SUN-TRACKING FOR PHOTOVOLTAIC SYSTEM IN EQUATORIAL ZONE COUNTRIES

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9 MARCH 2005

"I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor In Electrical Engineering (Power Industry)

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Date : 9/3/05

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A report submitted in fulfilment of the
requirements for the award of the degree of
Bachelor of Electrical Engineering (Power Industry)

Faculty of Electrical Engineering
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March 2005

"I declare that this study entitled "*Sun-tracking for Photovoltaic System In Equatorial Zone Countries*" is the result of my own research except as cited in the references. The study has not been accepted for any degree and is not concurrently submitted in candidature of any other degree."

Signature : ....
Name : SHALIZA BT. KAMARUDIN
Date : 9/03/05

To my beloved family

ACNOWLEDGEMENTS

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ABSTRACT

The study is to find out the declining angle ranges necessary for the photovoltaic (PV) system located in equatorial-zone countries to achieved highest power output throughout the year. The tasks are to study on how the PV system works, study the relationship of array's declining angle with the power output depending on the location, define the equatorial-zone with its countries located on it where the maximum output achieved significantly only when the sun-tracking system should be included, design the size of the motor needed for different type of PV panel, and compare the energy savings and other performances with the fix systems.

ABSTRAK

Tajuk projek ini adalah membuat pengkhususan untuk mencari penurunan susut untuk sistem photovolta (PV) di negara-negara zon tengah (khatulistiwa). Ia bertujuan untuk mencapai keluaran tenaga yang tinggi sepanjang tahun. Antara perkara yang perlu dilakukan untuk menjalankan projek ini adalah mengkaji bagaimana sistem PV bekerja, mengkaji hubungan antara sudut pancaran matahari dengan tenaga keluaran berdasarkan kepada lokasi. Kemudian mentakrifkan zon khatulistiwa serta lokasi negara-negara yang turut berada di dalamnya. Selain itu, kenalpasti maksiam keluaran yang tercapai jika sistem pengesan matahari diaplikasikan. Dalam pada itu, mengkaji saiz rekabentuk motor yang diperlukan untuk setiap jenis panel PV. Akhirnya membuat perbandingan antara sistem penjejak matahari dengan sistem PV tetap dari segi tenaga yang dapat dijimatkan, keluaran tenagan yang tinggi, kebolehupayaan untuk sinaran matahari yang maksima dan lain-lain.

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CHAPTER 1

INTRODUCTION

Photovoltaics (PV) is the term derived from Greek word for light - photos- and the name for unit of electromotive force - volt. Photovoltaics means direct generation of electricity from light. Recently this process is utilised by means of solar cells. The "solar cells", made from semiconductor materials such as silicon, produce electric currents when exposed to sunlight. By manufacturing modules which contain dozens of such solar cells and connecting the modules large power stations can be built. The largest photovoltaic power station that has yet been constructed is the 5 MW system at Carrisa Plain, California. The efficiency of photovoltaic power stations is presently about 10% but individual solar cells have been fabricated with efficiencies exceeding 20% [24]

The history of photovoltaics dates back to 1839 and major developments evolved as follows [24]:

- In 1839 Edmund Becquerel, a French physicist observed the photovoltaic effect.
- In 1883 Selenium PV cells were built by Charles Edgar Fritts, a New York electrician. Cells converted light in the visible spectrum into electricity and were 1% to 2% efficient. (light sensors for cameras are still made from selenium today).
- In the early 1950's the Czochralski meter was developed for producing highly purecrystalline silicon.

- In 1954 Bell Telephone Laboratories produced a silicon PV cell with a 4% efficiency and later achieved 11% efficiency.
- In 1958 the US Vanguard space satellite used a small (less than one watt) array to power its radio. The space program has played an important role in the development of PV's ever since.
- During the 1973-74 oil price shock several countries launched photovoltaic utilization programmes, resulting in the installation and testing of over 3,100 PV systems in USA alone, many of which are in operation today.

1.1 Photovoltaic System

The physics of the pv cell is very similar to the classical p-n junction diode (refer Figure 1.1). When the junction absorbs light, the energy of the absorbed photons is transferred to the electron systems of the material, resulting in the creation of charge carriers that are separated at the junction. The charge carriers may be electron ion pairs in a liquid electrolyte, or electron hole pairs in a solid semiconducting material. The charge carries in the junction region create a potential gradient, get accelerated under the electric field and circulate as the current through an external circuit. The current squared times the resistance of the circuit is the power converted into electricity. The remaining power of the photon elevates the temperature of the cell [9].

The origin of the photovoltaic potential is the difference in the chemical potential, called the Fermi level, of the electrons in the two isolated materials. When they are joined, the junction approaches a new thermodynamic equilibrium. Such equilibrium can be achieved only when the Fermi level is equal in the two materials. This occurs by the flow of electrons from one material to the other until a voltage difference is established between the two materials which have the potential just equal to the initial difference of the Fermi level. This potential drives the photocurrent [9].

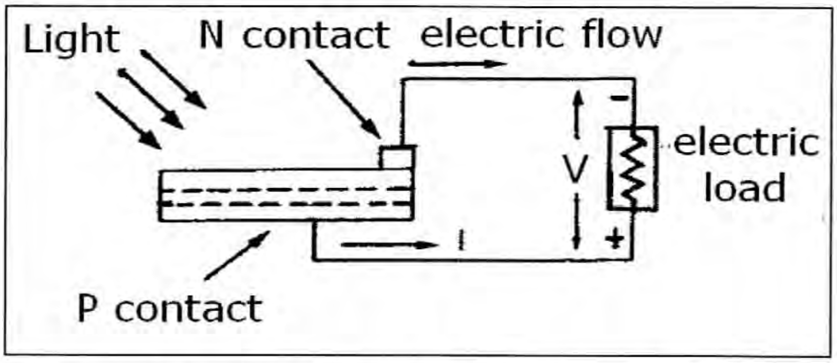


Figure 1.1: Photovoltaic effect converts the photon energy into voltage across the p-n junction [9]

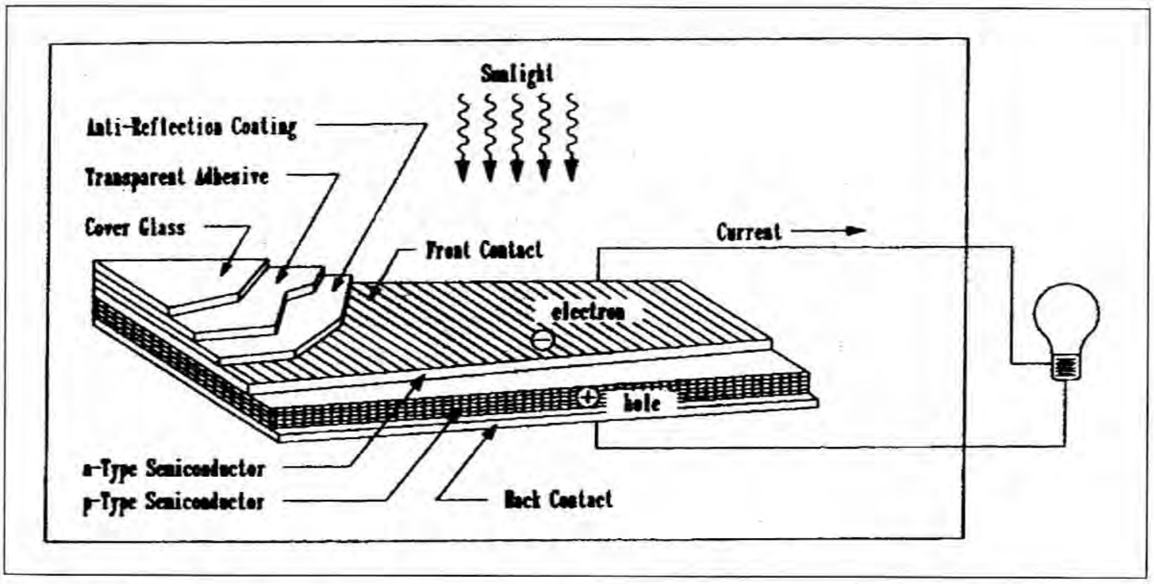
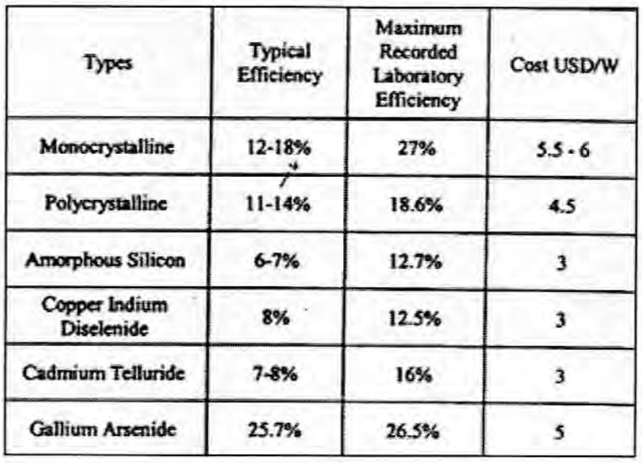


Figure 1.2: Basic construction of pv cell with performance enhancing features (current collecting mesh, anti-reflective coating and cover glass protection) [9].

Figure 1.2 show the basic cell construction. For collecting the photocurrent, the metallic contacts are provided on both sides of the junction to collect electrical current induced by the impinging photons on one side. Conducting foil (solder) contact is provided over the bottom (dark) surface and on one edge of the top (illuminated) surface. Thin conducting mesh on the remaining top surface collects the current and lets the light through. The spacing of the conducting fibres in the mesh is a matter of compromise between maximizing the electrical conductance and minimizing the blockage of the light. In addition to the basic elements, several enhancement features are also included in the construction. For example, the front face of the cell has anti-reflective coating to absorb as much light as possible by minimizing the reflection. The mechanical protection is provided by the cover glass applied with a transparent adhesive [9].

1.2 Photovoltaic Technologies

Table 1.1: Efficiencies and costs for various types of PV cells.[4]



Types	Typical Efficiency	Maximum Recorded Laboratory Efficiency	Cost USD/W
Monocrystalline	12-18%	27%	5.5 - 6
Polycrystalline	11-14%	18.6%	4.5
Amorphous Silicon	6-7%	12.7%	3
Copper Indium Diselenide	8%	12.5%	3
Cadmium Telluride	7-8%	16%	3
Gallium Arsenide	25.7%	26.5%	5

Today's solar cell production is almost exclusively based on silicon. About 80% of all modules are fabricated using crystalline silicon cells (multicrystalline and single crystalline) and about 20% are based on amorphous silicon thin film cells. The crystalline cells are the more common, generally blue-coloured frosty looking ones. Amorphous means noncrystalline, and these look smooth and change color depending on the way you hold them. Monocrystalline silicon has the best efficiency - about 14% of the sunlight can be utilized - but it is more expensive than multicrystalline silicon, which typically has 11% efficiency. Amorphous silicon is widely used in small appliances such as watches and calculators, but its efficiency and long-term stability are significantly lower; consequently, it is rarely used in power applications [23]. All the data above can be seen in Table 1.1 and Figure 1.3 [4].

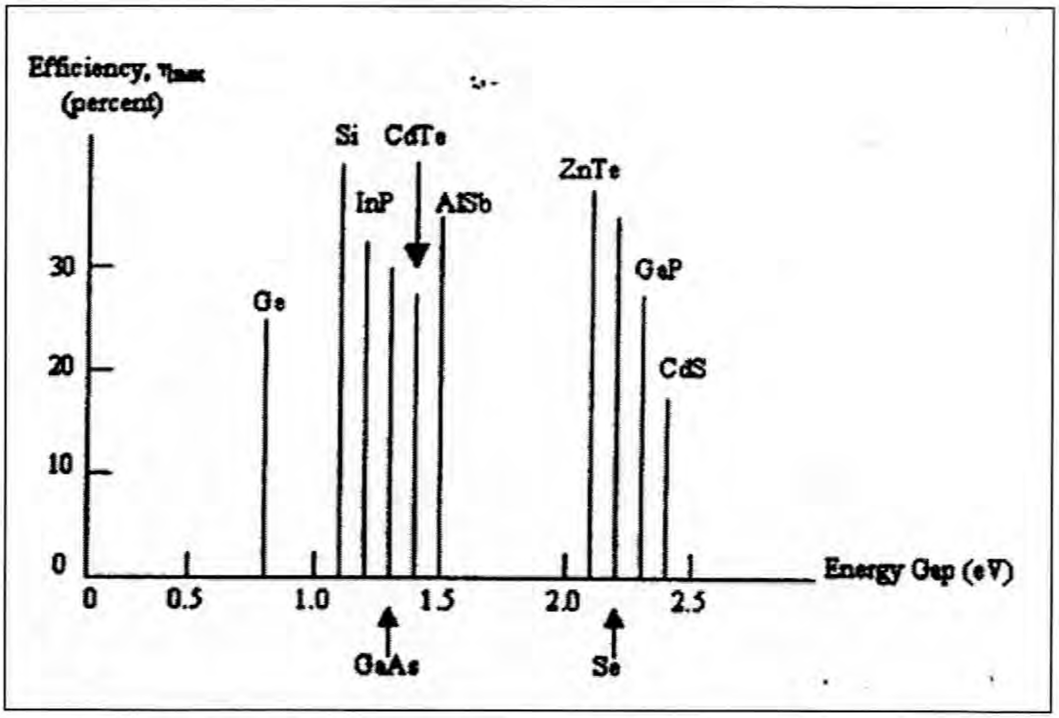


Figure 1.3: A calculated curve of the maximum efficiencies that can be obtained as a function of the energy gap for semiconductor materials made into a PV cell and illuminated with the solar spectrum outside the atmosphere [4].

1.2.1 Silicon Type

1.2.1.1 Single-Crystalline Silicon

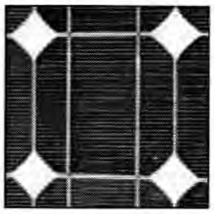


Figure 1.4: Single Crystalline PV [18]

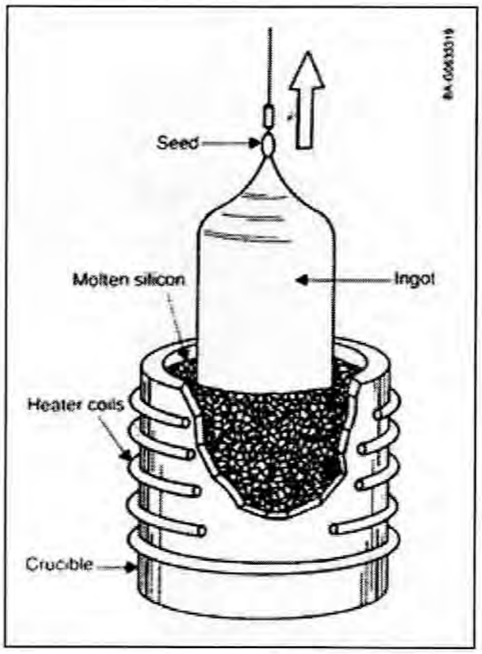


Figure 1.5: Single-crystal ingot making by Czohralski process. (Source: Cook,G., Photovoltaic Fundamental, DOE/NREL Report DE91015001, February 1995) [9]

The single crystal silicon (refer to Figure 1.4) is the widely available cell material and has been the workhorse of the industry. In the most common method of producing this material, the silicon raw material is first melted and purified in a crucible. A seed crystal is then placed in the liquid silicon and drawn at a slow constant rate. This results in the solid, single-crystal cylinder ingot (Figure 1.5). The manufacturing process is slow and energy intensive, resulting in high raw material cost. The ingot is sliced using a diamond saw into 200 to 400μm (0.005 to 0.010 inch) thick wafers. The wafers are further cut into rectangular cells to maximize the number of cells that can be mounted together on a rectangular panel.[9] The principle advantage of these cells are their high efficiencies, typically around 15% although the manufacturing process required to produce single crystalline silicon is complicated, resulting in slightly higher costs than other technologies [18]. While from the research; this cell has reached nearly 24-percent efficiency [13].

1.2.1.2 Polycrystalline Cells

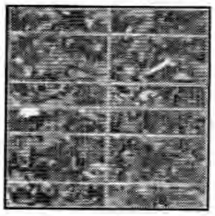


Figure 1.6: Polycrystalline PV [18]

The polycrystalline cells (refer to Figure 1.6) relatively a fast and low cost process to manufacture thick crystalline cells. Instead of drawing single crystals using seeds, the molten silicon is cast into ingots. In the process, it forms multiple crystals. The conversion efficiency is lower, but the cost is much lower, giving a net reduction in cost per watt of power [9]. From the research been done, the cells approach 18-percent efficiency, and commercial modules approach 14-percent efficiency [13].

1.2.1.3 Amorphous Silicon (a-Si) or thin film

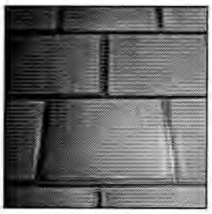


Figure 1.7: Amorphous Silicon PV [17]

A non-crystalline form of silicon, first used in photovoltaic materials in 1974. In 1996, amorphous silicon (refer to Figure 1.7) constituted more than 15 percent of the worldwide PV production. Small experimental a-Si modules have exceeded 10-percent efficiency, with commercial modules in the 5-7-percent range. Used mostly in consumer products, a-Si technology holds great promise in building-integrated systems, replacing tinted glass with semi-transparent modules [13]. Amorphous silicon vapor is deposited on a couple of μm thick amorphous (glassy) films on stainless steel rolls, typically 2000 feet long and 13 inches wide [9].

1.2.2 Gallium Arsenide (GaAs)

A III-V semiconductor material from which high-efficiency photovoltaic cells are made, often used in concentrator systems and space power systems. Research cell efficiencies greater than 25 percent under 1-sun conditions, and nearly 28 percent under concentrated sunlight. Multijunction cells based on GaAs and related III-V alloys have exceeded 30-percent efficiency[13]. Gallium Arsenide Cells (GaAs) is an attractive PV material. It has 1.43eV direct band-gap, along with a relatively high absorption constant. The used of GaAs are limited because of high production costs. One of its main advantage is there is no performance drop even with rise in temperature. Therefore, it is a good material for concentrator type solar cells. However, its disadvantage: gallium and arsenic are not so abundantly available compared to silicon. Thus, GaAs cells are rather expensive [21].

1.2.3 Cadmium telluride (CdTe)

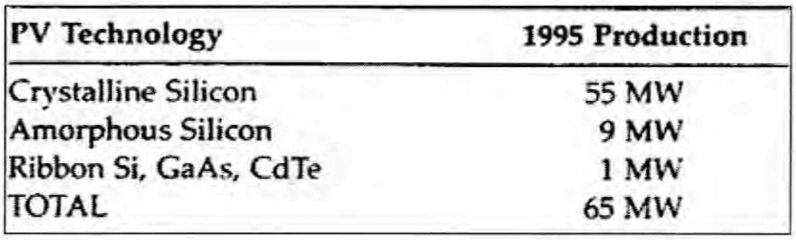
A thin-film polycrystalline material, deposited by electrode-position, spraying, and high-rate evaporation, holds the promise of low-cost production. Small laboratory devices approach 16-percent efficiency, with commercial-sized modules (7200-cm^2) measured at 8.34-percent (NREL-measured total-area) efficiency and production modules at approximately 7 percent [13]. The major problems plaguing the development of CdTe cells are the lifetime reduction of carries in the material and the difficulty of making low resistance contacts that do not degrade over time. Additionally, CdTe is attractive because of the variety of methods by which suitable layers can be produced. One of these ways is the electro-deposition of CdTe which is very feasible for commercial production of cells [4].

1.2.4 Copper Indium Diselenide ($CuInSe_2$, or CIS)

A thin-film polycrystalline material, which has reach the research efficiency of 17.7 percent, in 1996, with a prototype power module reaching to 10.2 percent. The difficulty in taking this technology to a production level lies in the difficulty in avoiding the formation of defects during deposition that prevent the formation of uniform layers [13]. The cost of CIS is more expensive than amorphous silicon or cadmium telluride modules because of the costs of raw materials. Indium is a moderately scarce resource; indeed if indium were converted into photovoltaic modules only 1% of our energy needed [17].

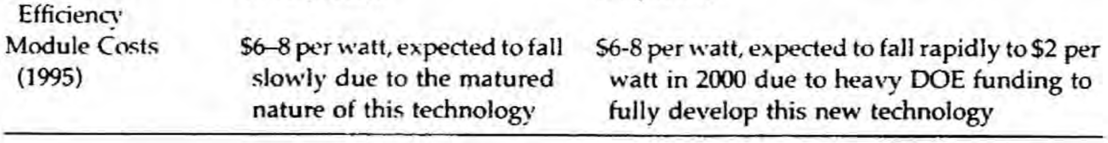
1.3 Production of various Photovoltaic cells

Table 1.2: Production Capacities of Various PV Technologies in 1995 [9].
(Source: Carlson, D.E, Recent Advances in Photovoltaic 1995. Proceeding of the Intersociety Engineering Conference on Energy Conversion, 1995)



PV Technology	1995 Production
Crystalline Silicon	55 MW
Amorphous Silicon	9 MW
Ribbon Si, GaAs, CdTe	1 MW
TOTAL	65 MW

Table 1.3: Comparison of Crystalline and Amorphous Silicon Technologies [9].



	Crystalline Silicon	Amorphous Silicon
Present Status	Workhorse of terrestrial and space applications	New rapidly developing technology, tens of MW yearly production facilities have been built in 1996 to produce low cost cells
Thickness	200-400 μm (.004-.008 inch)	2 μm (less then 1 percent of that in crystalline silicon)
Raw Material Cost	High	About 3 percent of that in crystalline silicon
Conversion Efficiency	16-18 percent	8-9 percent
Module Costs (1995)	$6–8 per watt, expected to fall slowly due to the matured nature of this technology	$6-8 per watt, expected to fall rapidly to $2 per watt in 2000 due to heavy DOE funding to fully develop this new technology

Almost all production has been in the crystalline silicon and the amorphous silicon cells, with other types being in the development stage. The annual productions of various photovoltaic cells in 1995 are shown in Table 1.2. The present status of the crystalline silicon and the amorphous silicon technologies is shown in