Techno-Economic Analysis of Solar Energy for Electric Power Generation in Nigeria

H.T. Abdulkarim

Department of Electrical/Electronics
College of Education, Minna, Niger State, Nigeria
talatuabdulk@yahoo.com

Abstract

This paper presents the global and regional availability of solar energy and, its feasible utilization for power generation. The sun as a free, abundant and inexhaustible energy resource, its use by solar energy and the importance of solar energy as the source of all other forms of energy were discussed. The technologies involving the concentration, collection and conversion of solar energy to power were also discussed. Solar-thermal and solar-electric systems were included. The cost of solar energy systems were analyzed, solar technologies were compared economically with conventional technologies of power generation considering present socio-economic environment to emphasize the need to supplement with and eventually replace existing power generation systems with available, abundant and inexhaustible solar energy system. One year of the Sun's output that the earth receives is equivalent to 42,000 times the World's total annual energy consumption. The terrestrial radiation on Nigeria's land area is 2.079 x 10^{15} kWh/year and average annual consumption of all forms of energy in Nigeria is 2.4026 x 10^{11} kWh and the electrical energy consumption in the year 2001 was 15 x 10^{6}kWh.

Keywords*: Solar energy, inexhaustible, power generation, sun, technologies, utilization, abundant.*

Introduction

Energy is the most basic need of all the people in the world and energy is needed more than ever. The energy from burning coal, oil and gas called fossil fuels are widely used but these energy sources are deplectable, non renewable and harmful to the environment. All the energy on earth comes primarily from solar energy. Solar energy is energy from the sun. It is renewable, inexhaustible and environmental pollution-free. The main sources of power generation today are fossil fuels and nuclear reaction. Hydro energy is also used. These are deplectable, non-renewable and pollute the environment. The hydro energy does not produce adequate and consistent power for the nation's consumption. Moreover, the exploration of these resources is expensive. The high cost of exploration techniques and the devaluation of the currency of a developing country like Nigeria have made the power from fossil fuels unaffordable for most people. (Nasir 2001). This results in the over-dependence on the relatively affordable hydropower. Considering the high cost of fossil power, the harmful effects of nuclear power, and the inconsistence of hydropower, solar energy is the best solution.

The sun radiates enormous amount of energy. It radiates energy in one year than people have used since the beginning of times (Williams *et al.* 1990). It takes millions of years for the energy in the sun's core to make its way to the surface, and then, just a little over eight minutes to travel to the earth. Solar energy travels to earth at the speed of light (Williams *et al.* 1990). Only a small amount of the energy radiated by the sun strikes the surface of the earth; one part in two million. Yet, this amount of energy is enormous.

Enough solar energy strikes the earth to supply its energy needs.

In 1831, it was discovered that the sun's energy could produce a photovoltaic effect. (Webb 1995). In 1878, solar to mechanical conversion was first demonstrated when sunlight was concentrated by focusing a collector on a steam boiler that ran a small printing press. (El-Wakil 1984). In the 1980s, selenium photovoltaic cells were developed that could convert sunlight into electricity with 1-2% efficiency but how the conversion was done was not understood. Solar power therefore remained a curiosity for sometime. In 1901, larger focusing collector in the form of truncated cone generated steam for a 4.5hp engine. Between 1907 and 1911, solar steam engine of several hp that were used for pumping water ere built. (Liebowitz *et al.* 1982) By mid 1950s the efficiency of 45 and later 11% had been achieved with silicon photovoltaic cells. From then, interest in solar power intensified. During the late 1950s and 1960, the space program took active role in the development of photovoltaic. The cells were perfect sources of electric power for satellite because they were rugged, lightweight and could meet the power requirements reliably. Unfortunately, the cells were not practical on earth due to the high cost of making them efficient and lightweight (Jack 1991). Consequently, further research was needed.

Climate is the average weather condition of a place over a given period of years. It is determined primarily by distance from the coast and secondarily by elevation. (Bradley 1995). Nigeria is entirely between the equator Nigeria's electrical energy consumption in the year 2001 is 15 x 10^6kWh and the tropic of cancer. Its climate varies from tropical to subtropical. There are two main seasons; the dry season lasting from October to March and the rainy season lasting from April to October. In the north, it is hot and dry, rainy season extends between April and September. In the south, it is hot and wet, rainy season extends between March and December. From December to March there is a long dry season. (Ojo 2000). Temperature at the coast rarely rise above 32°C. The north is drier with temperature range between 32°C and 42°C humidity is about 95% (Falade 1995).

The sun has been shining for about 4.5 billion years. It has enough hydrogen to burn for about 10 million years (Williams *et al.* 1990). All energy on earth is direct or indirect result of sun's energy. The sun's ultraviolet rays are absorbed by green matter of plant to make them grow. The plants and trees centuries ago were dead, buried, decayed and turned into coal, oil and gas. Waterpower comes from the sun; water is evaporated from the earth by the sun and this produces rainfall that fills the rivers, lakes, oceans, seas and reservoir. Wind power comes from the sun; unequal heating of the earth worldwide results in kinetic energy (Walters 1977).

The first concern to the designer of solar energy system is the availability of that solar energy in that region at present and at some other time in the future. The availability of solar energy on earth depends on geographical location and time scale. The sunshine hours and consequently the radiations in different zones differ. The sun's power reaching the earth is typically about 1000W/m^2 The total amount of energy that the earth receives daily is 1353W/m^2. (Hoff *et al.* 2000).

Table 1. Annual consumption of all forms of energy in Nigeria between1992 and 2001. Therefore, the average annual consumption is 2.41 x 10^{11} kWh/year

Year	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Energy(10^{11}kwh)	2.3	2.3	2.2	2.4	2.5	2.5	2.4	2.4	2.4	2.7

Harnessing Solar Energy

Solar energy has been harnessed for centuries. As early as the 7th century B.C., people have used magnifying lenses to concentrate the light into beam so hot that they could cause wood to catch fire (Zweibel 1990). Collectors are devices that collect the sun's rays from a large area and focus it on a small-blackened receiving area. Concentrators also work by collecting sunlight from a large area and focusing it on a small area. These systems use lenses or mirrors.

Utilization Of Solar Energy

The utilization of solar energy depends on its availability and appropriate technology (Nasir 2001). The idea of using the sun's power has held scientist in its grips for centuries (Bradley 1995). Given the finite element of the non-renewable resources the world is using, it was necessary to find renewable resources that would not get depleted.

In the beginning of this century, scientists and engineers began researching ways to use solar energy. The ability to use solar energy for heat was the first discovery. It was used to heat water and cook food. (Anderson *et al.* 1983). Producing electricity from solar energy was the second discovery. This is applied in many machines and appliances today.

Power Generation

Power generation is the process of converting energy from an available source to electrical energy in a form that is suitable for distribution, consumption and storage. Hydro, photovoltaic, thermal, ocean thermal, wind, waves and tide nuclear and solar are forms of energy that could be used to generate power. Solar energy can be used to generate power in two ways; solar-thermal conversion and solar-electric (photovoltaic) conversion.

Solar-thermal is the heating of fluids to produce steam to drive turbines for large-scale centralized generation. Solar-electric (photovoltaic) conversion is the direct conversion of sunlight in to electricity through a photocell. This could be in a centralized or decentralized fashion.

Solar-Electric (Photovoltaic) Conversion

Photovoltaic systems consist of direct conversion devices that focus direct sunlight on to solar cells for conversion to power. These cells could be their own collectors or can use concentrating collectors that focus the solar energy on them. The cells produce low voltage consequently, they are combined to form modules and the modules combined to form arrays.

Solar-electric (Photovoltaic) technologies convert sunlight directly into electrical power. Photovoltaic system is made up of a balance of system (BOS), which consists of mounting structures for modules, power conditioning equipment, tracking structures, concentrator systems and storage devices. Photovoltaic conversion could be small scale for stand-alone systems or large scale connected to national grid.

Techno-Economic Analysis

For the generation of power using solar energy to be viable, aside its availability, its costs must be competitive with conventional forms of power generation. One key competitive advantage of concentrating solar energy systems is their close resemblance to most power plants: concentrating solar power technologies use many of the same technologies, machines and equipment used by conventional power plants.

Concentrating solar power technology is the least expensive large-scale power generation, and, has the potential to make solar power available at a very competitive rate. Current technologies cost between ₦240-₦360 per watt (Adebayo 2000).

But 1 day = 24 hours

Therefore $\frac{240}{24}=10$ *and* $\frac{360}{24}=15$

This results in a solar power of between ₦10 – ₦15 per Kilowatt/hour. Future advances are expected to allow solar power to be generated for between ₦4 - ₦6 per kWh in the next few years

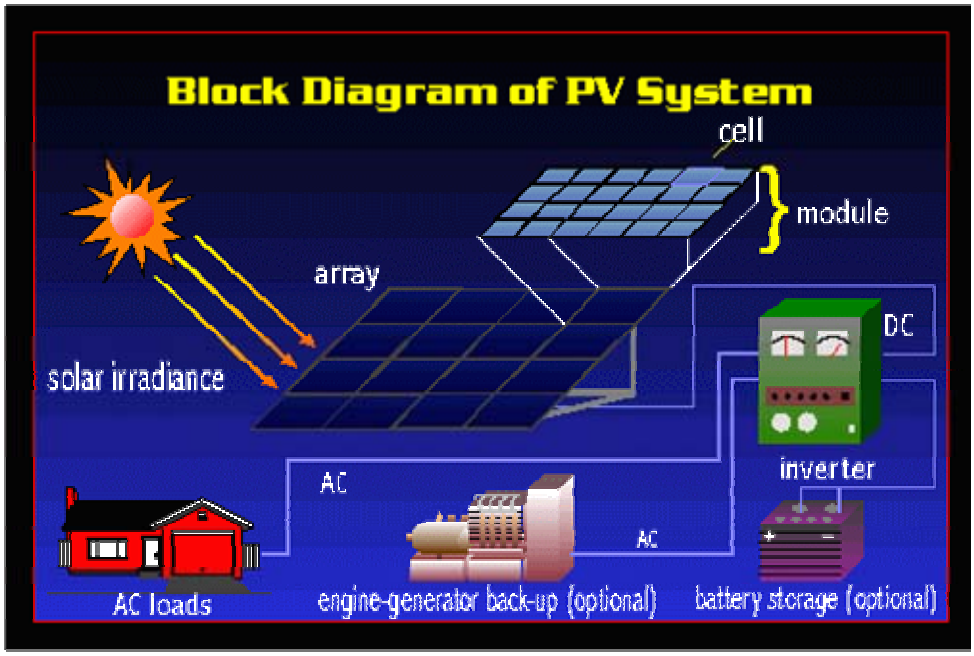

Fig. 1. Schematic of small-scale Photovoltaic System

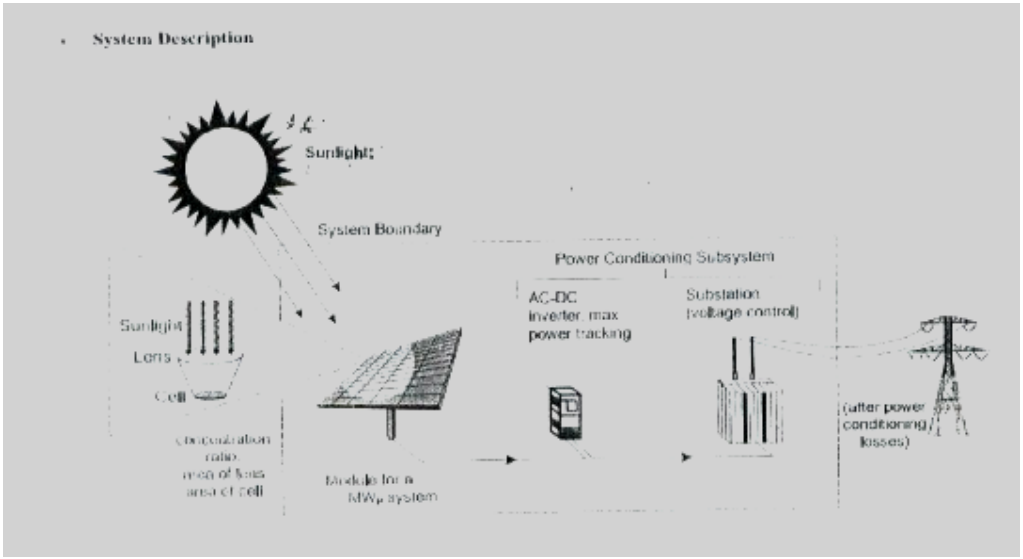

Fig. 2. Schematic of a large-scale photovoltaic system. Source: Green (1982)

Economics of Photovoltaics

In many applications, photovoltaic power is an available cost effective option. However, a number of factors influence photovoltaic energy costs. These factors are:

- Status of technological development
- Size of supply and market
- Status of manufacturing automation
- Economies of scale
- Cost per unit area
- Lifetime
- Module Efficiency.

The most important of these is the cell efficiency. This is the proportion of sunlight that is used to generate power. It greatly affects the cost of photovoltaic-generated power.

The following table presents systems and power cost of photovoltaic systems via flat

plates, flat plates tracking and concentrating types.

Table 2. Photovoltaic System and Power Costs between 1980 and 2000.Source: Christine (1980)

Photovoltaic system	Cost of electricity (₦/Kwh)		
	Mid 1980s	Mid 1990s	2000
Flat plate	45.9	15.9	4.2
Flat plate tracking	40.2	15.0	4.2
Concentrating plate	46.8	15.3	6.0

From Table 2, it can be seen that the cost of solar-electric photovoltaic energy have dropped tremendously between the mid 1980 and 2000.

Photovoltaic Module Output Power and Yield Computations.

Radiant energy from the sun to Nigeria's surface after atmospheric reflection, scattering and absorption is approximately 939W/m^2.

This radiant energy is available for over 5 hours per day on a stationary Photovoltaic module installed to receive maximum sunlight. A photovoltaic module with 1000m^2 surface area and with 10% power conversion efficiency would generate;

$$939.8 \times 1000 \times 10\% = 93980\,W \approx 94kW$$

For 5 hours per day and 31 days per month,

$$94 \times 5 \times 30 = 14100 \quad kWh \ / \ month$$

Most photovoltaic module cost less than ₦480 per watt output and is guaranteed for over 20 years. Hence, total photovoltaic module cost = 480 x 94000 = ₦ 45,120,000

Therefore, lifetime electric power output would cost;

(Measurements in terawatt hours per square kilometer per year)

$$= \frac{N45120000}{14570kWh/month \times 12\,months/year \times 20\,years}$$

$$= 12.905 \cong N13perkWh$$

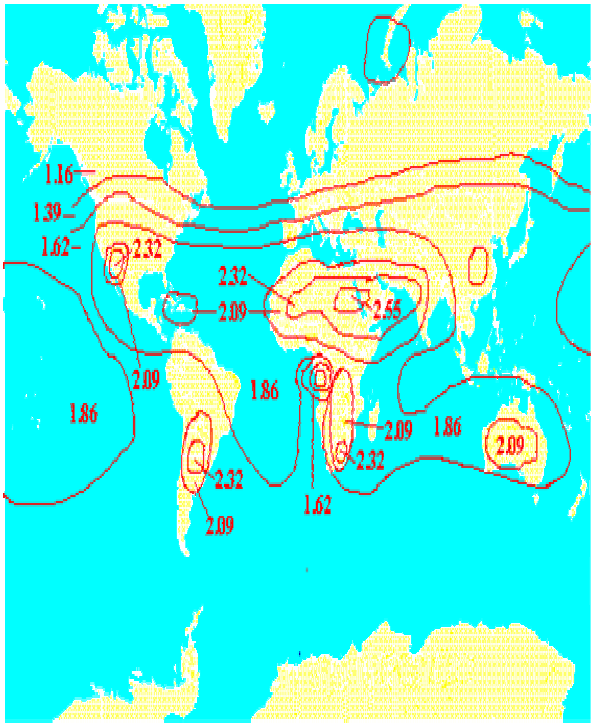

Fig. 3: Global distribution of the average annular solar radiation falling on a horizontal surface at ground level.

Analysis and Discussion

The earth directly receives 0.0000000455% of the sun's output. The world's annual energy consumption is 9.262 10^{13} kWh/year.

$$\frac{N \times 100}{9.262 \times 10^{13}} = 0.0000000455$$

$$\Rightarrow N = \frac{9.262 \times 10^{13} \times 0.0000000455}{100} = 42141.92$$

$$\cong 42000$$

This implies that one year of the Sun's output that the earth receives is equivalent to 42,000 times the World's total annual energy consumption. This indicates that solar energy is abundant. The extraterrestrial radiation received on earth was determined to be 1.729 x 10^{14}kW/m^2. 47% of this radiation reaches the earth's surface. (Cliff 1990).

$$\frac{47}{100} \times 1.729 \times 10^{14} = 81.263 \times 10^{12}\,kW/m^2$$

Therefore, the energy reflected, absorbed and scattered is relatively not a significant energy loss. The terrestrial radiation on Nigeria's land area is 2.079×10^{15} kWh/year average annual consumption of all forms of energy in Nigeria is 2.4026×10^{11} and the electrical energy consumption in the year 2001 was 15×10^{6}kWh.

This implies that the solar energy on Nigeria's land area is about 9,000 times the average annual consumption of all form of energy and 139 million times the electrical energy consumption. Hence, solar energy is available in Nigeria.

The advantages of solar energy as a means of generating power are obvious. It is abundant, pollution-free, renewable and cheap. It could be argued that the disadvantages are just as clear, current technologies are relatively inefficient, underdeveloped and initial cost ineffective. This view of the initial cost of solar power generation may seem true on the surface, but there are some other considerations to be made. Hydropower dams were built with government funds and they enjoy its assistance. Other means of power generation also enjoy government funds and subsidies. If solar power generation is given the same support, there initial and subsequent costs would be better.

Moreover, reading the map of the global distribution of the annular solar radiation falling on a surface at ground level (Fig. 3.), it can be plainly seen that there exists a sunbelt region that roughly extends around the globe with very high isolation areas of which Nigeria is a part of, effective solar-thermal stations are best situated in these regions. Furthermore, comparing the values of the direct radiation on a normal surface, which was calculated to be $939.8 W/m^2$ and the value of the radiation on a horizontal surface calculated to be $911.2 W/m^2$, its clear that the value on a normal surface is higher and more effective but in applications where the values of isolation on a horizontal surface is required the system would be improved upon by some sort of tracking and special positioning.

Solar power has made huge technological and cost improvements. From table 2, it can be seen that the cost of photovoltaic systems power have dropped tremendously between the mid 1980s and the year 2000. Moreover, concentrating plate power seem to be a bit expensive than flat plates but it's the least expensive because it gives more power output because production is enhanced both by tracking and by the use of lenses to concentrate light on the solar cell surface.

Solar-thermal power was found to cost between ₦10 and ₦15 per kWh while photovoltaic module power yield was computed to be ₦13 per kWh. National power presently cost ₦21 per kWh. This makes solar power competitive.

Finally, considering the cost of hydropower, the cost of losses during power failure, the massive environmental losses of fossil fuels, and the harmful effects of nuclear power, solar power is the best option.

Recommendations

1. A research into the availability of solar energy for power generation in specific areas should be carried out. The following areas may be considered.
   - Areas where the national power does not reach.
   - Places where conventional power stations are located.
2. Solar energy research to develop more efficient solar cells should be carried out.
3. Solar-thermal and solar storage systems should be investigated.
4. A research into the economies involving the initial and subsequent costs of solar plants should be looked into.
5. Harnessing solar energy using concentrators and collectors should be researched into.

Conclusion

The utilization of solar energy for power generation would reduce the over-dependence on hydropower, the adverse environmental effects of fossil power and the dangers of nuclear power.

A developing country like Nigeria where the power generated presently is insufficient and sunlight is usually abundant represents one of the biggest potentials for solar power generation. Solar power could be generated all

year round but it works best when the sun is at its brightest. Solar power generation can be adopted during the dry season when water level in the dams are low for sufficient hydro-power generation and there's high availability of solar radiation due to high sunshine hours compared with other seasons that are favorable for hydro-power generation.

Moreover, given both the immediate and long-term harmful effects of power generation through the burning of fossil fuels, the dangers of nuclear power generation and the insufficiencies of hydropower renewable energy sources are the best answer. With independent break-through that advance the technology combined with governmental and industrial cooperation, solar power is poised to take an ever-expanding role in power generation.

Sometimes when the fossil fuels are depleted, the problems with nuclear waste cannot be controlled and water levels in the dams are low, solar energy perhaps could be one of the most important powers of the future. With regards to high evaporation, nuclear waste and all other effects on the environment caused by conventional ways of power generation, we hope that the time when solar power will become more important than conventional power is not far away. We need a solar future if we are to live in a powerful and intact environment.

Finally, considering the availability of solar energy in Nigeria, present technologies for the conversion of this energy into power and the economies of the power generated, the generation of power from solar energy in Nigeria is viable.

References

Anderson, B.; and Michael, R. 1983. The Solar Home Book, Cheshire Books, Harrisville, NH, USA.

Bradley, D. 1995. Plants point the way to renewable energy. New Sci.121: 8.

Cliff, T.P. 1990. Essentials of Dynamic Universe, revised ed., West Publ., Minnesota, USA.

Christine, T. 1980. The Microeconomics of Induced Technical Change, in Induced Innovation. Techology, Institution and Development. Vol. 7, pp.91

El-Wakil, M.M. 1984. Powerplant Technology. Int. ed., McGraw-Hill, New York, NY, USA.

Falade, T.S. 1995. Solving Housing Problems in Lokoja. B.Sc. Research Report. Department of Architecture, A.B.U. Zaria.

Green, M.A. 1982. Solar Cells Operating Principles, Technology and Systems Application. Prentice Hall, Eaglewood Cliff, NJ, USA.

Hoff, E.; and Cheney, M. 2000. The Idea of Low Cost Photovoltaic. Energy J. 93: 17.

Jack, L. 1991. Photovoltaic; Unlimited Electrical Energy from the Sun Physics Today 64: 5.

Liebowitz, L.; and Hanseth, E. 1982. Outlook for the 80s. Solar-Thermal Technology 104: 30-35.

Nasir, A. 2001. A Technology for Helping to Alleviate the Energy Problems; Solar Energy for Cooking and Power generation. paper presented at the 3rd annual Engineering Conference of Federal University of Technology, Minna, Nigeria

Ojo, O. 2000. Fundamentals of Physical and Dynamic Climatology, 1st ed., SEDEC Publ., Lagos, Nigeria.

Williams, R.H; and Carl, J.W. 1990. Energy from the Sun. Amer. Sci. J. 43: 41.

Walters, S. 1977. Low loss energy storage flywheel. Mech. Eng. J. 99: 48.

Webb, J. 1995. By the light of the sun. New Sci. J.121: 40.

Zweibel, K. 1990. Harnessing solar power - The photovoltaic challenge. Physics Today 50: 13.

.