

# WIND HYBRID SYSTEMS TECHNOLOGY CHARACTERIZATION



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## HYBRID SYSTEM DEVELOPMENT HISTORY

Village hybrid energy systems employing renewable energy offer an attractive and practical approach to meet electrical power needs in rural communities around the globe. Technology advances over the past decade have made renewable energy sources more viable than ever in displacing diesel power to meet isolated grid-power needs. The key to long-term success for any village hybrid system is to install a well designed and well thought out power system, while keeping in mind the institutional framework and structure needed to provide long-term operation and maintenance for the system.

The first village hybrid systems were installed in Arizona and Utah in the late 1970s and were photovoltaic (PV) powered. These early systems helped pave the way for the emergence of wind power as another option for village power generation in the 1980s. Wind-diesel was considered because of the high costs for generating power in isolated systems. In Canada, there were more than 800 diesel generating sets [1] with a combined installed rating of over 500 MW. Remote power for the world was estimated at 10.6 gigawatts [2]. Of that, most was in diesel generator sets, as in 1990 there were an estimated 133,816 diesel generator sets ranging in size from 5 to 1000 kW [3] with a power rating estimated at 9.1 gigawatts. By 1986, more than a megawatt of wind turbines for wind-diesel systems were installed, although most were at large diesel systems. These were demonstration and/or prototype systems.

Different aspects of wind-diesel systems were presented at wind energy conferences in North America and Europe. A wind-diesel conference for Canada and the United States is held annually, [4]. Work on modeling, design, and operation had proceeded to the point where a guidebook [5] and a book on wind-diesel systems were published [6].

The University of Massachusetts worked on wind-diesel systems, especially modeling. Wind-diesel systems were developed and tested at Riso National Laboratory, Denmark; the Netherlands Energy Research Center, Petten, Netherlands; Atlantic Wind Test Site, Prince Edward Island, Canada; National Renewable Energy Laboratory, USA; and other locations. Primary work was conducted on developing wind-diesel systems for the retrofit market. This market would be for existing diesel generators in windy locations, which would be over 50% of the installed capacity [3].

The other market is for village electrification, estimated at 26 gigawatts [3] in 1990. The remote village power market is different in that hybrid systems now can be designed as a complete system with options of wind, PV, batteries, and diesel. The major problems are in sizing the components of the system, cost of the systems, and no volume production of systems with the corresponding price reduction. A number of prototype and demonstration systems have been installed (see Table of Hybrid Systems). An international conference on village power systems is held periodically [7]. An excellent source of information on village power is *Renewables for Sustainable Village Power*, <http://www.rsvp.nrel.gov>.

Diesel generators are universal because they do well on a broad range of criteria. There is an infrastructure for repairs, although it might be minimal, and the controls are simpler. In many remote villages the cost of diesel fuel is not the largest cost; therefore, the other costs have to be reduced. The first option to extend transmission lines is almost always uneconomical because of distances and the small village loads. The second option is to seek administrative economies of scale by merging utility organizations, even though the independent power plants must still be operated and maintained. There are some advantages, but near term rate reduction does not happen, because the regional utilities tend to take on costs that individual villages typically do not, such as higher level preventive maintenance as well as property damage and liability insurance.

## EARLY VILLAGE HYBRIDS

### *Papago Indian Village, Schuchuli, Arizona*

In 1978, the world's first renewable energy village hybrid diesel system, a 3.5 kW PV array, was installed to provide electricity for a community refrigerator, freezer, washing machine, sewing machine, water pumps, and lights for the village's 16 homes, church, and feast house. Water was pumped by a diesel engine, which was a drain on their financial resources because of the cost of maintenance and fuel. In 1983, the electric grid was extended to the village and then the PV was only used for pumping water.

### *Natural Bridges National Monument, Utah*

Prior to the installation of the PV system in May 1980, the Monument relied on diesel generators, operated continuously. The Monument consumed up to 200,000 kilowatt hours of electricity annually, and the noise and pollution was incompatible with Natural Bridges' pristine desert setting. With installation of the PV system (in 1980 it was the world's largest PV array) and the implementation of energy-efficient measures, the Monument now consumes about 70,000 kWh annually with over 90 percent of that coming from the sun. Most heating and cooking needs continue to be met by liquefied petroleum gas.

System components are PV (original Block III) modules nominally rated at 100 kW, inverter (50 kW), 39 deep cycle batteries (600 kWh), and diesel generator (40 kW) - all original components have been mostly replaced in the 1990's). Maximum draw down of the batteries is 450 kWh, enough for two days of operation. The automatic control allows the PV system to operate for extended periods without human intervention. Near full charge, the controller will disconnect (shed) one or more of the 48 array stations to prevent overcharging the batteries. It also starts the backup diesel generator automatically when the battery state-of-charge (SOC) falls below 20 percent.

The original batteries provided excellent service for 10 years. Then for two years the system was not operational. In 1992, the system was refitted with new batteries and the PV array was downsized to 50 kilowatts. By the late 1990s, the original PV modules were replaced with Block V modules working with a diesel generator to charge a battery bank. This is the oldest continuously operating renewable energy hybrid system in the world (since 1980).

## CURRENT SYSTEMS

A compilation of the hybrid systems greater than 4 kW is given in the Appendix 1, Table of Hybrid Systems. Laboratory test projects were not included. The table lists site name, location, sizes/manufacturer of components, and the current status of the system. Hybrid systems have a 65% or more failure rate, with failures due to components failing, poor maintenance, and inadequate support by systems suppliers after installation. Institutional issues related to lack of proper maintenance usually prove key in the death of most any village hybrid system (i.e., systems have often been installed and then walked away from and expected to survive on their own).

Developing countries desire hybrid systems for supplying energy for remote villages without increased infrastructure demands on the limited resources of the central governments [8]. The Homer Code from NREL compares the cost of hybrid systems with grid extension.

However the fairly simple installation and initial support for hybrid systems make the subsequent failures of many of these systems even more deplorable.

In some cases pilot projects and their location are selected for political reasons, without the needed local education, without trained local service personnel, and without consideration of the renewable energy resources. Field training and systematic follow-up to the system usage and operation would yield far greater rewards than the feel-good articles in local and international publications of a system that fails in two years or is simply unused due to failures that could be easily corrected by better trained local service personnel.

## **SIZES**

Hybrid systems come in many sizes to fit the need for energy and the resources available to the end users. Solar PV panels and gas/diesel gensets generally give good performance where fuel is readily available but utility power is not. Sizes of systems range from home sized (1 kW) up to village systems of megawatts with 500 kilowatts of renewables added to the generation mix. The expected contribution of the renewable energy was to reduce the dependence on the conventional fuel source and to stabilize the performance of the grid by making it less “one-dimensional” in its dependence on single sources of energy or to provide electrical power where none was available before. Small, single source, electrical power is generally PV (50 to 100 W) or, in some cases, a small wind turbine (100 to 300 W) and are not hybrid systems.

## **LOCATIONS**

Systems are located throughout the world from Latitude 67 North to South, an area covering 80% of the worlds’ population. Systems were added to existing mini grids, created as part of a new micro or mini grid and operated in standalone units. The local terrain varies from coastal flatlands to mountain villages, from seaside, highly corrosive environments to arid locations without significant moisture.

## **PUBLIC ACCEPTANCE**

In some villages, exposure to the first hybrid systems source led to an explosion of energy use. Load management needs to be considered for every hybrid installation since system designers cannot plan for unlimited growth in their initial system plans. Enforcing payments from the energy users seems one way to curb the exponential growth in system load, but it is feasible only if the costs are kept low so that energy value remains affordable. Adding water supply pumps to areas that rely on hand transported water in the past often gains in manpower resource what it costs in capital. As one researcher has said, “A 14 year-old girl who no longer has to carry water from a river 5 kilometers away, due to a small wind water pump system you have installed, is your friend for life.”

## KNOWN PROBLEMS

1. Cost: Too high for village systems. Systems are subsidized, and the question is by whom and for how much?
2. Operation, performance, and reliability are low:
  - a. Systems not operating. Long term O&M is a problem.
  - b. Local trained operators: If there is a system failure of any kind, lack of observation, diagnosis, and repair to get the system operating can take months or longer.
  - c. Management, tariffs, etc.: Unrestrained load growth on a village system cannot be supported. Free energy and no one at the local level has any ownership in the system. Minimal payment for energy has to be implemented at the local level.
3. Environmental: Corrosive and arctic environments require consideration in equipment and operation and maintenance.
4. Manufacturer/Sales Support: Pilot and demonstration projects require at least two years of support, whatever the cost.
5. Regional Infrastructure: Need enough systems installed in a region so you can have regional utilities to get economics of scale for administration and operation and maintenance.

Larry Flowers summarized the "Lessons Learned" [9], where the eight NREL Village Power Team members were polled concerning pilot projects. Five categories were chosen with sub problems or concerns:

1. Institutional: local partners, maintenance, tariff design, development coordination, delivery, planning tools, economics.
2. Pilot project characteristics: performance, replication mind-set, one-of-a-kind, proven technology, loads, diesel retrofits, performance monitoring, buy down, multiple projects.
3. Implementation process: political will, duration, commercial replication, solution bias, administration.
4. Operational issues: meters, energy efficiency, maintenance.
5. Technology developmental needs: hybrid systems, controls, lightning/corrosion, meters (low cost prepaid), resource data, integrators/package systems.

There is a lack of high-quality, well-documented information of the true performance and costs of hybrid systems. Through detailed monitoring and evaluation of pilot systems, a large discrepancy was found between the power produced by small wind turbines and energy production estimates based on the wind resource and the turbine power curve. The reasons for this discrepancy vary but can result in a 75% reduction in turbine output. Partial solutions include the wider use of discretionary loads and improved system control. System design impact should be considered and computer models need to be evaluated to accurately assess this problem [10].

## HYBRID CASE STUDIES

### GOOD EXAMPLE - KOTZEBUE, ALASKA

The primary objective of the wind/diesel hybrid project was to bring more affordable electricity to remote Alaskan communities [11]. Adding wind turbines to a diesel grid can lead to dramatic fuel savings. Fuel costs in remote villages can run from \$0.07 to over

\$1.00/kWh. Wind hybrid systems are also an avenue for the development of local jobs. When the energy needs of a community grows, existing fuel storage will have to be increased.

The Kotzebue Electric Association (KEA) Wind Farm has been in operation since 1998. It was a demonstration project showing how wind energy could fit in the energy mix of rural electric cooperatives. The experience gained from this project is expected to be directly applicable to remote villages worldwide.

Kotzebue Electric Association (KEA) grid has six diesel generators with a combined capacity of 11.2 MW. Annual peak and minimum loads are around 3.9 MW and 1.8 MW respectively. The Annual average load is about 2.5 MW. Loads are greatest during the winter months for heating and lighting. KEA maintains a high reserve capability to prevent loss of power during the winter. Critical loads include the heating of the town water supply. Typically, KEA runs two generators continuously during the winter with the rest as back up. KEA consumes on the average 1.4 million gallons of diesel fuel with an average efficiency of 14 kWh per gallon. The energy costs for the diesel generators were estimated at \$0.50/kWh. There is a potential ecological problem as huge bladders of diesel are stored onsite during the short summer season when the river is navigable by barge to off-load a year's supply of fuel at a time.

The wind farm of 10 wind turbines (Fig. 1) is located on a relatively flat plain four miles south of Kotzebue and half a mile from the coast. The area is characterized by treeless tundra. The site is well exposed to the easterly winter winds and the westerly summer winds. Energy costs for the wind turbines were estimated at \$0.13/kWh, and the wind turbines reduced the need for diesel fuel.



**Figure 1. AOC wind turbines at Kotzebue wind farm in Alaska.**

Annually, each of the AOC 15/50 turbines at the site is expected to eliminate the need for about 9,000 gallons of the diesel fuel that is normally used to produce electricity. The 10 turbines will reduce the annual fuel by about 90,000 gallons, which is about 6% of normal fuel requirements. At the 1998 cost of fuel to the co-op, 94 cents/gallon, this would save KEA and its member-owners around \$84,600 each year. In addition to direct fuel cost savings, the co-op will save money in reduced costs of storage and pollution control requirements associated with diesel fuel.

In the year 2000, the ten wind turbines produced 1.1 MWhs of electricity, which saved 78,000 gallons of diesel fuel. The wind turbines were shut down during part of the summer

due to construction on the distribution system, so availability was only 85% during that period. KEA expects to add two more turbines in the spring of 2002.

Atlantic Orient Corporation (AOC) manufactured the wind turbines. The AOC 15/50 is a three bladed, down wind passive yaw turbine, 15 m diameter, rated power of 50 kW. However, from the performance measured at the site, the power curve reached 66 kW. The AOC 15/50 turbine design is simple, rugged, and optimized for cold weather applications. The size of the turbine is appropriate for village grid applications and can be installed without large cranes. The AOC turbine is also designed to operate in harsh climates. The integrated castings and the fully enclosed generator provide protection. Heaters and arctic lubricants enhance performance in subzero temperatures. KEA built small heated control huts to provide a protected environment for personnel working at the site.

The first three turbines, Phase 1, were install in July 1997. Seven more turbines, Phases 2 and 3, were added in May 1999. KEA designed custom foundations for the AOC turbines consisting of freezeback pilings that serve to anchor each tower leg into the ground. These types of pilings are designed to prevent significant temperature changes in the permafrost. The original Phase 1 design was reduced in size for Phases 2 and 3 using longer but smaller diameter pilings resulting in significant cost savings.

As a demonstration project, the collection of performance data for the project was critical. As part of the DOE/EPRI Turbine Verification Program (TVP), the KEA wind farm has been continuously monitored, first with a Campbell Scientific system (Phase 1) and more recently with a Second Wind SCADA system (Phases 2 and 3). The Second Wind System allows for real-time monitoring and remote control of the turbines, interconnections with the turbine controllers, power quality monitors at each turbine, and a met tower with the full range of met data. The supervisory computer located at the wind farm allows a user at the utility office or other authorized site to view the turbine status and performance in real-time and to perform control functions and to download data.

Through the TVP program, the data are collected, analyzed, and archived by Global Energy Concepts. The SCADA allows for a level of monitoring and data collection not normally expected for a project of this size, but this database is proving invaluable in supporting the testing and development of the wind farm and the turbines. Through this testing, the local electric cooperative gained confidence in the technology for future projects.

The TVP program reports monthly on the wind farm performance including availability, energy production, maintenance and faults, and average wind. The wind farm is routinely achieving monthly availabilities in the high 90 percentile. During the winter of 1998-1999 the wind farm had 100% availability during four months of record-breaking wind and cold.

The peak energy production was achieved during February 1999 when the average monthly wind speed was over 7.5 m/s. As part of the TVP monitoring, AOC is able to compare energy production with the power curve and identify operational issues. One such issue at Kotzebue has been the tendency of some turbines to exhibit difficulty starting in light winds and low temperatures. Improved lubrication and heating of the turbines has helped. Another issue has been the increase over rated power production in cold temperatures. Peak power of 96 kW has been recorded, almost 50% greater than the rated peak power of 66kW. Although this power level is still within the design limits of the turbine, AOC adjusted the pitch of the turbine blades to reduce this peak power.

The TVP also reports on the number of faults and the downtime per fault. The data for Kotzebue are encouraging as they show both a low number of faults and a low outage time

per fault. The KEA wind farm results were achieved both through the turbine design and the utility support, both critical factors for successful projects.

As part of the support for the testing and development of the KEA wind farm, a power quality study was undertaken for KEA by M. Lodge of Island Technologies to determine the impact of the wind farm on the KEA diesel grid [12]. The study had two major components: (1) an analytical program of case studies for various levels of wind turbine penetration and the effect of turbine starting and stopping on the grid, and (2) a measurement program to determine voltage and current transients and steady states for normal and extreme operation of the turbines.

The KEA system was modeled using the software program, Distribution Primary Analysis Graphic (DPA/G). This program calculates load flow, line losses, equipment loading, and voltage profiles for a given distribution system. The 15 case studies were for 1, 3, 6, 12, and 24 turbines in three operating regimes: minimum turbine output, 40% turbine output, and maximum turbine output. The maximum wind farm output for 24 turbines was 1.2 MW, which corresponds to a penetration of 66%.

The conclusion from the analysis was that the wind farm would not produce any under- or over-voltage on circuit equipment. It was also concluded that it was not necessary to install any additional capacitance at the wind farm for power factor correction.

The steady-state voltage variation due to a shut down of all wind turbines was calculated to be less than 1%. It was concluded that the load level on the section of the grid connected to the turbines would not affect performance or power quality unless the wind farm output increased to over 1,200 kW (double the rated output of 660 kW).

Measurements were made of voltage and current transients and steady-state values for normal and extreme operation of the turbines. Normal operation included a normal start and a normal braking-to-stop cycle. Extreme operation included an across-the-line start followed by an emergency stop. During a normal start the turbine coasts up to speed before engaging the contactor, greatly reducing inrush transients. During an across-the-line start, the turbine is motored up to speed, resulting in a large inrush current that is reduced to acceptable levels after a few seconds.

The interpretation of these measurement results with the analytical results was that operating up to 24 wind turbines would not cause unacceptable power quality deterioration. It was recommended that because of the high instantaneous inrush current during startup, only one turbine be started at a time. In practice, no deterioration of power quality has been reported as a result of the wind farm operation and it has not been necessary to take any control action to prevent turbines starting simultaneously. Statistically, the likelihood of several turbine contactors closing within a few cycles of each other is very small due to the variance of wind and spread of the turbines.

The Kotzebue wind farm successfully demonstrated the viability of wind energy for remote Alaskan communities. The high availability through two Alaskan winters has shown that the technology is mature and that the local support infrastructure is in place. With the prospect of increasing diesel fuel prices and environmental restrictions on the transportation and storage of fuel in sensitive habitats, wind energy is the energy of choice for these communities.

Link: [http://www.kotzelectric.com/wind/wind\\_growing.html](http://www.kotzelectric.com/wind/wind_growing.html). This site has good photos of installation of the wind turbines.

## PROBLEMATIC EXAMPLE - XCALAK, MEXICO

The development of hybrid systems in Mexico has been clearly hindered by continued problems, which have plagued the Xcalak hybrid system since 1993. The early years of operation of the village hybrid electric system in Xcalak demonstrated that wind and photovoltaic technologies can be combined to provide abundant and reliable electric service in remote areas. However, the lack of attention to institutional issues led to inadequate system maintenance, excessive load growth, and eventual system degradation to the point of complete failure in 1999. The key hardware component to this failure was a first generation AES inverter from Australia, which failed four times and which AES had promised to replace but never honored their commitment. AES has now been largely discredited in Mexico (e.g., with CFE) due to their inaction and problematic inverters. The PV array continues to function (and charge the battery bank). Likewise, three wind turbines are functional, but the renewables power cannot be used due to lack of a functioning inverter to provide power to the town. The State Government of Quintana Roo is no longer interested in sinking any additional funds into the power system after expenses now totaling nearly \$1 million since system installation. They are now opting for conventional grid electrification of Xcalak. However, funding for the grid extension is not yet secured. Meanwhile, the Presidente Municipal will not allow the Xcalak system to be moved until after the community is electrified. Long term prognosis is that the State Government will move the salvageable parts of the Xcalak hybrid system to another community after grid electrification of Xcalak.

### A. Xcalak Description

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.

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, nor 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.

### 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 three to four hours during

the evening. When electricity is only available for a few hours in the evening, the typical village electrical load consists 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 unit. 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 generator has 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. Hoping to establish increased hours of electrical generation, the State pursued a wind/solar hybrid generation system.

#### Wind-Solar Hybrid System

The Xcalak hybrid system was built by Condumex S.A. de C.V. 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 (AES) 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 (DAS) 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 by the original project planners to maintain the Xcalak hybrid system. Currently, the entire renewables system is inoperative due to an inverter failure.



Figure 2. Xcalak wind turbines and PV array in Quintana Roo, Mexico.

#### 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.

#### **B. System Design, Installation and Operation**

##### 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 icemakers. 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% of this energy was to be provided by the renewable system, with the remainder supplied by a diesel generator.

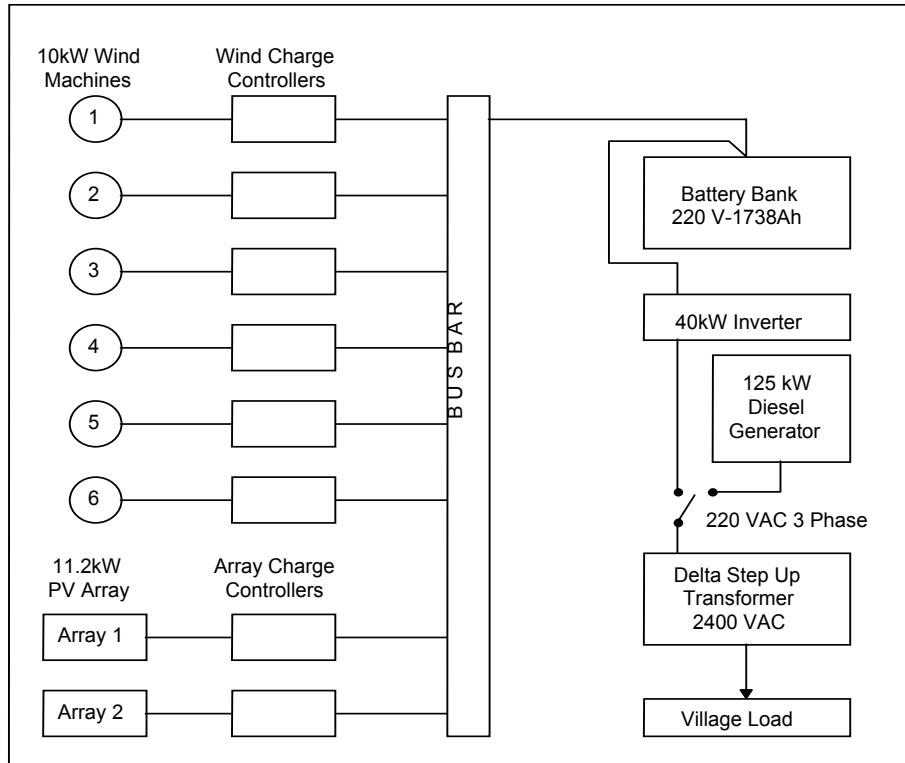
#### System Installation

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 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 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 weighed nearly 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

Figure 3. Xcalak hybrid system configuration.

### 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%.

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 new operations and administrative plan as presented herein.

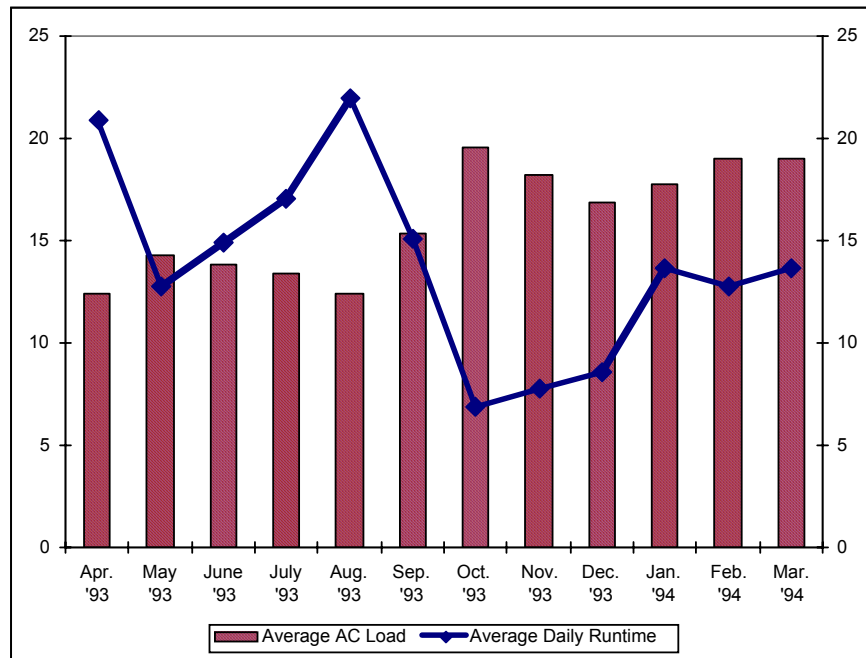
### C. System Performance

#### 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 are collected via a cellular phone link. The DAS has been maintained and has collected data since 1993.

Anemometers were installed at the wind turbine hub at a 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.



**Figure 4. Xcalak monthly load growth (kW) and daily runtime (hrs/day) 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 been curtailed by this time and was not much different than late 1994 (the inverter was down during the late October through December period).

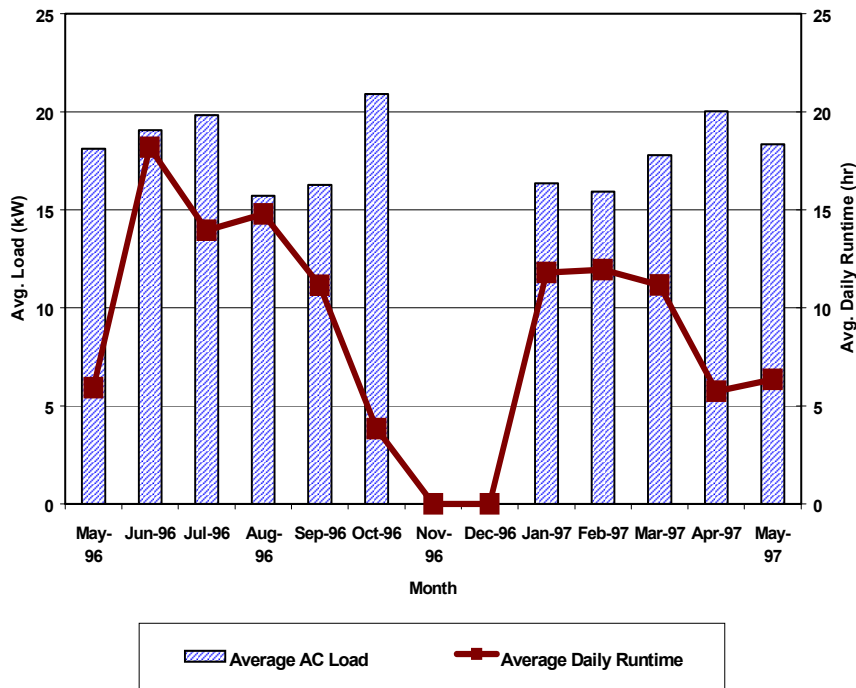


Figure 5. Monthly load (kW) and daily runtime (hrs) 1996-97.

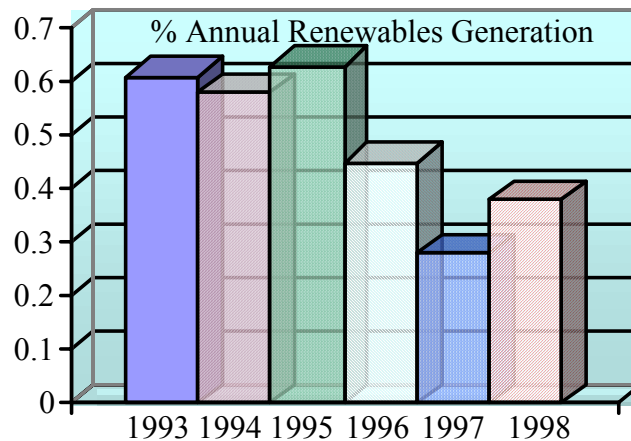
During the early years of operation (e.g., April 1993 to March 1994) the system produced 77.3 MWh of AC power. The wind machines produce about 80% of this energy. For example, in March 1994, the wind machines produced about 230 kWh per day, as compared to the PV, which produced about 44 kWh per day. 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.



**Figure 6. Annual portion of time that the renewables hybrid system powered the Xcalak community from 1993-98 (system did not function after 1998).**

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 Hybrid2 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 in April 2002.

#### **D. 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.

#### Inverter

The Australian made Advanced Energy Systems 40 kW inverter was designed to carry the village load. The AES inverter proved to be the achilles heel of the Xcalak hybrid system and led to its eventual demise. 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 allow 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.

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. 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. Without the inverter, no power can be delivered and the system is down due to inverter problems and lack of funds to fix the inverter or replace it.

### Wind Turbines

The Xcalak hybrid system includes 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 designer and installer (Condumex) 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.

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 need 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.

### 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.

#### 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.

#### 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, Energía 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 an inadequately sized service conductor.

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

### **E. Institutional Issues**

#### Background

The Xcalak hybrid system eventually became a colossal failure. After the Xcalak installation, there were only two new village hybrid installations in Mexico in the decade since, and a similar sized hybrid system in Belize decided to use only PV (100 kW) and forego wind. 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 and a failed inverter. This lack of maintenance, in turn, is the result of an inadequate institutional structure to operate, administer, and maintain the system. 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, Condomex 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.

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:

1. CFE was to install meters and rebuild the distribution system and train villagers in meter reading and basic billing and accounting.
2. The Municipality was to assist in strengthening administrative capabilities of the village electrification committee and, working closely with the CFE, develop a recommended tariff;
3. Condumex was to provide technical training.
4. 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 led to bitter fighting among villagers who refused to pay the same as their neighbors 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.

### Meters

As part of the NAFEC/SWTDI-supported effort, Energía Total led a team of UQROO students and village volunteers and installed 100 new aluminum 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 provided 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 could be implemented and an operations and maintenance fund established.

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. Unfortunately, soon after the meter installations the AES inverter failed for a fourth time. Despite promises by the manufacturer that they would replace the inverter, nothing was ever done and the Xcalak hybrid system has languished since that time.

## **F. Lessons Learned**

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 led to inadequate system maintenance, excessive load growth (53% during the first year alone), and eventual system degradation to the point of failure [13].

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.
- 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.

## **AVERAGE EXAMPLE - ISLA TAC, CHILE**

For the archipelago of Chiloe, Chile, which consists of 32 islands with more than 3,500 families, it is impossible to extend the grid because of the cost. A pilot wind-diesel project was installed in Isla Tac (Fig. 7), which was a cooperative program of Comision Nacional de Electricidad, Chile and the DOE, USDA. The cost was \$178,000, divided among USA (\$21,000 for equipment), the users (\$10,500), the electric company (\$60,000) and FNDR (\$86,500).

The system began operation in October 2000. Electricity (220 V, 50 Hz) is provided for the post office, school and 24 hours a day for 71 families (population 350) over a 13 km distribution system. The system has two Bergey 7.5 kW wind turbines, deep cycle batteries (48 V, 2100 Ah), two Trace inverters (4.5 kW each) connected in parallel, and a backup 12-kW diesel generator.

Operation and maintenance will be done by the Empresa Saesa, which signed a 10-year contract with the possibility for an extension of another 10 years.



**Figure 7. Isla Tac hybrid system in Chile.**

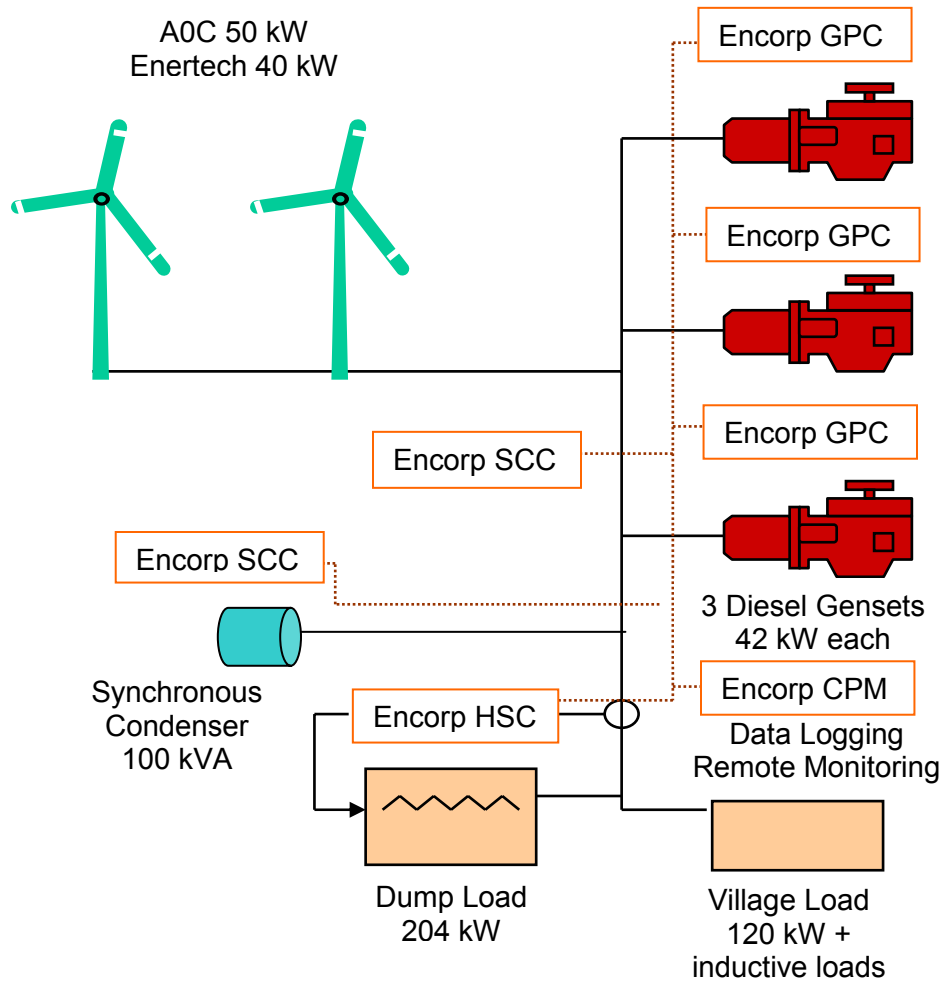
For further more information (in Spanish) on the project, contact:  
[http://www.chiloeweb.com/barra\\_editorial/lagos\\_tac.html](http://www.chiloeweb.com/barra_editorial/lagos_tac.html)

The system had losses of 42.1 percent during June 2001, primarily due to gale events and poor diesel dispatch. The peak load in the evening usually forces the diesel to start and remain operational for several hours per day, even if there is sufficient wind to provide all of the power requirements. During this time, however, the diesel is used to provide energy to the battery bank and the renewable generators continue to provide power, which is also stored, resulting in high battery voltages, turbine regulation, and lower renewable energy capture. The large renewable/battery capacity ratio of 14%, combined with gale wind events, result in the battery bank reaching a full state of charge early in the storm's cycle, as well as high spilled energy during the rest of the storm [9].

## **CURRENT HYBRID RESEARCH**

### **USDA**

Since 1996, the USDA - Agricultural Research Service, Bushland, Texas, has been researching various wind/diesel system configurations, control strategies, and storage schemes. The specific items under investigation are penetration (rates wind power/ consumer load), system configurations with and without storage, controls, bio-diesel generator fuels (soybean oil), resistive and inductive load concerns, power storage effects, and best storage methods and sizes. Additional investigation items have to do with reliability and maintainability of the system and its components. The test system power generators include three CAT 3304 powered diesel generator sets (three 42 kW, 1,200 rpm), two wind turbines [AOC 15/50 wind turbine (50 kW) and Enertech 44/40 wind turbine (40 kW)] and a battery bank. Water pumps, air blower, and a resistive load bank represent the variable village load (5-125 kW). Phase I test of control systems was without storage (Fig. 8).



**Figure 8. Phase-1 line diagram, without storage.**

High penetration for wind/diesel is defined as the wind providing at least 75% of the current load. For high penetration, wind/diesel power systems without energy storage, there are three operating stages: (1) diesel only, (2) wind/diesel, and (3) wind only. The transition between these three separate stages of operation is the most difficult part of system control. Both the wind and the load will fluctuate over short time periods.

The break points between each operating regime—all diesel, hybrid, or all wind—may be approximately based on the expected loads and the wind distribution at the site. The first break point is easiest to define as the point where wind generation is greater than 0, the lowest wind speed at which power is added to the micro grid. Finding the second breakpoint is more challenging. By combining the wind turbine characteristics and the wind profile, along with an estimate for the village loads, a minimum wind speed for supplying the entire village can be estimated. This wind speed is the point where the diesel generators can be removed from the grid and gives the greatest fuel savings. There may be times, however, when winds are too high and the diesel must be reconnected to ensure continued electric power if the turbines shut down at extreme wind speeds.

An estimate of a single 50kW turbine on a 40 kW base load with a no-storage, diesel microgrid, was made for the wind regime of the Texas Panhandle. Using this high

penetration (125% of base load) and the operating characteristics of this production model turbine, the annual percent of time that diesel-only operation occurs is 37%. Wind/diesel operation would occur 50% of the time in a year, and 13% of the year the wind would supply 40kW or more complete wind operation. The wind speed points for these three regions would be 0 - 5 m/s for diesel only, 5 - 9.9 m/s for hybrid operation and 10 m/s and above for wind only.

Using an experimentally verified rule of thumb for fuel savings in these bands, there would be zero fuel savings during all diesel operation, 20% in hybrid mode (0 - 60% as winds range from 5 - 9.9), and 100% savings when wind only operation. Total fuel saved would be 23 - 24% during a year. A generic formula to calculate the size of the "wind-only" band of operation, yields:

$$\text{Wind Band \%} = 0.26 * (\text{Penetration \%} - 100\%) ^ 0.38$$

Operation in the wind-only band for village systems yields the greatest fuel savings over a year, operating in hybrid configuration as much as possible is the next best region.

Targets to improve amount of operating time in hybrid mode are:

- Reduce wind speed cut-in of turbines by increased rotor area
- Use high penetration of turbines as can be economically afforded to increase the Wind Band % time
- Increase reliability of system controller to supply synchronous capacitance to maintain grid frequency with no diesel operation
- Rugged dump loads to shed unneeded power into useful storage at times of high wind/low village load.

Research is also being done into short-term battery storage (Fig. 9) to reduce diesel cycles during low/medium wind conditions when lightly loaded gensets are least efficient. Adding variable sized diesels with complex controllers is a second method to better match loads to resource; starting a 30 kW diesel instead of a 100 kW diesel for a 20 kW load is preferable over the long term.

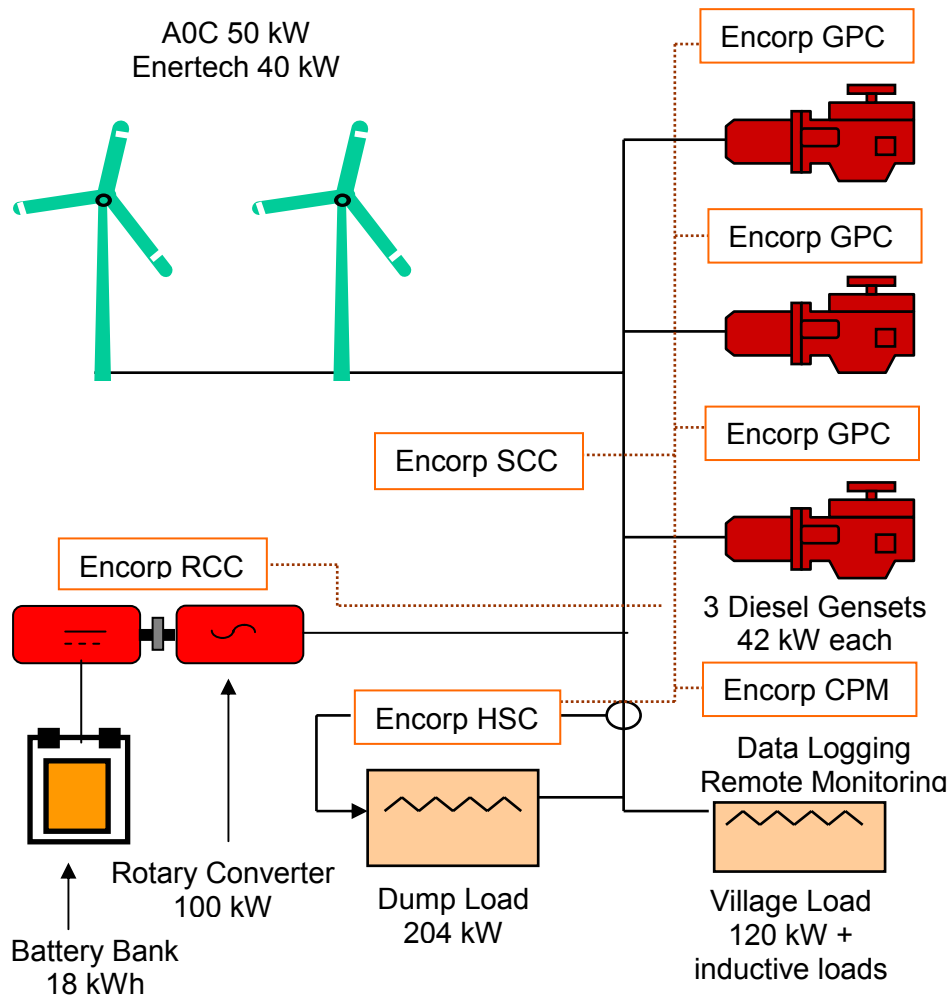


Figure 9. Phase 2 line drawing, with storage.

<http://www.cprl.ars.usda.gov/research.htm>

## NREL HYBRID POWER TEST BED

Researchers can simulate hybrid systems at the NREL's Hybrid Power Test Bed (HPTB) at the National Wind Technology Center (NWTC). The HPTB is the U.S. industry's laboratory to develop and test components, control systems, and integrated hybrid power generation systems. Using simulated village loads, researchers can evaluate the interaction of hybrid power systems under realistic conditions. Design engineers can evaluate the moment-by-moment dynamics of hybrid power system operation, gather data on long-term performance, or demonstrate innovative design concepts with the HPTB. High-speed data acquisition equipment monitors power quality, harmonic distortion, and electrical transients. A village load simulator with resistive and inductive elements can create power factors down to 0.5, allowing test engineers to evaluate system operation under severe conditions.

The HPTB includes a PC-based control and data acquisition system with a graphical interface in LabVIEW. Hybrid Power Test Bed equipment includes:

Wind turbines	1.5 to 100 kW AC, to 10 kW DC
Diesel gensets	125, 80, 40, 40 kW
AC renewable energy simulator	75 kW
DC battery banks	24, 120 and 228 volts
Village load simulators	To 120 kW, inductive and resistive

Projects at the HPTB include:

- Test inverters (Trace and Advanced Energy Systems)
- Develop and test a control and energy storage system for a high-penetration wind-hybrid project for installation at Wales, Alaska.
- Characterize a Northern Power Systems Village Power 50-kW power system module.
- Characterize the performance of the Northern Power Systems' 100-kW cold-weather turbine for hybrid applications.

[http://www.nrel.gov/villagepower/program/briefs\\_2000/hybrid.pdf](http://www.nrel.gov/villagepower/program/briefs_2000/hybrid.pdf)

## MODELS

### *Hybrid Power System Simulation Model (Hybrid 2)*

Hybrid2 was designed to study a wide variety of hybrid power systems. The hybrid systems may include three types of electrical loads, multiple wind turbines of different types, photovoltaics, multiple diesel generators, battery storage, and four types of power conversion devices. Systems can be modeled on AC, DC, or both buses. A variety of different control strategies/options may be implemented which incorporate detailed diesel dispatch as well as interactions between diesel gensets and batteries.

An economic analysis tool is also included that calculates the economic worth of the project using many economic and performance parameters. The Hybrid2 code employs a user-friendly Graphical User Interface (GUI) and a glossary of terms commonly associated with hybrid power systems. Hybrid2 is also packaged with a library of equipment to assist the user in designing hybrid power systems. Each piece of equipment is commercially available and uses the manufacturers' specifications. In addition, the library includes sample power systems and projects that the user can use as a template. Two levels of output are provided: a *summary* and a *detailed* time-step by time-step description of power flows. A Graphical Results Interface (GRI) allows for easy and in-depth review of the detailed simulation results.

### *Basic features*

Probabilistic/time series model: The model is based on time-series data but uses statistical methods to account for inter time-step variations in the wind and load. This method allows for a more accurate prediction of diesel operation and dispatching.

Diverse system architecture: Systems based on three buses containing wind turbines, PV array, diesels, battery storage, power converters, and a dump load.

Detailed dispatching options: Over 180 different configurations are allowed as well as a library of 12 different commonly used dispatch options, based on decisions relating to

how batteries and diesels will operate if included in the power system. The user is allowed to specify when the diesels are started, in what order, how they operate in relation to a battery bank, and when they are shut off.

On line library of manufacturers equipment and data files: Allows the user to easily create projects and power systems using pull down menus of commercially available components and power systems as well as resource data files. The library contains approximately 150 different wind turbines, PV modules, diesels, batteries, power systems, and resource data files.

Uses commonly accessible data to define components and systems: All components are easily defined from manufactures' specification data so that users can enter components not included in the NREL library. New entries become part of the library for use in other projects and systems.

### ***Very detailed economic analysis***

Detailed analysis on potential systems: Takes into account a wide variety of inputs from taxes to load information.

On line glossary: A glossary of commonly used terms to assist the user in defining projects and hybrid power systems

Hybrid2 includes a detailed economic model that allows the user to determine basic economic figures of merit for a particular simulation run. The economics engine uses performance information from the simulation and economic data supplied by the user to calculate parameters such as payback period, internal rate of return, cash flow and equipment replacement expenses. The user has wide versatility in determining the expenses of the project and what detail of inputs are to be included. Parameters such as grid extension, importation tariffs, system administration costs, and taxes can be included in the analysis. The economic package has been provided so that the user may conduct comparisons between different power system options and to estimate costs. Hybrid2 will also allow a user to conduct parametric analysis on certain cost parameters, such as fuel price, discount rate and inflation rate to help determine how the value of certain parameters can affect the viability of the project.

Description and software are available from the Renewable Energy Research Laboratory and the University of Massachusetts.

<http://www.ecs.umass.edu/mie/labs/rerl/hy2/intro.htm>

### ***HOMER***

The Hybrid Optimization Model for Electric Renewables (HOMER) is a model for designing standalone electric power systems. From information on electrical loads, solar and wind resources, and the performance and cost of various components, HOMER designs the optimal hybrid power system to serve those loads. HOMER can model any combination of wind turbines, photovoltaic panels, diesel generation, and battery storage. Comparisons can also be made between the optimal hybrid system and grid extension.

HOMER can perform sophisticated analyses and will assist the designer in developing insight into the complex nature of hybrid system design. HOMER performs hour-by-hour performance simulations for many system configurations and presents the resulting information in tables and graphs. Possible system configurations are ranked in order of increasing cost, and the composition of each system is indicated graphically.

<http://www.nrel.gov/international/tools/HOMER/homer.html>

HOMER Online is a simple online version of HOMER you can use without downloading anything. <http://analysis.nrel.gov/homer/login.asp>

### ***ViPOR***

ViPOR is an optimization model for designing village electrification systems. Given a map of a village and some information about load sizes and equipment costs, ViPOR decides which houses should be powered by isolated power systems (PV and/or wind) and which should be included in a centralized distribution grid. The distribution grid is optimally designed with consideration of local terrain.

<http://www.nrel.gov/international/tools/vipor/vipor.html>

### ***RETScreen***

RETScreen International is a renewable energy awareness, decision-support and capacity building tool developed by the CANMET Energy Diversification Research Laboratory. The core of the tool consists of a standardized and integrated renewable energy project analysis software that can be used to evaluate energy production, life-cycle costs, and greenhouse gas emission reductions for various types of renewable energy technologies: wind, PV, small hydro, passive solar heating, solar air heating, solar water heating, biomass heating, and ground-source heat pumps.

The PV program has three basic applications: on-grid, off-grid, and water pumping. For off-grid applications the model can be used to evaluate both stand-alone (PV-battery) and hybrid (PV-battery-genset) systems. The wind program has central-grid and isolated-grid connected wind energy projects, ranging in size from large scale multi-turbine wind farms to small scale single-turbine wind-diesel hybrid systems.

Link: Software is free

<http://retscreen.gc.ca/ang/menu.html>

## **QUESTIONNAIRE**

One of the goals of this compendium was to generate responses to an anonymous questionnaire for hybrid systems, planned or existing. A questionnaire (Appendix 2) was given to hybrid systems operators and developers at national and international conferences during the past year;

- Wind Power 2000, April 30 - May 4, 2000, Palm Springs CA
- Wind Power for the 21st Century, September 25-27, 2000, Kassel, Germany
- Village Power 2000, Dec 4-7, Washington D.C.

Only seven responses were received. The poor return rate was attributed to not requesting the return within one day, as attendees tended to place it with all the other material they had accumulated. Also during national conferences other, higher priority objectives were on the attendees' agendas. The objective was to try to establish the typical size of systems and expected sizes in future systems.

The goal of the questions was to develop a range of values for the various markets, applications, hardware costs and operational costs of existing or planned hybrid systems

from actual installations. Most respondents had an installed system, usually a Wind/Diesel or PV/battery/charger system.

The need for future system research by component type and capacity was asked, and the importance of grid integrations with non-conventional energy sources was gauged. The purpose of question 6 was an attempt to get a grasp of the desired voltage range and output form for the energy transmission. Question 7 covered areas of maintenance needs and training levels. We tried to get the respondents to tell us what conventional fuel sources would be considered most likely within hybrid systems in the future. And then the quality of the micro electric grid was targeted and acceptable levels of grid deviations from normal were determined.

## ANALYSIS OF FEEDBACK

When asked the size of systems for U.S. direct research, the response was 50 - 100 kW. This range of size was considered the optimal village size, easiest to match with existing components, and not too large to install in second in third world remote areas.

The following components were cited in order of preference for remote hybrid systems:

Wind turbines	10-50 kW
Bio-diesel gensets	50 kW
Wind turbines	1-10 kW
PV panels	single to 2 kW array
PV arrays	2 kW to 10 kW

The work most requested was to improve reliability and reduce maintenance and overall cost reduction by increased production. The research into bio-diesel would supply a twofold asset, providing a market for local agri-products as well as reducing dependence on further external costs for oil.

The microprocessor or computer controller itself was cited as the part needing the most improvement in reliability and ruggedness. Power monitoring of the grid was also an expensive item, yet a necessary component of the system to keep the voltage/frequency levels suitable for good power transmission and to maintain suitable power quality. High speed power switches were also noted as an area of concern, that they be more rugged and able to energize on zero crossing of AC voltage levels to minimize surges and unwanted harmonics in the micro grid.

DC systems have an advantage of being more readily understood in remote areas due to exposure to automotive battery systems; however, AC power is more readily transported and AC appliances are more available. 120/240 volt AC single-phase and 240-480 volt AC 3-phase micro grids were the two most marked system voltage/ configurations. The single-phase systems were selected for lighting and residential use, while the 3-phase was selected to handle industrial loads and to take advantage of the cheaper 3-phase gensets available. A side note was that for very large systems, greater than 200 kW, the system voltage should be even higher than 480 V.

When queried about the need for local/in-country system operators and the repair crews needed, respondents said that using a minimum of 50% local materials/ construction methods would reduce overall system costs and involve the locals at the onset of the project. Keeping the size of projects manageable for the anticipated grid size was noted as a method of keeping maintenance costs down. Systems can be worked on without significant outside involvement of tools and materials for unexpected repairs. Increasing

in-country training of systems developers, installers, and operators would allow for quicker response to system errors, making more people available system-wide to notice discrepancies or poor system performance. Suppliers need to offer a minimum 2-year warranty on parts, labor, and travel.

Bio-diesel research and hydrogen production for use in fuel cells as energy storage components of hybrids were requested. Some respondents were adamant that hydrogen storage/production research be upgraded to become a prime effort in US renewable energy research.

System component sensitivity was indicated as a way to reduce system costs, while still keeping adequate monitoring levels. The consensus was that monitoring needs to have sensors sample rate of 10-100 milliseconds, with control decisions made in 1-5 seconds (add load, reduce dump loads, turn on generators, and take generators offline).

Acceptable voltage deviations ranged from +/- 2 - 5 %. Higher than that would lead to premature appliance failures, lower than that would lead to noticeable brownouts and increase current versus power loads for transmission lines.

Allowable ranges of frequency fluctuation were higher in micro-grid applications than in conventional utility grid systems; a 3% variation was considered acceptable. This allows for simpler controllers and less stringent efforts on the part of the system controller to maintain frequency levels. These micro grids will often be the first exposure to utility power for many of the users and they will not be too disappointed with this level of variation over a day, when compared to no power availability.

A qualitative question about getting villagers to accept the new power grid resulted in a support for underground lines to reduce line maintenance and costs. The community has to be involved in the planning process to find out goals and to determine their expectation. The hybrid system needs to use fail safe or rugged "Black Box" technology, to minimize system interruption even at the cost of lower efficiency. If conventional generation is included, the units should be supplied in country, which would reduce dependence of small countries on developed countries.

Other comments included:

- Initial village installations need small size, so that maintenance requirements are manageable.
- Diesel grids need to be retrofitted with hydrogen storage/peak shaving systems, storable fuel cell, or heat engines to displace non-renewable fuels completely.
- Information needs to be disseminated(workshops) during system planning that is understandable to local users. Information for the general public about wise use of the energy will go a long way in keeping the micro-grid loads down during the initial operation.

## RECOMMENDATIONS

The known problems have not changed much over the last few years, only that a few more hybrid systems have been installed (see Appendix 1). The major problems have to do with cost, low performance and reliability, and institutional problems.

## RETROFIT DIESEL MARKET

### Low Penetration

No research needs to be done for low penetration of renewable systems. Essentially the problems have to do with operation and maintenance, as operators need to learn the characteristics of renewable systems. Comprehensive training on wind turbines, PV and inverters, and then the hands-on experience will suffice.

### High Penetration

**Recommendation 1:** The highest priority should be given to controllers, which determine the operational stages and integration with the conventional diesel gensets. Testing of the controllers near system limits of stability for extended periods of time is imperative. The next priority is the problem of incompatibility of the components: wind turbine and/or PV, controllers, batteries and diesel.

Controllers and the control strategy that will simplify the coordination and connection of multi manufacturers units into a seamless system are a top research priority. However, efforts also need to be placed on a standard methodology and robust and reliable control plan. While some fluctuations are allowed, overall power quality will not be compromised. The operating stages are diesel, hybrid, and renewable power. Addition of some storage can improve fuel savings by reducing diesel start/stops and by reducing idling. Idling units consume 30% of full-load fuel rates. This also requires a reliable starting mechanism for each independent genset. But the battery bank comes at a high initial cost, and maintenance for batteries is additional operating expense for the system.

## HYBRID VILLAGE SYSTEMS

Research has to be directed at reducing cost and improving performance and reliability. Many of these problems are intertwined with institutional issues at the local and regional level. Even though standardization and modular components would help reduce costs, the main problem is to have the standard, modular components in an integrated working hybrid system that is robust and has high availability. Economies of scale are needed to reduce costs for remote villages.

Computer models need to be simple, based on spreadsheets with graphics. "Beyond this, it should be kept in mind that every purveyor of a project or a technology brings along the output of a computer model showing that their project or technology has the lowest long-term cost. It may be obvious but I'd like to say that it is not enough to evaluate project economics with a complex computer model and a statement of factor inputs and results. Without sacrificing depth, greater simplicity and clarity is needed in economic evaluations of renewable energy..." [14].

**Recommendation 2:** Computer models need to be validated against village hybrid systems at three stages: planning/design, installation, and after at least two years of operation. A simplified spreadsheet tool of expected performance and costs with graphics output for planners who are not technical experts needs to be available.

**Recommendation 3:** Develop database on problems of village systems at the three stages: planning/design, installation (first 3 months of operation), and after at least two years of operation. Unless a database of component failures is available, it is difficult

to determine where research emphasis should be placed. Extend the current NREL village power database to include this information.

Concerns noted by people contacted include the following components:

Wind Turbines	Biodiesel
PV panels/arrays	Batteries
Controllers	Dispatchable Loads
Inverters	

1. Turbines are not available in size ranges for modular hybrid systems, there are not enough volume of turbines being produced to keep costs low, and the sizes currently in production make load matching difficult.
2. Use of biodiesel. What are the problems? What O&M procedures need to be changed for the diesel engines? Percent blend and sensitivity to temperature are present concerns.
3. PV is less complex, with no moving parts, low maintenance, although it is expensive. Even with current projections of production of 350 megawatts in 2002, and an estimate of 4,000 megawatts in 2010, the cost/kW is on the order of 3-6 times that of wind power. However, PV will be part of the energy mix.
4. Batteries currently offer the best method of energy storage for renewable systems and help to reduce the on/off cycles of gensets when used at low wind/limited sunlight times of the day. The greatest fuel savings occur when the gensets are shut down; even a small amount of storage would aid in those periods when renewable energy flow is just meeting or slightly under the village needs. The battery bank could supply the rest of the power until the batteries reach a low-charge point.
5. There are limited developers and suppliers of controllers that are compact and rugged enough to last in field conditions for the life of the system. This limited availability results in high initial costs and a lack of opportunity to develop a standard controller for general applications rather than a specific high-cost controller for each system as it is specified.
6. Dispatchable loads keep the grid stabilized and the renewables loaded no matter what the village requirements. It must be reliable and incrementally adjustable and have a rapid response to coincide with changes in the renewable/genset outputs and village needs.
7. Inverters are expensive and generally not repairable at the local level.

While the individual components can be obtained from current manufacturers, it is often a problem of the designer to size and integrate components to provide the best overall system. The integration of mismatched components will yield a working system, but not one that gives the best energy value over life of the system.

System costs have been a huge stumbling block to the sales of more hybrids. The lack of a manufacturer with modular systems of the same design is a major problem. If standard configuration, modular systems were available, instead of each system being a new prototype or demonstration project, real costs would be reduced. Manufacturers would be able to buy components in bulk, and a single standard design, tweaked to fit the locale, would ultimately lead to commercial success.

**Recommendation 4:** Develop a standard design with modular components for village hybrid systems. This would allow resources to be added as the load grows within the original design. A new design for each village power system is a waste of engineering effort and can not reduce costs.

## **NREL**

The following information from reference [10] reiterates the need for better computer models on energy production and cost and the need for compatibility of components.

A need exists for a better understanding of the impact of the ratio of renewable capacity to battery capacity, as there may be an economic trade-off between the size of the battery bank and the installed renewable capacity. Some options that can be used in the design of hybrid systems include:

- Improved use of discretionary loads so that any excess energy can be utilized.
- Renewable production/battery capacity ratios to fit more closely with projected weather patterns.
- Improved battery selection for the required voltage regulation.
- Improved system control through better automation, supervisory control, and operator education to reduce the losses associated with poor control of the diesel generator.

Computer models are useful in predicting component operation, dispatching, and performance, which are useful in system design, but may be over predicting the available production of renewable energy. Since the power systems are very dependent on climatic conditions and the battery, both of which can lead to highly reduced power capture, any design tool for hybrids must accurately address this issue.

## **EUROPE**

Recommendations from research groups in Europe [15] have stated that three areas are the main targets for continued efforts from all groups:

1. Reliability improvement in components and complete systems
2. Cost reduction
3. Low maintenance, easy to maintain and operate systems

To meet these targets the research is being focus on the following:

- Wind Assessment: improving methods and techniques to reduce cost for this part of a program
- Technology Improvement: Optimizing rotor/controls for SWECS, along with optimizing the overall system layouts/controls should be done. Among the prime targets are:
  - New blade designs for light wind regimes
  - Low Reynolds Number airfoils
  - Axial Permanent Magnet Generators
  - Switched reluctance generators
  - Passive yaw/passive power regulation
  - Energy Storage

In spite of the past growth and development of the industry in producing utility systems the state-of-the-art for hybrid systems has not been given the same support to reach cost effectiveness and high technical maturity. Cooperative projects of R&D, coordinated to use the best technology from each member is needed to improve the technology for all. Directing current testing facilities to develop norms and standards in their demonstration projects will help in the continued development of this market for Europe.

## **INSTITUTIONAL**

Finally, the institutional issues of social inequity, subsidization of the villagers, local oversight, and operation have to be addressed. When training takes place at the local level in remote villages, a trained renewable energy mechanic is given a high position in the village. He also is presented with skills that can bring even more valuable income in higher industrialized areas. This leads to a brain drain at the local level. Also the maintenance should be allocated so that the villagers do not feel that the new power source is simply a right or gift from a benevolent government, but is their responsibility to operate and upkeep. Charging even a pittance to ensure that the benefactors of the power are also the ones supporting its operation would make each one responsive to the real costs and value of this energy. This could also curb the unlimited growth in power use as more and more villagers become used to the advantages and benefits of reliable electricity. Village systems that were designed for 10% load growth over five years and that had increases of 20-30% in a single year can quickly be over taxed and fail prematurely.

**Non Research Recommendation: Develop regional utility systems or cooperatives for village power systems for administration and maintenance. The hybrid system is still operated at the local village. There have to be enough systems in a region or a state for a viable infrastructure.**

## **PROJECTED MARKETS, NEAR TERM (10 YEARS)**

Predicting the future of growth in the area of small village electrification/hybrids is not a simple process. Will U.S. trade conditions change in the future and with what countries? Will diversification of power production methods become increasingly important to smaller countries? Given this unclear future it is still possible to make some estimates and educated guesses for the future of this market.

Energy demand will not decrease in the near term (10 years) and most will be supplied by conventional generation. The use of renewable energy will impact diesel grid systems, especially in windy areas. Small wind turbines, 50 - 300 kW, can be shipped in containers, assembled and installed in areas with little or moderate infrastructure (cranes, concrete, and electrical connections). The operation will be modular, where 2 - 10 units can be added as needed and more as experience shows the renewable systems are cost effective and reliable

## **ASIA**

**China** has installed 350 MW in wind farms in 2001, so they have experience with large systems. More than 72 million people in rural areas are still not connected to the national electricity grid. Based on 1999 statistics, China has 124,561 villages with 8,891,586 households without electrical power. Around one third could be powered by renewable

energy [16], as grid expansion is too slow and expensive. The province of Inner Mongolia has a \$30 million fund per year for 5 years for rural electrification.

More than 140,000 mini wind turbines (60 to 200 watts) operate in China, of which more than 110,000 are located in Inner Mongolia. The annual production of mini wind turbines exceeds 21,000 units in the region. The Chinese government forecasts that the total installed capacity of mini wind turbines will be 30 megawatts in 2000 and 140 megawatts in 2020, with total energy generation of 90 and 450 gigawatt hours, respectively.

A China Renewable Village Power Project Development Guidebook for China Government decision makers and planners (in Chinese) will be published in January 2002. It will include seven chapters: General Instructions, Scenarios for Rural electrification, Financial Analysis and Boundary Conditions, Management and Business Models, Some Critical Issues and Case Studies, and Conclusion. An Annex will have step-by-step design procedures.

A survey of “China renewable village power system and potentials for commercialization” has been completed but has not yet been published (Report for UN). The preliminary results indicate there are 45 wind/solar or hybrid village power systems, with a capacity of 1,363 kW.

**Philippines:** The National Power Corporation owns and operates about 100 power plants, mostly fueled by diesel, ranging in energy production from about 15 kilowatt-hours (kWh)/day to 106,000 kWh/day [17]. There are currently large projects in the Philippines with village electrification sponsored by the USAID and World Bank that could employ village hybrid systems.

## LATIN AMERICA

Mexico and Brazil represent the largest potential markets in Latin America for hybrid systems. Mexico has over 5,000,000 people without power in over 70,000 small communities. Likewise, Brazil has over 25,000,000 persons without power in hundreds of thousands of dispersed small communities. Other areas, such as Central America, the Southern Cone, and the Caribbean also have significant potential for hybrid systems development with over 10,000,000 persons without electrical service.

## EUROPE

European Union members are looking at ways to successfully develop and market hybrid systems for the emerging nations, as well as supply high penetration systems for existing diesel powered micro grids to take advantage of regional renewable resources.

The main recommendations [18] for further development of the use of wind power in isolated power systems are as follows:

- to develop the use of wind power in isolated systems as concerted actions in national and international programs rather than as individual projects;
- to join forces in development of international standards for decentralized power systems with renewable energies as now initiated within EC;
- to develop best practice guidelines as dynamic documents with common references and based on updated experience from recent projects;
- to develop wind power in small to medium size systems following simple and proven approaches, e.g. by repeating and/or downscaling pilot and demonstration systems with positive track records;

- to filter down from the large-scale systems any technological achievements adaptable to smaller systems;
- to invest research and development in small systems to support development of rugged technology applicable for remote communities;
- to use modeling assumptions from the hardware reality for the types of systems that will be applied;
- to install experimental systems only at test benches prepared to serve as experimental facilities;
- to encourage the industry to offer medium-scale wind turbines (10 - 300 kW) for hybrid system applications - large wind turbine manufacturers need to give priority to allocation of production line capacity for smaller machines.

In summary, the technical capacity to design, build, and operate isolated power systems with high penetration of wind power exists, but the mature product and the market have not met. The above recommendations are seen as moves that would lead to development of the use of wind power in isolated power systems, but as in any technological development process, financing is needed.

A survey [15] from monitoring programs in France states that there were 276 renewable projects in the European Union, with only 24 projects in hybrid or wind only. The lack of a clear continuity of research efforts between all EU members conducting renewable research was a concern. A free flow of experiences between research groups is needed to reduce repeated mistakes. There is also a lack of sufficient reports and articles describing the work being done in member countries, making it difficult to build up a research knowledge database for improvement of future systems.

Spain has an increased interest in hybrid systems growing from the recent success of the utility scale wind farms in Tarrife. In the Canary Islands, two research groups (ITC and ITER) are active in testing these types of systems. Federal funds are funneled to CIEMAT test facility in Soria, Spain, for development of components and whole systems for autonomous hybrid systems.

## **UNITED STATES AND CANADA**

### **Alaska and Canada, remote villages**

Approximately 75,000 people live in 175 rural communities distributed throughout Alaska [19]. Of these, 42,427 people in 91 communities have a high potential for wind/diesel systems. Many of these are Native American communities. The largest Indian reservation in the U.S. that is not electrified is the Navajo Nation (~35% not electrified); however, these often represent scattered residents that could not be electrified as a village system per se.

## **AFRICA**

South Africa is only now looking seriously at hybrid systems for village electrification. The following systems currently exist or are in a planning phase:

1. 1 kW PV, 6 kW genset, 1 kW wind: Dr. Deon Raubenheimer is the lead researcher at this research site in Port Elizabeth, SA. Previously, the system was only used as a teaching tool. The system will now be used to power a local radio station. It is hoped a DAS will

be completed to fit to this hybrid to study energy patterns and develop design criteria of future hybrid systems.

2. 500 W PV, 4 kW genset: Mike Whitherton, lead researcher, phone +27-31-3085111. The system is currently powering a remote area school north of Durban in Kwa Zulu, Natal Province.
3. 150-250 kW PV/wind/diesel hybrid systems: Program driven by the National Electric Regulator, a government body. The contact person is Dr W. Barnard +27-11-8840118. One system will be powering the Hluleka Nature Reserve on the Wild Coast in the Eastern Cape Province of South Africa. Two similar systems will be powering two villages in the same area.

Design tools that will help plan or project the savings from hybrid operation have to be readily available, user friendly, and reliable. Being able to simulate the mix of renewables with existing or planned conventional energy will help developers see the benefits of renewables when they are, in fact, economically viable.

Training people at all levels in the general public is essential, so they do not waste the new energy source available to them. Local maintenance and installers need to be trained to reduce dependence on foreign knowledge and expertise, and the utility and government planners should be trained, so they can understand how renewables are viable, economic, and reliable sources of energy that can be exploited without dependence on foreign assets.

When prototypes of first system installations are made, there should be a concerted effort on the part of manufacturers to support viable projects and not just make the sale. While it takes a real effort to avoid making sales when the opportunity arises, developers and manufacturers need to take a long view approach when working in a country for the first time. It could be more advantageous to get it right and designed the first time, rather than sell them what they may ask for and it not really be the system they needed.

Maintaining a database of systems and seeing what has worked and failed in other locales would help developers and designers pick components and controllers with a proven record in the field, or avoid those that have shown to need more design or manufacturing improvements.

Finally, creating industry in the host country will pay off in the long run for U.S. manufacturers, reducing the costs of shipping and reduced down time by having materials readily available will make local government more apt to choose them over a competitor. Showing that the technology can be turned over to properly trained in-country representatives and letting them "work the territory" instead of U.S. representatives coming in as outsiders, should pay handsome dividends, as well as taking advantage of favorable exchange rates in managing company payrolls.

## WORLD GRID ACCESS SUMMARY

A good indicator of potential market size for village hybrid systems is the need for electrification around the globe. There are approximately 1.7 billion persons without electrical service around the world. The largest unserved electrical markets are those in Asia and Africa. See the table below for relative comparisons between unserved electrical markets around the globe.

Electrical access in Developing Countries by Region (Year 2000)

	Total Population		Electrical Access		
	Year 2000 (estimate)		With Access	Unserved	
	Millions	Millions	%	Millions	%
Total	5,060.0	3,391.7	67.0	1,668.3	29.2
Europe & Central Asia	477.1	472.4	99.0	4.7	1.0
Latin America & Caribbean	507.8	441.4	86.9	66.4	11.5
East Asia & Pacific	1,798.7	1,582.6	88.0	216.1	11.0
Middle East & North Africa	292.4	256.0	87.6	36.4	10.4
South Asia	1,343.5	529.5	39.4	813.9	52.2
Sub-Saharan Africa	640.5	109.7	17.1	530.8	66.7

Source: World Bank, 2001. Prepared from country level estimates using best available data.

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## APPENDIX 1. TABLE OF HYBRID SYSTEMS (> 4 kW)

Site	Location	Installed	Wind	PV	Gen	Batt	Inverter	KWh/Day	Status
Nannup	Australia		20KW SURVIVOR	0.44 kW BP	Lister Diesel	100Ah	4.5KW	40 kWh	<a href="http://solstice.crest.org/renewables/synergy/html/pi-brief.html">http://solstice.crest.org/renewables/synergy/html/pi-brief.html</a> <a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest5.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest5.html</a>
Tamala Station	Australia Shark Bay Western Australia		4.5 kW Dunlite Windlite		6 kVA Diesel	43 kWh 16 Exide RP 1350	2.5 kW AES		<a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest1.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest1.html</a>
Challa Station	Australia Western			1 kW	7 kVA Diesel	2200 Ah Alco	2 kVA Trace		<a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest8.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest8.html</a>
Wooramel	Australia Western		20 kW Survivor S20000	0.6 kW	11 kVA Lister	580 Ah	5.5 kW		<a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest10.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest10.html</a>
Keysbrook	Australia Mundijong, Western		5kW Synergy S5000	0.26 kW		11040Ah	2kVA		<a href="http://www.synergypowercorp.com/proj7.htm">http://www.synergypowercorp.com/proj7.htm</a>
Walyni & Ulkiya Homelands	Australia South		20KW Synergy S20000				25.5 KVA	23.3 kWh	<a href="http://solstice.crest.org/renewables/synergy/html/wuh2.html">http://solstice.crest.org/renewables/synergy/html/wuh2.html</a>
Murputja Resource Centre	Australia Southern		20KW Synergy s20000		690kW	4000Ah	10kVA	20-50kWh	<a href="http://www.synergypowercorp.com/proj2.htm">http://www.synergypowercorp.com/proj2.htm</a> Powers Aboriginal school
Isla Tac	Chile		7.5KW		12KW	2100Ah	4.5KW Trace		<a href="http://www.chiloeweb.com/barra_editorial/lagos_tac.html/">http://www.chiloeweb.com/barra_editorial/lagos_tac.html/</a>
Sulina Lighthouse	Romania Danube Delta		5 kW (1.5 kW + 3.5 kW)	4.25 kW			5.4kW (2.7kWx2)	22 kWh	<a href="http://www.icpe.ro/prod/en/06-hybrid.html">http://www.icpe.ro/prod/en/06-hybrid.html</a>
Papago Indian Reservation	USA Arizona	1979		3.5 kW					community was later electrified

Natural Bridges National Monument	USA Utah	1980		100 kW	40 kW	600 kWh	50 kW		System refurbished in 1993 and 1998. Oldest operating hybrid system in world. PV Block III modules <50% original rating were later replaced with Block V modules. <a href="http://www.nps.gov/nabr/pvsystem.html">http://www.nps.gov/nabr/pvsystem.html</a>
Risó National Laboratory	Denmark Roskilde	1985	55KW Bonus		35KW Bukh				<a href="http://www.rsvp.nrel.gov/library/hyinst.html">http://www.rsvp.nrel.gov/library/hyinst.html</a>
Savannah (8 CTACTS Off-shore platform)	USA Georgia	1987 1988 1997 1999	15 kW (7.5 kW Bergey x 2)	7.5 kW (2.5KW+5KW)	25KW Lister Petter	3000Ah (total)		423KWh (121KWh + 302KWh)	<a href="http://www.stswind.com/bergeyprojects.htm">http://www.stswind.com/bergeyprojects.htm</a>
Molokai (Zond)	USA Hawaii	1987			72KW MAN			100 kWh	
Jurf El-Daraweesh Village	Jordan Bt.Amman & Agaba	1987	66 kW 2 WECS Aeroman	10 kW	40 kW (2 x 20kW) asynch	1500Ah		280 kWh	<a href="http://www.nerc.gov.jo/electrification.htm">http://www.nerc.gov.jo/electrification.htm</a>
Rio Mayo	Argentina Chubut, South America	1990	120 kW Aeroman 30 kWx3		1230 kW Diesel				* <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=77">http://www.nrel.gov/villagepower/asp/project.asp?ID1=77</a>
Inner Mongolia	China	1990	10 kW (5 kWx2) Inventus-6		18 kW Diesel	57 kWh			* <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=219">http://www.nrel.gov/villagepower/asp/project.asp?ID1=219</a> Serves around 400 people
Foula Island	Scotland Atlantic Ocean, North	1991	60KW Windharvester		25.5KW Diesel 18 kW Hydro				1% of energy from diesel <a href="http://www.rsvp.nrel.gov/library/hyinst.html">http://www.rsvp.nrel.gov/library/hyinst.html</a>
Denmark	Australia Western	1992 1994	5 kW Survivor S5000	0.33 kW			4 kW		<a href="http://wwwphys.murdoch.edu.au/WebRAPS/dsr/casest7.html">http://wwwphys.murdoch.edu.au/WebRAPS/dsr/casest7.html</a>
Watarru Aboriginal Comm.	Australia	1992	20KW SURVIVOR	0.6 kW		540Ah gel-cell	30KW	60 kWh	<a href="http://solstice.crest.org/renewables/synergy/html/wat-brief.html">http://solstice.crest.org/renewables/synergy/html/wat-brief.html</a>

Waturru	Australia Pitjatjantjar a Lands of South Australia	1992	40kW (2)Synergy s20000	0.6 kW			415v phase	3	60 kWh	<a href="http://www.synergypowercorp.com/proj3.htm">http://www.synergypowercorp.com/proj3.htm</a>
Xcalak Village	Mexico Quitana Roo	1992	42 kW Excel (6)	11.2 kW Siemens	50 kW	1638 Ah GNB	40 kW AES		120-250 kWh/day	Inverter 4 failures system down since Oct. 1998 Wind turbines 3 functional PV is fine <a href="http://www.nrel.gov/villagepower/program/briefs_2000/xcalak.pdf">http://www.nrel.gov/villagepower/program/briefs_2000/xcalak.pdf</a>
El Junco and 3 others	Mexico Zacatecas	1992	11.6kW	1.6 kW	10kW					Insufficient wind resource to operate 4 wind hybrids done by IIE. <a href="http://www.nedo.go.jp/english/informations/121218/files/paper_mendoza.pdf">http://www.nedo.go.jp/english/informations/121218/files/paper_mendoza.pdf</a>
Maria Magdalena Village	Mexico Hidalgo Pachuca	1992	5 kW (1) Colibri	4.3 kW	16.7 kVA Diesel	132 kWh	??		45 kWh	System failed -1995, batteries failed, wind turbine did not function well. Disassembled * <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=208">http://www.nrel.gov/villagepower/asp/project.asp?ID1=208</a>
Ciparanti Village	Indonesia Java	1993	20KW SURVIVOR		4.8KW	200Ah	4KW Siemens		10 kWh	<a href="http://solstice.crest.org/renewables/synergy/html/cip-brief.html">http://solstice.crest.org/renewables/synergy/html/cip-brief.html</a>
Ciparanti	Indonesia Java,	1993	20kW Synergy S20000		4.8kVA	33600Ah	4kVA		20 kWh	<a href="http://www.synergypowercorp.com/project.htm">http://www.synergypowercorp.com/project.htm</a>
San Antonio Agua Bendita	Mexico Tenancingo	1993	20kW	12.4 kW	40kW	250 kWh				<a href="http://www.nedo.go.jp/english/informations/121218/files/paper_mendoza.pdf">http://www.nedo.go.jp/english/informations/121218/files/paper_mendoza.pdf</a>
Channel Islands	USA California	1994 1995	21.5 kW	29.5 kW	45 kW					<a href="http://www.eren.doe.gov/femp/tchassist/275.html">http://www.eren.doe.gov/femp/tchassist/275.html</a>
Moses Rock	Australia Yallingup	1994	5 kW Survivor S5000	0.3 kW	Diesel		2 kW Siemens			<a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest3.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest3.html</a>
Darling Scarp	Australia Western	1994	1 kW Soma	0.48 kW Solarex	Gas Honda	450 Ah	3.3 kW			<a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest9.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest9.html</a>
Payne's Find	Australia Western	1994		1.35 kW		1080 Ah	3 kVA Brutus			<a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest11.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest11.html</a>
Eneabba- Carnamah	Australia Western	1994		1 kW	5 kVA Diesel	12 kWh	2.5 kVA AES Sinemax			<a href="http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest14.html">http://wwwphys.murdoch.edu.au/WebRAPS/distr/casest14.html</a>

Penthinteme Aboriginal Comm.	Australia	1994	20kW (2)Synergys20000	1.8 kW	8kVA Kubota	27 12v sonnensheinn	5.5kVA	36 kWh	<a href="http://www.synergypowercorp.com/proj5.htm">http://www.synergypowercorp.com/proj5.htm</a>
Boomerang Bore	Australia Northern Territory,	1994	40kW (2)Synergys20000	1.7 kW			10kVa	54.9 kWh	<a href="http://www.synergypowercorp.com/proj4.htm">http://www.synergypowercorp.com/proj4.htm</a>
Campinas Village	Brazil Amazonia	1994		50 kW Solarex Cor. (total)	48KW diesel		AES	350 kWh	* <a href="http://www.rsvp.nrel.gov/progrm/briefs_2000/">http://www.rsvp.nrel.gov/progrm/briefs_2000/</a>
Joanes Village on Marajù Island	Brazil Amazonia	1994 2001	40 kW (10 kW x 4) Bergey	50 kW SSI		228 kWh		350 kWh CELPA	* <a href="http://www.rsvp.nrel.gov/asp/project.asp?ID1=221">http://www.rsvp.nrel.gov/asp/project.asp?ID1=221</a> <a href="http://www.northernpower.com/framesets/projects_fset_joannes_wind.html">http://www.northernpower.com/framesets/projects_fset_joannes_wind.html</a>
Morocco	Morocco North Africa	1994	150 kW Atlantic Orient		96 kW (48kWx2)				* <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=205">http://www.nrel.gov/villagepower/asp/project.asp?ID1=205</a>
Xiaoguandao Island	China (near Laoshan, close to Qingdao)	1995	25 kW	5 kW	30 kW Diesel	1000 Ah	30 kW		* <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=216">http://www.nrel.gov/villagepower/asp/project.asp?ID1=216</a>
North Manitou Island	USA Michigan	1996		11 kW Siemens	60 kW (2) Kohler	288 kWh	15 kW AES		<a href="http://www.eren.doe.gov/femp/millionroofs/pdfs/027853m_V3No1_spring2000.pdf">http://www.eren.doe.gov/femp/millionroofs/pdfs/027853m_V3No1_spring2000.pdf</a> <a href="http://www.commerce.state.mi.us/opla/erd/cases/case11.htm">http://www.commerce.state.mi.us/opla/erd/cases/case11.htm</a>
Carol Springs Mountain	USA Arizona	1996		25kW	60kW	600kWH	30 kW 3 phase		System performed poorly for first 2 years until many issues were resolved, 80% of load PV supplied <a href="http://www.sandia.gov/pv/symposium/D6 - Hill.doc">http://www.sandia.gov/pv/symposium/D6 - Hill.doc</a>
Dangling Rope	USA Utah	1996		160kW	(2)225kW	2.4 MWh		250kW	Approximately 80% of load supplied by Solar Resource. The battery bank and inverter was refurbished 2001 due to technical problems. <a href="http://www.sandia.gov/pv/symposium/D6 - Hill.doc">http://www.sandia.gov/pv/symposium/D6 - Hill.doc</a>

Cherry Creek	USA Colorado Denver	1996		25 kW Northern Power Grid Connect					<a href="http://www.northernpower.com/framesets/main_renewable.html?content=sub1_renew-projects.html">http://www.northernpower.com/framesets/main_renewable.html?content=sub1_renew-projects.html</a>
PICHTR	USA Hawaii Kahua Village	1996	24 kW (3x8 kW)	9.8 kW (245 W x 40)	36 kW Diesel	428 kWh	30 kW	360 kWh	* <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=191">http://www.nrel.gov/villagepower/asp/project.asp?ID1=191</a>
Pinnacles	USA California	1996		9.6	20 kW Kohler	4200 AH	24 kW (6) Trace 4kW	41	Completely functional <a href="http://www.eren.doe.gov/femp/techassist/530_pinnacles.html">http://www.eren.doe.gov/femp/techassist/530_pinnacles.html</a>
Jujuy	Argentina, South America	1996			50 kW Micro hydro 48 kW M. Pienz Diesel				* <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=71">http://www.nrel.gov/villagepower/asp/project.asp?ID1=71</a>
Costa de Cocos Hotel	Mexico Xcalak Qroo	1996	10 kW (1) Excel	1 kW	15 kW Diesel	?? L-16	(2) Trace		Wind turbine was destroyed in hurricane in 2000 due to corroded guywire, battery bank replaced 2001 and charged with PV and generator <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=17">http://www.nrel.gov/villagepower/asp/project.asp?ID1=17</a>
STAR hybrid test facility	USA Arizona Tempe	1997		60 kW	150kW	900kWh	50 kW 3 phase		455 kW load, Operates STAR building <a href="http://www.sandia.gov/pv/symposium/D6 - Hill.doc">http://www.sandia.gov/pv/symposium/D6 - Hill.doc</a>
Las Vegas	Argentina Santa Cruz	1997	20 kW (4 kW x 5) Eolux			800 AH Exide	4.5 kW Trace		
Krasnoe Village	Russia Arkhangelsk	1997	7.5KW Bergey (2)					96 kWh	<a href="http://www.caddetre.org/assets/no106.pdf">http://www.caddetre.org/assets/no106.pdf</a>
Bolshie Kozli Village	Russia Arkhangelsk	1997	10KW Bergey						* <a href="http://www.nrel.gov/villagepower/program/briefs_1998/russia.pdf">http://www.nrel.gov/villagepower/program/briefs_1998/russia.pdf</a>
KEA	USA Kotzebue, AK	1997 1999	660 kW AOC (10)		11,200 kW			1300	Completely functional <a href="http://www.eren.doe.gov/windpoweringamerica/pdfs/wind_diesel_options_alaska.pdf">http://www.eren.doe.gov/windpoweringamerica/pdfs/wind_diesel_options_alaska.pdf</a>
Volcanoes National Park	USA Hawaii	1998		0.9 kW ASE	4.5 kW propane	2800 Ah	Trace 4024		<a href="http://www.nrel.gov/ncpv/pdfs/26134.pdf">http://www.nrel.gov/ncpv/pdfs/26134.pdf</a>

Joshua Tree	USA California	1998		21 kW Siemens	35 Generac	250 kWh	30 Trace		<a href="http://www.eren.doe.gov/femp/techassist/joshua_mojave.html">http://www.eren.doe.gov/femp/techassist/joshua_mojave.html</a>
San Clemente Island	USA California	1998	450 kW (2 x NM 225/30)		2950 kW			210 kWh	<a href="http://www.nrel.gov/wind/24663a.pdf">http://www.nrel.gov/wind/24663a.pdf</a>
Yuma	USA Arizona Yuma	1998		105 kW	225kW	1700 kWh	150kW phase 3		99% of load provided with solar. <a href="http://www.sandia.gov/pv/symposium/D6 - Hill.doc">http://www.sandia.gov/pv/symposium/D6 - Hill.doc</a>
Nabouwalu	Fiji Vanua Levu	1998	6.7 kW Bergey	37.5 kW ASE America	200 kVA (2x100 kVA) Diesel	370 kWh	100 kVA	720 kWh	* <a href="http://www.nrel.gov/villagepower/asp/project.asp?ID1=192">http://www.nrel.gov/villagepower/asp/project.asp?ID1=192</a>
Chajul Biological Research Station	Mexico Chiapas,	1998		10.5 kW Siemens	6.3 kW Onan Propane	Exide	5.5 kW Trace	40 kWh	Functional. System was flooded in Hurricane Mitch (99) and inverter board replaced. <a href="http://www.re.sandia.gov/en/pb/nl/1/nl1-rt.htm">http://www.re.sandia.gov/en/pb/nl/1/nl1-rt.htm</a> <a href="http://www.rsvp.nrel.gov/vpconference/vp98/Posters/mexico.pdf">http://www.rsvp.nrel.gov/vpconference/vp98/Posters/mexico.pdf</a>
Megra Village	Russia Arkhangelsk	1998	10KW Bergey (2)					96 kWh	* <a href="http://www.nrel.gov/villagepower/program/briefs_1998/russia.pdf">http://www.nrel.gov/villagepower/program/briefs_1998/russia.pdf</a>
Wales Village	USA AK	1999	130 kW (65 kW AOC x 2)		411 kW (75kw+ 162kw+ 168kw)	130Ah (240 VDC)			<a href="http://www.eren.doe.gov/windpoweringamerica/pdfs/wind_diesel_options_alaska.pdf">http://www.eren.doe.gov/windpoweringamerica/pdfs/wind_diesel_options_alaska.pdf</a>
Tanadgusix Corp.	USA AK	1999	225KW Vestas V27		300KW (150 x 2) Synch.				<a href="http://www.awea.org/wew/829-1.html">http://www.awea.org/wew/829-1.html</a> <a href="http://www.northernpower.com/media/pdf/pb_stpaulisland.pdf">http://www.northernpower.com/media/pdf/pb_stpaulisland.pdf</a>
Canyons National Park Maze District	USA Utah	1999		7 kW	60kW(2)	132kWh	20kW		50% of load for ranger housing, visitor's center, etc. <a href="http://www.sandia.gov/pv/symposium/D6 - Hill.doc">http://www.sandia.gov/pv/symposium/D6 - Hill.doc</a>
Cayo Romano	Cuba	1999	10 kW Südwind		10 kW Lister		43	118	First Wind/Diesel Hybrid in Cuba. O&M in remote areas is main concern for system longevity. <a href="http://www.karen-berlin.de/wdh.html">http://www.karen-berlin.de/wdh.html</a> (auf Deutch)

Sagar Island Village	India	1999		26 kW			27 kVA 3 phase		<a href="http://www.aesltd.com.au/projects/sagar.htm">http://www.aesltd.com.au/projects/sagar.htm</a>
San Juanico Village	Mexico Baja CA Sur	1999	100 kW (10 kW x 10) Bergey	17 kW ASE America (5)	80KW standby gen. Diesel	1800Ah	90KW Trace		<a href="http://www.asepv.com/sanjuanpv/hyb.html">http://www.asepv.com/sanjuanpv/hyb.html</a>
Chorreras Ice maker	Mexico Chihuahua Aldama	1999		2.4 kW Siemens	6.3 kW Kohler	2200Ah	10 kW Trace (5 kW x 2)	8.9 kWh	Ice-making system. Some problems with poor water quality impairing ice-maker performance. <a href="http://www.re.sandia.gov/en/pb/pd/icemaking.pdf">http://www.re.sandia.gov/en/pb/pd/icemaking.pdf</a>
Rud	Norway	1999		2 kW	5Kw Micro-CHP LPG fuel				<a href="http://www.caddet-re.org/assets/200art8.pdf">http://www.caddet-re.org/assets/200art8.pdf</a> <a href="http://www.caddet.co.uk/assets/499news.pdf">http://www.caddet.co.uk/assets/499news.pdf</a>
Diamond Bar	USA California	2000		29 kW Solarex grid connect			3 KW Pacific PI-3000	142 kWh	<a href="http://www.northernpower.com/framesets/main_renewable.html?content=sub1_renew-projects.html">http://www.northernpower.com/framesets/main_renewable.html?content=sub1_renew-projects.html</a>
Rote Island	Indonesia NTT Province	2000	10 kW	22 kW	20 kW Diesel			48 kWh	<a href="http://www.e7.org/PDFs/E7_RESS_Indonesia.pdf">http://www.e7.org/PDFs/E7_RESS_Indonesia.pdf</a> (Pg. 23)
Atulayan	Phillipines Camarines Sur	2000	20 kW Synergy S20000(24v)	0.9 kW	75kVA	2000Ah	16.5 kVa (5.5kVA x 3)	36.5 kWh	<a href="http://www.synergypowercorp.com/proj9.htm">http://www.synergypowercorp.com/proj9.htm</a>
Mobile Hybrid Power System	USA California (portable)	2001		38.4 kW	300kW (150kWx2)		60kW		<a href="http://www.omegape.com/projects/agp.html">http://www.omegape.com/projects/agp.html</a>
Xiso Qing Dao Island	China Shandong	2001	7KW				40KW		* <a href="http://www.nrel.gov/international/china/pilot_projects.html">http://www.nrel.gov/international/china/pilot_projects.html</a>
Morn Salnave	Haiti	2001	1.2 kW (400 W x 3) AIR 403	2.24 kW Solarex	6.5 kVA Kubota Diesel	2256 Ah			<a href="http://www.southwestpv.com/Catalog/Morn_Salnave.htm">http://www.southwestpv.com/Catalog/Morn_Salnave.htm</a>
Hilaire	Haiti Hilaire	2001	2.4 kW (400 W x 4) AIR 403	2.24 kW Solarex	12.5 kVA Kubota	1128 Ah Lead Acid			<a href="http://www.southwestpv.com/Catalog/Hilaire.htm">http://www.southwestpv.com/Catalog/Hilaire.htm</a>

Pheriche	Nepal	2001	5kW Synergy S5000DD	0.75 kW					14000 ft alt. Worlds highest hybrid. <a href="http://www.synergypowercorp.com/proj11.htm">http://www.synergypowercorp.com/proj11.htm</a>
RAPS Indiana	Peru Indiana	2001		60 kW	200 kW Diesel	3000 Ah Gel Cell	160 kW (40 kW x 4)	600 kWh	<a href="http://www.climatetech.net/conferences/elsalvador/proceed/Sessi onII/PERU.PDF">http://www.climatetech.net/conferences/elsalvador/proceed/Sessi onII/PERU.PDF</a> <a href="http://www.climatechangedebate.org/pdf/IRPnewsletter.pdf">http://www.climatechangedebate.org/pdf/IRPnewsletter.pdf</a>
RAPS Padre Cocha	Peru Padre Cocha	2001		30 kW	100 kW Diesel	1500 Ah Gel-Cell	80 Kw (40 kW x 2)	300 kWh	<a href="http://www.climatetech.net/conferences/elsalvador/proceed/Sessi onII/PERU.PDF">http://www.climatetech.net/conferences/elsalvador/proceed/Sessi onII/PERU.PDF</a> <a href="http://www.climatechangedebate.org/pdf/IRPnewsletter.pdf">http://www.climatechangedebate.org/pdf/IRPnewsletter.pdf</a>

## APPENDIX 2. QUESTIONNAIRE AND TABLULATED RESPONSES

Thanks for responding to this Hybrid power questionnaire.

The US Government is prepared to fund hybrid power research for the 21st century. This questionnaire is meant to gather feedback as to what areas of research need to be addressed or avenues of research that should be suggested to the DOE. The responses that you provide will remain anonymous and will be compiled by the Alternative Energy Institute. The information is to be used as baseline information for a report to DOE, documenting the areas that are considered to have the greatest need for research efforts in this field. A response area in the later portion of this questionnaire will allow your input concerning any areas of concern that you feel were not fully covered in the listings. Once again thank you for your time and effort in responding.

1: Have you or your institute/company/university installed a hybrid system?

Yes  Not yet

If you have installed a system or systems, where were they located?

South America  Africa  Caribbean  Europe  
 Pacific Rim  Asia  North America  
 Arctic/Antarctic  Other

2: If you have experience with a hybrid system, please describe where it was located and what renewable/conventional systems were used.

3: Hybrid power systems seem to be a good method of delivering power to isolated villages and homes without the costly extension of grid service. What size power systems do you feel should be emphasized in US directed research for this purpose?

Please check all sizes you wish explored.

1--10 kW  10--50 kW  50--100 kW  100--200 kW  
 200--500 kW  Megawatt scale

4: Hybrid systems can be composed of several different renewable and conventional generating systems. Rank as 1, 2, 3 which of these components should you consider to be most important areas for study in viable hybrid components for systems marketable in the next 10 years. If the size range is not what you feel it should be, strike through it and write the size you feel should be considered.

a Wind turbine, 1-10 kW b Wind turbine, 10 - 50 kW c Wind turbine, > 50 kW d Micro-hydro 100 W-10 kW e Solar PV 100 W-2 kW f Solar PV 2 kW-10 kW g Ocean Thermal (    size) h Tidal Energy (    size) i Geothermal (    size)  
j Bio diesel gensets (    size) k Concentrating solar Stirling (1 - 10 kW) l Bio-fuel genset(    size)

5: Hybrid systems may have to interact with an existing micro-electric grid, however it should yet minimally impact that grid. To do this, control systems and components must be used to measure, react and reset to changes in inputs, outputs and conditions. Which areas do you feel more research or expertise is needed to prove the reliability and usability of components in field systems?

Please rank 1, 2, and 3 next to the sources you feel most need research to become suitable for hybrid systems.

- |   |   |  |  |
|---|---|--|--|
| <input type="checkbox"/> Anemometry           | <input type="checkbox"/> Power monitoring electronics | <input type="checkbox"/> Power control relays and switches | <input type="checkbox"/> System Controllers        |
| <input type="checkbox"/> Fuel sensors         | <input type="checkbox"/> Torque sensors               | <input type="checkbox"/> Monitoring systems                | <input type="checkbox"/> Vibration sensors         |
| <input type="checkbox"/> Corrosion prevention | <input type="checkbox"/> Tower installations          | <input type="checkbox"/> Dump loads                        | <input type="checkbox"/> Power mixing switchboards |
| <input type="checkbox"/> Other, please list   |   |  |  |

6: What voltage / system supply do you feel are most likely to succeed?

- DC, less than 50 volts     DC 100 -200 volts     AC 100-120 volts, single phase  
 AC 120-240 volts single phase  
 AC 240-480 single phase     AC 240 - 480 volt poly phase    Other

7: Hybrid systems will rely on local maintenance and repair crews that at times may be faced with very challenging and difficult tasks to repair technology that is relatively new to the area. What should the goal be to minimize field problems? Check all that you feel would be helpful.

- Require that 50% of materials/parts be from local sources. Local defined as able to be supplied in 1--2 weeks time frame as needed.  
 Require that systems the researchers study be limited in size/scale so that more projects can be installed and operated  
 Require the systems be fully operational from more than a single source of power, so that as one section/power source goes down the other or others can still provide limited power until fully operational.  
 Require in-county training as part of each project so that any project has at least two fully qualified operators/repair persons before project is operational.  
 Other ideas,

8: The use of any non-renewable fuel in the hybrid mix often leads to procurement and storage problems. What fuels should be considered to be the prime movers in a Hybrid system?

Please rank 1, 2 and 3.

- |                                     |   |  |                                  |
|-------------------------------------|---|--|----------------------------------|
| <input type="checkbox"/> OIL        | <input type="checkbox"/> COAL           | <input type="checkbox"/> GASOLINE/PETROL | <input type="checkbox"/> DIESEL  |
| <input type="checkbox"/> BIO-DIESEL | <input type="checkbox"/> OTHER BIO-FUEL | <input type="checkbox"/> HYDROGEN        | <input type="checkbox"/> METHANE |

9: Monitoring systems and controllers are available but limited in size and availability. Which of these sensitivity ranges do you consider sufficient for control of a hybrid system. Please check the minimum acceptable level.

- 1 millisecond     10 milliseconds     100 milliseconds or less     500 milliseconds or less  
 within a second     5 seconds or less

10: Variability of voltage in a hybrid system is a concern of the controller. What acceptable range of voltage fluctuation is the minimum that should be allowed? Please check the minimum acceptable level.

- +/- 2 %     +/- 5%     +/- 10 %     +/- 20%     +/- 30%

11: On systems that supply Alternating Current, the frequency variability can lead to damage of systems connected to the microgrid and requires the system controller to adjust to keep fluctuations within limits. what minimum acceptable level of frequency variability should be allowed? If significant variability is allowed, the loads must be rated to accept these fluctuations. Please check the minimum acceptable level.

- +/- 0.5 %     +/- 1 %     +/- 3 %     +/- 5 %     +/- 10 %

12: The effect of placing a microgrid in an isolated community might be minimized by careful planning and proper installation. Which of the following techniques would be helpful in getting a community to accept the new power source with minimal negative feedback?

Mark as + + , + , 0 , - , - - relative to great idea, good impact, neutral, poor suggestion or damaging

Use underground installation of power distribution lines

Minimize individual power metering and pool power payments based on total use. Requiring partial payment for power supplied is necessary to show the value of the energy, but reducing metering equipment lowers costs, spread cost over all users.

Require systems to have transmission capability of at least 5 kilometers so that remote installations are possible with power delivered away from power source. Extending limit grid transmission would allow placing renewable sources in beneficial locations but increase overall costs.

Require that resource assessment evaluations include local community as observers/participants to ensure that they were included in process.

Limit conventional power sources to those that are available in project country, do not place additional burdens on local governments by having them rely on foreign supplies to supply power.

Make system components more "black box" style, rugged, non-adjustable systems. These means that systems must work with only regular maintenance or component replacement. This would keep locals from modifying system for unintended operation. Places greater emphasis on controller complexity/adaptability.

Other Ideas or Comments

Appendix: AEI Questionnaire

**Thanks for responding to this Hybrid power questionnaire.**

### Tabulated Survey Responses

Question 1 and 2		
yes	N America	Test Bed Prince Edward Island, Canada Commercial installation ST-Pauls Island AK High penetration, No Storage, Wind-Disel Scenario
Not yet (2)		

Question 3					
1-10 kW	10-50 kW	50-100 kW	100-200 kW	200-500 kW	Megawatt scale
1		2	1	1	1

Question 4										
a	b	c	d	e	f	g	h	i	j	k
3/1	3/2	3/2	1/1	5/2	3/1				3/1	
	2			1					3 : 5-50 kW	

Question 5											
Ane	PME	PCR	SC	FS	TS	MS	VS	CP	TI	DL	PMS
			X			X				X	
	X	X	X								
NC											

Other

Question 6					
DC < 50 V	DC 100-200 V	AC 100-120 V single phase	AC 120-240 V single phase	AC 240-480V single phase	AC 240-480 V poly phase
other					
X			X		X
NC					

Other: For system larger than 200 kW- 4160V; Megawatt sale 12.5-25 kV

Question 7			
50% material local	limited size/scale	more than one source	in-couny training
other			
	X		X
X			Xx

Other: Require that system reliability be well proven before installation in remote areas is considered

Require that supplier offers about 2 year warranty, parts ,labor and travel

Question 8							
oil	coal	gas/petrol	diesel	bio-diesel	other bios	hydrogen	methane
			X			X	
			X	X		X	X
				1	2	3	

Question 9					
1 ms or less	10 ms or less	100 ms or less	500 ms or less	1 s or less	5 s or less
		X			
NC					

Other: 5 s to 1 min for decision making (start / stop for diesels)

10				
<input type="checkbox"/> 2 %	<input type="checkbox"/> 5 %	<input type="checkbox"/> 10 %	<input type="checkbox"/> 20 %	<input type="checkbox"/> 30 %
X				
	X			
NC				

Question 11				
<input type="checkbox"/> 0.5 %	<input type="checkbox"/> 1 %	<input type="checkbox"/> 3 %	<input type="checkbox"/> 5 %	<input type="checkbox"/> 10 %
	X to	X (std Network)		
	X	X		
NC				

Question 12						
underground	minim. indiv. power	transmission cap. 5 km	include local community	limit power	conv.	black style box
Others						
			X	X		X
others						

Other: two different requirements: New electrification small size; Retrofit into existing diesel + H2 storable fuel cell or heat engines to duplicate non renewable fuels completely