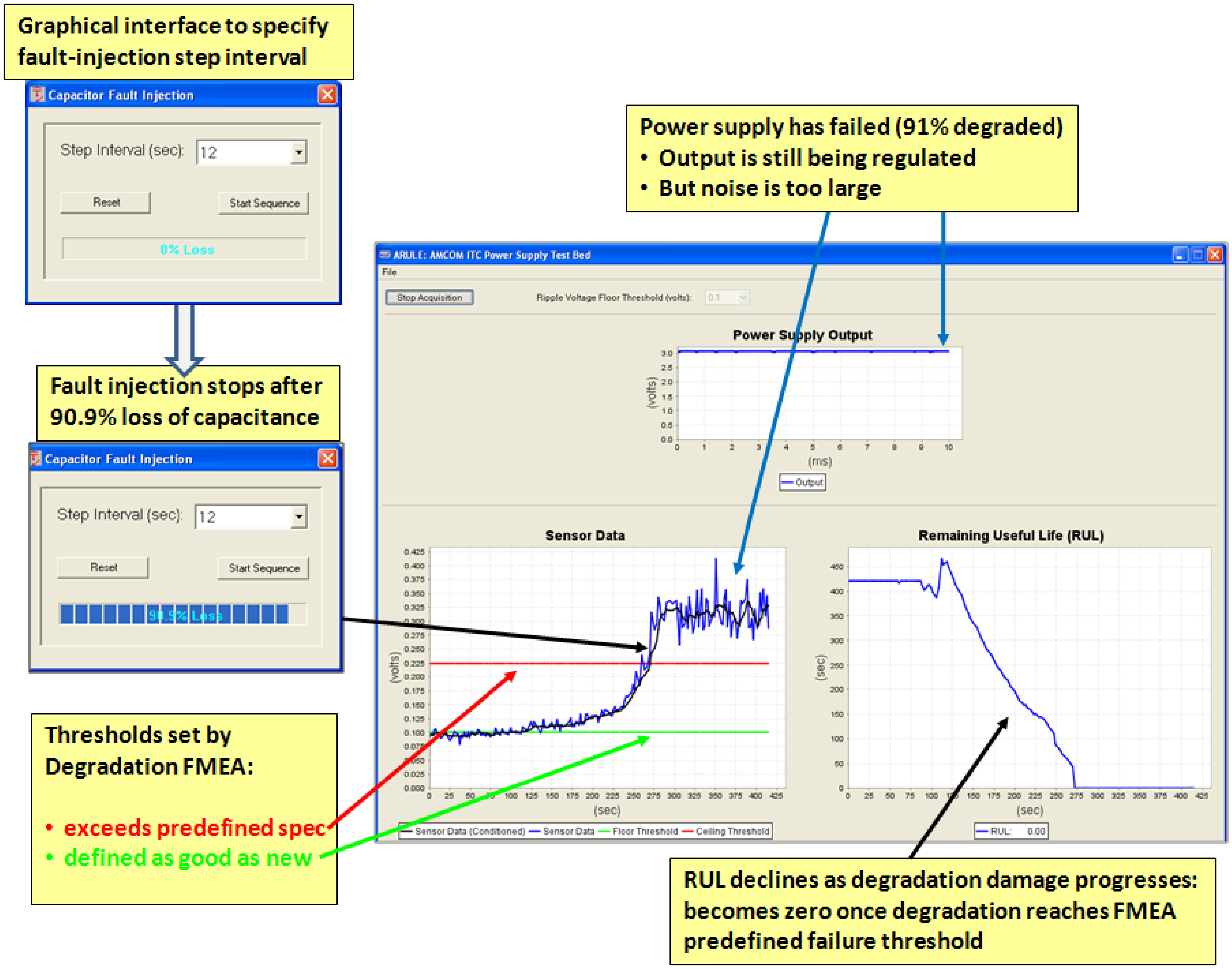

Figure 5: Display of RingDown power system analysis using HealthView PS™ on the Sentinel Network platform

Building a Fault Dictionary

The monitored signature waveform carries important information that can be used for service personnel. This involves a fault-seeding approach to map component faults with their resulting output waveform. Ridgetop has developed advanced tools for fault tree analysis and fault dictionary creation. For more information on fault dictionary tools, case-based reasoners, and other accessory products, contact your Ridgetop representative.

Example: RingDown and Sentinel Network Installation

To illustrate how the various components fit together, consider a commercial solar power inverter installation. A typical configuration that is currently in use at a water utility is shown in Figure 6. From prior analysis, it was determined that the primary source of failures was the power inverter module.

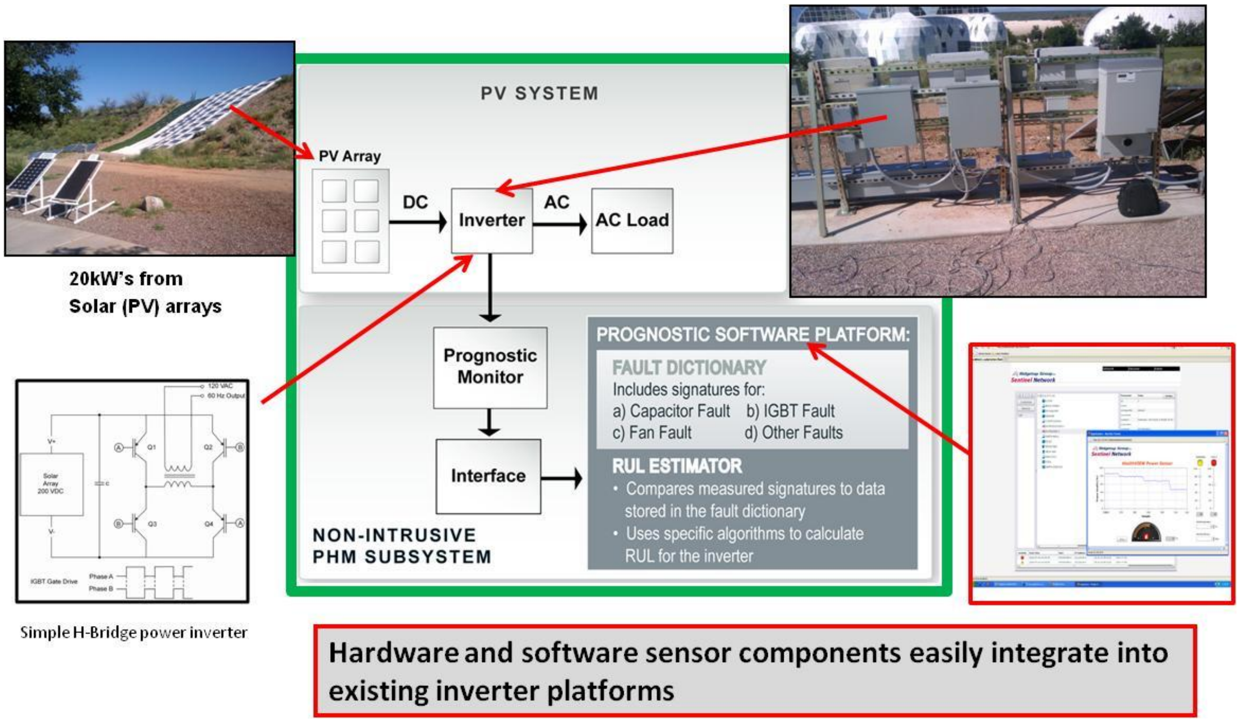

Figure 6: Prognostics-enabled solar power inverter installation

For the specific example of the power inverter diagrammed in Figure 6, the following items were required:

Function	Item	Purpose
Capture of RingDown signature	Current Probe	
Signal conditioning of signature with range gate, gain adjustment, digitization	Ridgetop custom PCB created for this application	Some non-recurring engineering (NRE) is required for signal processing. Design services can be provided by Ridgetop at nominal cost.
RingDown processing software, database, data fusion	Sentinel Network™	
Remaining useful life (RUL) algorithm	ARULE™ Reasoner	
Results display	HealthView PS™ graphical user interface	Included with RingDown license

Summary

RingDown is an effective tool for monitoring a wide variety of power systems. RingDown utilizes the eigenvalues of the system to determine the state of health and remaining useful life. This information is useful in scheduling condition-based maintenance actions to maximize system "uptime."

For more information, please contact your Ridgetop representative.

Ridgetop Group Inc.
3580 West Ina Road
Tucson, Arizona 85741 USA
Telephone: 520.742.3300
Email: sales@ridgetopgroup.com

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