WEB-BASED MONITORING SYSTEM USED TO EVALUATE THE PERFORMANCE OF A 2 KW PHOTOVOLTAIC ENERGY SYSTEM

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ABSTRACT

This paper presents a Web-based monitoring system installed on an experimental 2KW photovoltaic (PV) array. The system monitors and records climatological and electric energy data to evaluate the performance of system devices, including power conditioning equipment and appliances. Patterns of electricity generation and consumption are analyzed with accumulated data.

Why web-enable the instrumentation for a power system? Inter-networking provides access without geographic limitations. Additionally, network inter-connectivity enables the designer to put together a cohesive instrumentation system, using a collection of specialized hardware and software components arranged within the system such that each component can be most effectively installed, maintained, upgraded and applied.

1. MICRO-SOLAR TELECENTER

The photovoltaic-based array used to test the monitoring system is an experimental prototype of a Micro-Solar Telecenter. A Micro-Solar Telecenter is an educational facility, a stand-alone assembly of telecommunications equipment and personal computers powered by 2 KW of PV capacity and 24 hour battery backup.

Key features of the energy system for the Micro-Solar Telecenter are:

1. 2 KW photovoltaic Array at 48 Volts
2. Battery bank (sealed lead acid deep-cycle)
3. Charge controller and load controllers
4. Inverter.

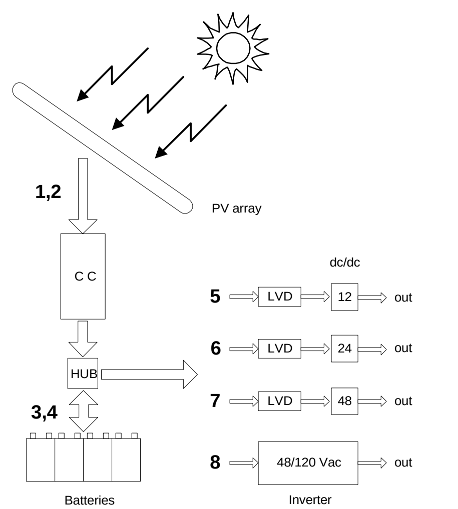

Fig. 1
Energy System and Electric Sensors

The energy system includes a distribution network with one ac circuit and three different dc circuits: 12, 24 and 48 Vdc. (See Fig. 1.)

2. WEB-BASED MONITORING SYSTEM

2.1 Key elements

Key elements of the instrumentation solution include:

- Sensors and transducers

Energy and environmental transducers for particular measurements are specified for appropriateness and cost, rather than being chosen from a proprietary solution set.

The standard Data Station uses eight sensors placed at strategic points in the energy system. The Data Station also includes climatological sensors that help to correlate weather conditions and renewable energy generation capacity, and to build a database of local weather patterns for a variety of community applications.

The variables to be measured include PV voltage, PV current, battery voltage, battery current, 12 Vdc current, 24 Vdc current, 48 Vdc current, inverter current (ac), PV incident solar radiation, outdoor temperature (near PV array), indoor temperature (in the computer lab or battery/inverter room), wind speed and direction, rain fall, etc. Other configurations can be created as appropriate.

- Digitization and logging, measurement and configuration

For the field application, the designer deploys an available networked data logger, rather than a custom development based on a construction set. We were able to find one designed specifically for Web-enabled energy and environmental monitoring. Field configuration uses a common browser, and if necessary, the logger can also be set up for remote reconfiguration. Customization is implemented in a data processor, running on a central data server using modern commercial software tools. This makes it possible, for example, to readily modify sensors based on field conditions and reconfigure the database immediately.

- Data processing and presentation

Rather than trying to make the field logger perform as a proprietary Web server, the data repository is implemented on a commercial-class database server hosted in a server farm with security, uninterruptible solar power and regular data backups.

The system integrator can choose from a short menu of customized data management services, or less expensive, standardized data repository services. Thus, the Web-enabled implementation successfully interconnects equipment-specific transducers and the data logger, with a standard database server and Web server.

2.2 Data Sets, Data Views

For power systems of any size, Web-enabled data presentations must serve the system's owners, operators, support staff and authorized viewers, i.e., the public.

- Owners and investors want to publicize the installation's aggregate cost performance and relevant public benefits. Their accountants want to download detailed metering records.

- Operators want to monitor the power system's operational status, so that they may be apprised of any problems that may arise.

- Remote diagnostic capability is especially cost effective for technical support, due to the expense inherent in taking diagnostic tools physically to these installations, especially in the case of deep rural locations.

- The power station is configured, commissioned, and verified using common browser interfaces into the data logger and central database parameters.

Because power operators need to stay abreast of system status, while accountants require accumulative energy quantity and cost reports, the data set must have both the resolution to serve near-real-time performance reporting as well as the storage capacity to maintain long-term accounting records. Web-enabled instrumentation shifts the data-intensive load to the data server. The field logger serves a simplified function set, and thus is selected for ease of installation and adaptability, rather than processing power, storage capacity or programmability.

2.3 Measurements and Calculated Values

Calculated values are a necessary part of a complete measurement system. In the Web-enabled system, calculated values are defined in the data processing configurations, one for each project site. The data systems administrator centrally manages customer sites and configurations. The project installer records site-specific measurement attributes and necessary calculations into the site configuration. This correlates data processes with loggers in the field.

2.4 Data and Device Interconnects: economy and adaptability

Once it is installed, the Web-enabled data logger functions to collect, time-stamp, and file data messages from digitizer nodes on its multi-point network and then transfers measurement data files to our data server over the Internet.

- The data-logger and its Modbus/RS-485 network supports one to many digitizer nodes, each of which handles 4 analog and 4 digital/counter channels, for accumulative electrical, water, or gas meters, and environmental sensors as appropriate. (See Fig. 2) For analog transducers, the current-loop, or 4-20mA interface, is standard, due to its simplicity, flexibility, and electrical noise-immunity. Typical calibrated transducers measure temperature, ac/dc Volts, Amps, Watts. Cumulative ac consumption measurements (kWhr) come across on a pulsed relay-closure protocol.

- Analog-to-Digital Converter (ADC) nodes read the 4-20mA channels, digitize and store the measurements, then transmit them as digital messages over the Modbus/RS-485 network to the data logger.

- The logger reads and files data messages from the RS-485 network. Utilizing a HTTP/PHP transfer script, the data files are transmitted to the data server over TCP/IP Internet.

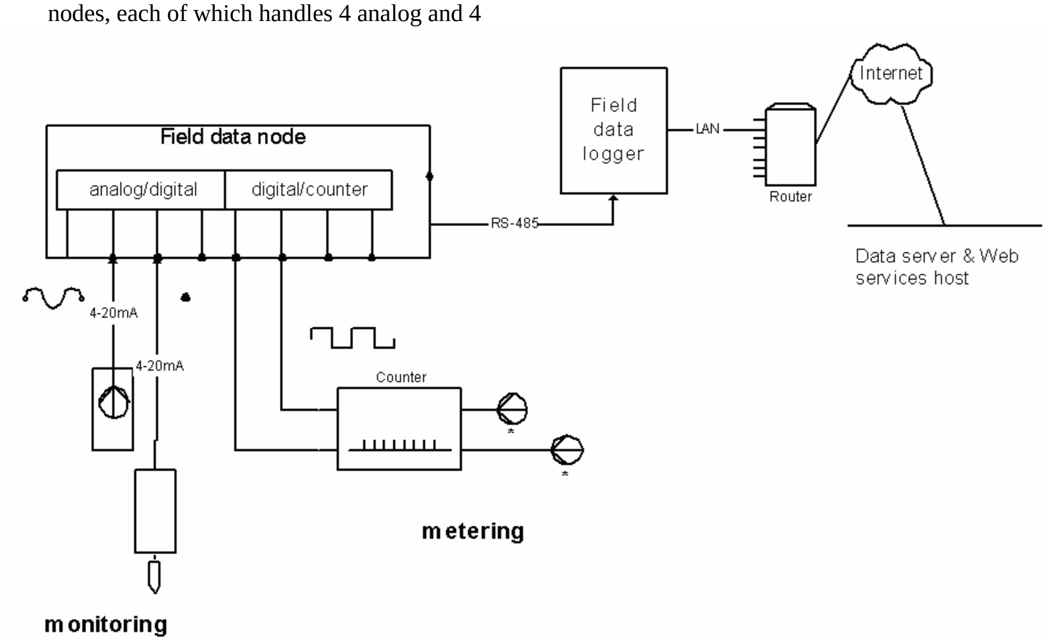

Fig. 2
Data path from sensors to Web Server

3. CASE STUDY

The energy and environmental monitoring system on the experimental photovoltaic array at the SolarQuest® Institute for Renewable Energy ("SQuIRE") has provided us with some interesting results:

3.1 PV array electric power generation.

The top line in the first graph indicates the current generated by the photovoltaic array. The lower line is the current being taken by the battery bank from the PV, or, if the current is negative, it indicates the current being delivered by the batteries to the loads. As is evident, the battery current is bi-directional. There is no other generator but the PV array, so this graph shows total current generated and consumed by the system. The spikes indicate an energy efficient refrigerator, the primary load connected to the system at the time of this test.

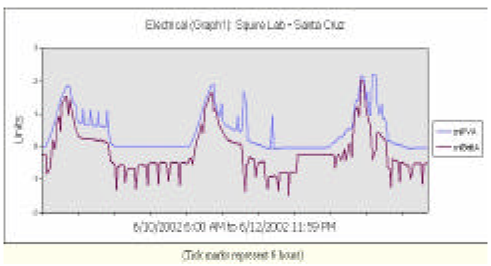

Fig. 3
PV generation and load profile
PV array current: top line
Battery current: lower line

The next graph (Fig. 4) illustrates the horizontal solar radiation during the same time interval.

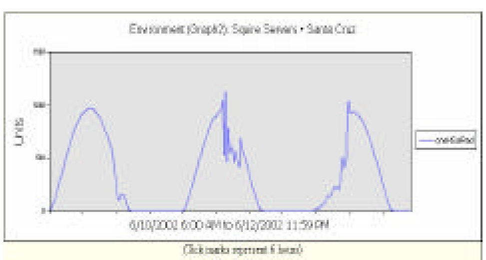

Fig. 4
Horizontal Solar Radiation, watts/m2

Note the solar eclipse at the end of June 10th, near the 6:00 PM mark. On the afternoon of June 11th the weather became cloudy and remained so all morning the next day, June 12th. The load depends on the batteries in the afternoon of June 11th in contrast with the previous day, where the daytime load was supported by the PV array.

3.2 Charge Controller Performance

Fig. 5, from May 2002, illustrates photovoltaic and battery voltage behavior. After several days of data collection we detected the poor performance of the charge controller. Notice how the battery voltage follows the PV array voltage practically point by point. Although the set-point for maximum voltage was 54 Volts, the batteries kept reaching an overcharging voltage of more than 60 Volts on sunny days. (The minimum low voltage disconnect set point was performing adequately.)

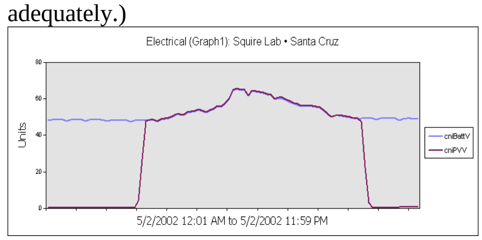

Fig. 5
Malfunctioning charge controller
Battery Voltage: Top Line
PV array voltage: Lower Line

As can be observed in Fig. 6, a new charge controller from a different manufacturer was installed at the end of June. This charge controller was able to maintain the battery voltage within the maximum and minimum set-

Fig. 6
Properly functioning charge controller
PV array voltage: Upper and Lower Line
Battery Voltage: Middle Line

points. The batteries became fully charged in the morning and when the voltage reached the maximum set point, the charge controller disconnected the batteries from the PV array. Due to the lack of a constant load in the system, the PV voltage rose up to its normal open circuit voltage (around 70 volts). Then when a load turned on, the PV array was capable of supplying the power demand. Notice the negative spikes in the PV voltage produced by the load.

3.3 Battery performance

The load controller regulates the power provided by the batteries. When the battery voltage drops to a defined set-point, a Low Voltage Disconnect ("LVD") mechanism isolates the load from the source, preventing excessive battery discharge, which could damage them. Considering the small size of the load and 4 batteries at 12V rated at 60 Amp-hrs, Fig. 7 demonstrates that the batteries are inadequate to back up the load through the night. A closer look at voltage (graph not shown) would demonstrate the rate at which the battery voltage drops from the maximum, or the fully charged state, to a discharged state. This information can be used to determine battery health and when necessary, send an automated warning message to maintenance personnel.

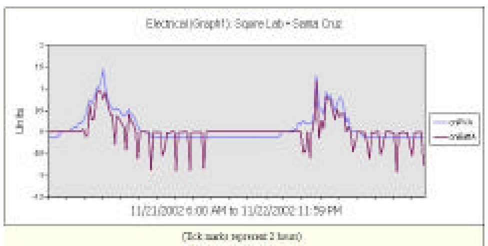

Fig. 7
Battery failure at night

The batteries remain fully charged during the day, and the PV array supplies the energy required by the load. Despite the state of charge of the batteries, around 4:00 pm, when the solar radiation begins to decline, the battery voltage begins to drop. For the rest of the evening and into the night, the load is supported by the batteries but the voltage continues diminishing even though the load demands only 1.5 Amps. It was found that one of the batteries was completely damaged, preventing adequate performance of the battery bank.

4. CONCLUSION

The Web-enabled instrumentation system (Fig. 8) makes possible the integration of disperse geographic locations, disparate equipment technologies, and various data requirements of the power system's owners, operators, technical support staff and authorized observers.

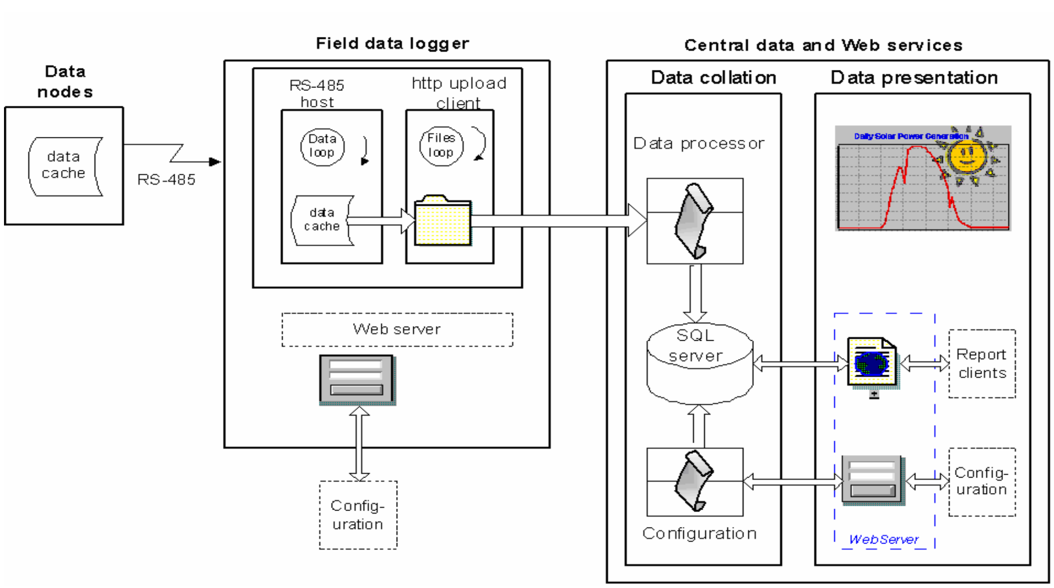

Fig. 8
Schematic of instrumentation and web-server environment