Supervisory Control and Data Acquisition Experiment Using the Advanced Communications Technology Satellite

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1. ABSTRACT
Satellite Supervisory Control and Data Acquisition (SCADA) was tested using the Advanced Communication Technology Satellite (ACTS) Ka-band signal and Ultra Small Aperture Terminal (USAT) ground stations. The SCADA system included a photovoltaic (PV)/diesel hybrid power generator designed to provide electricity to a rural community in a developing country. End-to-end baseline hardware checkout experiments have been completed. Results show that continuous two-second data transfers for real time monitoring can be completed with an error rate of less than 1%. The system recovers from simulated perturbations quickly and gracefully. Specifically, normal operation is resumed within 36 seconds following loss of power to any or all system component(s) and within one second following loss of communications link. Ka-band signal fade due to rain resulted in increased data transfer errors and loss of communications link, without effecting PV/diesel hybrid operation. Preliminary results suggest that data rates of 4800 bps and a link margin of 4 dB with a ¼ Watt transmitter are sufficient for end-to-end operation in this application.

2. INTRODUCTION
The lack of electrical energy in the rural communities of developing countries is well known. Equally known is the economic unfeasibility of providing much needed energy to these rural regions via electric grids. The economic advantage of renewable energy (RE) over conventional forms in meeting some of the energy needs of rural areas in developing countries has been well documented. Several efforts involving the use of renewable have been made over the years to address the problem of energy shortages in developing countries. However, these efforts have met with another impediment: the lack of personnel in the developing countries knowledgeable of, or skilled in, the operation and maintenance of renewable energy systems. Training programs on installation, operation, and maintenance of RE systems are used to meet this challenge. However, trained personnel must be allowed to complete the learning curve before they can be expected to exert meaningful impact on the energy supply problem in their countries. The use of a Supervisory Control and Data Acquisition (SCADA) arrangement would enable experts at remote locations to provide technical assistance to local trainees while they acquire a measure of proficiency with the system. Upon full mastery of the technologies, indigenous personnel may also employ similar SCADA arrangements to remotely monitor and control their constellation of RE systems, which expectedly would be scattered over large rural areas.
The portability of the Ultra Small Aperture Terminal (USAT) and the versatility of NASA’s Advanced Communications Technology Satellite (ACTS) as well as the advantages of Ka-band satellites, provide an opportunity for testing strategies for meeting the energy challenges of rural communities in developing countries. Both the satellite ground station and the consumer RE system could be supervised and controlled by an expert in a remote location using a SCADA system. This project is designed to test the performance of ACTS in a SCADA arrangement for remote monitoring of the health and performance of all major photovoltaic (PV) subsystems, and for investigating load control and battery charging strategies to maximize battery capacity and lifetime, and minimize loss of critical load probability.

This experiment will test and refine a SCADA system before its implementation in remote rural area. The setup consists of two custom designed PV-diesel hybrid SCADA systems, one located at Savannah State University and the other located at Florida Solar Energy Center, to be tested in this type of arrangement. The SCADA system at one terminal will monitor key system parameters at the other, remotely, to determine the health and performance of its power generation components, and provide remote control of system operation. The SCADA system will interface with both satellite and terrestrial communications networks. The Ka band communications link will use USAT ground stations and ACTS. The terrestrial link will use standard and Integrated Services Digital Network (ISDN) lines. The system will also be configured for local interface via a dedicated RS232 port.

3. EXPERIMENT DESCRIPTION
The three phases of the experiment are as follows:

(1) Baseline hardware performance—The primary purpose of this test is to validate network performance on an end-to-end basis without the satellite in the loop. First remote dial-in access to the PV-Diesel hybrid system was achieved via standard telephone line using LapLink software. Then a communications link was established between the experiment PC to a hybrid simulator without satellite or satellite modems. Continuous one-second data transfers performed to determine error rates. Power and communications link interruptions were simulated to test system recovery. The test setup is shown in Figure 1.

![Figure 1. Baseline hardware performance experiment setup](image-url)
As shown in Figure 1, the signal is converted from asynchronous RS232 to synchronous RS449 and back by a series of black boxes. The purpose of this conversion is to allow the computer, with its asynchronous RS232 input/output standard to interface with the satellite modems, which require synchronous RS449. Next the same tests were performed with the satellite modems in the communications link as shown in Figure 2.

![Figure 2. Baseline hardware performance experiment setup with satellite modems](image)

*(2) System operation, satellite in the loop (clear sky)*- The next logical test was to add the satellite (ACTS) to the communications loop and test the system end-to-end. Figure 3 shows this third configuration. The primary purpose of this test is to validate network performance on an end-to-end basis. Preliminary monitoring and data acquisition checkout tests have been completed using 2-second data transfers, first with a hybrid simulator and then with the actual PV/diesel hybrid system. Power and communications link interruptions were simulated to test system recovery.

Following these checkout tests, real and simulated loads will be used to evaluate different control strategies for the purpose of optimization. FSEC and SSU will alternate between hub and remote terminal functions.

![Figure 3. Baseline hardware performance experiment setup with satellite in the loop](image)
(3) **System Operation over a full weather range** - This phase extends the previous test, over a twelve-month period. This primary purpose of this test is to validate the telecommunications network performance and PV-Diesel hybrid performance on an end-to-end basis during a wide range of environmental conditions.

4. **PRELIMINARY RESULTS**

   (1) **Baseline hardware performance** – The delay introduced by hardware was negligible. Data rates of 4800 bps were determined to sufficient for this application. Error rates during continuous one-second end-to-end data transfers were less than $10^{-12}$ using the hybrid simulator. Link recovery from simulated loss of power was < 36 seconds. The communications link was re-established in < 1 second after simulated loss of link.

   (2) **System operation, satellite in the loop (clear sky)** – The delay introduced by the satellite (1/4 sec) was transparent to synchronization of satellite modem as well as to the PV-Hybrid computer. Data rates of 4800 bps and a link margin of 4 dB with ¼ Watt transmitter proved sufficient for end-to-end operation in this application. Error rates of less than $10^{-3}$ under clear sky conditions were recorded during two-second data transfers requested continuously over a two-day period.

   (3) **System Operation over a full weather range** - Data requests at two-second intervals during a rain event demonstrated that precipitation along the USAT-to-ACTS slant path does not effect the operation of PV-hybrid but may result in temporary loss of communications link and consequently failed data transfers. Figure 4 shows two rain events that correlated with periods of failed data transfers due to loss of communications link.

   ![Figure 4](image)

   **Figure 4. Periods of failed data transfers resulting from loss of link due to rain**

   For a sub-tropical region, the estimated amount of time that the fade will exceed the 4 dB margin is about 10% of time. The PV/diesel hybrid is designed to operate for several weeks before maintenance is required. As a result, hybrid performance is seamless to weather under normal operation, making a low margin system totally acceptable for this application. Unanticipated problems such as failure of the diesel engine can lead to loss of battery charge and automatic
load shedding as shown in Figures 5 and 6. In a real-life situation, this incident would result in total loss of power to a village. This incident demonstrates the need for SCADA in this type of system. Control strategies such as load shifting could prevent or at least delay total loss of power to the village until the diesel engine could be replaced or repaired.

Figure 5. Diesel engine failure resulting in battery drain by load

Figure 6. PV/diesel hybrid controller automatically sheds load due to low battery

Lightning damage to the experiment PC and to the hybrid controller delayed further testing of the system, as of the writing of this paper.

5. CONCLUSIONS
Baseline hardware performance test results demonstrate that continuous two-second data transfers can be accomplished under clear sky conditions with an error rate of less than 1%. Delay introduced by the satellite (1/4 sec) was transparent to synchronization of satellite modem
as well as to the PV/diesel-hybrid computer. End-to-end communications link recovery times were less than 36 seconds for loss of power and less than one second for loss of link. The system recovered by resuming operation without any manual intervention. This is important since the 4 dB margin is not sufficient to prevent loss of the satellite link during moderate to heavy rain. Hybrid operations during loss of link continued seamlessly but real-time monitoring was interrupted. For a sub-tropical region, the estimated amount of time that the fade will exceed the 4 dB margin is about 10%. These preliminary results suggest that data rates of 4800 bps and a link margin of 4 dB with a ¼ Watt transmitter are sufficient for end-to-end operation in this application.

Future tests will investigate different control strategies to optimize use of satellite-based SCADA with this PV/diesel hybrid system. SCADA of two remote hybrids, one at FSEC and one at SSU will also be evaluated. Finally, a combination of SCADA and remote training using one-Watt USATs will be implemented and tested.