UTHM
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SAMBUTAN ULANG TAHUN KE-25 UTHM 1993-2018

SYARAHAN PERDANA

Siri 3 / 2018

Oleh:

YBhg. Prof. Emeritus
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Creating Electricity From Sunlight : Progress in Science, Technology & Development of Photovoltaics

8 Oktober 2018 (Isnin) | 10.00 Pagi
Dewan Auditorium 6,
Shared Facilities KPM,
Kampus Pagoh

"Dengan Hikmah Kita Meneroka"

SYARAHAN PERDANA 2018

CREATING ELECTRICITY FROM SUNLIGHT:

PROGRESS IN SCIENCE, TECHNOLOGY AND DEVELOPMENT OF PHOTOVOLTAICS

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Universiti Tun Hussein Onn Malaysia

Penerbit UTHM

2018

ISBN: 978-967-2216-28-5

Terbitan: Pejabat Penerbit
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CREATING ELECTRICITY FROM SUNLIGHT:

PROGRESS IN SCIENCE, TECHNOLOGY DEVELOPMENT OF PHOTOVOLTAIC

Prof. Datuk Dr. Mohd Noh bin Dalimin

PREFACE

Over the last 20 years, solar energy has emerged to become an attractive source of energy, especially the photovoltaics (PV) solar cell and has attracted many students and researchers from various discipline, including my area of interest in applied solid state physics. The purpose of this writing is a lecture in the honour of the award of professorship in UTHM and I believe, as a material useful to other readers who are interested on the subject.

My interest in photovoltaics started when I was in Imperial College, London from my colleague who was working next door, doping sodium into silicon. I was later challenged by my supervisor before leaving London that I should consider doing applied physics that is relevant to the people of Malaysia then, in 1981, as compared to doing the basic research that I was doing in Blackett Laboratory, Imperial College. On joining UKM, in 1981, the physics department was interested in solar energy. Solar thermal application for hot water, solar dry of agricultural produce, and also in the source of solar energy-solar radiation. Obviously then, funding and postgraduate students were not yet available-almost none.

In 1986-1987, the solar energy research group decided to seek funding from abroad and we started to seek support from Japan, New Energy Development Organisation (NEDO). As a result the group was provided with (i) meteorological and pv testing system, (ii) 1.2 kW of photovoltaic (pv) powered water pumping system, (iii) feasibility study on the application of solar pv for rural electrification and village grid connection (10 kW and 100 kW) in remote areas and (iv) a mini grid of 100 kW solar pv in Marak Parak, Sabah. Through ASEAN-CIDA funding, the group was also funded for research in a large scale solar thermal system for the drying of cocoa beans in Tawau, Sabah using solar walls, a Canadian technology.

Chapter 2 of the book introduces the solar cell, the basic unit of a photovoltaics module, as a simple current generator and some of the receiving parameter that are used to compare and describe solar cells. The early history of modern photovoltaic development is also given, and the early history, reaching back to 1839, is also describe in a simple technical detail. As we look back into our knowledge of photon. How do we manage photon flux density within solar cell as increasing the photon flux and will decrease the solar cell cost (cost per unit of energy converted).

Chapter 3 describes the work by the author of application of solar electric system, namely photovoltaic solar cells (PV) in Sabah, Malaysia, and more recent development in large scale grid/ FiT application. Further elaborates on the necessary balance of system, and how it is used in Malaysia for some basic rural electrification, navigational aids and remote telecommunication. The second part of this chapter focuses on the various possibilities of its application in other parts of the world in countries like USA, Japan, UK, Germany, China and India.

In chapter 4, the author also discusses several issues and challenges in development of PV solar system. Also, we look at the applications of PV technology for power generation and how the world is looking at it as a new source of energy is a big way, how can we be independent of oil in the future and to resolve the concern of global warming and climate change. Last part of the book discuss the edge of the possible future without oil and the ending remarks.

Finally, it is hoped that this lecture and book published, will provide audience and readers, the basic information needed to understand the principles of photovoltaic system application and to undertake some decision in making solar as a source of energy for the future. There may be many setbacks to face, problems to overcome, and challenges to be fought, but one thing is certain, the sun will be with us every morning, every day, and the many more years as one can remember.

“Science is but a perversion of itself unless it has as its ultimate goal for betterment of humanity.”

(Nikola Tesla)

Thank you.

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September 2018

ACKNOWLEDGEMENTS

During my 35 years working on solar energy, dozens of brilliant and dedicated people helped me learn the subject, which deal with science, engineering and applied technology. I received invaluable help from countless experts in the energy science and engineering- academics, researchers and company executives-who took the time to share their insight into the most important effort, critical and timely for our future world. My very early mentors, namely Professor David Caplin and Prof Brian Coles of Imperial College London; Professor Baharuddin Yatim, Professor Muhammad Yahya, Professor Muhammad Mat Salleh, Professor Noramly Muslim, Prof Zakri A.Hamid and Professor Jailani Sukaimi from Universiti Kebangsaan Malaysia (UKM) were indeed very helpful. They introduced me to solar energy. My colleagues Professor Yusof Othman, Professor Kamaruzaman Sopian both of UKM, and Professsor Kamarulazizi Ibrahim of Universiti Sains Malaysia (USM), many more, in other universities and organisations, namely, Tenaga National Berhad, Sabah Electricity Sdn Bhd, in UMS, UPM and UM were very instrumental in my early work in solar energy. The local leaders and villagers in Marak Parak and Mandahan Sabah, in Quion Hill cocoa plantation of Tawau Estate in Tawau Sabah, those who by any way supported my effort to put in place solar photovoltaics and solar drying technology in society. Thank you.

I also like to thank my international colleague from ASEAN Centre for Energy, New Energy and Industrial Technology Development (NEDO) of Japan, CIDA of Canada, JICA of Japan, International Solar Energy Society (ISES) and World Renewable Energy Network (WREN) for their support and assistance. Special thanks to Professor Ali Sayigh of WREN of UNESCO whose patience and dedication to renewable energy and his support to developing countries is second to none. Professor Yoshihiro Hamakawa of Osaka University, Professor Robert Hills of Northumbria University Newcastle, Professor Peter Dunn of Reading University, Professor Bill Charters of Melbourne University, and many others who give their support and advice to move forward in our work on solar energy in Malaysia. Thank you to all my students, from Malaysia, Philippines, Ghana and Indonesia, for their work and dedications.

Thank you to Fuji Electric Corporation, and Ebara Corporation, both from Japan, Gading Kencana Sdn Bhd and MRI Industries Sdn Bhd of Malaysia for being very helpful industry-

academic partners in solar energy and storage technology since the beginning of my work. Thank you to Universiti Tun Hussein Onn Malaysia for giving me this opportunity to work, to lead and to participate in this lecture series. Thank you to the vice-chancellor, deputy vice-chancellors, the dean and all from UTHM. Without their support and cooperation, my role in UTHM will be impossible to complete.

Finally, thank you to my family members, who encouraged, inspired, and supported me during a seemingly endless working life. My children, who endured it all cheerfully; and especially my wife, Professor Datin Dr. Maryati Mohamed, whose love and dedication kept me working to complete this lecture series.

CHAPTER 1
DIRECT ENERGY FROM THE SUN

1.1 Energy and global warming

In the last decade, the problem of climate change, has been a subject of intense discussion among leaders in science and government, and more citizen are getting aware of its consequences, and how it poses to human societies, globally. The more we understand about the subject, the greater the difficulties faced by the citizen of the world, to look for alternatives, with limited time available.

Over the last century, the average global temperature increased by 0.7^{o}C. The Alps ice-top and the glaciers ice melting. Strength and frequency of hurricanes has increased, and heat waves are more common now. The concentration of carbon dioxide in the atmosphere has risen from 280 ppm to the current level of 330 ppm. But carbon dioxide is not the only heat-trapping gas known, to be emitted by our activities on earth. Methane from the farms and agriculture, and in the extraction of coal and natural gas extraction. Nitrous oxide, from fertilizer used in agriculture is also known to cause heat trapping.

What brought us to this is known. When we burn oil, when we use coal, and other fossil fuels, carbon dioxide is released. It concentration increases and the earth is facing what is known as the greenhouse effect, and global warming. In many large cities like Beijing, Jakarta and New Delhi, with population exceeding 10 million inhabitants, high consumption of fossil fuel especially in the transportation sector, is choking the cities with haze and pollutant, unhealthy to human.

The changes to our global climate involves not only physical changes in the weather, sea levels, food production, water, but also major political and social upheavals, including struggles to have access to scare resources and human migration.

Our best and most certainly the right investment is to stop or reduce the burning of fossil fuel, and invest into building more solar powered system, especially to reduce our dependency on fossil fuel for power generation and the transportation sector.

1.2 Introduction to solar energy

The energy from the sun is approximately 1.8 x 10^{11} MW, which is many thousands times larger than the present consumption rate on the earth of all commercial energy sources. Thus, in principle, the solar energy could supply all the present and future energy needs of the world on a continuing basis. This makes it one of the most promising of the unconventional sources of energy. In addition, solar energy is inexhaustible, environmentally clean, free and available in adequate quantities in almost all parts of the world where people live. Politically, it is not controlled by any nation or company, or by any person on earth. In peace or in war, the source will continue to provide the power needed.

However, there are many challenges associated with its use. It is a dilute source of energy. Even in the sunniest region of the world, the solar radiation seldom exceeds 1 kW per sq. m., which is low value for technological utilization. Consequently, large collecting areas are required in many applications and these result in excessive costs. Availability of solar energy varies widely with time. The variation in availability occurs daily because of the day and night cycle and also seasonally because of the earth's orbit around the sun (although this variation is less serious in Malaysia). In addition, variations occur at a specific location because of local weather conditions. Consequently, the energy collected when the sun is shining must be stored for use during periods when it is not available. The need for storage also adds to the cost of any system. Thus, the real challenge in utilizing solar energy as an alternative energy is of economic in nature. One has to strive for the development of cheaper methods of collection and storage so that the large initial investment required in most applications are reduced.

1.3 Solar radiation

In considering the use of solar energy it is necessary to know the energy falling on unit area of the earth's surface per year and also the seasonal and other variations must be taken into account. Some of the important factors affecting the distribution of solar energy over the earth's surface will be discussed. The surface temperature of the sun is around 5,800 K and the radiation corresponding to this temperature can be divided into three: high frequency, visible and low frequency (Table 1.1).

Table 1.1: The radiation corresponding to surface temperature of the sun

Frequency	Radiation type	Wavelength (microns, 10^{-6})	Fraction of energy (%)
High	Ultra-violet	0.2 - 0.4	9
Visible	Light	0.4 - 0.7	41
Low	Infra red	0.7 – 3.0	50

Energy is continuously released from the sun by a fusion reaction which produces 3.94 x 10^{23} kW of power. Radiation from the sun takes about 9.3 min to cover 150 milion kilometers to earth. The earth receives only a small fraction of total energy emitted by the sun with a total of 1.73 x 10^{14} kW or 340 W/m^2 averaged over the whole earth's surface.

1.4 Characteristic of solar radiation

Solar radiation is made up from electromagnetic waves which travel from the sun to the earth with speed of light, c. The wavelength, λ of the wave is related to the frequency by the equation of:

$$c = \lambda v$$

The velocity of electromagnetic waves when transmitted through materials is less than value of c for vacuum (3 x 10^8 m/s). It was Newton who first demonstrated that sunlight or white light can be split up into its different component wavelengths or colours known as solar spectrum. The solar spectrum contains wavelengths which are too long to be seen by naked eye (infra-red) and also wavelengths which are too short to be visible (ultra violet). Figure 1.1 gives a rough indication of the variation of intensity with wavelength of solar radiation. The vertical axis is given in units of watts per square meter per micron of wavelength; that is it gives the power per unit area between the wavelength range of λ and λ + 1, where λ is measured in microns. With these coordinates the area under the curve gives the total power per square meter radiated by a surface at the specified temperature.

The solar spectrum is roughly what would be given by a perfect radiator (black body) at a temperature of 5800 K. Water vapour, dust and absorption by various molecules in the air absorb certain frequencies strongly such that the spectrum received by the earth's surface is modified. The earth itself also radiates as a black body, but at a much lower temperature than the sun, around 300 K. It is seen that the earth receives its radiation at a short wavelength around a peak of 0.5 μ whereas it radiates to space at a much longer wavelength around a peak value of 10 μ, which is well into the infra-red. The relationship between the wavelength λ_{max} at which the power radiated is a maximum and the temperature of the body T is given by Wien's Law, which states

$$\lambda_{max} \times T \approx 3 \times 10^{-3} \text{ m/K}$$

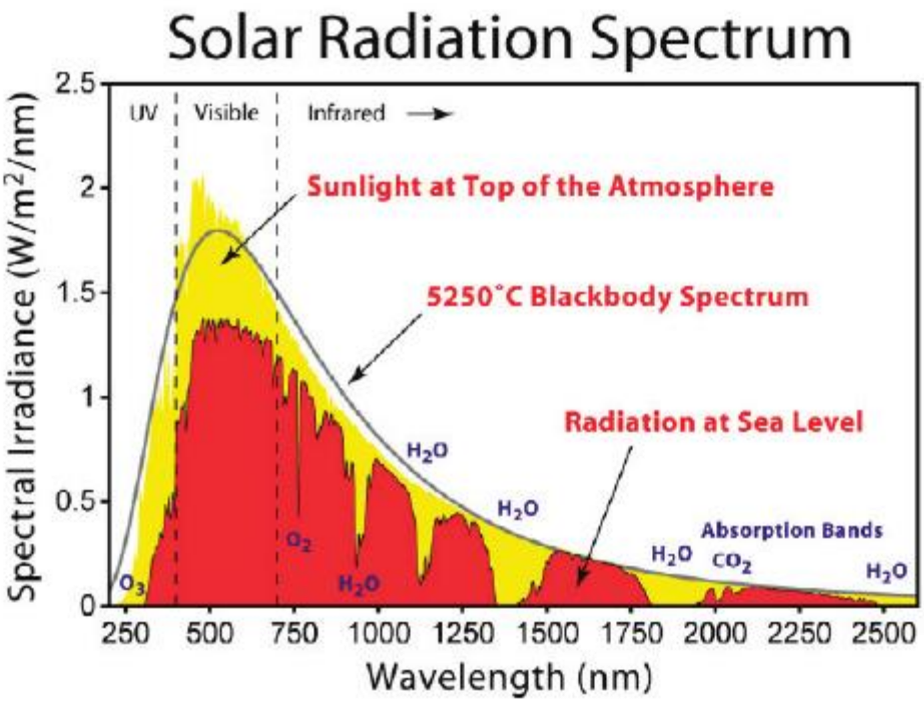

Fig 1.1: Solar spectrum

1.5 Quantum effect

Previously, sun radiation was described as electromagnetic waves obeying the relationship:

$$C = \lambda v$$

This is quite true but it is also found that electromagnetic waves show properties that might be expected from particles. In particular they behave as if they were made up of packets of energy, having an energy E which is related to frequency by the equation:

$$E = hv, \text{ where } h = 6.626 \times 10^{-34} \text{ Js}$$

These packets of wave energy are called photons and the equation which relates the photon energy to the frequency is called Planck's equation after the physicist who first developed the theory. The photosynthetic process depends on the quantum characteristics of solar radiation. The photocell also uses this mechanism.

Quantum conversion mechanisms rely on a minimum energy to remove an electron from its parent atom. The energy gap E_g that the photon must supply if the desired electron transition is to be achieved. If the energy E of the photon is less than the energy gap E_g then the effect will not occur. If the energy of the photon is exactky equal to the gap then the required will be available without waste. However if the photon has a higher energy than is required then the excess energy will be wasted and appear as heat. The choice of energy gap to achieve maximum power conversion is therefore a critical factor in the choice of materials for photovoltaic converters. If the energy gap is small then a large number of photons will have sufficient energy.

The average intensity or power/unit area falling on a surface of unit area placed at the earth's outer atmosphere and at right angels to the incident radiation is called the Solar Constant. In S.I. units, the Solar Constant is 1.36 kW/m^2. Apart from the very small fraction of solar radiation which is converted to fossil fuel all the energy received from the sun is eventually re-radiated into space. If this were not so the earth's temperature would rise continuously.

1.6 Insulation of the outer atmosphere

If the earth is represented as a sphere, then at the equator a horizontal surface at a point immediately under the sun would receive 1.36 kW/m^2 continuously. Horizontal sufaces on the same longitude but different latitudes would receive correspondingly less. If the earth were to rotate about an axis vertical to the earth's sun plane then all points at the same latitude would receive the same average radiation. This would be a maximum for points at the equator and zero for points at the pole.

In fact the earth does not rotate about an axis which is perpendicular to the plane of the orbit around the sun but instead rotates about an axis which is inclined at an angle of 23 1/2° to it. This modifies the solar radiation. The effect of this modification is to give rise to a seasonal variation of solar radiation. Surprisingly, more radiation falls on the polar regions in the summer than at the equator. An important feature is the absence of seasons at the tropics and the extremes of six month summer and six month winter at the poles. Another feature of significance is the twelve hour day, twelve hour night in the tropics compared to the short night/ long day summer cycle in temperate areas and the reverse in winter.

1.7 The effect of the earth atmosphere

As might be expected the earth's atmosphere considerably modifies the simple model given in the previous section. The length of path through the atmosphere will depend on the angle that the sun makes with the vertical at a particular position on the earth's surface. Some of the incident radiation is directly reflected by the earth's atmosphere, the remainder is absorbed either by the atmosphere or the earth's surface.

Above 150 km the incident radiation is not affected by the atmosphere: by 88 km the X-rays and some of the ultra violet have been absorbed. Between 18 and 15 km the greater part of the ultra violet has been removed. As the radiation approaches the earth's surface gas molecules in the air cause scattering, particularly at the shorter wavelength end of the spectrum. This effect gives rise to the blue sky and the red appearance of the sun. The latter is particularly pronounced at sunset and sunrise due to the increased parth length through the air. Clouds and dust also cause scattering and absorption.

It is seen that about 30% of the incident solar radiation is reflected by the atmosphere, a further 20% is absorbed on passing through the atmosphere and the remaining 50% arrives at the earth's surface, where 2% is reflected and the remainder absorbed. An amount equal to 23% of the original solar energy incident on the outer atmosphere is used in evaporation and the remainder is lost by long wave radiation. Since the atmosphere radiates long wave radiation to the earth's surface the net long wave loss from the earth's surface will be the difference between these two heat fluxes. About 0.2% is absorbed by the atmosphere in the form of winds and ocean currents. Photosynthesis accounts for only 0.05%. For the most favoured regions the average flux density is as high as 300 W/m^2 and the average for the tropics is about 250 W/m^2.

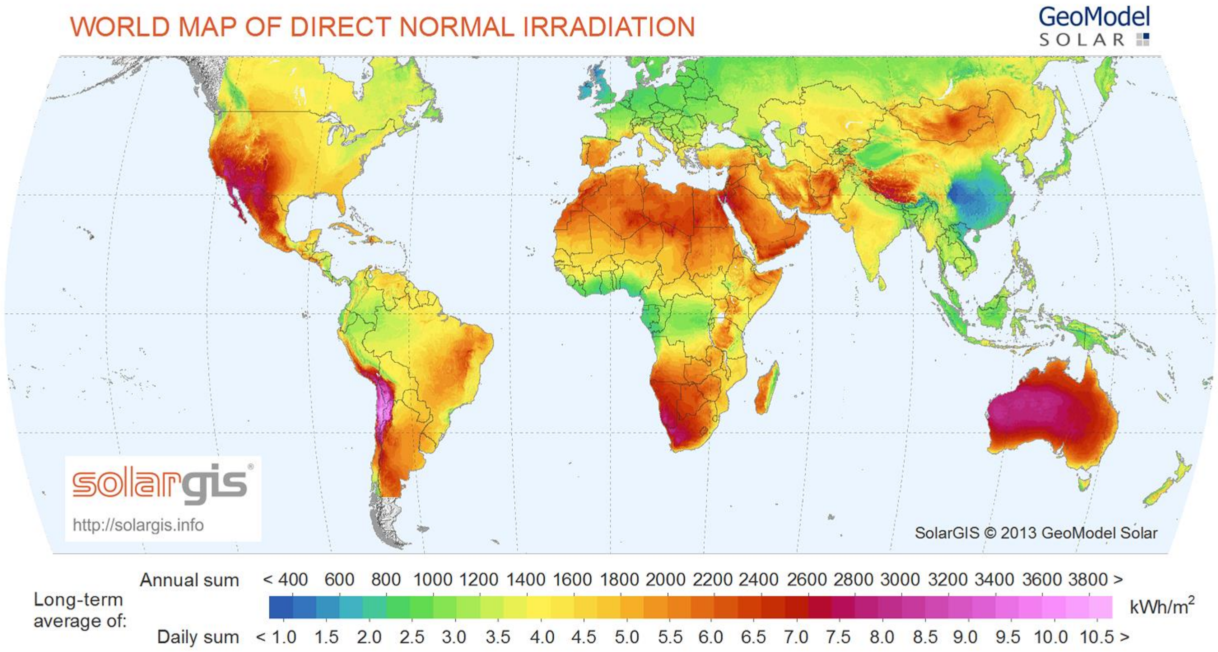

Figure 1.2: World map of direct normal irradiation

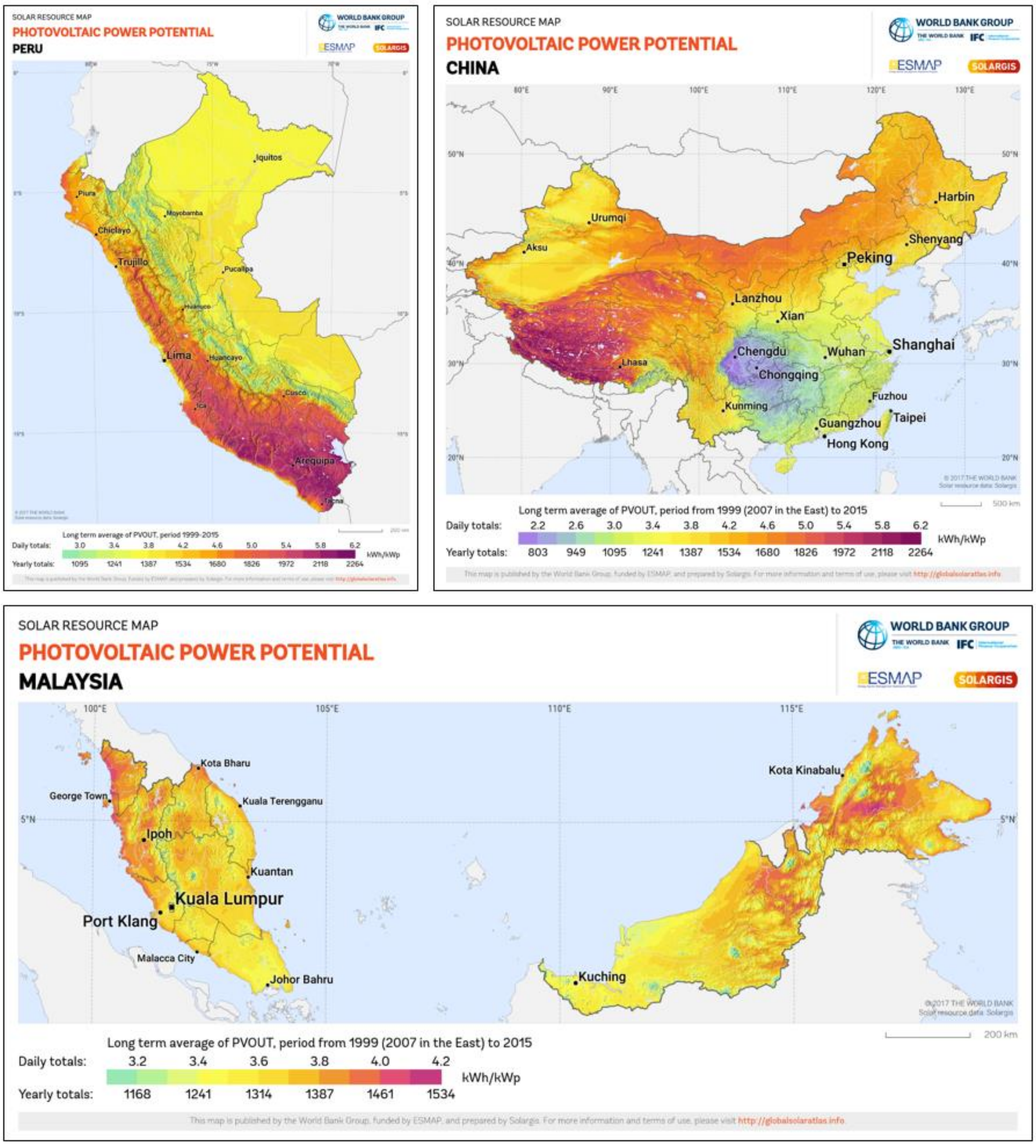

Figure 1.3: Comparison of solar power potential (pv) in three countries; Peru, China and Malaysia **Source for solar irradiation: https://solargis.com/maps-and-gis-data/download/china**

1.8 Solar radiation in Malaysia

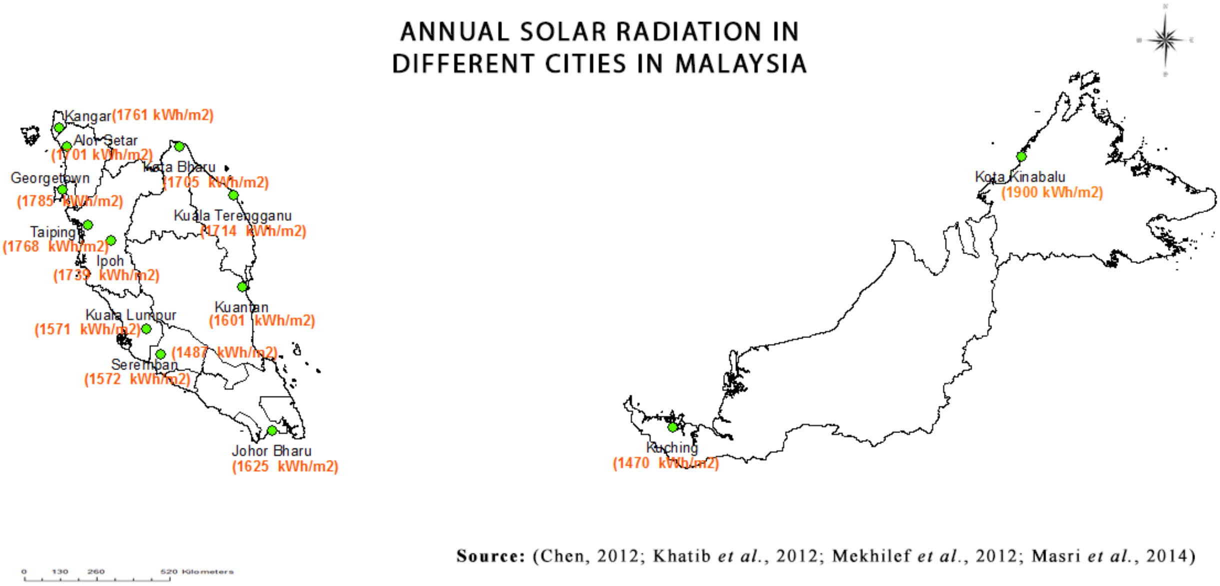

Figure 1.4: Annual solar radiation in different cities in Malaysia

Summary

As far as large-scale power generation is concerned, there is only one possible application, that is, the large scale electrical power generation with grid connection as a peaking power generator and to off-set power losses due to transmission (which may be caused by increase in resistance of transmission lines because of increase in temperature during the day). Other indirect applications, such as wind energy, energy plantation for biomass and alcohol production from plants and biogas, are clearly site specific and care would have to be taken in selecting sites.

As conclusions, there is of a strong opinion that solar technology in terms of scientific and theoretical principles, is well established. Its transformation into technological hardware which is intensively carried out in several countries will continue and when the aspect of environment is taken into consideration, the viability of large scale solar powered system may soon be established.

The practical use of solar energy has become a reality and has a great potential to be developed to benefit the needs of countries like Malaysia. However, applied R and D, technology assessment, prototype field analysis, assessment of the reliability of products including techno-economic and cost analysis, development of manufacturing technology, entrepreneurship, promotion, and eventual local manufacture will be needed. Greater inter-government cooperation, especially among the developing countries (such as the G15 countries) may be needed to assist each other in using their limited resources of manpower and capital.

It is also recommended that the government give sufficient priority to initiate a programme of action in the field of solar technology. This may require allocation of a solar technology programme to an existing appropriate institution and provision of relevant fundings and technical manpower and development of a practical work plan, such as the FiT programme.

Finally, the current development plan by the various government agencies in Malaysia especially the Ministry of Rural Development in providing electricity to the rural communities in Sabah and Sarawak and in several islands in Peninsular Malaysia should be continued and speeded up. Rural electrification is an important component of national development and the existence of solar technology has made the effort feasible in areas where earlier grid extensions system is not possible.

CHAPTER 2

S & T OF PHOTOVOLTAIC SOLAR CELLS

2.1 The general physics of photovoltaic

What is electron?

What is an electron? What is an atom? These two questions are to basic to be asked. However, it is good to remind us because they mean a lot in this technology and the basis of solid state physic.

Basically, all matters are made of particles called atoms. Atoms bond to each other to form elements, which contain only one kind of atom. Atoms consist of **three** parts, namely:

i. **Proton** – the basic of an atom, it identifies the element based on the number of proton (Z).
ii. **Neutron** – the number of neutrons in an atom is indicated by the letter N. The atomic mass of an atom is the sum of its protons and neutrons or Z + N. The strong nucleur force bond the protons and neutron together, the form the nucleus of an atom.
iii. **The eletrons** are much smaller, much lighter, then both neutrons and protons and orbits around them.

Niel Bohr proposed the **Bohr Model** of the atom in 1915. The model is described as the model based upon electrons orbiting around the positively charged nucleus, which have a set size an energy. The Bohr model is a planetary model in which the negatively-charged electrons orbit a small, positively charged nucleus similar to the planet orbiting around the sun. The modern atom is based on quantum mechanic, which we do not intend to discuss in this book.

The electrons of isolated atoms have well defined discrete energy levels. In solid material, in which atoms are close to each other and in term of the individual level, spread out and forms bonds. Thus in a semiconductor device, such as a diode or in our case a solar cell, the electron flow in the device will provide the electrons and works as a generator.

What is photon? (The smallest unit of light)

Photons are energy particles, with variable energy and sunlight is composed of these particles, photons. Since the solar radiation also has a wave-like character; the wavelength is being inversely proportional to the portion energy E, where E $\alpha \frac{hc}{\lambda}$, with *c* the velocity of light in vacuum (2.998 x 10^8 ms^{-1}) and *h* Plack's constant (6.626 x 10^{-34} Js).

The photovoltaic effect

The basis for photovoltaic energy conversion is the absorption of photons by a semiconductor. Absorption of photons (*photons in*), of some appropriate energy, the semiconductor materials will energize the electrons in the semiconductor materials (*electron out*) and a solar cell is made to operate.

The radiant energy, absorbed by a device, a photovoltaic converter, is designed to convert the incident solar energy, the photons, causes the proportion of an electron to a state of higher energy (an excited state). These electrons, which are at the excited state should be separated from the ground state by an energy gap which is large compared to k_BT, where k_B is the Boltzmann's constant and T is the temperature.

To complete the conversion process, the excited electrons must be extincted and collected. Thus a photovoltaic conversion is similar to photochemical energy conversion (e.g. in photosynthesis), in that the medium energy produces an electronic potential energy, rather than heat. In the case of photosynthesis, the excited electron population drives a chemical reaction, the conversion of CO_2 and water into carbohydrates, rather than driving an electric current. But in either are photovoltaic or photosynthesis, the solar energy results in a net flux of electronic potential energy constituting work.

2.2 Photovoltaic cells (a semiconductor p-n junction) and its characteristics

Photovoltaic or solar cells are made from semiconductor materials; that is, a solid material that conductor electricity when heat is available, but act as an insulator at low temperatures. At present, several materials are available for making solar cell, but most solar cells are made of silicon, which is considered as the most matured technology. A lot of research has been and still is going on to look for better and cheaper materials and may supersede silicon in the future.

In solid state physics, the electrical properties of semiconductors can be explained using two models, the *bond model* and the *band model*. The two models are described briefly below;

1. **The Bond Model**

The bond model is a model used to describe the uses of covalent bonds joining the silicon atoms, in order to describe the semiconductor behaviour as illustrated in Figure 2.1.

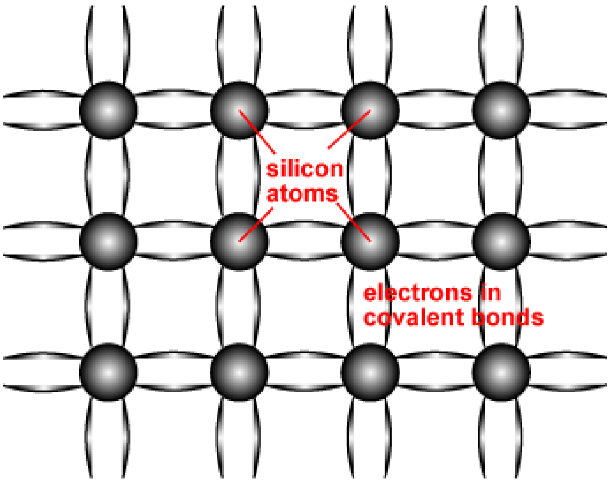

Figure 2.1: Schematic diagram of a covalent bonds in a silicon crystal lattice

At low temperature, the bond are intact and the silicon behaves as an insulator. At high temperature, some bonds are broken, and the conduction of electron can occur by two methods which are (i) electrons from broken bonds are free to move and (ii) electrons from neighboring bonds can move into the hole. The concept of moving hole is similar to that of a bubble in a liquid; although it is actually the liquid that moves, it is easier to describe the motion of the bubble going in the opposite direction.

2. The Band Model

This model described semiconductor behaviour in terms of the energy levels, between the valence bond and the conduction band (Figure 2.2).

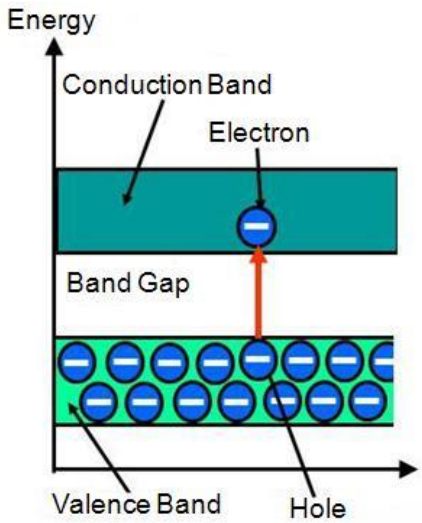

Figure 2.2: Schematic diagram of the energy bands for electrons in solid

The forbidden gap corresponds to the amount of energy needed to release an electron from the covalent bond to the conduction band, when the conduction of electron is possible. The holes remaining conduct in the opposite direction in the valence band, as described in the bond model.

Doping with other atoms

Atoms with one more valence electron than the semiconductor can be used to dop to produce ‘n-type’ material. Atoms with one less valence electron result in ‘p-type’ material (Figure 2.3).

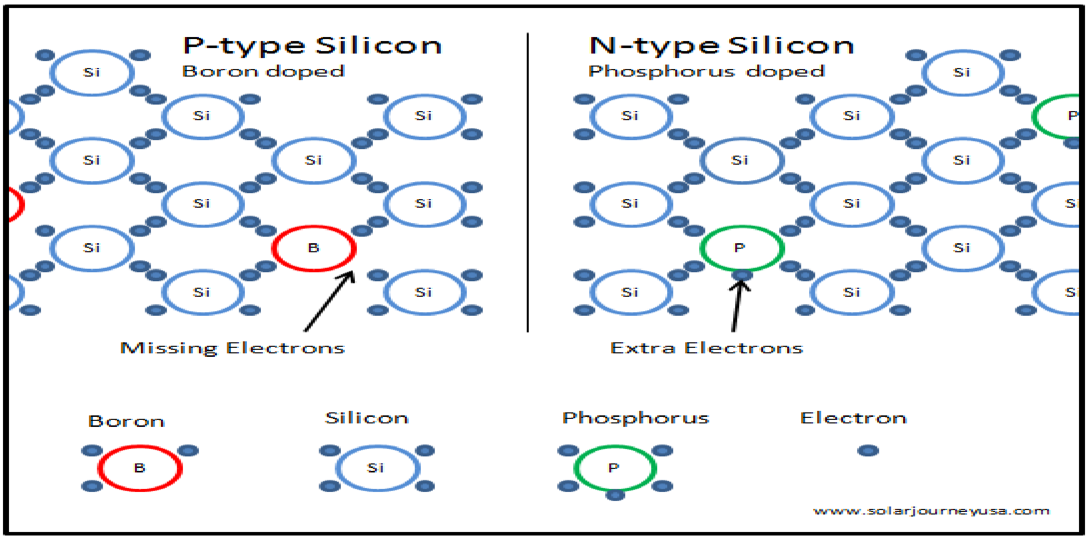

Figure 2.3: Doping with impurities; (a) 'p-type' doped with boron and (b) 'n-type' doped with phosphorus

Crystalline silicon

Let's take the simplest material, a crystalline silicon has a known crystal structure, with each atom ideally lying in a pre-determined position. Thus, all the known characteristic as described earlier is applicable, although the process of making crystalline silicon is longer than that in a multicrystalline and also amorphous silicon, although these are less ideal qualities.

P-N junction

If we joint n-type and p-type semiconductor materials (e.g. p-type silicon and n-type silicon), a p-n junction is formed (Figure 2.4).

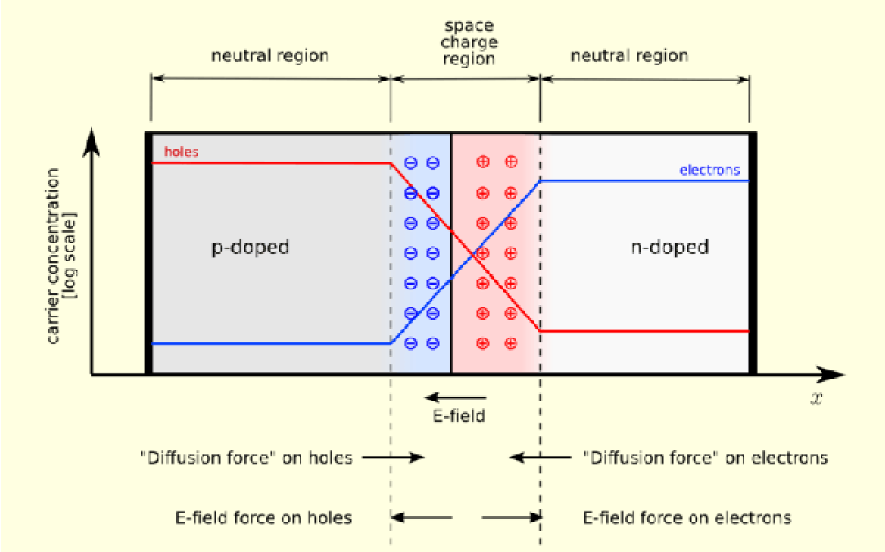

Figure 2.4: Formation of P-N junction

When light falls onto the junction, photons with energy (E_{pn}), the photons with energy greater than the band gap ($E_{pn} > E_g$), the energy will interact with electrons in covalent bonds, using up their energy to break bonds and create electron-hole pairs (Figure 2.5).

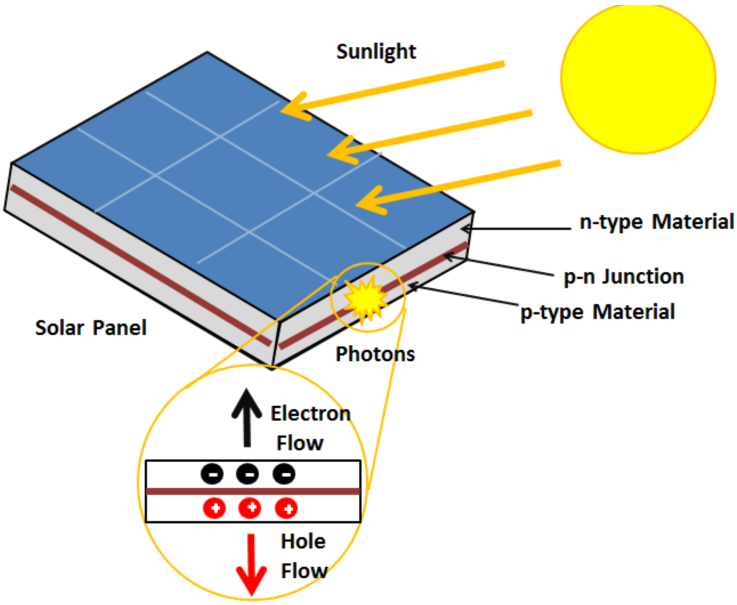

Figure 2.5: Photon in – electron out

In a simple form, the solar cell can be described as a cell made of semiconductor in which the incident photons are absorbed and create electron-hole pairs. In order that this pair, can dissipate its power in an external circuit, the electron (-ve) and the hole (+ve) must be separated. A voltage will be present between the external contacts of the circuit, and power can be generated in an external load.

2.3 Efficiency of photovoltaic solar cells

An efficienct solar cell must have the following:

i. Sufficient absorption of photons creating electron-hole pairs.
ii. The generated pair must be separated, electron in the n-type region and holes in the p-type region.
iii. The built-in potential must be sufficiently large.
iv. The atomic voltage drop, caused by parasitic resistances must be small.
v. The metal grid covering must be small, since thick metal layers are not transparent.

Meanwhile, the losses and limiting factors to the solar cell are:

i. Loss by long wavelength (low energy photons).
ii. Loss by excess energy of the photons (energy greater than the band gap).
iii. Loss by metal coverage (the metal contacts both +ve and –ve electrodes).
iv. Loss by reflection.
v. Loss by incomplete absorption of photons due to the limited thickness of the cell.
vi. Collection efficiency.
vii. Voltage factor (maximum operating voltage).
viii. The fill- factor (based on the I-V characteristic of the cell).

2.4 A brief history of the solar/ photovoltaic solar cell

The first photovoltaic device was demonstrated in 1839 by Alexandre - Edmond Becquerel (1820-1891), as a young 19 year old physicist working in his father’s laboratory in France.

He was the second of three generations of eminent French physicist. Becquerel conducted extensive research in the fields of magnetism, electricity and optics. However, the understanding and exploitation of this effect was to depend on some of the most important scientific and technological developments of the 20th century, namely;

i. development of the quantum mechanics in physics.
ii. the development of semiconductor technology, which is responsible for the electronics revolution and the photonics revolution now.

An interesting history of modern photovoltaic development is given by Lofershi (1993) and the early history, as early as 1839 is described by Crossley *et al*. (1968). A more recent history, was written by M.A. Green of UNSW entitled “The Path to 25% Silicon Solar Cell Efficiency: History of Silicon Cell Evolution” (Green, 2009). The chronology of solar cells development is given below:

A History of Solar Cells: How Technology has evolved

1839	Alexandre Edmond Becquerel, a French physicist observed the photovoltaic effect through electricity cell experiment when exposed to light.
1873	Willougby Smith, an English electrical engineer who discovered the photoconductivity of element selenium.
1876	William Grylls Adams, a physicist and Richard Evans Day discovered selenium producing electricity when exposed to light.
1883	Charles Fritts, an American inventor developed solar cell using selenium on a thin layer of gold (stuff of genius).
1904	Wilhelm Hallwachs invented a semiconductor-junction solar cell (copper and copper oxide).
1954	Bell Laboratories, a laboratory founded by Alexander Graham Bell invented first silicon photovoltaic (pv) cell.
1955	Western Electric began to sell commercial licenses for silicon pv technologies.
1957	AT&T assignor received patent for solar energy converting apparatus which was known as solar battery.
1958	U.S. Signal Corps Laboratories created n-on-p silicon solar cells.
1959	Hoffman Electronics introduced the use of a grid contact to reduce cell’s resistance.
1962	The launching of first commucation geostationary (AT&T) satellite,

	Telstar I was powered by solar cells.
1970	First highly effective GaAs heterostructure solar cells were created.
1982	Volkswagen of Germany began testing photovoltaic arrays mounted on the roofs of Dasher station wagons.
1986	ARCO Solar released the G-4000 as the world's first commercial thin-film power module.
1994	The National Renewable Eergy Laboratory developed a solar cell composed of gallium indium phosphide and gallium arsenide
1996	University of Stuttgart, Germany flew Solar Aircraft
2000	Sandia National Laboratories developed a new inverter for solar electric systems and Germany Renewable Energy Sources Act created Feed-in-Tariff (FiT) for solar.
2011	Fast growing factories in China push manufacturing costs down to about $1.25 per watt for silicon photovoltaic modules.
2013	Cumulative solar PV installations worldwide passed 100 GW.
2015	China ranked the highest cumulative installed capacity with total of 43.5 GW.
2018	**Professor Hirosaki Misawa, Hokkaido University scientist have developed a photoelectrode that can harvest 85 percent of visible light.**

Summary and references

In this chapter, the general physics of photovoltaic energy conversion have been described. It has been describe that there are **8** that can be defined. Obviously, it has taken a long time (since 1839) from the time photovoltaic effect was discovered until we began to see it used widely now, or ever much more in the future. *Changing from the addiction to oil and fire, to the electrons and protons and a source of energy is promising.*

1. Physics, Technology and use of photovoltaics. Overstraeten RJV and Mertens, RP. Adam Hilges ltd, 1985.
2. Sunlight into Electricity, Merrigan. J.A., Cambridge, 1975.
3. History of Silicon Cell Evolution, M.A. Green, UNSW, 2009.

Note:

***** *The absolute mass* and *absolute charge* of the electron were established more than a decade after electron was discovered by Robert A. Millikan (1868-1953). He received the Nobel Prize for Physic in 1923.

* *Electron* was discovered by J.J Thomson (1856-1940), in 1897, who was awarded the Nobel Prize for Physis in 1906.

* *Photon*, a quantized excitation of the electromagnetic field, displying properties of both wave and particle. It is messless, is a boson traveller at the speed of light and mediate the electromagnetic interaction between charged particles.

CHAPTER 3

SOLAR PHOTOVOLTAICS ELECTRIFICATION

3.1 Connecting the world to the power of the sun

'Solar is the answer to our future source of energy' – in 1990, more than 25 years ago, this was the opinion of a few. Back then, (and still is in many countries), the energy supply came from fossil fuel (oil, gas and coal) and hydroelectric power and nuclear energy (not in Malaysia), and for many villagers, they still rely on biomass energy like wood and charcoal. Power generation company and automotive manufacturers did not believe that solar energy can be of importance in providing the necessary power needed for development, growth and transportation, even among those in countries with high sunshine hours and solar radiation such as us the tropics. Many in the world, would like to have solar energy as 'good to have' technology, but not something you would want to rely on all the time.

Over the past few years, especially since the beginning of 2000, opinion have gradually change. As of 2015, market for solar energy is expanding and to new areas, and in some countries, solar is booming, for some very important reasons; namely cost and the negative effect of non-renewable energy sources like oil and gas and coal, towards global warming and climate change. More and more people are now convinced that if we continue to do the way we are 'business as usual' with no change in the energy type we use, the negative effect to the environment will be irreversible.

While the effect to the environment is less in nuclear energy, the nuclear disaster in Chernobyl (1986), and the more recent disaster in Fukushima Japan (2015), tragically demonstrated that there is no such thing as safe nuclear power. While in some countries of the world, they continue to operate the nuclear power plant, they yet to resolve to safely dispose of nuclear waste; which is why we must to stop making it. As of recently, energy policy and the tax incentive given to the industry, is making solar power as a source of energy slowly becoming more important.

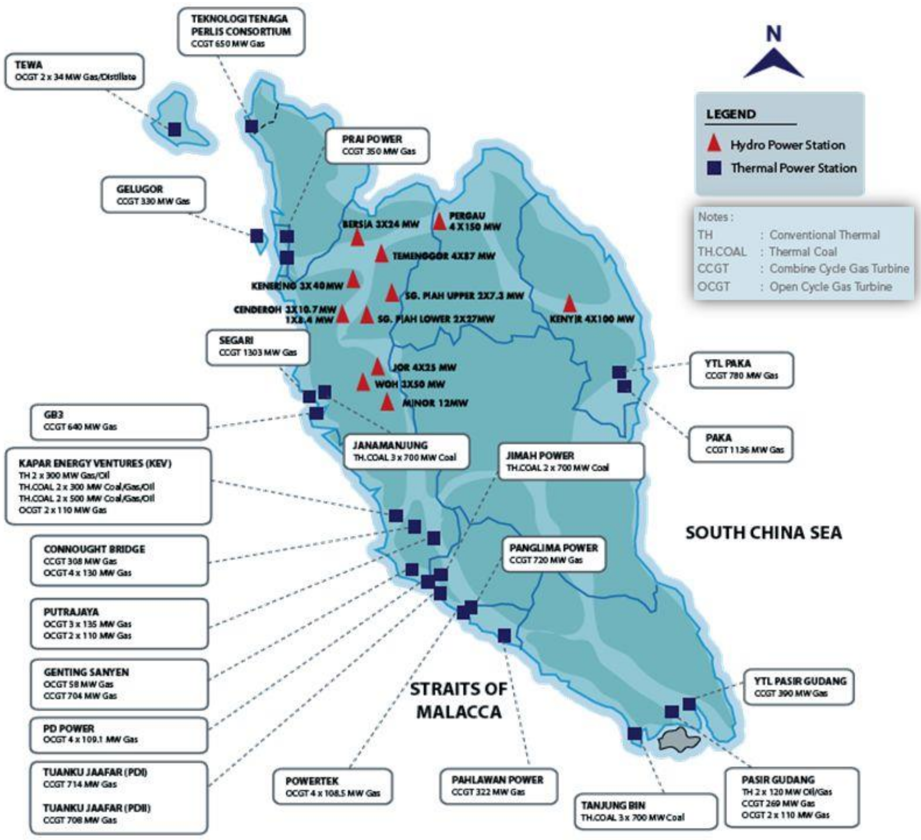

Figure 3.1: Major power station in Peninsular Malaysia

3.2 Recent and future development of solar energy in Malaysia

Solar electric use is growing rapidly, in Malaysia as well as in the world. The growth is dominated by the increased in the installation of photovoltaics. Malaysia's installed PV capacity currently stands at 296.5 MW, with 34.5 MW of new addition recently, according to SEDA (Sustainable Energy Development Authority).This is also shown by the increase of production of photovoltaic solar cells, which has increased at a rate of more than 40% each year, globally. In Malaysia, the significant increased has been mainly since the introduction of the feed-in-tariff by the government in 2004. Figure 3.2 shows the solar photovoltaic plants progression starting from 1990s to 2018.

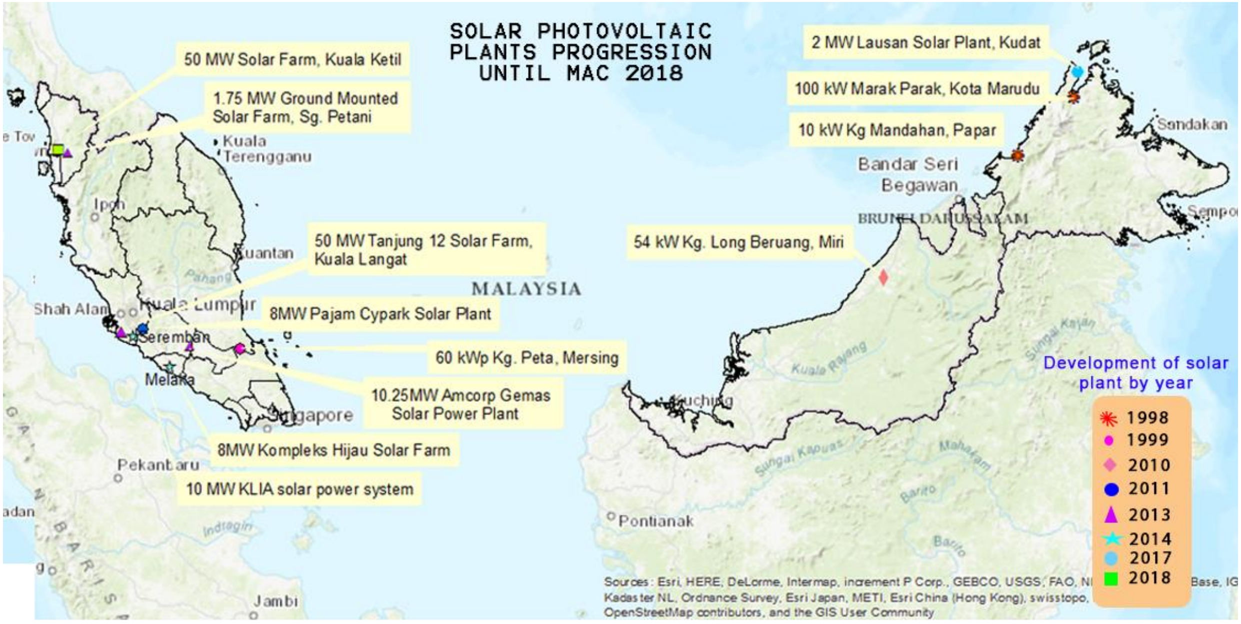

Figure 3.2: Solar photovoltaic plants progression in Malaysia (until March 2018)

Figure 3.3: National grid networks in Peninsular Malaysia (Source: Global Energy Network Institute)

This is also shown by the installation and commissioning of mini grid and FiT photovoltaic power generation in Malaysia, under the scheme as follows:

a) Malaysia project (Mini grid)

Mini grid is a set of electric generator and energy storage system which inter-connected to a distribution network to supply electricity for a localized group of customers. This small-scale electricity generation (10 kW to 10MW) could serve a limited number of consumers via a distribution grid that can operate in isolation from national electricity transmission networks. There are few mini grid project of the photovoltaic system had successfully established in Malaysia, including:

1. 100 kWp Marak Parak, Kota Marudu, Sabah, SHS (Pilot project)

Solar photovoltaic applications were first used for rural electrification back in the early 1980s. In October 1995, a 100 kWp PV project was commisioned at an area of 10 acre land in Kg. Marak Parak, Sabah which was supported by Ministry of Energy, Water and Communications (MEWC) and Japanese New Energy and Industrial Technology Development Organization. This system was implemented in stand-alone system and considered as pilot project to enhance the development of more effective and efficient PV technology in Malaysia.

This project was located in a remote village, 30 km from the nearest grid, connected through a mudroad. Moreover, the system consisted of 1887 solar panels (53 W each) and 252 lead acid storage batteries (2 V each), which considered as the main electricity resource for 80 consumers including household, school and hall. One diesel genset was also installed as a

standby power hybrid.

2. 60 kWp Kg. Peta, Johor, SHR (Mini grid)

A 60 kWp solar power system was installed in Kg. Peta, Mersing, Johor to support electricity for 60 villages. In fact, Kg. Peta was localised by Orang Asli Jakun. This project was commissioned in 1999 and consisted of solar panels, battery bank and a standby generator-set.

3. 54 kWp Long Beruang, Miri, Sarawak, SHR (Pilot project)

Long Beruang was located at remote area in Miri district and inhabited by Penan people. Previously, this area had no access to electricity supply, thus “Stimulus Rural Electrification Project” was implemented by Jabatan Kerja Raya (JKR) to set up a 54 kWp mini grid solar plant at area of 10 acres land in Kg. Long Beruang, Sarawak. This project was officiated in April 2010.

This 54 kWp stand-alone solar power system utilizes AC coupling system, which allows future grid connection and system expansion. The system was set up by 300 solar panels of 180 Wp each. The first load profile was collected after 8 months of the implementation in December 2010 and significantly supplied the electricity to 55 houses supporting 68 families and 301 people.

Malaysia project (Grid/ FiT-Feed in Tariff)

1. **8 MWp Kompleks Solar Hijau, Melaka** (Gading Kencana Sdn. Bhd.)

The 8MW Kompleks Hijau Solar has started feeding power into the national grid in December 2014. It is located at Hang Tuah Jaya, Melaka with an area of 17.7 acres. This project was developed by Gading Kencana Sdn. Bhd., installing a total of 29,092 Yingli PANDA monocrystalline 60 cell series panels and estimated about RM84 million for total cost of the project. As reported by **Gading Kencana (2015)**, this project is expected to successfully generate 10,120 MWh per year to supply power for 1,800 houses daily and avoid the carbon emission of 136,700 tonnes over 21 years.

2. **10.25 MWp Amcorps Gemas, Negeri Sembilan** (Amcorp Properties Berhad), completed in 2013; 4 months of installation.

A 10.25 MWp Solar Power Plant was developed by Amcorp Power Sdn. Bhd. at Gemas, Negeri Sembilan with the land area of 34 acres. The system was set up by using 41,076 solar panels, which is acknowledged as the largest grid connected (2014) in Malaysia Book of Record. It was commissioned in December 2013 and first operated in January 2014, which producing 1 million kWh of estimated energy monthly. It also could reduce carbon dioxide emission by 25,000 tonnes yearly and has a contract of 21 years FiT with TNB at 87.4 cents/kWh.

3. **8 MWp Pajam Cypark Solar Plant, Negeri Sembilan** (Cypark Resources Bhd), Integrated Renewable Energy Park, 15MW when completed)

This project was developed on a 26 hectares of landfill site in Pajam, Negeri Sembilan. The system consisted of 31, 824 solar panels. It was first commissioned in 2012 which provided 8 MW of power capicity during its phase 1 operational. In the future, it capable to generate power capicity up to 15 MW upon completion.

4. **50 MWp (2018), Kedah Solar, Kuala Ketil, Kedah** (Edra Power Holdings Sdn. Bhd.)

The project is expected to generate about 80,000 MWh of electricity per year developed over 104 ha at Kuala Ketil, Baling, Kedah. From 50 MWp, the system will be further upgraded to 500 MW in the future.

5. 50 MWp (2018), Tanjung 12 Solar Farm, Selangor, Malaysia

This project is considered as Large Scale Solar (LSS) for Tenaga Nasional Berhad (TNB) which is successfully progressing towards 50% completion (about 238,000 solar panels were set up). This project is covered an area of 97 ha of land and located in Kuala Langat, Selangor. This high scale project has costed about RM 339 million and estimated to be fully operated in November 2018.

A total of 2.08 GW of installed capacity is expected by the government of Malaysia, by 2020, with net metering policies and state support for large-scale solar projects to account for about 1.5 GW of the total. The increase in domestic production of polycrystalline silicon, an essential material for making solar cells, solar cells and photovoltaic modules manufacturing, is significant. Malaysia is poised to be one of the leading nations in the solar industry. The nation is currently ranked third in producing photovoltaic cells and modules, making it well positioned to benefit from the spill over effects of the growing solar power usage worldwide. A growth of between 12 to 20% over the next five years (MIDA 2017) is expected. The manufacturers involved are (Figure 3.1):

- Tokuyama Samalaju polysilicon plant (20,000 tons per year), Bintulu
- Scantec Solar
- Yingli
- First Solar in Kedah

- Q-cells, Selangor
- Sun Power in Melaka
- Panasonic Energy Malaysia in Kedah
- Twin Creeks Malaysia in Ipoh
- SunEdison

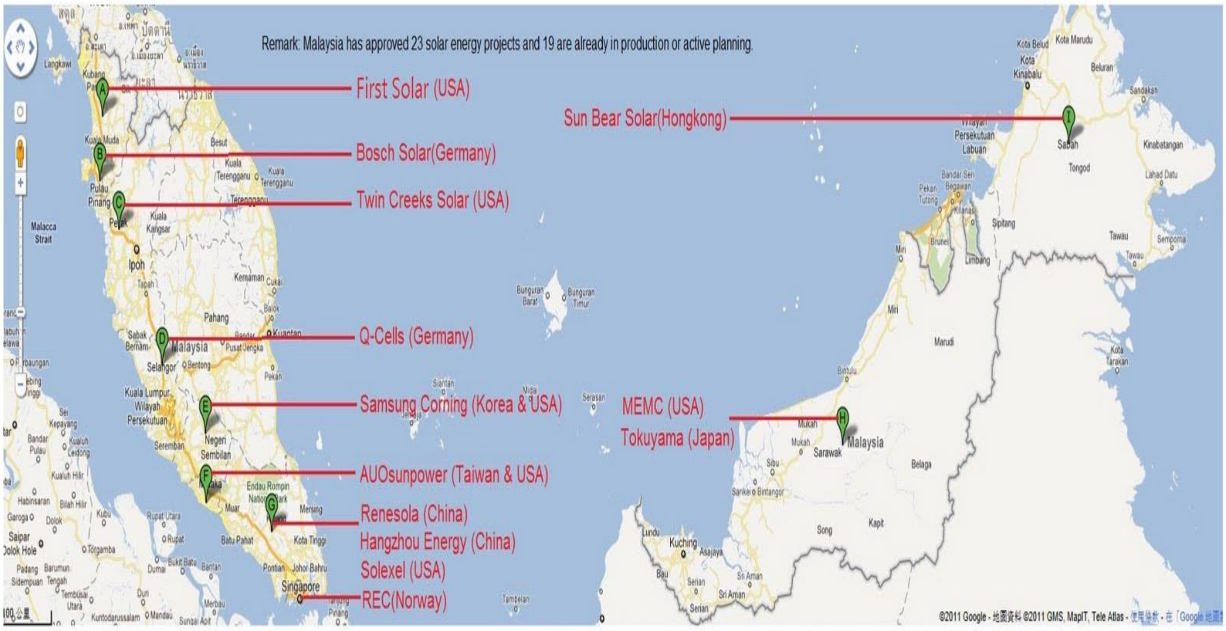

Figure 3.1: Manufacturer of solar products (modules and raw materials)

MIDA reported roughly 1.77 billion was invested in 2016, in seven PV production facilities, and about 11.1 billion of export was made in the same year, for the solar products. Xi'an Longi Silicon Materials Corp (LONG), the largest manufacturer of solar-grade mono-silicon products in the world, was reported to be setting up an integrated plant in Sarawak, with an investment of about RM1 billion, employing more than 2,360 jobs for the state.

Global market research firm, BMI research, recently cited Malaysia as one of the leading global investment destinations for renewable energy, especially solar, along with Singapore and Australia. The "economic and political climate" of the countries mentioned, "appear at the top of our Renewable Risk/Reward Index". The report also mentioned that the "supportive energy policy of Malaysia, alongside good access to finance and well-developed grid infrastructure especially in the Peninsular Malaysia, results in Malaysia's risk profile outperforming the regional average as well" the report stated **(Energy Malaysia, suruhanjaya tenaga vol13, 2017, www.st.gov.my).**

The use of solar energy will continue to grow, especially as the price per unit of photovoltaic system continue to decrease with advances in production methods, standardization of installation practices, and increased use of less expensive production materials. Some energy experts predict that by the year 2020, solar electricity will be available at Ringgit 0.20/kWh and will make up to an increase in energy portfolio of many countries in world.

MIDA of Malaysia, is launching the Malaysian Solar PV Roadmap 2030 programme with the goal of driving the country's solar power industry further. Malaysia aims to generate up to 2080 MW of energy from renewable sources by 2020. (Energy, Malaysia 2017).

3.3 Global project (Grid/ Feed-in-Tariff)

1. 648 MW Kamuthi Solar PV Power Generation, Tamil Nadu, India

This project is owned by Adani Power and first commissioned in March 2017. The system consists of 2.5 million solar panels, 576 inverters, 154 transformers, 6,000 km cables and 30,000 tonnes of galvanize steels as support. The land area covers about 2,500 acres which is equivalent to 60 Taj Mahals. The total cost of this project is 679 million US dollar and it is capable to generate enough electricity to 150,000 homes.


2. 1000 MW Solar PV, Datong, China

This project is owned by United PV and first commissioned in 10 August 2017. It was built on 1,500 acres of land area and consisted of 3.6 millions of solar panels, in Datong, China. 99 more similar solar farms across China will be built.

3. 579 MW Solar Star Solar Power Plant, Antelope Valley, California, America

This solar project was built on 3,200 acres of land area and first commissioned in June 2015. It is fully owned by BHE Renewables. It comprises 1.7 million of solar panels which is able to provide electricity to power approximately 255,000 homes. Significantly, reducing more than 560,000 tons of carbon dioxide emissions per year which is capable to remove over 2 million cars from the highways over 20 years.

Figure 3.2: The distribution of global large scale of photovoltaic projects

CHAPTER 4
ISSUES AND CHALLENGES

4.1 Limit to battery lifetime in photovoltaic applications

Most solar module manufacturers will normally quote that photovoltaic solar cells will last for more than 20 years, or even longer than that. However, in a system e.g. isolated stand alone village such as those in Malaysia, Sabah and Sarawak, the storage batteries is a necessesity. But most storage batteries will not last that long, around seven to eight years and yet is critical because of the need to supply electricity during the night and during the sunless days. While during the initial setting up of the system, the BOS is considered small in actual fact the battery will have to be replaced three times, in the line time of the modules.

4.2 Photovoltaic energy system capability to save carbon emissions

In the first chapter, it was stated that the current global warming and climate change faced by the earth can be reduced by changing from non renewable fuel such as oil and coal, to a renewable source such as solar energy. In addition, since the demand for electricity is growing, all over the world, we will see the growing importance of photovoltaic technology. Electrical energy only provide about 40% of energy use and will be even small contribution from solar photovoltaics. It is very unlikely that solar photovoltaic will contribute significantly to save carbon emission, at our current rate of development.

4.3 Optimal sizing of solar photovoltaic power systems under varied climates

The optimal sizing and the number of solar panels and the size of the storage battery to be used at a certain site is an economical decision. When the information available during designing stage is not complete, they tend to be oversized unnecessarily system. When proper solar irradiation and climatological data are missing tend to be oversized, i.e. increase the number modules and batteries beyond what is needed and thus oversizing the system, which is not economical.

4.4 Technical limit of solar photovoltaic energy to provide the power to the consumer through direct grid connection

In the present approach, direct grid connection (without intermediate stage of energy storage) is assumed as an obligatory solution to large scale application of solar energy. But strait connection of random intermittent power generations to a conventional grid can lead to a worsening of a system stability. This however is very much improved in recent application.

4.5 A village photovoltaic powered mini grid with a fixed maximum capacity (e.g. 100 kWpeak) versus increasing demand

In the case of the customers in Marak Parak, they are among the first village to get electricity from the solar grid. The problem with such a system is that it is not designed to handle increasing load due to increase in consumer and also an increase in the number of appliances used. Unless proper planning to increase the capacity and also the storage battery, the village system will not be able to function well. They were also facing the problem as mention in 4.1.

4.6 Quality of photovoltaic modules made by newer manufacturers (less than 25 years old)

It is obvious that under normal market forces, price reduction can be obtained through reduction in quality. The high reduction modules cost in the last 15 years can give rise to lower quality. This must be checked and the only good quality modules must be allowed to get to the industry.

CHAPTER 5
CONCLUSION

5.1 Energy global warming and climate change, and solar energy

The 1997 Kyoto Protocol clearly reflected the intense pressure from environmentalist the global carbon emission shoud be reduced further. The technology available today from photovoltaics and other various forms of renewable resources, should be the answer everyone is looking for the reduce carbon emission. *It is the courage and commitment of the country leadership to implement and adopt photovoltaic energy technology that will become an important step to reduce carbon emission.*

5.2 Lack of land area to built the solar farm

A major obstacle to contructing large solar farm is the availability of land. Obviously in a country like Singapore and Hong Kong, the cost of land can be more expensive than the photovoltaic system cost. However, more projects are developed using installation on water body as shown in Singapore, Japan, China and many more countries. This issue is slowly resolved and can be advantageous as the water can be cooling the solar photovoltaic modules, thus increasing its efficiency. *We may conclude that future solar farm will be built on cheap land cost, and even on lakes and sea areas.*

5.3 Reduction in price of solar modules

The reduction from more than $70 dollar US per kW in the early periods to less than 0.70 per kW in 2015 for photovoltaic module is indeed very encouraging. Credit should be given to manufacturers globally; China, Japan and Malaysia which provided such a cost advantage for power generators to consider going solar photovoltaics for the future power plants. *With such reduction, and possibly reduction in the cost of BOS (Balance of System), PV power will be the future.*

5.4 Improved efficiency of photovoltaic solar cell

As we get towards 2020, more and more research laboratories are coming up with higher and better efficient solar module and new solar cell. This development came through improving the cell efficiency of the well-understood silicon technology, from some 6 to 7% in the 1970s to a higher efficiency of 25 to 28% solar cell. Cell of a different material, e.g. perovskite is showing higher efficiency (more than 40%), is giving greater and better results for future applications.

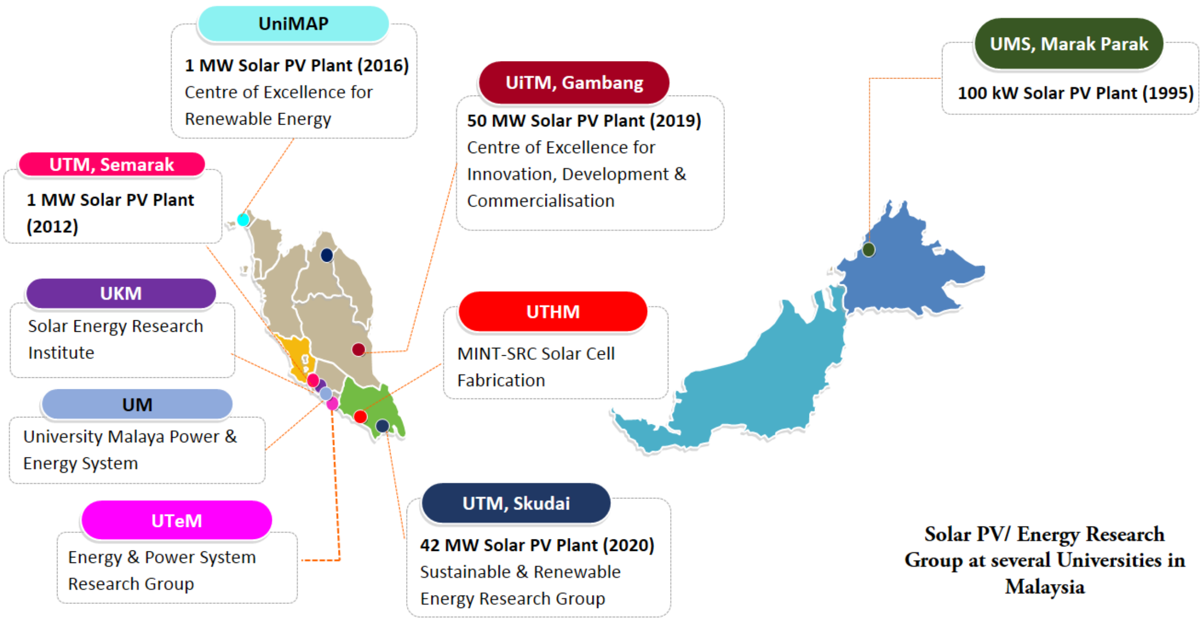

Figure 5.1: Distribution of solar PV or energy research groups at several universities in Malaysia

Continuous effect must be made to improve the cell efficiency of cell and modules, and obviously research labs in Malaysia (Fig. 5.1) are actively participating in the research works. In Fig. 5.2 is also shown the global research laboratory involved in such research.

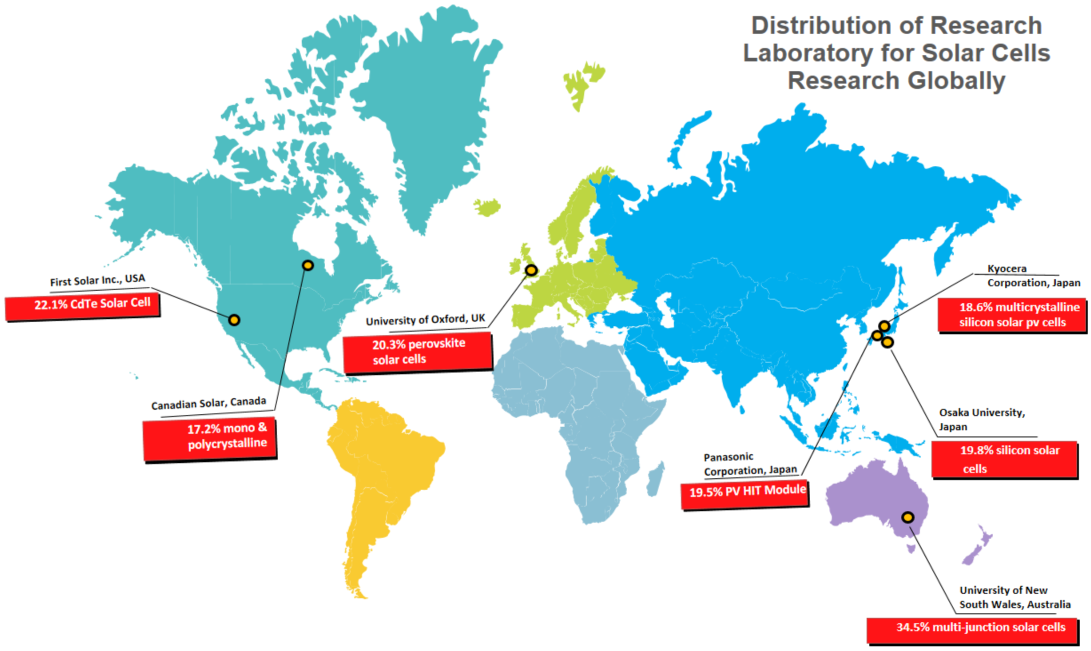

Figure 5.2: Distribution of research laboratory for solar cells research globally

5.5 Role of government

Feed- In-Tarrif (FiT), Net Metering and other forms of government participation is still needed as in some countries the bulk supply of photovoltaic electricity is still new.

5.6 Research funding for future development of solar cells and balance of system (BOS)

Laboratories all over the world should be well funded to pursue newer and better solar cells. From UNSW in Sydney, Australia, the Laboratory in Oxford University and those Japan private laboratories, we are seeing better cells and better efficiency module into the market; but we have to do more to save the planet.

Other industries involved in the balance of system, such also be well supported. This includes battery research such as lithium ion batteries by Tesla and Hitachi, which are not only useful for electrical car, but also very applicable in the power storge sector.

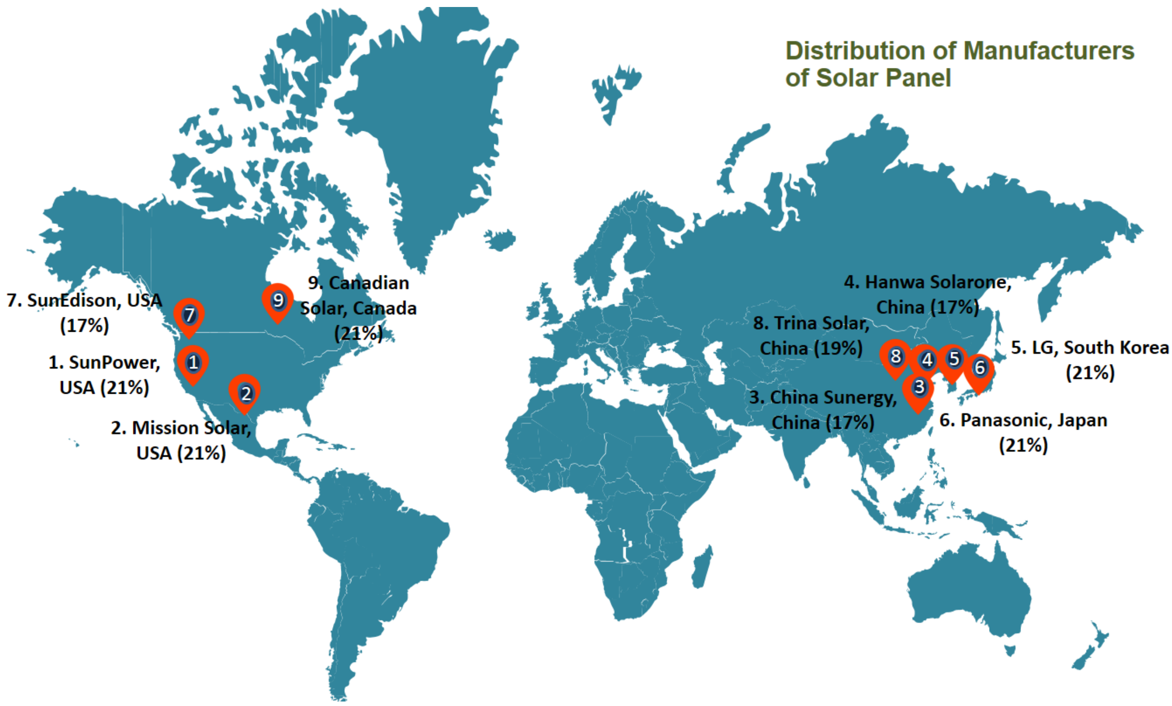

Figure 5.3: Distribution of manufacturers of solar panel

5.7 Skill development and society acceptance in the adaptation of solar technology in rural and remote communities

In many smaller rural electrification project especially in the remote communities, such as those shown in Marak Parak, Sabah (80 consumers) and Long Mui in Sarawak (50 consumers), development of local staff and local involvement in maintaining the system in necessary. Such effort must be planned from the early period of its implementation.

5.8 Future development

As more and more independent power producer is expected in the future, more electricity is generated from sunlight, more will be produced and made available to the consumer cheaply. In fact, it was reported that Chile is giving the power for free since many new plants are commissioned. Good for the environment.

25 years is not a long time to come and most of the module will have to be replaced. Our future issue will be the disposal of photovoltaic modules and what will be our solution to ensure is green.

Storage batteries have a shorter life span, about 7 years. Recycling of lead acid batteries is known and well practiced in many countries. However, lithium ion batteries is new and the recycling or its disposal must be well thought off.

5.9 End of oil in near

The good news for solar and other renewables is, the world is running out of oil. The club of Rome estimated in 1970 that oil will last for another thirty years. Further development give new figures, and with the increasing demand for oil, it will not be long before its supply will run out. It is estimated that we have a reserve of less than 1200 billion barrels.

However, new sources of oil is reportedly found, and continue to reassure the oil lobby, but there has been very few large-scale new discovery reported since 1990s. Thus, while the resource is limited, and the demand is increasing, we have no choice but to work towards working for renewables like solar energy.

5.10 Concluding remarks

In determining the economic viability of a photovoltaic system, the module efficiency and the long-term stability are considered as key parameters. Amorphous silicon solar cells looks the most promising technology, including the newer materials like gallium arsenide.

With the large decrease in the price of solar modules and many projects expected, the future is bright far photovoltaic technology.

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Designation	:	VK 5 – Professor

Field of Expertise

Field Category (KPT)	:	Physical Sciences
Field (KPT)	:	Condensed Matter Physics (Experimental)
Field of Specialization (KPT)	:	Electronic, Electrical, Materials, Renewable Energy, Solar Photovoltaics

Academic Qualification

YEAR	QUALIFICATION	DEPARTMENT/INSTITUTION
1981	PhD, Solid State of Physics, DIC	Blackett Laboratory, Imperial College of London
1977	MSc, Solid State of Physics	Bedford College, University of London
1975	Sarjana Muda, Fizika	FMIPA, Universitas Gadjah Mada, Yogyakarta

Management Experience

Year	Description
2008 - 2016	Vice Chancellor, UTHM (8 years)
2005-2008	Vice Chancellor, UMS (3 years)
1998-2005	Deputy Vice Chancellor, UMS (7years)
1995-1998	Dean, School of Science and Technology, UMS (3 years)
1992-1995	Deputy Dean, Faculty of Science and Natural Resources, UKM (3years)
1990-1992	Head, Materials Science Program, FSFG, UKM (2 years)

*UTHM = Universiti Tun Hussein Onn Malaysia; UMS = Universiti Malysia Sabah; UKM = Universiti Kebangsaan Malaysia

Publications (until 20 Sept 2018)

H $_{index}$ = 8, Citation = 238, i10-index = 8
(List of publications enclosed)

Teaching Experience

- Taught Physics for undergraduates in Physics since 1981 (in UKM, UMS, and UTHM).
- Taught sustainable development/ energy for undergraduates in Biodiversity since 2017 (in UTHM).
- Taught Physics for undergraduates in Medicine (1982-1985, UKM)
- Supervision of MSc and PhD students (UKM,UMS, UTHM)

Professional Societies/ Association/ Committee

Year	Description	Role	Level
2011-2015	Malaysia Examination Council (MPM)	Chairman	National
2014-2015	Vice Chancellors Council, Malaysia	Chairman	National
2014-2015	Malaysian Technical Universiti Networks (MTUN)	Chairman	National
1990-1995	International Solar Energy Society (ISES)	Chairman (Malaysia Section)	International
2013	Institution of Engineers, Malaysia (IEM)	Honorary Member	National
2005-2016	Vice Chancellors Council, Malaysia	Member	National
2015	Majlis Pengakap Malaysia	Member	National

Board Membership

Year	Description	Role	Level
2010 to date	KuTech Edu Sdn. Bhd.*	Chairman	National
2018 to date	Al Gazel Sdn. Bhd.*	Chairman	National
2010 – 2016	UTHM Holdings Sdn Bhd. *	Member	National
2010 – 2018	KYPJ Sdn. Bhd. **	Member	National

*100% owned by UTHM, **100% owned by state government of Johor

Awards

1.P.J.N	= Panglima Jasa Negara 2015, Datuk (Yang Dipertuan Agong)
2.D.P.S.K	= Dato' Paduka Setia Mahkota Kelantan 2008, Dato' (Kelantan)
3.P.G.D.K	= Panglima Gemilang Darjah Kinabalu 1998, Datuk (Sabah)
4.A.S.D.K	= Ahli Setia Darjah Kinabalu 1996, (Sabah)
5.Bintang Johor Darul Takzim	= Pengakap Malaysia (2017)

EPILOGUE

Academician Prof Datuk Dr Mohd Noh Dalimin is a Malaysian born physicist, who worked on diverse fields of science and technology, and established his involvement in university teaching and research, as well as working as a successful university administrator, through a multitude of research works and his position as the vice-chancellor of two Malaysian public universities. Using his networks of alumni of Gadjah Mada University Indonesia, and Imperial College London, and researchers in Malaysia and abroad, Mohd Noh developed solar energy research in universities where he was working and obtained funding support from international funding agencies, namely, Canadian International Development Agency (mainly for solar thermal technologies) and New and Industrial Development Organisation, Japan (mainly for photovoltaic technology). Transferring his incisive ideas into working models, and by physically constructing demonstration plants(versus making a model), both for solar thermal system and photovoltaic powered grid supplied electricity for remote villages, the end results, he showed that in a larger scale, photovoltaic technology is easier to use, and is more reliable to be made into a bigger plant.

Mohd Noh Dalimin was later appointed as the Chairman, of the Malaysia Section, of ISES-International Solar Energy Society, and indeed solar energy research in Malaysia today, has achieved greater significant, from the earlier small beginning in the early 1980.

His research journey, is made at the same time as when he was given the thrust to administer and lead two higher institutions in Malaysia i.e. In 2005, he was made the vice-chancellor of Universiti Malaysia Sabah, with the main campus in Kota Kinabalu; In 2008, he was appointed as the vice-chancellor of Universiti Tun Hussein Onn Malaysia, located in Johor. He is currently a professor in physics at Universiti Tun Hussein Onn Malaysia, Pagoh Campus.

Mohd Noh strong focus on sunrise technology that is solar photovoltaics, to be the power source of the future, has been proven in recent times. (Malaysia now have more than a total of 100 Megawatt installed PV power plant. India is now installing large powerplant using PV, mostly above 500 MW each. Especially in developing countries like Malaysia, Thailand and India, the technology is built into a mega scale power plants; several plants of 10 MW each in Malaysia, 500MW each in India, and many more in several developing countries). Our journey in solar energy research, will never ends, as long as energy is needed for human civilization, and the sun always rise from the east, every morning. Thank you.

Professor Ts. Dr. Wahid Razzaly

Vice-Chancellor

Universiti Tun Hussein Onn Malaysia

Date: 15th Sept 2018

SYARAHAN PERDANA 2018

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ISBN 978-967-2216-28-5

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