

Renewables for Sustainable Village Power

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RENEWABLES FOR SUSTAINABLE VILLAGE POWER

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INTRODUCTION

It is estimated that two billion people live without electricity and its services. In addition, there is a sizeable number of rural villages that have limited electrical service, with either part-day operation by diesel gen-sets or partial electrification (local school or community center and several nearby houses). For many villages connected to the grid, power is often sporadically available and of poor quality. The U.S. National Renewable Energy Laboratory (NREL) in Golden, Colorado, has initiated a program to address these potential electricity opportunities in rural villages through the application of renewable energy (RE) technologies. The objective of this program is to develop and implement applications that demonstrate the technical performance, economic competitiveness, operational viability, and environmental benefits of renewable rural electric solutions, compared to the conventional options of line extension and isolated diesel mini-grids. These four attributes foster sustainability; therefore, the program is entitled Renewables for Sustainable Village Power (RSVP). The RSVP program is a multi-disciplinary, multi-technology, multi-application program composed of six activities, including village applications development, computer model development, systems analysis, pilot project development, technical assistance, and Internet-based village power project data base. While the current program emphasizes wind, photovoltaics (PV), and their hybrids with diesel gen-sets, micro-hydro and micro-biomass technologies may be integrated in the future. NREL's RSVP team is currently involved in rural electricity projects in thirteen countries, with U.S., foreign, and internationally based agencies and institutions. The integration of the technology developments, institutional experiences, and the financial solutions for the implementation of renewables in the main line rural electrification processes in both the developing world and remote regions of the developed world is our goal.

APPLICATIONS DEVELOPMENT

While NREL is primarily a technology development laboratory, with an emphasis on science and engineering to underpin cost-shared, industry-based component and manufacturing process development, the RSVP program focuses on village applications. The main objective of the applications development activities is to investigate RE-based systems that will reduce the life-cycle cost and/or improve the performance of commercial RE systems, thereby expanding the market for renewables. Many of these applications have the potential to facilitate economic development within the village, a major goal of many international development organizations and host-country national and provincial governments.

Electrification of rural villages has the potential to power substantial economic development activities if the power is available during the daytime and the appropriate training and marketing infrastructure is available. However, in most smaller villages served by diesel gen-sets it is cost-prohibitive to provide daytime power and this economic development potential is not realized. Renewable energy systems are better suited to deliver 24-hour power in small villages where income generation and economic development are policy goals.

Currently the applications team is examining ice-making, water desalination, water purification, battery-charging stations, and village hybrid power generation. The ice-making project is attempting to "direct-drive" (i.e., no inverter) a commercial ice-making machine with a permanent-magnet-alternator-type (pma) wind turbine. A number of initial technical hurdles have been addressed (e.g., start-up surge requirement) while several others need to be resolved before this concept is ready for a pilot project. The work thus far has consisted of computer modeling, systems analysis, laboratory dynamometer testing, and limited field testing. This concept has significant appeal for remote, coastal fishing cooperatives. In the meantime, the more conservative and expensive approach of a pma wind turbine connected to a battery-inverter subsystem which, in turn, is connected to the icemaker will be field-tested.

In many remote, rural areas, families use lead-acid batteries for powering lights, radios, and televisions. The families transport these batteries to the nearest electrified town for charging on a weekly basis; carrying batteries is a considerable effort and inconvenience. Because many of these rural areas have good renewable resources in close proximity to the homes, a renewable-based battery charging station (BCS) appears to be a good solution for the villagers; it also offers the opportunity of developing a local micro-enterprise based on an environmentally friendly technology. Battery charging stations also provide an alternative approach to PV-powered solar home lighting systems (PV-SHS). Both PV and wind-hybrid BCS are being developed; while there are a handful of PV-based systems in the field, the wind-hybrid systems will be installed in pilot programs in 1997. The technical challenge of the wind-hybrid approach is to adapt existing power conversion devices to pma wind turbines for groups of batteries in such a way as to minimize the life-cycle cost of the system, including the batteries. Both individual battery control and "batch charging" (batteries charged in parallel on a single busbar) are being investigated. The leading concept will be field-tested in 1997.

Water is the lifeblood of many rural communities, yet water quantity and quality is often low. While PV and wind water-pumping technologies are commercially available for potable, livestock, and irrigation uses, adapting renewable sources to desalination and disinfection is just emerging. The RSVP team has investigated various desalination systems appropriate to village-scale needs and is in the process of experimentally characterizing a commercial vapor-compression distillation system for both brackish and sea water. Other institutions are evaluating alternative rural desalination systems; comparison of the performance and economics of these various approaches will be made. Additionally, a review of the alternative water disinfection processes adaptable to renewables, including direct solar, is under way.

Because many villages have either diesels dedicated to a particular use or a diesel mini-grid, they face both economic (fuel cost) and maintenance problems associated with remote diesel operations. Yet in many of these villages, the solar and/or wind resources are good enough to compete economically with the life-cycle

cost (LCC) of diesel operation. NREL has a significant program addressing the hybridization of diesel gen-sets with renewables. The recently developed Hybrid Power Test Bed is used to characterize the performance of emerging hybrid architectures, components, subsystems, and control strategies for a simulated village power load profile. The initial hybrid system test combined a 50-kW induction wind turbine with a 175-kWh battery bank and a 50-kW diesel gen-set. Currently scheduled tests include a 50-kW electronic inverter developed under NREL's PVMAT program and the control panel for the Alaska "high-penetration" wind-diesel retrofit project. Smaller hybrid systems, in the 1.5-10-kW range, are scheduled for testing later in 1997.

COMPUTER MODELS

A significant barrier to the adoption of the appropriate renewable technologies for rural villages has been the absence of analytic tools that accurately compare the alternative options, both conventional and renewable. To address this barrier, the RSVP team has developed a set of models that address 1) optimization of hybrid systems (HOMER), 2) the detailed technical and economic performance of hybrids (Hybrid2), and 3) the economics of alternative village electricity options.

While there are several models in use for evaluating the performance of hybrid systems, they suffer from either limited architectures, control strategies, availability, or user-friendliness. NREL, in collaboration with the University of Massachusetts, has developed the Windows-based Hybrid2 model that is versatile in its components/architectures/control strategy options and is publicly available. An extensive library of commercial components is included, as is the capability to input user-defined components and control strategies. Typical hourly wind and solar resource data are available to scale if site data are not available. Village load profile, system architecture and control strategy, unit costs, and financial parameters are inputs. The key outputs are component and system performance, diesel-fuel use, and economic parameters. This model is used regularly by analysts who want to compare the economics of hybrid system options to conventional diesel gen-sets.

Because of the limited experience with hybrid systems, analysts who want to investigate the technical and financial performance of hybrids have a difficult time getting started in selecting an architecture and control strategy that is appropriate for the given village load profile and the available solar and wind resources. To address this issue, the RSVP team developed a Hybrid Optimization Model for Electric Renewables (HOMER) using specialized optimization software. The analyst inputs solar and wind resource data, village load profile, desired service quality, unit costs, and financial parameters; the objective function is least life-cycle cost. The program searches for and selects the architecture and control strategy that provides the lowest LCC. This architecture becomes the input to the Hybrid2 model. It is particularly useful for sensitivity analyses on variables of resource, loads, diesel-fuel costs, and financial parameters.

Conventional rural-electrification methods include extending the utility grid or implementing an isolated diesel mini-grid. For those communities without these solutions, batteries, kerosene, and candles are used extensively, even in the remotest villages. Recently, the use of PV-SHS has been adopted by a number of countries as a viable alternative to non-grid lighting sources. The World Bank's Asia Technical Department (ASTAE) developed a spreadsheet model to compare PV-SHS to conventional electricity options for

Indonesia. The RSVP team has collaborated with ASTAE to expand the comparison to include wind and PV-based hybrids and an optimum mini-grid. This tool can now compare optimum RE-based hybrids to PV-SHS and conventional options, thereby providing an economic comparison of AC and DC options, both conventional and RE-based.

SYSTEMS ANALYSES

Because renewable solutions for villages are relatively new, the analytical capacity to evaluate options is limited. The RSVP team is collaborating with industry, government agencies, NGOs, and international organizations in analyzing village options using the aforementioned computer models. The analyses fall into three categories: prefeasibility, design, and post-installation system performance. The prefeasibility analyses generally are sensitivity analyses about the key parameters that the collaborators specify. During the last year, the RSVP team performed such analyses for small, remote wind-hybrids for villages in southern Chile, wind-diesel retrofits of isolated communities in southern Argentina, a 50-kW wind-PV-diesel mini-grid in northern Brazil, wind-PV-diesel retrofits in remote fishing villages in Mexico, a wind-diesel retrofit of an eco-tourism resort in Yucatan, diesel retrofits of mini- and micro-grids in eastern Indonesia, PV-wind hybrid household and village systems in Inner Mongolia, wind-PV school systems in Argentina, wind-diesel retrofit of remote locations in the Murmansk region of Russia and fishing villages in northwest Alaska. (The specific results of these analyses are published in other conference proceedings).

Because the RSVP team recognizes that industry uses its own set of design tools and methods, we generally do not conduct detailed design. However, we have worked with industry to assist them in the use of Hybrid2 so that they can adapt it for specific design studies. The use of systems analysis tools to evaluate the performance of operating systems has proven very valuable. While most village system installations are commissioned, they do not include performance monitoring data acquisition systems. The RSVP program and other technical organizations are encouraging some level of monitoring, since monitored data is the best, if not the only, way to determine component and system performance over time. Comparing actual performance to predicted performance can greatly help the system designer and component manufacturer improve their products. Because monitoring is both expensive and time consuming, a set of protocols has been developed for different levels of analysis. Reporting the results to the village-systems design community is critical to the continued improvement and competitiveness of RE-based systems.

PILOT PROJECTS

The role of pilot projects in the development of a sustainable RE-based rural electrification program is critical. Pilot projects require details; details require attention and commitment that lead to in-country knowledge; in-country knowledge is the beginning of sustainability. The pilot-project process addresses three critical areas: technical performance, economic competitiveness, and institutional viability. Because renewables are generally an unfamiliar solution to those who are responsible for the planning, implementation, and operation of rural electrification solutions, it is essential that the hardware be installed in-region. The process of site selection, load estimation, resource assessment, prefeasibility analyses, familiarization with commercial RE equipment and suppliers, system specifications, procurement development, installation and commissioning oversight, and analysis of performance data are extremely

valuable to the in-country participants. In many cases, the initial pilot project is heavily invested by the RSVP team, but subsequent pilots in other regions are led by the now-experienced in-country team.

Wind-electric and PV generators, and their balance of systems, are very different from conventional generation equipment in many aspects, and therefore somewhat intimidating to the regional rural electricity provider. To make the transition to comfort, the systems will need to perform as well as or better than the conventional solutions. Robustness, reliability, quality of service, and serviceability are the technical parameters that the local provider will be interested in evaluating. The performance data, including system, resource and load data, need to be collected, collaboratively analyzed, and reported to the project sponsors.

Most rural electrification programs have a methodology for comparing conventional options and providers' approaches and costs. It is important to integrate the renewable solutions into the existing methodology. The pilot projects form the basis for comparing the economics of RE-based systems to conventional solutions. However, the absolute costs of the pilot project are not the appropriate values for the comparative analysis; after all, the conventional options are mature with significant in-country investment and market. Therefore, it is important to make the comparisons with a joint-venture (conceptual) scenario, where some in-country manufacturing and assembly are combined with limited direct imports; add to this the parameter of reasonable volume and the comparison is appropriate for planning for the RE options. The bridging strategy of developing this in-country capacity can then be dealt with from a policy perspective.

While the technical veracity needs to be demonstrated, and the economic comparison needs to be made in the country context, the most significant value of the pilot projects is the development of the institutional viability. There have been countless RE-based, donor-aided rural projects that made technical and (long-term) economic sense, but never were replicated, and in many cases became non-operational because care was not taken in the institutional aspects of the project. RE systems, like all energy systems, require administration, operational, and maintenance attention/discipline. The administration includes the establishment of a tariff (or fee for service) structure that reflects the ability and willingness to pay, as well as energy use; the collection of revenues; the discipline of payment; the management (including training) of the operators and maintenance contractors; and the provision for operational and capital expenses. The type of institution that will serve the rural electricity needs will depend on the local situation and the regional and national regulatory and legal structure.

The RSVP team is involved with a wide variety of institutions in its pilot projects, including national and regional utilities (both public and private), electricity and fishing cooperatives, federal and regional government agencies, international and local NGOs, and private companies/entrepreneurs. In some cases, the operational aspects of the pilot system are divided among several institutions, with the administration by a different organization from that performing the daily operational support and the periodic maintenance. The RSVP team is involved in training of these institutions at the various stages of the project.

Currently, the NREL team is involved in thirteen countries in the design, implementation, and/or evaluation of rural village pilots; the countries include Argentina, Brazil, Chile, China, Dominican Republic, Ghana, Guatemala, India, Indonesia, Mexico, Russia, South Africa, and the United States (Alaska). The technical,

economic, and institutional lessons learned in these pilots will help lead RE adoption in other regions of these countries and establish a base for other country programs.

TECHNICAL ASSISTANCE

Because RE solutions for villages are not widely implemented, there is a substantial gap between the state-of-the-art knowledge of renewable technologies and applications and the in-country knowledge and experience. The RSVP team provides technical assistance to government agencies, private companies, and international institutions in the form of resource assessment, prefeasibility systems analysis, specification development, pilot project design and development, training, and performance monitoring and evaluation.

The estimation of the solar and wind resources is critical for the assessment of the competitiveness of these RE systems to conventional options. Historically, the quality of wind resource data, and to a lesser extent solar data, has been inadequate to make reasonable estimates of the performance of the RE systems. There is a substantial effort under way at NREL to assist countries in assessing their wind and solar resources. Based on recent information on the substandard quality of wind data in the developing world, a number of countries have begun programs to develop wind resource data in suspected windy regions. To assist in these efforts, NREL has undertaken a wind-mapping program that uses a variety of meteorological data bases, custom software, and state-of-the-art Geographic Information System (GIS) techniques to develop regional and, eventually, national wind resource maps. These maps help greatly in identifying regions of suitable resource for wind-based village systems, as well as regions where wind systems will probably not be viable. These maps have become the screening reference for identifying pilot project locations. These maps are useful for locating regions for additional anemometry to quantify the wind resource and project value. NREL wind mapping is under way in Argentina, Chile, China, Indonesia, Mexico, and the Philippines, with negotiations underway for similar efforts in the Dominican Republic, Thailand, and India.

The RSVP team's training efforts include participation in country workshops on wind, PV, village hybrids, and resource assessment. A valuable training experience is encompassed in the visiting professional program. Country engineers and analysts typically join the RSVP team in Colorado for a period of one to eighteen months to participate in experimental and analytical research projects. During their stay they are exposed to the latest technical developments in village systems, interact with the RSVP team members, and carry out projects appropriate to their countries. Visiting professionals have worked on battery charging stations, ice-making, hybrid systems model development, productive use load estimation, village mini-grids, wind mapping, and diesel retrofits. The visiting professional returns to his/her country with the knowledge of the current state of technology and analytical tools, and a personal connection to the RSVP team.

The RSVP program sponsors an annual village power conference in Washington, D.C., in order to update the international agencies on current RE-based village activities. Additionally, it is a forum for the discussion of alternative approaches, lessons-learned, and challenges to RE-base rural electrification among industry, NGOs, government agencies, international development agencies, and research organizations. Topics for discussion have included financing, country projects, computer models, institutional approaches, technical issues, operational sustainability, agency initiatives, and comparative economics.

PROJECT DATA BASE

The most common request by in-country officials and engineers is for information on successful projects in other countries. With the advent of the Internet, the ability to communicate quality, up-to-date information on a world-wide basis is rapidly emerging. The RSVP team has responded by making a data base on RE-based village power projects available through the Internet. The data base includes project descriptions, including location, application, system description, economics, financing, participants, and lessons-learned. There is a search engine that can locate specific aspects of interest to the inquirer. We currently have 155 projects in the data base and expect to have 250 by the end of 1997.

We also have taken advantage of the Internet to develop a village power discussion group of more than 100 professionals in the field of renewables and rural electrification from around the world. While anyone of the group can address the list-serve with a particular question, we also convene moderated discussions on village power topics.

SUMMARY

NREL has developed the RSVP team to address the enormous opportunity of bringing electricity to rural villages with economic and environmentally sustainable renewables solutions. While the program is only several years old, it is well positioned to help develop, communicate, and implement RE-based rural applications. A critical aspect of this effort is the partnerships with industry, in-country organizations, international development institutions, government agencies, national labs, and universities. The electrification of the rural world is an overwhelming challenge, but with international cooperation and ingenuity we intend to "make a go of it."