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# Navajo Tribal Utility Authority: Photovoltaic Hybrid Operation and Maintenance Process For a Sustainable Program

**Benjamin Mar**
Worcester Polytechnic Institute
Paul S. Veers, Manager (Org. 06214) Sandra Begay-Campbell, Technical Advisor
Sandia National Laboratories[1]
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## Abstract

The Navajo Tribal Utility Authority (NTUA) is a non-profit organization that provides electricity to the Navajo Nation. NTUA generates electricity for off-grid residents by providing solar and wind power stand-alone systems. Although NTUA has installed and maintained photovoltaic installation for over ten years, there has not been a congruent operation and maintenance (O&M) process throughout the five Navajo districts. This project will analyze and modify what currently exists and is built upon an O&M process that former Department of Energy (DOE) student interns (K. Candelaria, V. Sandoval, and S. Tsabetsaye) produced for NTUA along with a previous student report.[2] A break down of each step in the process of what needs to be accomplished and who needs to carry out the procedure will be described. NTUA electricians and managers along with Sandia National Laboratories' technical staff helped to capture the system model of the system maintenances and troubleshooting processes that NTUA performs in the field as well as in the office. Modifications to the O&M process should

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

result in a more efficient process for NTUA as well as a guide to determine what next steps should be taken. The deliverables will be two flowcharts and a document on the processes.

## Introduction

Imagine living, with no neighbors, 40 miles from the nearest paved highway in a mountainous region, with only kerosene lamps and flashlights to navigate through the darkness of night. This is how some Navajos live everyday life. Many homes on the Navajo Nation are so remote that extending the electrical grid lines would not be cost effective. Navajo Tribal Utility Authority (NTUA) is a non-profit tribal rural utility that serves as a co-operative to provide electricity to the Navajo Nation. NTUA is composed of five main districts with two sub-districts.

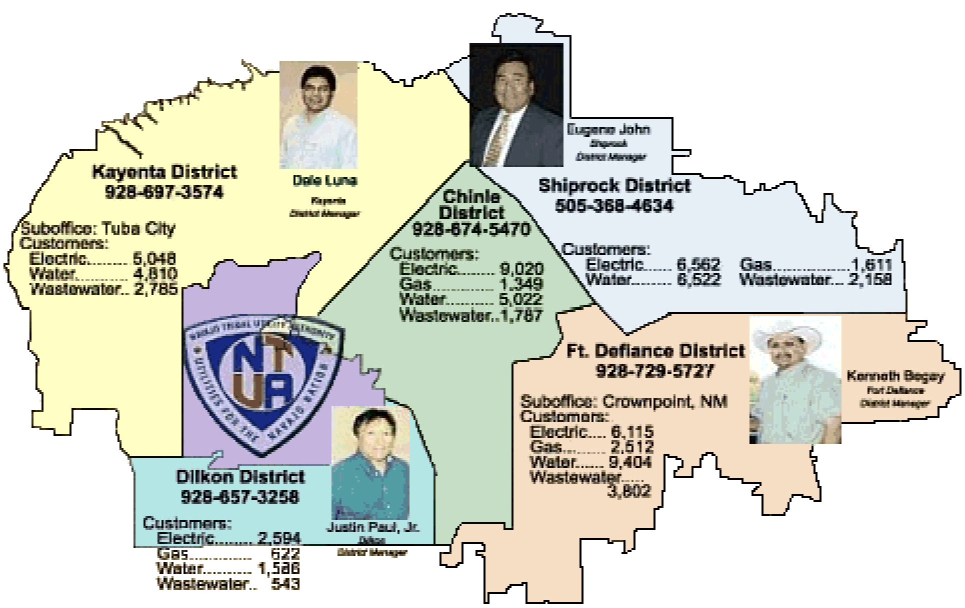


**Figure 1: NTUA District Map[3]**

NTUA estimates that 18,000 out of 48,000 homes within the Navajo Nation are without electricity[4]. In order to reach houses in remote locations, NTUA started a pilot

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[3] www.ntua.com, NTUA website

project in 1993 with 40 photovoltaic (PV) systems and it evolved into the Navajo Electrification Solar Project. PV technologies are sustainable sources of clean energy but the systems have to be maintained over time in order to efficiently produce electricity. Over the years, separate NTUA districts developed their own operation and maintenance (O&M) processes to keep the PV systems operating efficiently. This paper focuses on how NTUA's O&M processes have undergone changes in order to better serve its customers and what the O&M processes look like today.

## Evolution of NTUA's Photovoltaic Stand-alone System

NTUA's PV program has developed into four generational installments: 240/260-Watt systems, 640 Watt systems, and two 880 Watt systems (Phase I and Phase II). The pilot project that involved the 240/260 Watt systems provided the customers with direct current (DC) lighting and a single alternating current (AC) outlet to use small appliances like a radio. With the 640 Watt systems, the total available power increased significantly from the 240/260 Watt systems. The 640 Watt systems supply customers with AC power, which allows the 640 Watt unit to power many households appliances. Before designing the next generation of PV systems, NTUA assessed, with assistance from Sandia National Laboratories (Sandia) and New Mexico State University – Southwest Technology Development Institute (NMSU-SWTDI), how the current 640 Watt systems were performing and found

**Figure 2: 240 Watt Unit**

[4] Navajo Tribal Utility Authority, *Navajo Electrification Demonstration Program Navajo Electrification Solar Project*, Navajo Nation, Technical Progress Report April 21, 2004

that the batteries in the PV systems were the components that needed to be replaced most often due to the batteries being drained of charge and not receiving adequate charge to replenish the capacity. NTUA considered two options of combining the PV system with a propane generator or a small wind turbine to create a hybrid system. NTUA, who has a Memorandum of Understanding (MOU) with the U.S. Department of Energy and Sandia to help provide technological support, asked Sandia to draft specifications for the two options. The deciding factors in the choice between a propane generator and a small wind turbine were 1) that the wind turbine produced clean energy (with no pollution like the generator produces), 2) the wind turbine requires little maintenance while the generator requires routine maintenance and, 3) the wind turbine does not require an additional fuel source to run. With this information, the third system installment NTUA procured was the 880 Watt PV/wind hybrid systems with a few PV/propane generator hybrid systems (Phase I). This hybrid system helps provide more charge to the batteries as the small wind turbine serves as an

**Figure 3: 640 Watt Unit**

**Figure 4: 880 Watt Phase I Unit**

auxiliary power source to the PV array. PV technology's power production is limited by how much sunlight an array receives; so at night or on a cloudy day, a PV system cannot produce any electricity. The small wind turbine's power production depends on the wind, so the hybrid system can generate electricity during the night hours if there is enough wind. The fourth and most recent generational system is another 880 Watt PV/wind hybrid (Phase II), and the procurement implements changes from the third generation such as placing the inverter box vents behind the mounting panel to help prevent buildup of sand. A summary of NTUA's PV program is shown in Table 1. For a more extensive history on the generational installments of NTUA's PV program, refer to "A Decade of Changes to an Alternative Power Source for a Rural Utility" written by Sandia intern Jennifer J. Coots.

| | Financing | Customer Price / Month | Array Output | Total Kilowatt-hour / Day | # of Units | Manufacturer (Integrator) | NTUA Champion |
|---|---|---|---|---|---|---|---|
| **1993** | DOE - WAPA | $40 | 240 Watt<br>260 Watt | 1.3 kWhr/day | 40 | Solar Mart | Jimmie Daniels |
| **1999-2001** | USDA - RUS | $95 | 640 Watt | 1.6 Kwhr/day | 200 | Photo Com. / Kyocera | Paul Denetclaw |
| **2002-2003** | DOE - NEDP | $75 | 880 Watt hybrid small wind (Phase I) | 2.0 Kwhr/day | 40 | SunWize (NADAC) | Larry Ahasteen |
| | | $145 | 880 Watt hybrid propane generator (Phase I) | | 4 | | |
| **2003-2004** | DOE - NEDP | $75 | 880 Watt hybrid small wind (Phase II) | 2.0 Kwhr/day | 63 | SunWize (Ducommon Tech.) | Larry Ahasteen |

**Table 1: NTUA's PV Program History**

The O&M process helped NTUA's PV program evolve into more powerful systems that could be sustained more efficiently. For example, some of the charge controllers in the 880 Watt Phase I systems started to fail in the summer. The problem was that the maximum current rating that the charge controller could operate under was too close to the PV array's rated output current. The system design did not take into consideration the cloud edging effect. The cloud edging effect is when a cloud acts like a magnifying glass allowing the PV array to produce more current that peaks above the rated value. By designing the PV system close to the current limit, the charge controllers failed when the current supplied by the PV array peaked. With this information, the 880 Watt Phase II unit was designed with a charge controller that could function under peaking conditions.

The development of NTUA's PV program highly depends on designing PV hybrid systems with compatible components, but it also has a financial aspect. When looking at the 640 Watt units, the monthly payment was broken down into four areas: interest, principal cost of the equipment, installation costs, and O&M costs. The breakdown of the $95 monthly charge estimated $12 towards O&M per payment, which was determined from past O&M cost data.[5] When the 880 Watt systems became a reality for NTUA to install for customers, NTUA researched its past records to determine the cost of O&M from the 640 Watt systems. The data concluded that the O&M cost would be covered with a monthly $75. This piece of information helped decide the tariff rate for the 880 Watt unit; however, it brought up an issue with the 640 Watt unit as the O&M cost was not being met. The customer cost difference between the 640 Watt and the 880 Watt units is that the 640 Watt unit is a lease-to-purchase contract while the 880 Watt tariff covers O&M costs. Since customers signed a lease-to-purchase contract, NTUA cannot simply increase the monthly payment to reflect the costs of O&M. By knowing that the cost of O&M is not being covered for the 640 Watt systems, NTUA is now looking into options on how to support the O&M process for these systems.

[5] Interview with Larry Ahasteen, 7/8/2004

## Customer Education

Customer education is critical for PV system sustainability. The customer must realize that electricity produced from the PV system is limited. Unlike a grid-tied system that has no restriction in amount of electricity used, the customer has to monitor how long appliances are used and what kind of appliances are used; in other words, balance their electrical loads. The NTUA customer service representatives help customers understand basic concepts of how to use a PV system and if the system can meet their electrical needs. NTUA along with Sandia created a short video, "Power from the Sun," for customers to view about the PV systems NTUA has to offer. "Power from the Sun" was

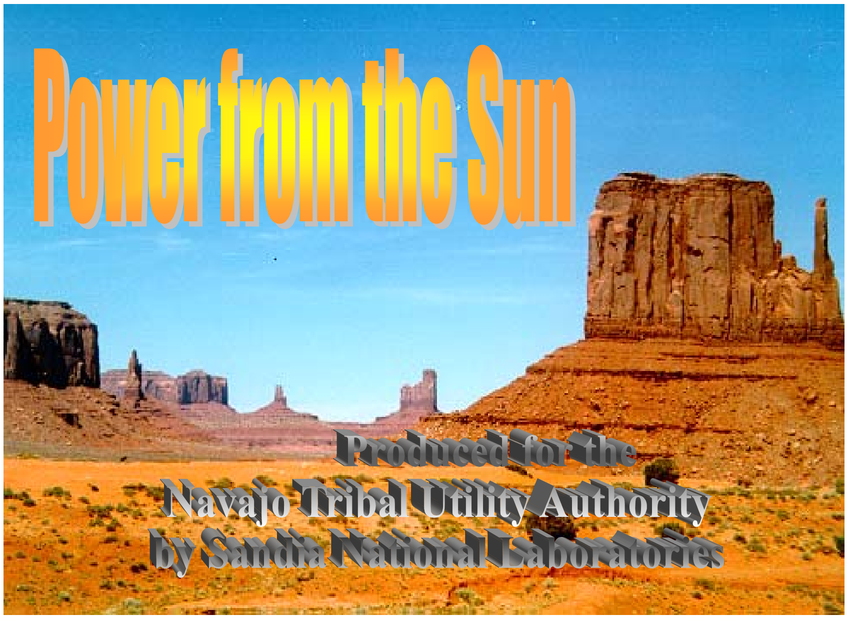


**Figure 5: Clip From "Power from the Sun"**

produced in English and Navajo. The video was made available in the Navajo language to allow NTUA to show the benefits of PV systems to customers in their native language. The mission of the video was to help customers make an informed decision on whether or not a PV or hybrid system was the correct choice for them.[6] "Power from the Sun"

[6] Interview with Connie Brooks, 7/19/04

covered the basic information on how a PV system works; as well as, what the PV system's power could and could not support. It also provided examples of how a PV system could benefit a family, such as lights so children can work on homework in the evening.

To reaffirm the customers' education on how to use their PV systems, the NTUA electricians review a list of acceptable appliances and perform a load analysis with the customer. For the load analysis, the electricians ask the customers what appliances they will be using and how many hours a day each appliance will be used. From the load calculations, the electricians can advise the customers as to whether their anticipated loads will be compatible with the electricity produced from the PV unit or if the customers need to modify which appliances to use and how long to use the appliances.

After the installation of the unit, the electricians give the customer some additional information.[7] The first handout is a customer checklist information sheet, which describes and illustrates the battery capacity meter (BCM), the inverter remote switch, and the load center. These three controls are the only interface that the customers can access. The electricians teach the customers how to interpret the BCM to see if the battery charge is at a good level to use appliances or if the battery charge is too

**Figure 6: NTUA electrician, Vircynthia Charley Teaching Customers**

[7] See Appendix 1-5 for documents

low and needs to recharge. The electricians then explain that the inverter remote switch and the load center allow the customer to switch the power on and off.

The second handout lists appliances that are acceptable to use and what should not be used. The third handout is a customer outage report. The electricians show the customers how to fill out the form in case a power outage occurs. The customer outage report was developed by NTUA's Kayenta district to help the electricians determine the cause of the power outage. With the outage reports, NTUA will be able to record how many PV systems fail throughout the year by entering the data into a power outage database. This will allow NTUA to track any trends within the different systems and across the five districts. Although the power outages are not currently entered into this database, it should become a standard in the near future.

After finishing with the handouts, the electricians remind the customers to keep PV modules from being shaded. Just a little bit of shade can severely lower the modules' power production since each PV cell is connected in series. If a single cell is shaded, the module can produce very little electricity because the shaded cell acts as if the cell is not connected to the rest of the cells, thus breaking the path for the electricity to flow through. The electricians also inform the customer to keep animals and people away from the systems. They suggest building a fence, which does not shade the unit, around the PV unit to protect equipment and deter damage due to vandalism.

## System Maintenance: Bi-Annual PV System Maintenance Process

NTUA determined that providing bi-annual maintenance on the systems would best serve the needs of the customers and the equipment.[8] When it is time for a

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[8] See Appendix 6 for Bi-Annual PV System Maintenance Flowchart

maintenance check-up, the district planner creates a work order and sends notifications out to the electricians and to the customers. The electricians set up a time with the customers to visit their residences and perform the maintenance. At the time of the maintenance, the electricians perform a hands-off (visual) system inspection. During this inspection, the electricians look for vandalism of any of the components, any shading of the PV modules, and observe the connections.

If electricians find a system that has been vandalized, they take pictures of the components that have damage for documentation and then interview the customers about the damaged equipment. The electricians write a report of the damaged components and the circumstances, which it is then sent to the district office. With the vandalism information, the district planner determines the cost of the repairs and writes a letter to the customers telling them about the vandalism and sends a bill to cover the cost of damages. If the customers do not pay the vandalism bill or if the customers are behind on payments, NTUA sends out electricians to repossess the unit.[9]

When vandalism occurs, it can be due to a power outage. Customers try to open the inverter box, which is locked with a unique key, to see if they can get the unit operational without the help of NTUA's electricians.[10] On rare occasions, PV modules are shot or hit with a heavy object. Vandalism did not

**Figure 7: Vandalized NTUA PV Module**

[9] Interview with Melissa Parrish, 7/8/2004
[10] Interview with Vircynthia Charley 6/25/2004

become a noticeable occurrence until 2001. In order to prevent future damage, separate NTUA districts set up their own vandalism policy and education for the customers. Customers are told to report any vandalism as soon as they are aware of it so that a report can be filed and the PV system can be repaired quickly.

After performing the hands-off inspection, the electricians talk with the customer about how the system has been performing since the last visit. The electricians help the customers fill out a checklist and a survey on how much the customers have been using each appliance, what appliances have been used, what the battery charge meter level has been, and if there have been any problems with running appliances. After the forms are complete, the electricians conduct the O&M procedures with specific safety precautions.

Electricity can kill if not handled properly. It is critical for people working with PV and hybrid systems to take precautions to protect themselves. NTUA's policy is for only trained NTUA electricians to service their equipment. With this policy, NTUA is responsible for the Navajo Nation's electric power supply. The customers pay O&M costs in order for the systems to be maintained and they are prevented from interacting with any of the main components of the PV system. Customers only have access to the BCM and the inverter remote switch.

It is important for the electricians to work safely around and with the PV and hybrid systems at all times. Vircynthia Charley, a journeyman electrician in NTUA's Kayenta district, created a PV safety kit designed specifically for working with the PV and hybrid systems. The PV safety kit is a toolbox that consists of an apron, face shield, baking soda, distilled water, and rubber gloves. The apron, face shield, and rubber gloves are worn to prevent any battery acid from splattering on the electrician. The baking soda is included to neutralize any acid leaks. The distilled water is used to clean the battery connection of corrosion along with using the distilled water to refill the batteries to the correct level. In addition to the PV safety kit equipment, electricians use a hard hat and low voltage level gloves that provide protection up to 600 volts.

**Figure 8: Sandia Interns Wearing Safety Equipment While Working with a PV Unit**

In addition to the components of the PV safety kit, it is important that all electricians manage their own equipment. If electricians loan their high voltage gloves to a co-worker, they must then check to see if there are any tears in the gloves. High voltage can shock through a pin-sized hole, which can be deadly if electricians fail to notice a tear or a hole. NTUA electricians are strongly encouraged to keep their equipment organized in order to know exactly where to find equipment.

For the O&M procedures, the electricians perform a system diagnostic. For the battery array, they use a hydrometer to check the voltage of each battery cell. The hydrometer measures the voltage by displaying the specific gravity of the battery's aqueous solution. After the electricians make sure that each cell is about 2.1 volts, they check the water levels and add distilled water to cells that need to be filled up to the correct level. It is vital that they use distilled water because tap water has minerals that would react with the sulfuric acid causing the battery life to be shortened. They tighten the battery caps when completing the battery service, check the wire connections to see if there is any corrosion, and then use a digital multimeter to measure the voltage across each battery and then across the battery array. They record the voltage reading into the unit's log book that resides in the inverter box and on their PV O&M data sheet.

In addition to measuring the batteries' voltage, they measure and record the battery string current. The same measurements of voltage and current are taken from the PV modules. They then check the voltage reading on the charge controller and record how many amps the customers are using. After the electricians finish with all of the data collection, they adjust the PV array to the correct seasonal setting (winter of summer tilt).

When the maintenance is complete, the electricians talk with the customers and tell them the status of the unit. If the battery array charge is low, the electricians will explain that the customers need to let the batteries charge back up. At this time, the electricians review the list of appliances that can and cannot be used, as well as perform a load analysis to see how the customer is using the electricity and make suggestions on how to reduce usage. The electricians answer any of the customers' questions and then send a notice, along with a description of the maintenance, to the district planner. The district planner takes the description and data from the maintenance and enters the data into an information database and then closes the job order.

## System Maintenance: Troubleshooting Process

The troubleshooting process starts with the customer contacting his or her customer service representative in the district office or if the electricians on a bi-annual maintenance trip find the system is not working and cannot repair it at that time.[11] When customers contact their district office, the customer service representative notifies the district planner so that the district planner can create a job order. When electricians cannot repair a system during a site visit, they will notify the district planner. With a job order open, the electricians are notified and travel to the site. At the site, the electricians interview the customers on how they have been managing their electrical loads. After collecting the information from the customers, the electricians restate the proper use of the limited supply of electricity provided by the PV and hybrid systems in order to continue the cycle of customer education.

The electricians assess the condition of the unit along with the information they received from the customers. If the electricians have the tools and the parts needed to repair the unit, they make the repairs. With the repairs complete, they record the repair report in their notes and in the log book. The electricians answer any of the customers' questions after the repair and then send a notice along with a description of the repair to the district planner. The district planner takes the description and data from the repair and enters the data into an information database while the electricians close the job order. If the electricians do not have the tools or the parts needed to repair the unit, then the electricians have to notify the district planner of what is needed to continue with repairs. The district planner can then request the replacement parts while the electricians disassemble the broken parts. When electricians get back to the district office, they ship out the broken parts to the manufacturers to determine why the part failed. As soon as the electricians receive the report and analysis of the damaged product, the electricians travel back out to the site and make the repairs to the system. With the repairs complete

[11] See Appendix 7 for Troubleshooting Flowchart

and the PV system operational, the electricians close out the work order. For the district planner's responsibilities, the district planner takes the report of the damaged product and updates the troubleshooting manual and enters the account information into their information database.

## Recommendations

These recommendations are a result from interacting with NTUA customer service representatives and electricians as well as making observations during field visits.

The first recommendation is to make sure that when the systems are initially being installed, the PV array is not shaded. A PV array with direct shading can dramatically lower the electricity generation.

Another recommendation is to have an open purchase order for distilled water. Gallons of distilled water are used in the maintenance of the battery arrays and distilled water is always needed. An open purchase order for distilled water would allow electricians to buy the distilled water for a number of O&M visits at one time. Without the open purchase order, the electricians have to take more trips in between site visits, which decreases their work efficiency.

In the context of work efficiency, another recommendation is to have a stock of parts for the appropriate system on the electricians' truck. By having spare parts on the truck, electricians would be able to replace malfunctioning equipment on the initial visit instead of making another trip. This practice would not only save time for the electricians to be able to work on more systems, it would cut down on the cost of transportation.

The next two recommendations address the customer education within the PV electrification program. First, it is recommended that all customers view the educational video, “Power from the Sun”, before enrolling into NTUA’s PV program. The video covers the basic information that is sometimes missed in a brief conversation where a potential customer goes into a district office for a few minutes to get some information. There have been many cases where the customers realize that a PV system cannot be used with an ordinary refrigerator. The second recommendation is to have customer service representatives observe an installation to see how the systems are set up. This would allow for better communication between the customer service representatives and the electricians. Both of them would be able to perform the customer education in a coordinated fashion.

In addition to customer education, an up-to-date training sessions on the new PV systems for the electricians is recommended. It is important for the electricians to know about the new systems, how to maintain them, and how to make repairs. By having current training sessions on the systems, electricians will be able to work with all the units more efficiently.

The last few recommendations focus on data and data collection. Currently, NTUA is implementing an automated notification to the electricians through their financial business database system. The electronic notification reminds the electricians that a bi-annual maintenance check-up on a PV unit is due. Unfortunately, this notification does not provide the generational unit type, so the electricians do not know which system they will work on unless they search through customer hard copy files. In addition to the automated notification, it would be beneficial to the electricians to see which type of unit they will service. It would also be beneficial for NTUA to collect all maintenance data whenever they work on a system. By combining all of the units' maintenance data, NTUA would be able to track trends on how the systems are

**Figure 9: Vircynthia Charley, Melissa Parrish, and Deborah Tewa Collecting Data**

performing. An added benefit would be to add NTUA's data into the DOE Reliability Database. The PV power outage database can help track major failures, but there might not be enough information to directly find the cause of the outages. With more specific data obtained in the maintenance process, the causes of the outages could be diagnosed.

## A Sustainable Program

In order to keep Navajo PV Electrification Program running, NTUA, Sandia and others involved in the program must help build sustainable processes and training. The sustainability of this program goes beyond the monetary needs of the program: it must be efficient. While obtaining funds for the equipment and labor is necessary for the program to continue, on-going electrician, customer representative, and customer training is needed along with well maintained documentation. Customer education is a vital component to keep the stand-alone systems operating effectively. Without the proper education, customers could over use their system, which shortens the expected life cycle of the systems. In addition to customer education, the NTUA electricians should keep up-to-date on the latest trainings on new hybrid systems, safety issues, maintenance and troubleshooting. It is important for electricians to uphold all safety requirements while working on the hybrid systems to avoid any physical harm. With the electricians being trained on the latest information on the PV systems, it will help electricians diagnose problems quickly and they will be able to work with the systems more efficiently.

Another component to keep the maintenance processes efficient is documentation. By having complete documentation of maintenance and troubleshooting of the stand-alone systems, it helps preserve the history of the systems. The history can then be used to address future issues that develop and also serve as lessons for what should or should not be done. It is vital to record problems with equipment and how the system was repaired so that in the future if the same equipment malfunction appears, electricians will know exactly what to do to correct the issue without spending additional time on the issue that has already been solved by another.

Together with all of the training and documentation to sustain NTUA's PV program, consistency throughout all five districts of NTUA could improve efficiency. Not having consistency in all five districts can lead to miscommunication. If one district performs maintenance with a unique PV O&M form, the form might be missing information that another district might need. When compiling data from all the districts, the data trends might be hard to combine if pieces are missing from some districts. Without consistency across all the districts, the reports that come into NTUA's headquarters cannot be combined into one report without great manual effort sorting through different report formats or fields. The standardization of forms and processes would help NTUA to create an efficient working model, which will prevent inconsistencies that could cause confusion between each district as well as with headquarters.

## My Experiences

Before I began to work with Sandia and NTUA this summer, I completed a school project in Thailand dealing with how PV technology affects the Lahu hilltribe's culture. My project team's initial concern was that the impact of the technology in the Lahu's village would damage their traditional way of life. When we spoke to the tribal leaders, they did not see that modernizing their village would be an issue, rather it was necessary to survive and a generational gap between the youth and the elders was damaging their culture. From this result of my project, I wondered how my tribe or other Native American tribes would view the use of PV technology.

This summer I was fortunate to work with NTUA as well as to observe Navajos and Hopis use their PV systems. I was able to construct some impacts of PV technology within these tribes by talking with the people who actively use the systems. From what I learned, the PV systems provide families with lighting so children can work on homework at night and family members can perform their own work so they are not limited by the available sunlight. By having electricity for some modern convenience, the younger generation can remain on the reservation. It is interesting to note the generational gap of how the elder generation and the younger generation use electricity. Anecdotally, some elders maintain their PV systems better than some young people. Use of electricity is not an essential need for the elders' traditional lifestyle; while it seems to be a necessity for the younger generations. From my conversations with Melissa Parrish, I learned that the elders only use electricity for lights and perhaps a few appliances; and their batteries system are well charged. However, homes that have large families with children and young adults tend to have batteries that never are charged up to a healthy charge level. I find it interesting that electricity is such a necessity for some of the younger generation's lifestyle in spite of their growing up without electricity. In the city, the electric supply is endless when connected to the electrical grid; but PV systems have a limited supply of electricity. The younger generation wants an endless supply of electricity or to be tied to the grid, but yet they live in very remote areas without financial means to connect to the grid. I wonder if this outcome will be the near future of the Lahu hilltribe's use of electricity as well.

This internship has been a great experience that has allowed me to share my perspective as well as learn from other perspectives. My work with other Native People in the engineering field has been an invaluable experience for me since I have not had this opportunity before the internship. This experience has helped me to see that a problem has many facets that cannot be answered entirely with technical answers, but must be complemented by societal, financial, and other considerations as well. By visiting current Native American renewable energy installations, I was able to see the implementation of an electrical engineering design with real world applications - a piece which can be overlooked by engineers when developing the latest technology.