Commonwealth Energy Biogas/PV Mini-Grid
Renewable Resources Program

Making Renewables Part of an Affordable and Diverse Electric System in California

Contract No. 500-00-036

Data Acquisition System User Manual for Comprehensive Large System Comparison

Project No. 3.2 Building-Integrated PV
Testing & Evaluation Project

Task 3.2.2 a(2) DAS Letter of Notification

Prepared For:
California Energy Commission
Public Interest Energy Research Renewable Program

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May 19, 2003

TO: Joe McCabe
Zhiqin Zhang
California Energy Commission

RE: Letter of DAS Notification – Task Deliverable 3.2.2 a (2)

Attached is the Large System DAS manual, which we would like to submit for the Project 3.2.2a Large System DAS Letter of Notification. Though the DAS is obviously not installed yet, it has been procured and is substantially complete in accordance with the following documentation:

- All major hardware has been procured including the datalogger and ancillary equipment, site computer, transducers, energy meters, and enclosures. Some miscellaneous installation-specific cabling and mounting hardware will be procured once the PV system and equipment room designs are complete. The Sunny Boy Control (used to collect data from the SMA inverters in System #3) will be included in the PV System purchase.
- DAS fabrication is substantially complete: equipment mounted in enclosures, internal wiring complete.
- Datalogger, I/O module, and multiplexer have been tested to verify operation and wiring, and a calibration check has been performed.
- Datalogger and Site Computer software is complete and operational.

During installation, the following tasks will be performed:

- Mount enclosures and meters in equipment room, weather transducers on roof, thermocouples on modules (and roof as necessary)
- Pull and terminate transducer signal cables, transducer and datalogger power, datalogger communications cable
- Install site computer; connect to: 1) datalogger, 2) Sunny Boy Control, and 3) IEUA facility LAN.
- Test DAS system and make operational

Please note that the manual and the miscellaneous files and documents it references are now placed on the password protected area of pierminigrid.org for you to access, under Project 3.2.2a (http://www.pierminigrid.org/Private/project32.html)

Text of this letter also emailed to recipients on date shown above.

Regards,

Charles M. Whitaker
VP Engineering

Data Acquisition System User Manual for Task 3.2.2a Comprehensive Large PV System Comparison

Commonwealth Biogas/PV Mini-Grid Renewable Resource Program[1]

Project 3.2 - Building Integrated PV Testing and Evaluation

1 Overview

The Comprehensive Large PV System Comparison (Task 3.2.2a) is intended to develop standardized PV system evaluation techniques and provide comparative data on systems relevant for Commonwealth Project 3.3 Building Integrated PV on Public Facilities. Under this project, three nominal 20kW systems will be installed on a Commonwealth Client facility. The three systems will be samples of commercially available products and will represent a range of module and inverter technologies and system configurations. A more complete discussion of Project 3.2 can be found in the PV System Evaluation Plan, which is available at www.pierminigrid.org/pubproject32.html.

A key aspect of this evaluation is the on-going monitoring of specific electrical operating parameters. The data acquisition system described in this document provides that capability.

1.1 Data Acquisition System

The Commonwealth/PIER Program Large PV Systems Data Acquisition System (DAS) is a collection of hardware and software that allows the status of the systems to be monitored and recorded for later analysis. A parallel evaluation project directed towards small systems includes a separate DAS sharing some of the features and components of this system and described in a separate document.

Figure 1 shows the arrangement of the major components in the Large PV Systems equipment installation. Natural boundaries for describing this equipment may be assumed depending on the context in which this system is discussed. For example, from the perspective of its contribution of power to the utility grid, this equipment may be regarded as a single demand-side distributed power system, with a boundary around the entire diagram. From the perspective of purchasing a single "system" from a vendor, boundaries may be drawn at the three 480V interfaces[2],. Finally, from the perspective of PV module technologies, boundaries may be drawn at the output of each inverter. The Data Acquisition System directly monitors the output at the inverter level, and by combining the data, the performance at the system or facility level can be computed.

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[1] The Commonwealth program is funded in part by the California Energy Commission Public Interest Energy Research Program.

[2] Two of the planned 20kW systems will each be based on a single 20kW inverter, while the third multi-inverter system will comprise 10 inverters, each 2kW and each powered by a different PV technology.

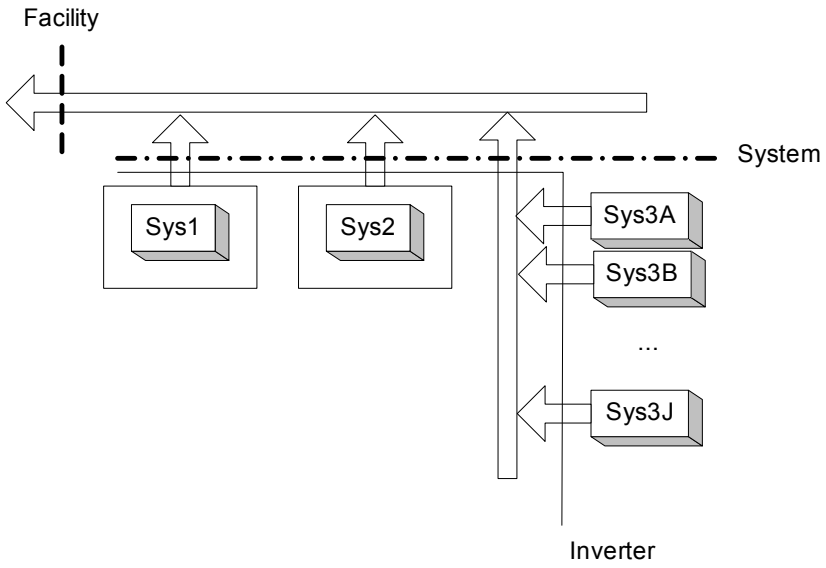

Figure 1. Large PV Systems Overview

1.2 This Manual

This manual is intended to provide a description of design and function of the Data Acquisition System hardware and software, to guide the user in the operation of the system, and to direct the operator as to where to find more information on its various components.

2 Hardware

The DAS hardware includes a datalogger-based (Campbell Scientific Model CR23X) monitoring subsystem for overall monitoring of the three large systems, and an inverter-based (SMA Sunny Boy Control) monitoring sub-system for operational monitoring and qualitative analysis of the sub-arrays of the multi-inverter PV system #3. Table 1 shows the parameters monitored by the datalogger and Table 2 shows the parameters monitored by the System #3 inverters.

Table 1 Datalogger Monitored Parameters

Parameter	Comments
DC Voltage	One per system (three total); measured at input to inverter
DC Current	One per system; measured at input to inverter
AC Voltage	One 480V measurement (line-to-line); one 120/208V 3 phase measurement (measured as one 120Vrms phase)
AC Energy	One per inverter (12 total); signal from pulse initiating watt-hour meters
Irradiance	One pyranometer for each of three array tilt angles
Wind Speed	Anemometer mounted on roof
Ambient Temperature	Thermistor in radiation shield mounted on roof
Array Temperature	Thermocouple mounted on back of one module in each array (12 total
Miscellaneous Temperature	One or more thermocouples may be mounted on and within the roof to evaluate the insulating value of some PV-roofing products

Table 2 System #3 Inverter Monitored Parameters

Parameter	Comments
DC Voltage	Voltage at the input of the inverter (V)
DC Current	Current into the inverter (mA)
AC Voltage	Inverter input voltage (nominally 208Vrms line-to-line)
AC Power	Power produced by inverter (kW)
AC Energy	Total for today and cumulative since inverter installation
Operating Mode	Mpp (maximum power point tracking), Off
Error Status	5 character text string, contents not specified

Figure 2 shows the PV systems major components, and notes the parameters monitored. In particular, dc parameters and irradiance are monitored at the system level while PV temperature and ac energy are monitored at the inverter level. The three pyranometers are centrally located (along with ambient temperature and wind speed) and oriented at the three tilt angles represented in the 12 array segments. For the multi-inverter System #3, dc parameters will be measured on one array segment.. The SMA monitoring solution is expected to provide sufficient accuracy for troubleshooting, and the single datalogger-instrumented segment will be used to compare and verify accuracy of the SMA monitoring equipment for the supplemental performance information they SMA will provide.

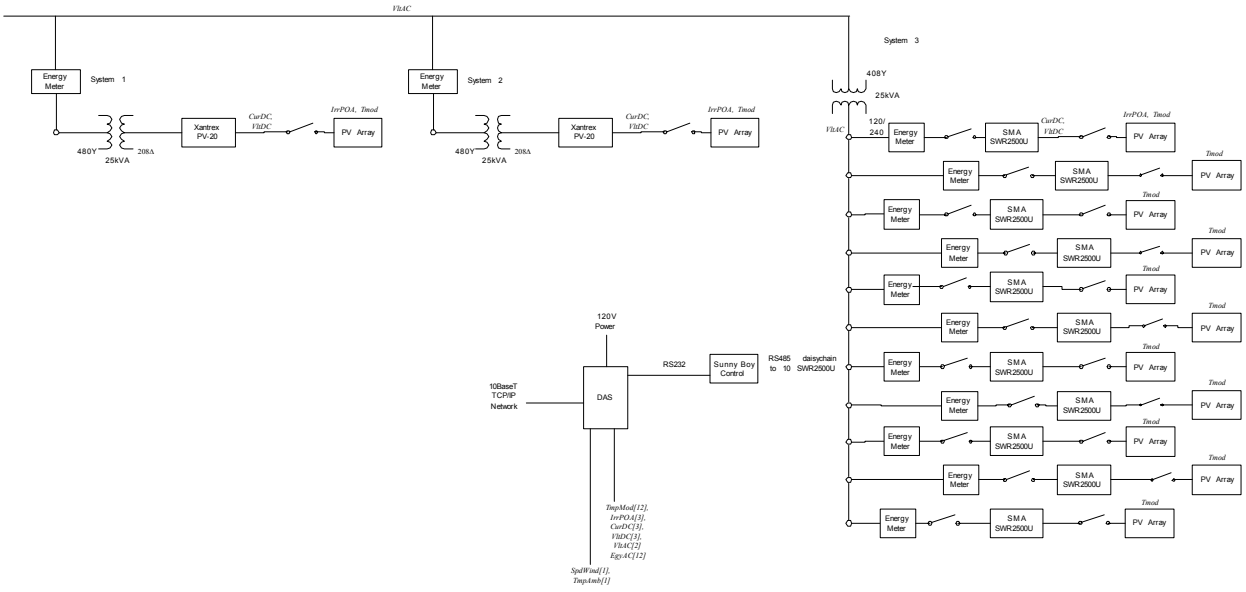

Figure 2. Large PV System Major Components

Figure 3 shows a block diagram of the DAS subsystems and components. The site computer communicates simultaneously via independent serial ports to the datalogger and inverter-based monitoring subsystems.

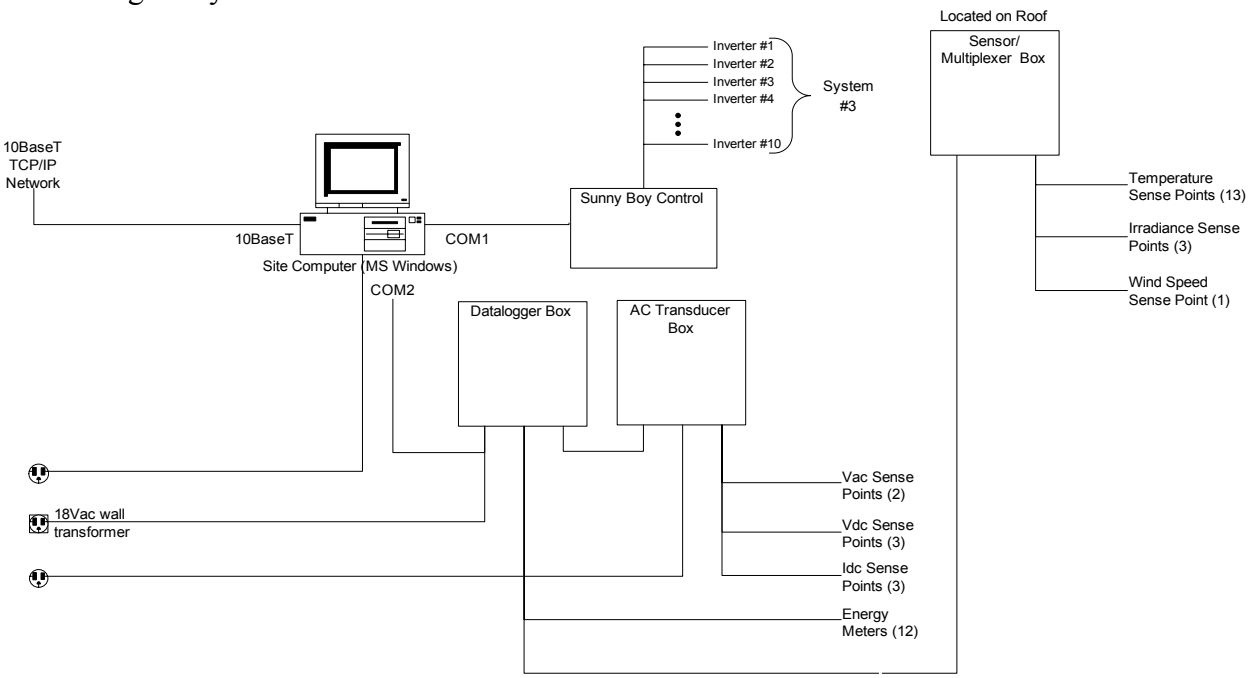

Figure 3. DAS Block Diagram

2.1 Datalogger Subsystem

The datalogger subsystem consists of a datalogger enclosure, transducer enclosure, multiplexer enclosure, weather sensors, and interconnection cabling. As shown in Figure 3, the datalogger communicates to the Site Computer via serial connection (COM2) The Datalogger and Transducer enclosures are located in the equipment room with the 12 inverters where all electrical measurements are made. Each of the 12 inverters is connected to the service panel through a pulse-initiating ac watt-hour meter that is monitored by the datalogger. A single ac voltage is measured for Systems 1 and 2, which use 480V three phase inverters. A separate ac voltage sensor is used for the 120/208V System 3. Dc voltage and current are measured for each system at the input to the inverter (inverter "A" on System 3 has the dc measurements). Signals from the pyranometers (irradiance), anemometer (wind speed) and thermocouples (ambient and array temperatures) mounted on the roof are routed through the multiplexer to the datalogger. The anemometer's pulse signal passes through the multiplexer enclosure but is not multiplexed. The datalogger is configured to monitor each channel once every five seconds and to store fifteen-minute averages of these channels as well as the maximum recorded windspeed.

Key datalogger subsystem components are defined in Table 3.

Table 3. Datalogger Subsystem Major Components and Transducers

Device	Manufacturer	Model	Location
Datalogger	Campbell Scientific	CR23 X	DAS Enclosure
Pulse Input	Campbell Scientific	SDM-IO16	DAS Enclosure
Analog signal multiplexer	Campbell Scientific	AM 16-32	MUX Enclosure
AC Voltage Transducer	Ohio Semitronics	VTR-001B and VTR-004B	Transducer Enclosure
DC Voltage Transducer	Ohio Semitronics	VT7-010B	Transducer Enclosure
DC Voltage Isolator + Current Shunt	Ohio Semitronics	VT7-016B + Current shunts as appropriate	Transducer Enclosure
Pyranometer	LI COR	LI-200SA	Rooftop (3 ea, 1 per array orientation)
Anemometer	NRG	#40	Rooftop
Ambient Temp Sensor/Radiation Shield	Campbell Scientific	Model 107 / Model 41301	Rooftop
AC Energy (Pulse initiating meter)	ABB	A1D Alpha Meter	Electrical Room

2.1.1 Documentation

Documentation for the individual datalogger subsystem components is supplied in a mixture of paper and electronic forms. Documentation of the CR23X datalogger is only available in hard-copy form,. Spec sheets and manuals for DAS components supplied in electronic form may be found in the `C:\EndeconDAS\Documentation\` directory of the Site Computer.

Drawings and terminal connection tables are stored in the files described in Table 4.

Table 4. List of Datalogger Subsystem Drawings and Terminations Tables

Filename	Description	File Type
`LgDASWHDiagrams.vsd`	Overview diagrams of DAS	Visio Drawing
`Lg_das_terminations.xls`	Tables identifying connection points for the DAS box (3 worksheets), Transducer box (2 worksheets), and multiplexer box (1 worksheet).	Excel Workbook

2.2 Inverter-based Monitoring Subsystem

The SMA Inverter Monitoring Subsystem consists of a Sunny Boy Control (SBC) unit, RS-485 interface modules for the SBC and ten inverters, and cabling. This subsystem reports dc voltage and current, ac power output, and inverter operating status for each inverter. This data may be viewed interactively at the panel of the SBC and data logged by the SBC is recorded to the hard disk.

The SBC is configured to sample data by polling at the maximum rate supported by the SBC-to-inverters communication channel. Data are stored in SBC memory every 15 minutes (per installed configuration).

2.2.1 Documentation

The DAS computer is connected via the COM1 serial port through an RS-232 serial cable to the Sunny Boy Control device. The SBC polls the inverters through the RS485 network to obtain operating data, and aggregates data over time to obtain long-term performance results. Connection drawings for the SBC are given in the Sunny Boy Control User Manual (At http://www.sma-america.com/ or on the Site Computer hard disk at `C:\EndeconDAS\Documentation\Datasheets\sma\`)

3 Software

Software for the DAS running on the Site Computer consists of Campbell Scientific LoggerNet for retrieving data from the Datalogger Subsystem, and the Sunny Control Data package from SMA used for retrieving data from the Inverter Monitoring Subsystem plus ancillary utilities to

facilitate remote access and data transfer. The sequence of data movements and processing are shown in. Figure 4.

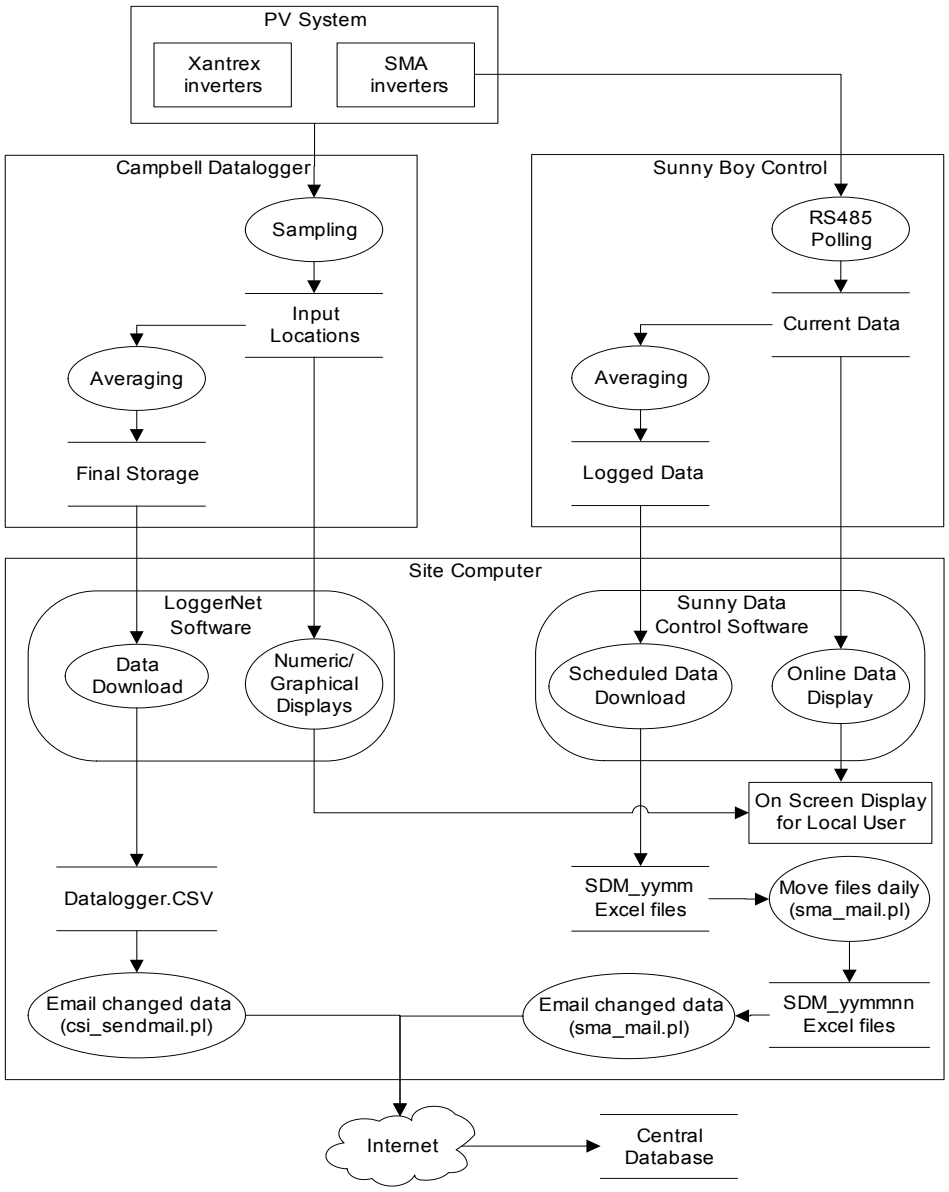

Figure 4 Data Flow Diagram

Software within the Campbell datalogger `(C:\EndeconDAS\23X\LgDASv1.CSI)` controls its behavior, determines which inputs to sample, how often to sample them, what calibration coefficients to apply, and how often to generate averages. The various sensors connected to the Campbell datalogger are sampled every 5 seconds, and the data placed in internal memory (Input Locations). Input Locations are available to the local LoggerNet numeric and graphical display functions. In addition each value is accumulated for statistical operations within the datalogger. Every 15 minutes, the datalogger stores accumulated results (averages and maximums) in a non-volatile circular buffer menu. The operation of the datalogger during loss of utility power is

supported for a few days by an internal lead-acid battery, but stored data will be retrievable even after sampling ceases when the battery is discharged. Note that during such power loss, none of the PV systems will operate nor will those transducers that require ac power to operate (ac and dc voltage and current, ac energy).

The SBC samples and stores data according to channel selections specified in the Sunny Data Control software, but neither the general purpose programmability nor battery backup feature is supported.

Real time display update rates to the local user for both data collection subsystems are limited mostly by the "sampling rate" in the respective devices: 5 seconds for the CSI datalogger and roughly 15 seconds for the SBC.

Long-term data trends are extracted from the "averaged" data streams from the CSI "final storage" and SBC "logged" data buffers. The LoggerNet data system downloads data every 15 minutes and triggers a script to transmit the newly recorded data to the Central Database. A single file containing uploaded data is maintained by LoggerNet on the Site Computer, and left undisturbed by the transfer of new data to Endecon Engineering. This file provides a temporary backup for data transmitted to the Central Database.

Data from Sunny Data Control are downloaded to the Site Computer hard disk only on a daily basis in Excel files. Normally, SDC creates a new file each month, however, the daily transfer of data to the Central database does not leave these files undisturbed: they end up as (approximately) daily files.

Data transfer from the Site Computer to the Central Database is accomplished using standard e-mail techniques. Email was selected due to its low impact on Internet firewalls and inherent support for data buffering. This approach can readily accommodate either a permanent high speed connection or a periodic telephone dial-up depending on what is available at the site.

Laplink will be used to support remote access by Endecon to the Site Computer for maintenance and troubleshooting (assuming we can access inbound TCP port 1547 through the facility firewall, if used).

Data received by the Central Database computer are used to compute performance measures. This computer forwards results to the web site for display. Real-time" data updates for remote users on the Commonwealth Mini-Grid Program website are implemented by tapping into these "averaged" data. Update rates for that display are on the order of 4 times an hour with a delay of no less than several minutes after the data were accumulated.

3.1 LoggerNet Software

Campbell Scientific LoggerNet[3] is actually a combination of programs used to configure their dataloggers, review current readings, and record data. LoggerNet comes with an extensive manual covering these features ("Loggernet21.pdf" in the `C:\EndeconDAS\Documentation\Software\` directory of the Site Computer), so this discussion will only cover the configuration used in this system.

The LoggerNet software should be running at all times on the Site Computer, to insure that data are transferred from the relatively limited storage capacity of the datalogger (a few weeks) to the extended capacity of the computer hard disk, and to relay recent readings to Endecon for processing and uploading to the project web site.

3.1.1 Viewing Real-time Data

Real-time data may be monitored numerically or graphically through the LoggerNet Communication window. To initiate real-time monitoring, go to the LoggerNet main window titled "Datalogger Support Software" and click the "Connect" button to activate the communication window.

The communication window may or may not automatically connect when it is opened, depending on whether it was "connected" when the window was last closed. If it does not automatically begin to update the "Station" clock display, confirm that the correct station is selected (in the current configuration, there is only one station, labeled "LgDAS") and click the "Connect" button to initiate communication.

Once communication is enabled, the primary display is #1, so click the "Data Displays"/"Numeric 1…" button. Note that the screen will update a few seconds after the channels are updated in the datalogger, which occurs once every 5 seconds.

The real-time display may be left active indefinitely if status logging is disabled (otherwise the disk would fill with unnecessary information about the success or failure of every communication with the datalogger). If the disk seems active while real time display is active, go to the Status window of LoggerNet and use the "Edit"/"Log Settings…" menu to disable logging to disk. These options may get enabled if someone is troubleshooting datalogger communications and forgets to disable them.

3.1.2 Overview of Datalogging Automation

LoggerNet data collection automation is configured in the Setup window. The contents of the right portion of this window change when different items are selected in the "datalogger network" configuration pane on the left portion of the window. For this project, the LgDAS datalogger is the key configuration item. Also, the "Tasks…" button on the Setup window opens the Task Master window used to configure what action happens when data are collected.

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[3] Note: LoggerNet was recently introduced as a replacement for Campbell's traditional PC208W software

To support web data reporting, data are collected every 15 minutes (schedule tab), Final Storage Area 1 must be enabled (Final Storage Area 1 tab) to append CSV data to `C:\EndeconDAS\CSIData\LgDASv1.dat`, and the Task Master "To_Mail" task attached to the LgDAS datalogger should be configured to activate the csi_sendmail.pl script (File Name = "`C:\Perl\bin\perl.exe`", Command Line Options = "`c:/EndeconDAS/bin/csi_sendmail.pl`", and Working Directory = "`c:/EndeconDAS/mailctl/`").

It is also recommended to maintain clock synchronization between the datalogger and the computer (Clock tab), assuming internet clock synchronization for the PC is enabled.

3.1.3 Viewing Logged Data

Because the data collection schedule causes LoggerNet to open the file `C:\EndeconDAS\CSIData\LgDASv1.dat` every 15 minutes, care should be taken to look at the time to make sure it is not near a 15-minute download interval before accessing the file. To minimize the amount of time you might conflict with LoggerNet, copy the file to a temporary file with a .CSV filename extension and open that file with Excel.

No templates for viewing logged data locally are included on the DAS computer graphically at this time. Plotted data will be available for the duration of the PIER project on the PIER website.

3.2 Data Emailing Script for LoggerNet Data

As noted above, data transfer to the central database computer is accomplished using e-mail. The `csi_sendmail` script (`C:\EndeconDAS\bin\csi_sendmail.pl`) is invoked by LoggerNet each time new data is added to the `C:\EndeconDAS\CSIData\LgDASv1.DAT` data file to send the newly added data records to the central database computer for analysis, archiving, and forwarding to the project web server. The script is written in Perl, so ActiveState Perl (http://www.activestate.com/) has been installed for the script to run. The script may be edited with any text editor (such as Notepad). Certain "library packages" (MIME::Lite and Net::SMTP) have also been downloaded from the Comprehensive Perl Archive Network (CPAN) and installed to facilitate the datalogging and uploading process..

The script includes certain variable definitions that may need to be updated if the processing or network environment changes. They are located just after the "Main (top-level) processing statements" comment banner. The smtpserver and fromaddress variables will have to be set to work with the local SMTP server. The local file and directory-specific variables would only need to be edited (in a copy of this script) if another email destination is desired.

The `csi_sendmail` script performs the following tasks:

The LoggerNet SPLITR program is invoked by the script to extract the most recently-downloaded data. The PAR file (`C:/EndeconDAS/mailctrl/LgDASv1A.PAR`) created by SPLITW is referred to and modified by SPLITR to keep track of which data has been downloaded. Therefore, the script saves both the updated and the old versions of the PAR file, leaving the old version in place until after the data are successfully emailed, and only then leaving the updated version in place.

Emailing requires outbound access to the Internet. If internet access is only available at specific times, the script will run, fail, and start over with the same data values plus any newly collected data the next time it runs. This feature provides a level of data integrity assurance.

3.3 Sunny Control Data

Sunny Control Data has also been installed on the Site Computer. This software provides a real time display of inverter performance, as well as retrieving averaged performance data from the Sunny Boy Control device and saving the data in Microsoft Excel-formatted files.

Operation of the Sunny Control Data package is described in general in the SMA Sunny Control Data Manual (available from http://www.sma-america.com/ or on the Site Computer hard disk at `C:\EndeconDAS\Documentation\Software\`)

3.3.1 Data Formats and Processing

Long-term data are stored in monthly Excel files stored in the directory `C:\Program Files\SMA Regelsysteme\Sunny Data Control\Plants\IEUA\`. Within this directory, data are stored in Excel files organized as described in the Sunny Data Control software manual. The exact layout of the files is partially determined by the sequence with which selections are made in the user interface.

Long-term data may be reviewed at the point of collection using Excel macros provided by SMA. However, the primary evaluation of data will be performed using a copy of the data automatically emailed nightly to the Central Database Computer for processing and subsequent transfer to the web database.

The "Sunny Control Data" software communicates with the "Sunny Boy Control" communications and datalogging device, which in turn scans the Sunny Boy inverters every 10-20 seconds. Sunny Control Data needs to remain active at all times to support automatic collection of recorded data.

3.3.2 Viewing Real-time Data

Real time data are shown in the "Online" tab of the main Sunny Data Control window, organized in a grid with one per inverter/Sunny Data Control device per grid square. Several operating parameters are available for each inverter, including ac and dc voltage, dc current, ac power, energy today and energy cumulative, operating mode, and error status.

Data are updated at the end of each polling cycle by the Sunny Data Control device, so the screen may only update every 20 seconds or so.

3.3.3 Overview of Logging Automation

The Settings window in Sunny Control Data (SCD) includes a "Data Request" panel at which the time of day[4] for data download from the Sunny Boy Control (SBC) device to the computer hard disk can be configured. For this system, data are scheduled to be downloaded at 12:20AM.

[4] The software only allows once per day downloading.

Sunny Boy inverters do shut down at night, so communication between the SBC and the inverters ceases, but the computer may still retrieve data from the SBC at night.

Downloaded data are stored in Microsoft Excel data files in the `C:/Program Files/SMA Regelsysteme/Sunny Data Control/Plants/sma_demo2/SBC1154 05195/` directory (or similar). The data are stored in a new file for each month. The files are named "`SDC_yymm.XLS`", where yy is the last two digits of the year and mm is the month (01-12). SDC places data from different inverters on different "worksheets" (tabs) in the same file. SDC orders the columns according to the sequence of clicks made to select them in the window during configuration, so the column order may not be consistent between inverters, but the channel names are stored in the first few lines of the XLS file.

3.3.4 Viewing Logged Data

SDC includes a menu item to activate an Excel macro for reviewing data, which is documented in the Sunny Data Control Technical Description (user's manual). However, this mechanism only shows the current day's data, as the daily transfer of data to the Central Database Computer removes older data from the monthly file.

3.4 Data Emailing Script for Sunny Control Data

The Perl script `sma_mail` (`C:\EndeconDAS\bin\sma_mail.pl`) emails any changed data files from the Sunny Data Control download directory to the Central Database Computer, and moves those files to the SMAData directory, appending a timestamp to the filename if the email was sent successfully. This effectively breaks the normal monthly files into daily files, except for the first day of the month, which is broken into a very small file on the first of the month, and the rest of that day's data is copied on the second day of the month to a separate file.

Since no feature for activating the emailing script is included in the Sunny Control Data software, the Windows Scheduler is used to activate the script at 12:35AM.

4 References

The following manuals are provided

Item	Location
Campbell 23X Datalogger Manual	Hard Copy
Campbell Scientific LoggerNet Manual	`C:\EndeconDAS\Documentation\Software\Loggernet21.pdf`
Sunny Boy Control User Manual	`C:\EndeconDAS\Documentation\Datasheets\sma\ SBC Tech Description.pdf`
Sunny Control Data Manual	`C:\EndeconDAS\Documentation\Software\SunnyControlData.pdf`
Perl "Manual" pages	Start Menu / Programs / ActiveState Perl / Documentation

Many Campbell Scientific manuals are available at their web site
http://www.campbellsci.com/manuals.html