IEEE POWER ENGINEERING SOCIETY
ENERGY DEVELOPMENT AND POWER GENERATION COMMITTEE
International Practices Subcommittee

EXTENDED FULL LENGTH PAPERS

PANEL SESSION: HARNESSING UNTAPPED SOLAR POTENTIAL AROUND THE WORLD[#]

IEEE 2003 General Power Meeting, Sheraton Centre Toronto Hotel, Toronto, Canada, Monday, July 14, 2003, Room Sheraton/Cinema 2, 2:00 p.m.

Chair: Tom Hammons, University of Glasgow, Scotland, UK. E-mail: T.Hammons@ieee.org
Co-Chair: Peter Meisen, GENI, CA, USA. E-mail: Peter@geni.org

This Panel Session reviewed the present status and future prospect of harnessing untapped solar power worldwide.

For the past two decades, the promise of solar energy has remained unrealized. While the costs of solar cells and thermal collectors have dropped significantly over that same period, the price for solar power is still two to five times that of traditional power sources.

Today, the market for solar energy is growing at 20% a year. All sectors of the business are advancing: distributed off-grid systems, grid connected arrays, and commercial and residential rooftop customers. This development is assisted by government tax incentives, renewable portfolio commitments, environmental concerns over climate change, and independent power producers making a business in the solar field.

In fact, solar energy development has been embraced by many of the largest energy companies in the world. BP, Shell, Siemens, and others have acquired leading market positions as this energy sector accelerates from it's long infancy.

Advocates have pointed to the unlimited potential of solar energy to power all the world's electrical needs. The Panel Session presented the story from those who are designing and developing these installations, and gave their perspective on the future of solar power in the world.

Principal contributors included:

1) Christy Herig, National Renewable Energy Laboratory, Golden, Colorado, USA (Photovoltaics as a Distributed Resource—Making the Value Connection)
2) Mossadiq Umedaly, Executive Chairman, Xantrex Technologies,Vancouver, BC, Canada (Inverter Systems Design Directions for Renewable Energy Applications)
3) Allen Barnett, President and Chief Executive Officer; and Howard Wenger, Vice President: Premium Power, AstroPower Inc., Newark, Delaware, USA (Solar Electric Power in the Mainstream)
4) Patrick Cusack, Arise Technology, Kitchener, Ontario, Canada. (Prepared Discussion--Harnessing Untapped Solar Energy Resources Around the World:)

Presented were the views of renowned international authorities on emerging technologies in solar electric power, photovoltaics as a distributed resource, and inverter systems design directions for renewable energy applications.

[#] This document has been prepared and edited by Tom Hammons, Chair of International Practices for Energy Development and Power Generation, University of Glasgow, 11C Winton Drive, Glasgow G12 0PZ, UK.

Each Panelist spoke for approximately 30 minutes. Each presentation was discussed immediately following the respective presentation. There was a further opportunity for discussion of the presentations following the final presentation.

The Panel Session was organized by Tom. Hammons, Chair of International Practices for Energy Development and Power Generation, University of Glasgow, UK; and Peter Meisen, President, Global Energy Network Institute (GENI), USA. Tom Hammons moderated it.

The first presentation was entitled: Photovoltaics as a Distributed Resource—Making the Value Connection. Christy Herig, National Renewable Energy Laboratory (NREL), Golden, Colorado, USA, Presented it.

Photovoltaics is the modular that is gaining share in the electric service market. The grid-connected distributed resource application is the fastest growing market for Photovoltaics. Though most of this growth is credited to Japan and Germany, the US market also increased by 25% in 2000. PV may be the ultimate distributed resource due to its modularity, resource availability and independence on fossil fuel. The value stream for PV extends far beyond energy related values. The traditional energy market paradigm with postage stamp rates and central station tax and policy benefits does not have financial instruments to allow realization of the extended PV-DR value stream. However, new policies, rate structures and green pricing programs result in financial relationships that combine the value streams of utilities, governments, and consumers. The panel presentation discussed analysis of the extended values for PV and demonstrated how policy and rates allow different types of investors to realize PV-DR values that exceed the high cost of this technology thus creating a grid connected PV market.

Christy Herig is a full time subcontractor for the National Renewable Energy Laboratory. For eight years prior to the subcontractor position she was a Principal Engineer at the Laboratory responsible for value analysis within the National Center for PV. Previous to the National Laboratory, Herig was a special projects engineer at Florida power Corporation for fifteen years, working in the full gamut of utility operations. Her educational background is Chemical Engineering.

The second presentation was concerned with Inverter Systems Design Directions for Renewable Energy Applications and was prepared by Mossadiq Umedaly, Executive Chairman, Xantrex Technologies, Vancouver, BC, Canada. This presentation discussed inverter design considerations for renewable energy applications, including the current status of inverter design, as well as balance of systems performance, reliability, and efficiency. In addition, other factors were addressed including system design and installation.

While most of the focus has been on photovoltaic modules, solar panels comprise only 45% of a solar system. Mounting arrays, controls, inverters and at times batteries makes up the rest of the system. Interconnection equipment is being standardized with improved efficiency and performance. Xantrex is enhancing 'balance of system' installation to insure proper performance. Newer inverter technologies are coming to communicate with the solar system owner, installer, and even the meter and utility company. But until regulatory barriers are removed and larger-scale deployments are insured, market penetration is slow.

Demand for solar power in the commercial and residential rooftop market sector continues to grow. Overall, grid–connected systems are becoming a more important part of the photovoltaic market, continuing a trend that started over five years ago when grid-connected systems were an insignificant fraction of the total market. The off-grid market is also growing as people continue to look for energy independence either through desire or necessity. Today, Xantrex inverters in commercial and residential PV schemes range from 500W to 225kW.

The presentation was given by Konrad Mauch, Director of Advanced Development for Zantrex Technology, Burnaby, BC, Canada.. He discussed inverter and BOS design basics, the current status, performance, efficiency, and the road ahead. Inverters and BOS components for RE systems have made major advances in the past five years. There is now a growing list of mature RE inverters in the market place that comply with nationally recognized interconnect and safety standards.

Konrad Mauch is Director of Advanced Development for Zantrex Technology, a leading North American manufactures of power electronic systems for renewable and distributed energy applications, Burnaby, BC, Canada. Konrad Mauch received his Bachelor and Masters degrees in Electrical Engineering from the University of British Columbia. He is a Member of IEEE and a Professional Engineer in the Province of British Columbia.

The third presentation was entitled: Solar Electric Power in the Mainstream. It was presented by Allen Barnett, Chief Executive Officer, and Howard Wenger, AstroPower, Newark, Delaware, USA.

The photovoltaic industry has focused on overseas markets to address the niche to service the two billion people in the world without electricity. But other markets exist in industrialized countries beyond the traditional remote power markets like water pumping and signage lighting AstroPower has been a leader in addressing conventional retail markets, such as Shea Homes in California, as well as commercial buildings in joint systems with PowerLight and others. Growing economies-of-scale in manufacturing need to be linked with a wide and continuing strategy focused on higher margin markets. Allen Barnet addressed AstroPower's experience in growing a modern industry based on mainstream markets.

Allen M. Barnett is President and CEO of AstroPower, Inc. AstroPower is currently the largest independent manufacturer of solar electric power products, fifth largest in the world, and one of the fastest-growing solar electric power manufacturing organzations.

Prior to founding AstroPower, Dr. Barnett successfully led three different organizations into positions of technical leadership in the development of high-technology products. He pioneered the development and manufacture of thin, crystalline silicon solar cells on low-cost substrates. An experienced inventor, Dr. Barnett has been awarded 23 patents and has been the recipient of seven R&D 100 awards for new industrial products. In addition, he has authored or co-authored more than 200 technical publications. From 1976 through 1993, Dr. Barnett was a Professor of Electrical Engineering at the University of Delaware.

Dr. Barnett received The Karl W. Boer Solar Energy Medal of Merit in April 2001 for pioneering high-performance, thin-crystalline silicon solar cells, founding and leading a world-class enterprise for the commercialization of solar electric products, and outstanding continuing service to the solar electric power community. In 1996, Dr. Barnett received the IEEE William R. Cherry Award for outstanding contributions to Photovoltaic Science and Technology. He was elected a Fellow of The Institute of Electrical and Electronics Engineers in January 1998 for contributions and technical leadership in the development and commercialization of photovoltaic solar cells.

The final presentation was a prepared discussion by Patrick Cusack, Arise Technology, Kitchener, Ontario, Canada. It was entitled: Harnessing Untapped Solar Energy Resources Around the World

Patrick M. Cusack, holds a B.A Math Degree, 1987, a B.Sc. Hons Degree in Electrical Engineering, 1987; a B.Sc. Hons. Degree in Computer Science, 1989, and a M.Sc. Degree in Electrical Engineering, 1990, all from Queen's University, Kingston, Ontario, Canada.

He is currently Vice President Engineering at ARISE Technologies Corporation, Kitchener, Ontario, Canada. ARISE designs and installs distributed generation systems and equipment, and distributes photovoltaic modules, small wind turbines, and standalone and utility interconnected inverters.

Each presentation is summarized below:

1. PHOTOVOLTAICS AS A DISTRIBUTED RESOURCE – MAKING THE VALUE CONNECTION

Christy Herig, Consultant, Subcontractor - National Renewable Energy Laboratory, Evergreen, CO 80439, USA, christy.herig@aol.com

1. INTRODUCTION

Photovoltaics, the modular, versatile, market-ready distributed generator, is gaining share in the electric service market. The grid-connected distributed resource (DR) application is the fastest growing market for Photovoltaics (PV). Though most of this growth is credited to Japan and Germany, the US market also increased by 25% in 2000[1]. PV may be the ultimate distributed resource (DR) due to its modularity, resource availability and independence on fossil fuel. The value stream for PV extends far beyond energy related values. The traditional energy market paradigm with postage stamp rates and central station tax and policy benefits does not have financial instruments to allow realization of the extended PV-DR value stream. However, new policies, rate structures and green pricing programs result in financial relationships that combine the value streams of utilities, governments, and consumers. Surprisingly, when the tangible values are analyzed for the US grid connected market; the solar resource ranks third to first policy and secondly rates. The panel presentation will present analysis of the extended values for PV and demonstrate how policy and rates allow different types of investors to realize PV-DR values that exceed the high cost of this technology thus creating a grid connected PV market.

As a distributed resource, PV attributes include the usual values of being near the load, and offsetting generation, distribution, and transmission losses and capacity requirements. PV-DR also has unique values of modularity, independence on fossil fuel price volatility, no environmental emissions or noise, and a generation profile caused by the same resource that drives utility system load peaks. However, these tangible values are often spread out over several stakeholders and it is difficult for the PV system investor to collect the full value potential for the investment. Traditionally, a residential or commercial consumer benefited only from utility bill, postage stamp electric service tariff savings, and this benefit may be diminished without net metering policies or interconnection standards. The customer-sited benefits to the utility grid and the various components in the electric service economic chain such as decreased line losses or G,T&D capacity deferral cannot be collected by the consumer investor, unless creative tariffs, policy, customer aggregation contracts, or other mechanisms are implemented to change the economic and operating paradigm of the traditional electric service industry. Figure 1 illustrates the concept of combining the values of multiple stakeholders to exceed the price of PV-DR.

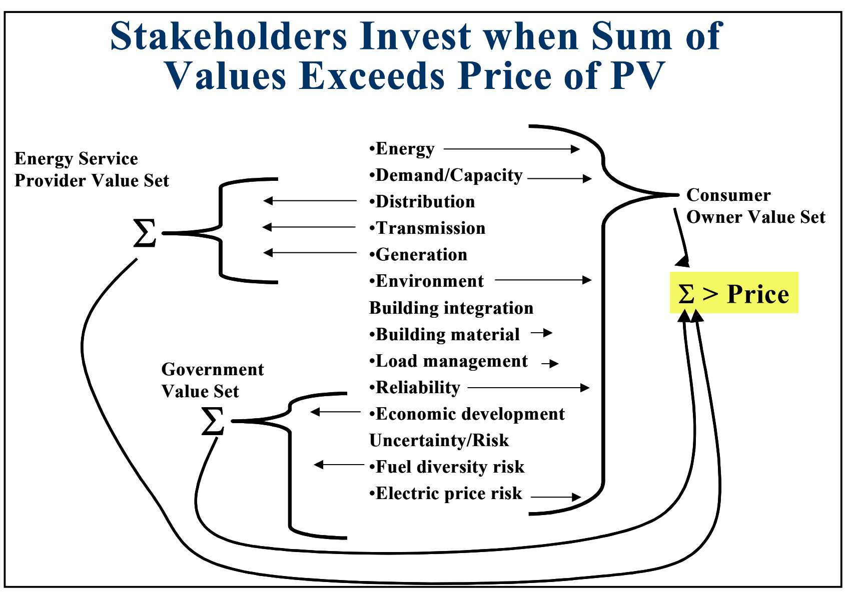

Figure 1. Concept of Combining the Values of Multiple Stakeholders to Exceed the Price of PV-DR.

2. *PV VALUE ANALYSIS – THE MATRIX*

Value analysis for PV-DR has focused on both individual value attributes and stakeholder perspectives. Multiple analysis projects have been organized into a matrix of stakeholders, by value attributes. The greatest barrier for PV in the gird-connected market is not just the high price, but competing the PV system price in the traditional monopoly electric service market. As electric service transitions to a more competitive industry, the traditional economic and operating paradigm has dispersed. Legislation accompanies regulatory issues, and the PV value analysis includes economic development, environmental metrics, and fuel diversity for the state. Utilities are identifying new market opportunities. The opportunity for grid-connected PV is to compete the price against the related electric service value, as well as other extended values. Changes to the electric service industry allow the service value to expend beyond kW's or kWh's from the grid service provider to values from multiple stakeholders, through creative policies, tariffs, and contractual mechanisms. The value matrix allows stakeholders to:

- Select a unique set of values. Through recent advent of the "energy crisis", repeated value analysis or review of value analysis made it evident that stakeholders, particularly purchase decision makers, identified value sets. And even when the stakeholders were similar, the "selected" value sets were unique. The Value Connection Matrix allows stakeholders to "shop" values.
- Identify financial relationships and new business opportunities. An electric service provider can examine both the customer and the utility value and identify contracts or tariffs to stimulate customer investment in DR in geographic locations of the greatest value to the utility.
- Provide metrics to policy makers to validate policy values while assuring consumer targeted policy benefits the customer enough to stimulate participation and revenue impacts to either the utility or the government are less than the benefits.

To exemplify the PV Value Matrix the panel presentation will first presents some value attributes, examples of stakeholders value sets, and then finally examples of the effect of policy and rate structure.

PV Value Attributes

Figure 2 illustrates PV value attributes for USA for energy production in kWh/kW-yr while Figure 3 shows the effective load carrying capacity and indicates per unit kW reduction for USA.

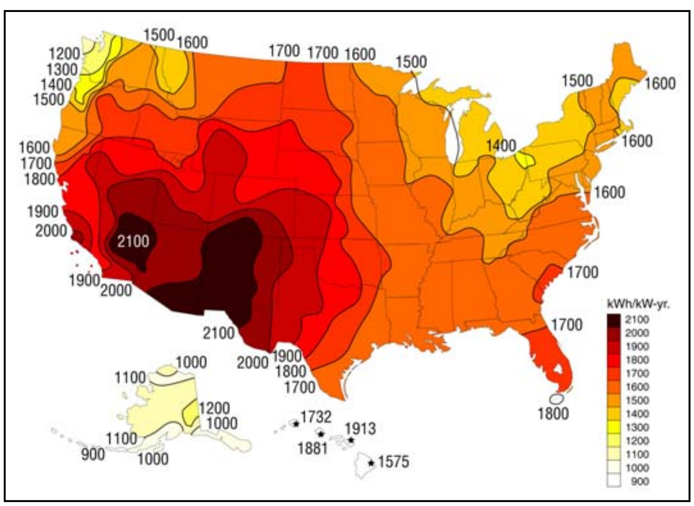

Figure 2. Energy for USA: Production in kWh/kW-yr

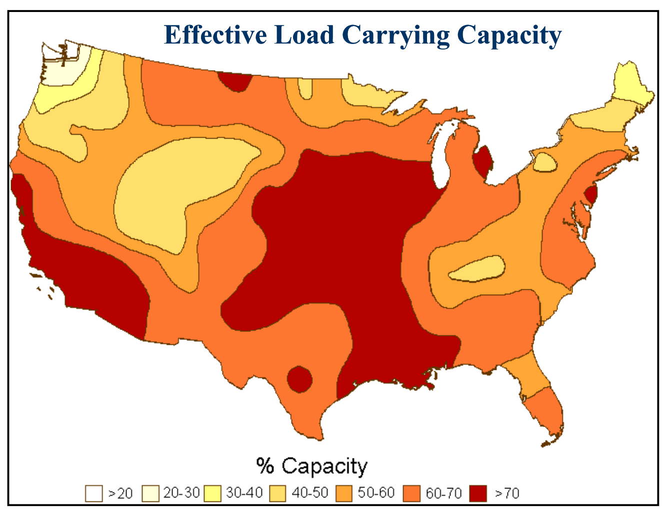

Figure 3. Per Unit kW Reduction

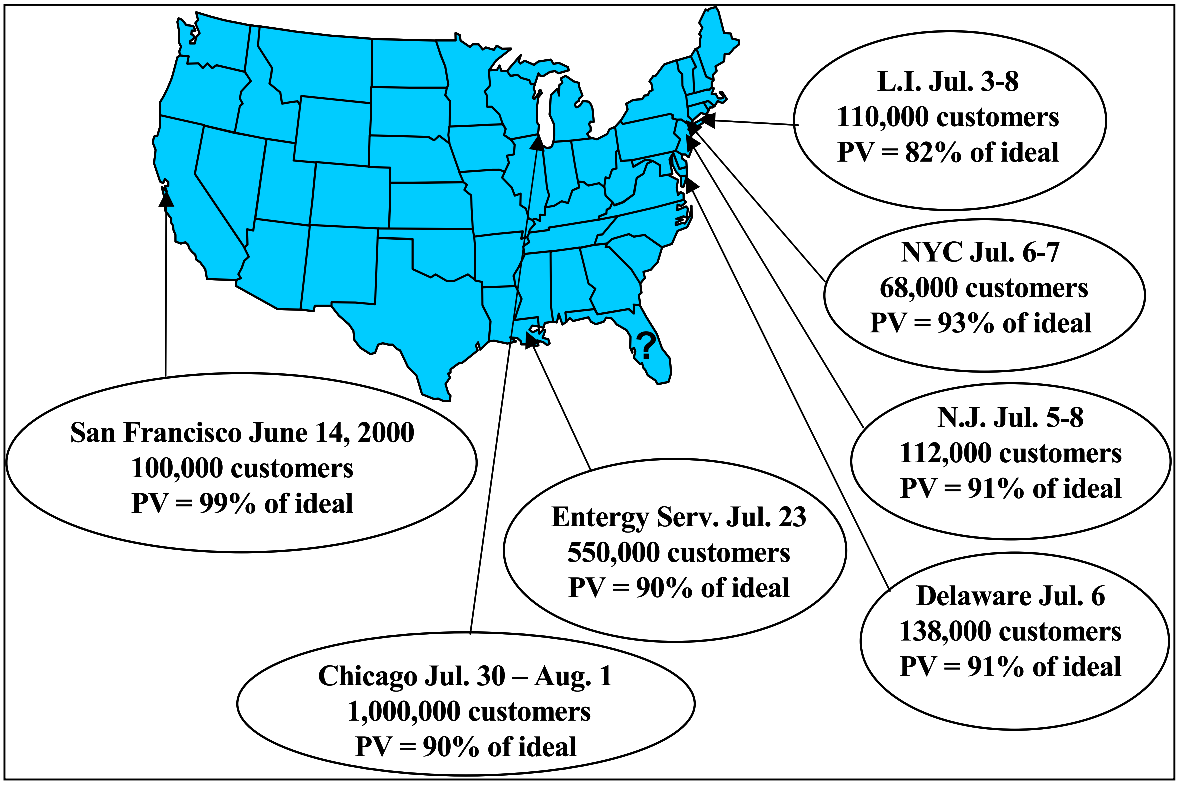

Figure 4. . Availability of the Solar Resource during major Power Outages

Energy and demand savings represent the largest tangible value stream for most of the US as well as the international grid tied markets. Figures 2 and 3 map these kWh production and the per unit demand values for the United States. The monetary value for demand and energy varies depending on rate structures. In California new inclining tiered rate structures result in a value of approximately 20¢/kWh. In Arizona the energy savings are valued at the lowest declining tier of the rates or 4¢/kWh. Declining tiered rates are a disincentive for all distributed resources including efficiency measures.

Reliability is another value stream important to consumers, though it is seldom measured for residential or small commercial energy users. Figure 4 indicates the availability of the solar resource during major power outages as a percent of the ideal resource. Historically most large utility system outages are caused by high system loading during heat waves. However even after hurricanes and ice storms the solar resource is still available.Consumers also identify environmental values with PV investment, though mostly intangible, utility green marketing programs, and state renewable portfolio standards result in emerging markets for the environmental attributes of solar produced energy.

Table 1: Analysis for AZ Environmental Portfolio Standard

Parameter	Result
Jobs Created by 2010	**600 jobs**
Wage, salary, and state income tax revenue (1998 - 2020)	**$200 million**
Global warming CO_2 emissions avoided by 2020	**12 million tons, $120 million**
Acid rain SO_x emissions avoided by 2020	**32 thousand tons, $85 million**
SMOG NO_x emissions avoided by 2020	**38 thousand tons, $40 million**

Source: H. Wenger, Pacific Energy Group

Utility and government stakeholder values are recently factoring into the consumer's value stream through innovative rate structures and policy. Figure 5 shows details of distributed resource value in several utilities. The

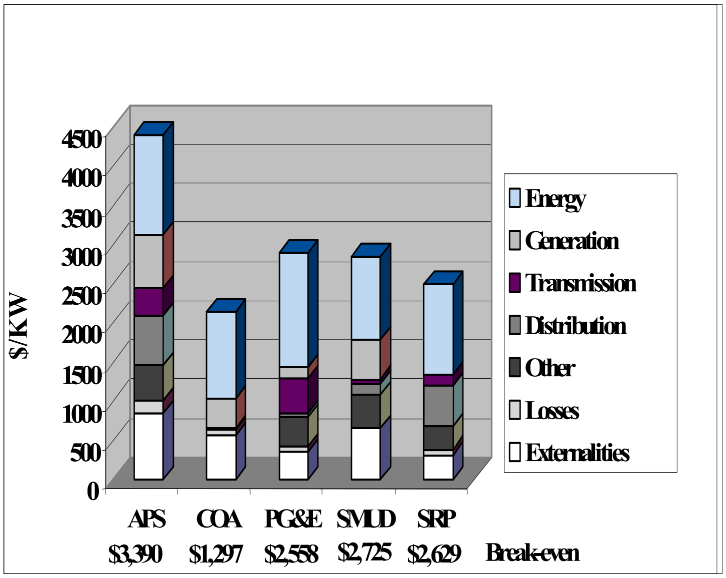

Figure 5: Utility Break-Even Values

average value for the utility system is approximately $1/W. These higher values reflect targeted areas where capacity or construction constraints increased the value. Federal, State and local governments' values are associated with infrastructure, economic development, environmental impact and fuel diversity. Table 1 shows the values recognized by Arizona during development of the State's environmental portfolio standard.

Figure 6 identifies the value components for commercial utility customers across the US. The break-even turnkey cost is the installed cost a customer can pay for a system and neither gain nor loose money over the life of the system. Policies and rates are the major value drivers. This policy and rate structure market has mushroomed over the

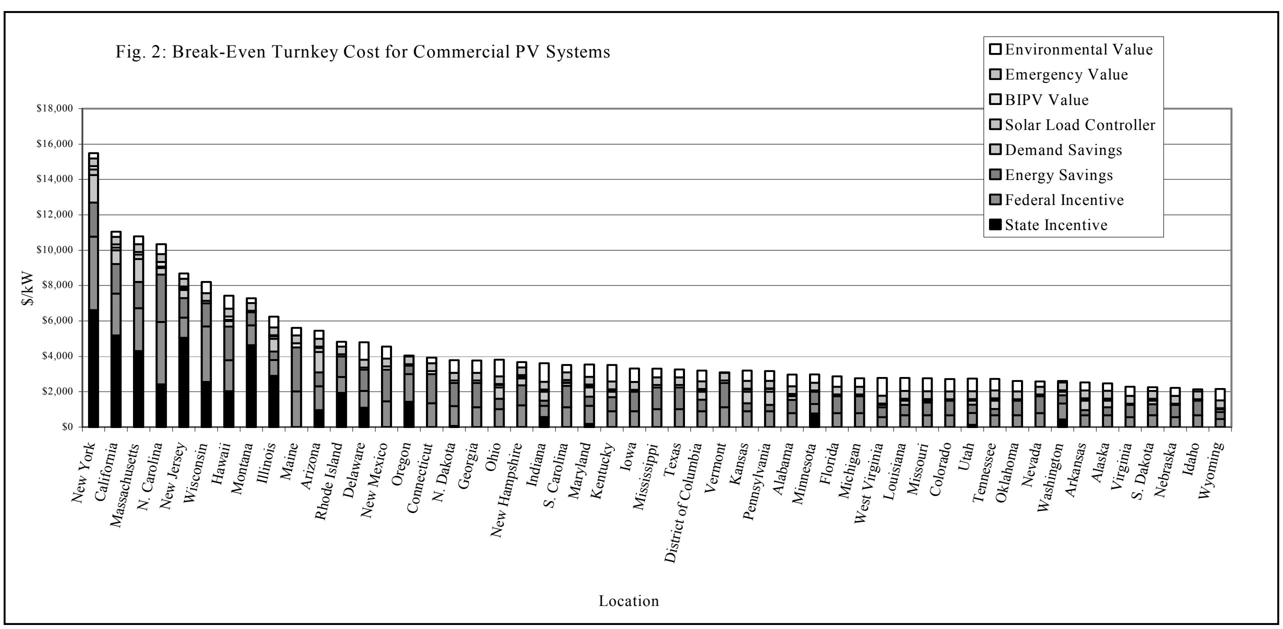

Figure 6. Break Even Turnkey Cost for Commercial PV Systems

past two years in the US. However, similar policies in Japan, Germany, and Italy have been in existence for the past decade and are the reason that the largest market sector for PV is now the grid connected distributed power market. This market sector nearly doubled world wide, and accounted for over half of the world's manufacturing capacity. In the US, this market sector has tripled in just the past two years.

Christy Herig is a full time subcontractor for the National Renewable Energy Laboratory. For eight years prior to the subcontractor position she was a Principal Engineer at the Lab responsible for value analysis within the National Center for PV. Previous to the National Laboratory, Christy was a special projects engineer at Florida power Corporation for fifteen years, working in the full gamut of utility operations. Her educational background is Chemical Engineering.
Government Values (infrastructure, economic development)

2. INVERTER SYSTEMS DESIGN DIRECTIONS FOR RENEWABLE ENERGY APPLICATIONS

Mossadiq Umedaly, Executive Chairman, Xantrex Technologies, Vancouver, BC, Canada.

ABSTRACT

This paper will discuss inverter design considerations for renewable energy applications, including off-grid and grid connected photovoltaic systems. Specific considerations and trade-offs are addressed including the current status of inverter design, as well as balance of systems (BOS) performance, reliability, and efficiency. In addition, other factors affecting system performance are addressed, including system design and installation.

1. INTRODUCTION

Demand for solar power in the commercial and residential rooftop market sector continues to grow. Overall, grid-connected systems are becoming a more important part of the photovoltaic (PV) market, continuing a trend that started over five years ago when grid-connected systems were an insignificant fraction of the total market. The off-grid market is also growing, as people continue to look for energy independence either through desire or necessity.

Xantrex inverters in commercial and residential PV systems installed to date range from 500W to 225kW. Improved system costs along with aggressive Federal and State incentives are helping to make PV systems economical for homeowners, commercial and industrial customers.

2. INVERTER AND BOS DESIGN BASICS

The inverter is the heart of the balance of systems (BOS) that makes up an integral part of a typical PV or renewable energy (RE) system. The inverter performs the essential function of DC to AC inversion, making RE power usable. It can also perform DC to DC conversion for storage or supporting DC loads. It also implements the utility grid interface, manages power quality and safety (anti-islanding). It must be tested and certified for sale to the residential and industrial PV markets.

The BOS also typically includes a combiner box, fuses and or circuit breakers, AC and DC disconnects, cables and conduit, transformer (if required), monitoring and communications system, and a user interface. The most important trend in BOS is integration. The continued success of the renewable energy industry depends on innovative systems development that provides a solution that is simple to install and maintain, and which maximizes the customers return on investment.

Xantrex currently offers single-phase inverters for off-grid and grid-interactive applications ranging in size from 500W to 5.5 kW and three-phase PV series of grid interactive inverters, from 10kW to 225 kW. These inverters have benefited greatly from design maturity, standardization, production volume increases, and rigorous testing. For a grid connected PV system, the inverter provides several key functions in addition to the fundamental conversion of the array DC power to AC power. The inverter's maximum power point tracking (MPPT) function ensures the optimal energy harvest from the PV array, and utility protection requirements are met by the inverter's internal protective functions as defined by UL-1741 [1]. Xantrex features UL-1741 listings for inverter models across its lineup, and has been in the forefront of securing UL-1741 and CSA 22.2-107.1-01 [2] for high power inverters over 20kW in size.

3. CURRENT STATUS

Xantrex inverters are being used across a broad range of RE applications. The majority of systems are standard rooftop arrays tied into a customer's AC panel to reduce energy and demand charges. This trend takes advantage of the expansion of net-metering tariffs in participating states to include larger, commercial scale PV systems in addition to residential systems. The program in California, for example, enables PV systems as large as 1 MW to now be eligible for net-metering. The net-metering capability is especially valuable for commercial and industrial customers with reduced energy demand on weekends. [3]

System designers of inverters and BOS components for PV, wind, micro-hydro or other RE systems and hybrid backup power systems face difficult challenges. Performance requirements are increasing constantly. Higher reliability, lower cost, and improved efficiency requires the use of relatively advanced and complex power conversion technology. Technology exists to meet these challenges. Both the RE market and inverter manufacturers are maturing. There is sufficient economic incentive and organizational capability to convert technology into successful mainstream products and solutions.

4. PERFORMANCE

The past five years have seen significant progress in power electronics. Components such as power MOSFETs, IGBTs, and overload protection circuits have been made simpler and more reliable. Control circuit designs have been simplified with emphasis on more efficient operation at higher switching frequencies, resulting in lower cost, size, and weight for harmonic filter components. [4]

While the RE inverter industry is still reliant on other industries, such as automotive and variable speed motor drives, to drive advances in component technology, significant improvements have been made in the performance and ruggedness of power semiconductor devices.

Figure 1. illustrates the high level of inverter efficiency that is now being realized in the Xantrex high power PV Series industrial grid-interactive platform.

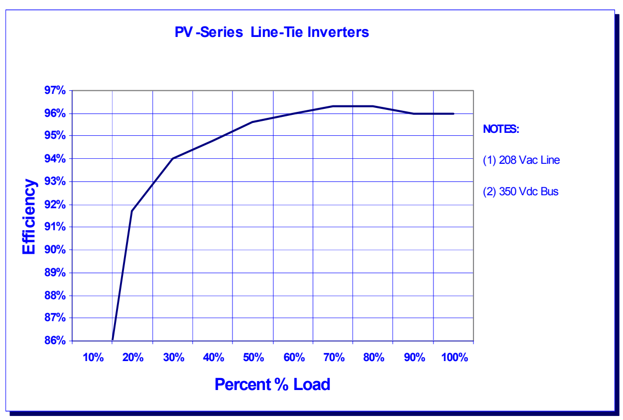

Figure 1. PV Series Performance Efficiency

Embedded micro-controllers are ubiquitous in modern RE inverters, and some utilize Digital Signal Processors. Software based control has made it possible to meet utility interconnect standards, offer improved user controls and displays, and provide multi-function power converters that operate in grid-interactive and stand-alone modes.

Several residential scale RE inverters are in series production with annual volumes into the thousands and even tens of thousands of units. Xantrex has made significant advance in higher power systems for industrial applications as well. Virtually all Xantrex high power inverters are tested and approved to the UL-1741 standard, reflecting the standardization as these systems move into series production also.

System standardization is also made possible by market growth, standards development, and power electronics technology advancements. These advances allow manufacturers to adopt more efficient manufacturing processes, automate business processes, and provide a quality product from a mainstream ISO 9000 compliant manufacturer.

The practical advantage is that inverter manufacturers devote engineering resources to performance improvement and cost reduction rather than “engineer to order”. This allows integrators to develop packaged PV systems, and installers to develop standard installation practices.

5. RELIABILITY

Many barriers to widespread market acceptance that existed in earlier generation products have been overcome, including power quality, electrical safety certification, interconnect issues, and interfacing to PV array or other RE inputs. Attention to thermal management, power electronics control, and HALT (highly accelerated lifetime testing) by manufacturers provides the industry the level of reliability the mainstream RE market requires.

A major selling feature of RE systems is that they should offer a long, maintenance-free operating life. PV modules are rugged assemblies with no moving parts and can be expected to have a long lifetime. The PV module industry has evolved the technology and design to provide modules with over twenty year warranties.

Many perceived 'reliability' issues with PV installations are associated with partial shading of arrays, improperly installed PV arrays (not tilted on axis), or undersized wiring between system components, all affecting the perceived expectation of power production. The UL1741 requirements that the inverter must disconnect for 5 minutes when voltage levels are outside a band centered at the nominal system voltage, may cause frequent drop outs when the PV system is located on a high impedance utility grid and there are local loads exhibiting startup surge currents that cause voltage dips. These system issues should be considered to prevent undesirable system performance or nuisance shutdowns.

The inverter is typically the most complex element in the PV system, performs a number of critical functions, and is typically the first place an indication is given when the system or components fail. Rather than degrading in performance over an extended period, it can stop working entirely. Failures directly attributed to the inverter or its components can include Insulated Gate Bipolar Transistor device (IGBT) failures, control board component failures, failures of protective devices, or component manufacturing defects. To demonstrate expected operating life in excess of 10 years will require not just technology and component improvements but a change in the design and manufacturing processes used by the industry.

There are generally two types of failures, software failures that affect performance, and hard failures that stop producing power. Proper design considerations, site planning for optimum thermal performance, and ensuring protective devices are properly installed will decrease failures associated with installation and environmental conditions.

Many failures or system performance issues commonly attributed to the inverter are ultimately caused by external factors. Installations must be carefully designed to ensure the DC input voltage from the array is properly configured within the manufacturer specifications. It is important to consider the high and low temperature variations and the maximum power point of the array during system design. Often the inverter is installed either outdoors or in an indoor environment that presents unique challenges. Exceeding design limits with respect to ambient temperature, humidity, and exposure to the elements may reduce system availability. The most common cause of issues perceived to be inverter related are fluctuations in utility grid voltage and frequency - which per UL-1741 requirements causes the inverter to intentionally shut down. This fact must be considered in the design of the system to prevent undesirable system shut-downs.

Software issues can also account for some portion of performance problems in newly released inverters. Manufacturers realize that they must improve the rigor of their software development processes and increase coverage of their design verification testing as products become more sophisticated.

6. EFFICIENCY

Factors affecting system efficiency are myriad. Typically the expected AC power output of a system is impacted by many variables. Module mis-match can account for 2-3% efficiency loss. DC circuit wiring can account for an additional 2-3%. The inverter will generally add another 4-6%, while an isolation transformer will add another 2-3%. Other factors that can have a dramatic affecting efficiency include ambient temperature and array soiling. [5][6][7]

7. THE ROAD AHEAD

The *US Photovoltaic Industry Roadmap* states that the PV industry is seeking to partner with inverter manufacturers to "create highly reliable, relatively inexpensive, flexible, trouble-free inverters" [8]. To achieve this goal, effort is required in several areas including regulatory, technical standards, reliability and performance.

In regards to regulatory, the basic framework of national standards for grid interconnection and electrical safety is in place. This includes the National Electric Code, UL 1741, and forthcoming IEEE P1547 interconnection standard [9]. Common standards must be adopted by all jurisdictions. PV systems exporting to the grid under a net-meter arrangement by definition draw greater scrutiny from the local electric utility. It is therefore critical for inverters to have the certified utility protection measures defined in UL-1741. An inverter listed to UL-1741 ensures the system will shut down if it detects the utility voltage or frequency outside prescribed limits, and incorporates active anti-islanding controls to ensure exporting power cannot be sustained for more than two seconds given an unusual balanced load condition at the time of the utility outage. Certified anti-islanding controls allow systems to be installed without expensive (or constraining) utility relays such as reverse-power relays or a substation transfer trip scheme.

More development is needed to mature the industry and provide the framework and tools to third party certification, compliance, and testing facilities. Increased focus and involvement of the PV and inverter manufacturers in the standards creation, through fruition will provide a collaborative effort in the renewable energies industry. The objectives and goals of standards evolution and BOS integration are to provide consumers, residential and commercial customers the ease of owning RE systems as if ordering an appliance or an automobile.

8. CONCLUSION

Inverters and BOS components for RE systems have made major advances in the past five years. We can safely say that the "garage shop" days are over. There is now a growing list of mature RE inverters available that comply with nationally recognized interconnect and safety standards.

Market acceptance and proliferation of renewable energy systems will depend on the diligence and determination of inverter and BOS manufacturers to provide simple and reliable systems, supported by common standards that are adopted by all relevant jurisdictions.

9. REFERENCES

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Konrad Mauch is Director of Advanced Development, Xantrex Technology,

Mossadiq Umedaly, Executive Chairman, Xantrex Technologies, Vancouver, BC, Canada is etc.

3. SOLAR ELECTRIC POWER IN THE MAINSTREAM

Allen M. Barnett, President and Chief Executive Officer, AstroPower Inc., Newark, Delaware, USA, *Fellow, IEEE,* and. Howard Wenger, Vice President: Premium Power, AstroPower Inc., Newark, Delaware, USA

***Abstract*--Solar electric power is rapidly becoming a mainstream consumer product. The technology is on a rapid growth trajectory and is on its way to becoming a significant part of our energy mix.**

I. INTRODUCTION

With increased manufacturing capacity and enhanced technology, the solar electric power industry is well poised to meet the ever-growing demand for clean, renewable electricity. Solar electric power provides economic and environmental value - and that value is causing increased numbers of consumers to bring solar electric power home in the United States, Japan, Germany, other developed countries, and many developing countries.

Solar electric power continues to power rural villages throughout the world. While the technology will continue to improve the quality of life by bringing power to these villages, growth of the technology will be driven by grid-connected markets in developed countries.

II. MAINSTREAM MOMENTUM

The solar electric power industry has achieved some significant milestones recently, which have driven the technology directly into the hands of the mainstream U.S. consumer. Solar electric power is being incorporated into new home construction by many of the nation's leading homebuilders. In partnership with AstroPower, Inc., the Home Depot, the world's largest home improvement retailer, is selling solar electric home power systems in more than 100 of its stores. And, technological breakthroughs are making solar electric power ideally suited for homeowners who want to generate their own electricity cleanly and quietly.

Electricity industry deregulation, which began almost a decade ago, has increasingly offered consumers the ability to choose their electricity suppliers. When offered this choice, consumers prefer solar power to all other generating technologies.

Homeowners are choosing solar power over other generating technologies because they seek energy independence and cost stability and they are eager to protect the environment. They seek an affordable, reliable supply of electricity. When given the opportunity, consumers support the technology by consistently voting for bond issues, tax credits, rebates, or buy-downs in order to make it an even more feasible energy option.

The solar electric power industry is expected to be as much as a $50 billion industry by the year 2020. In that same time period, the industry is predicted to grow to employ more than 150,000 in the United States alone [1]. These jobs will largely be in the high-value, high-tech field. This is unprecedented growth.

Figure 1. Home Depot stores in California, New Jersey, New York and Delaware are selling solar electric home power systems directly to homeowners.

Figure 2. Incentives, such as net metering, are making solar electric power a more feasible energy option on homes such as this one in Delaware.

III. TECHNOLOGY ADVANCEMENTS

The emphasis is on the industry to develop products and solutions that will best meet the needs of the residential market. With homeowners in the United States choosing solar electric power in rapidly growing numbers, the industry is moving quickly not to meet, but to exceed, their expectations. The residential market is the industry's fastest-growing market segment. As a result, solar electric power companies are beginning to offer packaged systems that were specifically designed with the homeowner's needs in mind. For example, AstroPower offers its fully packaged SunLine™ and SunUPS® solar electric home power systems with a meter so homeowners can monitor system performance. The meter illustrates to the homeowner how much electricity his or her solar power system is producing and how much electricity the home is using. It's a tool that brings solar power technology closer to the consumer, and one that often leads to a better understanding of energy efficiency and utilization.

Over the next 20 years, the industry will work with governments to further research and development of low-cost, high-quality solar power products - and strengthen the technology solar power manufacturers.

The industry continuously reinforces its commitment to develop processes and technologies that increase the efficiency and productivity of its manufacturing operations. The leading solar power manufacturers are making the investment in R&D, and they require the ongoing support of the public sector. This support comes in the form of continued investment in the nation's intellectual and research networks at national laboratories, universities, and industry research organizations. According to The U.S. Photovoltaic Industry Roadmap, this investment will guarantee needed improvement in existing technologies and the development of new and better technologies. "These next-generation photovoltaic devices and products are vital for meeting future energy needs and maintaining U.S. leadership [1]."

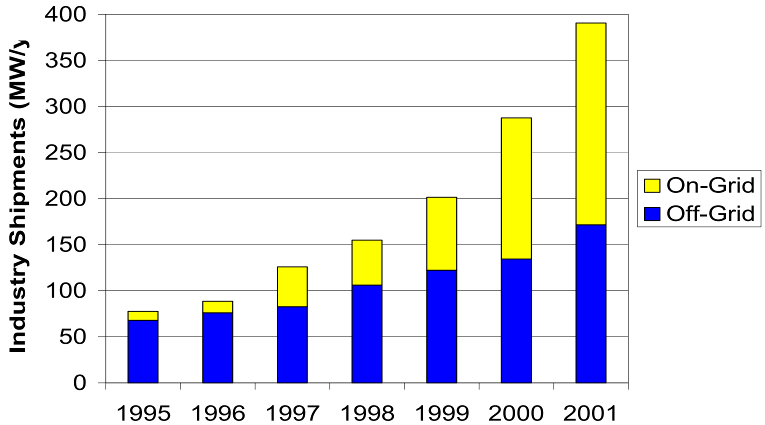

Fig. 3. On-Grid Solar Power Capacity Worldwide

Fig. 4. New home communities, such as this Premier Homes community in Northern California, are beginning to offer solar power systems as standard features.

IV COMMERCIAL PROJECTS

In addition to residential applications, solar electric power is ideally suited for large-scale commercial and municipal projects. In the form of rooftop- and ground-mounted systems or building-integrated photovoltaics (BIPV), solar power is generating electricity and creating a positive environmental image for corporations, retail outlets, and office complexes around the world.

Solar electric power provides demand peak shaving for commercial properties, enabling organizations to lower their energy costs. In addition, rooftop-mounted commercial systems protect a roof, while reducing the heating and cooling requirements of the building.

The largest solar-powered manufacturing facility in the world incorporates both BIPV and a roof-mounted system. AstroPower's new 158,000 square-foot manufacturing and office facility features a 30-kilowatt BIPV façade as well as a 310-kilowatt rooftop system, which incorporates more than 2,400 AstroPower solar modules. The combined solar electric power system meets all of the office's energy needs.

Fig. 5. This 100-kilowatt Berkeley, CA power plant is composed of 39,000 state-of-the-art AstroPower solar cells.

V. CORE OF THE U.S. ENERGY MIX

Currently, solar electric power systems furnish bulk electric power in the United States at $0.10 to $0.25 per kilowatt-hour. This is compared to electric generation from coal plants of $0.03-$0.04 per kilowatt-hour. Because solar electric power is generated at the point of use, its value should be compared to retail rates, which are $0.10-$0.25 – similar to present costs.

Consumers and the solar power industry seek the implementation of intelligent incentives that enable more consumers to reap the benefits of solar power technology. These incentives, which include net metering, will enable consumers to generate their own electricity and take control of their energy futures.

Solar electric power is leading the development of a new energy services market, in which technology does not simply supply energy. Where service is the driver, the technology must meet the demand for energy management (reducing peak loads for users), back-up or emergency power, and environmental improvements (reducing pollution that adversely impacts air quality). When solar electric power is analyzed in this services context, its economics dramatically improve.

Furthermore, in areas where utility rates are rising, solar electric power as a service technology is quite competitive at current equipment prices.

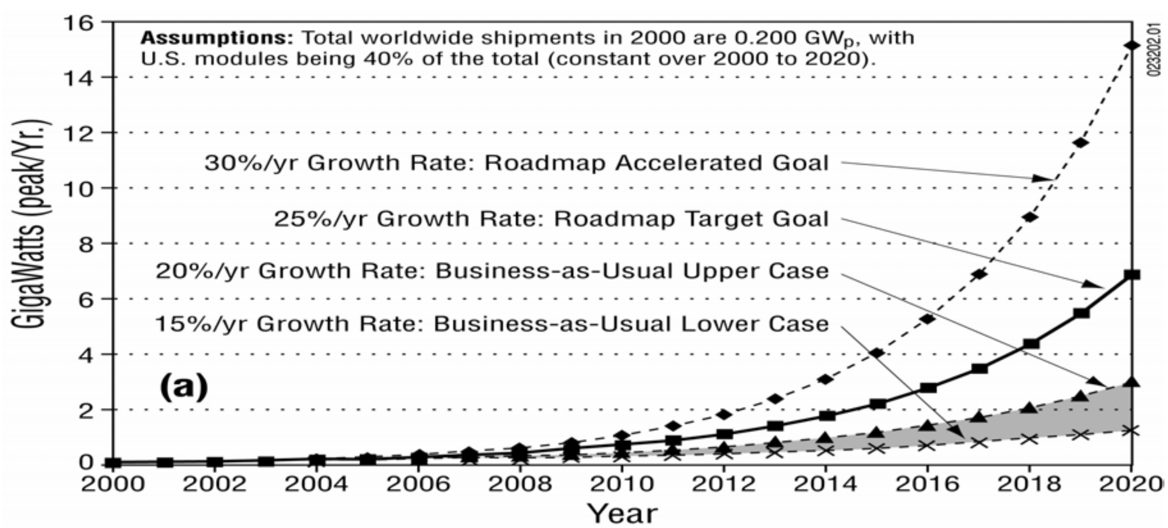

Figure 6. U.S. Solar Power Market Shipments

VI. CONCLUSIONS

Solar electric power will play a major role in the energy future of the United States and the global economy. Recent studies indicate that solar electric power has the potential to provide energy services in the United States over the next 50-70 years that, in energy units, could be eight to 15 times more than ANWR oil and approximately the same as all known U.S. domestic reserves.

Energy, the economy, and environmental security are at the forefront in the United States. Added to these issues are the global economy and utility restructuring as well as energy efficiency and reliability. The need to improve systems for generating and delivering energy within the United States is strong.

These challenges will best be met with a well-defined national energy policy that features renewable energy - in particular, solar electric power - at its core. Solar electric power provides energy independence. It provides economic value. And it provides environmental security. A U.S. energy policy that promotes the technology and furthers its development will ensure our country's energy future - and our security. Says The U.S. Photovoltaic Industry Roadmap: "A portfolio of renewable energy technologies could provide a significant fraction of the nation's electricity generation and, in concert with other generation sources, provide more reliable power.

To grasp the potential of solar-generated power, the total electricity demand for the United States today could be supplied by PV systems covering only 0.4% of the nation in a high-sunlight area - an area about 100 miles by 100 miles. In reality, though, this power generation will be distributed across the United States, bringing generation sources close to the consumer point of use."

Dr. Allen M. Barnett is President and CEO of AstroPower, Inc. AstroPower is currently the largest independent manufacturer of solar electric power products, fifth largest in the world, and one of the fastest-growing solar electric power manufacturing organizations.

Prior to founding AstroPower, Dr. Barnett successfully led three different organizations into positions of technical leadership in the development of high-technology products. He has been active in photovoltaic research and development since 1975, specializing in thin-film materials and device design. He pioneered the development and manufacture of thin, crystalline silicon solar cells on low-cost substrates. An experienced inventor, Dr. Barnett has been awarded 23 patents and has been the recipient of seven R&D 100 awards for new industrial products. In addition, he has authored or co-authored more than 200 technical publications. From 1976 through 1993, Dr. Barnett was a Professor of Electrical Engineering at the University of Delaware. Dr. Barnett received his Ph.D. in Electrical Engineering from Carnegie Institute of Technology and his M.S. and B.S.E.E. from the University of Illinois.

Dr. Barnett received The Karl W. Boer Solar Energy Medal of Merit in April 2001 for pioneering high-performance, thin-crystalline silicon solar cells, founding and leading a world-class enterprise for the commercialization of solar electric products, and outstanding continuing service to the solar electric power community. In 1996, Dr. Barnett received the IEEE William R. Cherry Award for outstanding contributions to Photovoltaic Science and Technology. He was also elected a Fellow of The Institute of Electrical and Electronics Engineers in January 1998 for contributions and technical leadership in the development and commercialization of photovoltaic solar cells.

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4. HARNESSING UNTAPPED SOLAR ENERGY RESOURCES AROUND THE WORLD: PREPARED DISCUSSION

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Abstract

Solar Electric (Photovoltaic or PV) modules have the potential to supply a significant portion of the industrialized countries electric energy requirements. Despite the potential, the diffuse nature of solar energy means that this industry is still in its infancy with an energy density output that pales in comparison with traditional generation sources. PV is, however, already accepted in many applications, and is being applied in electrification projects. Inverter technology is mature and reliable. Standards and guidelines for interconnecting distributed power generators (DPGs) with electric grids are under development, and are summarized. Additional technical and commercial issues yet to be addressed are discussed.

keywords: *Solar Electric, Inverter, Distributed power generation, interconnection standards.*

1. INTRODUCTION

This paper presents a review of the status of solar electric (PV) generation. PV is still a relatively "young" industry. Total worldwide manufacturing capacity is less than that of a medium capacity turbo generator. The technology is at an advanced stage and requires higher penetration rates to increase manufacturing volumes and decrease costs.

Applications for PV technology range from small standalone systems to megawatt scale fully integrated utility interconnected systems. PV and other renewable distributed resources are considered as some of the best technology for electrification in developing countries, especially where the infrastructure costs of electrification (distribution and control systems) exceed the benefits to sparsely populated areas with small users, and do not provide a return on investment to utilities. This paper reviews the state of the utility interconnected solar electric generation industry and its fit with the established electricity distribution system.

Inverter technology to convert PV dc electricity to ac electricity to operate common household appliances are common, well developed, and tested to modern product standards. New standards for inverters designed for interconnection with electric power systems are in use in some countries. Guidelines and standards to interconnect distributed power generators (DG) with electric power systems (EPS) have been developed. In addition to the inverter technology, the guidelines and standards govern the performance and requirements of the balance of system (BOS) components and installations.

2. STATE OF THE SOLAR ELECTRIC INDUSTRY

Electrical energy is one of the most versatile forms of energy and has become indispensable in modern society. The world's electricity consumption is expected to increase from 12,833 TWh in 1999 to 22,230 TWh in 2020 at an annual growth rate of 2.7%, according to the U.S. Energy Information Administration [1]. Barring the development of new storage technologies, however, electricity cannot be stored. Storage as chemical energy (in batteries or other fuel sources such as hydrogen) or potential energy in pump back hydro electric systems is required once electricity has been generated. Centralized generators and distribution systems have, by necessity, developed techniques to manage generation to match load, and avoid the need for storage. As a result generation and distribution systems are sized for peak loads, which typically occurs during daylight hours in most developed countries. With deregulation, and improved technology, the excess capacity of generation and distribution systems over peak loads has been decreasing. There is still significant load differences between peak and off peak energy usage.

Distributed energy systems share this characteristic. In off-grid or stand-alone systems the electricity generated by solar energy is either used immediately or stored, typically in batteries. In newer utility interconnected systems excess electricity generation is "stored" in the distribution system. The energy offsets other energy requirements in the distribution system, and has a good correlation with peak generation. The "stored" energy is then withdrawn when required, usually during off peak periods. This is a classic example of level loading a resource, in this case the generation and transmission resource. The International Energy Agency (IEA) has several implementing agreements with its member countries, including the PVPS, under which Task 7 has studied the potential of utility interconnected building integrated photovoltaic (BIPV) systems in supplying member countries electrical energy requirements. Significant penetration of the energy market is possible. The potential penetration ranges from less than 15% of electricity use in Japan, less than 30% in Germany, to almost 60% in the US. Interestingly, Japan is the largest installer of PV (accounting for over 30% of demand), Germany is the second largest installer, and the US follows.

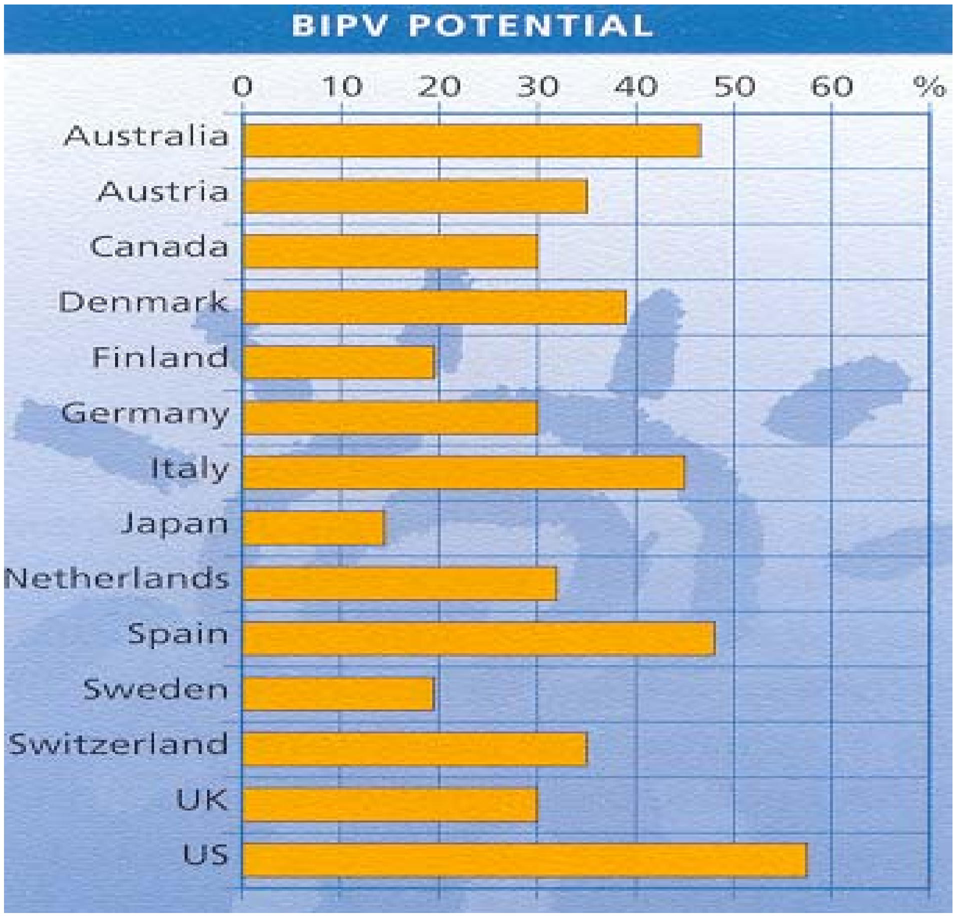

FIGURE 1: Percentage of national electricity consumption that can be provided by PV roofs and facades in selected IEA countries. (Assumes solar yield of 80% and PV system efficiency of 10%). Taken from Figure 12 of *Report IEA – PVPS T7-4 : 2001 (Summary)* [2]

Solar Electric technology has been applied in limited scale in the built environment since the early 1980's, and in distributed standalone systems (including space) since the 1950's. As costs have decreased the number and scope of applications have increased dramatically. The technology is pervasive in remote power systems, marine buoys, remote communications systems, remote monitoring, and livestock fencing and watering applications. It has been applied in large scale utility interconnected applications since the mid 1990s. Utility interconnected systems have now become the dominant application for PV, with the majority applied to residential construction. As shown in Figure 2, the number of grid or utility interconnected systems has increased dramatically since the end of the century. Figure 3 shows the world factory PV production, or the amount of PV at standard test conditions that was manufactured for each year. Although the graph shows dramatic volume growth and cost decreases a little perspective is required. The rated PV power is achieved for about four hours each day, on average, in the IEA countries. This equates to a capacity factor under 20%. In 1994 the author was an electrical engineer with GE Power Systems, in Schenectady New York. A large air cooled turbo generator under development at that time was conservatively rated at 292 MW, with an capacity factor expectation well in excess of 90%. Global manufacturing capacity of PV exceeded this level in 2001, but energy output (rating times capacity factor) will not exceed this level for several years. PV is still a small, relatively young industry when compared to established energy sources. Based on projected growth rates, investments, and the cost experience curve, installed PV capacity should exceed 2 GW, and may exceed 4 GW by 2020, yielding between 2 and 4 TWh of energy. This is a significant portion of the world wide electricity energy growth over that same time frame, but is still a small component of overall generation. In most countries DG will still depend upon the traditional distribution system, and must be tailored to optimally work with that system.

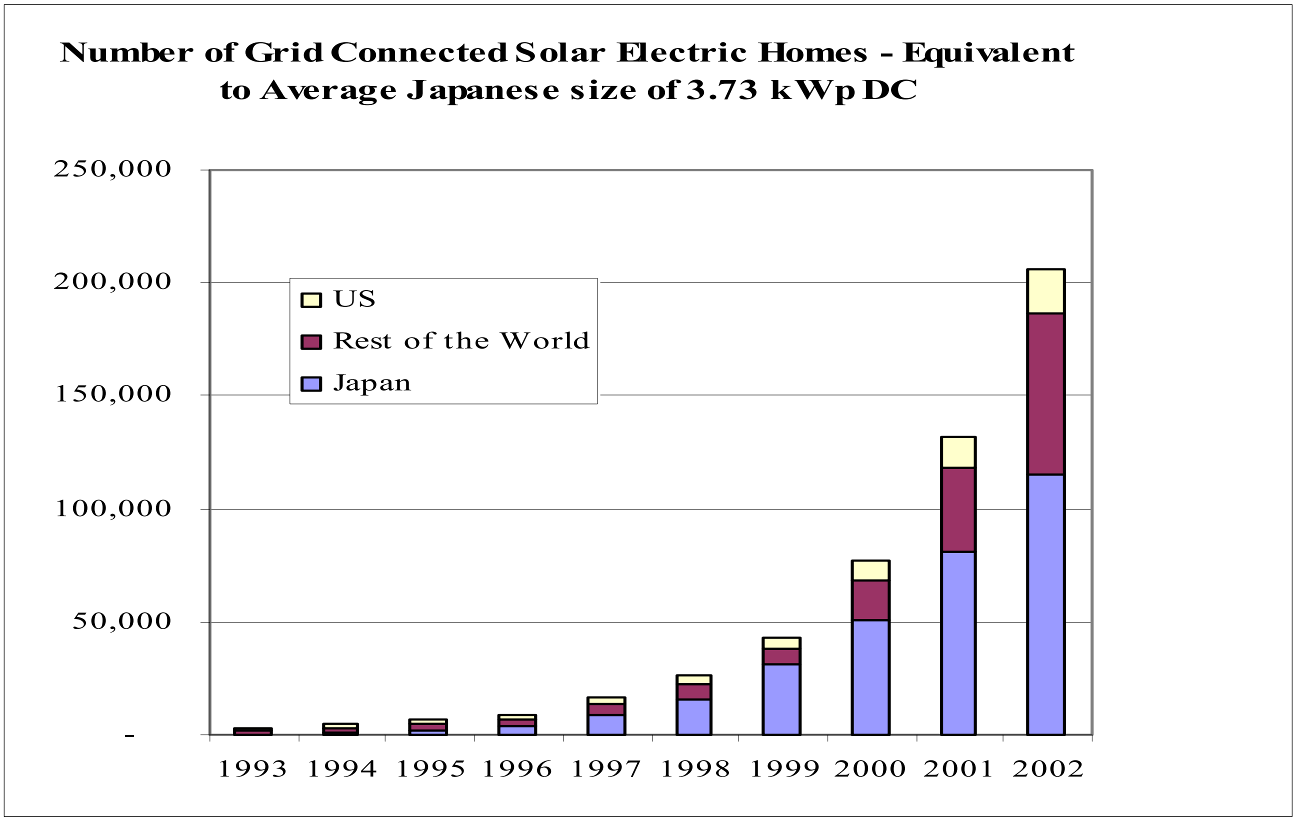

Figure 2: Number of Grid Connected Solar Electric Homes by year based on a standard home size system in Japan. Data was extracted from various sources to build this chart.

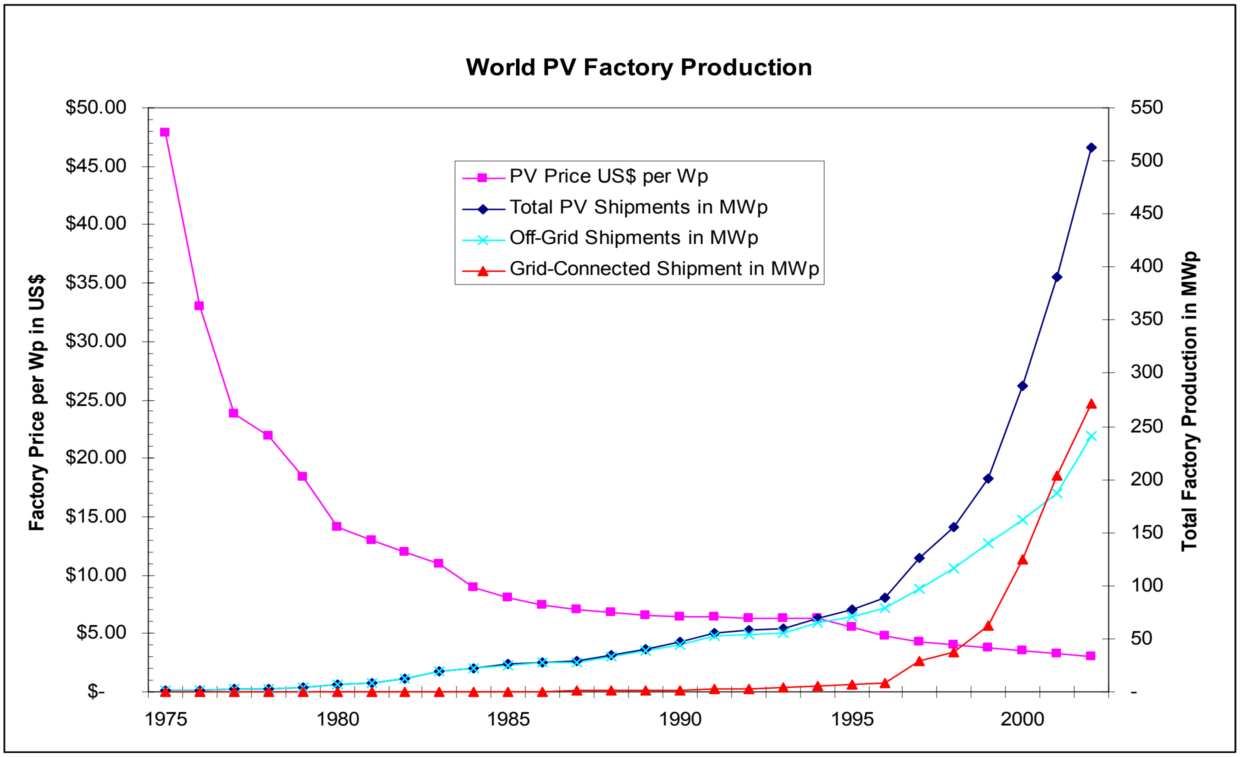

Figure 3. World PV Factory Production

3. INTERCONNECTING DISTRIBUTED POWER GENERATORS WITH ESTABLISHED ELECTRIC POWER SYSTEMS

The majority of distributed power generators are expected to connect to an area electric power system at the distribution level, either through a point of common coupling (PCC) to supply power to other loads on the area EPS, or directly in parallel with loads after a point of common coupling. The infrastructure to mount PV systems is largely in place or will be in place, as residential, industrial, commercial, and institutional utility interconnected systems will be mounted on existing or new buildings. The buildings are connected to the existing distribution systems. Siting the generation in close proximity to the loads reduces transmission losses, and can increase the effective capacity of distribution systems by offsetting transmission requirements.

The existing power distribution systems and generation controls were designed based on a structure of central generation stations and thus are not designed to take advantage of active generation at the distribution level. Significant efforts must be made among all stakeholders including equipment manufacturers, utilities/wire owners, national codes and standards organizations, developers, end users and legislators to overcome these barriers. In order to realize the multiple benefits of distributed power generators to consumers, utilities, and society at large, technological and operational guidelines for DG interconnection must be developed such that the DGs will not impose negative impacts on the reliability and safety of the existing electric power systems. Widespread penetration of DG will require new approaches to distribution system voltage regulation, for example. Voltage may not decrease from transformers to connected customers when local generation exceeds local loads. New automatic transformer tap changers and active voltage regulators, and dispersed sensing technology, may be required. Future inverter technology with enhanced distribution system communication protocols to alter power factor and follow utility voltage regulation requirements could participate in the solution, although voltage regulation is recognized as a utility responsibility.

4. STANDARDS AND GUIDELINES FOR ELECTRIC POWER SYSTEMS

The history of Electric Power Systems (EPS) has been one of technology outpacing standards and guidelines. Since the first local power systems were developed, and then interconnected, regulation has followed to protect customers from the technology itself, and to enhance reliability and stability. Regulation also protected consumers from system operators who were given "natural" monopolies to distribute power in local areas. The technology resulted in ever larger centralized generating stations, with ever lower costs, and large transmission systems to distribute the electricity to decentralized loads. Many believe that this paradigm has exhausted its usefulness, that the technology has arrived to allow a transition to decentralized generation mostly supplying the decentralized loads. Small scale distributed generation such as photovoltaics can play a significant part in the decentralized generation. New regulations are required to allow the seamless and safe interconnection of distributed generation into the distribution and transmission systems. The question of whether new regulations to address local issues of load shedding or load management to complement the responsibility and authority for distributed generation has not been addressed.

Current standards for interconnected power systems include reliability and stability. There are standards and guidelines set up to govern interconnected multi-jurisdiction (multiple states and provinces) in North America. Similar standards exist in the European Union. Other standards have been developed by organizations such as IEEE and IEC, and adopted by provincial, state, or national standards organizations. Several of these standards are discussed here.

4.1 Reliability and Load Shedding: In North America utilities and distribution systems are widely interconnected and are formed into geographic coordinating councils which have developed rules to govern the power reliability and stability between distribution systems. Frequency and voltage maintenance are two of the key goals, and rules governing generator additions and load shedding to maintain voltage levels and frequency are published [3]. In most cases distributed generation is connected to the distribution network and subject to the load shedding schemes and does not participate in network stability maintenance. The opportunity to use distributed resources in this manner would require a new approach to the product safety standards and existing interconnection standards.

4.2 ***Power Quality*** Power quality on distribution systems is generally governed by standards on the system voltage, and on harmonic issues. In North America, Voltage Range A of *ANSI C84.1 - 1995 Electrical Power Systems and Equipment - Voltage Ratings (60Hz)* [8], and *CAN3-C235-83 Preferred Voltage Levels for AC Systems, 0 to 50,000 V* [7] specify the voltage level windows that utilities should maintain at the customer PCC. These voltage levels are chosen so customer equipment works safely, reliably, and efficiently. Utilities employ various means to deliver electricity at these levels, and take remedial action on a situational basis to bring voltage within these levels when excursions occur. Response varies considerably with the range of the excursion and the number of customers affected.

Standards generally concerned with power quality as expressed by harmonics and "flicker" govern allowable voltage harmonic distortion at the PCC. The voltage total harmonic distortion limits are 5% total and 3% for individual frequencies [9]. To achieve this goal, the total demand distortion (TDD) at a connected PCC, which is defined as the total harmonic current distortion as a percentage of maximum demand load current [10], [11], shall be less than 5% when a connected to a clean EPS voltage. Each individual harmonic shall be less than a specified level. *IEEE 519-1992 Recommended practices and requirements - harmonic control* allows maximum individual harmonic current distortion as a percent of the maximum fundamental load current to be specified [9]. Some utilities have adopted the medium and high voltage power system limits in the IEC 61000 Technical Reports [12], [13]. It is assumed that the distortion emissions limits [14], [15] would apply on the low voltage EPS and correspond to the inverter equipment limits on those distribution systems. The IEC limits appear to be higher than the IEEE limits.

In this milieu new decentralized and distributed generation sources require standards and guidelines governing their interconnection and response to abnormal system conditions. The new standards must recognize and reinforce the safety and reliability aspects of the current distribution systems which will transport the majority of power from centralized generation for the life of current generation and distribution infrastructure. They should leave room for the new generation to grow to a substantial portion of the generation mix, and contribute to system stability and reliability (for example through support during low voltage or frequency disturbances) when sufficient penetration levels have been achieved. Many standards and guidelines have been developed recently, and are reviewed below. Specific items that have been adopted but are still subject to misunderstanding or misinterpretation are discussed in Section 5.

The IEEE has developed practices and standards for interconnection, IEEE 929 and IEEE 1547, discussed in more detail in section 4.3. International standards include many IEC standards written or under development for interconnection. IEC Technical Committee 64 Electrical Installations and Protection against Shock have published IEC 60364-7-712 *Electrical Installations of Buildings - - Part 7-712: Requirements for Special Installations or Locations - Solar Photovoltaic (PV) Power Supply Systems*. The International Energy Agency (IEA) has established collaborative R&D agreements within the various member countries, including the Photovoltaic Power Systems Programme (PVPS). The IEA-PVPS task group V has studied interconnection of PV extensively, and has issued many reports. Task group 7 has studied the impact and potential of PV in the built environment.

In the USA, many states have interconnection requirements, with at least 38 requiring some form of net metering. In California, the *California Electric Rule 21* specifies technical and policy issues that utilities under jurisdiction of the California Energy Commission must adhere to in allowing distributed resource interconnections. In Canada, several regulators and most utility companies have developed their own guidelines for distributed power generators connected to their distribution systems. These guidelines and requirements generally cover a portion of the generation resources available for interconnection, but many advocates consider them biased toward requirements for large scale generators.

4.3 *IEEE Standard for Interconnecting Distributed Resources with Electric Power Systems (IEEE Standard 1547)*

In 2000 the IEEE published IEEE929 *Recommended Practice for Utility Interface of Photovoltaic (PV) Systems up to 10 kW* [4]. This document took several years to reach approval, and was a watershed in how to approve interconnections, and specifying a test to verify island detection of inverters. Work is currently underway in IEC Technical Committee 82 (TC82 Solar Photvoltaic Energy Systems) to incorporate this standard in IEC 61727 Photovoltaic (PV) Systems - Characteristics of the Utility Interface.

IEEE Standards Coordinating Committee 21 on Fuels, Photovoltaics, Dispersed Generation, and Energy Storage [16] subsequently formed a working group to develop *IEEE Standard 1547, Standard for Interconnecting Distributed Resources with Electric Power Systems* [5]. Formed in 1999, the working group had members represented utilities, government agencies and regulators, DG equipment manufacturers, DG developers and end users, consultants, and academia.

This standard establishes criteria and requirements for interconnection of distributed resources (DR) with electric power systems. It provides a uniform standard for interconnection of distributed resources with electric power systems, and provides requirements relevant to the performance, operation, testing, safety considerations, and maintenance of the interconnection. It covers both rotating and static (inverter based) distributed generation technologies up to 10 MW.

Three working groups are developing additional standards to supplement IEEE Standard 1547. These draft standards are IEEE P1547.1 *Standard Conformance Test Procedures for Interconnecting Distributed Energy Resources with Electric Power Systems*, IEEE P1547.2 *Draft Application Guide for IEEE Standard 1547, Interconnecting Distributed Resources with Electric Power Systems*, and IEEE P1547.3 *Draft Guide for Monitoring, Information Exchange, and Control of Distributed Resources Interconnected with Electric Power Systems*.

4.4 *Canadian MicroPower Connect Interconnection Guideline*

Supported by Natural Resources Canada and Industry Canada, Electro-Federation Canada took the initiative in 2001 to form the MicroPower Connect Technical Committee with a mandate of developing Canadian *MicroPower Connect Interconnection Guideline for inverter based micro-distributed resource (DR) systems connected to 600 volt or less distribution systems* [6]. This Guideline reviews and specifies technical requirements for the interconnection of inverter-based DRs with the existing power distribution systems, to avoid negative impacts on system reliability and safety. This national Guideline is the result of a two year consensus work of the MicroPower Connect Technical Committee representing various stakeholders across Canada including utilities/wires owners, DG equipment manufacturers, government agencies and regulators, and academia, with input from external reviewers. This document is interesting because it was developed from the perspective and characteristics of the distribution system the DG is interconnected with, not the size of the DG.

4.5 *Inverter Based Technology for Interconnection*

Photovoltaic dc energy must be converted to ac “grid quality” energy via a static converter, or inverter, for interconnection with an EPS. Inverter technology has matured rapidly, and many certified products are now available. Product standards address the power quality issues discussed above. In addition safety issues such as disconnection requirements from the EPS during abnormal conditions are specified and tested. These include requirements to monitor EPS voltage and frequency and cease operation outside specified windows. These are considered passive island detection methods. Additional requirements are to disconnect during specified tests designed to simulate balanced island conditions. Specific methods are not required, but and active attempt by the inverter to improve detection, or upset the balance, is required. These methods are referred to as active island detection

The main North American product safety standard for PV inverters is *UL1741 - 1999 Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems.* This second draft standard is widely recognized as the western standard for PV system equipment and has been evaluated in other standards writing efforts. The corresponding Canadian standard is CSA 107.1-01 *Commercial and Industrial Power Supplies*, which has general power converter standards with additional clauses (chapters) devoted to PV and Utility Interconnected equipment. IEC Technical Committee 82 (TC82 Solar Photvoltaic Energy Systems) is in the process of developing IEC 62109 - *Utility Interconnected PV Inverters* and IEC 62116 - *Islanding detection test for Utility Interconnected Inverters*

5. TECHNICAL AND COMMERCIAL ISSUES

System Frequency. Interconnection agreements between utilities specify that frequency deviations shall be limited to a specified range. Distribution systems will typically begin shedding loads (i.e. black out customers) if the frequency decreases below 59.1 Hz. Loads are typically shed in blocks of 5 to 6%, with each new block shed at 0.2 Hz decrements. Generators are typically required to maintain generation for at least 3 minutes down to 58.5 Hz, and maintain generation for fractions of a second down to 56.5 Hz. IEEE Standard 929 recognized that DGs will be affected by the load shedding scheme because they are connected on the distribution circuits that will be affected. In order to maintain safe operation the DGs monitor frequency and cease to energize the utility when the frequency is outside the range 59.3 - 60.5 Hz for low voltage distribution systems, which generally conforms to the load shedding schemes of utilities and minimizes island non-detect zones for distributed power generators [4]. The limited range of normal operation assumed in IEEE 929, and incorporated into the product standards, recognizes that inverters should disconnect for safety reasons so they do not support an island. However, it also means that before a power system begins shedding load it will lose its interconnected distributed generation, which may exacerbate brown out conditions into blackout conditions. IEEE 1547 recognized that large distributed generators may be able to help support the power system and requires them to have adjustable set points that will be set in co-ordination with local EPS.

Voltage Disturbances [4,10,11]. An interconnected system shall detect the rms or fundamental frequency value of the EPS voltage. At abnormal voltages, a DG shall cease to energize the EPS within a specified clearing time. IEEE Standard 929-2000 provided a guideline for a nominal 120V based system. Other voltage levels are presented in percentage of the nominal voltage. For larger DG units, the voltage protection level and DG disconnection time should be adjustable. The “normal operation” range of the inverters in the product standard is wider than the range the utility attempts to maintain (section 4.2). The range was set in recognition of the utility voltage regulation equipment, which may take minutes to function. Manual voltage regulation methods may take days or weeks. The DG should not change utility line conditions so the utility voltage regulation equipment has time to function. As with the frequency, when large penetration levels are reached DG will be able to support the EPS. DG is required to disconnect when brown out conditions are reached so a brownout may exacerbate into a blackout.

Islanding [4,5]. An Island is a condition in which a portion of an area EPS is energized solely by its distributed power generators and loads, while electrically isolated from the remainder of the area EPS. An unintentional island presents a hazard for personnel safety and equipment safety. A DG is required to detect the island condition and cease to energize the area EPS within 2 seconds of the formation of an island. This is relatively easy to achieve unless another generator, such as a run of river synchronous generator with voltage regulation, is capable of providing the voltage and frequency reference. Certain distribution system transformer and grounding configurations can also inadvertently supply a reference on three phase systems with an open phase. This is a problem for transformers and loads as well as DGs.

Disconnecting Means: Small systems in the Netherlands may be connected to the EPS by plugging a number of modules connected to a small inverter into a standard wall receptacle. Larger systems, and those in other countries, must be connected to dedicated point, typically a dedicated breaker or a fusible switch. In many cases local, national, or EPS electrical codes may require an external disconnect so the utility responsible for the EPS may disconnect the system. Requirements on the disconnect vary widely, and local utilities interpret national requirements differently. There is broad agreement that the requirements for inverter based interconnected systems are different than those for rotating generation equipment. Rotating generators, for example, still generate voltage when not connected to the EPS due to residual magnetism of the rotor (self excitation). Static inverter based systems do not. Therefore the disconnecting means for rotating generation should be capable of being safely closed onto a short circuit. Rotating generation equipment contribute fault currents based on their excitation and their subtransient and transient impedance. Inverter based systems have limited fault current contributions. Current controlled (current source with respect to the EPS) inverters, in particular, have inherently limited fault contributions, especially when connected to PV systems. The disconnecting means for rotating equipment must therefore have high fault current handling capabilities which are not required for inverter based systems. In most cases small, inexpensive disconnecting means are adequate and allowed for small PV system interconnections. The cost of installing the disconnect exceeds the cost of the disconnect. This is exceedingly frustrating for DG owners who expect the disconnect will never be operated, particularly as penetration levels increase.

Metering: Most technical interconnection standards avoid discussion of metering requirements. Installation requirements for meters are largely commercial in nature, and range from using standard meters but allowing them to run in reverse, using two parallel meters (one for import and the other for export), two meters in series (detented), and digital meters calibrated in both directions. For small PV systems it is important that commercial requirements do not add an extra cost burden on the systems. Many utilities or service providers have tested the meters normally installed in dwellings in reverse and found they meet required levels of accuracy, but are prevented from using them due to lack of test standard recognition or manufacturer type designation.

Net Metering: When export to the EPS is allowed most jurisdictions adopt a feed in tariff that is significantly higher than power cost and require a second meter, or allow the DG owner to use a single meter and pay retail rates for the net electricity. The period over which the power is netted varies from each billing cycle to annually. While annual net metering is preferred by DG owners, utilities often prefer billing cycle net metering, with the caveat that they will not pay for excess electricity. Whatever method is used, it is clear that DG owners are in effect using the EPS as their battery, and the EPS requires compensation as a result. Compensation can come in many forms, from the contribution due to the "premium" value of PV generated electricity (usually coinciding with peak power usage), reduced transmission losses, fixed monthly charges, or possibly time of use pricing that adequately reflects EPS costs.

6. CONCLUSION

This paper reviews the status of the PV generation industry and its potential to impact national electricity generation. With deep penetration levels in a mature industry and current growth rates, PV could supply 15% of Japans electricity needs and up to 60% of demand in the US. The paper reviews and discusses the issues of interconnecting distributed power generators with electric grids. The main international standards are introduced, their status discussed, and some contentious issues reviewed in more detail. It is expected that in the near future, international interconnection standards and guidelines for distributed power generation will be available.

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