Study of a renewable energy of photovoltaic system engineering essay

Besides, the guidelines to Account for and Report on Greenhouse Gas Emissions and Removals for Buildings (Commercial, Residential or Institutional Purposes) in Hong Kong 2010 Edition of EMSD and EPD report that climate change has become a challenge to the international community. The Government of the Hong Kong Special Administrative Region is committed to working closely with the international community in formulating measures to reduce greenhouse gas (GHG) emissions.

Being a service economy without any major energy-intensive industries, electricity generation is the major source of GHG emissions in Hong Kong, accounting for over 60% of the total local emissions. The second largest GHG emission source is transport sector (16%), followed by waste (12%). Among various end uses of electricity, buildings account for some 89% in Hong Kong. Therefore, red ucing electricity consumption for building operations is instrumental in bringing down our GHG emissions. It will also have the co-benefits of reducing operational costs and improving the local and regional air quality.

GHG emissions associated with the electricity purchased based on a territory-wide default value of 0. 7kg/kWh in Hong Kong and these specific emission factors are available from the 2 nos. of electric companies (CLP - The China Light & Power Company Ltd. & HEC - The Hong Kong Electric Company Ltd.) from years 2002 to years 2007 in Hong Kong as following:

Photovoltaic System

More renewable energy sources may help containing fossil fuel use, thereby reducing greenhouse gas (GHG) emissions. Solar energy is one of the renewable energy being widely used over the world mainly due to its clean and emission free properties. Solar energy can be used in many ways which can provide the heat energy, mechanical power and electrical power. One of the most common methods is to convert solar radiation into electricity through the use of photovoltaic (PV) technology. The sunlight will converted to electricity using photovoltaic solar cells. The photovoltaic cells are usually bundled together in panels and modules to produce the increased power. The PV panel advantages are no pollution, quiet operation and require a little maintenance. Over the past few years, photovoltaic technologies have been developed rapidly.

To promote greater adoption of renewable energy technologies in Hong Kong, the Energy Efficiency Office (EEO) of the Electrical and Mechanical Services Department (EMSD) always seeks opportunity to promote the use of new renewable energy technologies. Attention is now being paid to the flexible amorphous thin-film technology in view of the increasing popularity for applications in overseas countries

Renewable energy is ready to be inexhaustible, harnessed and more importantly is a clean alternative to fossil fuels. Photovoltaic System is the type of the renewable energy in Hong Kong and aim to have 1 and 2% of Hong Kong's total electricity supply met by power generated by the year 2012. The world population of 10 billion by the year 2050, the world's fossil fuel resources will advance more depletion rapidly according to the increasing global energy demand at the world.

Photovoltaic is a method of generating electrical power by converting solar radiation into direct current electricity using semiconductors that exhibit the photovoltaic effect. The photovoltaic power generation employs solar panels composed of a number of solar cells containing a photovoltaic material. Photovoltaic device directly and silently convert light energy to electricity. No-post installation energy input other than the light source virtually. The sun is required normally. Materials presently used for photovoltaic include monocrystalline silicon, polycrystalline silicon, amorphous silicon, and cadmium telluride and copper indium gallium selenide/sulfide. Due to the growing demand for renewable energy sources, the manufacturing of solar cells and photovoltaic arrays has advanced considerably in recent years.

Many solar photovoltaic power stations have been built which mainly in Europe region.

As of December 2011, the largest photovoltaic power plants in the world are the Golmud Solar Park (China, 200MV), Sarnia Photovoltaic Power Plant (Canada, 97MV), Montalto di Castro Photovoltaic Power Station (Italy, 84. 2 MW), Finsterwalde Solar Park (Germany, 80. 7 MW), Ohotnikovo Solar Park (Ukraine, 80 MW), Lieberose Photovoltaic Park (Germany, 71. 8 MW), Rovigo Photovoltaic Power Plant (Italy, 70 MW), Olmedilla Photovoltaic Park (Spain, 60 MW) and the Strasskirchen Solar Park (Germany, 54 MW)

Advantages of Photovoltaic System

For the renewable energy, solar power is pollution free during use. Production end wastes and emissions are manageable using existing pollution controls. End of user recycling technologies are under development and policies are being produced that encourage recycling from producers. PV installations can operate for many years with little maintenance or intervention after their initial set up. So that, after the initial capital cost of building any solar power plant, operating costs are extremely low compared to existing power technologies. Grid-connecting solar electricity can be used locally thus reducing transmission and distribution losses. Compared to fossil and nuclear energy sources, Very little research money has been invested in the development of solar cells, so there is considerable room for improvement. Nevertheless, experimental high efficiency solar cells already have efficiencies of over 40% in case of concentrating photovoltaic cells and efficiencies are rapidly rising while mass production costs area rapidly falling.

1. 5 Environmental Impact of PV System

The most important feature of solar PV systems is that there are no emissions of carbon dioxide - the main gas responsible for global climate change - during their operation. Although indirect emissions of CO2 occur at other stages of the lifecycle, these are significantly lower than the avoided emissions. PV does not involve any other polluting emissions or the type of environmental safety concerns associated with conventional generation technologies. There is no pollution in the form of exhaust fumes or noise.

Decommissioning a system is unproblematic. Although there are no CO2 emissions during operation, a small amount does result from the production stage. PV only emits 21, 65 grams CO2/kWh, however, depending on the PV technology. The average emissions for thermal power in Europe, on the other hand, are 900g CO2/kWh. By substituting PV for thermal power, a saving of 835879 g/kWh is achieved.

The benefit to be obtained from carbon dioxide reductions in a country's energy mix is dependent on which other generation method, or energy use, solar power is replacing. Where off-grid systems replace diesel generators, they will achieve CO2 savings of about 1 kg per kilowatt-hour. Due to their tremendous inefficiency, the replacement of a kerosene lamp will lead to even larger savings, of up to 350 kg per year from a single 40 Wp module, equal to 25kg CO2/kWh. For consumer applications and remote industrial markets, on the other hand, it is very difficult to identify exact CO2 savings per kilowatt-hour.

Recycling of PV modules is possible and raw materials can be reused. As a result, the energy input associated with PV will be further reduced.

If governments adopt a wider use of PV in their national energy generation, solar power can therefore make a substantial contribution towards international commitments to reduce emissions of greenhouse gases and their contribution to climate change.

By 2030, according to the EPIA-Greenpeace Solar Generation Advanced Scenario, solar PV would have reduced annual global CO2 emissions by just over 1, 6 billion tonnes. This reduction is equivalent to the output from 450 coal-fired power plants (average size 750 MW).

Cumulative CO2 savings from solar electricity generation between 2005 and 2030 will have reached a level of 9 billion tonnes.

Carbon dioxide is responsible for more than 50% of the man-made greenhouse effect, making it the most important contributor to climate change. It is produced mainly by the burning of fossil fuels. Natural gas is the most environmentally sound of the fossil fuels, because it produces roughly half as much carbon dioxide as coal, and less of other polluting gases. Nuclear power produces very little CO2, but has other major safety, security, proliferation and pollution problems associated with its operation and waste products.

1. 6 Energy Payback

A popular belief still persists that PV systems cannot " pay back" their energy investment within the expected lifetime of a solar generator - about 25 years. This is because the energy expended, especially during the production of solar cells, is seen to outweigh the energy eventually generated.

Data from recent studies shows, however, that present-day systems already have an energy payback time (EPBT) - the time taken for power generation to compensate for the energy used in production - of 1 to 3. 5 years, well below their expected lifetime. With increased cell efficiency and a decrease in cell thickness, as well as optimized production procedures, it is anticipated that the EPBT for grid-connected PV will decrease further.

The figure hereafter shows energy payback times for different solar cell technologies (thin film, ribbon, multicrystalline and monocrystalline) at different locations (southern and northern Europe). The energy input into a PV system is made up of a number of elements, including the frame, module assembly, cell production, ingot and wafer production and the silicon feedstock. The energy payback time for thin film systems is already less than a year in southern Europe. PV systems with monocrystalline modules in northern Europe, on the other hand, will pay back their input energy within 3. 5 years.

Figure - Energy payback times for range of PV systems (rooftop system, irrad. 1700 resp. 1000 kWh/m2/year)

1. 7 Future Markets of PV System

International Energy Agency Photovoltaics Power Systems Programme (IEA PVPS) newsletter issue35, 2011/09/01, Page 6 report that The PV market continues to grow faster than expected and prospects for the future remain strong - as long as policymakers encourage a stable and sustainable approach to market development.

The global PV growth trend in recent years has been astonishing. In 2010, growth was higher than 100%, with capacity additions close to 17 gigawatts (GW) from 7. 2 GW installed in 2009. At the start of 2011 the total installed world capacity was close to 40 GW, producing some 50 terawatt-hours (TWh) of electrical power every year. Most of that increase was due to the rapid growth of the German (7. 4 GW) and Italian markets (2. 3 GW), though other countries also showed significant development.

However in many countries the rapid price decreases have led PV close to competitiveness. With PV system prices down in certain market segments to around €2/ Wp ($2. 8), the cost of generation of electricity from PV went down in sunny countries to less than €0. 15/ kWh. There are few doubts about the ability of PV prices to drop significantly and bring electricity costs below 10 eurocents ($0. 14) in the five coming years.

Chapter 2 Literature Review

This part of the thesis summaries the related work by other researchers. The focus is on those researches that the related to my own area directly which is the study of the photovoltaic system.

2. 1 PV Technology

Photovoltaic technology is the direct conversion of the electricity from the sun light. The first PV cells, it was only realized in year 1954 after the development of material science and manufacturing of solid state devices. Nowadays, it is extensively accepted as a good technology to generate electricity directly from sun light with minimal environment pollution and as one of the possible alternatives to fossil fuel energy sources.

At photovoltaic system, it has many ways to apply the PV to obtain the solar energy. Solar electricity, year 2004, Markvart. T. report that in the development of semi-conducting devices manufacturing, it mainly consist of silicon, the development of PV cells from the by-products of semi-conductor industry lower the cost and made civil application of PV feasible.

Throughout the history of development of PV, its dominating applications have long been the stand -alone applications. In a stand-alone photovoltaic system, PV is the only way and source of energy powering the electrical load. It has not other external electrical power sources. To supply for the demand when there is no sunlight such as deep in the night. The PV system has not enough sun light to transform into the electricity. It requires some kinds of energy storage such as battery, fuel cells, and water tanks and so on. These types of systems are widely used for the rural area and the faraway area which power network is not more maturity. IEA PVPS trends in photovoltaic application, survey report of selected IEA countries between 1992 and 2010, T1-20: 2011 show that these stand alone photovoltaic system fell below about 4% of total world-wide photovoltaic installations. Nowadays, the dominating type of photovoltaic application is the grid connecting photovoltaic system producing the clean power for supporting the electricity grid. From year 2000 to 2010, the percentages of gird connected in the reporting countries are from about 55% to 95%.

IEA PVPS T1-20: 2010, percentages of grid-connected and off-grid PV power in the reporting countries.

The operational principle of the grid-connecting photovoltaic system is used the cells to convert the solar radiation into electricity. When the light shines on the cell it creates an electric field across the layers, causing electricity to flow. The direct current (DC) electricity from the PV modules to alternating current (AC) with sophisticated power electronic devices and then supplies the power to the loads in conjunction with the utility grid. It services as a supplementary power source to main stream generation with fossil fuel, nuclear or other conventional means from the utility. Effectively the grid-connecting photovoltaic systems use the grid power as the storage and also the complementary source. It would supply the loads together with the gird when there is not enough from the sun, and would generate excess power into the grid when the PV system could provide more than the loads is needed. This is the fastest uptake type of PV application and became the dominant type by the end of 1999 (IEA PVPS T1-11: 2002, P4). Luther et al. (2003, p. 98) argued that this type of PV system will be contributing to the main-stream power production towards the reduction of CO_2 emission in industrialized countries. Hence the course of change in PV application indicates a development of its role in supplying power to remote areas where no other means of electricity could be easily available and then to supporting the modern society in reducing the adverse effect of burning fossil fuels.

The grid-connecting photovoltaic system is the most popular type of solar PV system for homes and businesses in developed areas. Connection to the local electricity network allows any excess power produced to feed the electricity grid and to sell it to the utility. Electricity is then imported from the network when there is no sun. An inverter is used to convert the direct current power produced by the system to alternative power for running normal electrical equipment.

2. 1. 1 Grid-Connected Domestic Systems

This is the most popular type of solar PV system for homes and businesses in developed areas. Connection to the local electricity network allows any excess power produced to feed the electricity grid and to sell it to the utility. Electricity is then imported from the network when there is no sun. An inverter is used to convert the direct current power produced by the system to alternative power for running normal electrical equipment

2. 1. 2 Grid-Connected Power Plants

These systems are also grid-connected, produce a large quantity of photovoltaic electricity in a single point. The size of these plants range is from several hundred kilowatts to several megawatts. Some of these applications are located on large industrial buildings such as airport terminals or railways stations. This type of large application makes use of already available space and compensates a part of the electricity produced by these energy-intensive consumers.

2. 2 Crystalline Silicon

Crystalline Silicon is the most mature photovoltaic industry technology. It has been developed since the 1950s which had the relatively high conversion efficiency of about 11% to 15% at Standard Test Conditions. Standard Test Conditions (STC) is the convention adopted by the photovoltaic industry benchmark for the performance of a PV cell under the particular testing circumstances. This way of characterization of PV modules has its limitations. Crystalline silicon is still dominating the PV market and is expected to do so for the near future. Meanwhile, in its crystalline form, pure silicon has a grey color and a metallic luster. Like a germanium, silicon is rather strong, very brittle and prone to chipping. The crystal structure of the silicon is resembles the diamond cubic crystal structure. The structure is very stable and less susceptible to degradation due to the heat and light. It also used in a high efficiency photovoltaic applications. In terms of charge conduction, silicon is an intrinsic semiconductor which means that unlike metals it conducts electron holes and electrons which may be released from atoms within the crystal by heat and thus increase silicon's electrical conductance with higher temperatures. This particular property enables crystalline silicon PV to last for over 20 years and remain functional. Some of the PV manufactures are offering the warranty of over 20 years.

Crystalline silicon can subdivided into 2 types. It is mono-crystalline silicon (m-Si) and poly-crystalline silicon (p-Si). On the mono-crystalline silicon, it is the earliest commercialized technology for applications. It requires the high energy input to produce the raw materials for m-Si cell by single crystal growth. A less energy demanding casting procedure of Silicon crystal was therefore developed to lower the production cost. IEA PVPS trends in photovoltaic application, survey report of selected IEA countries between 1992 and 2010, T1-20: 2011 show that due to its lower module price, the p-Si of photovoltaic system is becoming popular gradually. These two manufacturing technologies dominate the market of PV system and in year 2003 accounted for over 85% market share.

The thickness of crystalline silicon PV cells is from 0. 13mm to 0. 3mm. It needs the suitable protection for the relevant mechanical reason. So, to provide the relevant mechanical protection, the most common method of the PV modules for crystalline Si is the cells embedded in the glass layers. This enables a natural integration with building since glass is one of the most widely deployed building materials.

The manufacture process of the Crystalline Silicon photovoltaic cell

(Picture from EPIA - European Photovoltaic Industry Association)

2. 3 Amorphous Silicon

Amorphous is the term describing the characteristics of silicon atoms grouped together forming the PV cell. The amorphous literally means formless. The structure contrasts with its crystalline counterpart which is much more stable and high efficiency. One of the main reasons for developing amorphous silicon (a-Si) PV technology is the lower production cost. The lower production cost is brought about by the lower energy input for the deposition of silicon layer onto the substrate instead of high temperature crystal formation (Luther et al., 2003, p55) and the significantly less amount of silicon required for the cell production (Deng and Schiff, 2003, p. 508). The thickness of silicon coating on the substrate is usually in the range of about 0. 001mm. That is less than one-hundredth of that of crystalline silicon PV cells. The significant decrease in raw material used enable a-Si module to be sold at a much lower price per unit area than that of crystalline silicon modules especially at the time of ever increasing price of silicon due to the competition between manufacturing of computer chips and PV modules.

In its amorphous state, the photo-electric property of silicon is subjected to light-induced degradation. The effect was reported by Staebler and Wronski, therefore known as the Stabler-Wronski effect (Goetzberger and Hoffmann, 2005, p. 60). After an initial degradation of about 10% - 20% decrease in conversion efficiency, the electrical properties of the a-Si cells will be stabilized. It is now a common practice for the manufacturers to publish the stabilized efficiency. The stabilized STC efficiencies of commercial a-Si PV modules are around 4% - 8%. In order to improve the conversion efficiency of the a-Si modules, some manufacturers stack layers of Si depositions to capture more photons. Although with lower efficiency, a-Si PV cells are widely applied in indoor applications for small electronic appliances attributing to its better response to weak light. It is the third most widespread type of PV technology after crystalline silicon the a-Si has been used as a photovoltaic solar cell material for devices which require very little power such as pocket calculators and toys.

Since the thin layer of a-Si can be deposited onto various types of substrate. This enables the form of PV modules made of a-Si having a much greater variety. Furthermore, silicon in its amorphous form does not have the limitations of thickness or mechanical strength as in crystalline form. These special properties facilitate its application in a flexible form. This is very suitable for producing PV modules for building applications. Together with its performance being less affected by the heat built up in the modules, it can be a good candidate for applications in hot climates. The a-Si PV modules area commercially available for installation onto the roofs of buildings either applied onto the finished roof or integrated into the roof covering. The advantage over traditional PV panels is that they are very low in weight. It is not subject to wind lifting and can be walked on. The comparable disadvantages are increased cost and reduced efficiency.

Flexible a-Si PV modules can made as roofing material

2. 4 Other Thin-Film Technologies

Thin-film is the general term for PV cells produced other than those thick layers of crystalline silicon. Amorphous silicon is the earliest commercialize thin-film technology. Its development was mainly from the drive to lower production costs by using significantly less rea material and energy input during the manufacturing process. Other new comers comprise Copper Indium Diselenide (CIS), Cadmium Telluride (CdTe) and so on.

In 1975, a Copper Indium Diselenide (CIS) cell of 12% efficiency was successfully demonstrated at the USA's Bell Labs and work at the National Renewable Energy Laboratory (NREL) developed the technology under the US department of Energy's thin film program during the 1980's, consolidating the technology's promise (Zweibel, 1990, pp. 161-180). Due to the collapse of research funding in the US it was almost another 10 years before Siemens Solar Industries (SSI) produced the first commercially CIS modules in late 1990s. A family of similar compounds has also been developed such as CuInSe2, CuGaSe2, CuInS2, Cu2 and so on. the coating of thin film CIS onto substrate was found to be more flexible and easily manipulated (Goetzberger and Hoffmann, 2005, p. 65). Therefore CIS is the major material used within this family of compounds.

Similar to a-Si, CIS can be coated into many types of substrate. The choices of CIS modules are wider. For example, flexible CIS modules and modules on polymer back sheets can be found on the PV market. However, due to the rapidly evolving technology, the manufacturing process and even the compound used for CIS modules are ever changing. Second generation CIS modules was reported by Palm et al. (2004) and more development is imminent. With the flexibility in manufacturing the modules, CIS can be one of the candidates for building integration.

These can further be divided into ordinary Building-Integrated Photovoltaic (BIPV) system and Photovoltaic (PV) systems and the solar cells in the market can be classified into two main categories: Crystalline Silicon Cells and Thin-Film Cells. PV cells are generally made either from crystalline silicon, sliced from ingots or castings, from grown ribbons or thin film, deposited in thin layers on a low-cost backing.

The performance of a solar cell is measured in terms of its efficiency at turning sunlight into electricity. A typical commercial solar cell has an efficiency of 15% about one-sixth of the sunlight striking the cell generates electricity. Improving solar cell efficiencies while holding down the cost per cell is an important goal of the PV industry.

Cadmium Telluride (CdTe) has a similar long history in the whole group of thin-film PV modules. Due to its tolerance to defects and grain boundaries, simple and easy to handle deposition process is possible for this material (Luther et al. 2003, p. 70). Technology wise this type of material should have been booming. The major hurdle now is the market acceptance since both Cadmium and Telluride are toxic materials although CdTe itself is stable and harmless to the environment. Furthermore, different countries have different regulations regarding Cadmium containing materials (Deb, 2002). This uncertainty might increase the risk factor in investing production plant for CdTe and BP Solar was reported to have closed their CdTe plant (Luther et al. 2003, p. 72).

Synergising with the technology advancement in device handling and manufacturing process in semi-conductor industry, there are emerging technologies for thin film PV cell (Sopori, 2003, p. 308). These include crystalline silicon thin film (m-SiTF), micro-crystalline silicon (Î¼m-Si) and so on. However, they are still new technology and even not yet commercialized.

Due to the longer history of development, crystalline silicon PV modules are still the more common to apply for the building envelope nowadays. But due to the PV modules brittleness, it have to be well protected by the glass layer and backing. It is this intrinsic nature of crystalline silicon that determines the formation and hence limits its applications on buildings. On the other hand, the thin film photovoltaic technology can be applied on many more substrate and the flexible film modules are available for thin film besides glass-glass modules and glass film modules that are common in crystalline silicon technology. The different size, form, material used can apply to the different building design. Hence, the applications of thin film photovoltaic modules are better than the crystalline silicon nowadays.

2. 5 Electrical Characteristics and Performance

PV modules can serve as the building envelope to keep out the weather and control heat gain. To analysis the electrical performance of a PV module, both the instantaneous power output and the energy yield over the time period under investigation has been considered. Instantaneous power has been normalized to per unit power under Standard Test Condition (STC) for easy comparison between different types of technology. Each PV panel is rated under industrial STC of solar irradiance of 1, 000W/m2 with zero angle of incidence, solar spectrum of 1. 5 air mass and 25â„ ƒ cell temperature. Electrical characteristics from manufacturers include maximum rated power, open circuit voltage, short circuit current, maximum power voltage, maximum power current and the temperature coefficients . Also, the energy yield has been normalized in a similar manner. The methodology of evaluation of performance has been based on the Standard IEC 61724 (1998).

2. 6 Photovoltaic Simulation

In the photovoltaic system simulation, the prediction of the PV module performance is the core part of the simulator. Normally, the modeling is based on the physical characteristics of the photo electric effect at the semi-conductor. The simulation is calculated the photo-current generated by a certain amount of the irradiance at the surface of the semi-conductor at specific physical conditions. Nowadays, the most of the commercial photovoltaic system simulation programs is the temporal series of data being simulated such as RETSCREEN, PVPSYST, PVSOL, PV-Design Pro, Hybird2 HOMER and so on.

2. 6. 1 RETSCREEN

The RETScreen software is a program developed by Natural Resources Canada for evaluating both financial and environmental costs and benefits for many different renewable energy technologies. RETScreen has a specific Photovoltaic Project Model that can model PV array performance for many locations around the worldncludes a climatic database including average measurements for 4'700 ground stations, compiled from over 20 different sources, and covering the period 1961-1990. These data are presented as a unique coherent database, and present numerous parameters including Irradiation, air temperature and wind velocities.

2. 6. 2 PVSYST

PVsyst software has been developed at the University of Geneva in Switzwerland. This is an excellent package for design and analysis of a solar photovoltaic system. It is widely used due to the many parameters available for the user to modify. This software is oriented towards architects, engineers, researchers and holds very helpful tools for education. Both stand-alone and grid-connected PV as well as solar water pumping system could be designed by using PVsyst.

2. 6. 3 PVSOL

The PVSol program is photovoltaic system analysis software developed by Valentin

Energy Software in Germany with an English language version distributed by the Solar

Design Company based in the UK. The first version of PVSol was released in 1998.

2. 6. 4 PV-Design Pro

PVDesignPro software is a commercially available software model developed by the Maui Solar Energy Software Corporation (MSESC) and SNL for photovoltaic systems modeling. The software incorporates algorithms from both of SNL's PV array and inverter performance models as well as SNL's database of PV module and inverter parameters. NIST uses a custom version of PVDesignPro for comparing different PV technologies and predicting PV module performance for BIPV applications. The program uses an hourly time-step for modeling system performance.

2. 6. 5 Hybrid2

Hybrid2 is described as a probabilistic time series computer model for evaluating the performance and economics of hybrid electricity generating systems. It was developed by the Renewable Energy Research Laboratory (RERL) at the University of Massachusetts Amherst with support from NREL. This program is an engineering design model for hybrid systems consisting of PV, wind, generators and battery storage for both on-grid and off-grid systems

2. 5. 6 HOMER

HOMER is a hybrid system model developed at NREL in 1993 for both on-grid and offgrid systems. A unique capability that HOMER offers is the ability to find the optimal configuration based on price estimates as well as perform sensitivity analysis to help understand tradeoffs between different technologies and economic considerations. The software has the ability to compare multiple system configurations as well as different battery types. HOMER uses the KiBaM code for battery life modeling as described below in Section 4. 2. 1. The model can incorporate the following componen