Photovoltaics in Canada's North

by Michael Ross, Sylvain Martel, and Eric Usher

The Tanquary Fiord warden station is nestled at the end of a long fiord that penetrates the heart of the Ellesmere Island National Park Reserve. Though located at 81ºN, the surroundings are, for the high Arctic, lush and full of life: on a typical day, arctic hares dot the plane behind the warden station, musk ox can be seen grazing on the nearby mountain slopes, bright arctic flowers track the sun around the sky, and the wake of a duck creases the reflection of an iceberg in the waters of the fiord. In a harsh northern way, it is peaceful and beautiful-- peaceful, except for the drone of the gasoline generator that supplies the station with electric power, and beautiful, as long as one averts one's gaze from the hundreds of empty gasoline barrels forming a rusty echelon at the perimeter of the wardens' residences.

This, at least, was the situation until 1994. In that year, the gasoline generator was replaced by a hybrid power system: while a generator was kept as a backup, most of the power is now supplied by a small photovoltaic (PV) array and wind turbine. The turbine and the photovoltaic array, which converts sunlight directly into electricity, charge a battery bank. The battery stores electricity for those periods of time when it is cloudy and calm and consequently the electrical loads-- which include lights, water pumps, a washing machine, a television, a VCR, stereos, a microwave, and other standard appliances-- exceed the combined output of the PV array and the wind turbine. Now the generator runs only infrequently, reducing maintenance costs, fuel consumption, local pollution, and noise.

The hybrid power system was installed after a study by the CANMET Energy Diversification Research Laboratory (CEDRL) showed that photovoltaics were not only feasible, but also cost effective for this application. The study was conducted under the aegis of *Photovoltaics for the North*, a five-year, $1,000,000 joint research, development and technology transfer program of the CEDRL in Varennes, Québec, the Aurora Research Institute in Inuvik, Northwest Territories, and the Nunavut Research Institute in Iqaluit, Northwest Territories. The objectives of the program are to develop and implement clean and reliable energy supplies for northern climates and to improve the knowledge base and skills of the residents of the Northwest Territories. In this way, the program strengthens Canada's commitment to sustainable energy.

Electricity Generation in the Northwest Territories

In southern Canada, most consumers requiring electricity are connected to the electric grid. In the Northwest Territories, on the other hand, *no* sites are connected to the North American grid. Rather, each community or cluster of communities has its own isolated grid and associated generation equipment. This situation reflects the region's low population density and enormous scale: though more than one-third of Canada's land is contained in its borders, the Northwest Territories has only 66,000 residents, dispersed among 65 far-flung communities.

Presently, diesel fuel and water are the resources used to generate electricity in the North. The Northwest Territories Power Corporation sells approximately 450 GWh annually. Hydropower developments in the vicinity of Great Slave Lake supply about half of this; diesel generators scattered throughout the Territory are responsible for the remainder. Private diesel-electric installations, located at mines, telecommunication stations, and remote hunting and fishing camps, generate an additional 120 GWh each year. Thus, about 60 % of the region's electricity-- or about 350 GWh annually-- is generated from diesel fuel.

While hydropower is relatively inexpensive and reliable, there are significant drawbacks associated with diesel-electric generation, as the Tanquary Fiord example demonstrated. The most obvious of these is cost. Transporting the fuel to the communities is expensive; delivered fuel costs range from $0.55 to $1.30 per litre and at remote sites like Tanquary Fiord the price is even higher. As a result, electricity costs between $0.25 and $1.00 per kWh, though residential and commercial consumers are subsidized and generally pay less than the full cost. Further, the heavy reliance on diesel ties electricity costs to fluctuations in the price of oil. In many northern communities, local pollution is problem: on cold, still days, emissions shroud the community like a thick fog. Noise makes diesel generators unpopular, as well. Many generating stations were built on the outskirts of expanding communities; now that the town has been built around the generators, residents complain about their continuous hum. Moving the stations outside of the community is expensive, and precludes the use of waste heat from the generators. At remote sites, which often must operate unattended, the reliability and maintenance requirements of generators inflate their cost: service calls can be very expensive, and the cost of a failed generator can be the loss of an essential telecommunications link, for example. In addition, there is the risk of fire and leakage associated with the storage and transport of fuel.

Why PV?

The problems associated with diesel-electric generation have created a willingness to consider alternatives such as photovoltaic power. Initially, PV may not be an obvious choice, since the long, dark, and very cold northern winter seems at odds with the goal of using sunlight to generate electricity. In reality, PV operates more efficiently at cold temperatures, and the Arctic summer provides long days of plentiful sunshine: on a summer's day, a PV system in the Arctic can generate far more electricity than a similar system at the equator.

PV has a number of strengths. Importantly, it is a proven technology. PV systems are already installed throughout the Northwest Territories at installations ranging from critical military telecommunications repeater stations to houseboats on Great Slave Lake. Other advantages emerge when PV is compared with fossil fuel-powered generation. First, the system requires no fuel and can function for long periods of time without maintenance. Second, it has a reputation for high reliability stemming from the fact that it contains no moving parts-- a PV panel will generate electricity for twenty years or more without any intervention. Third, PV systems have no emissions-- either noise or pollution. The combination of these advantages has made photovoltaics the least-cost option at many remote sites requiring a small, reliable power supply.

With such impressive characteristics, why has PV not supplanted generators? The principal reason is cost. A PV array costs about $5 per Watt of peak generating capacity (Wp); the not insignificant cost of batteries, inverters, controllers and installation must be added to this. This cost cannot be compared with the purchase price of diesel generating capacity, however, since with a PV panel one is essentially paying up front for a twenty-year fuel contract.

PV system costs have dropped significantly in the last twenty years, and will continue to do so in the future, as technological advances in PV cells and manufacturing techniques appear in the marketplace, and economies of scale become established. The cost of PV per Wp has fallen from about $100 in 1970 to $5 today, and is projected to further decrease to about $2 by 2010. As prices drop, PV systems will become increasingly attractive in the Canadian North.

The *PV for the North* Program

The need for clean and reliable energy sources combined with the high cost of diesel fuel in the Northwest Territories has created opportunities for photovoltaics, and *PV for the North* helps Canadian companies and northern residents exploit these opportunities. The program consists of three phases. Phase A laid the groundwork for the further implementation of photovoltaics: promising applications and barriers to the use of PV in these applications were identified, and studies demonstrated the feasibility of the technology to potential users. Phase B focuses on developing new PV technologies tailored for the northern climate, building awareness and transferring expertise to the North, and encouraging the use of PV in the most promising applications identified in Phase A. Phase C was a highly successful three day conference on renewable energy in cold climates, held in May 1998. This international conference brought experts and users together, disseminated information, and showcased Canadian companies and products.

Cost-Effective Applications for PV

Phase A identified many applications for which PV is cost-effective *right now*. These applications tend to be remote and generally require a modest but reliable power supply. For example, in a CEDRL study it was shown that NorthwesTel could save $750,000 over 20 years by replacing the primary (non-rechargeable) batteries used to power its twelve VHF repeater sites with PV systems. NorthwesTel is now embarking on this transition. UHF and microwave repeater stations and navigational aids are also candidates.

The large seasonal variation in the amount of sunshine available complicates the use of PV in the North: while solar energy may be plentiful in the summer, it is scarce or even nonexistent in the winter. Battery storage can be used to transfer some energy from the summer to the winter, but this tends to be expensive. Phase A pointed out two other approaches to this problem: summer-only applications and hybrid systems.

The seasonal variation in solar energy affects not just northern PV systems, but northern residents as well. Outdoor activities that the hardiest soul would not contemplate during the winter are common during the summer. People visit cottages, groups of families set up remote hunting and fishing camps far from their communities, tourists come to explore the area's parks, firewatchers install themselves in fire towers, and researchers head off across the tundra to collect data. Often the electrical loads at these sites are fairly small-- a radio, a few lights, a laptop computer-- and the power system must be simple and reliable. For these summer-only applications, PV can be an excellent choice. In addition, the warmer summer temperatures can create other applications, such as exhaust fans for attics. These are commonly installed in houses with electric service, due to the simplicity of installation and control: one doesn't need to remember to turn these on and off, since the sun does it automatically.

When larger loads must be powered year-round, the benefits of PV can be combined with some other power source-- typically a fossil fuel powered generator, though wind turbines, thermoelectric generators, and primary batteries can also be used-- in a hybrid system. This system combines PV's low operating and maintenance costs with the power-on- demand available from generators. Hybrid systems are often cost-effective for medium size loads, ranging from 2 kWh to 60 kWh per day. Hybrid systems can be ideal for remote residential, telecommunications, and cathodic protection applications.

Sometimes existing prime power generators for variable loads can be "upgraded" to hybrid systems by adding batteries to form a cycle charging system, then adding PV panels as capital becomes available. This has the advantage of spreading the high capital cost of the photovoltaic system over a longer period of time.

While these applications create a market for PV right now, the medium-term market has even more potential: as prices drop, it will become economical to use PV to reduce fuel consumption and maintenance costs on remote community grids. This suggests that PV may be widely implemented in northern communities before it appears at a significant scale in southern Canada and the USA. On the North American grid, the cost of building additional capacity tends to be high, but the unit cost of generating electricity is low. Unfortunately, since PV depends on an intermittent resource, it is hard to convince utilities that it has capacity benefits. In northern communities with diesel generation, however, the principal cost of electricity is fuel, and each litre of fuel that is not consumed because of PV generation represents a significant savings. In a CEDRL study, it was shown that these avoided cost benefits-- based on fuel and maintenance savings only-- could be valued at about $2.50 to $5.50 per Wp of PV installed. In other words, when PV's installed price in the North reaches this level, it will become economical to supplement diesel community grids with PV power; it is expected that this will happen within ten to fifteen years. It is interesting to note that at the best sites in California, PV has a similar avoided-cost benefit, but only when environmental credits for pollution reduction and transmission and distribution costs have been factored in. That is, PV seems to make as much sense in the Arctic as it does in sunny California.

While PV cannot replace all the diesel generation on the remote community grids, this market still has enormous potential. In a *PV for the North* study it was shown that PV could be used to provide up to half of a community's power without having to dump much electricity during the summer. Even if PV represented just 5% of the remote grid power generation in the Northwest Territories, this would result in the installation of 15 MWp of PV-- six times the total capacity of PV installed in Canada at the end of 1995.

Knocking Down Barriers to Market Penetration

While the high capital costs of PV and subsidized electricity prices are economic deterrents to large-scale implementation of PV in the North, Phase A also identified various cultural, social, technological and organizational barriers. Through various initiatives, Phase B has focussed on removing these barriers.

Northerners tend to be familiar with the conventional energy sources, such as generators, with which PV competes. People are not aware of PV's capabilities and often assume that solar energy doesn't function when it is cold. In addition, some opinions of renewable energy have been formed on the basis of early experimental or demonstration projects, which lacked the reliability of today's technology. Phase B has attempted to address these problems by making PV more visible within communities and by disseminating information about PV.

On Canada Day, 1995, a 3.5 kWp PV array, discreetly incorporated into the facade of the Nunatta campus of the Arctic College, in Iqaluit, was "switched on". Financed by the *PV for the North* program, designed by Dirk & Price Engineering Ltd., and installed by a local electrical subcontractor, this is the first diesel-grid connected PV system in the Northwest Territories. As a demonstration, it raises awareness of PV. Equally importantly, the system will provide valuable operating experience for the future, when grid-tied PV systems become cost-effective: this system will provide hard data essential to fostering support for major investment.

Workshops and numerous meetings have heightened PV's profile in the North and helped southerners better understand the opportunities in the North. In 1995, workshops were held in Iqaluit and Inuvik, and the CEDRL met with over 30 northern companies, government departments, and nongovernmental organizations. In November of that year, seven groups from the Northwest Territories were funded to send representatives to the annual conference of the Solar Energy Society of Canada, in Toronto.

Phase A also noted the limited number of companies working in the field and the lack of northern technical expertise related to PV. Phase B has tackled this through training programs, training systems, and close cooperation with northern companies. In September of 1996, a hybrid training system was inaugurated at the Inuvik Research Centre. This system, which consists of a 1.4 kWp PV array, an 850 Wp wind turbine, a 5 kW generator, batteries, and a 360 ° tracker for the PV array, will be used by northern residents and companies to learn about hybrid systems; it will also provide a "test bench" for investigations into the optimal operation of hybrid systems in the North. The PV panels were manufactured by CANROM Photovoltaics Inc. of Hamilton, the wind turbine was supplied by Prometheus Energy of Concord, Ontario, and the system incorporates an inverter from Statpower Technologies, of Burnaby, B.C. In the spring and summer of 1996, a course covering PV, small wind turbines, and diesel generators in hybrid systems was taught in Inuvik, Yellowknife, Iqaluit, and Rankin Inlet, four of the main communities in the Northwest Territories. In addition, five northern residents have spent one to two months in PV training sessions at the CEDRL. One of these northerners has set up a PV company in the eastern Arctic; since the inception of the PV for the North program, the largest PV company in the western Northwest Territories, Midnight Sun Energy, has grown from one part-time to three full-time employees. In the autumn of 1997, a third demonstration project was inaugurated: one of NorthwestTel’s UHF radio stations in the remote and mountainous Nahanni National Park was converted from a genset system to a hybrid system with photovoltaics. The experience and confidence gained through this demonstration should convince NorthwestTel to install photovoltaics at other UHF stations.

In the last years of the PV for the North program, a book and a video were prepared in order to ensure that the expertise and momentum of the program would not be lost after the program’s conclusion. *Photovoltaics in Cold Climates*, a book aimed at decision-makers, engineers, and installers, will be published in November of 1998 by James & James and distributed internationally. As a collaboration between PV for the North and the International Energy Agency’s Photovoltaic Power Systems Program, the book was written by experts from Canada and around the world. For more general audiences, a video introducing photovoltaics and explaining their operation and use in Northern Canada has been developed. Just as the book fills a need for a comprehensive examination of the issues related to photovoltaics in cold climates, the video addresses photovoltaics from the perspective of a Northern Canadian, and contains many images of the North.

Developing New Technologies

The harsh northern climate creates special difficulties for all technologies-- difficulties that often are not fully appreciated in the southern climates where photovoltaic components are generally developed. While the PV panel itself performs extremely well in the cold, batteries and electronic components do not fare so well. This creates a niche for Canadian technologies and Canadian companies; Phase B has attempted to capitalize on this opportunity.

While they do not fail, batteries do perform poorly when they are cold. In order to increase the useable capacity of the batteries used in cold climates, the CEDRL, working in conjunction with Soltek Solar Energy of Victoria, B.C., has developed an insulated battery enclosure with a thermal reservoir of phase change materials. This enclosure maintains the batteries at a reasonable temperature throughout the winter, ensuring that useful battery capacity does not drop below a certain level. This means that smaller battery banks can be used, reducing cost.

When snow and ice accumulate on PV panels, less light reaches the solar cells and they produce less electricity. In general, such accumulation is very rare, but at certain sites this can be a problem. The Montréal consultancy of TN Conseil has developed a passive device that melts off snow and ice. The CEDRL has performed modelling and testing to establish the range of conditions for which this technology functions and to optimize the design.

The mathematical models used to estimate the amount of solar radiation available for a PV system are not particularly accurate for sites at high latitudes. The University of Waterloo has conducted a study for the PV for the North program to determine how these models can be improved. The result will be an upgrade to the WATSUN-PV simulation software; this will make WATSUN-PV the most appropriate tool for modelling PV systems, not just in northern Canada, but Antarctica, Scandinavia, and northern Russia.

In order to assist Canadian installers and system houses, the CEDRL has initiated various component testing programs. The ongoing battery test program focuses on the operation of lead-acid batteries at cold temperatures; this data, essential for system sizing, is not generally available from manufacturers. Commercially available charge controllers are currently being tested in the CEDRL climate chamber. In the upcoming year, testing of photovoltaic modules in variable field conditions, as opposed to the standard test conditions, will begin at the CEDRL. The results from these testing programs will provide the information necessary for the design of more reliable and less costly PV systems.

Land of the Midnight Sun, Land of Opportunity

PV's high reliability and low maintenance and operating costs make it cost-effective for a wide range of small, remotely-situated loads; the use of photovoltaics in larger applications will continue to grow as system prices drop. Programs like *PV for the North*, working in conjunction with Canadian companies and northern residents, are knocking down the barriers to the widespread implementation of this technology. The opportunities are considerable, not only for Canadian business, but also for ordinary people who wish to live sustainably in a clean environment.

For more information about photovoltaics or the Photovoltaics for the North program, contact Sylvain Martel at the CEDRL by phone (450 652-6747), fax (450 652-5177), or e-mail (sylvain.martel@.nrcan.gc.ca).