Solar Module Quantum Efficiency Characterization System (LabVIEW Sheds Light on Solar Cell Quality Improvements)

by
Richard M. Brueggman
President & CEO
and
Gregory C. Cala, Ph.D.
Chief Technology Officer
Data Science Automation, Inc.
USA

Category:
Validation Test

Products Used:
LabVIEW 2009
USB-6525 Solid State Relay Module
PS-4 24 Volt DC Power Supply

The Challenge:
Develop an application to productively measure the quantum efficiency of solar panel modules across a wide spectrum of conditions.

The Solution:
Integrate several scientific instruments, off-the-shelf software applications and light sources into a flexible architecture with an intuitive user interface that requires minimal training and reduces test time from nearly fifteen minutes to less than three minutes.

Abstract:
Photovoltaic (PV) module designs are tailored to optimize the conversion of light to electricity under a broad range of conditions. Material and production quality are critical. As designs and manufacturing processes are optimized, it is crucial that characterization of the quantum efficiency be made to correlate the changes. The measurements here leveraged a Fourier Transform Infrared (FT-IR) spectrometer. Multiple light sources were needed to provide sufficient signal in all wavelengths of interest.

Background
The process of characterizing a PV module consists of several steps:
- Controlling the light sources
- Calibration of the light source
- Positioning of the PV module in the light path
- Making the electrical connections to the PV module
- Selecting a recipe of sequential conditions to run
- Controlling the illumination and PV bias voltage
- Triggering the FT-IR measurement
- Analyzing the spectral response
- Recording the results of quantum efficiency versus wavelength

In conjunction with the primary process above, several secondary processes take place concurrently:

- Requiring a calibration at least every 12 hours
  - Permitting a calibration at any time
- Warn of excessive lamp hours for bulb replacement to prevent diminishing light.
- Remove FT-IR laser contribution that is not present during calibration
- Apply pass/fail limits to calibration and analysis results
- Uploading ACSII data to a remote, networked enterprise database

User Interface and Operation

Calibration

Although the application was developed in close cooperation with a quality engineer, the expectation was that the primary end-user would be a technician that would be processing large quantities of PV modules. Emphasis was placed on ease of use and minimal operator interaction while requiring operator selection of parameters that might change on the test request document.

Upon startup, the application reads a configuration file that includes the time of the last calibration and the detector used for that prior calibration. If more than 12 hours have elapsed, a new calibration is required before PV characterization data is permitted. The calibration procedure requires the positioning of a calibrated silicon detector with known quantum efficiency into the light path in place of the PV module. With a known quantum efficiency, the light intensity over the wavelength range of interest (400 – 900 nm) can be calculated. Knowing the intensity, allows the calculation of the quantum efficiency from the measured response profile from the FT-IR spectrometer. Even when a calibration is not required, the operator has the opportunity to force a calibration.

Figure 1 shows that in addition to the calibration information, there are indicators for the usage of the light sources to ensure that bulbs are replaced well in advance of their expected end of life when intensity can degrade relatively quickly (within the 12 hour calibration interval when intensity is presumed to be constant). Two light sources are used to provide sufficient intensity across the spectrum of interest: a quartz-tungsten-halogen (QTH) lamp (Newport 69931 300 watt power supply and 67011light) and a blue light emitting diode (Thorlabs DC2100LED). Both light sources are programmatically controlled via USB and RS-232 serial interfaces using custom LabVIEW drivers developed for this application by Data Science Automation.

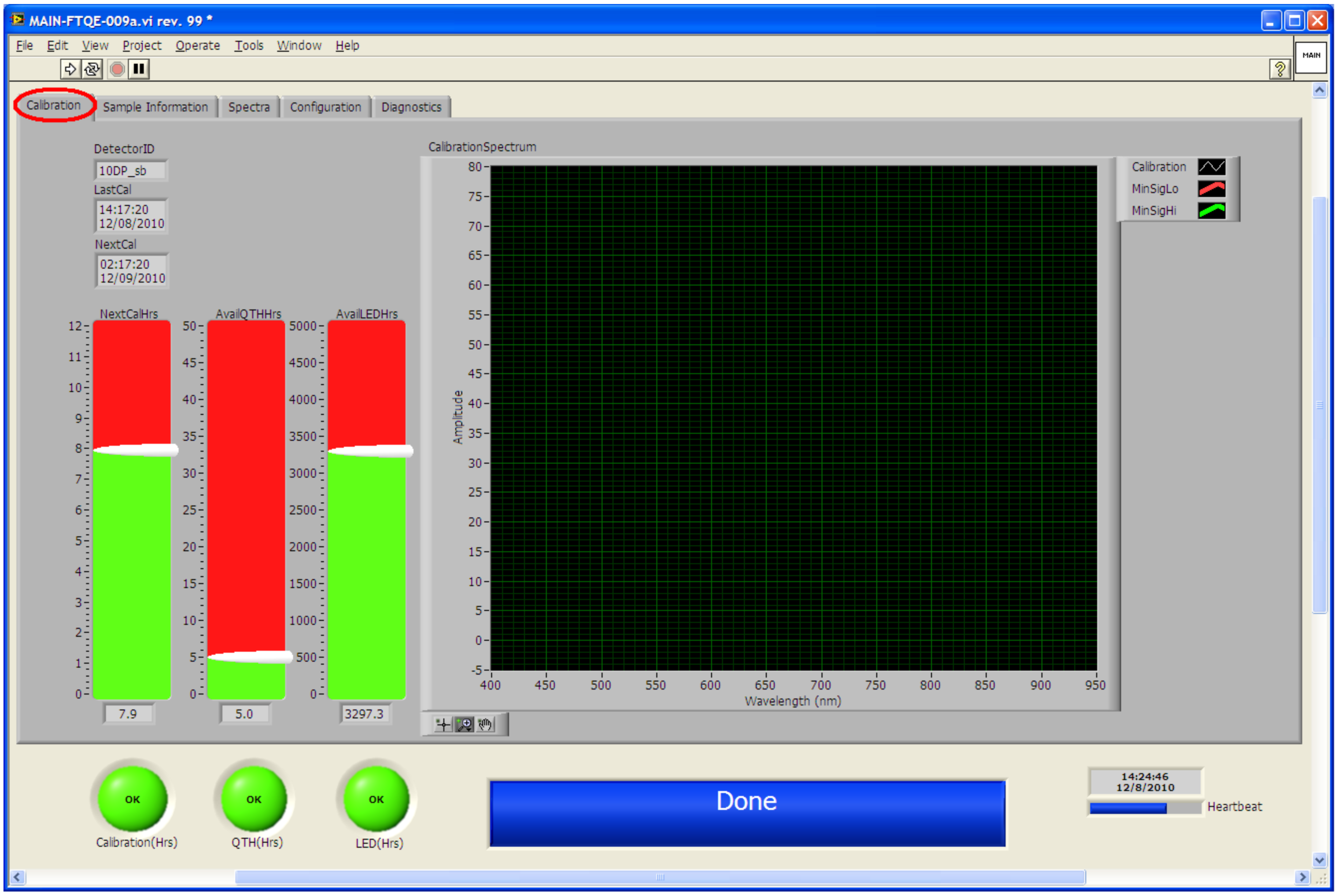

Figure 1. Calibration and Lamp Hours.

Test Configuration

Once it has been verified that a current calibration is in place, the operator is required to enter descriptive information about the PV module to be tested (Figure 2). A Windows API DLL function call is used to automatically identify the operator based on their Windows login and a lookup table in the configuration file that associates login names (employee ID) with personal names.

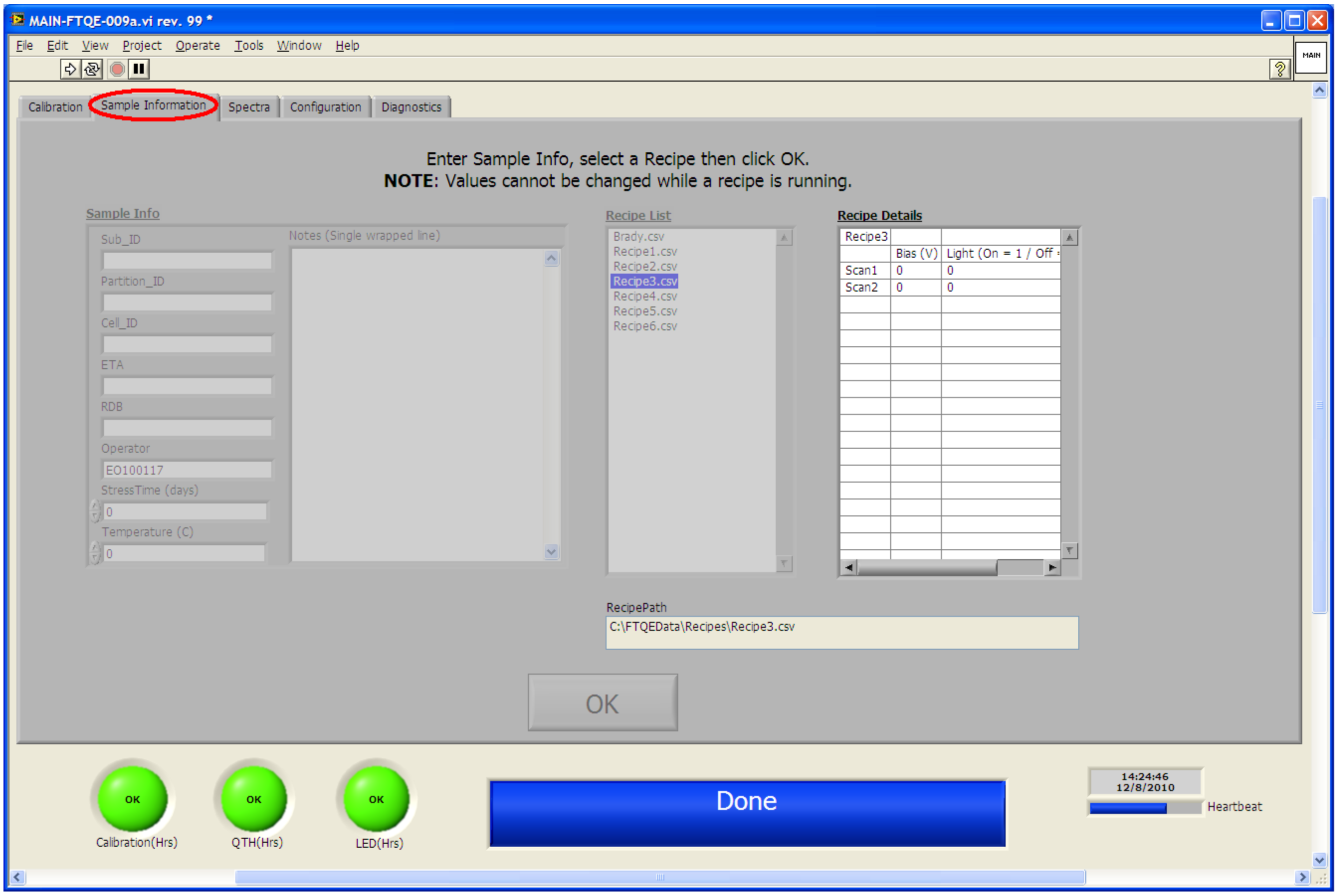

Figure 2. Sample Information and Recipe Selection.

In addition to entering sample information, the operator must select one of the “recipes” previously configured by an administrator. Although adaptable to include other parameters, currently the recipe includes a sequence of light and voltage bias conditions. As the operator selects different recipes, the recipe steps are displayed in the Recipe Details table and the path to the recipe file is displayed.

Test Data and Analyses

Once a recipe has been selected, the LabVIEW application configures the light and voltage bias conditions and fires a solenoid that actuates the electrical probe tips connected to the pre-amp to permit the voltage bias to be applied. The voltage bias is set using a LabVIEW driver developed for a Stanford Research SR570 Low Noise Current Pre-Amplifier. The spectral response is acquired using a LabVIEW driver that utilizes a DDE (Dynamic Data Exchange) interface to OMNIC software that controls the Nicolet 8700 FTIR spectrometer. The Nicolet 8700 is currently distributed under the ThermoFisher / ThermoScientific brand. The sweep of wavelengths takes several seconds depending on the configuration of the OMNIC software macros. During the sweep, the OMNIC software becomes front most but is hidden programmatically using a Windows API DLL function call. The blue “Done” object at the bottom of the user interface (Figure 3) is a progress bar and displays various status text messages. Figure 3 shows that as each recipe step is acquired, the resulting spectra are displayed and the indication of the recipe step is incremented. Prior to updating the graph displaying all of the spectra for the current specimen, a range check is made based upon pass/fail criteria read from the configuration file at the startup of the application. If a spectrum does not meet the pass criteria, a pop-up dialog (Figure 4) graphically displays the spectrum and the acceptance limits and terminates the recipe without saving the data to the enterprise database.

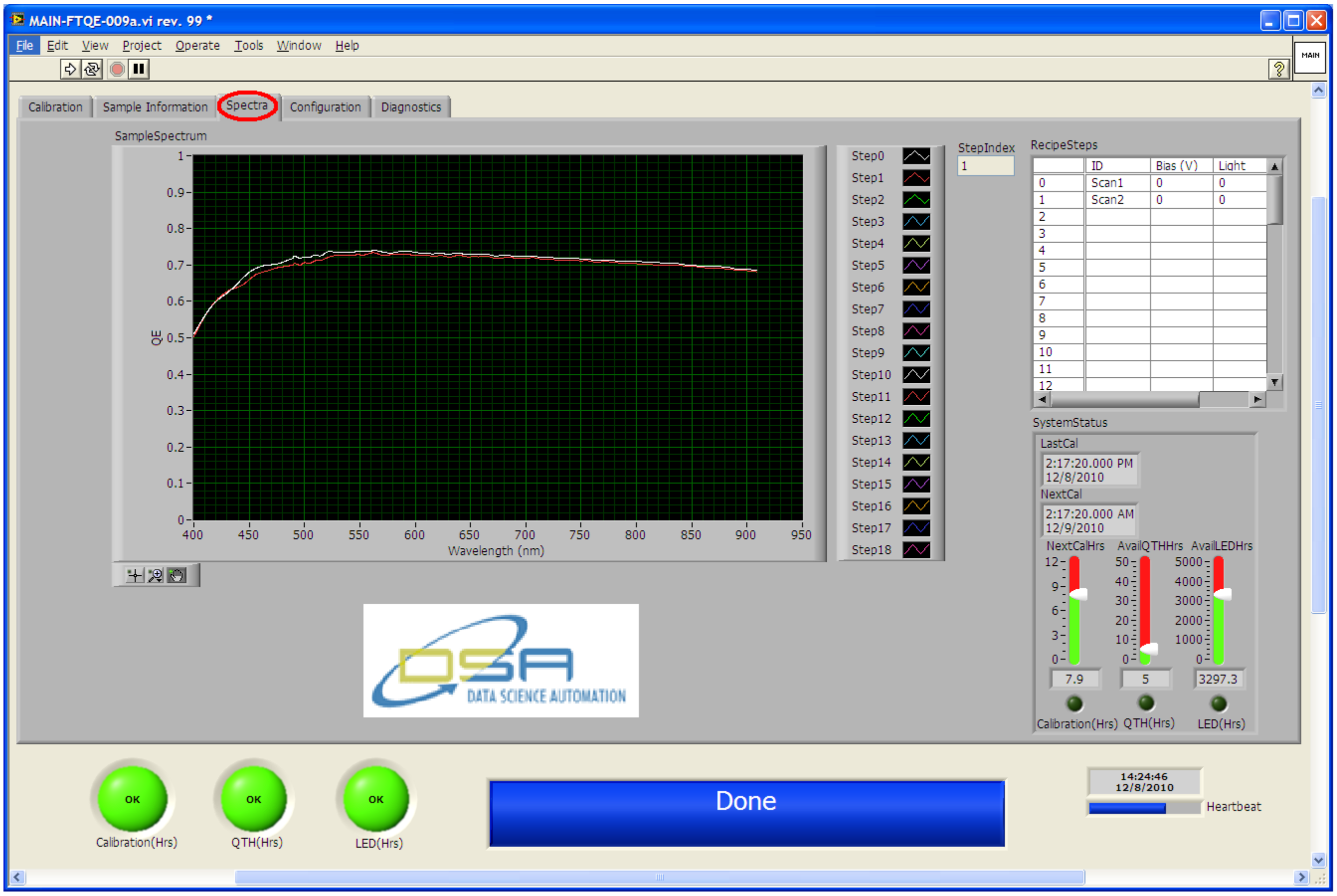

Figure 3. Spectra, Selected Recipe and Current Recipe Status.

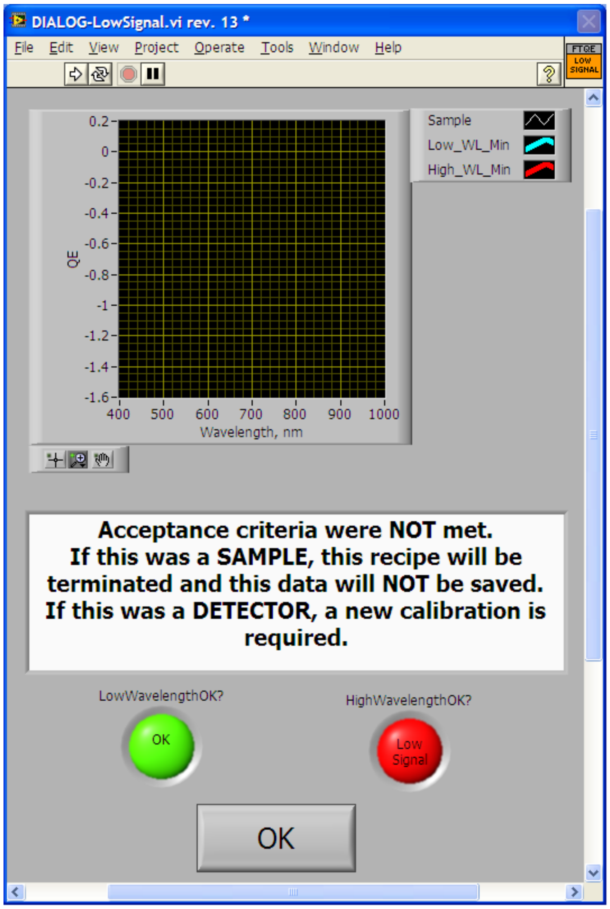

Figure 4. Specimen Failure Alert Dialog

Auxiliary Displays

To enhance application support and insight, two auxiliary displays are provided. A Configuration tab (Figure 5) consolidates the groups of configuration parameters read from the configuration file along with the operator information.

A Diagnostics tab (Figure 6) illustrates the sequence of state transitions from the main application state machine architecture along error handling data structures. The Diagnostics tab also provides two switches to allow operator overrides. One controls the suppression of the display of the OMNIC software during the spectrum acquisition. The other allows manual control of the pneumatic actuator that makes the electrical connections for the voltage bias from the pre-amp.

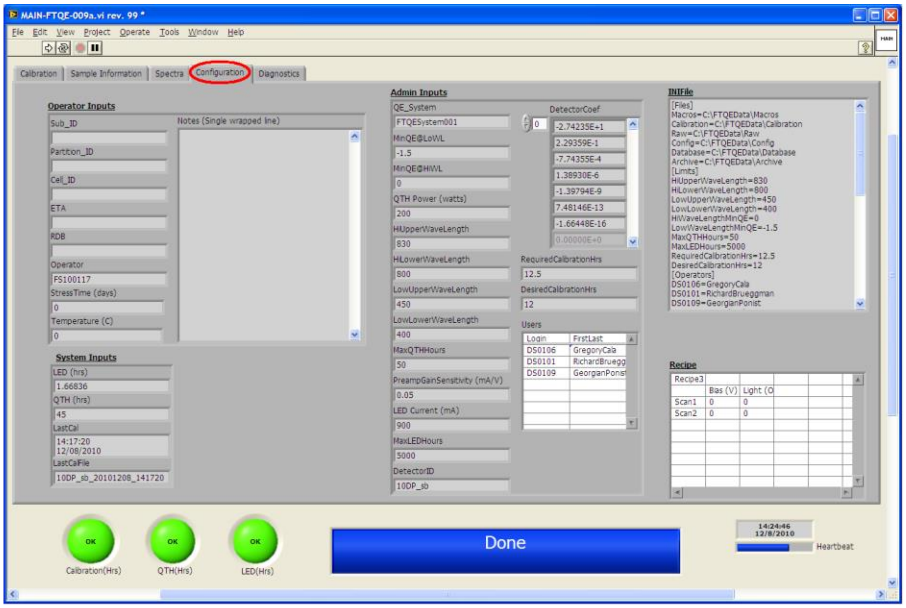

Figure 5. Configuration Information

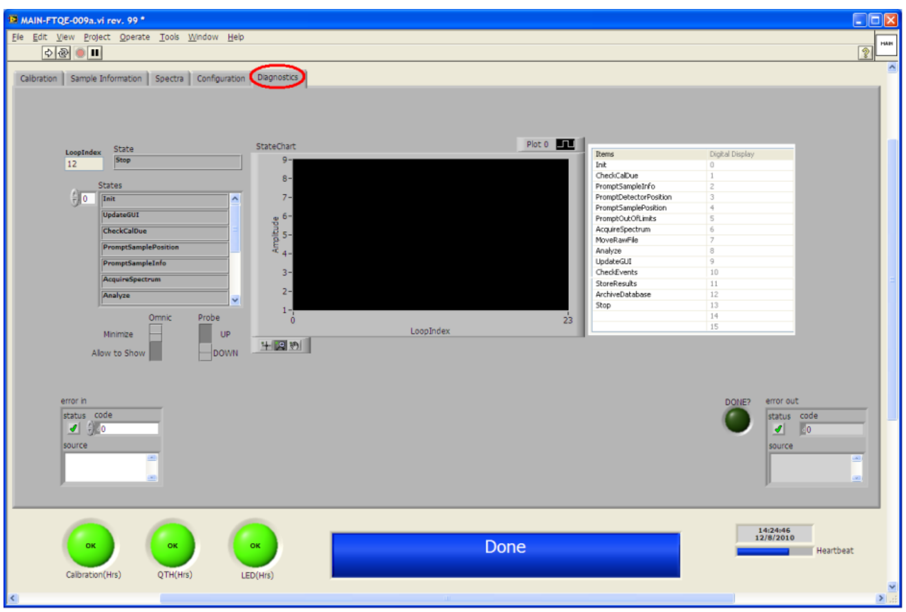

Figure 6. Diagnostic Information

Conclusions

Through the implementation of a collaboratively designed state machine, Data Science Automation developed an application to characterize the quantum efficiency of photovoltaic solar cells under a user configurable range of operating conditions. As a result of the automation of this process, 500% more modules can be characterized each shift. The intuitive interface requires minimal training and allows a more cost effective labor force for operation resulting in savings of as much as $90,000 per year.

Planned enhancements include automation of the motion control for the X-Y stages. This will eliminate the need for operator positioning of the detector for calibration and allow characterization of the multiple PV cells on each PV module.