**THE EFFECTS OF SOLAR POWER ON THE ECONOMY OF NIGERIA**

**BY**

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 **ENUGU STATE**

**JULY, 2018**

**TITLE PAGE**

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 **BEING A PROJECT TOPIC SUBMITTED TO THE DEPARTMENT OF PHYSICS AND ELECTRONICS, FACULTY OF NATURAL AND APPLIED SCIENCES, GODFREY OKOYE UNIVERSITY, THINKERS CORNER, ENUGU STATE**

**IN PARTIAL FULFILLMENT OF THE REQIUREMENTS FOR THE AWARD OF THE BACHELOR OF SCIENCE (B.Sc.) DEGREE IN PHYSICS**

**JULY, 2018**

**DECLARATION**

I, Opara Nnamdi Ogechukwu; with the registration number U14/NAS/PHY/002 is a bona fide student in the Department of Physics and Electronics under the Faculty of Natural and Applied Sciences in Godfrey Okoye University. I would like declare that the work entitled the effect solar power on the economy of Nigeria was submitted by me in partial fulfillment of the requirements for the award of the Bachelor of Science (B.Sc) in Physics and Electronics, is my original work and has not been submitted either in part or full for any other degree or diploma either in this or any other tertiary institution.

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**Opara Nnamdi Ogechukwu date**

**CERTIFICATION**

This is to certify that this research entitled the effect solar power on the economy of Nigeria was written by Opara Nnamdi Ogechukwu with registration number U14/NAS/PHY/002, presented to the Department of Physics and Electronics of Godfrey Okoye University, Enugu. Has been assessed and approved by the department of Physics, Godfrey Okoye University Enugu.

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**Mr. MADU, F. O DATE**

**(PROJECT SUPERVISOR)**

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**EXTERNAL SUPERVISOR DATE**

**DEDICATION**

This project is dedicated to my beloved mother Mrs. Justina who helped and encouraged me with her prayers and finances.

**ACKNOWLEDGEMENTS**

My acknowledgement goes to Almighty God for His gift of knowledge and understanding that has been there from very beginning until the very end.

My profound gratitude to my lovely mum and my siblings for their encouragement and financial assistance.

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**ABSTRACT**

*The study on the effect of solar power**aimed to examine the effect solar power on the economy of Nigeria, to examine the effect of solar power on poverty alleviation in Nigeria, to investigate on the factors affecting the effective implementation of solar in most industries in Nigeria, to compare the cost of implementation of solar power to other sources of power. The materials for the study include: Solar photovoltaic modules, Array mounting racks, Grounding equipment, Combiner box, Surge protection (often part of the combiner box), Inverter, system meter and kilowatt-hour meter, Array DC, Inverter DC ,Inverter AC disconnect, Exterior AC disconnect. The study focused on commercialization of solar energy.*

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**CHAPTER ONE**

**INTRODUCTION**

**1.1 BACKGROUND OF STUDY**

The continuous growth of scarcity of energy (both mechanical and electrical energy in Nigeria has grown overtime); is one among the factors hampering the industrial growth and economic progress in Nigeria.

The federal government of Nigeria through the ministry of power have put in so much effort to fix the problem of power instability in Nigeria; setting up of new power plant will be heavily dependent on import of highly volatile fossil fuels or the over-utilization of the available mineral resource thereby affecting the export of crude oil and other resources in Nigeria.

It is therefore very important to tackle the energy crises through judicious utilization of abundant renewable energy resources such as Biomas energy, solar energy, wind energy and geothermal energy. Apart from the effective utilization of the energy supply, renewable resources will help Nigeria in mitigating climate change.

Solar Power a clean renewable resource with zero emission has got tremendous potential of energy which can be harnessed using a variety of devices. With recent developments, solar energy systems are easily available for industrial and domestic use with the added advantage of minimum maintenance. Solar energy could be made financially viable with government tax incentives and rebates. Most of the developed countries are switching over to solar energy as one of the prime renewable energy source. The current architectural designs make provision for photovoltaic cells and necessary circuitry while making building plans.

Recently according to (Federal Ministry of Environment, 2013) stated that there have been several renewable energy projects in many countries which shows clearly that renewable energy can directly contribute to poverty alleviation by providing a substantial amount of energy needed for creating businesses and employment especially in rural communities that have not yet been connected to the National grid. Several renewable energy technologies are presently being used to supply energy for cooking, space heating, lighting, automobiles, etc. The combination of energy efficiency, conservation, and renewable energy resources, should allow Nigeria to meet any future increase in demand without increasing its reliance on non-renewable resources (Federal Ministry of Environment, 2013). Solar energy can be seen as the anchor behind various forms of renewable energy.

According to (Tyagi et al., 2013) stated that it anchors hydro power where the hydrological cycle is being controlled by the sun as well as Wind Power where the movement of air is due to the heating effect of the sun on the atmosphere. In general, heat, kinetic energy, electrical energy and chemical energy can be provided via solar energy conversion

**1.2 STATEMENT OF THE PROBLEM**

What instigated the study on the effect of solar power is the over reliance on electricity as a source of power. The maintenance cost of the power sector of Nigeria is really a major clog on the wheel of the growth and development of Nigeria. Most of the huge industries in Nigeria could not run effectively because daily consumption of fuel, diesel etc to run most of their big machineries. The above effect is also seen in the small and medium scale enterprises in Nigeria; it is obvious that the switch to solar energy will go a long way in solving the problems associated with the unavailability of power from other sources such (electrical and mechanical) but there are still some issues at hand which is the cost of implementing the solar power by most of the small and medium scale enterprise. Even with the developments the issue of implementation needs to be tackled.

**1.3 OBJECTIVES OF STUDY**

The main aim of the research work is to examine the effect of solar power. Other specific objectives of the study include:

1. To examine the effect of solar power on the economy of Nigeria
2. To examine the effect of solar power on poverty alleviation in Nigeria
3. To investigate on the factors affecting the effective implementation of solar power in most industries in Nigeria
4. To compare the cost of implementation of solar power to other sources of power
5. To proffer solution to the above problem

**1.4 RESEARCH QUESTION**

The study came up with the following research questions in order to ascertain the above stated objectives. The research questions are stated below as follows:

The main aim of the research work is to examine the effect of solar power. Other specific objectives of the study include:

1. What is the effect solar power on the economy of Nigeria?
2. What is the effect of solar power on poverty alleviation in Nigeria?
3. What are the factors affecting the effective implementation of solar in most industries in Nigeria?
4. Is there any difference in the cost of implementation of solar power to other sources of power?

**1.5 SIGNIFICANT OF STUDY**

The study on the effect of solar power after completion will be of immense benefit to Nigeria as a country, the federal government of Nigeria, the power sector, the small and medium scale enterprises and other research students that wishes to carryout similar research on the above topic as the study will reveal the effect of the implementation of solar power on the economy, the effect will also be seen in the area of poverty alleviation etc.

**1.6 SCOPE OF STUDY**

The study on the effect of solar energy is limited to Nigeria only as it will discuss other source of power the country is blessed with and their effect on the economy of Nigeria.

**1.7 ORGANISATION OF STUDY**

This section deals with the organization of the research work in chapters; the chapter one of the research work will cover the background of the study, the statement of problem, the aims and objectives of study, significance and the scope of study, the chapter two will deal with the review of related literature on the effect of solar power. The chapter three of the research work will cover the areas of materials and method. The chapter four will cover the area of generation and commercialization of solar power in Nigeria while the chapter five will cover the summary, conclusion and possible recommendation for the research work.

**1.8 DEFINITION OF TERMS**

**SOLAR POWER:** is the conversion of sunlight into electricity, either directly using photo-voltaic (PV), or indirectly using concentrated solar power. Concentrated solar power systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam

**BIOMASS:** is organic matter derived from living, or recently living organisms. Biomass can be used as a source of energy and it most often refers to plants or plant-based materials that are not used for food or feed, and are specifically called lignocellulose biomass

**GEOTHERMAL ENERGY:**is the heat from the Earth. It's clean and sustainable. Resources of geothermal energy range from the shallow ground to hot water and hot rock found a few miles beneath the Earth's surface, and down even deeper to the extremely high temperatures of molten rock called magma

**CHAPTER TWO**

**REVIEW OF RELATED LITERATURE**

**2.1 INTRODUCTION**

This chapter gives an insight into various studies conducted by outstanding researchers, as well as explained terminologies with regards to the effect of solar power.

The chapter also gives a resume of the history and present status of the problem delineated by a concise review of previous studies into closely related problems.

**2.2 SOLAR ENERGY**

Solar energy is most commonly exploited in three ways:

• Photovoltaic systems – for electricity generation;

• Solar thermal power plants – to obtain electricity and heat;

• Solar thermal systems – for thermal energy

**2.2.1 PHOTOVOLTAIC SYSTEMS**

A photovoltaic (PV) system generates electricity directly from solar energy radiation. Photovoltaic systems (PV cells) are based on semiconductor materials such as silicon in a variety of designs and semiconductor compounds such as GaAs or CdTe, which are less widespread. PV systems do not emit greenhouse gases in electricity generation. Building-integrated PV systems have a minimal impact on the environment and landscape. Larger PV plants are often built on free land or agricultural land. In that case, their impact on land is expressed in terms of flora and fauna, respectively. Maintenance of land covered with PV modules involves complete or partial removal of plant life which is drastically disrupted. There are also indirect impacts on wildlife (habitat change, food, etc.). PV modules require periodic maintenance by washing the absorptive surfaces, thus polluting the water. Manufacturing of PV modules requires large amounts of energy. Impacts of power plants producing energy needed for manufacture of PV modules are also listed as negative impacts of PV plants. Also, emissions during transport are listed under negative impacts. Positive effects of these types of power plants are far more significant than the negative ones. In PV electricity generation, there are no CO2 and greenhouse gas emissions. During power plant operation, there is neither emission of particles that cause respiratory problems in humans and animals nor emission of heavy metals such as lead (Pb) nor noise [2][3]. Sociopolitical impacts: PV systems are constructed often in all developed countries, especially on the roofs of buildings. This opens up jobs in PV system fabrication and installation, encouraging thereby regional development and reducing the demand for electricity from conventional sources. PV systems have become standard in areas where there is no access to the electricity network (cottages, etc.). PV systems can be easily incorporated into smart grid models. A big problem with those systems is the investment costs, which are relatively high. The reason for a slow rate of development in the Republic of Croatia are the quotas that limit power supply connection to only 5 MW per year. The reason for this is the lack of money in the state budget for the promotion of RES. Fig. 1 shows locations of PV systems installed by 2014. The impact on the grid: PV systems are connected to the distribution network. One of the advantages of these systems is the short-circuit current that is slightly higher than the nominal, which reduces investments in safety equipment.

When measuring power quality (EN50160) by connecting a PV plant, in most cases noticeable harmonic distortion can be seen, but within limits. This is due to power electronics in the inverter and nonlinear loads in the household. Also, at THD, voltage is not ideal; there is little distortion. PV power plants have a negligible impact on the voltage asymmetry, but it still exists.



**2.2.2 SOLAR THERMAL POWER PLANTS**

There are three basic designs of solar thermal power plants, i.e.:

 • Solar thermal power plants with parabolic collectors,

• Solar thermal power plants with a central tower,

• Solar thermal power plants with parabolic dishes. In all three versions, water is heated (evaporated), and the rest of the plant is based on classic steam power plants. Environmental impacts: Solarthermal power plants occupy a large area and the impacts on land and wild-life are similar to those of PV systems. These power plants are built for high power and they greatly reduce CO2 emissions. In a hybrid version, CO2 emissions are increased. Unlike PV systems, large volume of water is required for cooling or as a working fluid, or for washing reflective surfaces which affects water quality. The reflected rays of sun can cause sunburn to the birds flying near the towers. They are built in desert areas, which further reduce the impact on wildlife. Sociopolitical impacts: This type of power plants can supply electricity to smaller cities; therefore, they can be the basis of regional development. They provide much greater employment opportunities due to greater complexity of the plant in relation to PV systems. Also, they may be partially equal to conventional power plants of medium size, and hybrid versions can be completely equal. Currently, there are no solar thermal power plants in Croatia. Impacts on the grid: Solar thermal power plants have the same working principle as steam power plants; therefore, they are completely equal to conventional power plants in terms of the quality of electrical energy. Time-of-day dependence can be eliminated by a hybrid version of the plant, where natural gas is mostly used for heating water at night and cloudy days during the year. These power plants are built more often in desert areas, which requires an additional transmission grid to populated areas

**2.2.3 SOLAR THERMAL SYSTEMS**

A solar thermal system is a system that uses solar energy to produce energy for heating or for hot water. Environmental impacts: Water is heated exclusively by solar energy; there is no need for fuels and combustion, which makes these systems environmentally friendly. Problems occur due to higher needs for hot water where the collectors are placed on the land. The time of day is also a major problem with these systems. Insulated containers are needed for storing water in bad weather conditions. There are hybrid versions with gas or electricity, where the problem of the lack of radiation is eliminated. Sociopolitical impacts: Solar thermal systems provide employment opportunities during the construction of the system and later in maintenance. In Croatia, solar thermal systems are mostly installed in parallel with PV systems in order to acquire greater privileged electricity prices. In warm months during the year, these systems may completely reduce the cost of heating domestic hot water. The problem is the initial investment, which is quite high in comparison with the standard of the Republic of Croatia. The potential for solar thermal systems in Croatia is very good (1.2–1.6 MWh/m2, a year). According to [8], energy production from solar thermal systems is 183 TJ/year. According to the Energy Strategy of the Republic of Croatia, the target is installation of 0.225 m2 of solar collectors per capita by 2020.

**2.3 ENERGY OF BIOMAS**

Biomass is the most complex form of RES because it covers a wide raw material base; the location of biomass energy usage can be separated from the location of biomass production. Biomass energy can be exploited in three different ways, i.e.:

 • Biomass power plants;

• Biogas power plants;

• Biofuels (biodiesel and bioethanol)

**2.3.1ENVIRONMENTAL IMPACT**

Biomass power plants are based on the same principle as conventional power plants, what is different are the type of fuel. It uses various remains of forestry, agriculture and livestock, which are directly burned or gasified. Unlike other RES, these plants have direct emissions of greenhouse gases and particulate matters, but they take into account continuous renewal of fuel, the amount of produced CO2 is equivalent to consumption in the process of photosynthesis. Large land areas are needed to grow biomass in any of the forms which has a direct impact on the eco-world in those areas (herbicides, pesticides, fertilizers). For the production of biofuels (biodiesel and bioethanol), a large area of cultivable land is needed. For the production of biodiesel waste, edible oils are also used. Greenhouse gas emissions are reduced depending on the concentration of biofuels in classic fuels.

**2.3.2 SOCIOPOLITICAL IMPACTS**

Biomass energy provides great opportunities for the development of rural areas and employment in those areas. Of all RES, this type has the highest employment potential in production and preparation of biomass, power plant construction, management and maintenance of power plants. The same holds for biofuels. The disadvantages are the noise of machines and jobs in the plants, often unpleasant smell, and the fact that these plants are unacceptable for urban centers.

**2.4 NIGERIA AND OUR FAVOURABLE LOCATION**

Nigeria, having a land mass of 923,768sq.km, is situated in the West African region and lies between longitudes 3 degrees and 14 degrees and latitudes 4 degrees and 140 degrees (Nigeria Embassy, 2013). Nigeria receives abundant sunshine all the year round being just above the equator. The sunshine duration averages 6.5 hours daily with an average flux of 5.55 kWh per square meter per day. This implies that Nigeria receives 4.851x 1012 kWh of energy per day from the sun. The solar radiation intensities range from 3.5-7.0 kWh per square meter per day increasing from the South to the North (Oseni, 2012). This energy source could be available for 26% of the day (9.00am-4.00pm). These facts and figures regarding Nigeria’s geographical location clearly indicate that the potential to generate significant amount of electrical energy from solar energy is very high for Nigeria. However, very little has been done in this direction as the government is yet to take pragmatic steps towards developing and implementing policies and plans that will serve as a base line on which solar energy utilization in Nigeria can thrive.

**2.5 ELECTRICAL ENERGY GENERATION POTENTIAL FROM SOLAR ENERGY IN NIGERIA**

The energy generated in Nigeria is grossly inadequate, hence the need to improve structures on ground, and also introduce alternative energy technologies (i.e. renewables) to complement current government efforts to provide sustainable energy for the citizens (Federal Ministry of Environment, 2013). Nigeria’s present electricity supply is highly insufficient and epileptic; a situation which has led to individuals corporate and government organizations making alternative arrangements to provide electric power for their installations using various generators with a wide range of power capacity. No doubt, this has increased the cost of production and by direct consequence supports inflation and a lower standard of living of Nigerian Citizens. The additional cost these installed generators bring with their usage is that of environmental degradation which has become a major concern in our world today. Thinking “renewables” is therefore a general approach that has been identified to fill in this energy shortage without degrading our environment. According to Nnaji and Unachukwe, (2010), Nigeria (lying in the tropics) receives abundant sunshine, where about 1500PJ (about 258 million barrels of oil equivalent) could be available annually from solar energy, if solar appliances with 5% conversion efficiency were used over only one per cent of the total land area of the country for about six months of a year. A giant feat recorded by some scientists at the United States energy department, National Renewable Energy Laboratory (NERL) in August 2008 set a world record in solar cell efficiency with a photovoltaic device that converts 40.8% of light that hits it into electricity (National Renewable Energy Laboratory, 2008; Tyagi et al., 2013). Higher PV cell efficiencies are still being pursued; hence the total land mass requirement will continue to be on the decrease. With this improvement in technology, Nigeria will therefore need a land mass smaller than 1% of its total landmass to get the required energy needed. Oseni (2012) gave a detailed analysis of energy trends in Nigeria between the year 2007 and 2008. The author extensively presented ways of improving household access to electricity and energy consumption pattern in Nigeria with a focus on using renewable energy alternatives. According to the author, the country receives an average solar radiation at the levels of about 19.8MJm-2 per day and average sunshine hours per day estimated at 6hday-1 . With an average solar radiation level of about 5.5kWh per day and the recent improvements in PV panel efficiencies, it is possible to generate 190550GWh of solar electricity per year with solar panels covering only 1% of the entire land mass of Nigeria (Oseni, 2012). The energy demand in Nigeria will continue to increase as the Nigerian population continues to increase and as the energy demand per person increases due to fast urbanization. This means that the pressure on existing energy sources will continue to increase. Although Nigeria is known as a major producer of fossil fuel (which is a primary energy), a greater percentage of her secondary energy needs are supplied by expensive imports. According to Oseni (2012), Nigeria consumed 8.41 million tonnes of oil equivalent of petroleum products in 2007 with more than 93% of it imported where fossil fuel provided about 61.4% of the total indigenous primary energy production, with crude oil (49.9%) and natural gas (11.5%). Although fossil fuels contributed immensely to indigenous production, they contributed only 17.8% to the total primary energy consumption in the country (Oseni, 2012). This is the case because most of the crude oil produced as primary energy resource is exported in their crude state. This situation has given Nigeria less value than what would have been available if the capacity to refine the abundant raw crude oil for consumption in the country was installed. Presently in Nigerian refineries, the flaring of natural gas resulting in serious environmental issues is still the norm rather than the exception. A greater capacity to refine crude oil without addressing these issues will lead to further pollution of the environment, a situation that has dire impacts on citizens. It is therefore necessary that other alternatives be considered as supplements to crude oil so as to create an energy utilization balance for the Nigerian economy.

**2.6 ISSUES OF SOLAR ENERGY UTILIZATION FOR GENERATING ELECTRICITY**

Solar energy utilization for generating electricity no doubt has several advantages which include: low operational andmaintenance cost, a very high meantime between failures of about 20-30 years, noiseless and no moving parts during operation, availability of PV panels in different sizes or modules over a wide range of power rating, perceived environmental friendly nature with respect to release of greenhouse gases, global warming, ozone layer depletion, etc. However several issues arise in generating electricity from solar energy. These issues include:

**Long Energy Pay-Back Time**

Sherwani et al. (2010) carried out a review of the life cycle assessment of solar PV based electricity generation systems. According to their findings, the variation in the energy pay-back time (EPBT) and greenhouse gas (GHG) emissions have been dependent upon many factors, such as the type of solar cell, solar panel orientation and angle, irradiation of the location, difference installation (integrated or non-integrated systems as well as facade, flat roof and solar roof tiles), efficiency of the Balance of system (BOS) components, size (capacity) of the system, lifetime of the system and the electricity mix of that particular country and year of study. The main issue that arises from this is that EPBT influences the decision of investors to invest in electrical energy generation using PV panels. If investors perceive the EPBT in solar PV based electricity generation systems to be too long, they may decide to seek for alternative investments which will hinder the growth of the Solar PV electricity generation Industry. It is therefore necessary that the energy pay-back time of solar PV based electricity generation systems be reduced considerable through continuous improvements in designs to facilitate production of PV cells that are cheaper and yet have higher efficiencies.

**High up Frontal Capital Cost**

Another major down side of solar energy utilization in generating electricity is the high up frontal capital cost compared to its conventional energy alternatives (Chigbo, 2010). The general perception is that this technology is not yet mature hence it is only suited for particular markets and even then will require heavy subsidy to make it viable. This is quite erroneous to some degree as many countries such as Germany, the United States and China have succeeded with their solar energy utilization plans and are already enjoying the numerous dividends (Tyagi et al., 2013). Solar voltages have been powering space modules since the beginning of space programmes and talking about the cost, the high up frontal capital cost can be handled by letting Giant companies and Governments playa part in the programme by bringing in the much needed up front capital and recouping their investment over time.

**Ignorance of the Benefits of the Technology**

Another serious setback to the solar energy program is ignorance of the benefits of this technology. Awareness of the opportunities offered by solar energy and its technology is low among members of the public and private sector stakeholders. This lack of information and awareness creates a market distortion that results in higher risk perception for potential renewable energy projects. According to Kok et al. (2011), energy conservation interventions have frequently failed because they often did not take the full range of significant influences on human behaviour, into account. There is therefore a need for dissemination of information on solar energy resource availability, benefits and opportunities to the general public in order to raise public awareness and generate activities in the sector. Kenya has taken giant steps in the number of solar power systems installed per capital (but not the number of watts added). More than 30,000 very small solar panels are sold in Kenya annually, as more Kenyans adopt solar power every year than they make connections to local grid.

**Requirement of Large Expanse of Land**

Another major issue in the use of solar PV panels is the large expanse of land required for their installation. Clearly, moving to solar energy as a major energy producer would mean an enormous reallocation of land and resource use. However with the continuous improvement in PV efficiencies, the required space per Kwh of electricity generated will continue to be on the decrease.

**Low efficiencies of PV panels**

Low efficiency of PV panels is another draw draw-back presently limiting the widespread diffusion and usage of PV cells in generating electricity. PV panel efficiencies must be increased to establish their acceptance in the energy market. Table 1 shows some materials used for making PV panels and their efficiencies. It can be seen from the table that GaAs cells which uses multi-junction cells have the highest efficiencies so far. It is believed that exploiting the multi junction technology will provide the future PV panels with higher efficiencies. PV panel efficiencies and output power decreases due to increase in temperatures hence the need to provide cooling at high illumination conditions. Dust and humidity also reduce the efficiencies of solar PV cells to lower values

**Solar Irradiation**

Solar irradiation which varies throughout the entire day and affects the efficiency and output of PV cells is another issue being considered in using solar cells. Increase in solar irradiance increases the PV module efficiency because the high number of photons hitting the module increases and many electron-hole pairs are formed which will produce more current. During the night, solar irradiation is zero hence PV cells will have zero output at night. A simple way to solve this problem is to incorporate another renewable energy source such as wind energy with the solar PV modules so that they will deliver the required power at night. Electricity storage in batteries is also useful to make electrical energy available during these periods when solar irradiation is low or not available.

**Environmental Pollution**

Although solar PV cells are generally acclaimed to be environment friendly, their by-products during the manufacturing process and waste after their useful life can also constitute environmental hazards. Raw materials for making solar PV cells are obtained through mining operations which may cause danger to miners. In addition, mining machines involve usage of fossil fuels such as petrol and diesel which also cause environmental pollution through emission of hazardous gases and heavy metal from the mines. As more PV cells are manufactured and installed, the environmental pollution which results through their manufacturing process and disposal after their useful life will also be on the increase.

**Long life storage and long distance transportation (Goffman, 2008)**

The problem of storing large amount of solar energy after it has been converted to electrical energy is a huge challenge yet to be overcome before solar energy becomes a major contributor to the world energy grid. A major infrastructure investment will be necessary for such a storage system to be possible. Also, transporting the energy from where it is produced to where it is needed is another huge challenge to be overcome. A new high- voltage, direct-current (HVDC) power transmission backbone would have to be built using Direct Current for this to be possible

and also the need to address the inefficient use of energy has been identified as key barriers to the development of the sector. The Authors present a four stage pragmatic plan that will help Nigeria to harness her abundant solar energy as a means of providing sustainable electrical energy generation in Nigeria. This plan can serve as a vital document to build on in the development of the renewable energy policy for Nigeria. The four stages described in the plan are

1. Solar PV Panel Technology Development Stage

2. Solar/Wind Power Plant Development Stage

3. Commercialization Stage

4. Evaluation

**CHAPTER THREE**

**3.0 MATERIALS AND METHOD**

**3.1 SYSTEM COMPONENT**

Pre-engineered photovoltaic systems can be purchased that come with all the components you will need, right down to the nuts and bolts. Any good dealer can size and specify systems for you, given a description of your site and needs. Nevertheless, familiarity with system components, the different types that are available, and criteria for making a selection is important.

Basic components of grid-connected PV systems with and without batteries are:

* Solar photovoltaic modules
* Array mounting racks
* Grounding equipment
* Combiner box
* Surge protection (often part of the combiner box)
* Inverter
* Meters – system meter and kilowatt-hour meter
* Disconnects: - Array DC disconnect - Inverter DC disconnect - Inverter AC disconnect - Exterior AC disconnect

If the system includes batteries, it will also require:

* Battery bank with cabling and housing structure
* Charge controller
* Battery disconnect

**3.2 SOLAR MODULES**

The heart of a photovoltaic system is the solar module. Many photovoltaic cells are wired together by the manufacturer to produce a solar module. When installed at a site, solar modules are wired together in series to form strings. Strings of modules are connected in parallel to form an array.

**Module Types –**Rigid flat framed modules are currently most common and most of these are composed of silicon. Silicon cells have atomic structures that are single-crystalline (a.k.a. mono-crystalline), poly-crystalline (a.k.a. multi-crystalline) or amorphous (a.k.a. thin film silicon). Other cell materials used in solar modules are cadmium telluride (CdTe, commonly pronounced “CadTel”) and copper indium diselenide (CIS). Some modules are manufactured using combinations of these materials. An example is a thin film of amorphous silicon deposited onto a substrate of single-crystalline silicon. In 2005 approximately 90 percent of modules sold in the United States were composed of crystalline silicon, either single-crystalline or poly-crystalline. The market share of crystalline silicon is down from previous years, however, and continues to drop as sales of amorphous silicon; CdTe and CIS modules are growing.

**Building Integrated Photovoltaic Product:** PV technology has been integrated into roofing tiles, flexible roofing shingles, roofing membranes, adhesive laminates for metal standing-seam roofs, windows, and other building integrated photovoltaic (BIPV) products. BIPV modules are generally more expensive than rigid flat modules, but are anticipated to eventually reduce overall costs of a PV system because of their dual purpose.

**Rated Power:** Grid-connected residential PV systems use modules with rated power output ranging from 100-300 watts. Modules as small as 10 watts are used for other applications. Rated power is the maximum power the panel can produce with 1,000 watts of sunlight per square meter at a module temperature of 25o C or 77o F in still air. Actual conditions will rarely match rated conditions and so actual power output will almost always be less.

**3.3 OVERVIEW OF EXISTING SYSTEM**

A photovoltaic (PV) system is able to supply electric energy to a given load by directly converting solar energy through the photovoltaic effect. The system structure is very flexible. PV modules are the main building blocks; these can be arranged into arrays to increase electric energy production. Normally additional equipment is necessary in order to transform energy into a useful form or store energy for future use. The resulting system will therefore be determined by the energy needs (or loads) in a particular application. PV systems can be broadly classified in two major groups:

* + 1. Stand-Alone: These systems are isolated from the electric distribution grid. Figure 1 describes the most common system configuration. The system described in Figure 1 is actually one of the most complex; and includes all the elements necessary to serve AC appliances in a common household or commercial application. An additional generator (e.g., bio-diesel or wind) could be considered to enhance the reliability but it is not necessary. The number of components in the system will depend on the type of load that is being served. The inverter could be eliminated or replaced by a DC to DC converter if only DC loads are to be fed by the PV modules. It is also possible to directly couple a PV array to a DC load when alternative storage methods are used or when operating schedules are not of importance. A good example may be water pumping applications were a PV module is directly coupled to a DC pump; water is stored in a tank through the day whenever energy is available.

**Grid-Tied:** These systems are directly coupled to the electric distribution network and do not require battery storage. Figure 5.2 describes the basic system configuration. Electric energy is either sold or bought from the local electric utility depending on the local energy load patterns and the solar resource variation during the day, this operation mode requires an inverter to convert DC currents to AC currents. There are many benefits that could be obtained from using grid-tied PV systems instead of the traditional stand-alone schemes. These benefits are:

1. Smaller PV arrays can supply the same load reliably.
2. Less balance of system components are needed.
3. Comparable emission reduction potential taking advantage of existing infrastructure.
4. Eliminates the need for energy storage and the costs associated to substituting and recycling batteries for individual clients. Storage can be included if desired to enhance reliability for the client.
5. Takes advantage of the existing electrical infrastructure.
6. Efficient use of available energy. Contributes to the required electrical grid generation while the client’s demand is below PV output

Grid-tied photovoltaic system 2

Hybrid systems may be possible were battery storage or a generator (or both) can be combined with a grid connection for additional reliability and scheduling flexibility (at additional cost). Most of the installed residential, commercial and central scale systems use pre-fabricated flat plate solar modules, because they are widely available. Most available reports on PV system costs are therefore related to this kind of technology and shall be our focus in this chapter. Other specialized technologies are available (e.g., concentrating PV systems), but not as commercially available as the traditional PV module

**3.4 PHOTOVOLTAIC SYSTEMS TOTAL COSTS OVERVIEW**

The PV industry is rapidly maturing because of worldwide environmental concerns and its energy production potential due to the widely available free solar resource. The industry is in a race to achieve grid parity (PV energy costs equal to conventional utility costs) and increase competitiveness in the energy markets. PV system installed costs range from 4,600 to 19,500 $/kW (typically the size of the PV array is used to determine the kW or W rating of the system when complete system costs are considered). Common figures are 8,000 $/kW for grid-tied systems, and 14,000 $/kW for stand-alone systems. Energy production costs are typically estimated above 0.18

$/kWh in the United States, yet these energy costs are highly dependent on the available solar resource at the location under study and cannot be used as a general reference. Table 1 summarizes available cost information for PV systems (stand-alone and grid-tied) in the US and Europe. It is important to understand the factors that directly and indirectly affect system costs and viability, to properly identify the potential of this technology in a particular market. Table 1 summarizes some of these factors

**TABLE 1**: Summary of Installed PV System Cost information

|  |  |  |  |
| --- | --- | --- | --- |
| **Study** | **$/kWp** | **$/kWh** | **Year of Report** |
| NREL [12] | 7,400-14,000 | - | 2001 |
| IEA [11] | 7,180 | - | 2003 |
| EPV Industry Association and Greenpeace [11] | 7,866-11,144 | 0.33-1.30 | 2004 |
| Komor [8] | 4,500-8,000 | 0.20-0.50 | 2004 |
| BP Solar UK [11] | 9,745-19,490 | - | 2005 |
| NREL[# presentacion] | 6,000-25,000 | - | 2005 |
| NREL [13] | 7,560 | - | 2006 |
| San Francisco Environment [11] | 9,500 | - | 2007 |
| EIA [11] | 8,000-12,000 | 0.21-0.82 | 2007 |
| NREL [14] | 9,000 | - | 2008 |
| Solarbuzz [6] | 6,000-10,000 | 0.20-0.40 | June 2008 |

Some of the reports may include system data for several years; in these cases the year of publication is included. Cost information is therefore affected by time span, data set size and system variety.

**Table 2** Summary of Factors Affecting PV System Costs and Feasibility

|  |  |
| --- | --- |
| Factors | Facts |
| Grid connection | * Grid-connected systems do not need batteries which reduces considerably initial capital costs and energy costs.
* For a comparable load, grid-tied systems use smaller PV arrays than stand-alone systems.
* Grid-Tied systems are estimated to cost ~$4,800/kW less than stand-alone systems including inverters and batteries according to the study in [12] for systems built in the US between 1997-2000.
 |
| Distance to nearest | * Stand-alone
 | systems | tend | to | become | feasible | in |
| utility grid | locations which are far from electrical distribution networks.* Grid extensions can cost thousands of dollars per mile of transmission line.
 |
| Solar resource | * Solar resource will not affect capital costs but the availability of solar energy does affect the cost of producing energy, hence the payback period for the investment.
* According to [12], location is considered the second largest factor affecting PV system cost performance.
* Location can have influence on shading patterns, soiling, operating temperature and solar resource variations.
 |
| BOS (tracking) | * Balance of system components is estimated to represent 30-50% of the total costs of a PV System [8].
* Most cost reductions for PV systems over the last decade are in BOS components including inverters [13].
* Local safety codes or regulations can require additional balance of system costs for the installation.
 |
| Type of installation , Mounting, size and Space | * When flat roofs are considered, 10o tilt uses 30% more roof area when flat roofs are considered [9]. Commercial and industrial clients prefer horizontal

installation to maximize flat roof utilization and to lower mounting expenses.* Retrofit installations tend to be more expensive than those planned for new buildings. According to [13]:

 Large residential projects are ~$1.2/Wac less expensive. Affordable Housing projects are ~$1.9/Wac less expensive. Custom New House ~$0.18/Wac more expensive.* Large Scale systems tend to be less expensive on a per watt basis. Due to the volume or the purchases, developers take advantage of wholesale prices or discounts. This is also true for large residential projects as discussed above.
* Due to capital cost restrictions, stand-alone systems tend to be smaller or used for smaller loads.
* Grid-tied systems tend to be larger because they provide lower capital costs and energy costs for larger loads.
 |
|  | * Typically larger systems tend to have lower cost per kW. According to [12] costs diminish ~$40 for every additional kW.
 |
| Module technology | * Modules account for 40-50% of total system costs, according to [6] and [8].
* Module efficiency determines the total area needed to install the system. Less area per watt is desired to maximize roof or land use.
* PV modules that require less material, energy and time to develop have lower costs (details below).
 |
| PV production | * Supply and demand laws have been slowing the cost of PV modules in the last years. Market shortage of PV modules has been particularly driven by high demand and silicon supply shortage.
* US production of both silicon and PV modules is constantly increasing to satisfy the demand.
* Many research efforts today seek to reduce the quantity of materials used per module, one example is thin-film cell technology.
* A doubling in PV production results in ~20% module price reduction [13].
 |
| Time and Learning Curve | * According to [12], next year cost reduction for systems built in the US between the years 1997 and 2000 is ~ $600/kW.
* According to [13], a 7.3% annual decline has been observed on small scale system costs since 1998. Large scale systems showed lower reductions, yet these tend to be less expensive for each watt of capacity.
* Lower component costs are complemented by the acquired knowledge by system designers and installers who can perform their jobs more efficiently as they gain experience, reducing overall costs as well.
 |
| O&M | * Most PV systems do not have notable O&M costs especially grid-tied systems.
* The study in [9] suggests $11/kW/yr. for small residential and commercial systems and $27/kW/yr.
* According to [8], O&M costs may range between 0.4 to 9.5 cents/kWh although most tend to the lower limit.
* Most small scale grid-tied systems do not have moving parts and therefore maintenance is minimal.
* Large-scale systems may use tracking systems and therefore may require more work.
 |
|  | * Battery assisted systems may require acid refills when valve regulated batteries are not used.
* Some arrays will require regular cleaning. This could represent additional costs especially for large scale systems.
* Tree branch trimming may be also considered O&M costs were applicable.
* Batteries, inverters and charge controllers will probably require at least one replacement during project lifetime, it is therefore important to consider equipment lifetime and replacement cost as part of O&M costs during a projects lifetime. Insurance and inspection should also be considered.
 |
| Energy Use and Cost | * System size depends mostly on energy use, solar resource and component efficiency.
* Reducing energy consumption greatly reduces the initial capital cost investment necessary.
* The average energy use for the US is ~10W/ft2 [14].
* Average residential energy use in Puerto Rico is

~800kWh/month.* PV systems can be cost competitive in locations with high energy prices and Net metering programs. The assumption that PV is expensive is therefore relative to the solar resource and utility energy prices in a location.
 |
| Indirect benefits (home value, GHG reduction, etc.) | * Home appraisal is estimated at ~$20 for every $1 reduction in annual utility bills [14].
* Customers would pay 10% more for a solar equipped residence [14].
* Emissions reductions provide a wide range of economical, environmental and health benefits. These are difficult to quantify, yet they cannot be ignored.
 |
| Available grants or Incentive Programs | * PV technology is considered very expensive in most applications; therefore several strategies have been implemented to jumpstart the widespread use of the technology. Some of these are:

 Tax Deductions Renewable Energy Credits Emissions Reduction Credits Net Metering Programs Accelerated Depreciation Grants* Not all have positive effects; therefore incentive programs should be carefully tailored.
 |
| Financing and economic variables | * Debt term, debt ratio, interest rate and project life have market effect on payback time and energy costs.
* Small systems (residential or commercial) can be financed at 7-8.5% interest rates [9], these numbers coincide with local financing institutions.
* Larger systems can be financed at lower rates.
* Project specific financial parameters are not the only factors having effect on PV system economic performance. The economic performance is also affected by external parameters like inflation and energy escalation rates.
* Energy costs in Puerto Rico are currently between

$0.21 and $0.25, and rising due to the heavy dependence on petroleum derived fuels (June 2008).* In Puerto Rico inflation is 8%, energy cost escalation rate is 14% [28].
* Utilities generally use MARR values between 3 and 18%. The 6 to 11% range is most common [26], [27].
* According to [29], average MARR values for private investment (big money) or corporations are:

 40% for high risk investments (new products, new business, acquisitions, joint ventures). 25% for medium risk investments (capacity increase to supply forecasted sales). 15% for low risk investments (Cost improvement, make v.s. buy, capacity increase to meet existing orders).* MARR values for individuals are not commonly available and are difficult to calculate.
* 20 year debt terms are common for utilities.
* 12 year debt terms are common for developers.
* Residential systems can be financed with debt terms in the range of 5 to 15 years. Is systems are financed as part of residential mortages, debt terms would tend to the upper limit. Personal loans tens to the lower limits.
* 5 year MACRS depreciation methods are common in many incentive programs.
 |

Reference [13] reports price indexes in $/Wac , the authors suggest a 0.84 conversion factor for $/Wdc (W=Wdc). All $/kWh are reported on the AC side

**3.5 PHOTOVOLTAIC ENERGY EQUIPMENT: GENERAL CHARACTERISTICS AND COSTS**

Cost information on individual components and labor affecting the overall cost of grid- tied PV systems is compiled below along with a brief description of each item. The data for individual components represents the estimated average unit cost for an individual unit, not considering bulk or wholesale special prices. The information found agrees with the total costs information compiled in the previous section.

1. Photovoltaic (PV) Modules: The basic building block of a photovoltaic module is the photovoltaic cell; these convert solar energy into electricity. The power output will depend on the amount of energy incident on the surface of the cell and the operating temperature of the photovoltaic cell. The power output of a single cell can supply small loads like calculators or watches, but in order to be useful for high energy demand projects these cells must be arranged in series and parallel connections. A photovoltaic module is an array of photovoltaic cells pre-arranged in a single mounting mold. The type of module is therefore determined by the cells that compose the module itself. There are three dominating cell technologies:
	* Monocrystalline: As the name implies, these are cells that are grown from a single crystal. The production methods are difficult and expensive. These tend to be more efficient (more power in less area) and more expensive.
	* Multicrystalline: The production process allows multiple crystalline structures to develop within the cell. It is easier to implement in a production line. It is relatively cheaper than mono- crystalline at the expense of lower efficiency.
	* Thin-film: Uses less silicon to develop the cell (hence the name thin film) allowing for cheaper production costs (silicon is in high demand). It tends to be less expensive but has also lower efficiency.

The overall efficiency of the module will depend on the cell efficiency and placement within the module, and on the laminating materials used. The standard testing condition (STC), defined as a total irradiance of 1000W/m2 and an ambient temperature of 25oC, is used to define module ratings. Typical module efficiencies range between 11% and 17% for crystalline technologies at STC; most of the commercially available modules are in the lower bound of this range. Thin-film module efficiencies range between 6% and 12% [57]. Since 2003 total PV production grew in average 50%, whereas the thin film segment grew almost 80% and reached 196 MW or 8% of total PV production in 2006. About 90% of the current production uses wafer-based crystalline silicon technology. The main advantage of this technology was that complete production lines could be bought, installed and manufactured within a relatively short time. This predictable production start-up scenario constitutes a low-risk placement with high expectations for return on investments.

Figure 4 displays the trend of the price index for photovoltaic modules over the last year. The price index represents the average price per watt of photovoltaic modules in the market. The information used to generate the graph only considers individual modules with ratings over 125Wp; the price index might be lower if modules are purchased in larger quantities at wholesale price [6]. Table 4 summarizes the lowest prices recorded for each technology type. New thin film photovoltaic modules are expected to be available for as low as $2/Wp during the year 2009 [19]. Most PV manufacturers extend warranties for 20 to 25 years for their PV

Figure 4 PV Module Price Index for 2007-2008

**Table 4 Lowest for PV Price Index Recorded Technologies**

|  |  |  |
| --- | --- | --- |
| **Technology** | **Price (January)** | **Price (June)** |
| Multicrystalline | $4.28/Wp | $4.17/Wp |
| Monocrystalline | $4.35/Wp | $4.35/Wp |
| Thin-film | $3.66/Wp | $3.74/Wp |

The technology is receiving much benefit from research that strives to make existing technologies cheaper and more accessible. The Energy Information Administration (EIA) reports that 26 companies were expected to introduce new photovoltaic products in the market in the year 2007 [1]. Recent years have presented new alternatives to the way solar modules are built and implemented.

Examples of creativity include shingles and windows that use photovoltaic cells as part of their design. Architects and engineers have developed ways to use PV modules in building facades substituting them for regular building materials, hence reducing the net cost of the PV generated energy. The approach is known as building integrated photovoltaic (BIPV) architecture.

1. **Inverters**: Inverters are used to transform DC current into AC currents. In the photovoltaic industry, inverters can be classified into two broad categories:
	* **Stand-Alone Inverters**- These inverters are meant to operate isolated from the electrical distribution network and require batteries for proper operation. The batteries provide a constant voltage source at the DC input of the inverter. Inverters can be classified briefly as:

 Square Wave Inverters

 Modified Sine Wave Inverters

 Sine wave inverters (quasi-sine wave).

Voltage and current waveforms produced by inverters are never perfect sinusoids (even for sine wave inverters); therefore some harmonic currents are expected during normal system operation. Total harmonic distortion (THD) is a measure of the harmonic content in current and voltage waveform. The type of inverter used will depend on the load that it will serve. Resistive loads could tolerate square wave inverters which are cheaper and easier to develop. Motors and sensitive electronics will need inverters that are able to produce almost perfect sinusoidal voltage and current waveforms in order to operate correctly. These tend to be more expensive and difficult to design. The designer should choose inverters according to load types and power requirements. Modern stand-alone inverters have software applications embedded that monitor and control equipment operation.

* + **Grid-Tied Inverters**- These inverters operate coupled to the electric distribution network and therefore must be able to produce almost perfect sinusoidal voltages and currents. The operating requirements for these types of inverters are in most cases determined by the local utilities, yet most utilities rely on existing standards to determine feasible technologies. The most referenced standards in the United States are the IEEE1547 and the UL 1741. These standards include the minimum requirements that manufacturers should include into their inverter designs in order to prevent adverse effects in the distribution grid [20]-[24]. Normally, embedded software applications monitor and control equipment operation to comply with standard requirements.

 There are two main categories of grid-tied inverters. Line-commutated inverters derive their switching signals directly from the grid line currents. The low switching frequencies produce harmonic currents that need to be filtered out. In the case of small single-phase inverters the bulky and expensive filtering networks are not practical. In the case of large three phase inverters, multiple units could be connected through a multi-phase isolation transformer at the utility output, filtering any unwanted currents [21]. Self-commutated inverters derive their switching frequencies from internal control units as they monitor grid conditions, in particular frequency and voltage. High switching frequencies (3 – 20 kHz) are used and therefore lower current harmonic content is possible without the need of using large filtering networks. Self-commutated inverters can be either voltage source inverters or current source inverters. PV modules behave like voltage sources; therefore our interest will be in voltage source type inverters. Voltage source type inverters can yet again be subdivided into current control and voltage control types. In applications where there is no grid reference, voltage control schemes are used and the inverter behaves as a voltage source. Where a grid connection is used the current control scheme is used and the inverter behaves as a current source. These inverters use the utility voltage as reference to provide the current available from the PV, and are not able to operate as an island. The advantages of current control voltage source inverters are [23]:

 Power Factor (PF) ~ 1 (employing a simple control scheme).

 Transient Current Suppression: The fault current is limited in the range of 100% to 200% rms rated current. The fault contributions of these inverters are limited by their control and protection system. The fast switching frequencies these inverters use, allow them to detect large currents that may exceed their semiconductor ratings and stop operation within 0.5 cycles [25].

Some stand-alone inverters can also be operated as grid-tied inverters or in combination with other renewable energy sources as part of hybrid power systems. Modern inverters can achieve efficiencies higher than 95% (especially grid-tied inverters) and are warranted for 5 to 10 years in most cases. Most inverters have efficiencies above 85%. Figure 5.4 describes the price trend of inverter technologies on a per watt basis for the year 2007. The statistics do not separate existing technologies.

****

Figure 5 Inverter Price Index for 2007-2008

1. **Batteries:** These are most commonly used to store energy in stand-alone applications for use at times when no irradiance is available (e.g. night, rainy day). Batteries are also used for a diverse number of applications including stand-by power and utility interactive schemes. PV batteries require tolerance to deep discharges and irregular charging patterns. Some applications may require the batteries to remain at a random state of charge for a prolonged time. The most common technology used in PV systems is the lead-acid battery. These batteries are available in two major categories:
	* Flooded (Vented)- This is the regular battery technology most people are used to. It tends to be the cheapest option when only initial costs are of interest. In this battery, overcharge results in the conversion of water into hydrogen and oxygen gases. The gases are released into the atmosphere; hence the batteries require that the water is replaced adding a maintenance cost to the system.
	* Valve Regulated- The chemical characteristics of these batteries allow for maintenance free operation because the oxygen is allowed to recombine with the hydrogen within the battery. The recombination has a maximum rate which depends on the charging current. If excess pressure builds up, it is vented through valves to the atmosphere, proper charge control can limit this effect. These batteries tend to allow deeper discharge cycles resulting in smaller battery banks and are expected to have longer life times. There are two main technologies available: Absorbed glass mat (AGM) and Gel. Another advantage of these sealed batteries is that most are spill proof.

Nickel-Cadmium batteries can also be used in PV applications, especially where extreme temperatures are expected that could lower the battery life of lead-acid batteries. Some batteries of this technology allow discharges of 90% or more of rated capacity and tolerate prolonged periods at sub-optimal state of charge without damage or memory effect. Nickel-Cadmium batteries are 3 to 4 times more expensive per stored kWh and are highly difficult to dispose off due to their toxic potential. Battery technology is relatively old, and is often regarded as the weakest link in photovoltaic systems. Improper care of the batteries can seriously affect battery lifetime. Figure 6 displays the price trends for battery technologies within the lead-acid type



1. **Balance of System Components (BOS) and Charge Controllers**: BOS components typically constitute 30-50% of total system costs. They are all the additional elements necessary in order to properly install the PV system. The minimum requirements are regulated in the 2005 NEC (the 2008 version is now available as well) [7]. A comprehensive overview can be found in [18] BOS components may include:

 Conductors, conduits and boxes

 Overcurrent Protection (e.g. Fuses and Breakers)

 Ground Fault Protection

 Mounting Gear (support structure)

 Disconnects

 Metering Equipment

 Maximum Power Point Trackers

 Charge Controllers

 Battery Enclosures

The cost of the support structure could vary considerably depending on whether the system is to be mounted on the building wall, or roof, or whether it is to be ground mounted. For an array installed flush into a ceiling, support structure costs are negligible. More complicated structures may cost ~$200/m2. Tracking system costs are in the $300 to $1,200 per m2. Large or simple structures are in the lower boundary region of this range. Small complicated tracking systems are in the upper boundary region of this range.

System installation is in the $900 to $2,500 per kW [26]-[27]. Installation costs depend on system size, location and complexity. Larger systems could require heavy machinery and larger crews. Land based systems could require terrain preparation and trench digging.

Electrical equipment could cost ~$700/kW for simple or residential systems and

~$1,500/kW for industrial systems [26]-[27]. Costs are determined by system complexity and system size. Stand-alone systems generally have higher costs than grid-connected systems on a per watt basis.

Charge controllers are part of the electrical equipment costs. These control the current flow from the PV array to the battery in order to ensure proper charging. These controllers disconnect the PV array from the battery whenever produced energy exceeds battery storage capacity or the load whenever charge levels are dangerously low or reach a certain threshold. It is common for charge controllers to monitor battery voltage, temperature, or a combination of both to determine depth of discharge. The controllers extend battery life and are a safety requirement of the National Electrical Code (NEC) for residential and commercial installations. It is important to select a proper charge controller and controller settings for the battery type selected for the system. Some controllers can be adjusted to accommodate different battery types; some are built for specific battery technologies exclusively. Today, commercially available controllers can achieve efficiencies as high as 95%. Most charge controllers currently available rely on solid state technology to control current flowing into the battery bank; still some electromechanical relay versions available. Electromechanical relays can only perform classic on/off control (therefore little flexibility is possible), this control strategy can still be rough on the battery. Solid state controllers are more varied or flexible in terms of control strategies. Some of the possibilities are:

 On-off

 Constant Voltage

 PWM, constant voltage and with current regulation

 MPPT

Figure 6 displays the price trends of charge controllers over the last year. The price index for charge controllers is described in terms of the current rating. Price information does not distinguish between the different controller technologies, but most products available in the market today are based on solid state technologies and dominate the cost trends for this report.



Figure 6 Charge Controller Price Index for 2007-2008

The PV industry is relatively new. The industry has space for small companies which specialize in specific equipment, or large corporations which have expanded their product range to include PV related equipment. A list of component manufacturers has been compiled in Table 6.

|  |  |  |  |
| --- | --- | --- | --- |
| **PV Modules** | **Inverters** | **Batteries** | **Charge Controllers** |
| Air Therm | Advanced Energy Systems | Akku Solar | Apollo Solar |
| Aten Solar | Advanced Electronic Supply (AES) | Banner Batterien | Blue Sky Energy |
| Atersa | Beacon Power | Bären Batterie GmbH | BZ Products |
| Atlantis | Cherokee Electronics | C&D Batteries | DIREC |
| BP Solar | Exeltech | Concorde | Enermaxer |
| Canrom | Fronius | Crown Battery Manufacturing | ETA Engineering |
| Conergy | Go Power! Electric Inc. | Deka | Flexcharge |
| Duravolt | Heart Interface | Delco | GeoSolar |
| Energie Bau, Koln (EBK) | Omnion | Deta Batteries UK Ltd | Heliotrope |
| Eurosolare | Outback | Douglas | ICP Solar |
| Evergreen Solar | PowerPro (Tumbler Technologies) | Dyno | Lyncom |
| GPV | PowerSine | East Penn-Deka Manufacturing | Outback Power |
| GE Energy | PV Powered | Exide | Pico Electronics Inc |
| GPV | Sharp Electronics | General Battery Corporation (GBC) | Plasmatronics |
| Heliodinamica | SMA Regelsysteme | GNB | Morningstar Corporation |
| Helios Technology | Solarix | Hoppecke Batterien | Pulse Energy Systems Inc |
| IBC | Solsum | HUP Solar One | SES Flexcharge USA |
| ICP Solar | Soltek | Industrial Battery Engineering (IBE) | Specialty Concepts Inc |
| Isofoton | Statpower | MK Batteries | Sunwize Steca |
| Kaneka Corporation | Studer | Moll Batterien | Sun Selector |
| Kurzsolar | Xantrex Technology Inc | Northern Battery | SunAmp Power |
| Kyocera Solar |  | Optima | SunWize Technologies Inc |
| Mitsubishi Electric |  | Prevailer | Trace Engineering |
| Mitsubishi Heavy |  | Rolls Battery Engineering | Uhlmann Solarelectronic GmbH |
| MSK Corporation |  | Resource Commander | Vario |
| Matrix Photowatt |  | SEC Industrial Battery Co |  |
| Schott Solar |  | Solar Electric Specialties |  |
| Sanyo Solar |  | Sonnenschien |  |
| Sharp Corporation |  | Surrette Battery Co |  |
| Solara |  | Trojan Battery |  |
| Solar-Fabrik |  | US Battery |  |
| Solarwatt |  | Varta AG |  |
| SolarPort |  | Yuasa |  |
| Solarwerk |  |  |  |
| SolarWorld |  |  |  |
| Solon AG |  |  |  |
| SunPower, Spain |  |  |  |
| SunPower Corporation |  |  |  |
| SunSet |  |  |  |
| Suntech Power |  |  |  |
| Sunware |  |  |  |
| Total Energie |  |  |  |
| Webasto |  |  |  |
| Solmec |  |  |  |
| Uni-Solar |  |  |  |
| Yingli Solar |  |  |  |

* + 1. **3.6 PV MODULES**

A number of solar cells electrically connected to each other and mounted in a support structure are called a photovoltaic module. Modules are designed to supply electricity at a certain DC voltages such as 12, 24 or 48 volts. The current produced is directly dependent on how much light hits the module. Multiple modules can be wired together to form an array. A larger area of a module or array will produce more electricity. PV modules are rated on the basis of the power delivered under Standard Testing Conditions (STC) of 1 kW/m² of sunlight and a PV cell temperature of 25 degrees Celsius (°C). Their output measured under STC is expressed in terms of “peak Watt” or Wp nominal capacity [54]. A typical crystalline silicon module consists of a series circuit of 36 cells, encapsulated in a glass and plastic package for protection from the environment. Although PV modules are warranted for power output for periods from 10-25 years, they can be expected to deliver amounts of energy (voltage and current) for periods of 40 to 50 years [53]. Typical electrical information supplied by the manufacturer includes:

* + - * Polarity of output terminals or leads
			* Maximum series fuse for module protection
			* Rated open-circuit voltage
			* Rated operating voltage
			* Rated operating current
			* Rated short-circuit current
			* Rated maximum power
			* Maximum permissible system voltage

Table 7 and Table 7 summarize characteristics of various PV cell technologies

Table 5.5 Photovoltaic categories by semiconductor selection

|  |  |
| --- | --- |
| Crystalline silicon solar cells Market Share: 93% | * Monocrystalline, produced by slicing wafers (up to 150 mm diameter and 350 microns thick) from high-purity single crystal.
* Multicrystalline
 |
| Thin Film Solar Cells Market Share: 7% | * Amorphous silicon
* Pollycristalline materials: Cadmium Telluride (CdTe), Copper indium (gallium) Diselenide (CIS or CIGS).
 |

Table 5.5 Advantages and Disadvantages by solar cell technologies

|  |  |  |
| --- | --- | --- |
| **Cell Type** | **Advantages** | **Disadvantages** |
| **Single Crystal Silicon** | * Well established and tested technology
* Stable
* Relatively efficient
 | * Uses a lot of expensive material
* Lots of waste in slicing wafers
* Costly to manufacture
* Round cells can’t be spaced in modules efficiently
 |
| **Polycrystalline Silicon** | * Well established and tested technology
* Stable
* Relatively efficient
* Less expensive than single Crystalline Si
* Square cells for more efficient spacing
 | * Uses a lot of expensive material
* Lots of waste in slicing wafers
* Fairly costly to manufacture
* Slightly less efficient than Single Crystalline Si
 |
|  |  |  |
| Ribbon Silicon | * Does not require slicing
* Less material waste than single and polycrystalline
* Potential for high speed manufacturing
* Relatively efficient
 | * Has not been scaled up to large-volume production
* Complex manufacturing process
 |
| Amorphous Silicon | * Very low material use
* Potential for highly automated and very rapid production
* Potential for very low cost
 | * Pronounced degradation in power output
* Low efficiency
 |

**3.7 INVERTERS**

Inverters are electronic solid-state devices used to transform electric energy from DC to AC, as shown in Figure 5.7. The simplest inverter can be accomplished with a circuit similar to that shown in Figure 5.8. The ideal switches in the circuit may represent MOSFETs, IGBTs or bipolar transistors (depending on the power and voltage requirements). If the switches are turned on and off at the required AC frequency (S1&S3 and S2&S4), a square wave voltage can be obtained as shown in Figure 5.9. This is a simple control strategy, yet no control of load voltage is possible and high harmonic currents and voltages are present. High frequency pulse width modulation techniques are used to diminish harmonic distortion and provide load voltage control. Harmonic content may cause overheating in motor loads due to higher copper losses as well as uneven magnetic fields affecting overall operation. Sensitive electronic loads may also display erratic operation. Today, advanced control schemes and creative topologies allow the creation of AC with very low harmonic distortion; three phase designs are also possible by incorporating additional switches.



Figure 5.7 Representation of DC to AC conversion Process

Figure 5.8-Single Phase Inverter Conceptual Circuit

****

****

Many industries have found applications for inverters; hence design requirements tend to be specific to the needs of a particular application. A whole new industry has evolved around the need of a proper inverter to accommodate the needs of the relatively new solar industry, with both big and small manufacturers entering the market. PV modules produce DC outputs which are dependent on the irradiance, temperature and load operation. Stand-alone inverters operating with energy storage or batteries need a small DC voltage operating range to allow for voltage differences due to battery state of charge, and surge capacity to allow for safe and uninterrupted transient event operation. Grid-tied systems do not normally incorporate energy storage; hence larger DC voltage operating ranges are needed to accommodate both the varying operating conditions and module configurations. Maximum power point tracking control algorithms are normally included to take full advantage of the PV module energy production capabilities. Advanced protection functions are normally also included in order to guarantee safe operation in parallel with the distribution grid. These are just examples of specific requirements for PV inverters in their specific applications. The following section shall summarize current PV inverter characteristics, industry status and trends, especially in the grid-tied market, which is currently of most public interest. The industry challenges attended include:

1. Reliability
2. Inverter lifetime improvements
3. Higher inverter efficiencies
4. Production cost reduction
5. System and installation cost reduction
6. Unreliable or inadequate components or parts
7. Safety
8. Grid connection issues
9. Optimal circuit topologies, etc.

Grid-Tied inverters operate coupled to the electric distribution network and therefore the operation requirements are quite different from those of stand-alone inverters. Figure 5.10 shows a simple block diagram of a grid-connected PV system. Energy Storage is not considered in most grid-connected applications, hence it is not included in the diagram, but it could be an option depending on the reliability needs of the owner. In general terms the system can be divided into the solar panels and the power conditioning equipment, which includes: the maximum power point tracker, the inverter, the galvanic isolation (optional), and protection and control features. These components are commonly integrated in the same enclosure or unit as a way to reduce production and installation costs; hence it has been customary in the PV industry to refer to the combination of all these elements as the inverter. We shall adopt this practice.

Figure 5.10-Grid-Connected PV System Block Diagram

It is commonly said that grid connected PV systems are as good as their interfaces between the DC and AC power segments. As an example, the best solar modules in the industry will not be of great use if the power is not transformed efficiently and safely to useful levels at the load side. For the utilities it is of no use to allow the integration of DG systems that could degrade the quality of the electric power in the distribution network. Inverter failure will prevent any useful energy being produced. Proper inverter systems should include or consider the following:

**Maximum Power Point Tracker (MPPT)** - Nominal voltage and current conditions will not be available from the PV array at all times due to constant changes in solar irradiance. Figure 5.11 displays the I-V curves for a PV module at different operating characteristics. The MPPT guarantees optimum power is always obtained from the PV modules at any given operating condition. Different algorithms have been developed to achieve MPPT control, some achieving more than 98% of the PV array output capacity. The most popular is the Perturb and Observe (P&O) algorithm, this algorithm increases or decreases voltage in small steps and monitors the power output until maximum power point is found. A summary of available literature is available at



Figure 5.11- I-V Curves for a PV Module at different operating conditions

* **Inverter-** Inverters have the task of DC/AC conversion. There are two main categories of grid-tied inverters. Line-commutated inverters derive their switching signals directly from the grid line currents. The low switching frequencies produce harmonic currents that need to be filtered out. In the case of small single-phase inverters the bulky and expensive filtering networks are not practical. In the case of large three phase inverters, multiple units could be connected through a multi-phase isolation transformer at the utility output to filter any unwanted currents; the transformers should be rated to withstand additional heating due to harmonic current copper losses [20]. Self-commutated inverters derive their switching frequencies from internal control units as they monitor grid conditions, in particular frequency and voltage. Self-commutated inverters can be either voltage source inverters or current source inverters. PV modules behave like voltage sources; therefore our interest will be in voltage source type inverters. Voltage source type inverters can yet again be subdivided into current control and voltage control types. In applications where there is no grid reference, voltage control schemes are used and the inverter behaves as a voltage source. Where a grid connection is used the current control scheme is preferred and the inverter behaves as a current source. Operating the inverter under current control limits the possibility of active voltage regulation, a high power factor can be obtained with simpler control circuits (usually the power factor is kept as near to unity as possible), and transient current suppression is possible when disturbances as voltage fluctuations occur. Another advantage is that current related power quality disturbances related to inverter operation, like harmonics, can be controlled with easeand independence from voltage quality which then depends entirely on the utility. Problems caused by unusual utility voltages should be the responsibility of the utility because they are commonly associated to more complicated problems. It is important to understand that customer compliance to any standard should be independent to utility compliance to the same issue; the utility should not assume that the customer has total responsibility. The disadvantage of operating using current control is that it cannot operate as an isolated power source. Some inverters are able to handle both control functions to operate as grid connected and also provide conversion for storage batteries working as a backup.
* Table **5.6** summarizes the characteristics of voltage source inverters under different control strategies [23]. According to a survey from the IEA for inverters under 50kW, 19 % of inverters in the market use voltage control and while 81% use current control. High switching frequencies (3
* – 20 kHz) are used in some designs; therefore lower current harmonic content is possible without the need of using large filtering networks. The only problem is that higher switching frequencies result in higher losses reducing the efficiency of the inverter. Designers must find a balance between efficiency, power quality and size. Table 5.7 summarizes some of the tradeoffs associated with high efficiency according to

Table 5.6 Voltage vs. Current Control

|  |  |  |
| --- | --- | --- |
|  | Voltage Control | Current Control |
| Inverter main circuit | Self-commutated voltage source inverter (DC voltage source) |
| Control objective | AC voltage | AC current |
| Fault short circuit current | High | Low (limited to rated current) |
| Stand-alone operation | Possible | Not Possible |
| Higher Conversion Efficiency via | Semiconductor Costs | Magnetic Costs | Heat Removal Costs | RFIGeneration | Size to Weight | Circuit Complexity |
| Lower Switching Frequency |  | Increase | Decrease | Decrease | Increase |  |
| Lower Semiconductor Conduction Losses | Increase |  | Decrease |  |  |  |
| Natural Convection Cooling vs.Forced Convection |  |  | Increase |  | Increase | Decrease |
| Switching Auxiliary Power Supply vs. Linear | Increase | Decrease |  | Increase | Decrease | Increase |
| Lower Dissipation Snubbers |  |  |  | Increase |  | Increase |

* + - **Voltage and Frequency Synchronization**-Inverters should operate without problem for normal fluctuations of voltage and frequency at the utility grid side. The controllers must include protection devices that continuously monitor the grid voltage and frequency. If these go outside of the tolerable ranges established the unit should trip within an acceptable time frame, while permitting inverter operation through instantaneous voltage sags or swells. Inverter must inject current in phase with utility voltage (Power Factor=1).
		- **Islanding Protection-** Islanding occurs when a DG continues to energize a distribution network that would otherwise be de-energized for any reason (e.g. Breaker opens because of a fault). It has been determined that this is a low probability event and the probability of continued operation of DG’s is also very low, especially for residential grid tied PV systems which would not be able to perform load following. Yet in the event that load balance occurs, islanding represents a safety hazard.

Islanding protection is a requirement for all grid-connected distributed generation (DG).

* **Inverter Reaction to Faults-** Inverters rely on solid state technology for its operation and, unlike generators and motors; they have no inertia or considerable amounts of energy stored within them which means that they can react to faulted conditions almost instantly. The reaction of the inverter will depend on what it “sees” as terminal voltage and apparent load impedance during a fault. In event that the detection scheme takes longer than the anticipated or simply does not work, fault contributions, if any, will still be quite low, compared to utility short circuit currents, since inverters cannot supply currents much larger than the rated load current, the condition will cause the device to disconnect. Most grid-tied inverters are designed to operate under current control. These inverters use the utility voltage as reference to provide the current available from the PV, and are not able to operate as an island. The advantages of current control voltage source inverters are [23].

 PF~1 (employing a simple control scheme).

 Transient Current Suppression: The fault current is limited in the range of 100% to 200% rms rated current. The fault contributions of these inverters are limited by their control and protection system. The fast switching frequencies these inverters use, allow them to detect large currents that may exceed their semiconductor ratings and stop operation within

0.5 cycles [25].

* **Power Quality-**The concerns are mainly harmonic and DC current injection into the local distribution grids. A report of the IEA found that most PWM inverters can keep harmonic injection levels below 5% [8]. Harmonics cannot be eliminated completely due to the switching process involved in PWM, but high switching frequencies and filtering are used to lower THD at the AC output. Flicker problems should not be a major concern in the approval of inverters because voltage fluctuations on the DC side depend on solar irradiance, and have proven to be quite slow; also these inverters will operate as current sources and at unity power factor and reactive power demand in residences is not considerable.
* **DC Isolation (Galvanic Isolation) –** The early low power inverter designs incorporated a low frequency transformer at the output of the inverter; these are still present in most of the larger three phase inverters. In some cases an external transformer is used. The transformers could be regular ∆-Y distribution transformers in case of a three phase output or a single phase isolation transformer with a 1:1 ratio for low voltage single phase a connection. The transformers are used to prevent possible by product DC currents produced by semiconductor switching from being injected into the distribution network (DC currents may cause saturation of distribution transformers) and are commonly used as part of the harmonic filtering network within the inverter. The transformer also provides a safe grounding point while maintaining electrical isolation. The isolation transformer was a requirement in many electrical codes and utility regulations, yet most codes are no longer requiring galvanic isolation (including the NEC). Inverter designers have found ways to mitigate the problems mentioned before into acceptable levels. It is possible to use high frequency (HF) transformers embedded in an internal high frequency conversion stage, these are small, lightweight, and provide the electrical isolation Line Frequency (LF) transformers provide. Common line frequency transformers used in inverter outputs cause losses of around 2% and are the larger part of the inverter’s weight and cost. Transformerless designs are also possible, yet a regular full-bridge inverter cannot be used as a suitable grid-connection if both sides are to be grounded (the NEC requires PV arrays with operating voltages over 50V to be grounded), hence special circuit topologies are used. The Transformerless designs are cheaper, more efficient, and lighter. Modern power electronic devices tend to use more silicon and less iron.

The operating requirements for these types of inverters are in most cases determined by the local utilities, yet most utilities rely on existing standards to determine feasible technologies. The most referenced standards in the United States are the IEEE1547 and the UL 1741. These standards include the minimum requirements that manufacturers should include into their inverter designs in order to prevent adverse effects in the distribution grid [20]-[25]. Normally, embedded software applications monitor and control equipment operation to comply with standard requirements. Table 5.8 summarizes the disconnection requirements for grid-tied inverters operating under abnormal system conditions. The disconnection requirements are meant to protect the inverter and surrounding equipment as well as maintenance personnel servicing utility lines. Some inverters have better response than the minimum established by standards. The inverters are required to have a 5 minute wait time until they reconnect after normal grid operation is resumed. Table 5.9 displays harmonic current injection limits (even harmonics are limited to 25% of the limits in the table). DC current injections are limited to 0.5% of the rated current.

Table 5.8 Disconnection Requirements According to IEEE 1547

|  |  |
| --- | --- |
| **Condition** | **Trip Time** |
| Islanding | 6-120 cycles |
| V < 50% | 6 cycles |
| 50% < V < 88% | 120 cycles |
| 88% < V < 110% | Normal Operation |
| 110% < V <137% | 120 cycles |
| 137% < V | 2 cycles |
| 98.8%>f>101% | 6 cycles |

Table 5.9 Harmonic Limits According to IEEE 1547

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Odd Harmonic Order** | **H<11** | **11≤h<17** | **17≤h<23** | **23≤h<35** | **35≤h** | **TDD** |
| **%** | 4 | 2 | 1.5 | 0.6 | 0.3 | 5 |

**CHAPTER FOUR**

**SOLAR ELECTRIC GENERATION**

**4.0 ELECTRIC GENERATION WITH SOLAR CELLS**

The photovoltaic effect is the basic physical process through which a PV cell converts sunlight into electricity. Sunlight is composed of photons (like energy accumulations), or particles of solar energy. These photons contain various amounts of energy corresponding to the different wavelengths of the solar spectrum. When photons hit a PV cell, they may be reflected or absorbed. Only the absorbed photons generate electricity. When this happens, the energy of the photon is transferred to an electron in an atom of the cell (usually silicon atoms). The electron is able to escape from its normal position associated in the atom to become part of the current in an electrical circuit.

To produce the electric field within a PV cell, the manufacturers create a junction of two different semiconductors (types P and N). The most common way of making P or N type silicon material is adding an element that has an extra electron or has a deficit of an electron. Silicon is the most common material used in manufacturing process of photovoltaic cells. Silicon atoms have 14 electrons, where the four electrons in the last layer are called valence electrons. In a crystal solid, each silicon atom normally shares one of its four valence electrons in a covalent junction with another silicon atom. The silicon crystal molecule is formed of 5 silicon atoms in a covalent junction.

The process of doping introduces an atom of another element into the silicon crystal to alter its electrical properties. The element used for doping has three or five valence electrons. Usually Phosphorus is used to make the N type (Phosphorus has 5 valence electrons) and Boron the P type (Boron has 3 valence electrons). In a polycrystalline thin-film cell the top layer is made of a different semiconductor material than the bottom semiconductor layer

**4.1 COMMERCIALIZATION OF SOLAR POWER**

The path towards achieving sustainability in energy supply on a global scale is one of the key challenges for the twenty-first century. Since the industrial revolution, industrialized societies worldwide have had a consistent dependence on fossil energy sources to achieve economic growth. This dependence on fossil energy sources is still reflected in the global energy market at present. However, concerns about global climate change and energy security, particularly due to a high dependence on oil, have put pressure on governments to diversify their energy supply. In diversifying energy supply, the transformation of the energy industry has been identified as a key challenge for a sustainable energy future (Holdren, 2006; Jacobsson and Bergek, 2004; Jacobsson and Johnson, 2000; Unruh, 2000). This suggests that incumbent firms in this industry have a vital role in the development and commercialization process of renewable energy technologies. When looking at the key high-potential renewable technologies for widespread diffusion, wind energy is the most developed renewable technology. With an average annual growth rate in installed wind power capacity between 1980 and 1998 of 55% (Jacobsson and Johnson, 2000), and an average annual growth rate of 25% from 2002 to 2006 (REN21, 2008), wind energy has reached a cost-competitive level with fossil fuel-based energy technologies, and is the most widespread renewable energy technology (Gross et al., 2003). Contrary to the mature development stage of wind power, solar photovoltaic (PV) technology is an emerging technology, which grew relatively slow in the1990s, i.e. 22% annually (Jacobsson and Johnson, 2000). However, from 2000 onwards, investments in solar PV capacity have increased considerably, even leading up to an annual growth rate of 70% in grid-connected solar PV instalments in 2008 (REN21, 2009), and has thus become the fastest growing energy technology worldwide. With this global momentum in the growth of solar PV technology, a major avenue emerges to analyze the strategic approach of incumbent firms in the energy industry towards the development and commercialization of solar PV technology, as their powerful position in the industry might give them a pivotal position in the diffusion process of solar PV.

**4.1.1 towards the diffusion of renewable energy technologies**

Renewable energy has the potential to replace conventional fuels in four distinct sectors: power generation (grid-connected), transport fuels, water and space heating, and rural (off-grid) energy (REN21, 2008). As each of these energy sectors has its own characteristics, a renewable energy future is unlikely to depend on a single prevailing ‘silver bullet’ technology ending fossil fuel dependence. Instead, a wide spectrum of various renewable technologies will be more suitable for meeting the diverging demands of each of these four sectors. As Gross et al. (2003) identify, one of the most notable features of renewable forms of energy is the diversity of technologies, thereby indicating that renewable energy diffusion will lead to diversification in energy sources making energy markets less dependent on fossil fuels as a single source of energy. Experimentation with various renewable energy sources on a non-commercial basis commenced around 1973, when governments started investing considerable amounts of money on renewable energy research and development (R&D) as a reaction to the first major oil crisis in that same year (Jacobsson and Johnson, 2000). Since the early 1990s, commercial development of various forms of renewable sources has occurred, resulting in a range of modern renewable technologies of which solar PV, wind power, concentrating solar power (thermal and PV), marine power (wave and tidal), and modern biomass offer the best opportunities for widespread diffusion. Conventional renewable sources, predominantly traditional biomass and large hydroelectric installations, supplied around 17% of the world’s energy demand around the start of the century, but do not offer significant sustainable growth opportunities towards the future (Gross et al., 2003). Although modern renewable technologies currently account for only 1% of the world’s energy demand, projections of their contribution in meeting the world’s energy demand around 2050 range from 20% to 50% (World Energy Assessment, 2000). Embedded in the larger development of moving from fossil fuels to renewable technologies, solar PV has emerged as the fastest-growing technology in recent years with huge diffusion potential towards the future. The first commercial efforts to develop solar PV technology were initiated by the oil crises of the early 1970s, with governments investing in R&D to develop a solar alternative to fossil fuels (Tsur et al., 2000). However, these policies for stimulating solar investments lacked a long-term perspective and were strongly correlated with fossil-fuel price fluctuations. With fossil-fuel prices decreasing in the mid 1970s, investments in solar R&D decreased tremendously, with technological development only continuing for several smaller niche markets. From the mid-1980s to mid-1990s solar PV capacity started to grow with a modest growth rate of 15% (Gross et al, 2003), with an increasing importance for grid-connected systems after 1995 (World Energy Assessment, 2000). Influenced by an increasing awareness of issues such as energy independence and negative environmental consequences (e.g. climate change) of fossil fuel combustion in the early 1990s, R&D investments became more centred on developing a long-term-oriented alternative to fossil fuels compared to the 1970s. Investments in solar PV increased extensively after 2000 due to increased cell efficiency, reduced capital costs, and favourable policy, leading to annual growth in grid-connected solar capacity of 60% from 2002 onwards (REN21, 2008). The most vital component of solar PV technology is the solar cell, as the solar cell establishes the photovoltaic effect and therefore determines the conversion efficiency. Growth potential of solar PV essentially depends on two aspects: the achieved conversion ratio in the solar cell and the capital costs (installation and materials) associated with solar cell production. Solar cell types currently being commercialized are single-crystal cells (17% efficiency in 2007), polycrystalline (15% efficiency in 2007) and amorphous silicon (10% efficiency in 2007), which all are considered to be the first generation PV technologies. These technologies require major energy and labour inputs, which prevent significant production costs reductions, but are currently the most-installed type of solar cells (REN21, 2008). Second generation solar cells offer much greater potential for cost reductions and efficiency enhancement. These are thin-film cells that currently offer only 9-12% efficiency, but are in an early development stage with extraordinarily high potential for conversion ratios up to 60%, compared to 30% for first generation cells. In 2007, only 7% of solar cell production was thin-film cells, but they gained acceptance as a mainstream solar cell due to manufacturing maturity and decreased production costs. Despite this acceptance, conversion ratios are far from their potential, making it more viable to further invest in R&D before large-scale commercialization will take place (REN21, 2008). Goetzberger et al. (2002) define three scenarios for cell efficiency enhancement and cost reductions: (1) the continued dominance of present single-crystal and polycrystalline cells, (2) the introduction of new crystalline thin-film materials of medium thickness, and (3) the breakthrough of true thin-film materials that could potentially dramatically increase cell efficiency. All scenarios are equally plausible on the long term, although the first and second generation solar cells are more short term oriented and currently visible in the market, while third generation is more likely to occur in a longer timeframe (Gross et al., 2003). From an industry life cycle perspective, two main phases in industry evolution can be identified: a formative period and a market expansion period (Jacobsson and Bergek, 2004; Klepper, 1997; Utterback and Abernathy, 1975). The formative period is characterized by uncertainty in technologies, markets, and regulations, whereby a range of competing technology designs exist. Within this formative period, Jacobsson and Bergek (2004) identify four process features: market formation, entry of firms and organizations, institutional change, and the formation of technology- specific advocacy networks. All four features are beginning to emerge in the solar PV industry, whereby the first two are especially interesting in the light of this paper. Market formation is characterized by growth in multiple niche markets for which the technology is superior, usually also involving favourable government policy and investment incentives. It appears that the solar PV industry entered its market formation stage around 2004, when favourable policy towards solar PV became more widespread and solar PV was developed for multiple grid-connected and off-grid niche applications. This phenomenon is referred to as ‘protected spaces’ or niches, where technological learning process can take place, and where price of performance of the technology can be improved (Jacobsson and Bergek, 2004; Kemp et al., 1998). Three factors are particularly important in this industry’s formative period. First, solar cell efficiency and capital cost reduction for large-scale diffusion need to be achieved (Goetzberger et al., 2002; Gross et al., 2003; REN21, 2008). Second, policy should be developed to allow development in solar PV niche markets to support the learning effect from ‘learning by doing’, which positively influences large-scale diffusion of solar PV technology (Gross et al., 2003). Tsur et al. (2000) suggest that this diffusion process should be evolutionary rather then revolutionary in nature, also emphasizing that government-funded stimulating R&D programs should be adopted that are substantial and persistent in nature. Third, firm entry is essential in shaping the development path of an emerging technology, predominantly due to the resources and competences they bring into the industry (Jacobsson and Bergek, 2004). With solar PV growing tremendously, and huge opportunities for firms from various backgrounds to enter this growing market, assessing the impact of businesses on solar PV development is therefore essential.

**4.2 SOLAR PV DIFFUSION**

To investigate the behaviour of incumbent firms in the oil and gas industry regarding solar PV development and commercialization, we applied a multiple case study methodology. This methodology facilitates gaining rich understanding of the context in which the phenomenon is embedded (Yin, 1994). In this paper, the unique phenomenon is the emergence of a renewable energy technology in the oil and gas industry, which is fundamentally different from the fossil fuel-based technologies that are currently widely diffused in the supply chains of large oil and gas incumbents. As our sample we chose three major players in the European oil and gas industry, which have made ‘substantial’ investments in solar PV in the recent past: BP, Royal Dutch/Shell and Total. We collected data about corporate behaviour on solar PV development and commercialization from both corporate and independent third-party sources, thereby assessing whether the articulated corporate position of these firms on the importance of solar PV technology was in line with perceptions from outside. Data collection included corporate publications (i.e. firm annual reports and CSR/sustainability reports), publications of trade associations (i.e. the European PV Industry Association, the Energy, Solar Energy Industries Association, and the Solar Electric Power Association), and newspaper and magazine articles (i.e. New York Times, Wall Street Journal, Washington Post, Guardian, Economist, and Time magazine). To guide the analysis of the data, we first developed a research model (see figure 1). Our starting point was the assumption that the emergence of solar PV technology in the established oil and gas industry presents incumbent firms with a fairly disruptive technological innovation. Literature on the emergence of disruptive innovations shows that small entrepreneurial ventures provide the more heterodox, breakthrough innovations, while incumbent firms generally engage in incremental, sustaining innovations to optimize technology performance (Baumol, 2002; Bower and Christensen, 1995). At the same time, however, the bulk of expenditures in R&D and related innovative activities, are not carried out by small entrepreneurial ventures but by large oligopolistic firms (Ahuja and Lampert, 2001; Baumol, 2002). With the model we therefore envisaged gaining understanding of how incumbent firms can stimulate the development and commercialization of disruptive technological innovations, including the use of acquisitions and joint ventures as ways to gain control over disruptive innovations, rather than gaining insight into how small entrepreneurial ventures introduce new innovations and organically grow into larger corporations.

**CHAPTER FIVE**

**SUMMARY OF FINDINGS, CONCLUSION AND RECOMMEDATION**

The main aim of the research work is to examine the effect of solar power. Other specific objectives of the study include:

1. To examine the effect solar power on the economy of Nigeria
2. To examine the effect of solar power on poverty alleviation in Nigeria
3. To investigate on the factors affecting the effective implementation of solar in most industries in Nigeria
4. To compare the cost of implementation of solar power to other sources of power
5. To proffer solution to the above problem

**5.1 SUMMARY OF FINDINGS**

The following observations correspond to the results shown above:

The base case assumptions do not reflect immediate savings or grid parity. The yearly costs associated with the PV system are more than the expected savings during the first half of the project life. The annual savings are considerably greater on the second half of the project. It is interesting to notice that in base case conditions the cumulative cash flows are not far from reaching zero before the end of the project lifetime, even when conservative assumptions have been made. Cumulative cash flows would be shifted one year in favor of the owner if inverter replacements costs are halved, current projections indicate that this could be the case by the time the inverter replacement is needed. The results could be much better if system size is increased hence reducing the estimated annual O&M costs per kW which are dominated by the required insurance. We have chosen to use a 25 year life for the project to match typical manufacturer warranties. PV modules can have life times of over 50 years, the potential long range benefits are evident from the results provided in this analysis. Under the base case conditions the use of PV technology could be considered a better choice over regular utility service on the long term. The lack of immediate savings or grid parity suggest that only wealthier clients that are able to overcome the additional operational expenses during the first half of the project life will invest in such technology. The allowed tax credits could help shift the possible market for this technology. The current law governing PV tax credits allows the flexibility of dividing the allowed tax credits over a period of up to ten years, allowing the owner to use the credit in a manner that best suits its interests. The credit has the potential to completely damp the additional yearly costs associated with the PV system for approximately five years of operation and reducing the energy payback period by 4 years if a 25% credit is awarded. Cost damping for ten years is possible if a 50% credit is awarded; in this case cumulative cash flows would only be negative for eight years after the inverter is replaced (unless inverter costs are successfully lowered).

**5.2 CONCLUSION**

The effects of capital cost variations are considered in Table 5.25 to Table 5.27. The effects of deviations of up to 50% in initial capital costs have been determined. Capital costs up to 20% less than those used in the base case analysis could be expected for small systems (e.g. residential or small commercial). Capital costs below 20% of the base case costs could be expected for large systems or large volume clients (e.g. industrial, large commercial, utility and developers). Capital costs larger than the base case capital costs could represent installations using energy storage or custom modules or installations. According to the results, a reduction of 50% of base case initial capital costs will still require the system owner to incur in excess annual costs for the first 5 years of system operation. In this case the 25% tax credit could damp all excess costs.

**5.3 RECOMMENDATION**

It is interesting to notice that systems in the residential/small commercial capital cost range have payback periods smaller than the project life span although a conservative energy cost escalation rate has been used

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