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# Navajo Tribal Utility Authority Solar Program System Data and O&M Initiative for DOE Solar Technologies Database

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## Abstract

This study analyzed (based upon somewhat limited observations) the effectiveness of NTUA's Kayenta District Photovoltaic O&M form and how the study's use might aid in establishing actual costs for the installation and maintenance of 880-watt hybrid PV systems on the Navajo Nation. The observations are limited to the 17 units in use at the time of this study.

## Sandia National Laboratories' Tribal Technical Assistance

In 2000, the DOE and Sandia signed a Memorandum of Understanding (MOU) with the Navajo Nation, the largest American Indian tribe in the United States, to advance renewable energy opportunities for the tribe and its membership. The MOU was built upon foundational work of the early 1990s, which included a developmental project on the reservation to deploy 240-watt photovoltaic (PV) systems (to primarily provide nighttime lighting to Navajo homes that did not have electricity service).

With primary facilities in Albuquerque, NM and Livermore, CA, Sandia has broad-based research and development programs contributing to national security, energy and environmental technologies, and economic competitiveness. The relationship between Sandia, the Navajo Nation and its utility enterprise, the Navajo Tribal Utility Authority (NTUA) has been beneficial. The Navajo Nation reservation provides a unique research opportunity to learn about a residential PV program for remote stand-alone systems. The PV systems managed by the NTUA Solar Program, unlike most residential PV systems deployed in the U.S., are the primary source of electricity for their remote and off-grid customers. While most residential installations are installed primarily due to our nation's current environmental conscience or to secure taxation credits, PV on the Navajo reservation is growing because, though costly, it provides a viable technical option to providing electricity to those without it.

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Sandia regularly conducts research studies of PV systems, focusing on various aspects including cell research, systems design and integration, and operation and maintenance (O&M) practices. In June 2007, Sandia received a request to collect NTUA PV system information as a contribution to the Solar Technologies Database. The Database contains information about both the performance and physical data specified by manufacturers and the performance parameters and data of on-line systems. A benchmarking form served as the basis for the collection of data for this study. These findings are discussed later in the body of this paper.

In the Fall 2007, Sandia gained the support of the NTUA Solar Program's Fort Defiance, Arizona, headquarters office and the Kayenta District "to gather, analyze and report on performance metrics for stand-alone photovoltaic systems which have been deployed to provide residential power in northeastern Arizona" within the boundaries of NTUA's Kayenta District. This study included data on the 880-watt PV/wind hybrid systems located in the Kayenta District. This effort began in September of 2007, and concluded in December of 2007.

## The Navajo Tribal Utility Authority

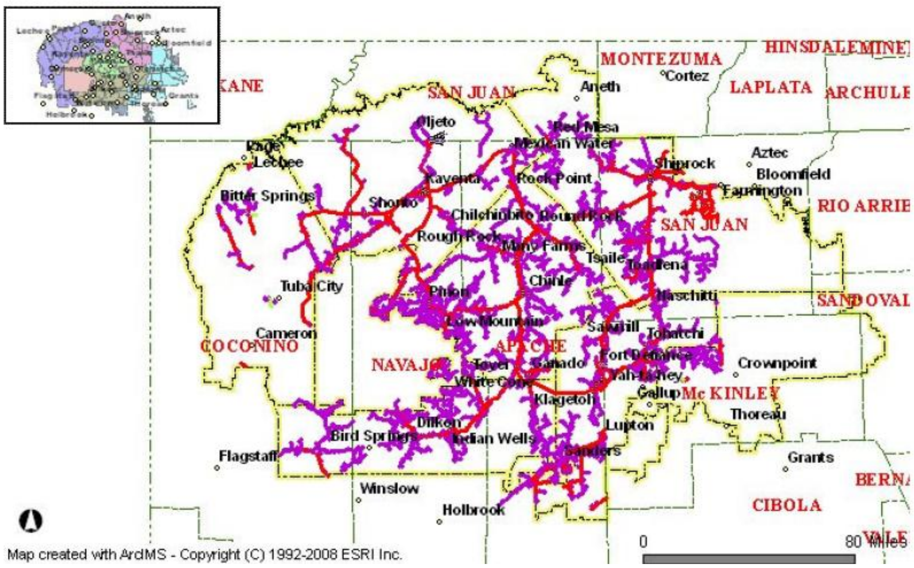
NTUA is the tribal enterprise of the Navajo Nation that provides utility services, including electricity, water, sewer (wastewater), natural gas and solar electricity throughout the 27,000 square mile Navajo reservation. The reservation, which is often compared in size to the state of West Virginia, is home to over 180,000 mostly Navajo people in the states of Arizona, New Mexico and Utah.

The Navajo reservation is located on the Colorado Plateau west of the southern Rocky Mountains and extends to the Colorado River. The region is classified as high plains desert with numerous canyons and rising mesas throughout the reservation. The Navajo people traditionally led lives in harmony with the land and practiced a traditional economy of cattle and sheep herding, which still continues today. Historically, the Navajo people lived a semi-nomadic lifestyle in which homesteads were built adjacent to vast parcels of land to support grazing. Over time, the Navajo people continued to reside on large tracts of land for herding; often homes are widely scattered—so community living is often the exception rather than the norm for the reservation.

The Navajo reservation, like many other American Indian reservations, is remote and isolated and located away from any significant population center. The closest urban areas are Phoenix and Albuquerque, which are approximately two hours away at their nearest points and as far as five hours away at their most distant points. Salt Lake City is over eight hours away. The most striking trait, and one which is difficult to comprehend for many, is the absence of many modern conveniences on the reservation. Much of the reservation is underserved by public utility services, including electricity, water, and telephone services to homes, with an aged and sub-standard highway transportation system. It is ironic that the largest American Indian tribe in the nation must contend with the most severe living circumstances for not just Indian Country but also for the nation.

The economies of scale required by most public utilities cannot be met on the Navajo reservation due to the low population density and vast distances between the townships that exist. Most regions with similar characteristics must be subsidized via public policy (e.g. the Universal Service Fund for telephony) or can offer rated structures for services (e.g. normalized prices for urban and rural users). As a result, prices for NTUA services are elevated in comparison to average rates for the local states and the U.S.

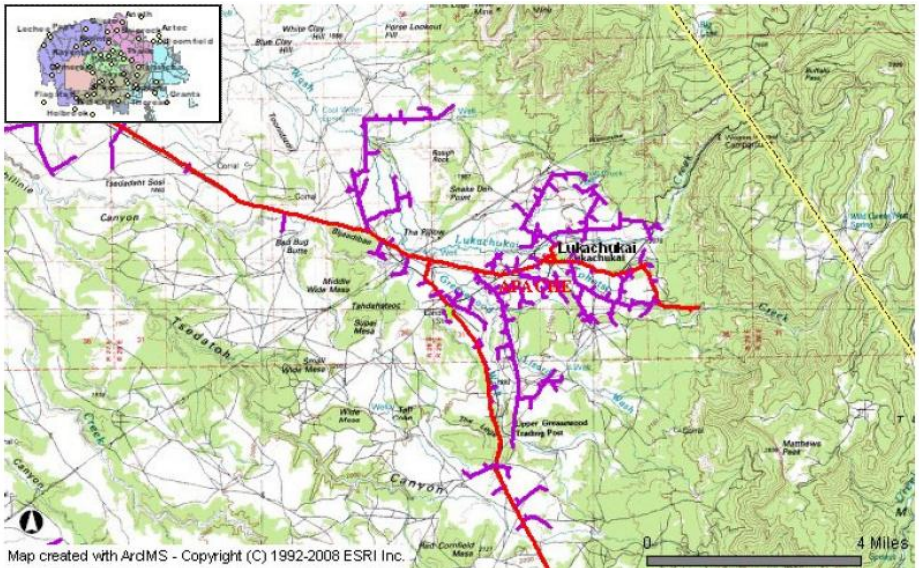
NTUA provides electrification to the reservation through the resale of purchased power via its distribution network. NTUA is the sole utility for most of the reservation, though other utility service providers exist along the fringe of the reservation boundaries. The extent of the distribution network is shown in the following electricity map available from the NTUA website (www.ntua.com):




**Map 1: NTUA Power lines across the Navajo Reservation**
(Source: Navajo Tribal Utility Authority)

The illustration, Map 1, shows that the distribution power line network is centered throughout the “heart” of the reservation. The power lines in red are the three-phase power lines, which carry larger loads and are for power distribution over long distances. The power lines in purple are the single-phase power lines which are used for local power to homes and communities. (Note that NTUA also has a third class of power lines, which are laid underground, in the township of Kayenta, Arizona.)

While at first glance the map might suggest that electricity penetrates the entirety of the reservation, recall that the map covers an area of 27,000 square miles. The actual line network is exaggerated in the figure and a enlarged view of a local community better illustrates the NTUA distribution network. Map 2 (below) shows the power line network in and around Lukachukai, Arizona—a community selected at random. The map shows an area which is approximately 10 miles by 20 miles, or approximately 200 square miles.




**Map 2: NTUA Power lines of Lukachukai, Arizona**
(Source: Navajo Tribal Utility Authority)

This view shows a localized view of the power lines as they exist in a Navajo community. Lukachukai sits on the fringe of the Arizona-New Mexico border at the base of the Lukachukai Mountain. The community has a population of approximately 1,500. However, there are hundreds of additional families near Lukachukai (within the area of the map) who remain un-served. There are very few extensions off the main three-phase power line between established communities, which are typically large distances apart.

The Sandia Tribal Energy team recently participated in the filming of a television segment about renewable energy initiatives on tribal lands. A home between St. Michaels, Arizona, and Ganado, Arizona, was selected for filming. While in route to the home, the team noticed that the power lines followed the tribal road we were driving on. Houses located immediately off of the road, which are adjacent to the power line, had electric lines running to their homes. However, homes which are close to but not located along the road—distances no greater than perhaps 100 yards from the power line—did not have power lines running into their homes. It was astonishing that some homes, easily within eye's view while driving in the shadow of power lines, sit "in the dark" on the Navajo reservation.

There are two primary reasons why this situation occurs repeatedly. The low density of homes makes line extensions cost prohibitive. The average cost for line extensions is now in excess of $35,000 per mile for single-phase lines. (The cost of line extension for 3-phase lines is $60,000-$80,000 per mile.) To ensure the efficient use of future investments into the electricity service, the NTUA has imposed a minimum criterion for the number of homes to be served per mile for future line extensions. That criterion is eight families per mile. Given the low density of homes on the reservation, this minimum is rarely attainable.

A second reason for underserviced electrical needs is that the NTUA is set up as a not-for-profit entity. Therefore, it cannot raise significant cash reserves to fund future line extensions. Neither is it able to raise cash reserves to build new substations to increase the capacity of its network. Thus, after years of adding new customers, the NTUA is faced with the dilemma of having reached its capacity of available electricity for its current power distribution network. In some cases, the addition of new customers would result in poor quality of service issues as many would become end-of-line service customers. In such an instance, NTUA could not offer, in good faith, quality service due to anticipated electric spikes and power surges and temporary interruptions to service.

Further, from a customer perspective, the low incomes on the reservation and the abnormally high cost of living leave families unable to share the cost of line expansion. The net of these circumstances result in a harsh reality: many Navajo families will likely never receive on-grid electrical services in their homes. Neither the Navajo families nor NTUA is to blame for high costs. Rather, the economic circumstance of the high-cost services in an impoverished, rugged and remote area poses a very difficult challenge to the electrification of the reservation.

Faced with these realities, the NTUA began to explore the possibility of providing a remote electrical service for customers who did not have electricity service. Renewable energy technologies provided a viable solution. Since 1999, in collaboration with Sandia National Laboratories' Solar Program, the NTUA has developed the largest off-grid residential PV program in the nation. Today, the Solar Program consists of almost 300 PV systems (hybrid units, hereafter noted as PV systems) available in two offerings: 640-watt systems and 880-watt systems enhanced with small wind turbines.

The PV systems owned by the NTUA are designed as stand-alone systems; as such they do not intertie with the electricity utility grid. The systems include the following components:

- PV modules
- Frame for modules
- Battery bank
- Inverter
- Load center
- BCM

The 880-watt PV systems were designed to generate 2 Kw-hrs of energy per day. These systems, however, are augmented by AirX 220-watt wind turbines to take advantage of the seemingly continuous wind that blows throughout the reservation. Fortunately for these hybrid systems winds are more prevalent at night, when electricity use is lessened so the battery banks are able to be recharged. Customers who have the hybrid systems demonstrate a clear preference for the hybrid systems over those that are PV only.

## The Kayenta District Office

The Kayenta District, which is one of seven districts, has the largest number of PV units among all districts. Of the 299 PV systems owned by the NTUA, the district has a total of 83 640-watt and 17 880-watt PV systems-- a total of 100 PV units. This represents one-third of the Solar Program's units. The focus of this study is the 17 880-watt PV systems, which are actually wind-hybrid systems. Of the 17 PV-wind hybrid systems, 16 were deployed at the time of the study and 1 was in the yard (due to non-payment repossession) awaiting redeployment. (By comparison, only 53 of the 83 640-watt systems were deployed at the time of the study, due to repair.)

The primary contacts for this study at the Kayenta District Office were Louise Madison, Customer Service Representative in the Customer Service department, and Vircynthia Charley and Melissa Parish, Electrician Journeymen in the Electrical Department. Each of these ladies was instrumental in explaining the organization of the Kayenta District, their roles in the Solar Program, and the lifecycle processes of Solar Program customers, especially for problem calls which come in to the district office.

For troubleshooting calls, which is how NTUA references problem calls initiated by customers, Louise provides the first line of support for NTUA customers who are having service problems with their PV systems. Louise documents the customer problem in Service Notifications to begin the Troubleshooting call flow process. Louise and other Customer Service agents do not attempt to analyze the troubleshooting calls over the phone with the customers because the NTUA wants to minimize customers' working on the PV equipment. Louise also creates periodic Operations and Maintenance (O&M) visits / calls, based on routine maintenance scheduling or upon request by the Solar Program team.

The primary work assignment for Vircynthia and Melissa is maintaining the electric systems for the water pump and filtration system in the Kayenta District, so responsibility for Solar Program O&M and Troubleshooting service orders is secondary. As such, they are eventually in contact with every Solar Program customer because service orders require an in-person visit.

## O&M Service Calls

Operations and Maintenance (O&M) service calls are scheduled visits whose purpose is keep systems in "good health," which optimizes the amount of electricity generated for customer use and extends the life of the system. This is achieved by ensuring that a number of preventative maintenance activities are performed, including:

- Ensuring that connections are tight and secure
- Filling batteries with distilled water to recommended levels
- Clearing the load center box of dust and debris
- Verifying that the charge controller is working correctly
- Verifying that the BCM is in good working order

- Adjusting the tilt of the solar array

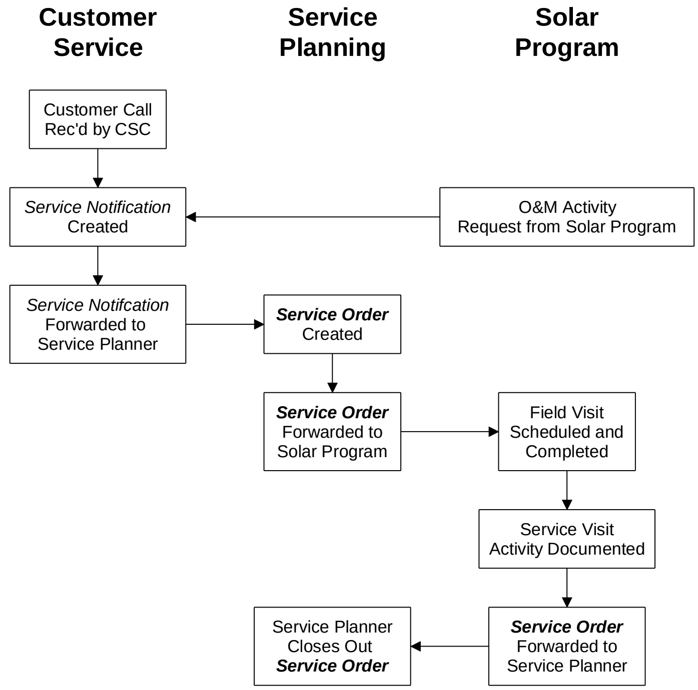
A goal of the NTUA Solar Program is to schedule bi-annual O&M service visits near the occurrences of the equinoxes in March and September, when the earth is at its nearest and farthest points from the equator of the earth. These events are also the midway points between the summer and winter seasons. NTUA policy calls for systems to be adjusted twice a year at a 15° tilt for the summer season and a 60° tilt for the winter season. These angles have been calculated based on the latitude and elevation for the Kayenta District service area to optimize the amount of direct sunlight to the module surface areas.

However, a deviated Fall / Spring schedule often occures for pragmatic reasons. For example, the Solar Program team may be called to a customer location for an unscheduled visit (e.g. a troubleshooting service order) due to a local system problem. During troubleshooting visits, the team often performs its O&M services while at the customer premises. This reduces multiple trips to customer locations. Another reason for a deviated schedule is that the Solar Program electricians are often pulled away for high priority jobs and have to reschedule O&M visits based on the needs of the district. Winter proves to be particularly challenging because many solar customers live in remote locations that are significant distances off of main roads—including some "roads" which are impassible due to ice and flooding.

## SAP: NTUA's ERP System and Service Notification/Order Call Flow

The NTUA utilizes the SAP enterprise database tool for its business management system. SAP is implemented as an Enterprise-wide Resource Planning (ERP) tool which incorporates supply-chain, financial, human resource and project information in a common database to support business operations. NTUA's SAP tool also includes the customer relationship management (CRM) functionality, which includes call center support and customer records. SAP tracks all customer service requests from their creation through their resolution. Thus, SAP is the primary repository for all information related to supporting Solar Program customers. The following diagram captures the basic call flow for a typical Solar Program service call.

## ~~NTUA Solar Program Field Visit Call Flow~~




Service requests follow a two-step process: 1) Service Notifications, which document communications between the Customer Service and Service Planning functions, and 2) Service Orders, which document communications between the Service Planning and Solar Program functions. The creation of a Service Order is predicated on the existence of a Service Notification.

Service Notifications are created by the Customer Service function and are a notification to the Service Planning function that a Service Order needs to be created and routed to the appropriate service group. In the broader sense, the reasons for creating a Service Notification include the application for Solar Program services by prospective customers, an internal order for the installation if PV/wind hardware at a customer location, to interrupt or terminate services due to non-payment, or to perform an internal administrative task related to a Solar Program customer. For the purposes of this paper, which focuses on tickets that engage the Solar Program electricians, most calls will be created because 1) the customer called in to report a problem with their system or 2) the Maintenance Scheduling team or Solar Program is requesting a Service Order so it can schedule and perform O&M services on a system. Note that all work performed by Solar Program electricians is predicated on the existence of a Service Order.

Service Orders received by the Solar Program are typically for 1) Service Entry Inspections and installations of hardware; 2) troubleshooting; 3) O&M services; or 4) interruption or termination of services. Service Entry Inspections (SEI's) are performed at locations at which new services will be provided. Elements of SEI's include inspection of the service entry loop (e.g. electrical meter) and wiring in the home. Installation activities include delivery and installation of hardware (pole for wind turbine, wind turbine, PV system), installation of an electrical system, and verification of system integrity. SEI and installation activities are outside the scope of this paper.

Troubleshooting calls are created when customers call into the Customer Service Call Center to report a problem with services. These problems can be varied, from low output by the system calls to periodic interruptions in service to termination of service. As mentioned above, the Solar Program technician may opt to also perform O&M services during the troubleshooting customer visit.

The calls of most interest to this study are the scheduled O&M calls. As described above, these are scheduled preventative maintenance activities. During an O&M call, the Solar Program electricians follow a prescribed list of activities to ensure that the systems are maintained in optimal working condition. The Kayenta District has developed a "Photovoltaic O&M" (PV O&M) form (see Appendix) which is used during O&M activities. The form documents the activities of the service call, including current performance metrics, and notes made by the electrician performing the service. The form also documents the specific actions taken as well as any interaction between the customer and Solar Program. Finally, the PV O&M form includes information used by the financial team for determining the costs for each call. This original form completed at the time of the O&M visit is filed in the customer files maintained by the Solar Program (this is the secondary source of documentation about the service call). The PV O&M form is also used for troubleshooting calls.

The information contained in the PV O&M form is entered into the Service Order as an update and queued to the Service Planning team. The Service Planner then ensures that the information in the service order is complete and then TECOs the ticket. The term 'TECO' is a SAP terminology which indicates that, from a service perspective, the Service Order has been completed. The Service Order, though, remains open for processing by other groups, such as the Financial Organization. Thus, costs for the call may be determined and charged to the correctly. Another example of a Service Order activity after it has been TECO'd is that a bill may be generated to a customer for abuse to a system.

PV services are interrupted for payment delinquency. If a customer eventually does not pay, the services may be terminated. Termination involves disconnection from the customer premises and removal of the PV system to the district yard. (Note, in one case, electricity generation using a PV system did not work for a customer's energy demands and the system was moved at the customer's request.) Once a system becomes available, a new prospective customer is notified of the availability of the system and it is subsequently redeployed as a new installation.

## Study Approach

This study was based upon the service records for the 880-watt PV/wind hybrid systems in the Kayenta District. Records were located 1) on-line in the NTUA's SAP system for business management (primary source) and(2) in hard copy form in the files maintained by NTUA Kayenta District office (secondary source). Every ticket which could be located in the SAP system and/or in the hard copy files was pulled during this study. A total of 20 880-watt PV customers have existed in the Kayenta District since the program's inception in 2002. A total of 160 tickets were located in this study.

## Study Findings

The purpose of this study was to collect and analyze performance data about the NTUA's Solar Program. Only the 880-watt PV/wind hybrid systems were included. The 640-watt systems were not included in this study due to systematic failures inherent in the design of those systems, which flaws have resulted in the replacement of failed parts and a tolerance for damaged components in the system, which implies that there remain degraded systems in the environment. Additionally, O&M practices were premature at the inception of the program but have since been improved. Finally, administrative changes in the business management system discarded much of the original data so information was no longer available for troubleshooting and O&M service calls.

The objectives for this study were articulated in the Statement of Work prepared for this project:

1. Collection and analysis of PV system performance data for Sunwize 880-watt systems
2. Entry of data into DOE Solar Technologies database
3. Determination of O&M costs relative to industry standards
4. Review of O&M practices and opportunity to reduce cost

Three of the four objectives had been completed at the time of this writing. The NTUA headquarters office is in the process of identifying key measurements required to complete objective 2. Findings for objectives 1, 3 and 4 follow.

1. **Collection and analysis of PV system performance data for Sunwize 880 watt systems**

A total of 169 Service Notification/Service Orders (hereafter referred to as service requests) were located for service calls for 20 different customers since the 880-watt system offering began in 2002. Of these service requests, 15 were created for internal NTUA administrative purposes, 46 were for SEI and installation activities, 15 tickets were for disconnect of system at the customer locations, 6 tickets were to reconnect systems at customer locations, and 7 tickets were for removal of systems from the customer premises. The remaining tickets are designated as troubleshooting (32) and

O&M (48) service requests. However, O&M was also performed under two Disconnect/Remove and three Troubleshooting service requests.

The primary references for data for this study were completed PV O&M forms. A total of 24 (of 48) contained completed information. Use of the word 'complete" in this context, requires further explanation. The PV O&M form was designed to provide a comprehensive snapshot of the status of the system. In other words, the intent was to design a document that would collect all of the necessary measurements required during either a troubleshooting or O&M service request. It is not necessary to collect all information for every service request to gain a complete snapshot of the system. For example, the form is captures 'specific gravity' measurements, which are only used when troubleshooting a battery problem. If a system problem is with the wiring or electricity generation of the system (not battery related) there is no need to measure the specific gravity readings of the battery bank.

Three types of service call information are collected on the PV O&M form:

- Customer Information
- Quick Glance Problem Matrix
- Service Call Charge Data

**Customer Information.** The PV O&M form requests basic information about the customer, the PV system to be worked on and the date that the Solar Program received the Service Order from Service Planning. The format of the form is as follows:

| | | | |
|---|---|---|---|
| **Customer Name:** | _______________ | | |
| **Location:** | _______________ | | |
| **Solar Power Unit #:** | _______________ | **Date Received:** | _______________ |

**Quick Glance Problem Matrix.** The problem reference matrix helps 1) to classify the type of customer problem and 2) to document the weather conditions at the time of the service request visit. In the 24 completed PV O&M forms referenced in this study, the problem section was not used. Weather conditions were referenced for 20 of 24 of the service requests, with weather being cited as a problem in four of the service requests. An example of a weather problem for the Solar Program electricians would occur on a windy day. Due to the high amounts of sand and debris stirred in the air on windy days, the Solar Program electricians would not open the batteries and risk getting sandy deposits in batteries or the likelihood of getting unwanted sand in the battery bank and load center boxes, which effects ventilation in each enclosure.

| Power System Unit | STATUS | | DESCRIPTION OF PROBLEMS | | | |
|---|---|---|---|---|---|---|
| | OK | PROBLEM | *(Circle One)* | | | |
| Solar Array | | | Factory | Vandalism | Aging ( WX/Non Wx Related) | |
| | | | Wiring | Installation | | |
| Charge Controller | | | Factory | Internal Fault | Set Points | Unknown |
| | | | By Pass | External Fault | Connections | |
| Battery | | | Factory | Mechanical | Connections | |
| | | | Known | Electrolyte | | |
| Inverter | | | Factory | DC Disconnect | Wiring | Unknown |
| PV Structural | | | None | Design | Unknown | |
| Fuses | | | Short | Open Circuit | Battery | Array |
| Inverter- Control Box | | | Known | Design | Factory | |
| | | | None | Connections | Vandalism | |
| Wind Turbine | | | Factory | Vandalism | Lightning | |
| | | | Wiring | Installation | Blade | |
| WT- Charge Controller | | | Factory | Internal Fault | Set Points | Unknown |
| | | | By Pass | External Fault | Connections | |
| | | | | | | |
| Weather Condition | | | Raining | Windy | Partly Cloudy | |
| | | | Foggy | Cloudy | Sunny/Clear | |

**<u>Service Call Charge Data</u>.** Key information, such as Service Order number, the date of service and NTUA resources used in completing the call, are documented in the bottom section of the O&M PV form. This information is used to calculate the costs of the service call, including:

- NTUA personnel: The NTUA personnel involved in servicing a call is documented by noting their employee numbers in the call and the amount of time required to complete the call. The Finance organization calculates the cost of personnel resources based on an employee's job classification by referencing the employee number.

- Travel: The cost of travel is determined using the 'Mileage' and 'Unit #' information. Mileage is determined to be the distance travelled from the NTUA employee's prior point of origin to the service call location. The unit number is the vehicle number used by NTUA personnel while servicing the call and it is used to calculate cost of use, based on classification of the vehicle.

| | | | |
|---|---|---|---|
| **Service Order #:** | | **Hours:** | |
| **Serviced by:** | | **Mileage:** | |
| **Date of Serviced:** | | **Unit #:** | |

A third cost element, materials used during the service call, is not recorded in a specific location on the PV O&M form.

A total of five system metrics are collected on the PV O&M form. These include:

(1**) Tilt of Solar Array**. As discussed in the previous section, the Kayenta District has adopted the practice of biannual O&M services and adjusts the surface of the PV arrays to 15° and 60° angles from the surface of the ground. These are considered the winter and summer tilts, respectively.

| | |
|---|---|
| **PANELS ADJUSTED FOR:** | (Winter) or (Summer) |

(2**) Distilled Water Used**. The amount of water used during a service request visit is recorded. Typically, distilled water is used when 1) adding water to the batteries in the battery bank or 2) for cleaning system hardware, such as cables. This measurement is used for charge-back for materials used and is a part of the materials cost of the call. This is the only 'materials' cost explicitly reported on the PV O&M form. Four of the five sections listed above are grouped together at the top of the PV O&M form. A fifth section, Service Call Charge Data, is located at the bottom of the form.

| | |
|---|---|
| **DISTILLED WATER USED:** | ________ Gallons |

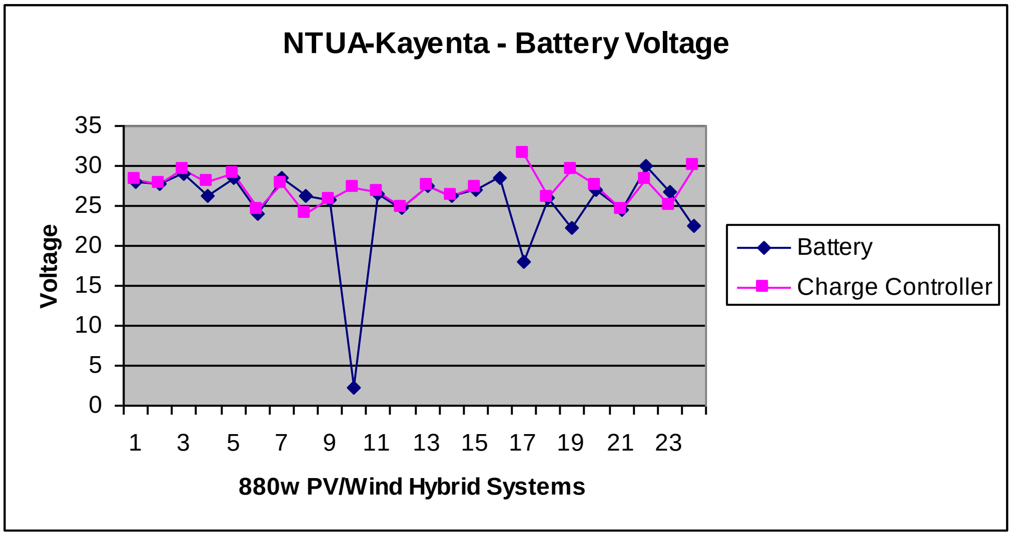
(3) **System Voltage**. When the PV modules have either direct or indirect (e.g. through the clouds) sunlight, an electric potential is created across the modules and the array. The batteries also possess a voltage when charged. System voltage reading may be taken at any of these points. The Kayenta District takes readings at three points in the system:

1. Voltage of the battery a) taken manually across the battery bank and b) read on the charge controller
2. AC Voltage ($V_{AC}$) read on the inverter
3. Voltage of the PV array taken manually across the array

These readings are recorded as follows:

| | | | | |
|---|---|---|---|---|
| **VOLTAGE READINGS:** | Overall Battery: | ________ | AC Output: | ________ |
| | Charge Controller: | ________ | Array: | ________ |

The following chart shows the voltage readings over the battery bank, taken both manually and from a digital readout:



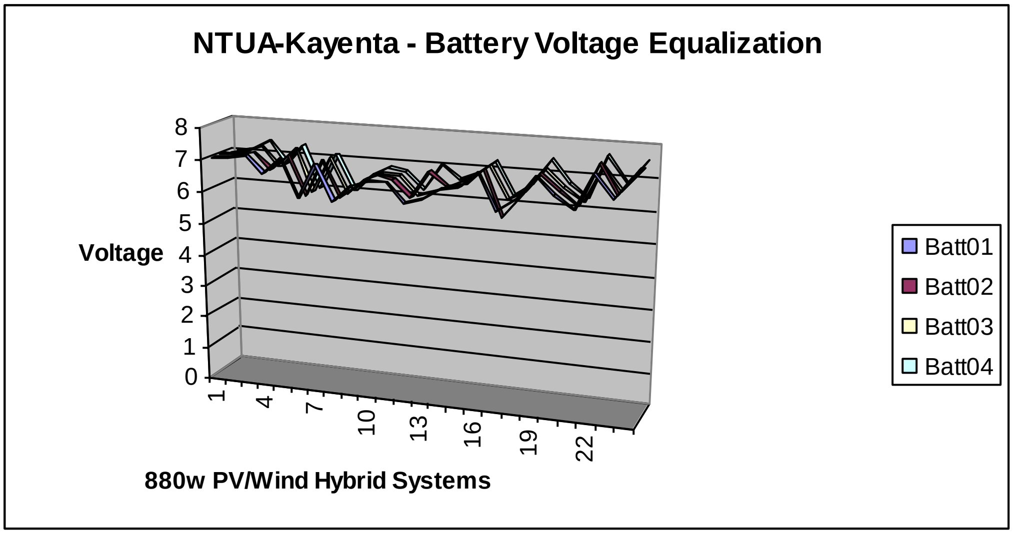

Ideally, the manual readings and digital readings taken from the charge controller would match perfectly on this chart. However, the charge controller periodically requires recalibration or it will give incorrect readings. The implication of an out-of-calibration charge control might either allow a battery bank to become overcharged or prevent a battery from fully charging. Charge controllers can be easily recalibrated by Solar Program electricians. In the event of a true charge controller failure, the system is typically reconfigured to bypass the charge controller to allow the system to continue in operation for the customer. However, a new part should be replaced promptly to minimize risk of damage to the system.

NTUA electricians take an additional set of battery voltage readings for each individual battery in the battery bank:

| **BATTERY TEST** | Batt# 1 | Batt# 2 | Batt# 3 | Batt# 4 | Batt# 5 | Batt# 6 | Batt# 7 | Batt# 8 |
|---|---|---|---|---|---|---|---|---|
| *Voltage* | | | | | | | | |
| *Specific Gravity* | | | | | | | | |

For an 880-watt PV system, the battery bank is comprised of four batteries; 8 batteries are used for 640-watt PV systems, the other system in the NTUA environment.

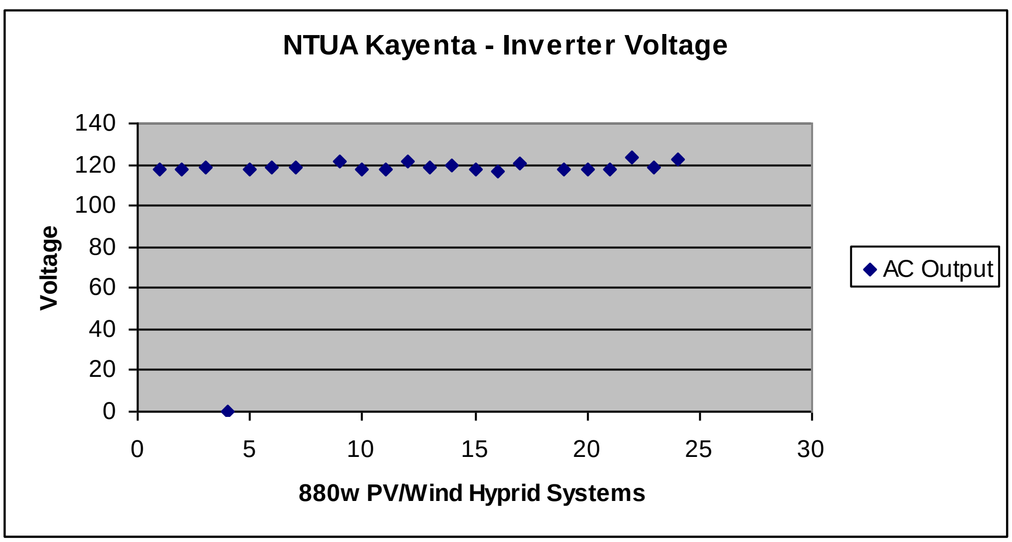
The voltage of each battery is measured and compared to the voltages of the remaining batteries in the battery bank. Equalization across batteries, meaning that the voltage load is shared equally in the battery bank, is the goal of these measurements. If a battery's voltage load deviates significantly from that of others, it is an indication that the batteries need to be maintained or that a battery cell may be failing and need to be replaced.



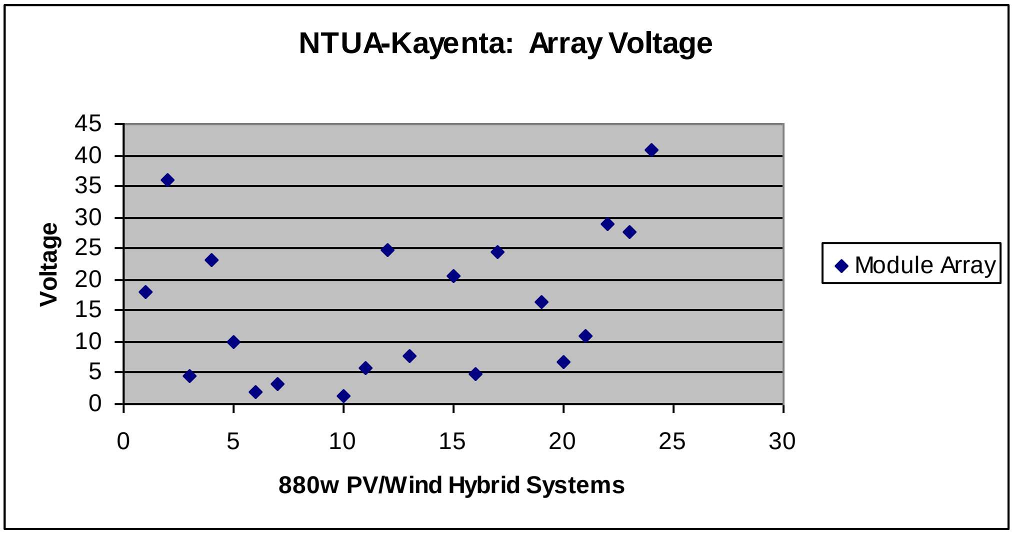

As can be seen in the above chart, the voltage reading for each of the batteries in the data set is relatively close for all systems. The most significant deviation exists for system 14, in which the difference is 6.3v in two batteries and 7.0v in the other two.

A second reading that can be taken is the specific gravity of each battery. The specific gravity of the electrolytes in a battery cell indicates the amount of charge in a battery. The amount of electrolytes and, indirectly, the battery's ability to recharge, provides another indication of the health of a battery.

A second set of voltage readings are taken from the inverter. The average voltage for the inverter readings is 119.2$v_{AC}$:




The inverter voltage reading is taken as a digital reading from the inverter. The desired voltage output is 118-120 $v_{AC}$. The array voltage is recorded manually across the 2x4 array of 110v solar modules.  This reading is varied for each system based upon the availability of sunlight, temperature and other environmental factors.



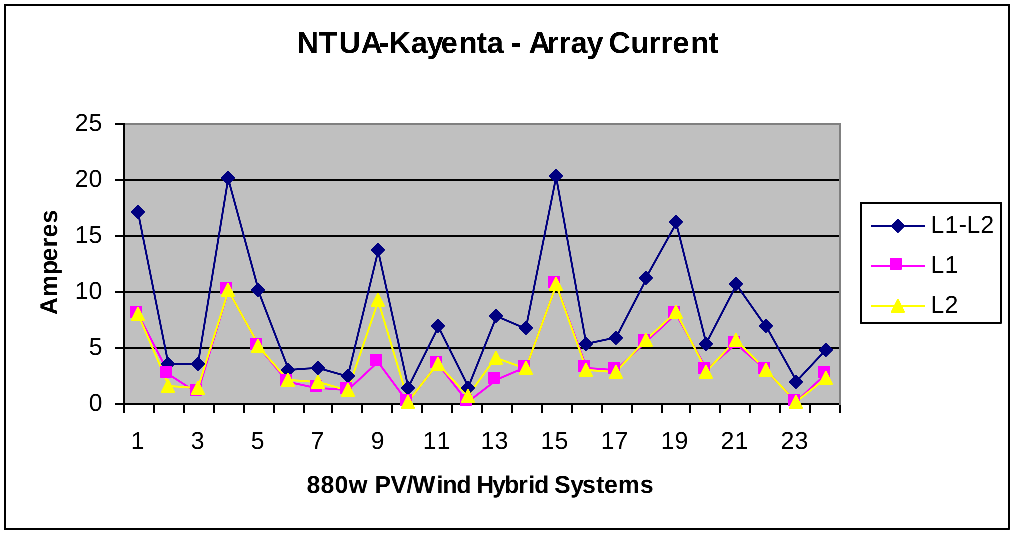

(4) **System Amperage**. The amount of current in the PV system may be taken at several different points, much like the voltage readings can be taken at different points in the system.  The Kayenta District takes current readings at three points:

1. Current produced by the PV array
2. Current of the battery bank
3. Current utilized by the customer

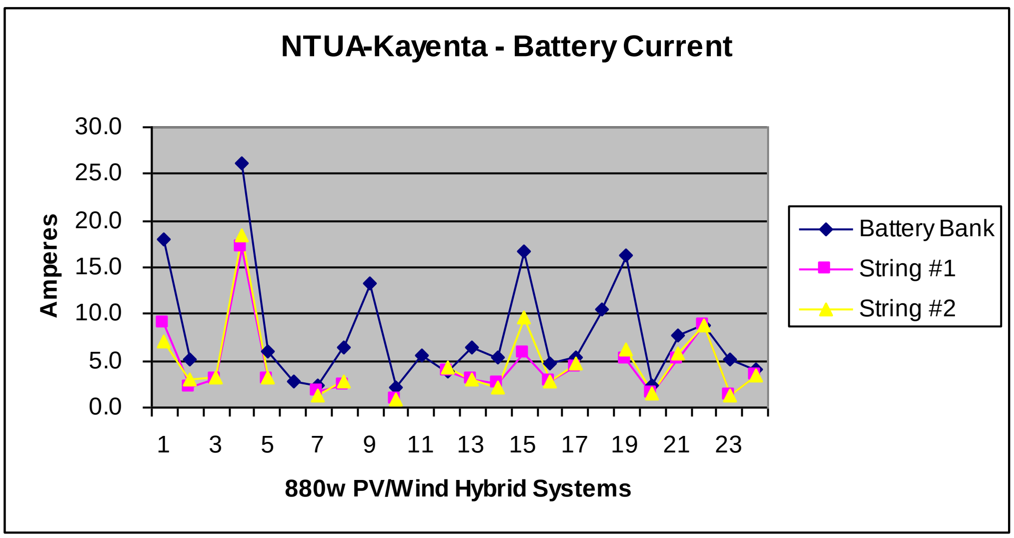
The readings are recorded as follows:

| AMPERE READINGS: | Array | | Battery | | Customer | |
|---|---|---|---|---|---|---|
| | L1-L2 | ______ | String | ______ | Load | ______ |
| | L1 | ______ | #1 | ______ | | |
| | L2 | ______ | #2 | ______ | | |

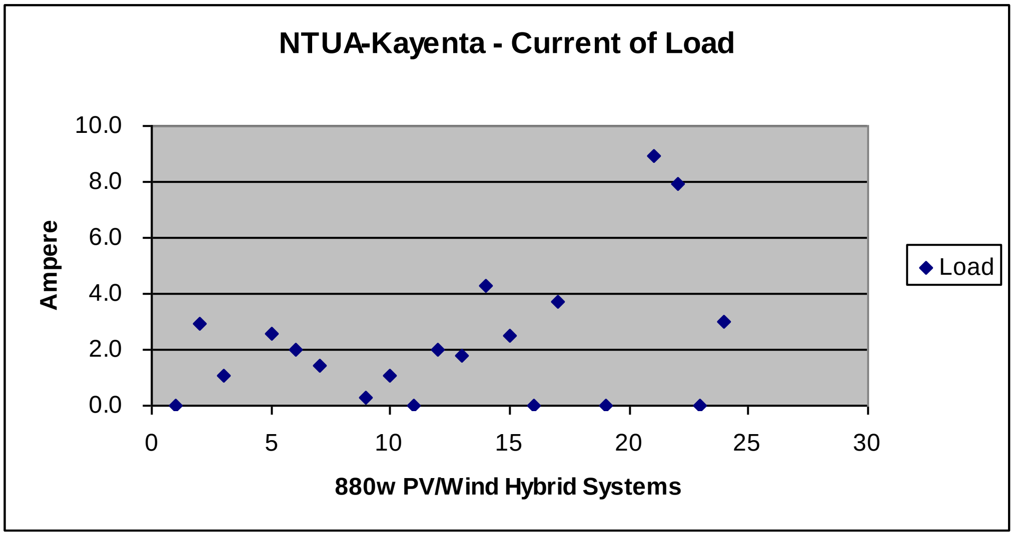
The current across the PV array is taken across the two array lines (four modules in series in each line) and across the entire PV array (two lines in parallel):




The second readings are for current going across the battery bank. The readings are taken across the two battery strings (two batteries in series in each string) and across the battery bank (two strings in parallel):




The final set of readings is of current loads of customers at the time of the service call. Like the array voltage, this reading will vary by customer and by system and is a reading of use.




(5**) System Modules.** These measurements represent the performance of PV systems deployed in the NTUA Kayenta District. They represent a subset of the NTUA Solar Program population and differ from the performance of systems in the remaining six districts.

2. **Entry of data into DOE Solar Technologies database**

The DOE Solar Technologies database is a tool designed "to support the continuing development of a suite of analysis, modeling, and benchmarking tools" to promote current and future implementations of solar energy and, specifically, to support the DOE Solar American Initiative. Specific needs are for initial cost, performance, and reliability information from deployed systems. The requirements for this study are to enter customer and system information for the Kayenta District into the access database for presentation to the NTUA Engineering Department. The NTUA content will comprise the off-grid, remote data in the database. The next step will be to add system component information and purchase price and installation cost information for the NTUA's 640w and 880w PV systems. The final step will be to enter performance data on an on-going basis as a repository of NTUA Solar Program performance. As indicated earlier, the NTUA headquarters office is in the process of identifying key measurements required to complete this objective from the Statement of Work.

3. **Determination of O&M cost relative to industry standards**

This study provides the opportunity to determine NTUA's internal O&M and troubleshooting costs for services. Costs for the 880-watt systems have never been determined. Instead, the pricing model for the 880-watt systems has been based upon the estimated costs for the 640-watt systems, which were determined prior to 2002. A major reason the actual costs have not been determined is due to the complexity of the SAP tool, which limits NTUA's ability to generate the customized reports that would provide this information. Determining actual costs is especially important as the NTUA actively seeks to find ways to improve system performance, increase the number of systems and customers for the program, and improve its financial position.

The collection of financial data was included while retrieving completed service call information. The SAP system generates Cost Report for Service Orders which contains cost information. The SAP system reports costs in eight different categories for 880-watt service calls (part of this study). The categories are:

- Utility Material (PV system price to NTUA)
- Vehicle Rental (Use of External Equipment)
- Labor (Time and Travel)
- Internal Equipment (Parts and Materials)
- Headquarters (HQ) Administration
- District Administration
- Customer Account

The O&M and Troubleshooting costs are determined by summing two of these categories, Labor and Internal Equipment. The Labor components include: resource utilized during the call (based on employee number), time spent servicing the call, and travel, which is determined by bill rate for the vehicle used and distance travelled. The Internal Equipment is comprised of materials used during the call (e.g. distilled water) and replaced parts (e.g. inverters, wiring). Note that the Utility Materials, Vehicle Rental, HQ Administration, District Administration and Customer Account categories are used during the installation of a PV system.

Based on these findings, the results are as follows:

**O&M and Troubleshooting Costs for 880-watt Systems**
**NTUA - Kayenta District**
**2002-07**

| | Per Event | # of Events per Year* | Monthly Cost, per System | Annual Cost, per System |
|---|---|---|---|---|
| O&M* | $130.19 | 2 | $21.70 | $260.38 |
| Troubleshooting | $238.94 | 6.4 | $7.50 | $89.95 |
| Total | | | $29.19 | $350.33 |

*O&M is scheduled event (twice per year)

**Troubleshooting costs are random events. Annual number of events and cost information based upon historical data (2002-2007)

The average cost for an O&M call is $130.19, per event for the 880-watt systems, based upon the O&M calls located in this study. Since NTUA policy suggests that O&M service is to be performed twice per year, the annual cost for O&M per unit is $260.38.

Spread over twelve months, the monthly cost is $21.70. This is much lower than the $70.00 per month O&M cost estimated in 2002.

The calculation of average O&M cost requires the omission of two calls: the first call did not contain charge information in its Service Order; the second call had O&M performed at the time of installation of a system and cost $1,313.86. With these exclusions, there were 22 calls used in the calculation of the average O&M costs. The minimum cost was $29.49 and the maximum cost was $327.42. The median cost was $105.26 and the mean cost was $130.19. The high cost call ($327.42) required leveling of the system, a necessary (albeit atypical) maintenance activity. It should be noted that this single call increased the average cost for O&M calls from $120.80 to $130.19.

Based upon the findings of a study completed by Arizona Public Service (APS) and Sandia National Laboratories of residential and commercial PV systems, the annualized cost for PV units with tracking systems was determined to be 0.35% of initial cost. The study established a target range for O&M of 0.3%-0.5% of original installation costs. The average systems and SEI/installation cost, based upon individual cost information in the ticket histories for all 17 880-watt PV systems, was $15,662.65. Thus, the average annual cost for O&M services in the Kayenta District was $260.38/$15,662.65 = .0166 or 1.66% over the $\text{target}_{MAX}$ of initial installation cost. This difference can be attributed can be attributed to many factors including:

- Higher costs for services in a rural area
- Lack of economies of scale on the Navajo reservation
- Manually intensive O&M practices (no on-line monitoring available)
- Grid-tied equipment (stand-alone systems have battery banks and other parts which are residential scale, not industrial scale)
- The comparison group is for newly installed (and technologically advanced) equipment

The cost for troubleshooting calls is philosophically very different and understanding their cost less intuitive than for O&M costs. Troubleshooting calls are event driven, meaning that they are only created when a failure occurs within a PV system. In the five years since NTUA began the 880-watt system offering, there have been 32 troubleshooting calls, which averages to 6.4 calls per year. The average cost for troubleshooting services is $238.94 per call. The annualized cost for 6.4 calls per year for the Kayenta District 880-watt PV systems is $1,529.22, based on the current inventory of 17 880 PV/wind hybrid systems. Spreading this annualized cost across 17 systems results in a $7.50 monthly cost or $89.95 annual cost for troubleshooting per system.

The costs for three calls were excluded from the calculation of the average troubleshooting cost because cost information was not included in the Service Orders. With these exclusions, based on costs for 29 calls, the minimum cost of a troubleshooting call was $22.44 and the maximum cost of a troubleshooting call was $604.04. The median cost was $176.10 and the mean cost was $238.94. There were four troubleshooting calls that cost in excess of $500.00. These calls required the replacement of inverters and a charge controller (which are high-cost items) and repeated visits to a customer location because of overuse of the system (customer abuse).

The 32 troubleshooting calls were called in by 14 of the 20 customers over the five-year period. One customer created six of the calls and two customers created four calls. The remaining customers (17) called in two or fewer calls over the five-year period—which is consistent with the average number of troubleshooting calls per system: 1.88 calls per system over the five-year period. Of note is that six customers never made a troubleshooting call.

4. **Review of O&M Practices and Opportunity to Reduce Cost**

The Solar Program is built upon an environment of approximately 300 PV systems dispersed throughout the Navajo Nation. After these units have been purchased and installed, the longevity of their life-cycles is largely dependent upon their care and treatment by: (1) nature and the elements, (2) the customers, and (3) the Solar Program. While there is little control which the Solar Program can provide over the weather, there are proactive steps which the Solar Program team can take to mitigate any undesirable effects toward the Solar Program hardware. These include the standard practices of ensuring the units are positioned so intrusive shadowing on the modules is eliminated, the battery banks and enclosed containers are secure from dust and moisture, and the wind turbines are not damaged by turbulent wind or birds.

Customers are educated about the use and limitations of their PV systems when they become PV customers of the NTUA. Specifically, customers are informed that they do not have access to a limitless supply of energy - like standard grid-tied customers; the electricity generation is restricted by the capacity of the system and excessive use or overuse will damage system components. However, as it is human nature to test limits and for the users of the systems to be energy consumers; therefore, the PV systems do see overuse.

The NTUA Solar Program has a requirement for periodic maintenance activities which is likely unique to other NTUA lines of business. This is a responsibility common for all PV systems, especially those which are off-grid with power storage features. Such a system typically includes a battery, a charge controller, an inverter and PV modules. Since remote capabilities are not available for monitoring PV systems, they must be checked manually by an NTUA electrician.

**Summary Observations Included as a Part of this Intern Study Paper**

The most significant tool in NTUA's service program is the Kayenta District O&M form which documents its *de facto* process for servicing O&M calls. The form is also used for recording system measurements during troubleshooting calls. The Kayenta District O&M form is succinct and captures information which could be used for measuring performance, identifying system-wide problems, and identifying the occurrences of customer abuse to the systems. The information is also valuable for documenting a unit's customer and long-term histories. Finally, it serves as documentation for NTUA in the event that a complaint is raised against NTUA or its employees. Reducing redundancy as data is entered onto the form would further enhance the effectiveness of this form. Clarification of the flow of information from the Customer Service group to the field team would also enhance the form's effectiveness.

An objective of improving O&M practices is to optimize the performance of PV systems for customer use. A benefit which affects the bottom line is that it extends the life-cycle of the equipment. A tertiary benefit should also be that it lowers the life-cycle cost of the equipment by lowering troubleshooting and O&M costs. An area which has not been explored to date is tracking costs related to the Solar Program, and collection of actual program costs would help reduce overall costs. Once program costs are available, NTUA could then determine the "typical" costs for the program. It follows that NTUA should be prepared to incur costs for maintaining PV systems throughout the life of a system. To enable this, charge costs could be provided so the warehouse could release parts to electricians for O&M and troubleshooting call. For example, parts that are worn due to customer abuse could be documented and those costs passed on to customers.

Finally, the approach of the Solar Program regarding O&M practices has been one which gives autonomy to each district to develop its own processes and encourages the treatment of PV system support on an individualized case-by-case basis. In an effort to reduce any adverse effects this decentralized approach might have inadvertently caused, the following suggestions might be taken under consideration by NTUA:

- Engage to get all systems in optimal working condition and redeploy PV systems to paying customers.
- Resolve Tariff/Contract Agreements: Currently, the NTUA shoulders the burden of ownership liability under a lease-to-own purchase agreement
- Provide a work-around solution for customer billing until new customer contracts are in place
- Standardize Solar Program operational practices across the company
    - Districts use common tools
    - Districts use common measurements
    - Teaming: electricians view one another as a resource
    - Perform as a measurement-based line of business
    - Set goals for the Solar Program:
        - X% Utilization
        - Cost $\leq$ Price
        - Revenue $\geq$ Cost

## APPENDIX

### PHOTOVOLTAIC O & M
KAYENTA DISTRICT

Customer Name: ______________________ Date Received: ______________________

| SUBSYSTEM | STATUS OK | PROBLEM | DESCRIPTION OF PROBLEM (Circle One) | | | |
|---|---|---|---|---|---|---|
| ARRAY | | | *FACTORY<br>*WIRING | *VANDALISM<br>*INSTALLATION | *AGING (WX / non-Wx related) | |
| CHARGE CONTROLLER | | | *FACTORY<br>*BYPASS | *INTERNAL FAULT<br>*EXTERNAL FAULT | *SET POINTS<br>*CONNECTIONS | *UNKNOWN |
| BATTERY | | | *FACTORY<br>*KNOWN | *MECHANICAL<br>*ELECTROLYTE | *CONNECTIONS | |
| INVERTER | | | *FACTORY | *DC DISCONNECT | *WIRING | *UNKNOWN |
| PV SYSTEM | | | *NONE | *DESIGN | *UNKNOWN | |
| FUSES | | | *SHORT | *OPEN CIRCUIT | *BATTERY | *ARRAY |
| INVERTER BOX | | | *KNOWN<br>*NONE | *DESIGN<br>*CONNECTIONS | *FACTORY<br>*VANDALISM | |
| WEATHER CONDITION | | | *RAINING<br>*FOGGY | *WINDY<br>*CLOUDY | *PARTLY CLOUDY<br>*SUNNY/CLEAR | |

**PANELS ADJUSTED FOR:** SUMMER OR WINTER **DISTILLED WATER USED:** __________ GALLONS

**VOLTAGE READINGS:**

OVERALL BATT: __________ CHARGE CONTROLLER: __________ AC OUTPUT: __________ ARRAY: __________

| BATT. #1 | BATT. #2 | BATT. #3 | BATT. #4 | BATT. #5 | BATT. #6 | BATT. #7 | BATT. #8 | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | VOLTAGE |
| | | | | | | | | SPECIFIC GRAVITY |

**AMPERAGE READINGS:**

ARRAY: **L1 - L2:** __________ **BATT. STRING:** __________ **LOAD:** __________

**L1:** __________ **#1:** __________

**L2:** __________ **#2:** __________

| **MODULES:** | | | | | |
|---|---|---|---|---|---|
| Top | | | | | |
| Bott. | | | | | |

**T:** Isc: ______ Voc: ______ **B:** Isc: ______ Voc: ______

**REMARKS:** ________________________________________________

________________________________________________

________________________________________________

________________________________________________

________________________________________________

________________________________________________

Svc. Order # : __________________ Hours: __________________

Serviced By: __________________ Mileage: __________________

Date Serviced: __________________ Unit #: __________________

**(05/03-VC)**