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PHOTOVOLTAICS AS A WORLDWIDE ENERGY SOURCE

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Photovoltaic energy systems have historically been treated as a bulk power generation source for the future. However, utilities and other agencies involved with electrification throughout the world are beginning to find photovoltaics a least-cost option to meet specific loads both for themselves and their customers, in both off-grid and grid-connected applications. These expanding markets offer the potential of hundreds of megawatts of sales in the coming decade, but a strategy addressing both industrial growth and user acceptance is necessary to capitalize on this opportunity.

INTRODUCTION

Nearly 600 GW of new electrical generating capacity is estimated to be needed worldwide during the next decade, of which over one-half will be required by developing countries [1]. The capital requirements for these capacity increases are expected to be over US$100 billion annually [2]. If current trends persist over the next 20 years, developing countries will be consuming as much energy as the industrialized nations do now. Yet a large proportion of the rural populations in these countries will continue to lack access to utility power due to the cost and difficulty of extending electrical grids to these dispersed communities. If no other alternatives are made available, nearly 45 percent of the new capacity over the next decade is expected to be coal-based and 36 percent will be large hydroelectric. Lack of capital also often encourages the purchase of fossil-fuel-based generation equipment that is less expensive on a first-cost basis but also less efficient and less environmentally clean than many other available options. This unfortunately promotes greater fuel usage and worsens the environmental impact. Recent trends indicate that carbon dioxide emissions in the developing countries could exceed those of the developed countries during the next ten years.

Environmentally benign technologies that harness energy from the sun and are also adaptable to distributed applications are particularly promising for helping to meet these challenges [3]. Solar thermal, photovoltaics, and wind electric technologies are making significant technical strides and are widely adaptable due to the availability of an abundant, indigenous solar/wind resource over much of the earth. Large-scale solar thermal and wind systems are now becoming economically attractive (at US$.07-US$.09/kWh) for bulk utility electric power generation [4-5]. Photovoltaics, while not yet as economical for grid-connected applications as wind and solar thermal, has found a major role as a power source for remote and distributed applications because of its high reliability and inherent modularity.

Energy from photovoltaic systems is less costly today on a life-cycle basis than alternative sources in an increasing number of applications where conventional utility power is not readily available, especially when fuel supply and operation and maintenance costs are considered. Thousands of photovoltaic systems worldwide are providing reliable, cost-effective energy for communications, lighting, home power, water pumping, water purification, vaccine refrigeration, navigational aids, environmental monitoring, and a host of other military, utility, commercial, residential, and recreational uses [6-7]. For providing modest levels of power for lighting, radio, television, fans, battery charging, and other small consumer loads in rural homes and communities currently without utility access, photovoltaics is the most sensible choice of all the power system alternatives. The modularity of photovoltaics allows small system needs of this type to be met more reliably and

economically than with engine-generators.

For larger load requirements, the combination of photovoltaics (and other renewable energy technologies such as wind and microhydro generators), diesel generator, and battery storage into "hybrid" configurations can provide higher system reliability and availability at a more reasonable cost than would be possible with any one technology alone. Diesel hybrid systems are receiving increasing interest today for providing electrical power in remote communities and for small utility grids, such as those on islands.

The world's utilities that will need to utilize photovoltaics if it is to have a major impact on energy supply in the future. Utilities have recently begun to explore the additional high-value-added benefits that photovoltaics can provide in distribution line support and demand-side management [8-9]. Utilities and rural cooperatives servicing small, dispersed loads are finding that photovoltaics systems can offer cost-effective customer service options today. Stand-alone photovoltaic systems for water pumping are being supplied to ranches by power supply authorities in the western U.S. today in lieu of line extension because it is more cost-effective than installing and maintaining an under-utilized power line [10]. However, while renewable energy technologies such as photovoltaics are gaining in acceptance, they are not gaining as rapidly as may be necessary to impact the energy needs of the coming decade.

In the last decade, the problem of market growth and user acceptance might have been attributed to technical immaturity and the need for a "breakthrough." This is not the case today. The challenge facing photovoltaics is not the discovery of some new technology but rather industrialization and manufacturing development resulting in the production capacity needed to meet today's demands. The successful strategy for developing photovoltaic technology into a significant energy supply option must evolve with the growing maturity of the technology. Factors such as manufacturing process development, development of phased markets, product standardization, user education and awareness, infrastructure development, as well as policy and financial equitability must now be considerations in government programs. To achieve the promise of photovoltaics for the future, a strategy directed at the utility market is needed that both supports industry growth and addresses the issues of user acceptance.

Any successful strategy must recognize that the photovoltaic industry is very immature in terms of production capacity at this time, with little more than 100 MW of photovoltaics installed worldwide. To place this in perspective, today's total installed capacity of photovoltaic systems is about 5 percent of the installed capacity of wind electric systems. At these low production levels, user acceptance is restricted to those few familiar with the technology. These low production levels also impact the price of the technology, both through manufacturing cost and market supply and demand. Without needing any breakthroughs, today's photovoltaic technology appears capable of reaching the manufacturing cost levels necessary for widespread utility applications. This progress can be achieved through use of optimized manufacturing processes that are cost-effective at high production levels. This is the same path for cost reduction that has been followed in the commercialization of other products, ranging from automobiles to calculators. Price reductions will follow as production levels increase significantly to allow market supply and demand options to operate. Lowering of production costs, price reductions through supply increase, and significant installed capacity levels all necessitate massive industrial investment in manufacturing if photovoltaics is to have an impact in the next decade.

The U. S. Department of Energy has set a goal of 1500 MW of U.S. photovoltaic products installed by the year 2000. This requires that industry production capacity grow at unprecedented rates of about 40 percent per year for the next decade. Industry will be willing to make these investments only if there are significant markets to sustain corresponding demand growth. This market growth depends not only on price reductions but also on widespread user acceptance. Certainly the utility industry, which is traditionally risk averse, will not utilize large-scale photovoltaic generation until its members are convinced of the reliability and availability of the technology. Therefore, the strategy must utilize currently cost-effective applications as stepping stones to the larger energy systems of the future. In the utility sector, this strategy begins by demonstrating there are many applications for which a photovoltaics system will be the most cost-effective means of serving a load today and even more applications will be cost effective in the near future.

The utility strategy currently being pursued by the U.S. National Photovoltaic Program through Sandia National Laboratories is a realistic approach, which builds on the benefits of the technology, such as modularity, reliability, and lack of environmental impact. The strategy is based on incorporating photovoltaics into an integrated utility planning process, in which selection of a supply option is based on the lowest lifecycle energy cost for meeting each of the utility loads. Such "least cost" or "integrated resource" planning is rapidly gaining recognition as the ideal approach to utility planning, whether for rural or urban electrification, in developed and developing countries. In its most mature form it is technologically neutral, focussing on the need for energy and the load's specific requirements and characteristics, rather than the energy source.

The strategy currently is directed at demonstrating a wide spectrum of near-term, cost-effective applications to the utility. For the purposes of this discussion, these applications are broken into four main groups:

1) utility-owned, off-grid systems
2) off-grid, customer-service systems
3) utility-owned, grid-connected distributed generation
4) customer-owned, grid-connected on-site generation.

In general, the off-grid systems are cost effective today, while the grid-tied systems are expected to achieve cost-effectiveness by the middle of the decade. For the cost-effective systems, the strategy relies primarily on education and cost-shared introductory projects, while the efforts directed at the future systems include analysis activities and pilot projects. In all of these applications, cost-effectiveness is determined by significant capital savings in addition to the value of the energy produced; that is, none of these applications can be evaluated without looking at the total costs and benefits to the utility.

UTILITY-OWNED, OFF-GRID SYSTEMS

The first of these groups encompasses utility applications that are very similar to the majority of commercial applications today, such as those in the telecommunications industry or in remote sensing and control. Utilities have numerous uses for small power sources, often at sites very difficult or expensive to power conventionally. Lighting for transmission towers, sectionalizing switches, microwave communication links, and cathodic protection for structures are typical of this class of applications. This market is not expected to be large in terms of megawatt sales, probably less than half a megawatt per year in the U.S.A. The advantage to including this market in a utility strategy is that the applications are cost-effective today, and they introduce the systems in the areas of the utility where user acceptance is expected to be the most difficult to obtain otherwise--system operations, and transmission and distribution engineering.

The transmission line remotely-controlled sectionalizing switch is a good case for studying this group. These switches need a source of energy to keep a battery charged for occasional-use powering switch operation. The energy requirements are small, and the typical source is the utility line, requiring the use of a transformer and battery charger. At transmission line voltages, the transformer alone can cost $10,000 or more, while costs at sub-transmission voltages are typically $3000. The installed cost of a photovoltaic system of 50 to 100 Watts to charge the battery is a small fraction of the installed cost using the conventional approach. At the present time, over a dozen utilities are pursuing the installation and evaluation of these switches. In addition, four switch manufacturers have developed packaged systems and are selling their products directly to utilities.

Tower lighting is another utility use receiving widespread attention. While several utilities throughout the world have evaluated this application over the past decade, it is now receiving widespread interest. These systems, like many others in this classification, have very high value. Pacific Gas and Electric has estimated that a photovoltaic system providing lighting for a 190 foot tower at the south end of San Francisco Bay will result in savings of more than 25 times the initial cost of the photovoltaic system over its expected lifetime.

OFF-GRID, CUSTOMER-SERVICE SYSTEMS

This second group of applications results when the utility chooses to meet selected customer loads by on-site generation rather than by line extension and connection. This choice may be the consequence of the cost of line extension for remote sites, or due to high line maintenance costs, or a result of loads too small to justify the expense of service. This application has been found to be a significant market and is an excellent example of the impact of determining the least-cost option for providing customer services.

Rural electrification is an obvious example of this type of application. In rural communities in the U.S.A, as in other parts of the world, the density of loads is significantly smaller, and the length of individual distribution lines is much greater, than in urban communities. Because of this, numerous utilities with rural service areas in the western and midwestern regions of the United States have been investigating the use of distributed generation systems to meet isolated customer loads.

Water pumping systems for livestock are a key example of distributed generation now being developed with the assistance of the National Photovoltaic Program. Several case studies showed that it is less expensive to replace an existing line with localized generation than to maintain the line. Typically, payback times for on-site generation relative to line maintenance in regions with exposure to strong storm conditions have been about two years. Photovoltaics has been the principal generation system used in these applications, although wind electric options are also being utilized. Usually, these systems are utility-owned and installed to service the customer's load. Utility capital cost recovery is achieved through monthly lease or service agreements. Unlike conventional grid service, energy usage is no longer a factor in energy supply economics. Again, this is a least-cost option for the utility, resulting in savings in line operation and maintenance costs, which cannot be recovered from the customer.

Other applications in this classification range from billboards and lighting systems to power for remote cabins. For each of these applications, an on-site energy source may be the least cost supply option for both the customer and the utility. This concept of least-cost supply is being implemented by many state regulatory groups in the U.S.A. For example, the Public Utility Commission of Colorado has enacted a rule that states "...[customer's meeting specific conditions], when requesting of the utility a cost estimate of a distribution line extension, shall receive a photovoltaic system cost comparison." This comparison is provided at no cost for customers whose monthly energy use (kWh) divided by the mileage of the line extension is less than or equal to one thousand (kWh/mi).

The international aspects of the utility strategy lie primarily in this customer service option category. The parallel between least-cost planning for selecting a customer energy source in rural United States and the approach to rural electrification in countries like Mexico should be apparent. The cost of bringing utility power via transmission and distribution lines to currently non-electrified villages is very large, especially in light of the anticipated small loads in these areas. For the majority of the households, the power will be used for lighting and radios. Individual community centers or health clinics may need energy for vaccine refrigeration or other related loads. Community water supplies may also be involved, but even with all of these loads aggregated, individual household and/or community energy systems are usually more cost-effective. Using a least-cost model, numerous governments and national utilities have begun to use photovoltaic systems in an integrated approach to electrification planning, resulting in solutions such as 5000 household systems being installed as the first step in a countrywide electrification program in Mexico, and photovoltaic and wind diesel hybrid systems to power islands in Indonesia.

An interesting case study in the village electrification case is the work currently being pursued by the Alaska Energy Authority (AEA) with the support of Sandia's Photovoltaic Design Assistance Center [11]. There are over a hundred remote villages in the arctic regions of Alaska, many of these currently powered by diesel generators. It has been estimated by the AEA that the actual cost of providing this electricity is between $1.00 and $1.50/kWh, due to the expense of fuel delivery. The loads and solar resource have been studied in several villages since 1989. Based on these data, a conservative estimate of the payback period for displacing fuel use through photovoltaic-augmented diesel-generator hybrid systems is 10-12 years. Analyses such as these and field experience with hybrid systems in Mexico and in several island applications have made the diesel hybrid option one of the most promising photovoltaic applications for international rural electrification. It has been estimated that this international market will exceed the domestic (U.S.A.) utility market for grid-connected photovoltaic systems during this decade.

UTILITY-OWNED, GRID-CONNECTED DISTRIBUTED GENERATION

The third class of utility photovoltaic applications in the phased introduction strategy involves the use of photovoltaic systems for generation within the utility, but at a distribution level. Many times in the operation of a utility's transmission and distribution system remedial action must be taken to alleviate some local condition. These conditions can include local load spikes resulting in short-term overload on transformers and lines, voltage oscillation due to long line runs combined with locally varying loads, and poor power quality due to the introduction of loads with harmonic-generating properties. Recent analyses have shown that photovoltaics may have an important part to play in solving these problems by providing a source of localized generation with a time of output closely matched to the time of problem occurrence.

Some of the earliest and most complete data on the impact of photovoltaic systems were provided by the New England Electric System's (NEES) experiments in Gardner, Massachusetts. In the mid-1980s, NEES planned an experiment to see how photovoltaic generation would impact a rather long distribution line feeding a residential area. There were concerns that the variability of the solar resource, combined with the variability of the load, would cause significant power quality and voltage fluctuation problems on the line. Thirty roof-mounted residential arrays combined with state-of-the-art sinewave power conditioning systems were installed in 1986. Since that time the utility and its contractors have published several reports on the performance of the system. These reports indicate that the distributed generation sources actually significantly stiffen the line, improving power quality and reducing voltage fluctuation. This is an example of a grid-connected photovoltaic system providing a valuable service, which has a capital cost savings associated with it, in addition to the value of the energy generated. Obviously systems in such applications have a higher breakeven cost than those used solely for bulk generation.

While the data from the Gardner project have been available for some time, the recent interest in this application area is the result of work done by D. S. Shugar of Pacific Gas and Electric (PG&E). He has analyzed a specific substation within the PG&E system that has a high daytime peak. Given load-growth trends, the peak is such that it could cause the transformer to be replaced early in its design lifetime, and it could even result in a need for rebuilding the local distribution system. Shugar found that the proper placement of localized generation on the customer side of the substation could reduce and/or eliminate the need for transformer replacement and line reconductoring. If successful, the resultant value of the photovoltaic system would be two to three times higher than that obtained by the energy value alone. While other sources could be used for this generation, photovoltaics has a good match to the peak, has no local environmental impact, and does not require a support infrastructure such as fuel delivery.

At present there are two activities under way within the National Program directed at this application, which has come to be referred to as "distribution line enhancement." Because of the load-profile-specific nature of this application, individual utilities will need to analyze their own systems to find target applications. In addition, there is a need to validate the analysis approach as it applies to other utilities' planning processes. As a result, the National Photovoltaic Program is funding between six and twelve utilities to analyze their systems and develop decision criteria which they can use for deciding when such applications are appropriate. The second activity is the fielding of a prototype system within the PG&E system as part of PVUSA. Typical photovoltaic systems installed under this scenario are expected to be between 500 kW and 5 MW, although smaller systems may have limited usage. It is expected that these two efforts will provide a complete characterization of the system economics as well as the beginnings of a market assessment within the next eighteen months. If these efforts validate the value of this application, an annual market of between 100 and 200 MW is anticipated in the U.S.A.

CUSTOMER-OWNED, GRID-CONNECTED, ON-SITE GENERATION

These customer-owned, grid-connected applications share many of the economic benefits of the utility-owned distributed generation systems, differing principally in owner economic evaluation parameters (discount rates, required return on investment, etc.) and in the value of the energy offset by the photovoltaic energy. A utility will see much the same effects on its distribution system from 500 kW of customer on-site generation as it would from 500 kW of photovoltaics installed at a substation to provide local distribution line enhancement. The customer-owned system would be slightly more efficient since it eliminates line and distribution transformer losses. Because of the location of these systems on the customer side of the meter, unless the presence of these applications is explicitly acknowledged by the utility, their impact and appearance will make them almost indistinguishable from conventional demand-side management options. The utility will see a need for less energy delivery to the customer, but the customer's loads will not be disrupted.

The economics of these systems will be very dependent on rate structures and the degree to which the utility shares its savings with the customer. Certainly these systems will not be utilized unless they save the customer money. Typically these savings would be by offsetting demand charges and energy cost under time-of-day rates. The latter situation is easy to achieve, with the photovoltaic energy value derived by offsetting the higher utility charges for power during peak demand times. By contrast, the demand charge savings is somewhat problematic due to the stochastic nature of solar radiation. However, a number of these applications operating on a given utility would probably achieve the desired system-wide capacity effect. Thus, a different approach to demand charge structure may be necessary for such systems to derive their due economic benefit. Neither of these options, however, addresses the system savings accrued by the utility as a result of the installation of these systems. Since these systems have the same impact as the line enhancement systems mentioned above, they may result in significant capital savings for the utility. In the future, utilities might find that fostering the installation of these applications by some form of financing package or shared-savings program may offer the least-cost option to the solution of localized distribution system problems. This type of incentive would be similar to that presently being offered by some utilities engaged in demand-side management programs.

There are several studies under way to determine the value of photovoltaic systems for demand-side management now under way with National Photovoltaic Program sponsorship. One such study is looking at insolation data on a regional basis to develop a methodology for predicting system value. Another study is looking at existing system data and local utility rates to access the existing economic opportunities for photovoltaics. The policy area is expected to be investigated next, since the economics of this application type depend so heavily on assuring equitable accounting of rather unique utility and customer benefits.

In the application validation area, several utilities are currently investigating the use of photovoltaic systems as a demand-side management option with the technical assistance of the national program. Niagara Mohawk Power Corporation is evaluating a 15.4-kW system in a project in Albany, New

York, while the City of Austin Municipal Utility is assessing the impact of a photovoltaic system located on a youth hostel. Another prototype system will be installed in New York State in the near future as the New York Power Authority's host site under PVUSA. The U.S. Department of Energy itself decided to investigate this application by installing a 6.7-kW array on the new Energy Child Development Center located adjacent to the DOE offices in Washington, DC.

The customer-owned on-site generation option is probably the largest potential market of all of the four application types discussed here; however, its full realization also requires the most significant changes in rate structures and policies. The ease of obtaining these changes will depend on whether early experiments and economic analyzes verify the value of these systems. Since such systems have the potential of saving both the utility and customer money, they could rapidly become the shining star of photovoltaic applications.

SUMMARY

It is not realistic to assume utilities will purchase massive quantities of photovoltaics when some price threshold is reached. Throughout the history of introducing new products to the marketplace, there has been a need to find a way to build production capacity and user acceptance simultaneously. The strategy described in this paper is an attempt to address that requirement. This program of technology validation and market development is not all that is needed. Financial institutions must be made aware of the benefits of renewable energy technologies if they are to be expected to fund the massive industrial growth required, as well as to provide funding for utility projects. Similarly, the policy-making bodies must be educated as to the costs and benefits of photovoltaics and other renewables to assure that utilities are allowed to make decisions on a level economic playing field. These issues are not restricted to the developed world but are just as true for the developing world. The future of photovoltaics and other renewables requires the utilization of integrated resource planning procedures by utilities, the availability of financing, and reasonable policy approaches, in addition to technology evolution and production engineering.

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REFERENCES

1. "Energy Technology for Developing Countries: Issues for the U.S. National Energy Strategy," Applied Science Division, Lawrence Berkeley Laboratory, Berkeley, California, LBL-28407, UC-400, December 1989.
2. E.A. Moore and G. Smith, "Capital Expenditures for Electric Power in the Developing Countries in the 1990s," Industry and Energy Department Working Paper, Energy Series Paper No. 21, The World Bank, February 1990.
3. "The Potential of Renewable Energy: An Interlaboratory White Paper," Office of Policy, Planning, and Analysis, U.S. Department of Energy, Washington, DC, SERI/TP-260-3674, DE90000322, March 1990.
4. "The California Experience with Solar Thermal Power," Solar Industry Journal, V.1, N.3, p. 19, 1990.
5. R. Lynette, "Status and Potential of Wind Energy Technology," Proceedings of the Windpower 90 Conference, September 24-28, 1990, Washington, D.C.
6. A. Van Arsdall, H.N. Post, J.W. Stevens, and M.G. Thomas, "Photovoltaic Systems for Utilities," SAND90-1378, Photovoltaic Systems Design Assistance Center, Sandia National Laboratories, October 1990.
7. A.V. Poore, H.N. Post, and M.G. Thomas, "Photovoltaic Systems for Government Agencies," SAND88-3149, Photovoltaic Systems Design Assistance Center, Sandia National Laboratories, revised May 1989.
8. D.S. Shugar, "Photovoltaics in the Distribution System: The Evaluation of System and Distribution Benefits," Proceedings of the Twenty-First IEEE PV Specialists Conference, Kissimmee, FL, May 1990.
9. E.C. Kern, Jr. and M.C. Russell, "Lessons Learned With Residential Photovoltaic

Systems," Proceedings of the Twenty-First IEEE PV Specialist Conference, Kissimmee, FL, May 1990.

10. R. H. Hill, "Photovoltaics in the Utility Sector," Solar Industry Journal, V.2, N.3, p. 31, 1991.
11. S. J. Durand et al., "The Alaska Energy Authority PV-Diesel Hybrid Assessment and Design Program," Proceedings of the Twenty-Second PV Specialist Conference, Las Vegas, NV, October 1991 (to be published)