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LESSONS LEARNED FROM THE XCALAK VILLAGE HYBRID SYSTEM: A SEVEN YEAR RETROSPECTIVE

Robert E. Foster
Southwest Technology Development Institute, New Mexico State University
MSC 3 SOLAR, P.O. Box 30001, Las Cruces, New Mexico, 88003-8001 USA
Tel: (505) 646-3948, Fax: (505) 646-3841, rfoster@nmsu.edu

Ronald C. Orozco
Energía Total, P.O. Box 2644, Corrales, New Mexico, 87048 USA
Tel: (505) 890-1534, Fax: (505) 890-1559, ronorozco@energiatotal.com

Arturo Romero-Paredes Rubio
Ecoturismo y Nuevas Tecnologías S.A. de C.V.
Paseo de las Palomas #166, Las Alamedas, Atizapán de Zaragoza, Estado de México, 52970 Mexico
Tel: 52-5-824-1358, aromerop@mail.internet.com.mx

Abstract – The Xcalak village wind/solar hybrid system, installed in August 1992, has shown that a proper institutional support structure is key to overall system success. Unfortunately, the Xcalak hybrid was planned without any long-term support structure and "donated" to villagers incapable of maintaining such a complicated system. In March 1993 the system was instrumented by New Mexico State University to evaluate system performance. As the system aged without a maintenance program, so did the renewable energy power generation proportionally decrease. This paper outlines the general performance and conditions of the Xcalak system from 1992-1999. The authors summarize basic steps that were taken to support the failing system in 1998-99, how a tariff structure was created and institutionalized, and what the current status is of the Xcalak hybrid system and community organization.

1. INTRODUCTION

1.1 *Xcalak - Mexico*

Xcalak is a small remote village located on the coast of Southeast Mexico, in the State of Quintana Roo (18.2°N latitude and 87.8°W longitude). The community has about 400 inhabitants who make a living through fishing and small scale tourism. The community is located near the Chinchorro Bank, part of the second largest coral reef system in the world. Xcalak was an important maritime commercial port until it was devastated by Hurricane Janet in 1953, from which its population has never fully recovered. When the village was rebuilt, a diesel-powered mini-grid was provided by the Mexican government.

Fig. 1. Aerial view (looking North) of Xcalak, Mexico.

In 1992, the State Government of Quintana Roo funded the installation of the world's largest (at that time) and now longest operating wind/solar village hybrid system in Xcalak. The State had other experiences with renewable energy such as photovoltaic (PV) lighting systems for the Pino Suárez and Rojo Gómez communities in Cozumel province. The idea was to provide additional hours of power for the community beyond the 3-4 hours per day that the diesel was normally operated. A power line extension to Xcalak was estimated to cost over $3 million, thus the State looked to renewables as a more inexpensive solution. In 1991, the State of Quintana Roo opted to electrify the village with a centralized renewable hybrid energy system installed as a retrofit augmentation of the existing centralized diesel system. The combined wind/photovoltaic hybrid system hardware cost was approximately US$450,000.

The technical results of the PV lighting system efforts had proven acceptable, but the resulting social issues of the case of Xcalak, have presented much more of a challenge than PV lighting systems. The road for continuous hybrid system operation has not been an easy one, or even possible, for Xcalak. While the various technologies are proven, the institutional and organizational issues for this system and community have proved to be the most difficult to overcome.

1.2 *Diesel Grid System*

Diesel operation has often proved problematic for these types of villages, with the high maintenance requirements and fuel supply problems. As is typical in many Latin American diesel-powered villages, power is often only available for about 3-4 hours during the evening. When electricity is only available for a few hours in the evening, the typical village electrical load consisted of lights, television, and radio. The few village refrigerators and icemakers that exist are propane powered, since electricity is only available for a fraction of the day.

Xcalak had gone through a variety of diesel generators over the years, initially with a 250 kW unit from the 1930's, and afterwards with a 125 kW unit, and later with a smaller 30 kW. The larger units were oversized for the community loads. The 2,400 V electric distribution grid in Xcalak dates from the 1950's. The transformers are museum pieces and are not used elsewhere anymore.

The diesel generators have historically only been operated typically three to four hours in the evening. The community members have paid small amounts of funds for diesel fuel, while at other times the government has contributed diesel fuel. However, there are times when the diesel was not operated for a week or more due to lack of fuel and funds. On other occasions, the diesel has been out of service for weeks when maintenance is needed. In a hope to establish increased hours of electrical generation, the State pursued a wind/solar hybrid generation system.

1.3 *Wind-Solar Hybrid System*

Condumex S.A. DE C.V built the Xcalak hybrid system. The generation system consists of six Bergey Windpower nominally rated 10 kW Excel wind turbines and 11.2 kW of Siemens PV modules. Energy is stored in two battery strings using 216 GNB Resource Commander batteries for a combined total of 1738 Ah at 220 volts. The stored energy is provided to the town's electric grid via an Advanced Energy Systems 40 kW sinewave inverter. A separate diesel generator also powers the community grid independently (must be manually transferred).

In March 1993, the Southwest Technology Development Institute (SWTDI) at New Mexico State University designed and installed a data acquisition system to monitor system performance for Sandia National Laboratories (SNL). The purpose of the system monitoring was to learn more about how wind/solar hybrid systems function. NMSU monitored the system from 1993-96 for SNL and later in 1997-99 for the National Renewable Energy Laboratory (NREL).

Originally the wind and PV system output was adequate to nearly meet the entire village's electric power demand for 24-hour power. However, the village loads rapidly grew after system installation. By 1997 the Xcalak renewables system provided less than 30 percent of total community power due to significantly increased loads and lack of system maintenance (down from over 60% in 1995). The diesel generator was often needed once again for providing about three hours of power during the evening. No provisions had been made originally by the original project planners to maintain the Xcalak hybrid system. Currently the entire renewables system is inoperative due to an inverter failure.

Fig. 2. Xcalak wind turbines and PV array.

1.4 *Hybrid System Rehabilitation*

In 1998, SWTDI helped organize an ad hoc group of various Mexican and U.S. partners in an attempt to revitalize the Xcalak system. The purpose was to establish a long-term mechanism for tariff collection which could provide a financial base for continued systems operation and maintenance (albeit for the renewables generation or diesel generation). A community electric committee was formed to operate the system, electric meters were installed, and billing was initiated based on actual electric energy consumption.

The SWTDI implementing agent was Energía Total. Assistance was provided by the Universidad de Quintana Roo (UQROO), the Fideicomiso Xcalak representing the State of Quintana Roo, the Municipality of Othon P. Blanco, and the Comisión Federal de Electricidad (CFE). Funding for this effort was provided from the North American Fund for Environmental Cooperation (NAFEC), the State Government of Quintana Roo, and the American Wind Energy Association (AWEA). Additional in-kind support was provided by NREL, SNL, and Bergey Windpower (BWC).

Electric meters and new service entrance equipment was installed on all homes in June, 1999. This has allowed the community for the first time to charge users based on actual electric consumption (there were no meters previously). These funds should allow the community to have an equitable income source for future electric system operation and maintenance. However, the community still faces challenges in finding the skilled technicians required to maintain the renewables system and in raising sufficient funds for future system expenses such as battery bank replacement.

2. SYSTEM DESIGN AND INSTALLATION

2.1 *Original System Design Calculations*

The original design proposed in 1991 contemplated electrification of 80 homes in Xcalak (although there were actually only 60 inhabited homes at the time). Three types of electrical consumers exist in town: residential, commercial, and public services. Each home was assumed to have a load consisting of six fluorescent lamps, two fans, blender, color television, radio, and an iron. In addition, 50 streetlights of 55 Watts each, a community water pumping system, a 100 kg/day ice-maker, a school, a clinic, a 25 room hotel, 2 diners, and a church were considered in the original system sizing calculation.

Residential consumers can be grouped into two principle categories. On one side, there are those with low demand, who have only two or three lights, a radio, and occasionally a small black and white television in their home. On the other side, there are those who have a variety of appliances, including refrigerators, freezers and washing machines, similar to a middle-class family in the city. The freezers are used to freeze products from their fishing activities. The second group uses ten times more energy than the other group.

Loads that were considered prohibitive for the renewables system were refrigerators and ice-makers. It was originally proposed that these loads be served by liquid petroleum gas. A two-year financing program was proposed to allow villagers to purchase these appliances if they were interested. The total energy demand for the village was estimated at 150 kWh/day. All but 10 percent of this energy was to be provided by the renewable system, with the remainder supplied by a diesel generator.

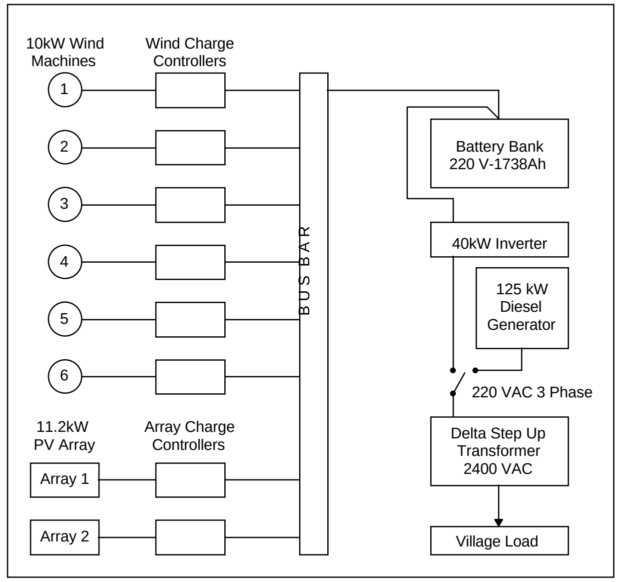
2.2 *System Installation*

The original Condumex proposal to the State of Quintana Roo to meet the anticipated load was for the installation of 22.4 kW of PV, 100 kW of wind generators, and a and a 3,500 A-h battery bank. The State was unable to fund a hybrid system of that size, and halved the original recommended design to 11.2 kW PV and 60 kW wind. In May 1992, a formal contract was placed for system installation, which was completed at the end of August of that year. Condumex was also responsible for the maintaining the system for the first two years of operation.

System components for the Xcalak hybrid came from a variety of countries, including Mexico, United States, Canada, and Australia. The remote Xcalak site was difficult to access, and with a wide variety of components from around the globe, logistics were complicated for system installation.

Some parts of the system were fairly simple to install, such as the PV array. While other parts, such as the battery bank, which nearly weighed 14 tons, and the six wind generators, with towers weighing nearly 10 tons, required special care and effort for installation. Civil works for this sandy beach soil with a water level at only 3 meters required special care in engineering. However, by June 1992, the installation was underway for a successful August completion. The Xcalak hybrid system proved to be a learning experience for all involved with the installation, and later with operation.

The system one-line diagram is shown in Figure 3. The renewable energy system was designed to supply 150 kWh/day during the low wind months. The output of the system is 220 Vac-3 phase and is stepped up to 2400 Vac-3 phase for distribution.



Xcalak Power System One-Line Diagram

Fig. 3. Xcalak hybrid system configuration.

2.3 *System Operation*

The Xcalak hybrid was operated and maintained for the first two years by the original installer under contract to the State of Quintana Roo. Afterwards, the State owned the system and “gave it” to the community (although the community did not particularly want to own the system). No technical assistance, nor information, was provided to the community on how to maintain the system. Nor was any type of mechanism set up to allow for tariff collection. The people of Xcalak were not paying anything for electricity at this point, only using what energy was available from the renewable energy system. The diesel was never operated during the first three years after the hybrid system installation. Since the users were not paying for electricity, the system saw tremendous load growth as more electric appliances (e.g., freezers) were added in the community . For instance, from April 1993 to March 1994, the village load grew 53 percent.

Later, the community began charging a flat fee for energy to help purchase some diesel fuel, water for the batteries, etc. However, this flat fee still left the users free to use as much energy as they wanted. Currently, a new tariff structure is being implemented along with a new operations and administrative plan as presented herein.

3. SYSTEM PERFORMANCE

3.1 *System Monitoring*

A data acquisition system (DAS) was installed in March 1993 by SWTDI, SNL, the Instituto de Investigaciones Eléctricas, and Condumex. The DAS monitors hourly average system performance parameters. The data is collected via a cellular phone link. The DAS has been maintained and collected data since 1993.

Anemometers were installed at the wind turbine hub height of 24 meters in the north section of the wind field. On a yearly basis, Xcalak is a Class-3 wind site with an average wind speed of 6.4 meters/second at 24 meters. The lowest wind period occurs during the fall, and the highest wind season is late spring and late summer.

Figure 4 shows the average daily instantaneous load and average daily inverter runtime by month for the first year of operation. The average daily instantaneous power load in April 1993 was 12.4 kW, and the inverter was on an average of 21 hours per day. This means that the system provided energy production of about 260 kWh/day at that time. The daily average instantaneous power load in Xcalak increased significantly during the first 18 months of operation from 12.4 kW in April 1993 to 19 kW in March 1994, a 53% increase.

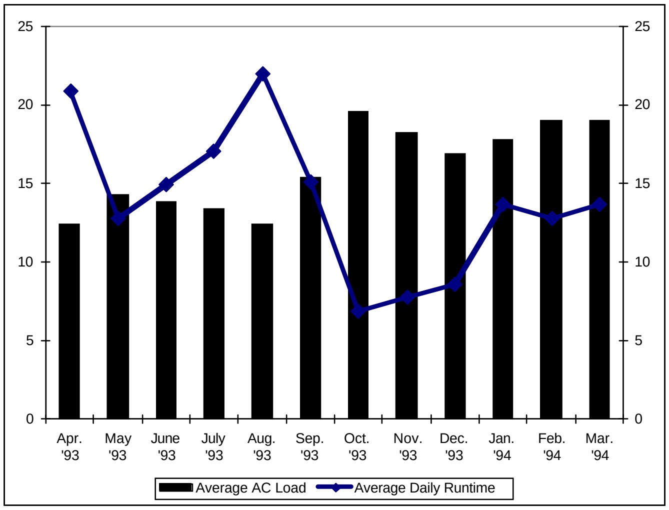


Fig. 4. Xcalak monthly load growth (kW) and average daily runtime (hrs/day) during 1993-94.

Since the renewables system can only produce a fixed amount of energy, an increase of instantaneous power demand dictates a decrease in the daily inverter runtime. Understandably, the average daily inverter runtime decreased for the system as the load grew. In March 1994 the average daily runtime was 14 hours per day as compared to 21 hours per day in April 1993, which was a decrease of 50%. Load growth more or less stabilized as system performance decreased; people were no longer purchasing appliances since they could not be used as much. The average daily load and runtime for 1996-97 is shown in Figure 5. Note that the load growth had curtailed by this time and not much different than late 1994 (the inverter was down during the late October through December period).

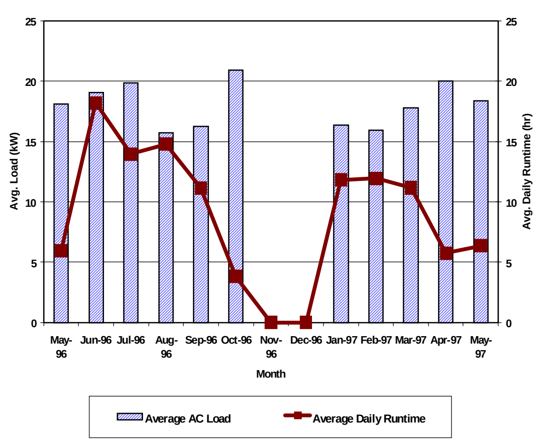


Fig. 5 Monthly load (kW) and daily runtime (hrs) 1996-97.

During the early years of operation (e.g., April 1993 to March 1994) the system produced 77.3 MWh of ac power. The wind machines produce about 80% of this energy. For example, in March 1994, the wind machines produced about 230 kWh per day, as compared to the PV, which produced about 44 kWh per day. Since most of the energy is produced by wind machines, the system availability has always been dictated by the wind resource and not the solar resource.

The total energy provided and used each month is directly proportional to the available wind energy. In October, when the wind resource is lowest, the total energy provided to the village averaged 140 kWh/day during the early years, close to the original predicted performance of 150 kWh/day. In the high wind months, the total energy provided averaged about 240 kWh/day during the early years.

Using the actual power curve from the machines in Xcalak, a wind-utilization factor can be determined for each turbine by month. The factor is the ratio of the energy actually produced in the battery charging configuration to the energy, which could be produced under optimum energy-transfer conditions. During the peak of renewables generation, wind-utilization factors varied from a high of 97% in the low wind months of October, November, and December to a low of 68% in the high wind months of May and September. Each of the wind charge controllers are independent and have separate set points. As the batteries approach full charge, the controllers regulate the wind machines. During the low wind months, the batteries do not reach full charge as often; thus, the wind machines are utilized more.

As hybrid system maintenance issues were ignored, the renewable energy production of the system decreased. The actual percentage of time that the renewables portion of the electric system provided power from 1993-98 is shown in Figure 6. During the first three years of operation, the diesel generator was never used. The increase in generation from 1997 over 1998 is due to UQROO maintenance efforts.

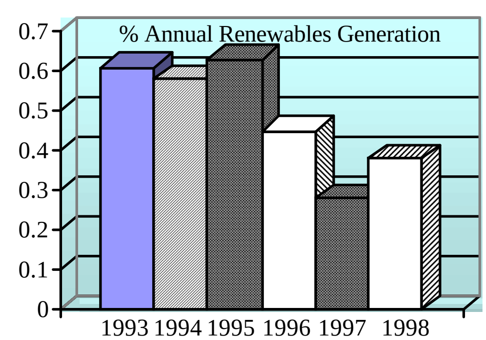


Fig. 6. Annual percentage of time that the renewables hybrid system powered the Xcalak community from 1993-98.

Important knowledge has been gained due to the long-term monitoring of the Xcalak hybrid system. For instance, Xcalak system monitoring results served as a key element of the database for NREL in developing the Hybrid 2 simulation program. The Xcalak system also has served as an example of pitfalls to avoid for the 100 kW wind/solar village hybrid system in San Juanico, Baja California Sur, Mexico, which was inaugurated only last month.

3.2 *Technical Challenges*

The Xcalak hybrid system is located in one of the most challenging tropical salt spray environments in the world. The system itself lies a mere 100 meters from the water's edge. This unforgiving salt spray environment is a challenge for any piece of hardware to survive. A maintenance infrastructure in such a harsh environment is absolutely critical, however no such long-term infrastructure was contemplated in the original project. Thus, many of the hybrid system components have suffered from a general lack of maintenance and have degraded over time. While some ad hoc attempts by UQROO, AWEA, CFE, and others have been made to conduct occasional repairs, there has been no consistent maintenance program for the system and no responsible party for conducting such maintenance.

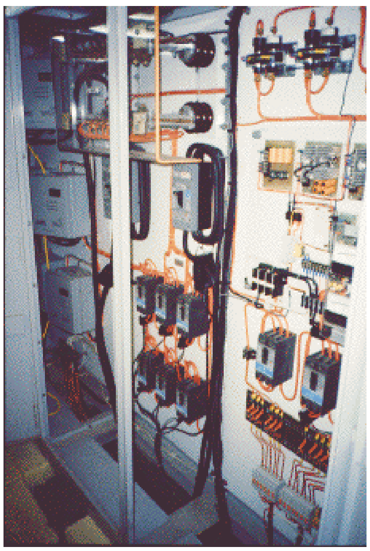


Fig. 7. System disconnects and controllers for the PV array (foreground) and wind turbines (rear).

3.3 *Inverter*

The Australian made Advanced Energy Systems 40 kW inverter was designed to carry the village load. There was also a manual transfer switch to the generator to carry the village load for long periods of time when there might be little wind. There was no provision to charge the battery bank from the generator (via the inverter) in the original system design. Later boards were developed for this type of inverter that now allows for this provision, although the Xcalak system has not been upgraded.

The AES inverter has faced a difficult job in Xcalak with highly unbalanced system loads due the use of a few large distribution transformers - thus restricting optimal phase balancing. These conditions have caused the inverter to suddenly disconnect at times. The inverter literally baked some of the its wire insulation, which was later replaced. Failed inverter fans caused overheating and significant corrosion of internal inverter components. Inverter corrosion was further exacerbated by drawing humid air from below ground concrete raceways. Some of the inverter analog meters have not functioned well.

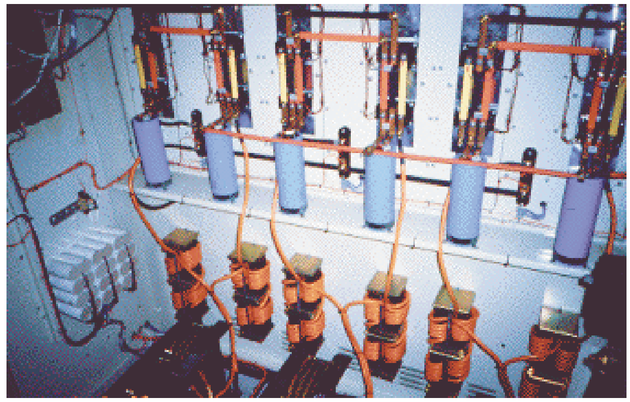


Fig. 8 40 kW Xcalak inverter.

The inverter has had four major failures since installation where the insulated gate bi-polar transistors (IGBT's) have blown due to surges, mostly related to area lightning events. Three times the electronic circuit boards have been repaired or replaced, and the inverter has not been functional since the fall of 1998 due to a failure in the controller cards during a lightning event. The inverter manufacturer has promised to repair and upgrade the inverter, but has not yet set a final date for this intended repair. There is no one locally capable of conducting this repair. Presently all renewable energy generated by the wind turbines and the photovoltaic system is lost due to the inoperative inverter. All power to the community is currently provided by the diesel generator, normally only operated three to four hours in the evening.

3.4 *Wind Turbines*

The Xcalak hybrid system inlcudes six BWC Excel 10 kW wind turbines. No special request or specification for anti-corrosive hardware was made by the system installer. Thus, it comes as no surprise that with continual exposure to salty air, corrosion and eventual failure of the wind turbines occurred. In 1998, all six wind turbines were lowered and locally rebuilt to the best of the abilities of the UQROO.

Another aspect also not understood by the original system installer was that these wind turbines, with a 3 phase AC variable frequency output, were rectified for battery charging. Thus, held at a constant battery bank voltage, they are only capable of producing a maximum of about 7 kW of power in this configuration.

Fig. 9. Xcalak wind turbines in 1992.

Lightning has been an occasional hazard for the Xcalak wind turbines during severe storms, despite normal system grounding. One wind turbine failed about seven months after installation due to a lightning strike, and was quickly removed and repaired. Three years later, lightning once again struck and slightly damaged two turbines that were repaired locally. A third lightning storm in the fall of 1998 again took out two wind turbines and the inverter.

There have been other components that have had to be repaired, such as replacing the guy lines (the original galvanized ones had severely corroded after five years). Four turbine nose cones whose supports had rusted were replaced. The turbine tower disconnects and fuses suffered severe corrosion and were replaced in weatherproof enclosures. All of the furling winches and lines have been replaced due to corrosion. All of the turbine furling dampers, which corroded to the point that the turbines would not unfurl, were replaced with appropriate corrosion proof dampers provided by BWC. Most of these maintenance activities occurred in 1996 under AWEA sponsorship.

However, by January 1998, only one wind turbine was actually generating power. UQROO, with some guidance from BWC and EyNT, rewound all of the turbines and replaced the permanent magnets in 1998. Thus, by late summer of 1998, five of the six wind turbines were once again providing power. Two turbines are in need of a some repair after a lightning event during the fall of 1998, and one turbine has blades that need to be rebalanced. Five of the wind turbine controllers require some repair at present.

3.5 *PV Array*

The Siemens M-75 PV modules have performed reliably and not suffered any problems. Minor corrosion is visible on some of the galvanized module frame screws. Module degradation in this hot and humid tropical climate has been within acceptable ranges and within manufacturer guarantees. The Condumex designed PV controller has never failed. The only time the PV system went off-line was in 1995 when crabs ate through some wire insulation in the raceway and shorted the PV array (no harm to the system but the crabs were fried). This short was quickly repaired by the local office of CFE (the national electric utility). CFE support for the hybrid system has varied over the years and has normally been limited to occasional good neighbor actions on the distribution side. They have no mandate to operate small community power systems such as Xcalak.

3.6 *Battery Bank*

The GNB Resource Commander batteries have performed reliably since installation, this despite a hot climate and somewhat frequent and abusive charge and discharge cycles. The PV array helps maintain the battery bank charged when the wind turbines are off-line. One battery was randomly removed for dissection by GNB in 1994. The battery was found to be in excellent condition. Only one cell out of 216 cells has failed to date. It is difficult to quantify how much longer the seven-year-old battery bank will operate adequately, however the batteries are still functional.

Fig. 10. Battery bank for the Xcalak community.

3.7 *Distribution and Secondary System*

A 2,400 volt Delta primary distribution system provides 120/240 volt Wye open secondary circuit through five 50 kVA step-down transformers. The distribution system was installed by CFE and maintained by them when formally requested to do so by the State of Quintana Roo.

Secondary services typically connected with 12 or 10 AWG two-wire conductor wrapped around the open secondary 4/0 open secondary conductor. Most services were connected without a meter and, in many cases without any fused disconnect means - some houses were hardwired such that all lights were on whenever electricity was available!

In May 1998, Energia Total completed a detailed analysis of the primary and secondary distribution system in Xcalak. Findings were that the primary system was capable of serving up to four times the existing load without significant voltage drop. However, low voltage found at several delivery points was due to poor secondary connections and inadequately sized service conductor.

With funding support from NAFEC and NMSU, Energia Total recently lead a group of students from UQROO and village volunteers on a 14-day campaign to replace all existing service drop conductor to #6 or #8 AWG. They installed new #6 AWG service entrance conductor, new aluminium meter bases, new meters, and a new non-metallic load center with a minimum 20 Amp breaker at 100 service points within the village.

Fig. 11. Universidad de Quintana Roo students pre-wiring meter base and load center in Chetumal (1999).

CFE and UQROO are currently collaborating in the repair of all distribution transformers. Once this is complete, the Xcalak distribution system should be capable of serving loads in excess of three to four times the current demand without significant voltage degradation.

4. INSTITUTIONAL ISSUES

4.1 *Background*

The Xcalak hybrid system is considered by many as a failure. After the Xcalak installation, there were no new village hybrid installations in Mexico for six years, and a similar sized hybrid system in Belize decided to use only PV (100 kW). Under closer examination, the root cause of most Xcalak system outages has not been poor equipment design or acts of God, but rather the lack of simple and regular maintenance. This lack of maintenance, in turn, is the result of an inadequate institutional structure to operate, administer, and maintain the system. Perhaps this situation is a classic example of a technology solution improperly introduced into a village setting without adequate "buy-in" and villager participation and training.

During the first two years of system operation, Condumex bore the responsibility for system operation and maintenance for the State. No individual kWh meters were installed, no bills were issued, and no revenues were collected during this period. In addition, more people were moving into Xcalak and hooking themselves up on the electric grid on their own. Eventually, a flat-fee tariff was implemented by an ad-hoc village electrification committee in 1996 to generate revenue for the purchase of diesel to serve the increased demand and compensate for declining renewables power availability.

Fig. 12. The man on the electric pole is conducting an unauthorized and home-made Xcalak grid connection (1994).

In October 1994, an attempt was made to transfer ownership and operational responsibility of the hybrid system to the village electrification committee. Highlights of the proposed transfer are as follows:

- CFE was to install meters and rebuild the distribution system and train villagers in meter reading and basic billing and accounting;
- the Municipality was to assist in strengthening administrative capabilities of the village electrification committee and, working closely with the CFE, develop a recommended tariff;
- Condumex was to provide technical training;
- And villagers were to implement the proposed tariff and implement the proposed administrative changes

Unfortunately none of the partners to this agreement kept up their end of the deal and the village electrification committee became the default institutional structure for operation, maintenance and administration of the system for the next five years.

Without the help of meters to fairly implement a use-based tariff, the village electrification committee relied on the good faith of villagers to pay a flat fee for energy consumption. This lead to bitter fighting among villagers who refused to pay the same as their neighbours who obviously used much more electricity than they did. The situation deteriorated to the point in 1998 where only about 50 percent of the community was regularly paying the equivalent of about US$5.00 per month for electric service from a system that lacked maintenance and provided only 4-6 hours of electricity per evening.

In 1997, SWTDI successfully presented a proposal to NAFEC to introduce meters at each service point and present recommendations for a cost-recovery tariff and introduction of administrative management improvements.

4.2 *New Metering System*

As part of the NAFEC/SWTDI-supported effort, Energia Total lead a team of UQROO students and village volunteers, and installed 100 new aluminium meter bases and new meters for every residence and commercial establishment in the village of Xcalak. This effort took place in June 1999 and was supported by CFE with personnel and material assistance.

These meters provide a much-needed tool in the re-construction of the hybrid system at Xcalak by providing a means through which a use-based energy tariff can be implemented and a operations and maintenance fund can be established.

Fig. 13. Universidad de Quintana Roo student assisting with meter installations in Xcalak, June 1999.

The budget required for directly supporting the institutional efforts in Xcalak, including the hardware and installation cost for meters and new service entrance equipment was about US$50,000 - or less than 7 percent of the total installed system cost. Had this investment been made up front during the first year of the project, performance history of the Xcalak hybrid system would undoubtedly be considerably better than that reported today. Simple preventative maintenance steps could have been funded all along with revenues generated from a use-based tariff and managed by the villagers. Thus, project planners for similar projects such as this should plan from the start for this type of expense.

4.3 *Tariff Reform*

As part of the NAFEC-funded effort, Energia Total developed a series of recommended tariffs for implementation in Xcalak. The underlying assumption in the tariff analysis is that, like all other village electrification systems in Mexico, the villagers are not expected to recover the entire capital cost of the generation system.

The new meters will be used by the villagers to determine actual energy use and further refine a tariff based on actual energy usage (no good point-of-use consumption data are available at this time).

Since the renewable energy system was inoperative when the new meters were installed, the first tariff proposed was based on the cost of operating a diesel genset. A simple structure with a fixed cost of US$5.00 minimum per month for the first 15 kWh and a US$0.20 per kWh for all subsequent energy usage is proposed. Interim meter reading information may allow the base charge to include up to 30 kWh per month, depending on consumer reaction to the proposed rate. The rate is based on estimated cost of diesel fuel and basic diesel genset maintenance and administration.

Once the renewable energy system is functional, the results of a more detailed tariff analysis can be implemented. This analysis was developed by Energia Total with assistance from NREL, and is based on the premise that energy supplied by the renewable system should be available to all villagers on an equal basis. Those residents or commercial establishments imposing an energy demand on the system beyond the capability of the renewables system should pay the full cost of diesel generation. Since the output of a fully functional renewable system in Xcalak is expected to produce on average about 200 kWh per day or 60 kWh per client per month, the following tariff was derived:

Fixed Cost	- US$9.00 for first 60 kWh per month
Variable Cost	- US$0.20 per kWh for additional kWh

4.4 *Administrative Structure*

After considerable discussion with village leaders over a 12-month period and based on more than three years of working in the village of Xcalak, Energía Total developed a proposed administrative structure that maximizes local participation while addressing local limitations.

The proposed administrative plan calls for transformation of the existing Fideicomiso (or trust fund) which was originally established to channel State funding for assistance to Xcalak, into a permanent institutional structure called the Fideicomiso Operativo Xcalak (FOX). A detailed document has been developed which presents the goals, structure, policies and regulations of this new entity.

The new FOX will have a governing board with majority representation from the villagers and minority voting membership from the State of Quintana Roo, the Municipality of Othon P. Blanco, and UQROO. Responsibilities of each officer of the governing board are presented along with detailed administrative policies regarding routing and extra-ordinary activities of the board are presented. Creation of sub-contract for operation, maintenance and routine administration of the system is also recommended. This sub-contract relationship provides for local participation to a point while inviting outside participation to meet more strict operations and reporting requirements established by the FOX.

The recommended institutional plan also calls for creation of two bank accounts within the FOX. An Operations Fund will be used to routine expenses such as fuel and spare parts. All revenues collected by the sub-contractor will be deposited in this account. Monthly the governing board will review the balance in the Operations Fund and make transfers to a Reserve Fund that will be used for extra-ordinary expenses such as major repair or system improvements. This structure should provide an adequate system of checks and balances without imposing cumbersome bureaucratic procedures. This structure is based on specific recommendations from the existing village electrification committee who were concerned about any potential mismanagement of funds and welcomed a more open and transparent accounting system.

4.5 *Service Contracts*

Prior to any villager receiving a new meter and being connected to the system, each was required to sign a service agreement. This service agreement serves as a contract between the client and the FOX within which the basic terms of service are presented. For example the client agrees to adhere to the policies and regulations as adopted by the FOX including tariff structure and disconnect policy.

4.6 *Energy Efficiency*

An aggressive energy efficiency program was implemented by the UQROO and Energía Total through which 200 compact fluorescent lights were distributed within the village. UQROO also developed three flyers on energy efficiency and appliance usage. The implementation of a use-based energy tariff in a village where people are accustomed to paying a minimal flat fee (or paying nothing!) for electricity will definitely provide fertile ground and receptiveness to even the simplest energy efficiency measures.

5. CONCLUSIONS AND RECOMMENDATIONS

The early years of operation of the hybrid electric system in Xcalak clearly demonstrate that wind and photovoltaic technologies can be combined to provide abundant and reliable electric service in remote areas such as found in many coastal regions of the developing world. However, the lack of attention to institutional issues lead to inadequate system maintenance, excessive load growth (53% during the first year alone), and eventual system degradation to the point of failure.

For hybrid systems to be a viable and sustainable energy solution for remote village applications, an adequate and manageable institutional structure must accompany the technology intervention. The need for accurate meters installed at each point of service is required to empower local leaders to establish a use-based tariff that is equitable and manageable. Villagers need to be trained on how to operate an equitable tariff system.

Distribution system improvements and energy efficiency measures should be incorporated in all renewable energy projects to optimize energy use, reduce system losses, and improve service quality. Key lessons learned from the Xcalak hybrid system experience are as follows
:

- Maintenance is critical for long-term system survival;
- System ownership and responsibilities need to be established early on;
- Metering is key for successful operation of village hybrid systems;
- Local village support and training is crucial for a successful hybrid system;
- Long-term planning is needed for all village hybrids;
- Corrosion proof hardware for coastal locations is required; and,
- Battery charging from the generator is needed to enhance system efficiency and battery life.

To avoid failure, village hybrid systems must include realistic system sizing and proper institutional controls from the onset. Planners must allow for anticipated load growth, a realistic tariff structure, and a means to meet future maintenance requirements. Only then can these types of large village hybrid systems better serve villagers in meeting their electrical needs.

REFERENCES

Orozco R., Morgenstern J. (1999) Propuesta de Establecimiento de Tarifas en Xcalak por Consumo de Energía - Reporte Final. Report for New Mexico State University and the North American Fund for Environmental Cooperation.

Orozco R., Kissmann S. (1999) Plan Administrativo para el Fideicomiso Operativo Xcalak. Report for New Mexico State University and the North American Fund for Environmental Cooperation.

Orozco R., Mettler R., - Energía Total (1998) Technical Report - Primary, Secondary, Service Entrance and Efficient Lighting for Xcalak. Report for New Mexico State University and the North American Fund for Environmental Cooperation.

Orozco R., Romero A., and Foster R. (1997) Recommended Institutional Solutions for the Xcalak, Quintana Roo Village Hybrid System. Report for U.S. Export Council for Renewable Energy, GHO II-14-01, Washington, D.C.

Romero A. (1996) X-Calak, El Nombre de un Sistema Hibrido. Report for New Mexico State University.

Bergey M. (1996) Xcalak - A Story of Re-Electrification. *Solar Today*, Vol. 10, No. 6, Nov/Dec, American Solar Energy Society.

Orozco R., (1995) Institutional Issues Related to the Xcalak, Quintana Roo Hybrid Electric System. Report for NRECA International.

Durand S., Foster R., Roberg J., Romero A., Pate R. (1994) First-Year Monitoring Results of the Wind/PV Hybrid Power System in Xcalak, Quintana Roo, Mexico. *In Proceedings of AWEA Wind Power 1994,* 10-13 May, American Wind Energy Association.

Foster R., Durand S. (1993) Site Survey for the Hybrid Electrical Generation System: Xcalak, Quintana Roo, Mexico. Report for Sandia National Laboratories, Division 6218.

Foster R., Durand S. (1992) Instrumentation for the Hybrid Electrical Generation System: Xcalak, Quintana Roo, Mexico. Report for Sandia National Laboratories, Division 6218.