New Applications for Photovoltaics

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Photovoltaics (PV) already offers a competitive alternative in many high value applications. For example, in low power instrumentation (e.g. traffic counters, calculators, etc.), PV is commonly preferred over batteries. The evolution of new and appropriate applications for PV play a significant role in bridging the PV market from where it is today to the future and bulk power generation. PV can be considered a practical alternative wherever

? Cost does not make it unacceptable;
? PV can perform reliably in the specific application and location; and,
? A practical sized array produces sufficient energy

As with any commodity, cost plays a prominent role. However, being the lowest priced alternative is not always necessary. Applied in niche market applications, PV's favorable extrinsic features (e.g., unattended operation) can outweigh an otherwise higher price. Once it is assured that price alone does not eliminate PV as an option, performance characteristics can be compared against those of other energy options. PV has intrinsic properties which can make it favorable in some applications, inappropriate in others. Some of the favorable properties of PV are:

? Mobile
? Decentralized/independent
? Modular
? Quiet and non-polluting
? Low maintenance/near-perpetual energy source
? Mature technology

These are balanced against unfavorable characteristics which can make PV unsuitable in many applications:

? Low energy
? Area intensive
? Fragile
? Heavy
? Intermittent/non-deterministic energy production

The best candidate applications which match PV's strong points are to be found in electrical loads with some combination of the following characteristics: remote or inaccessible to the grid; small, daytime only; outdoors or with outdoor access; conventionally powered by an expensive energy source; difficult to service or fuel. Using these guidelines, several major market sectors that offer favorable new applications for PV are as follows:

1. Transportation
2. Remote Instrumentation and Monitoring
3. Commercial and Industrial Lighting and Signage
4. Water purification
5. Refrigeration
6. Building Envelope Temperature Control
7. National Defense

NEW APS CASE STUDIES: PV ICEMAKING [1]

A unique commercial PV powered ice-making system was installed in March 1999 to serve the fishing community of Chorreras, Chihuahua. SWTDI and Sandia worked closely with the State of Chihuahua in implementing and monitoring the project with support from the New York State Energy Research and Development Authority, DOE, and USAID. The ice-maker system was designed and installed by SunWize Technologies.

The concept of solar-powered ice production in the remote desert is not a trivial one. High summer ambient temperatures in excess of 40°C, as well as winter temperatures below freezing, create an abusive environment for batteries. The PV hybrid system consists of a 2.4 kW PV; APT Power Center; 24 Vdc 2200 Ah battery bank with 2 V cells; two Trace 3.6 kW modified sinewave inverters stacked to provide 60 Hz, 240 Vac single-phase power for the icemaker; and one Kohler 6.3 kW propane generator to provide backup battery charging.

The ice-maker is set to run a dozen 15-minute automatic ice-making cycles each day. The hybrid system provides a daily average of 8.9 kWh at 240 volts to the ice-maker. The system COP is about 0.65 and a total of 97 percent of the energy has been supplied by the PV, while less than 3 percent has been supplied by the back-up generator. Overall ice production averages about 85 kg of ice per day. The system has worked well in producing ice on a daily basis with only some initial minor control problems and water line calcification which requires that the lines must be cleaned every nine months.

The system can produce over 25,000 kg of ice per year from the solar alone. Assuming a value of US$0.30 per kg of ice (for this remote site where it must be hauled in), this implies that a simple payback for the ice-making system is about 7 years. Taking into account the value of reduced fish spoilage, actual payback is under 5 years for the PV ice-maker. Overall, it is anticipated that ice production over the system lifetime, with future battery replacements and system maintenance, should be about US$0.15 per kg. The system has proven that a properly designed, operated, and maintained system can indeed produce a significant and valuable resource, such as ice, even in the middle of the desert. Such a system requires local buy-in and follow-up. Long-term commitment and follow-up by the project partners is required for continued project success. This project is an example of using PV to meet local needs and contributing to local economic development while developing a new market for PV.

PV DIRECT DRIVE REFRIGERATION

A direct drive PV powered refrigerator technology developed by SOLUS for NASA has been field tested in New Mexico by SWTDI for Sandia under the Mexico Renewable Energy Program due to interest in the Mexican market. The SOLUS refrigerator uses thermal storage, and a direct connection is made between the cooling system and the PV panel. This is accomplished by integrating a water-glycol mixture as a phase-change material (PCM) into a well-insulated refrigerator cabinet and by developing a microprocessor-based control system that allows direct connection of a PV panel to a variable-speed dc compressor. This allows for peak power-point tracking from the PV panel and elimination of batteries from the system. The refrigerator uses a vapor compression cooling cycle with an integral thermal storage liner, PV modules, and a controller. The high efficiency refrigerator employs a variable-speed dc compressor and there are no batteries or inverter, thus realizing substantial system cost savings.

The SOLUS refrigerator was operated by SWTDI on 120, 90, 80, and 60 Wp PV modules. Six gallons of water at ambient temperature were placed inside the refrigerator unit and removed each day. The peak current the compressor drew was 3.7 amps while averaging 2.9 amps throughout the day at 15.2 volts and had a power consumption of 45 to 56 watts. For instance during the 120 Wp case, 7.4 peak sun hours were available, and the PV array (120W) produced a daily average of 870 Wh of dc energy while the refrigerator used an average of only 433 Wh per day of dc energy at an average of 15.2 volts The net energy (energy produced minus energy consumed) of the system was 438 kWh. The 120 watt array originally recommended was actually much larger than necessary for the Chihuahuan desert climate of southern New Mexico to power the refrigerator even at its peak energy demand. The maximum peak power consumed by the variable dc compressor was 56.2 W while averaging 45.4 W/day.

Temperature data collected by SWTDI showed adequate temperature control within the refrigerator cabinet, despite ambient conditions of 30 - 40°C in Las Cruces. If the refrigerator is not cycled sufficiently, its contents can freeze after several days. As smaller arrays were tested, the energy consumption for the unit remained constant. The refrigerator operated successfully for the 120, 90, and 80 Wp cases, but the 60Wp PV module was too small to meet compressor start up needs. For the 120 Wp case, the refrigerator would typically go through 8 to 12 start-up cycles in the morning. However, for the 80 Wp PV modules, the refrigerator would experience over 200 start-up cycles in the morning. This adds to a lot of needless stress for the mechanical and electronic parts. The main cause for these "false starts" is the refrigerant fin cooling motor. This small motor, which is intended to help the unit run more efficiently, is causing the unit to require much more power than is actually needed. These types of problems need to be further evaluated in different climate regimes. To this end, SWTDI is working with Sandia and NASA in additional field testing on the Navajo Nation, Mexico, and Guatemala. Likewise, SWTDI is working with SOLUS and Sandia in expanding this innovative refrigeration concept to PV milk tank coolers for Mexico.

PV REFRIGERATED TRAILERS [2]

SWTDI working with Sandia and SOLUS has been exploring the potential for using PV for refrigerated trailers. There are over 200,000 refrigerated trailers in the U.S. The conventional refrigeration unit is either powered via hydraulic drive installed on the truck's engine, or, more commonly, by an integrated, independent, four cylinder, liquid cooled diesel engine. A typical refrigeration unit weighs between 1300 and 2000 pounds.

SOLUS conducted a feasibility study of the development of a practical PV powered refrigerated trailer for the U.S. trucking market. First, it was determined that any proposed trailer must be capable of maintaining sub-freezing as well as refrigerated temperatures since cargo varies widely. Compared to refrigerated temperatures, maintaining freezing temperatures increases the thermal load by 50 percent and decreases the refrigeration system efficiency by 50 pecent.

Over the course of a typical day, a typical 53 foot trailer requires 82.8 kWh to maintain frozen conditions. Based on high-efficiency, closely packed modules, a 5.7 kWp PV array could be mounted on the trailer's roof. The daily energy produced by this array will necessarily vary with solar exposure. Array output was estimated at a high of 43.4 kWh for a typical Phoenix day to a low of 32.3 kWh for a typical Boston day. The proposed system would not use batteries for electrical storage, but instead, a PCM would store thermal energy. This PCM would consist of a 23 percent NaCl eutectic solution sized for energy storage equivalent to 18 hours of cooling.

Three major system improvements were proposed to facilitate making PV power practical for refrigerated trailers: 1) reduce the thermal load; 2) improve the efficiency of the refrigeration unit; 3) incorporate an auxiliary power source for backup. Reduction of the thermal load can be accomplished by using vacuum panel insulation in the walls of the trailer. Vacuum panel insulation with an R-value of 30, can reduce the thermal load of a conventional trailer from 3131 W to 1534 W. Next, though the refrigeration units on standard trailers are efficient, their efficiency can be improved by more than 25 percent through the use of a 2-stage compressor. Enlarging the condensor and evaporator areas can improve efficiency up to 35 percent. The last of the system improvements would be the inclusion of an auxiliary power unit for periods of prolonged cloudiness. The auxiliary power unit could be a diesel generator, wheel mount generator, or connection to shore (grid) power. Additional study and design work is needed to fully develop this application.

CONCLUSIONS

The fundamental properties of PV make it an attractive power source in many, as yet, unexplored applications. In refrigeration for instance, there has been an evolution of technology development leading away from battery systems to direct drive and battery-free systems.

REFERENCES

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[2] Rosenthal, A. and D. Bergeron, " Meeting Customers' Needs - New Applications for PV,"Photovoltaic Systems Syposium, SNL, DOE, Albuquerque, New Mexico, July 20, 2001.