International Journal of Research Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 17
December 2017

Advantage of Photovoltaic Power Generation

Chandrasekhar, Ankit Katara, Rishikesh Meena, Lovekush Meena, Kalpesh Meena

Department of Physics, Students, B.Sc. First year,

Parishkar College of Global Excellence, Jaipur, India

ABSTRACT:

This report is an overview of photovoltaic power generation. The purpose of the report is to provide the reader with a general understanding of photovoltaic power generation and how PV technology can be practically applied. There is a brief discussion of early research and a description of how photovoltaic cells convert sunlight to electricity. The report covers concentrating collectors, flat-plate collectors, thin-film technology, and building-integrated systems. The discussion of photovoltaic cell types includes single-crystal, poly-crystalline, and thin-film materials. The report covers progress in improving cell efficiencies, reducing manufacturing cost, and finding economic applications of photovoltaic technology. Lists of major manufacturers and organizations are included, along with a discussion of market trends and projections. The conclusion is that photovoltaic power generation is still more costly than conventional systems in general. However, large variations in cost of conventional electrical power, and other factors, such as cost of distribution, create situations in which the use of PV power is economically sound. PV power is used in remote applications such as communications, homes and villages in developing countries, water pumping, camping, and boating. Grid connected applications such as electric utility generating facilities and residential rooftop installations make up a smaller but more rapidly expanding segment of PV use. Furthermore, as technological advances narrow the cost gap, more applications are becoming economically feasible at an accelerating rate.

INTRODUCTION

This report is the result of Gale Greenleaf's October 19, 1998 request for proposal. Bill Louk and Tom Penick responded to her request with a proposal, dated October 30, 1998, to continue earlier research on photovoltaic power generation. The proposal was approved and resulted in continued research followed by a presentation on November 30, 1998 and this final report on photovoltaic power generation.

PURPOSE OF THIS REPORT

In this report we have assembled information from numerous sources to provide an objective overview of photovoltaics for power generation. We present the reader with a summary of the basics of photovoltaic power conversion, list the primary technologies, describe the most popular applications, and list manufacturers and organizations involved in photovoltaic power generation. Our purpose is to digest the volume of available information and provide a useful summary for engineers and others who might become involved in photovoltaic power generation.

AVAILABLE INFORMATION ON PHOTOVOLTAIC POWER

There is an enormous supply of articles on the subject of photovoltaic power. Most articles are narrow in scope, perhaps announcing a recent breakthrough or discussing a particular project or application. The internet provides a great deal of information as well, with web sites sponsored by government agencies, industry groups, and manufacturers. We did have some difficulty finding an overview of the subject. Most books on photovoltaics are at least five years old and cover the technical aspect of photovoltaics without providing an assessment of the practicality of using photovoltaics for power generation.

WHY PHOTOVOLTAIC POWER REQUIRES STUDY

The high cost of generating electrical power using photovoltaic cells compared to conventional coal-, gas-, and nuclear-powered generators has kept PV power generation from being in widespread use. Less than 1% of electricity is generated by photovoltaics. However, there are a few applications in which PV power is economical. These applications include satellites, developing countries

International Journal of Research Available at https://edupediapublications.org/journals
e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 17
December 2017

that lack a power distribution infrastructure, and remote or rugged areas where running distribution lines is not practical. As the cost of photovoltaic systems drops, more applications become economically feasible. The non-polluting aspect of PV power can make it an attractive choice even when conventional generating systems are more economical.The manufacture of photovoltaic systems has increased steadily for the last 25 years. It is inevitable that engineers will be called upon to develop photovoltaic technology or will be involved in projects using this technology. Many existing reports on photovoltaics cover only one facet of the technology and sometimes writers inflate their reports on behalf of the company involved. There is a need for an up-to-date, objective understanding of photovoltaic power generation. With this goal in mind we have created this report.

PHOTOVOLTAIC TECHNOLOGY

Scientists have known of the photovoltaic effect for more than 150 years. Photovoltaic power generation was not considered practical until the arrival of the space program. Early satellites needed a source of electrical power and any solution was expensive. The development of solar cells for this purpose led to their eventual use in other applications.

DISCOVERY AND DEVELOPMENT OF PHOTOVOLTAIC POWER

The photovoltaic effect has been known since 1839, but cell efficiencies remained around 1% until the 1950s when U. S. researchers were essentially given a blank check to develop a means of generating electricity onboard space vehicles. Bell Laboratories quickly achieved 11% efficiency, and in 1958, the Vanguard satellite employed the first practical photovoltaic generator producing a modest one watt. Table 1 chronicles early development of photovoltaics [1].In the 1960s, the space program continued to demand improved photovoltaic power generation technology. Scientists needed to get as much electrical power as possible from photovoltaic collectors, and cost was of secondary importance [2]. Without this tremendous development effort, photovoltaic power would be of little use today.

Table 1. Early photovoltaic development

YEAR	DEVELOPMENT
1839	Antoine-César Becquerel, a French physicist, discovered the photovoltaic effect. In his experiments he found that voltage was produced when a solid electrode in an electrolyte solution was exposed to light [3].
1877	W.G. Adams and R.E. Day observed the photovoltaic effect in solid selenium. They built the first selenium cell and published "The action of light on selenium," in *Proceedings of the Royal Society* [1].
1883	Charles Fritz built what many consider to be the first true photovoltaic cell. He coated the semiconductor selenium with an extremely thin layer of gold. His photovoltaic cell had an efficiency of less than 1% [4].
1904	Albert Einstein published a paper on the photoelectric effect [1].
1927	A new type of photovoltaic cell was developed using copper and the semiconductor copper oxide. This device also had an efficiency of less than 1%. Both the selenium and copper oxide devices were used in applications such as light meters for photography [3].
1941	Russell Ohl developed the silicon photovoltaic cell. Further refinement of the silicon photovoltaic cell enabled researchers to obtain 6% efficiency in direct sunlight in 1954 [3].
1954	Bell Laboratories obtained 4% efficiency in a silicon photovoltaic cell. They soon achieved 6% and then 11% [4, p. 8].

lls were first used in space on board the Vanguard satellite [1].

POWER OUTPUT AND EFFICIENCY RATINGS

The figures given for power output and efficiency of photovoltaic cells, modules, and systems can be misleading. It is important to understand what these figures mean and how they relate to the power available from installed photovoltaic generating systems.

Power Ratings

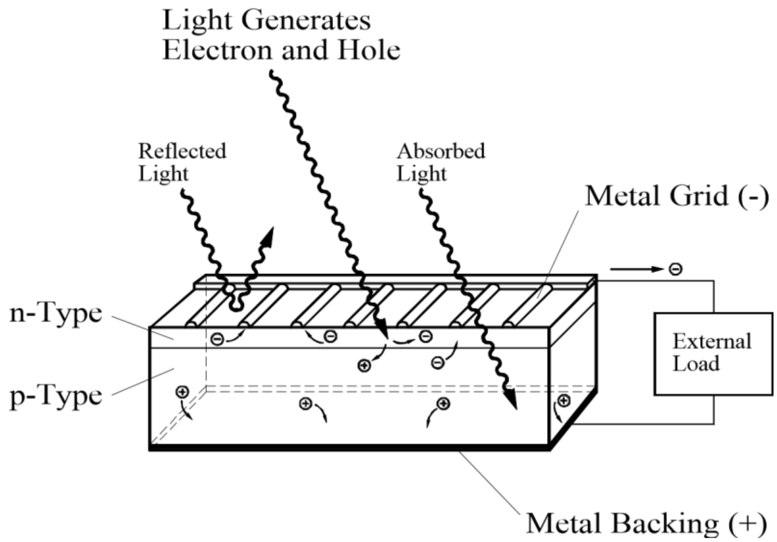
Photovoltaic power generation systems are rated in peak kilowatts (kWp). This is the amount of electrical power that a new, clean system is expected to deliver when the sun is directly overhead on a clear day. We can safely assume that the actual output will never quite reach this value. System output will be compromised by the angle of the sun, atmospheric conditions, dust on the collectors, and deterioration of the components. When comparing photovoltaic systems to conventional power generation systems, one should bear in mind that the PV systems are only productive during the daytime. Therefore, a 100 kW photovoltaic system can produce only a fraction of the daily output of a conventional 100 kW generator.

Efficiency Ratings

The efficiency of a photovoltaic system is the percentage of sunlight energy converted to electrical energy. The efficiency figures most often reported are laboratory results using small cells. A small cell has a lower internal resistance and will yield a higher efficiency than the larger cells used in practical applications. Additionally, photovoltaic modules are made up of numerous cells connected in series to deliver a usable voltage. Due to the internal resistance of each cell, the total resistance increases and the efficiency drops to about 70% of the single-cell value. Efficiency is higher at lower temperatures. Temperatures used in laboratory measurements may be lower than those in a practical installation [5, p. 57].

CONVERTING SUNLIGHT TO ELECTRICITY

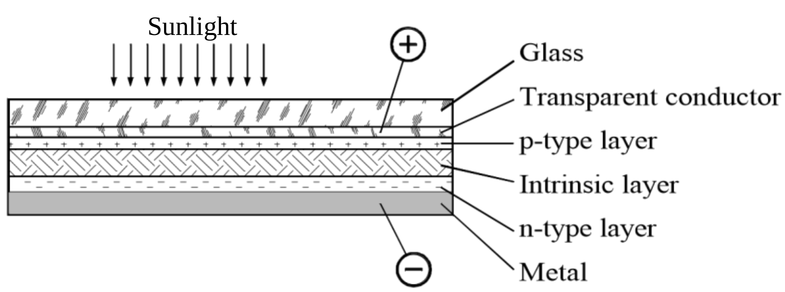
A typical photovoltaic cell consists of semiconductor material (usually silicon) having a pn junction as shown in Figure 1. Sunlight striking the cell raises the energy level of electrons and frees them from their atomic shells. The electric field at the pn junction drives the electrons into the n region while positive charges are**Figure 1. How solar cells work [4, p. 22].** driven to the p region. A metal grid on the surface of the cell collects the electrons while a metal back-plate collects the positive charges [2].



Thin Film Technology

Thin-film solar cells are manufactured by applying thin layers of semiconductor materials to a solid backing material. The composition of a typical thin-film cell is shown in Figure 2. Sunlight entering the intrinsic layer generates free electrons. The p-type and n-type layers create an electric field across the intrinsic layer. The electric field drives the free electrons into the ntype layer while positive charges collect in the p-type layer. The total thickness of the p-type, intrinsic, and n-type layers is about one micron. Although less efficient than single- and polycrystal silicon, thin-film solar cells offer greater promise for large-scale power generation because of ease of mass-production and lower materials cost. Thin-film is also suitable for building-integrated systems because the semiconductor films may be applied to building materials such as glass, roofing, and siding [6].

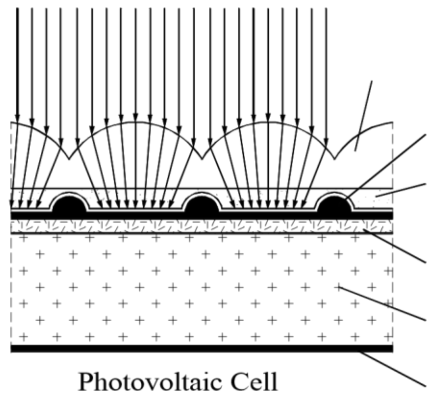
Using thin films instead of silicon wafers greatly reduces the amount of semiconductor material required for each cell and therefore lowers the cost of producing**Figure 2. Typical thin-film amorphous silicon construction.** photovoltaic



e-ISSN: 2348-6848
p-ISSN: 2348-795X
Volume 04 Issue 17
December 2017

cells. Gallium arsenide
(GaAs), copper indium diselenide (CuInSe2), cadmium telluride (CdTe) and titanium dioxide (TiO2) are materials that have been used for thin film PV cells. Titanium dioxide thin films have been recently developed and are interesting because the material is transparent and can be used for windows [7].**Tin Oxide** Tin oxide is a conductive material that is transparent when in a thin layer. Tin oxide is used in place of a metallic grid for the top layer of thin film photovoltaic sheets [8].**Amorphous Silicon (a-Si)** Amorphous (uncrystallized) silicon is the most popular thin-film technology. It is prone to degradation and produces cell efficiencies of 5-7%. Double- and triple-junction designs raise efficiency to 8-10%. The extra layers capture different wavelengths of light. The top cell captures blue light, the middle cell captures green light, and the bottom cell captures red light. Variations include amorphous silicon carbide (a-SiC), amorphous silicongermanium (a-SiGe), microcrystalline silicon (µc-Si), and amorphous silicon-nitride (a-SiN). [2, 6, 9].**Cadmium Telluride (CdTe) and Cadmium Sulphide (CdS)** Photovoltaic cells using these materials are under development by BP Solar and Solar Cells Inc [2].**Poly-crystalline Silicon** Poly-crystalline silicon offers an efficiency improvement over amorphous silicon while still using only a small amount of material [2].**Copper Indium Diselenide ($CuInSe_2$) and Copper Indium Gallium Diselenide** These materials are currently being investigated, and have not been used commercially for photovoltaics [2].

Concentrating Collectors



By using a lens or mirror to concentrate the sun's rays on a small area, it is possible to reduce the amount of photovoltaic material required. A second advantage is that greater cell efficiency can be achieved at higher light concentrations. To accommodate the higher currents in the photocells, a larger metallic grid is used. For example, in a system witha 22X concentration ratio, the grid Incident Light covers about 20% of the surface ofthe solar cell. To prevent this from Prismatic Cover blocking 20% of the sunlight, a prism is used to redirect sunlight onto theMetal Gridline (-) photovoltaic material, as shown inAdhesive Figure 3. A second problem is the higher temperatures of aconcentrating system. The cells may n-Type Silicon be cooled with a heatsink or the heatp-Type Silicon can be used to heat water [10, 11].Metal Contact (+)
Only direct sunlight, not scattered by clouds or haze, can be concentrated.**Figure 3. Prism cover for high-current solar**Therefore, the concentrating**cell [12].** collectors are less effective in locations that are frequently cloudy or hazy, such as coastal areas [7].

HOW MUCH POWER IS AVAILABLE FROM THE SUN?

Sunlight reaches the Earth's outer atmosphere at a strength of 1367 watts per square meter, defined as AM0, or "air mass zero." Atmospheric losses reduce the sun's power to about 1000 W/m^2 when the sun is directly overhead on a cloudless day [13]. Figure 4 shows the average daily sunlight falling on a square meter surface which has been tilted toward the southern horizon at an angle equal to the latitude of the location. Note that diffused as well as direct sunlight is considered, making this map applicable to flat plate collectors.

PRODUCTION CONSIDERATIONS

In the past, low-grade silicon was bought from semiconductor manufacturers for use in building solar cells. With improvements in the manufacturing process, silicon manufacturers are able to consistently produce the more profitable semiconductor-grade silicon. As a result, it is becoming difficult to buy low-grade silicon. There has been much discussion about building a production facility dedicated to the production of silicon for solar cells [2].

PHOTOVOLTAIC APPLICATIONS

Photovoltaic power generation has been most useful in remote applications with small power requirements where the cost of running distribution lines was prohibitive. As PV power becomes more affordable, the use of photovoltaics for grid-connected applications is increasing. However, the high cost of PV modules and the large area they require continue to be obstacles to using PV power to supplement existing electrical utilities. An interesting approach to both of these problems is the integration of photovoltaics into building materials.

BUILDING-INTEGRATED SYSTEMS

Building-integrated photovoltaic (BIPV) systems offer advantages in cost and appearance by incorporating photovoltaic properties into building materials such as roofing, siding, and glass. When BIPV materials are substituted for conventional materials in new construction, the savings involved in the purchase and installation of the conventional materials are applied to the cost of the photovoltaic system. BIPV installations are architecturally more attractive than roofmounted PV structures.For example, United Solar Corporation produces photovoltaic shingles that replace normal asphalt shingles. Each PV shingle replaces a seven-foot long row of asphalt shingles, and any roofer can install them. Normally, only one-third of a roof needs to be covered with PV panels to produce sufficient power for the average home [21].Glass manufactured with photovoltaic properties is available for use in skylights and windows. The architect can select from several colors of transparent photovoltaic glass. The tint color and depth is controlled by the type and amount of semiconductor material used in the construction of the photovoltaic glass [22].BIPV systems can provide electrical power for the home on a small scale or can be used in large buildings for large-scale power generation. The Georgia Tech Aquatic Center in Atlanta, Georgia, is the site of a BIPV demonstration project. The roofing material of the center provides an output of 340 KWp and is the largest system of its type [23]. In the higher latitudes, due to the lower angle of the sun, building facades are sometimes made of BIPV materials.

OFF-GRID APPLICATIONS

The majority of photovoltaic power generation applications are remote, off-grid applications. These include communication satellites, terrestrial communication sites, remote homes and villages, and water pumps. These are sometimes hybrid systems that include an engine-driven generator to charge batteries when solar power is insufficient.

115 kW Hybrid System at the Dangling Rope Marina

An example of a hybrid system is the 115kW installation at the Dangling Rope Marina in Arizona. The U.S. National Park Service removed a diesel generator system and installed a $1.52 million PV-propane hybrid system. The Park Service anticipates saving $2.3 million over the next 20 years, while eliminating the possibility of a diesel oil spill when transporting fuel by barge [24].

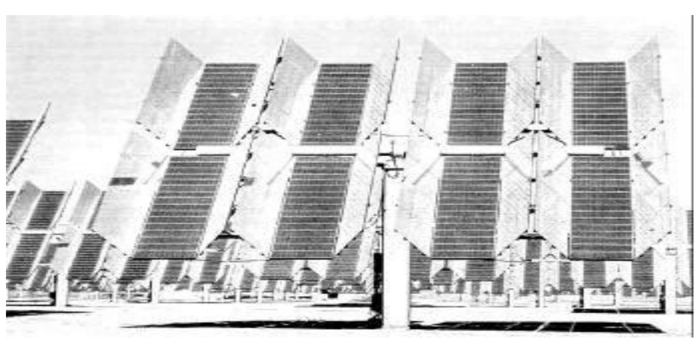
GRID-CONNECTED APPLICATIONS

In grid-connected application, the DC power from solar cells runs through an inverter and feeds back into the distribution system. Grid-connected systems have demonstrated an advantage in natural disasters by providing emergency power capabilities when utility power was interrupted. Although PV power is generally more expensive than utility-provided power, the use of gridconnected systems is increasing.The cost of producing electric power with photovoltaics is about $0.18 per kWh, two to four times as much as utility-provided power. There are special cases when photovoltaic power is more economical than power produced and distributed by conventional means. More than 100 U. S. electric utilities have used photovoltaic power to economic advantage. Also, the interest in *green* power is great enough to override economic concerns in some cases. For example, the City of Austin's Solar Explorer Program allows subscribers to voluntarily support local photovoltaic generating projects with a surcharge to their electric bill [15, 25].

Large-scale utility applications

Early large-scale utility applications have been demonstration projects to help assess the viability of photovoltaic power generation. They provided a platform for study and permitted numerous U. S. electric utilities to plan and execute PV installations that are economically productive. Several demonstration projects are described below.

6.5 MW System at Carissa Plains, California The largest photovoltaic generating facility ever constructed was the 6.5 MWp array at Carissa Plains, California, shown in Figure 5. The facility used single-crystal cells manufactured by Siemens Solar in fixed modules with reflectors. The plant went online in 1984 but has since been dismantled [7, 26].**300 kW System at 3M Austin** This



concentrating-collector demonstration system went online in March 1990. It was a cooperative effort of the U.S.**Figure 5. 6.5 MWp facility at Carissa Plains,** Department of Energy, the State of**California [26].**Texas, the City of Austin, Sandia

National Laboratories, ENTECH, and 3M Corp. The system was dismantled a few years ago and donated to a non-profit organization in the Texas panhandle. At the time it was the oldest continuously-operated system of its kind in the country [11, 27].**342 kW System in Atlanta** This system was installed at the Georgia Institute of Technology inAtlanta as a demonstration project for the 1996 Summer Olympics. An array of 2856 photovoltaic modules, each with 72 multicrystalline silicon solar cells, is installed on the rooftop of the Aquatic Center. The DC power is fed into an inverter and then into the center's electrical system [23, 28].**1 MW System in Germany** This system uses fixed, grid-connected, modules with monocrystalline cells (14.5% efficient) manufactured by Siemens Solar. The photovoltaic generating facility was built in 1997 for DM 15 million ($9 million USD) [29].

Small-scale utility applications

By locating power generation at the point of power consumption, distribution losses are eliminated (about 12% for a rural electric utility). The practice of locating small power sources near the sites of end users is called "distributed generation." This term may apply to photovoltaics, wind generators, small reciprocating-powered generators, and small turbine generators [30].

THE ECONOMICS OF PHOTOVOLTAIC POWER GENERATION

Photovoltaic efficiency and manufacturing costs have not reached the point that photovoltaic power generation can compete with conventional coal-, gas-, and nuclear-powered facilities. The cost of photovoltaic power (when storage is not required) is two to four times that of conventionally produced power. It is difficult to define this relationship precisely due to wide variations in the cost of producing and distributing conventional electrical power and other variables. Due to the wide range of these variables, some applications of photovoltaic power are economically superior to conventional systems.

Remote Applications

A European Photovoltaic Industry Association survey covering the 1990-1994 time period showed that approximately three-fourths of PV applications involved remote locations. Remote applications include satellites, remote telecommunications sites, remote homes and villages, water pumping, camping, and boating [5, p. 34]. Remote applications can become economically feasible because of the expense of constructing distribution lines and power losses sustained in transmission of conventional power. PV facilities may be located at the point of power consumption and do not require the purchase or delivery of fuel.If a remote site requires a dependable power source or has large loads, a hybrid system may be a better option. This may consist of photovoltaic cells and a diesel generator charging a bank of batteries. In such a hybrid system, the PV cells reduce the amount of fuel consumed. The batteries reduce the runtime required of the generator. Charging the batteries during generator runtime permits the generator to operate in a more efficient load range [24].

Peak Load Relief

In warm-climate areas, peak load demands occur on sunny days due to heavy use of airconditioners. This coincides with the productive period for photovoltaic power. By locating photovoltaic collectors at the end of a distribution line, a power utility may be able to defer the construction of additional conventional generating capacity as well as defer an upgrade of the distribution line.

Photovoltaic System Components

We often see the cost of photovoltaic modules reported in dollars per watt. At the retail level, the cost of photovoltaic modules is currently about $5/watt. But photovoltaic modules account for only 25% to 50% of the cost of a PV system. To achieve substantial cost reduction, the expense of system components will need to be addressed. Also, poor component efficiencies can compromise the total system efficiency. PV systems can have efficiencies as low as 50% due to losses in inverters, batteries, and system voltage drops [31].

Green Power

Economic feasibility is not always the determining factor in selecting a power generation system. With interest in green (ecologically friendly) power growing, both consumers and providers of electrical power are turning to the use of photovoltaics in spite of its higher cost.

Industry Forecasts

A 1996 study published by the International Energy Agency (IEA), concluded that demand for alternative energy would grow strongly, yet renewable sources would only account for about 1% of total energy produced in 2010. This does not include hydropower, which would constitute about 3% of the energy supply. The World Energy Council estimates that renewable power could provide 5-8% of the total energy demand by 2020, but only with continued support for research and development [10].

MAJOR MANUFACTURERS

The five companies listed below are major producers of photovoltaic modules. All have been involved in products for aerospace as well as land-based systems including thin-film technology. Some have achieved this status by recent buyouts of established PV manufacturers.

Siemens Solar

Siemens Solar is the largest manufacturer of photovoltaic cells. The parent company, Siemens, is a diversified producer of electrical equipment, involved in all types of electrical power generation, with an established worldwide marketing and distribution system [2].

Enron Corp. (Solarex)

Enron Corp, headquartered in Houston, Texas, is the largest natural gas provider in the United States. Enron, in partnership with Amoco, acquired the 25-year old photovoltaics manufacturer Solarex. Solarex is the largest manufacturer of polycrystalline silicon photovoltaic modules and cells [2, 30, 32, 33].

BP Solar, Inc.

BP Solar, Inc., is a subsidiary of British Petroleum. BP Solar has been in business 16 years, with sales of $100 million in 1997. BP solar dominates the European market [2, 34].

ASE GmbH (ASE Americas, Inc.)

ASE is a German company with a U. S. division in Massachusetts called ASE Americas [35].

Matrix Solar Technologies (Photowatt International)

Matrix Solar Technologies is located in Albuquerque, New Mexico. In 1997, they bought out Photowatt International of France. Photowatt claims to have the thinnest poly-crystalline cell in the industry [36].

CONCLUSION

Photovoltaic efficiency and manufacturing costs have not reached the point that photovoltaic power generation can replace conventional coal-, gas-, and nuclear-powered generating facilities. For peak load use (no battery storage), the cost of photovoltaic power is around two to four times as much as conventional power. (Cost comparisons between photovoltaic power and conventionally generated power are difficult due to wide variations in utility power cost, sunlight availability, and numerous other variables.)

APPLICATIONS OF PHOTOVOLTAIC POWER

Distinct advantages to PV power, such as zero pollution and absence of the need to transport fuel to the generating site, make it attractive in many applications. As efficiency improvements and manufacturing cost reductions inch PV power toward economic parity with conventional power, these applications become more numerous. This economic trend is reflected in the recent expansions of manufacturing capacity and the acquisitions of PV manufacturers by larger corporations [2].The use of photovoltaics as the sole source of electrical power requires the use of batteries or other storage. The cost of electrical storage prevents PV generation from replacing conventional power generation. PV systems with electrical storage are only feasible for low-power, remote applications. For remote applications requiring more power, a hybrid system may be practical. This may consist of photovoltaic cells and a diesel generator charging a bank of batteries. In such a hybrid system, the PV cells reduce the amount of fuel to be transported to the site. The batteries also reduce the runtime required of the generator, and charging the batteries during generator runtime permits the generator to be operated in a more efficient load range [24].

REFERENCES

[1] "The History of PV," *http://www.pvpower.com/pvhistory.html*, November 15, 2015.

[2] Mark Hammonds, "Getting Power From the Sun; Solar Power," *Chemistry and Industry*, no. 6, p. 219, March 16, 2012.

[3] "Energy Conversion: Development of solar cells" Britannica Online. *http://www.eb.com:180/cgi-bin/g?DocF=macro/5002/13/245.html*, October 21, 2011.

[4] Kenneth Zweibel and Paul Hersch, *Basic Photovoltaic Principles and Methods*, New York: Van Nosstrand Reinhold Company, Inc., 2010

[5] "Volume 3: The World PV Market to 2010," *Photovoltaics in 2010*, Luxembourge: Office for Official Publications of the European Communities, 2006.

[6] "Taking Off of New Photovoltaic Energy Revolution," *Japan 21st*, May 2004.

[7] Stuart Baird, "Energy Fact Sheet: Photovoltaic Cells," *http://www.ohrets.com/photovoltaics-factsheet.htm*, November 13, 1998.

[8] "About Photovoltaics," *http://www.eren.doe.gov/millionroofs/whatispv.html*, U. S. Department of Energy, November, 28, 2003.

[9] Gail Robinson, "Breakthroughs Lead to Economic Mass-Manufacturing – Confab Sees Rise in Photovoltaic Usage," *Electronic Engineering Times*, October 20, 1997.

[10] "Book of the Year (1997): Business and Industry Review: Energy: Alternative Energy," Britannica Online, *http://www.eb.com:180/cgi-bin/g?DocF=boy/97/K02595.html*, October 21, 1998.

[11] M. J. O'Neal, R. R. Walters, J. L. Perry, A. J. McDanal, M. C. Jackson, W. J. Hesse, "Fabrication, Installation, and Initial Operation of the 2,000 sq. m. Linear Fresnel Lens Photovoltaic Concentrator System at 3M/Austin (Texas)," *Twenty First IEEE Photovoltaic Specialists Conference—1990*, vol. 2, pp. 1147-1153.

[12] "Technology," *http://www.entechsolar.com/techno.html*, ENTECH, Inc., November 2, 1998.

[13] Jack L. Stone, "Photovoltaics: Unlimited Electrical Energy From the Sun," *Physics Today*, September 1993.

[14] "Million Solar Roofs Implementation Plan," *http://www.seia.org/milroofs/msr.htm#_Toc398105146*, Solar Energy Industries Association, November, 28, 1998.

[15] "Solar Explorer Rider," *http://www.electric.austin.tx.us/solar-explorer/index.html*, City of Austin, November 24, 1998.

[16] "Great Expectations Held for Photovoltaic Power Generation," *Japan 21st*, p. 17, May 1996.

[17] Kazuo Inamori , "Promoting Dissemination of PV Power Generation Systems," *Japan 21st*, p. 21, May 1996.

[18] Canrom, *http://www.canrom.com/solar/index.htm*, November 18, 1998.

[19] Glenn Hasek, "Solar Shines Brighter," *Industry Week*, p. 24, April 20, 1998.

[20] James Fisher, "Government Plans to Introduce Solar Energy to Schools," *Building Design*, p. 2, October 3, 1997.

[21] Bill Siuru, "What's New in Solar Power," *Electronics Now*, vol. 69, no. 8, p. 53, August 1998.

[22] "Glass Panels Produce Electricity," *Engineering News-Record*, vol. 238, no. 2, p. 16, January 13, 1997.

[23] "Olympics: Renewable Energy at the Games," *http://www.eren.doe.gov/teamenergy/energy.html*, U.S. Department of Energy, November 18, 1998.

[24] Rob Dougherty, "Hybrid Photovoltaic-Propane System Powers Remote National Park," *Energy User News*, vol. 21, no. 11, p. 16, November 1996.

[25] "Periodic Data And Trends," *http://www.ases.org/solar/fbpdt.htm*, The

American Solar Energy Society, November 27, 1998.

[26] "Industry-Photovoltaic Power Stations1," *http://www.nedo.go.jp/nedoinfo/solarDB/photo2/1994-e/4/4.6/01.html*, November 23, 1998.

[27] Email from Matt Fagan, 3M Public Relations, 3M Austin Center, Austin, Texas, December 1, 1998.

[28] John Teresko, "Solar power; Photovoltaics at Georgia Tech.," *Industry Week*, p. 29, May 19, 1997.

[29] "Fact Sheet: New Munich Trade Fair Center," *http://www.altonet.com/~solarpv/060p.htm*, Siemens Solar Online, November 24, 1998.

[30] Robert Swanekamp, "Distributed Generation: Options Advance, but Toward What Pot of Gold?," *Power*, vol. 141, no. 5; p. 43, September 1997 / October 1997.

[31] Timothy B. DeMoss, "Wake Up and Smell the System," *Power Engineering*, vol. 101, no. 5, p. 8, May 1997.