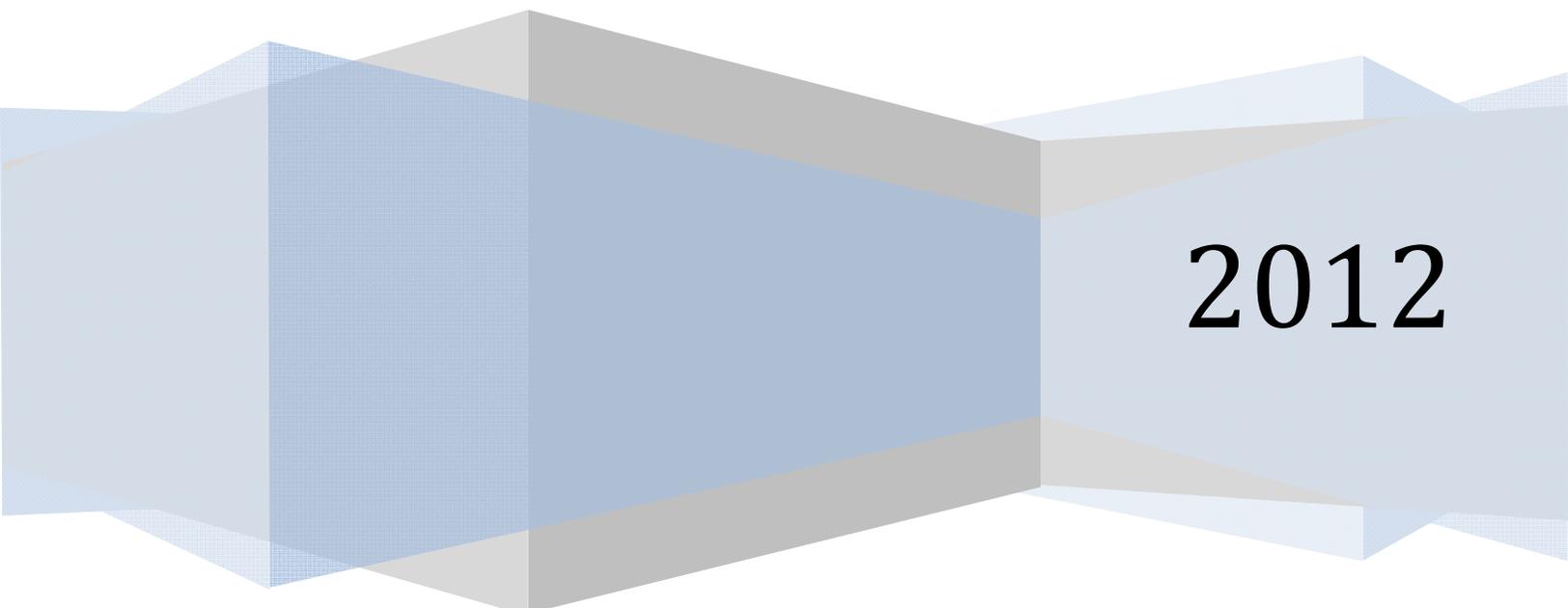


Photovoltaic Simulator

User Manual

InteGrid Lab – EECL, CSU



2012

This manual was originally written by Peter Vieira from the 2009-2010 Senior Design Team. Major revisions were made by Andrew Geck from the 2011-2012 Senior Design Team.

This manual is intended to provide an overview of the hardware and software associated with the Photovoltaic (PV) Simulator so that anyone unfamiliar with the system can have some understanding of how the system operates, of how to run a simulation, and of how to collect and observe the output data from the system. For more detailed information on the underlying theory and system operation, please consult the following files which should be located on the lab PC in the "*C:\PV Simulator Documentation\Reports*" folder:

PVEmulatorDocumentation.pdf -- "Adapting King's Model to Design a DC Bus Photovoltaic Emulator." Written by Joel Nelson. Summer 2009.

InteGridFinalReport2010.pdf -- "Final Report: InteGrid ~ Photovoltaic Simulator" Written by B. Ambon, M. Fox, J. Taylor, P. Vieira. May 2010.

PVFallReport2011.pdf -- "Grid Tied Photovoltaic Simulator" Written by Andrew Geck. Fall 2011.

PVSpringReport2012.pdf -- "Grid Tied Photovoltaic Simulator: Final Report" Written by Andrew Geck. Spring 2012.

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Safety

The Photovoltaic Simulator is equipped with safety in all parts of the system in order to protect the system and its operators. It was built according to National Electrical Code. The photovoltaic systems section of the code, Article 690, was used to ensure adequate installation and safety measures.

Lock Out/Tag Outs

- The 480V_{AC} PV Simulator 80A Fused Disconnect fed from CBPB01 must be locked out/tagged out whenever the PV Simulator is not in use.
- Lockout/tagout procedures must be adhered to on all outgoing circuit breakers connected to the power grid or InteGrid when not in use.

Circuit Breaker Safety

- All circuit breaker and disconnect doors must be bolted or latched shut at all times to prevent possible harm to operators or the system.
- The 24V battery supply from the InteGrid switchgear must be connected at all times for the safety circuit to work.

Built-in Safety

Any of the following actions will activate the safety circuit, triggering the shunt trips on all of the Eaton/Cutler-Hammer AC breakers, thereby powering down and isolating the system from the 480V and 240V sources:

- Pressing the Emergency-Stop button on the outside of the control cabinet.
- Pressing the Emergency-Stop button on the LabVIEW front panel while the program is running.
- Removing the DC or AC connection covers on the Summit® DC Power Supply while power to the 24V circuit is connected.
- If the 120V power to the PV Simulator control cabinet fails.
- If the 480V AC input voltage to the Summit® DC Power Supply drops below 354V_{AC}.
- If the Bitronics power meter is configured to activate a digital output when the AC current exceeds a given limit, it will activate a relay. This limit should be set to the maximum AC output current for the inverter being operated to improve the safety of operation.

Warnings

- The fan switch to the Preload Resistor Bank must always be on while DC output power is on in order to cool the resistors and prevent overheating.
- Each Preload Resistor Bank (5 resistors each) contains an inline fuse which is located in their respective DC disconnect box. These fuses must be open and the DC disconnect must be open to conduct maintenance on the Preload Resistor Banks.
- Check for latent voltage before conducting maintenance on any device.
The DC supply and inverters contain large capacitors which store charge and could be dangerous for several minutes after power is removed.
- A common ground runs from the 480V Main Distribution Panel to the entire PV Simulator, including the frame, boxes, cabinet, conduit and devices. Do not touch any hot lines to any of these pieces of metal or a short will occur.
- Do not operate the output of the Summit® DC Power Supply above 600V nominal. This would exceed the voltage rating of the cables used for the DC connections and the inverter maximum input limits.
- The Bitronics power meter must be configured to trip its output relay to the shunt trip circuit at the max AC output current of the inverter under test to ensure maximum safety of operation.
- The Bitronics power meter measures non-scaled voltage, therefore caution must be taken when around the voltage terminals on the meter or possible injury could result. These terminals will have 480V or 240V on them when live.

System Description

Introduction

The Photovoltaic Simulator is an advanced PV emulator that allows for the testing of solar generation systems with the use of simulated photovoltaic arrays and physical grid-tied solar inverters in the range of 2 – 25kW. It is adaptable to inverters with 208V_{AC}, 240V_{AC}, and 480V_{AC} output connections.

The controls for the simulator use measured current and voltage signals, and a pre-recorded solar irradiance profile to operate the DC power supply. The response of the DC supply is made to behave as though it were a PV array. Each half of the power supply can be connected to a different inverter and can operate independently at up to 25kW. The inverters have their own stand-alone control systems to monitor their DC inputs, convert the DC to AC power, and push the AC power onto the grid connections.

The LabVIEW front panel user interface provides a means to setup, initiate, and observe a simulation. The behavior of the DC supply is recorded by the program and saved to a file at the end of the test.

The system is also equipped with a Bitronics AC power meter to observe and record the AC output properties of the system. The information from this device can be used to observe the effect of the AC output from the PV Simulator on the rest of the grid to which it is attached.

Hardware Components

This section describes all the major components of the PV Simulator. An image and some basic information are provided for reference. For more detailed information on the components, manuals and spec sheets can be found on the control PC in the "*C:\PV Simulator Documentation\Manuals & Datasheets*" folder. If files are available for a component, the file name(s) will be given in the description.

- Summit® DC Power Supply – 25kW x 25kW Dual Output**
 (S/N 673426, M/N 3152700-204B)

Converts incoming 480V 3Φ AC into two independent DC sources.
 It is controlled by the N.I. cDAQ through the user cables. A serial cable is connected to the control PC for setup and configuration purposes only.

Input: 480V 3Φ AC.

Output: Minimums: 100W, 50V, 1A

Maximums: 25000W (each side), 1000V, 83.3A



Front of unit.



Back of unit.

Files:

"Summit 25kW x 25kW 57000015-00B User Manual.PDF"

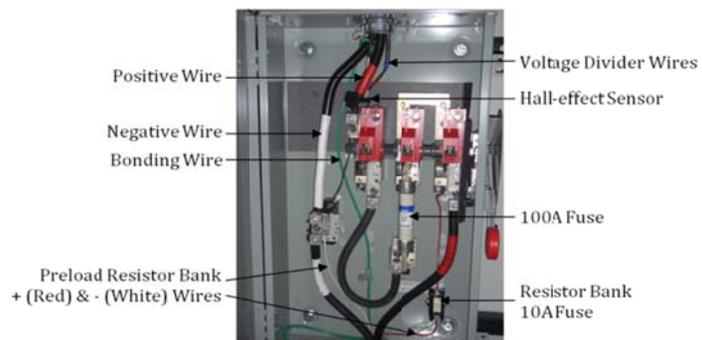
"Summit VFP User Manual.PDF"

- Fused DC Disconnects (x2) – 600V rated**

Located between the DC output of the supply and the connections to the inverters.



Exterior of Disconnects.



Interior of Disconnects.

▫ **PVPowered 30kW Solar Inverter - 480V**
(S/N PV0300BACF0310100299)

Converts incoming DC source to 480V 3Φ AC. The inverter has a Maximum Power Point Tracking routine to modulate its own output. It also automatically matches the phase and frequency of what it sees at the AC connection point. Actual output power is limited by the 25kW available from the DC supply.



Input: Maximums: 600V DC, 100A DC
MPPT Range: 295-500V DC
Output: Nominal: 480V 3Φ AC
Maximums: 30kW, 41A
Frequency Range: 59.3-60.5 Hz
Power Factor: 0.95 to 1.0

File: "PVP-30kW-480V Inverter Datasheet.PDF"

Note: A printed manual for the PVP30kW is available with the physical documentation.

▫ **PVPowered PVP3500 and PVP2800-XV Solar Inverters - 240V**
(S/N PV35240041007322 and 280XV111005714)

Convert incoming DC source to 240V 1Φ AC. Each inverter has a Maximum Power Point Tracking routine to modulate its own output. It also automatically matches the phase and frequency of what it sees at the AC connection point. Only the PVP3500 is connected at this time.



PVP3500: (on left)

Input: Maximums: 500V DC, 26A DC
MPPT Range: 200-450V DC
Output: Nominal: 240V 1Φ AC
Maximums: 3.5kW, 19A
Frequency Range: 59.3-60.5 Hz

PVP2800-XV: (on right)

Input: Maximums: 500V DC, 15A DC
MPPT Range: 170-450V DC
Output: Nominal: 240V 1Φ AC
Maximums: 2.8kW, 14A
Frequency Range: 59.3-60.5 Hz

Files: "PVP2800 & 3500 Datasheet.pdf"

"PVP2800 & 3500 Inverter User Manual.pdf"

Note: A printed manual for the PVP3500 is also available with the physical documentation.

- **AC Circuit Breakers** – 208V_{AC} 3φ, 240V_{AC} 3φ, 480V_{AC} 3φ A, 480V_{AC} 3φ Main (not shown) – Cutler-Hammer breakers with shunt trip accessory.



These are the points of connection to InteGrid and the main AC supply for the simulator. The shunt trip modules are activated by the safety circuit to isolate these sources from the simulator.

Files:

- "Circuit Breaker-Cutler-Hammer I.L.29C101G.PDF"
- "Shunt Trip-Cutler-Hammer I.L.29C140F.PDF"

- **Control PC**

The computer controls the simulator through communication with the N.I. cDAQ located in the main control cabinet. It also has a serial communication cable connected to the DC supply for configuration and setup of the limits on the DC supply.



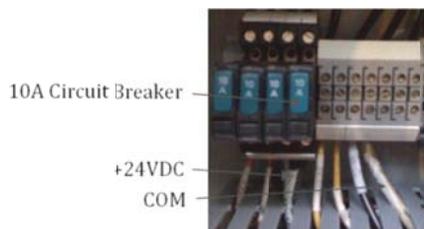
Installed Software:

Windows 7, Matlab 2009, LabVIEW 2009.

File: "JPK Desktop Computer.pdf"

- **24V Battery Supply**

This is the source for the 24V safety and control circuits for the simulator.



These breakers are located in the third section of SG3B in the basement. They are supplied from a battery attached to a charger located behind SG3B. The source runs from this breaker to the point of connection inside the main control cabinet of the simulator.

▫ **Main Control Cabinet**



Exterior of Main Control Cabinet



Interior of Main Control Cabinet.

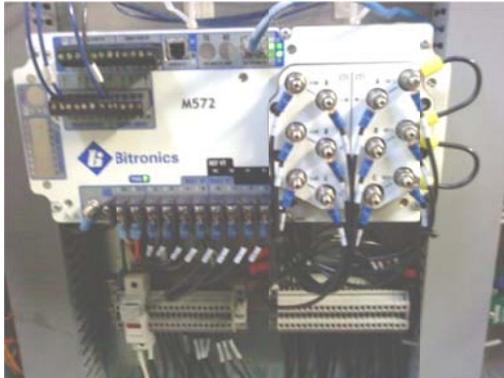
The main control cabinet contains the following components:

1. Stack light indicator: Illuminates green when main AC breaker is open, and red when main AC breaker is closed.
2. Emergency Stop Push Button: Push in to activate safety circuit. Pull out to deactivate and allow breakers to be reset. Breakers have to be reset manually.
3. Bitronics meter and connection terminals: see details below.
4. Fuse blocks for line voltage feeds to Bitronics: open to remove voltage on Bitronics.
5. 15V DC power supply: see details below.
6. 120V supply to PV Simulator and receptacle.
7. Uninterruptable Power Supply (UPS): see details below.
8. Connections to safety circuit, relays, and Hall sensors: see details below.
9. National Instruments Compact DAQ (cDAQ): see details below.
10. User Cable Breakout Boards: see details below.
11. 24V Supply connection and control relays: see details below.
12. CT Shorting block terminals: see details below.
13. Linksys Ethernet Hub: see details below.

The user should not need to open the control cabinet under normal circumstances. Only open for maintenance, configuration during setup, or troubleshooting. Follow safety precautions and check for potentially hazardous voltages before doing any work inside the cabinet.

- **Bitronics M572 Power Meter**

The Bitronics has a digital input connection from the cDAQ, a digital output to a safety circuit relay, and an Ethernet cable connected to the hub in the cabinet. All the voltage and CT terminals on the meter have short jumpers installed to the terminals located below the meter. If any connections need to be changed, it is suggested this be done at the terminals below rather than on the meter itself. The 120V feed to the meter is also protected by a small 3A fuse.



The meter is presently configured to measure the 480V and 240V AC output.

Files: "Bitronics M572 Datasheet.pdf"
"Bitronics M57x User Manual.pdf"

- **+/- 15V Power Supply – Phoenix 2938743**



This supply takes a 120V AC input and creates a positive and negative 15V DC supply for the Hall effect sensors on the DC bus.

File:
"15V Power Supply - Phoenix 2938743.pdf"

- **Uninterruptible Power Supply**

The UPS is a single phase 120V backup and surge protection system.



The control PC, monitor, and the Linksys hub are plugged into the battery backup ports on the UPS. The supply for the cDAQ is plugged into a surge suppression port. This way, loss of the 120V source removes power to the cDAQ, which triggers the safety circuit.

- **Relays (x2)** – Siemens 3TX7110-5JC03 1NO/1NC, 24V coil



One of these relays is operated by the Bitronics, the other by the cDAQ. Both are triggers for the safety circuit. The terminals to the left are the connections to the safety circuit, and the terminals to the right are the connections to the Hall effect sensors located in the DC disconnects.

File: "Siemens3TX71.pdf"

- **National Instruments CompactDAQ-9178**

The chassis contains the following modules:

- NI 9472 8-Channel 24 V Sourcing Digital Output Module
- NI 9422 8-Channel 24 V Sinking/Sourcing Digital Input Module
- NI 9472 8-Channel 24 V Sourcing Digital Output Module
- NI 9472 8-Channel 24 V Sourcing Digital Output Module
- Spare Slot
- NI 9422 8-Channel 24 V Sinking/Sourcing Digital Input Module
- NI 9263 4-Channel, +/-10 V, up to 100 kS/s, 16-Bit DAC Analog Output Module
- NI 9205 32-Channel +/-10 V, up to 250 kS/s, 16-Bit ADC Analog Input Module



The cDAQ chassis communicates with the control PC through a USB connection, and runs LabVIEW programs executed on the PC. The cDAQ controls the DC power supply by sending signals through the user cables attached to the breakout boards located below the cDAQ.

There are a number of spare input and output terminals available for future expansion and modification of the system.

The 9205 Analog Input module has been configured to take differential measurements to reduce the effects of noise on the incoming signals. This effectively reduces the number of analog inputs to 16.

Files:

"NI CompactDAQ Datasheet.PDF", "NIcDAQ-9178.pdf "

"NI9472-9474.pdf", "NI9422.pdf", "NI9263.pdf", "NI9205.pdf"

- **User Cable Breakout Boards**– WINFORD: BRK37M Rev C



The boards provide termination points for the connections between the cDAQ and the Summit® DC power supply user cables. The 37 conductor cables are shielded to reduce noise, and the terminals on the breakout boards also allow sections of shielded cable to be installed to the final connections on the cDAQ terminals or the control relays.

File: "brk37m_rev_c_datasheet.pdf"

- **Control Relays** - Automation Direct 781-1C : 1NO/1NC, 24V coil



These relays are the interface for the digital input signals for the Summit® DC supply. The supply interprets certain pins in the user cable shorted to a common return pin as digital inputs. The digital outputs from the cDAQ operate the relays to perform the shorting action. There are six relays for each half of the supply.

To the left of these relays is the point where the 24V source enters the simulator control cabinet. The small fused disconnects are provided as a means to remove power to the system for maintenance or troubleshooting.

File: "AutomationDirect781-1Crelays.pdf"

- **CT Shorting Blocks** (x3) – Southern Transformer SB-6TC, (x1) - SB-4TC



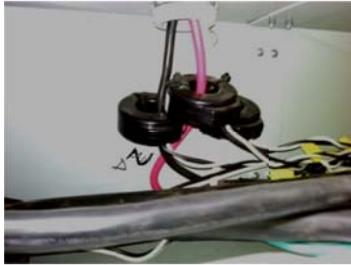
The shorting blocks provide a location to short together the CT leads. This provides an added measure of safety if the metering configuration ever needs to be altered later, as open CT leads can develop extremely high voltages.

- **Linksys Ethernet Hub**



Provides Ethernet communications to various devices in the system. The incoming feed is attached to the building network at the EECL.

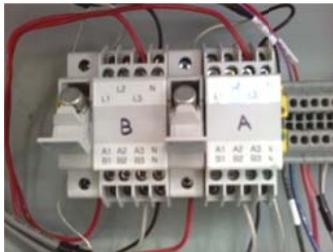
- **Current Transformers (x4) – Flex-Core AL-101, (100:5 Ratio)**



These are located in the wireway below the AC breaker connections to InteGrid. They are connected to the CT shorting blocks in the control cabinet, and from there, run to the CT terminals on the Bitronics.

File: "Flex-Core AL-101 CTs.pdf"

- **Voltage Dividers (x2) – Sustainable Automation HPVD-3-480, (100:1 Ratio)**



These are located in the upper DC wireway above the DC disconnects. They provide a point to directly measure the DC bus voltage for each half of the DC supply without having the DC disconnects open during a test. They can also provide a scaled down voltage that could be used as an analog signal to another device.

File: "Voltage Dividers-HPVD-3-480 Datasheet.pdf"

- **Hall Effect Sensors (x2) – Tamura L03S100D15, (100A:4V Ratio)**



These are located on the positive DC lead in the DC disconnects. They provide a direct measurement of the DC bus current that is sent to the analog input module in the cDAQ.

File: "Hall Effect Sensor - Tamura L03100D15.pdf"

- **Preload Resistors (x10)** - Huntington Electric HPK600



These resistors provide the preload required by the Summit® DC supply. There are five resistors wired in series, with the whole string connected in parallel with each half of the DC bus.

Each resistor is 50 Ω nominal, but the measured value of each string together is about 240 Ω .

File: "Resistors - Huntington Electric HPK600.PDF"

- **Heat Sinks (x6)** – Manufactured in-house



The resistors are mounted to the heat sinks to provide extra heat dissipation capacity. Each heat sink is large enough for two resistors.

One of the heat sinks has a thermocouple probe attached to it for possible temperature monitoring.

- **Fans (x3)** – EBM-Papst 9906



The fans operate on 120V and supply extra cooling for the heat sinks and resistors. The switch to turn on the fans is located next to the preload resistor box. Be sure to turn on the fans any time the DC supply is in use.

File: "Fans - EBM Papst 9906.PDF"

Software

This is a list of all the major programs used in the operation of the PV Simulator. Additional details on each program are given in later sections that describe their use.

- LabVIEW 2009 - from National Instruments
- Matlab 2009 - from Mathworks
- Summit Virtual Front Panel (VFP) - from Advanced Energy
- BiView v2 - from Bitronics: Areva T&D
- Configurator r3 - from Bitronics: Areva T&D

Setup & Configuration

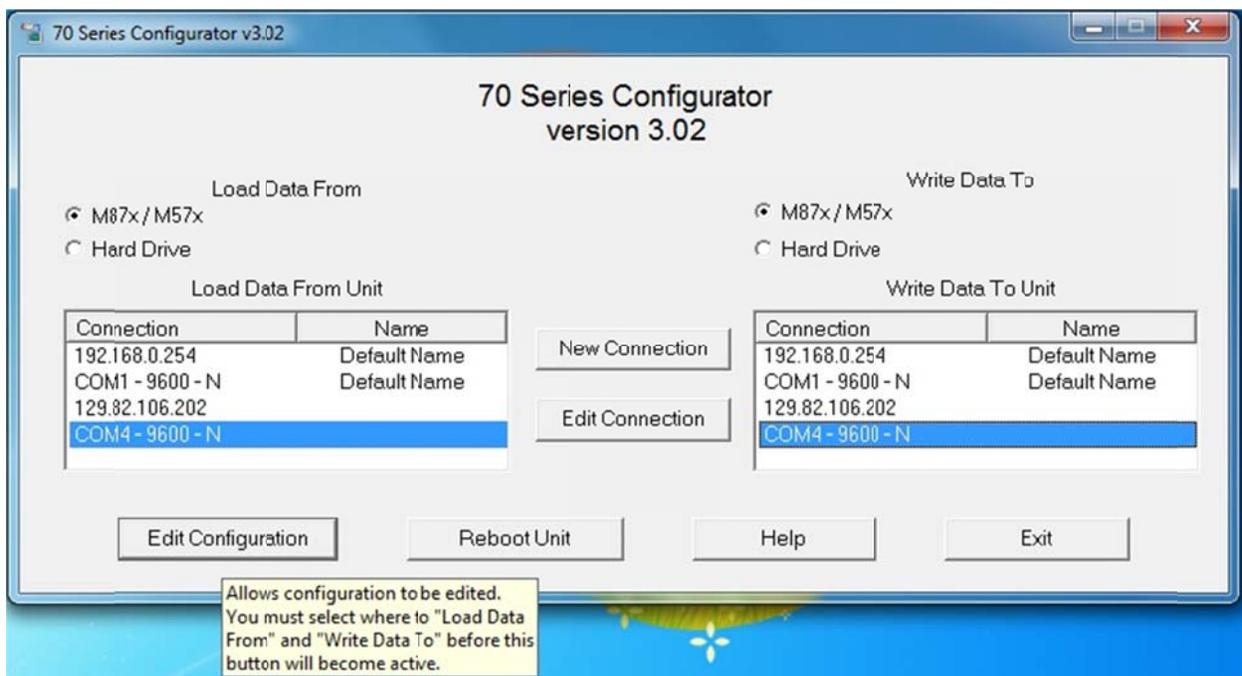
The PV Simulator can be modified for a number of different configurations of hardware, metering, or data recording. If any changes are desired, consult the following sections to ensure safe and proper operation.

Bitronics Power Meter Setup

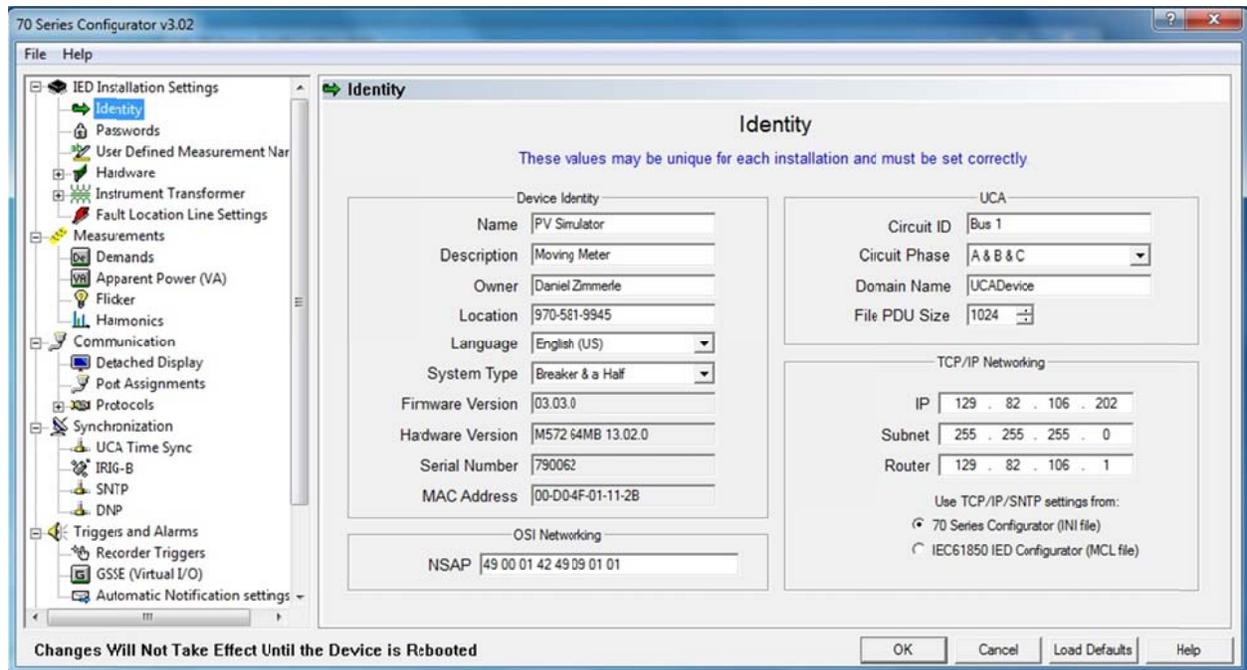
The Bitronics M572 power meter can be configured to measure various values on the AC output of the inverters depending on specific triggers. The meter's voltage and CT connections should be wired according to the AC bus and inverters in use, and the software should be configured to record the appropriate desired measurements. The meter is capable of both waveform and disturbance recordings. For optimum safety, the digital output of the Bitronics should be configured to activate if the AC current exceeds the maximum rating of the inverter being tested.

To run the configuration process, the spare communication cable from the Bitronics to the open serial port on the back of the control PC needs to be plugged in.

1. Go to Start>All Programs>Bitronics>70 Series>Configurator r3, or select the shortcut icon on the desktop.
2. Select "M57X" under the *Load Data From* section.
3. Select "M57X" under the *Write Data To* section.
4. Set the connection to the correct COM (serial) port (4).
5. Select "**Edit Configuration**".



Once the Configurator opens, the following screen appears with the various configuration options on the left.



Under Instrument Transformer>Ratios:

- Set CT ratios to 100:5 for the Flex-Core AL-101 current transformers.
- Set VT ratios to 1:1 for direct connections without PTs.

Under Triggers and Alarms>Recorder Triggers:

- Set Waveform and Disturbance Recorders to trigger on a Digital Input 1 “high” signal. This is the input from the cDAQ digital output.
- Set Digital Output 1 to go high when current is greater than inverter max. This is the trigger for the Bitronics relay in the safety circuit.
- Set Waveform and Disturbance Recorders to trigger on any other desired values.

Under Recording Modes>Disturbance or Recording Modes>Waveform:

- Select desired values to record in each case.

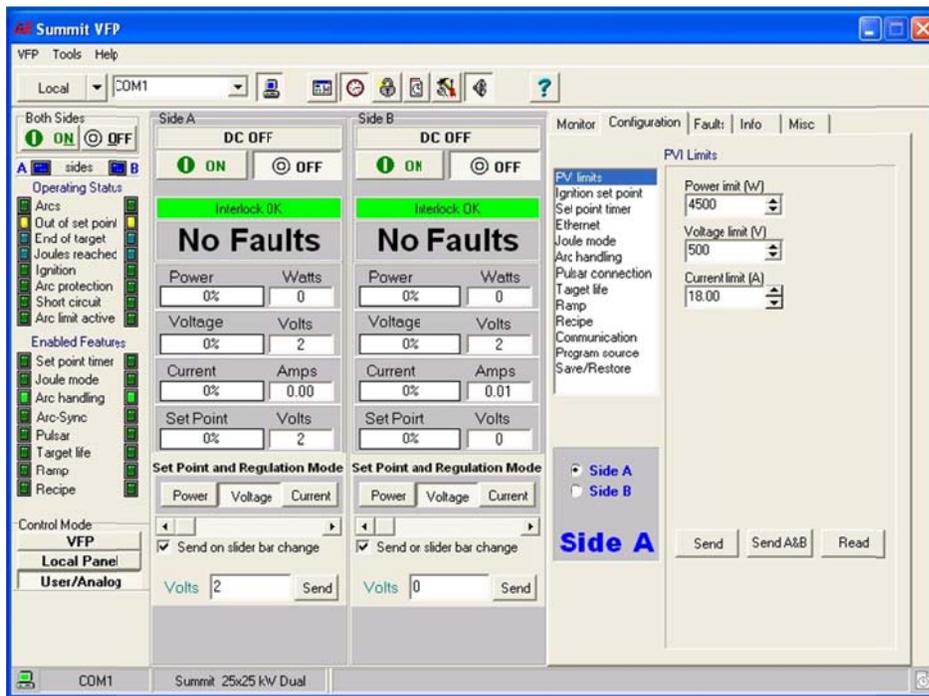
Once all desired changes have been made, hit the "**OK**" button and allow the unit to reboot for the changes to take effect.

Refer to the *Bitronics M57x User Manual* for more detailed instructions on setting up CT's, triggering, data collection, and measurement recording.

Summit® DC Power Supply Setup

The AEHost Bus Virtual Front Panel software is used to set current, voltage, and power limits, regulation mode, and control mode on the Summit® power supply. These limits must be set to ensure safe operating conditions. The 480V AC feed to the power supply must be on in order to communicate with it. Refer to the Turn-On Procedure on page 20 for instructions on turning the power supply on.

1. Go to Start>All Programs>Windows Virtual PC>Windows XP Mode.
2. Go to the Virtual PC's Start>All Programs>Advanced Energy>Summit VFP, or select the shortcut icon on the virtual desktop.
3. If any changes are made, click on the "Settings" button in the Toolbar and confirm



the power supply's "Unit Address", "Baud Rate", and "Communication Mode". Refer to page 4-26 of the Summit® DC Power Supply User Manual and page 3-9 of the Summit Virtual Front Panel User Manual for details.

4. In the Communication Controls section, set the connection to Local and to the correct COM (serial) port. This should be

COM1 of the virtual machine.

5. Under *Control Mode* click on **VFP** to use serial communication.
6. Click the "connect" button, , to connect to the power supply.
7. Under the *Configuration* tab on the right, select *Program Source*. Set the VFP to *Internal*, the Local/panel to *External*, and the User/Analog to *External*
8. Under the *Configuration* tab, select *PVI Limits* and set the power, voltage and current limits for each half of the supply. These numbers depend on the Power Supply and inverters in use. Add extra power to the power limit to account for the power dissipated across the pre-load resistors, or the supply may limit the power available to the inverter.
9. Now change the *Control Mode* back to **User/Analog**. This places the supply back under the control of the cDAQ.
10. Click the "connect" button, , again, to disconnect from the power supply.
11. Exit the VFP program, then log out of and close the Virtual XP window.

LabVIEW Program Setup

There are two LabVIEW programs written to operate the DC supply. Both are available through shortcuts located on the control PC desktop.

The first is a manual operator, which can be used to operate the supply as a constant source. It requires manual operation of all digital and analog controls, and should only be used for special testing by someone familiar with the system. It uses no information about the inverters or potentially simulated PV modules. More detailed information will not be provided here.

The primary program is the PV Simulator LabVIEW program. It uses inverter and module data, predetermined irradiance values, and measured current and voltage values during the simulation to automatically operate the DC supply as though it were a real PV array. Listings of inverters, modules, and irradiance profiles already exist in the program, but additional information can be added if desired.

Adding Inverters & PV Modules

Inverter and PV module models that do not exist in the lists in the simulator program can be added manually. This is done by adding a row for each in the “Inverter&Module Data.xls” excel file.

- Navigate to *C:\PV Simulator\Inverter&Module Data.xls* and open the file.
- Click on the *Inverter Data* sheet and add a row containing all known data for the new inverter, entering data under the appropriate column header.
- Click on the *Module Data* sheet and add a row containing all known data for the new module, entering data under the appropriate column header.
- Save the file. When the LabVIEW PV Simulator program is reopened the lists will be updated.

Adding Irradiance Data

Three options exist to simulate irradiance data from days not already saved on the control PC:

- Go to <http://www.nrel.gov/midc/research/> and download desired irradiance *csv* files to *C:\PV Simulator\Irradiance Data\RecordedProfiles*. The files being used on the system are from the "SRRL 10Hz Direct Normal" section of the site.
- Use the *IRModifierGUI.m* Matlab program, located at *C:\PV Simulator\Irradiance Data*. This program can modify existing recorded profiles, generate new simple profiles, select a shortened portion of a profile, or join two profiles together. It saves its output to the *ModifiedIR.txt* file. It is recommended this file be copied into the *TestingProfiles* folder and then renamed with an appropriate description.
- Manually place a generated file in the *RecordedProfiles* or *TestingProfiles* folders. Be sure to conform to the format of the other existing text files.

When the simulator program is reopened these new data files will be selectable.

Operation

Test Preparation/Turn-On Procedure

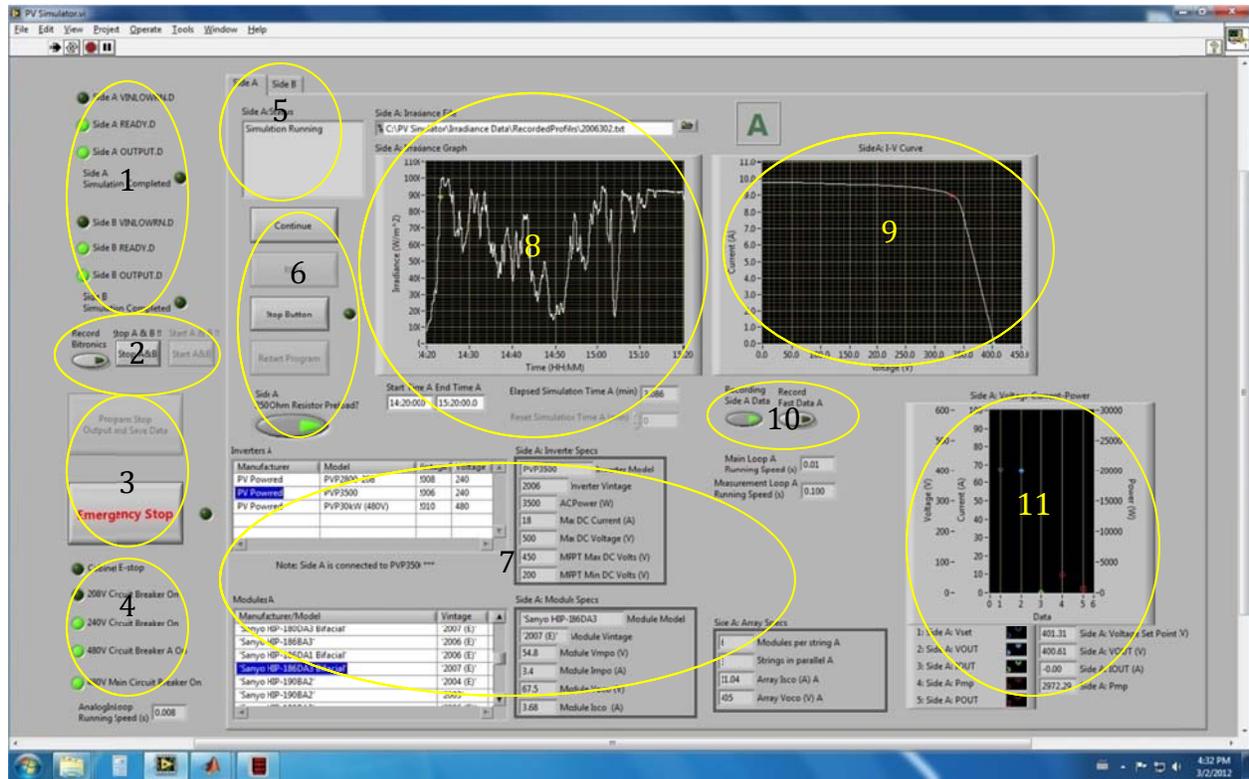
The following procedure must be performed every time a simulation is conducted:

1. Determine whether or not either of the Preload Resistor Banks will be used. If so, open the appropriate DC disconnect box and close the 10A fuse located below the positive terminal on the output side of the disconnect. Also, **be sure to turn on the fan switch located to the side of the upper DC wireway**. If the Preload Resistors will not be used, open the fuses and close the DC disconnect doors.
2. Open *PV Simulator.vi* located at *C:\PV Simulator\PV Simulator.vi*, or select the shortcut icon on the control PC desktop. **Special Note:** Since the simulator program uses some embedded Matlab scripts, the control PC must have access through the Ethernet hub to the CSU campus network in order to retrieve a license from the servers before the *PV Simulator.vi* will load.
3. Make sure all circuit breakers and disconnects are open.
4. The Load Bank or InteGrid AC grid connection should be turned on by an experienced operator in the lab following the InteGrid lock-out/tag-out procedures.
5. Hit the "Run Program" arrow icon in the LabVIEW PV Simulator program. This will activate the safety circuit relay so that the AC breakers in the system can be closed.
6. Remove lockouts and close the AC breakers and disconnects to the devices being attached to InteGrid for the simulation.
7. Close the DC disconnects and switches to the devices being used in the simulation.
8. Turn on the Summit® Power Supply by closing the main circuit breaker, then removing the lockout from, and then closing, the main fused disconnect. Once the DC supply has powered up, the status indicators on the LabVIEW interface should show that they are ready, and a simulation can begin.

From this point, follow the directions for running a simulation with the PV Simulator program. See the descriptions of the interface and walkthrough in the following sections.

PV Simulator LabVIEW GUI

The following instructions refer to the PV Simulator.vi file. A sample image is displayed and all the major parts are described, then a descriptive walk through for a simulation will be given in the next section.



1. Status Indicators: These are digital inputs from the Summit® DC supply, except for the "Simulation Completed" indicators which light up when either side finishes a test.
2. The **Record Bitronics** button activates the digital output to trigger a recording on the Bitronics. It is recommended to hold this in for a few seconds so the meter has a chance to register the input. To retrieve these recordings, please see the "Bitronics" part of the "Output Data" section of this manual. The other two buttons can start or stop both sides of simulator at once.
3. The **Program Stop** and **Emergency Stop** buttons will end the simulation. Pressing the Emergency Stop button will also activate the safety circuit.
4. Status Indicators: These are digital inputs from the E-Stop button on the main cabinet, and from the AC breakers. They indicate whether various contacts are open or closed.

5. A & B Tab control and Status window: Selecting one tab or the other will move between the windows for Side A or Side B of the simulator. Each side can run a simulation independently, and has identical controls and indicators. The large text "A" or "B" towards the top middle of the screen provides a quick reference of which tab is currently open. A tab does not have to remain open for the simulation to continue to run. The Status window provides the user some quick instructions during the start of a test, and an indicator of the state of the simulation during and after a test.
6. The upper four buttons are for starting, stopping, or resetting the sides of the simulator program independently. The **250 Ohm Preload Resistor?** button changes DC current calculations for the measurements so that only the current flowing to the inverter is used in the voltage setpoint calculations. The default setting for this button is to be enabled.
7. Inverters and Modules: The two lists on the right show all the inverters and modules loaded into the simulator. The default inverter for Side A is the PVP3500, and the default inverter for Side B is the PVP30kW. After selections are made, the three boxes on the right display some of the important properties associated with the inverters, modules, and calculated array that will be used for the simulation.
8. Irradiance Graph: Clicking the folder icon will open a dialog box to select an irradiance profile text file to use for the simulation. The selected irradiance will be displayed on the graph after the file loads. As the simulation runs, a green tracking dot will display where the simulator is in the irradiance profile. The Start and End Time boxes can be used to select a shortened section of the loaded profile. The Elapsed Time box displays how much real time has passed since a simulation was started, which should be useful for determining if the five minute warm-up period of the inverters has elapsed.
9. PV Array I-V Curve: This graph displays the I-V curve for the calculated array at the present level of irradiance. The red dot shows the Maximum Power Point, and the green tracking dot displays the actual measured voltage and current.
10. Data Recording: These buttons control if, and at what rate, data from the simulator is collected. The default rate is 10 Hz. Selecting "**Fast Data**" changes the rate to 1 kHz. This information is only the DC behavior related to the supply.
11. Display of values: This graph displays some of the measured and calculated values for the simulator as it runs. The legend below the graph explains which values are displayed.

PV Simulator Walkthrough

In the following description, some physical steps will only need to be performed once, while the program related steps can be followed for either Side A or Side B of the simulator.

1. Perform steps 1 through 4 of the Turn-On procedure. (See page 20.)
2. Click on the LabVIEW “Run” button, , to start the program. (Step 5 of Turn-On)
3. Perform steps 6 through 8 of the Turn On procedure. (See page 20.)
4. Click on the small folder icon and select an *Irradiance File* from the popup. This populates the *Irradiance Graph*.
5. Enter a *Start Time* and *End Time* for the test (in units hh:mm:ss).
6. Select the inverter to be tested using the *Inverter* list.
7. Select the PV module to be emulated using the *Modules* list.
8. Verify the calculated array size is correct, i.e. current and voltage levels are within attached inverter limits.
9. Press the **250 Ohm Preload Resistor?** button so that it is illuminated if the preload resistor bank will be used. The default setting for this button is to be enabled. This changes DC current calculations for the measurements so that only the current flowing to the inverter is used in the voltage setpoint calculations.
10. Press the **Continue** button to calculate the I-V curves that will be displayed throughout the test. This should take at least a few seconds to complete, depending on the length of the simulation being calculated.
11. When ready, Press the **Run** button to begin the test and start measuring/recording data. You can press the **Run** button independently on each tab (A or B) or the **Start A&B** button if both sides are ready to begin.
12. The test should begin and the DC supply will start producing output. Each of the inverters has a five minute "warm-up" period where it checks for adequate incoming voltage before it begins to produce AC output.
13. The test will run until it has gone through the loaded irradiance profile, at which point the "simulation completed" indicator should illuminate, and DC output from the supply should cease.

14. To end the simulation and download all the simulator data to the “*MEASURED DATA*” folder, press the **Program Stop Output and Save Data** button. The files will be generated and saved to the folder located at *C:\PV Simulator\MEASURED DATA\Y-M-D HH:MM*.

A few of the buttons can be pressed at any time during a simulation:

1. Press the **Record Bitronics** button to record AC output data on the Bitronics meter. It is recommended to hold this in for a few seconds so the meter has a chance to register the input. Refer to the *Setup & Configuration* section to configure the triggered recording on a digital input on the Bitronics meter.
2. Press the **Stop** button or the **Stop A&B** button to turn the DC power supply output off. This pauses a simulation. The simulation can be resumed, but the inverters will go through another five-minute warm-up period. Enter the elapsed time into the "Reset Simulation Time" box while the **Stop** button is still latched in, release the **Stop** button, and then press the **Run** button to resume a simulation from the entered elapsed time.
3. Press the **Emergency Stop** button while a simulation is running to trip all the circuit breakers and isolate the system if an emergency situation develops. This completely stops a test, and no output data files are generated.
4. After manually stopping a simulation, press the **Restart Program** button to start over from the very beginning of a simulation.
5. Press the **Record Fast Data** button to record data at 1kHz instead of 10Hz.

System Turn-Off Procedure

The following procedure should be performed when turning the system off after the test is complete and the LabVIEW program has stopped:

1. Ensure DC supply output is off, and allow the unit some time to run the cooling fans.
2. Open the 480V main circuit breaker and disconnect to the DC supply and lockout/tagout the disconnect.
3. Open the AC circuit breaker connections to InteGrid that were in use and lockout/tagout.
4. Open the remaining AC disconnects or DC disconnects that were closed for the test.
5. Open the main tie breaker to InteGrid in the switchgear downstairs, and open the main InteGrid breaker & lockout/tagout upstairs.
6. Turn off the preload resistor cooling fan switch.

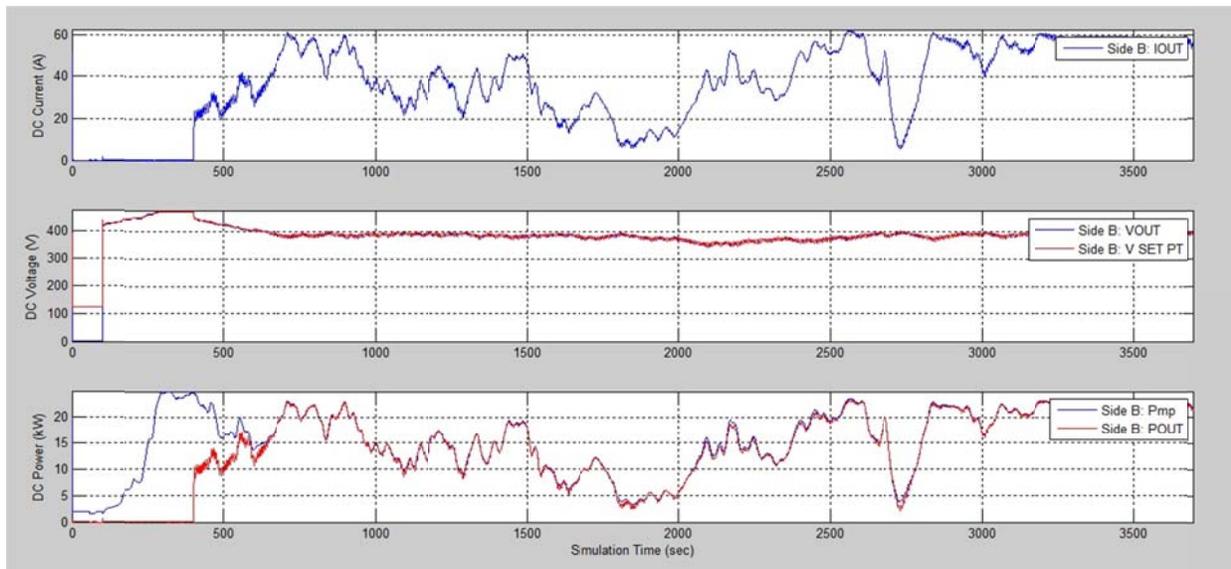
Output Data

There are two primary sources of output data for analysis of the PV Simulator system. The DC characteristics are recorded by the LabVIEW PV Simulator program and output as text files at the end of a test. The AC characteristics are recorded by the Bitronics meter system and must be retrieved separately. The data from the Bitronics can also be observed or collected while a simulation is running.

LabVIEW

When the **Program Stop Output and Save Data** button is pressed, all the test data will be saved in a folder entitled with the date and time of the test. Up to four separate files are created, two for each side of the DC supply, depending on if one or both sides of the simulator were run. One file contains the properties of the simulation, such as the date and time of the test, the inverter, PV modules, and irradiance file used, ect. The other contains the numerical data collected from the simulator.

In order to analyze this data, a Matlab file, "AnalyzeDataDraft7.m", must be copied from the *C:\PV Simulator\MATLAB* folder and saved to the folder containing the LabVIEW data. Once copied, open and run the .m-file. This loads the various numerical data into a Matlab data structure and, if the file is not empty, creates the following plots.



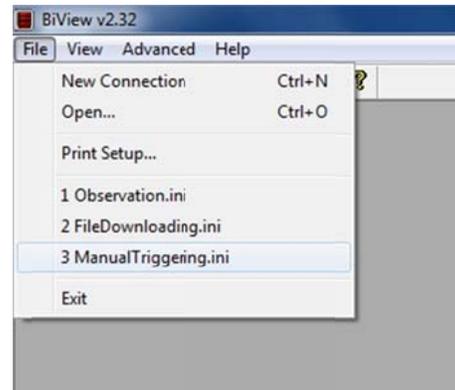
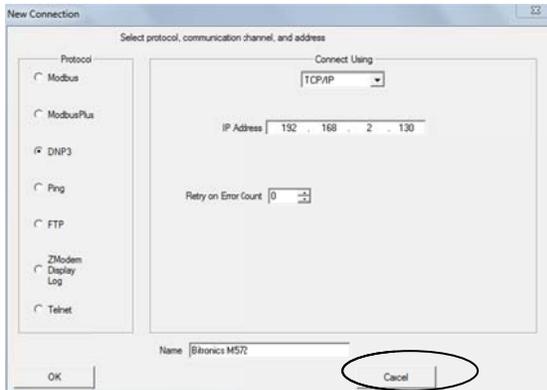
Each plot is versus the simulation time in seconds. The top plot shows DC current (IOU). The second graph is of DC voltage (VOUT in blue, V SET PT in red), where VOUT is the actual output of the power supply, and V SET PT is the commanded voltage to the power supply. The third graph is of DC power (Pmp in blue, POUT in red), where Pmp is the max power point of the solar array being simulated, and POUT is the actual power output to the inverter. A separate figure, not shown here, also shows the absolute deviation of the

DC voltage relative to the voltage set point, and the DC power relative to the max power point of the simulated PV array. The data structures created can also be saved and manipulated as desired. There are a total of 15 different variables recorded for each side of the simulator. Please see the PVSpringReport2012.pdf -- "Grid Tied Photovoltaic Simulator: Final Report", for more details on the data collected.

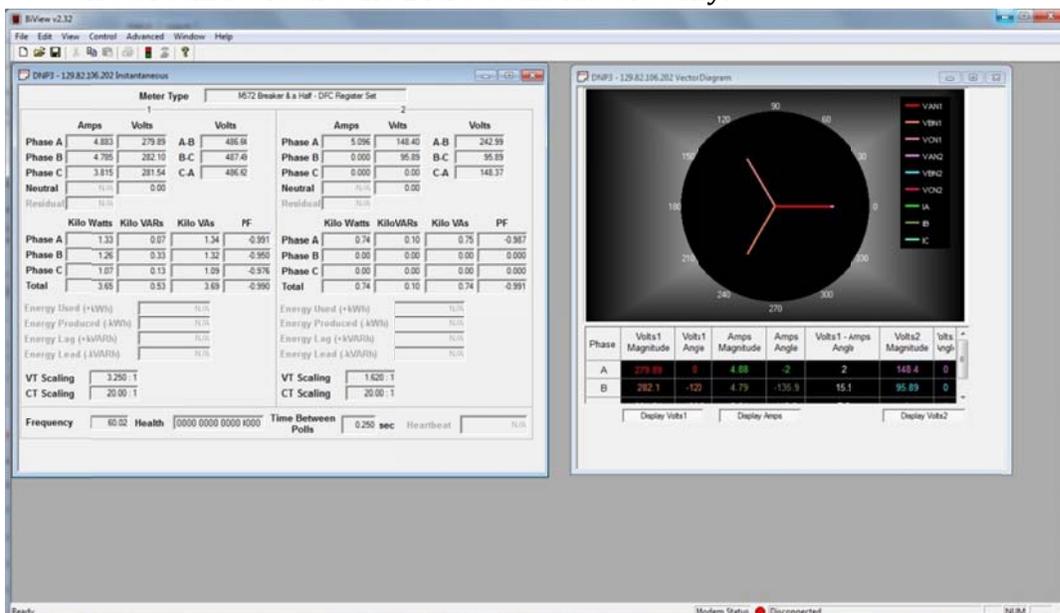
Bitronics Interface

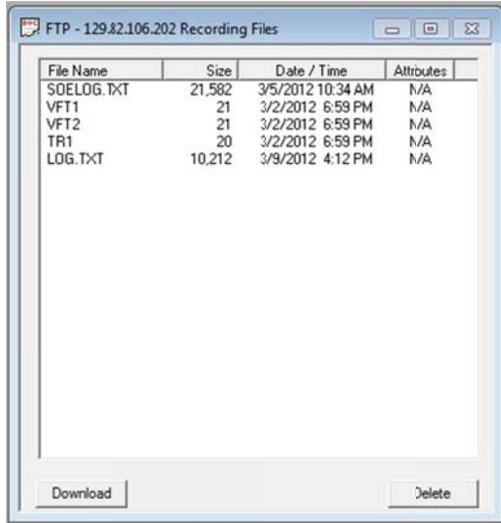
The Bitronics power meter measures the AC bus continuously, and has provided software to view, collect, and download this data. To access the Bitronics from the control PC during testing, consult the following the procedures below.

1. Go to *Start>Programs>Bitronics>BiView v2*, or select the shortcut icon from the desktop.
2. Select **Cancel** on the sub-window that opens inside the BiView program.



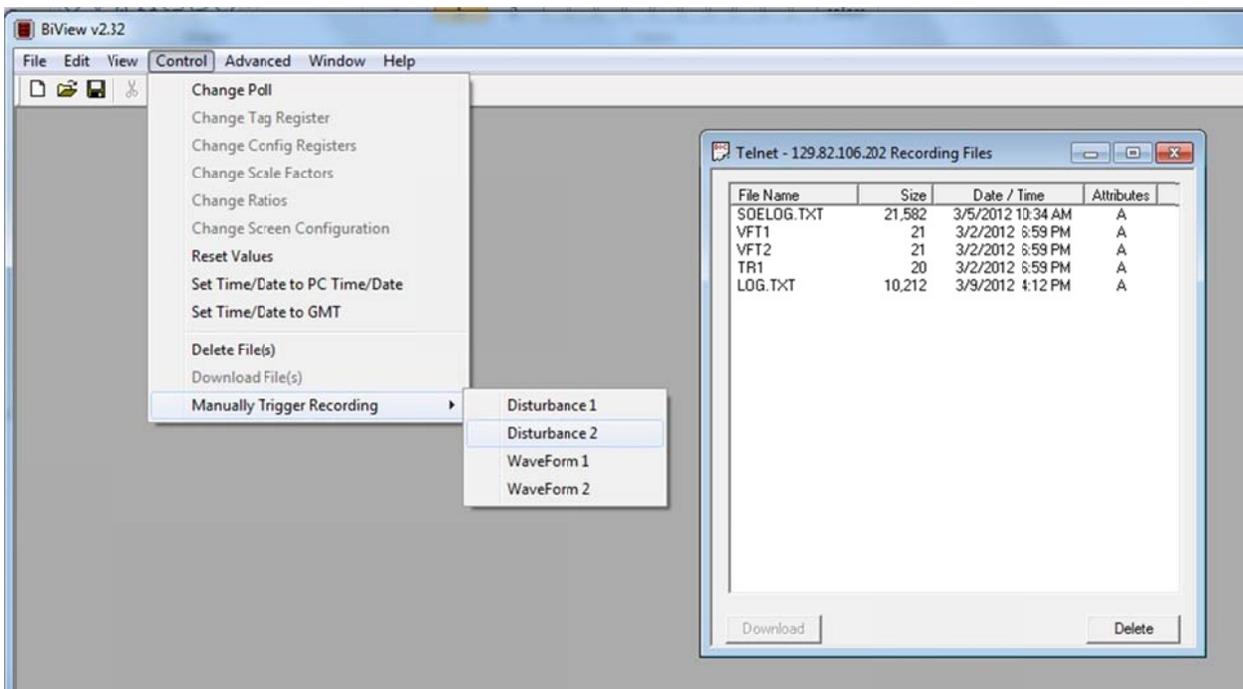
3. Go to the *File* dropdown menu in the program.
4. Selecting *Observation.ini* will open a DNP3 connection and load a screen that displays the present values measured by the Bitronics. The scale factors shown for the CTs and VTs are the DNP3 scale factors only.





5. Selecting *FileDownloading.ini* will open an FTP connection for fast downloading of the recorded files located on the meter. It is suggested that these files be downloaded to the *C:\BitronicsRecordings* folder, or to the folder created by LabVIEW for the simulation being run.

6. Selecting *ManualTriggering.ini* will open a Telnet connection that allows for manual triggering of recordings, outside of the operation of the simulator program.



Once the files have been downloaded, they can be processed as desired. Please see the *Setup & Configuration* section to configure the information recorded by the Bitronics meter.

Appendix:

Suggested Maintenance

The filters on the front of the preload resistor box should be cleaned occasionally to ensure adequate air flow for cooling the resistors.

The cooling fins of the heat sinks on top of the small inverters should also be cleaned occasionally.

Information on Electrical Schematics & Matlab codes

Please see the printed electrical schematics located in the pocket of the main control cabinet door. Current versions of the Matlab codes used in the simulator can be located on the control PC at *C:\PV Simulator\MATLAB*

Glossary/Abbreviations

AC	.....	Alternating Current
ADC	.....	Analog-to-Digital Converter
CBPB01	.....	Circuit Breaker Panel Board 01
cDAQ	.....	Compact Data Acquisition
CSU	.....	Colorado State University
csv	.....	comma separated value
CT	.....	current transformer
DAC	.....	Digital-to-Analog Converter
DC	.....	Direct Current
DNP3	.....	Distributed Network Protocol
EECL	.....	Engines and Energy Conversion Lab
E-stop	.....	Emergency Stop
FTP	.....	File Transfer Protocol
GUI	.....	Graphical User Interface
IR	.....	Irradiance
I-V	.....	Current - Voltage
kS/s	.....	kilo-samples per second
NC	.....	Normally Closed
N.I.	.....	National Instruments
NO	.....	Normally Open
PC	.....	Personal Computer
PTs	.....	Potential Transformers
PV	.....	Photovoltaic
SG3B	.....	Switch Gear 3B
UPS	.....	Uninterruptable Power Supply
VFP	.....	Virtual Front Panel
VTs	.....	Voltage Transformers

User Notes:

Use this area to write down any desired additional information: