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REMOTE MONITORING SYSTEM DESIGN - SUSTAINABLE SYSTEMS FOR THE NAVAJO TRIBAL UTILITY AUTHORITY

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The main objective of this paper is to recommend an optimal system for remotely monitoring Photovoltaic (PV) and PV/wind hybrid power systems located on the Navajo Nation through the Navajo Tribal Utility Authority's (NTUA) Solar Program. The emphasis of the paper will be on developing a robust and cost-effective Data Acquisition System (DAS) for monitoring extremely remote sites. The system will be designed for the 660-Watt (W) photovoltaic (PV) and 880-Watt (W) hybrid (PV and small wind turbine) systems and for future installations. Some references will be made based on experiences in the NTUA's Kayenta district.

The NTUA began installing 240W and 260W standalone PV systems in 1993 and have gone through four generations of upgrades; there are now more than 350 sustainable systems that are deployed on the Navajo Nation. The fourth generation consists of 880W hybrid small wind systems. Even though PV power can be 5-10 times more expensive than grid power generated from hydropower, natural gas and coal/lignite generating plants;[2] PV becomes more economical for remote customers when comparing costs to extend electrical lines from the grid, costing homeowners approximately $27,000 per mile, see Figure 1 for a map of the Navajo Nation.[3] Elevations on the Navajo Nation range from 10,388 feet to 2,722 feet; it is entirely on the

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[1] Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United Sates Department of Energy's National Nuclear Security Administration under contract DE-AC-04-94AL85000.
[2] http://www.worldwatch.org
[3] Tsabetsaye, S., "Navajo Tribal Utility Authority: Electrification Demonstration Program Developing a Sustainable Tribal and Rural Cooperative Solar Program", Sandia National Laboratories, SAND 2003-3202P.

Colorado Plateau overlapped into the southern Rocky Mountains and Río Grande Rift, within four mountains: Blanca Peak to the east, Mount Taylor to the south, San Francisco Peak to the west, and Mount Hesperus to the north.

Figure 1. Map of the Navajo Nation

DATA ACQUISITION SYSTEMS UP CLOSE

DAS units are real-time sensor monitor data logging instruments for stand-alone PV powered systems. Staff from the Southwest Technology Development Institute – New Mexico State University (SWTDI-NMSU) have designed and installed DAS units in the Kayenta district of the Navajo Nation. The units record daily power load, PV current, battery voltage, battery current, and module temperature (see Appendix for specifications). All of this information is stored in a non-volatile flash memory that records up to 250 days of hourly data. Data is retrieved from the DAS units biannually by Navajo Tribal Utility Authority (NTUA) electricians via a laptop using DAS Monitor 2.0 software through the RS-232 port (see Figure 2 for the setup).

Figure 2. Laptop – DAS Setup

Locations for DAS units were selected based on the level of usage; systems that have been subject to over-usage receive DAS units. Those selected include eight 660W PV units and one 880W hybrid wind/PV unit. It is the responsibility of the NTUA electricians to provide feedback to customers regarding their usage based on DAS information. DAS units serve a crucial purpose: they are the main source of feedback for NTUA PV customers who are not properly utilizing their systems. Electricians are constantly reporting to customers that their electrical load is too high and their energy consumption must be modified to prolong the lifetime of the PV system. The batteries are the main components of concern due to issues with discharging; that is, batteries are being drained of charge more quickly than they are being replenished to full capacity.[4] This action decreases battery life significantly.

DAS analyses have the ability to show trends in the systems and serve as the main source of information for the next generation system. Some examples of witnessed trends are understanding why some batteries reach end-of-life more rapidly than others and determining PV module energy production, which is beneficial for choosing modules.[5] Results obtained regarding load management are useful for designing future PV Hybrid systems and modifying existing systems.[6] Finally, the DAS serves as a maintenance tool when customers request assistance for their failing systems. Often times, it is not a component failure, but an over-usage issue that can be identified by the electricians reviewing DAS output. SWTDI-NMSU has generated two reports thus far containing DAS analyses.

ISSUES WITH REMOTE PHOTOVOLTAIC SYSTEMS

Many of the installations are in remote locations and are significant distances from each other, several in mountainous terrain and on dirt roads making traveling to the sites difficult. Families are spread far apart to support their livestock in high desert zones.[7] This scenario provides a viable technical option for rural electrification using PV systems; existing power infrastructures do not reach these locations thus making PV more affordable than extending the grid (approximately $27,000 per mile). Importantly, it supports choices made by customers to live remotely. The bi-annual trips taken by two NTUA electricians necessitate approximately one

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[4] Benjamin Mar, "Navajo Tribal Utility Authority: Photovoltaic Hybrid Operation and Maintenance Process For a Sustainable Program," Oct. 2004.

[5] PV Hybrid System First Performance and Data Report, Southwest Technology Development Institute, September, 2000.

[6] Luis F. Alegria, University of Massachusetts, "Remote Monitoring System Design and Results from a Typical Rural PV Solar Home System," 2002.

[7] Jennifer J. Coots, "A Decade of Changes to an Alternative Power Source for a Rural Utility", October. 2004.

month of labor to maintain the systems, download DAS and travel to the nine locations.[8] For example, the distance from Kayenta, Arizona to Chilchinbeto, Arizona, is 28 miles and required 3 hours to maintain two systems. In addition to bi-annual maintenance visits, NTUA will receive approximately 15 calls per month from PV customers alone; most calls due to failures from over-usage. Often, when electricians arrive to repair the system, customers will turn off their electrical loads because they are aware that they are over-using their system. Customers' reported usage often contradicts usage patterns generated from the DAS systems.[9]

Due to limited resources and other responsibilities, there are months when the electricians are unable to download DAS information, hence information is lost and reduces analyses conducted on the system (see Appendix for a list of electrician responsibilities). There are currently no electricians assigned exclusively to the solar work. The installed DAS units can store up to 250 days of information; beyond this length of time the data is overwritten. When the systems are not checked for extended periods of time (close to 250 days), the download of data takes more time For example, it took more than 20 minutes to download data from a site that was left for more than 250 days.

REMOTE MONITORING SYSTEMS POTENTIAL

The number of DAS units will grow in the near future from nine to twenty-four according to NTUA's plans to add DAS units to fifteen of the 880 PV Hybrid Systems. A more robust sustainable energy system could be created by remotely monitoring the PV systems in real-time. The following is a list of the benefits of such a system:

- Minimize the number of trips taken by electricians to maintain systems that are failing

[8] Vircynthia Charley, NTUA electrician journeyman, Personal Interview, June 2005.
[9] Melissa Parrish, NTUA electrician apprentice, personal interview, June 2005.

due to over usage.

- Address problems with systems before failures.
- Allow more time for electricians to attend to other responsibilities.
- Decrease operation and maintenance costs Generate monthly load information for customers. (Customers want to know more about their systems and how to properly use them; they pay $95/month for the operation and maintenance of their systems. Customers are amazed with the information available from DAS units.[10])
- Allow more in-depth analyses to be conducted on the systems because data will always be collected.

Currently, systems are typically serviced after they are failing. A remote system for monitoring could serve a dual purpose--it would allow the NTUA to improve customer service and cut costs, and it would support industry life-cycle information by generating performance curves. There is potential to generate monthly energy bills for customers. These bills could include daily energy usage, daily peak power, daily peak module temperature, daily peak irradiance and monthly totals similar to grid-tied customers' energy bills. This information would increase much needed customer awareness of their systems; the customers would be able to determine exact time periods during which loads must be reduced. A program could be developed that would alert NTUA when systems are being overloaded, thus creating a more proactive (rather than reactive) operations and maintenance process. Some customers have generators readily available that are capable of recharging batteries. Customers could be notified immediately to recharge their batteries or disconnect loads to recharge batteries upon discovery. Warnings could be included in their bills and subsequent charges could be made if over-use

[10] Melissa Parrish, NTUA electrician apprentice, Personal Interview, June 2005.

patterns are not modified.

IMPLEMENTING A REMOTE MONITORING SYSTEM

DAS units are accessible by telephone modem, allowing complete data collection from off-site locations via radio, satellite, or cellular communications. Two systems of remote monitoring were analyzed in detail: satellite and radio. Cellular communications were considered; however, there are currently too many DAS locations that are not serviceable by this means. The following is a list of desired features for the remote monitoring systems:

- Feasibility
- System compatibility with existing DAS and future DAS installations
- Serviceability for remote locations
- Cost effectiveness
- Robust configuration for future growth of DAS installations and PV systems.

Radio Communications as a Remote Monitoring System

As a rural utility, the NTUA currently utilizes a 900MHz supervisory control and data acquisition (SCADA) system that monitors their electrical substations, water tank levels and eventually natural gas levels. There is potential to add PV systems to the existing SCADA system by connecting a modem and a radio antenna to the current DAS configuration via the RS-232 port (see Figure 3). There is a 1A power requirement for data transmission. SCADA has the capacity to reach a 15 mile radius within line of site of the SCADA antenna; it incorporates a Point to Multi Point System (MAS), at a Baud rate of 1200 and utilizes 8979 protocol. DAS units generate ASCII files that can be converted to 8979 protocol for transmission purposes. SCADA towers are located in the following areas on the Navajo Nation: Black Mesa, Preston Mesa, Pinon (repeater), Earpoint, Roof Butte, Na-ah-tee Mesa, Navajo Mountain, Piney Hill, and Dezza Bluff. See Table 1 for costs associated with radio Transmission.

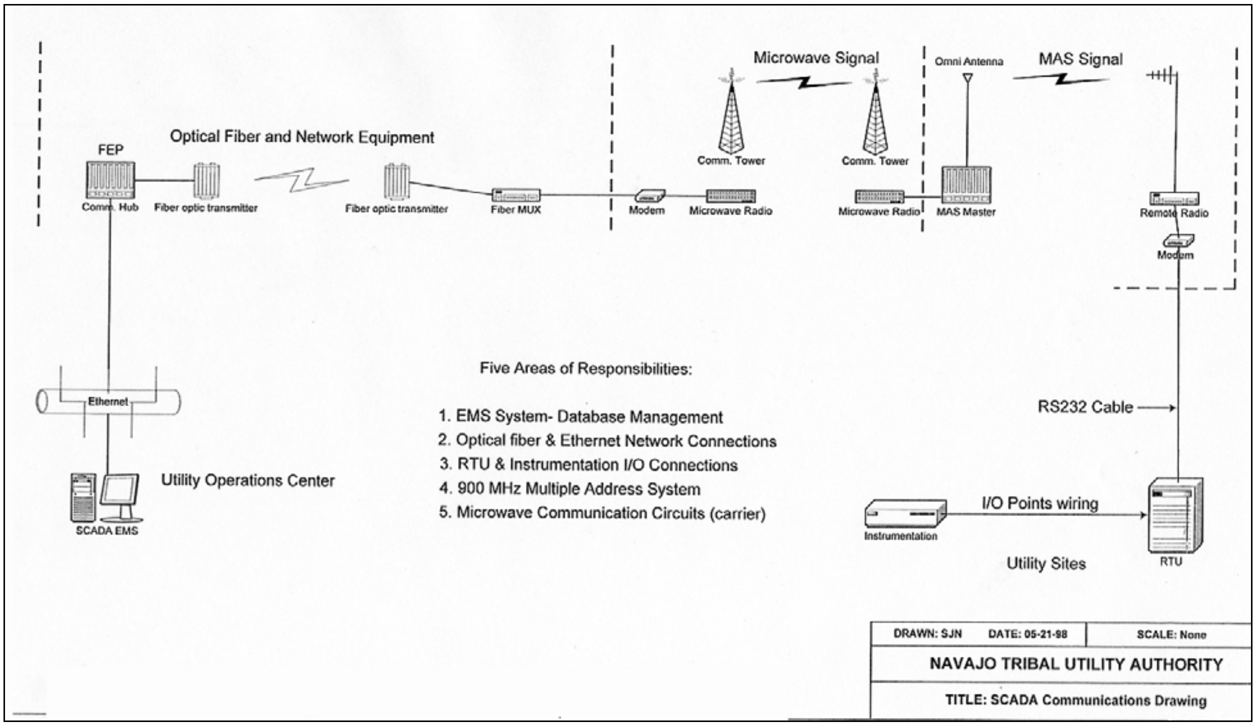

Figure 3. Radio Communications Section

RADIO TRANSMISSION			
Item Description	**Description**	**Unit Price**	**Cost**
Modem & Antennae Configuration	10 units	$ 1,500.00	$ 15,000.00

Table 1. Radio Transmission

There are some limitations to implementing this design. If the sites are not within a 15 mile radius of one of the towers or repeaters, a more expensive and less desirable course of action would need to be pursued. A $10,000 repeater tower must be installed in order to transmit the information. The NTUA communications department is currently mapping out existing and future DAS locations to determine serviceability. One consideration might include incorporating communications solely for systems that are serviceable and do not require this additional hardware.

Satellite Communication as a Remote Monitoring System

Bouncing signals off a satellite is a reliable system of communications that has been widely used for remote installations, especially in locations where no other reliable RF or telephone coverage is available, see Figure 4 for the general setup. Satellite communication is also recommended when infrastructure cost (such as the need to use repeaters for a non-satellite system) is an issue. Currently ONSAT's Digital Equity Network® has satellite towers in all 110 Chapters (community centers) on the Navajo Nation, see Figure 5 for locations.

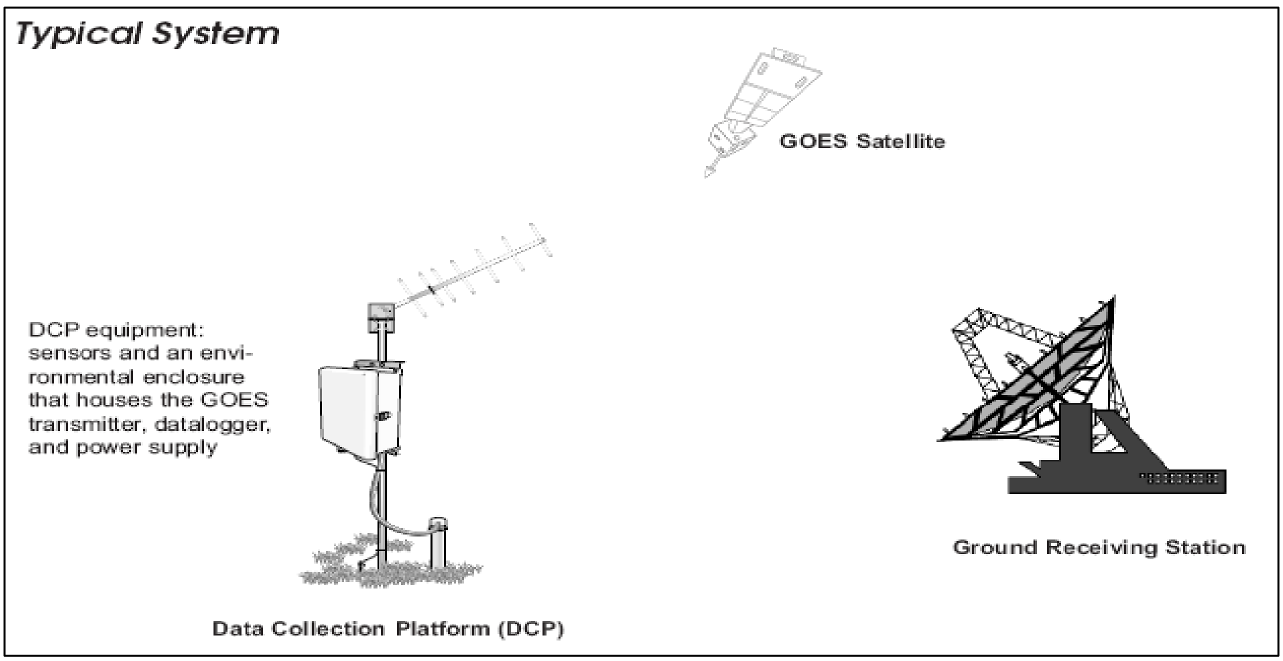

Figure 4. Typical Setup for satellite communications

The Digital Equity Network® is a private, wireless network that connects customers to high-speed internet.[11] In 1998 the Bill and Melinda Gates Foundation gave approximately $6 million to the Navajo Nation to set up a computer network that would link the central government to all of the chapter houses.[12] Today each chapter has between three and 14 computers available to the public. Onsat is a global company that assists developing countries set up computer networks in rural areas. ONSAT uses Ku and C-band satellite systems.

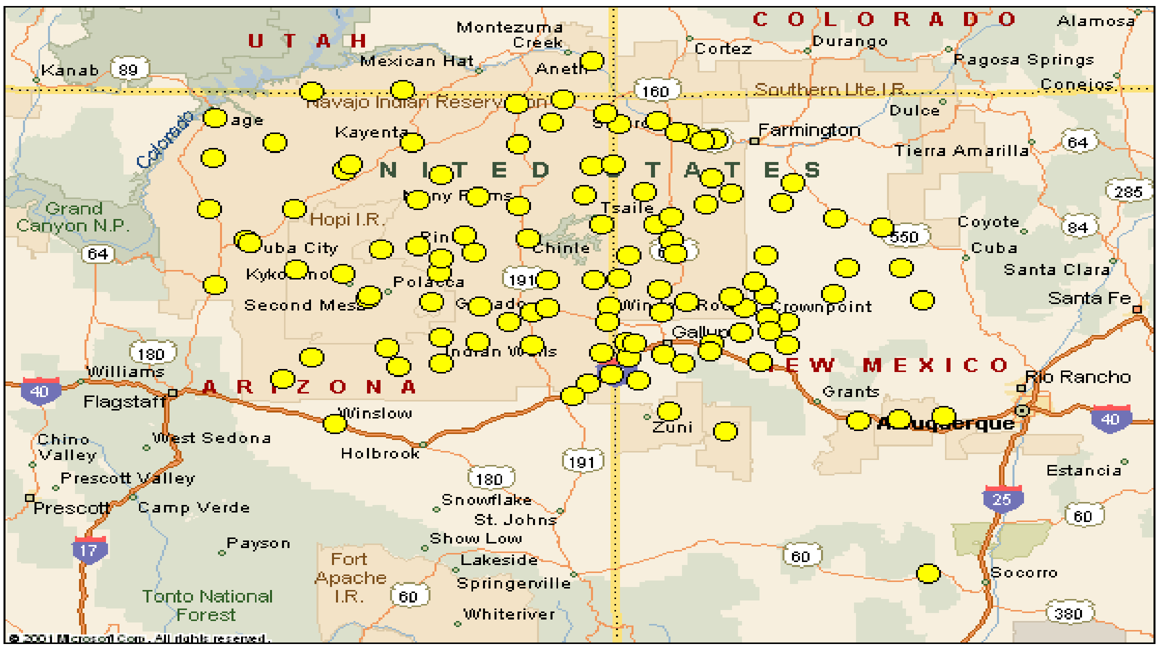

Figure 5. Onsat Satellite Locations

There is potential to utilize existing satellite installations for transmitting DAS information to a central location at a reduced price. In order to be able to connect to the chapter house satellites, the DAS systems require a transmitting antenna; they must be within 10 miles of the chapter house and within line of site. If it is not within line of site, it must be within 2 miles of the chapter house. A modem and antenna would be required to be connected to the DAS in both of these instances. If it is not within 2 miles of line of site, a satellite must be installed on

[11] Navajo Times, "Computers Connect grassroots Dine to Internet age," [Internet], http://nnden.org/cms/kunde/rts/nndenorg/docs/447326249-03-03-2005-15-54-54.pdf, February 2005.
[12] Navajo Times, "Computers connect grassroots Dine to Internet age", February, 2005.

site. The cost per year for satellite services is $100; see Table 2 for costs for hardware requirements that are a one time cost.

Device	**Cost/unit ($)**
Satellite transmitter system	$ 500.00
*Satellite	$ 3,000.00

Table 2. Hardware requirements for satellite communications

*Satellite will not be required for systems within 10 miles of a chapter house

There are additional opportunities associated with installing satellite communications for PV purposes. ONSAT's Digital Equity Network® can connect customers to a wireless-broadband network which could include Voice over Internet Protocol (VOIP). The requirement for these services is that antennas must be installed at individual homes, which would already be fulfilled for the PV systems. It would eliminate future installations of more expensive land-based internet services and connect customers without cables. In addition, it is not limited to specific areas like land-based communication infrastructure. Individuals who have never had internet access would then have a choice in whether or not to connect. Satellite broadcasting is considered one of the safest means of transmitting data and for internet purposes. Furthermore, it would allow wireless connectivity for laptop computers. PV customers would then have the option to become connected to the internet.

This satellite service would only be available for customers who have computers, and the computers would have to be powered by the solar electric systems, requiring approximately 70-watts. The option for internet and phone services would be made available through the satellite system connected to the DAS. NTUA could attract new customers for this reason alone. There is even potential to spur economic development by bringing internet and phone services to these remote areas. This application of satellite services for broadband would not happen immediately, but is to be considered as a potential resource for the future.

UPGRADING STORAGE & DOWNLOADING SYSTEMS

NTUA has indicated interest in installing 15 new DAS units on some 880-watt hybrid units. Because this is an extensive number, an alternative manufacturer was explored for the DAS. A reputable DAS for PV applications is Campbell Scientific, Inc. CR10X. This datalogger was selected because it is comparable to the SWTDI DAS that is presently installed (see Appendix for the data spec sheet). The CR10X is specified to operate up to 50^{o}C (122^{o}F), whereas the SWTDI DAS is specified to operate up to 70^{o}C (158^{o}F). Even though outside temperatures do not reach this high, the systems are installed in a small enclosed area that exceeds outside temperature given that the boxes contain additional electronics (see Figure 6). The Campbell dataloggers can be tested to ensure operation of up to 80^{o}C. See Table 3 for cost information).

Figure 6. Inside the NTUA PV System Box

DAS				
Item Description	**Parts list**	**Qty**	**Unit Price**	**Cost**
Campbell Datalogger	CR10X	15	$ 1,221.00	$ 17,032.95
Temperature testing		15	$ 125.00	$ 1,875.00
TOTAL				$ 18,907.95

Table 3. Costs for 15 Campbell Datalogger units

* There is a 7% discount for 10 or more DAS systems.

POCKET PCs FOR DATA RETRIEVAL

Laptop computers are currently being utilized to retrieve DAS information. Because a remote monitoring system will not be implemented immediately, alternative data storage/retrieval devices were investigated for the interim as a substitute to the laptop. More specifically, Pocket PCs or Palm Pilots were found to be a more economical device compared to the laptop. The following is a list of criteria that assisted in selecting a Pocket PC:

- Compatibility

- Reputable device
- Minimum 206MHz processor
- Minimum of 16MB of storage
- Recharcheable battery
- Auto adapter battery charger available
- Option for storage expansion
- Cost effectiveness
- Availability

A list of Pocket PCs were selected based on this criteria, see Table 4 for the key specifications for Pocket PCs that were investigated. An expensive Pocket PC is not necessary for this particular application; the more costly Pocket PC includes features such as wireless communications, 4GB hard drive, and Bluetooth technologies that are not imperative. The HP Compaq iPAQ 3765, iPAQ hx2110, iPAQ hx2110 and Palm Tungsten T-5 have been tested by Campbell Scientific for compatibility with the CR10X datalogger and were deemed compatible. Even though the iPAQ hx2400 was not tested by Campbell, it has a serial port that allows connectivity to the DAS. One desirable feature for the Pocket PCs is a relatively fast processor and a sufficiently large hard drive. This is because of the size of the files that are being downloaded. In a previous example, it took 20 minutes to download a 500k file with a laptop that has an 866MHz processor and a 64MB hard drive. Although this was an unusual example where data was not being collected bi-annually, it provides a general idea of how long the process can take. The iPAQ 3765 has a 206MHz processor and HP stopped making them.

Preferred devices are the Palm Tungsten T-5 and the HP iPAQ hx2400; they both have adequate processors, sufficient storage, and quality batteries. The HP iPAQ hx4705 has all of these features, but it is more costly due to a larger battery, wireless communications, and a slightly faster processor. The **HP iPAQ hx2400** appears to be the better option compared to the T-5 for a reasonable data retrieval solution for PV applications. For $30 more, it has a 520MHz processor compared to 416MHz, has an added safety feature that allows secure storage in case of a power loss, and has a 1440mAh Lithium Ion battery compared to a 1050mAh battery.

Features	**iPAQ 3765**	**Palm Tungsten T-5**	**iPAQ hx4705**	**iPAQ hx2110**	***HP iPAQ hx2400**
Cost	$150.00	$349.99	$554.95	$349.00	$379.00
Model Year	2001	2005	2005	2005	2005
Processor	206MHz Intel StrongARM	416MHz Intel XSCALE	624 MHz Intel Bulverde	312 MHz Intel® PXA270	520 MHz Intel® PXA270
Size	64 MB RAM, 32 MB ROM	256MB (160 flash 55MB ROM)	192MB (128 ROM 64 SDRAM)	128 MB (64 MB ROM and 64 MB SDRAM); (includes 20 MB iPAQ File Store)	128 MB total memory; 20MB iPAQ File Store (includes 20 MB iPAQ File Store)
Battery type	650mAh lithium-polymer	1050 Lithium Ion	1800mAh Lithium-Ion	920 mAh lithium-Ion	1440 mAh lithium-Ion battery
Serial	Yes	Yes	Yes	Yes	Yes
USB	Yes	Yes	Yes	Yes	Yes
IR	Yes	No	No	Yes	Yes
Wireless	No	No	Yes	No	Yes
Bluetooth	No	yes	Yes	Yes	Yes
Software	Microsoft Windows CE	Palm OS® 5.4	Microsoft Windows Mobile™ 2003 Second Edition Software	Microsoft Windows Mobile™ 2003 Second Edition Software	Microsoft Windows Mobile™ 2003 Second Edition Software
Warranty	1 year	1 year	1 year	1 year	1 year
Expansion	Optional Compaq expansion pack	SD, SDIO, MMC	SD slot	Integrated Compact Flash Type II (CF) and SD slots	Integrated Compact Flash Type II (CF) and SD slots
Additional Features		4G hard drive		HP ProtectTools	HP ProtectTools

Table 4. Palm Pilot Comparison

NEXT STEPS FOR REMOTE MONITORING SYSTEM IMPLEMENTATION

Based on information gathered thus far, satellite communications is the optimal solution for NTUA's PV applications. Both infrastructures require line of site, radio within 15 miles, and satellite within 10 miles. Given the installed communications structures for satellite, there are

110 satellite receivers compared to less than 10 radio towers; thus increasing probabilities and quality of communication. Satellite is more affordable than to add a transmission system, costing $500 compared to $1500 for radio. If the sites are not within line of site, it would cost $3000 to install a satellite receiver, and $10,000 for a new radio tower. The satellite infrastructure provides an opportunity for future internet and VOIP services.

There is still research left to be done in order to implement such a project. The option for SCADA communications is still being pursued for security reasons. It would be beneficial to follow through with at least the beginning stages for this type of infrastructure in case satellite is deemed unfeasible. Permission must first be granted from the NTUA SCADA division to utilize their system for PV applications. They are currently conducting a serviceability study to determine whether or not sites will be serviceable. GPS maps have been provided for more than half of the locations; the locations of the remaining sites are still in process of being mapped.

For a satellite communications infrastructure to move forward, ONSAT will also have to conduct a serviceability analysis. The first installations should include sites that are closest to chapter houses that do not require an additional satellite. Customer reliability should be considered when selecting these first sites because it is an expensive upgrade. The purpose of this communications infrastructure is to not only transmit DAS information, but also bring potential internet and VOIP services that are costly and require a computer.

Four Pocket PCs are recommended to replace the laptop; it would be advantageous to have multiple Pocket PCs for backup purposes and in order to have a reliable system in place, redundancy is essential. The Campbell dataloggers will satisfy the impending demand. The satellite transmitter is connected to the DAS through a modem that is powered by a battery. The battery would be charged by a separate solar panel with its own regulator. A 20W photovoltaic power supply would suffice thus providing an independent power system from the customer's PV or PV Hybrid unit (see Appendix for Campbell MSX-20 20W panel specifications). Separate power available solely for communications is a cleaner solution and it may be necessary depending on the power requirements for communications. Another option for powering the communications is to charge the battery from the customer's PV or Solar Hybrid System; this option depends on how the communications are configured. Power requirements for the system can be minimized through transmission scheduling; for example, transmission could occur once daily.

A configuration has not yet been determined; however, the preferred setup would include a distinct power system for communications, which may prove to be advantageous in the long run as systems develop and broadband services become an option. A variety of configurations can be tested to determine the optimal setup.

In order to create a dependable system for the future, NTUA should consider assigning a position dedicated solely to PV. Expertise is readily available within NTUA to fill this role. Responsibilities might include developing a customer's usage bill, developing a program that flags over-usage patterns, conducting data analyses regularly, maintaining communications, and organizing PV trainings for electricians. It is evident from the history of PV within the NTUA that the systems requested will continue to grow in demand. In a ten-year span, systems have matured from 240W to 880W hybrid small wind systems with more than 350 installations.[13] The potential for internet access may make the PV systems more attractive to customers.

A satellite communications system for remote monitoring would be a viable option to support existing DAS installations and would prove to be a robust system for the growth that is

[13] Benjamin Mar, "Navajo Tribal Utility Authority: Photovoltaic Hybrid Operation and Maintenance Process For a Sustainable Program," Oct. 2004.

projected to occur in the near future. This type of system would not only minimize long-term maintenance costs of the PV systems, but end up providing multiple resources for customers that could include monthly billing information and potential internet services. Steps have been outlined for implementing such a project, along with some recommendations for customer selection. Further research must be conducted to design the final configuration.

MY EXPERIENCES

I am currently a graduate student pursuing a degree in Energy Engineering with a solar option. I have obtained a Bachelors of Science degree in Electrical Engineering. This particular project has given me the opportunity to become more familiar with communications infrastructures and how they can be tied to remote PV applications. It provided an interesting research topic because of its cutting edge nature. I had the opportunity to visit numerous PV sites within the Navajo, Hualapai, Hopi, and Cahuilla Nation. This has provided me with more exposure to PV systems in action for a multitude of applications and become more familiar with the PV hardware and a variety of mounting structures. I have learned that it takes time and serious effort to adjusting to a PV system as a user. There are limitations that must be better understood by the user and there are many ways to address this. The purpose of the DASs became clearer to me and how they could serve as a better tool for the users. Spending time with electricians that service the PV systems was also beneficial. Their expertise exposed me to issues with remote PV and working with limited resources.

I also participated in an energy audit for a remote home owner. This provided me with a real life opportunity to put into practice what I have learned in class with matching loads to PV systems. I can better identify energy losses and provide some solutions to decrease these losses. It was a modern home with a 3kW PV system; this experience reiterated the fact that no matter how large the system, the users still have to be conscientious of their energy consumption patterns.

A “Women in PV Workshop” provided me the opportunity to work with women to install a 1kW system for a high performance school in Florida. This was my second installation and my first pole mount installation. It provided a unique learning environment and proved to enhance my technical skills. The installation was concluded with a ceremony organized by the school which further displayed their support for the system. It is important to have a level of support in order for a sustainable project to be successful.

Not only did I increase my technical capacity for PV, but I have witnessed some facets of Tribal and federal government relations from the government side. It is important to continue to build and maintain good relationships between the federal government and Tribal Nations while remaining aware of cultural values. Tribal Nations do have unique cultures that must be considered for any government project and it increases the success of the project when that awareness is there. I have previously worked within the government on Tribal projects and have come to better understand this important aspect.

My goals include continuing to work on Tribal Nation renewable energy projects as I increase my capacity. This internship has exposed me to numerous Tribal renewable energy projects in action and has contributed to increasing my aptitude in many aspects. I attended a conference for Tribal Nations that have fossil fuels as energy resources. This conference was attended by many Tribal Officials; it raised my awareness to the direction in which they will be going in terms of energy production. I hope to continue to attend these types of conferences and bring the knowledge that I have obtained back to my Tribal Nation.