CHAPTER II

REVIEW OF RELATED LITERATURES AND RESEARCH

The basic facts of Cambodia and Kampot province

1. General background

Kampot is a charming tiny province where can rich in the French's colonial atmosphere and has blessed with plenty of natural resources and more beautiful views. It located along the bank of the Kampong Bay river (Tonle Kampong Bay) where it can overlooking the good scenery of the Dam Rey mountains (Phnom Dam Rey) and it is largely covered by a nice green paddy field and tropical forest. It is more popular for sleepy backwater feel, namely Teuk Chhour, which strongly had attracted many tourists to stay there for a few days, especially on vacation and public holiday. Kampot province is an oldest and famous place where can host relatively high attractiveness of western people and Asian people for visiting and staying there with a beautiful coastal area which called the rise-star (Dara reah) in the southwest part of the country and the Bokor hill resort (Bokor heaven). Actually, there are a lot of western owned such as hotels, guesthouses, restaurants, bars, beer gardens and night clubs.

At the present time, Kampot is a famous grows first-class of black pepper, durian and other fruits. Kampot is a tourism province of the Kingdom of Cambodia which has rapidly increased population, economic development and infrastructures. On the other hand, electricity power production of this province is actually rapid increasing from time to time and year to year too.

2. Geography

The geographical location of Kampot province of the Kingdom of Cambodia is located between latitude of 10.7^0 N and longitude of 104.28^0 E. Kampot is one of the provinces in the Kingdom of Cambodia is situated in southern part of the country that has border with Koh Kong and Kampong Speu to the north, Takeo to the east, Sihanouk Ville to the west and Kep province as well as long coastal areas on the gulf of Thailand to the south. The total land area of Kampot province, Cambodia is about 4,873 km^2 that it consisted of 08 districts such as 1) Angkor Chey, 2) Banteay

Meas, 3) Chhouk, 4) Chum kiri, 5) Dang Tung, 6) Kampong Trach, 7) Teuk Chhour and 8) Kampot Town (Kampot krong).

With the location, the climate of Cambodia is typical to Southeast Asia which is monsoonal. The season is marked by two distinct seasons known as tropical wet and dry. The southwest monsoon brings the rainy season from mid of May to the end of September or to early October, and the northeast monsoon gives the flow of drier and cooler air that lasts from early November to April. Based on previous reported and studied, temperature of the country did not very much different. The variation is mostly due to difference in topography and the presence of clouds cover. On the average, temperatures could be as high as 35 degree Celsius (°C) during dry season, especially in March, April and early of May and as low as 20 degree Celsius (°C) during the winter or cool months in November, December and January and even the Kampot province. The Figure 2 is shown the map of Kampot province, Cambodia.

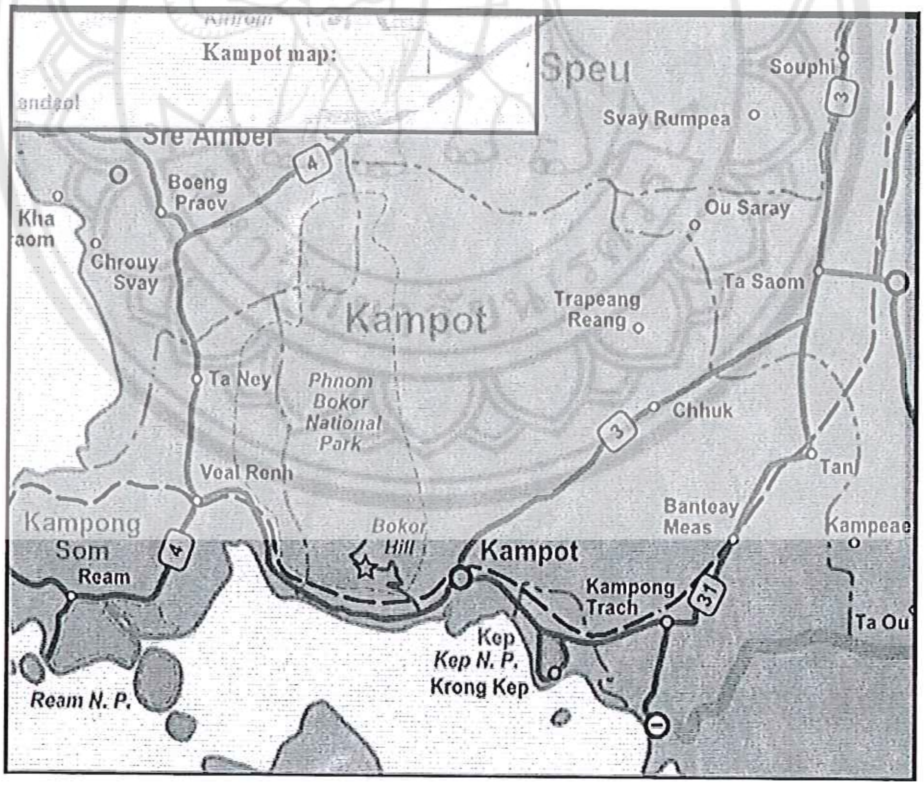

Figure 2 The map of Kampot province

Source: Ministry of Interior, http://www.interior.gov.kh

3. Population size

As of the year 2012, Cambodia population was about 14,805,358 people. About ninety percent of Cambodian people are the Khmer origin and they speak the Khmer language (Cambodian language) and believe in Buddhism, which is an official language and religion in the country. Cambodia's population is very relatively homogeneous and gets some influences from Indian and Chinese. It has many minority groups such as the Khmer Loeu is about 997,968 who are living in the north-east and border of the country; Vietnamese is nearly half of one million who are living along the Mekong river and Tonle Sap river and they are good in business and fishing activities; Chinese is about 1,380,000 who are living everywhere, especially in downtowns and most of them are very good at business jobs; Cham (Khmer-Islam) is about 875,000 who are good at agriculture and small enterprise jobs such as rice, fishing, goldsmith, blacksmith, lathe operator, construction worker, carpenter, artist, etc.; and other ethnic groups. The country's birth rate was around 2.54 per 100 in 1980s. Its population growth rate was about 1.70% in 2012, significantly higher than those of the Japan, Kingdom of Thailand, the Republic of South Korea, the Republic of Singapore and the Republic of India. The Khmer language is a member of the Mon-Khmer sub-family of the Austroasiatic language group, which was born in 500 years B.C. French, one of the languages of government in Indo-china peninsula, for example the Kingdom of Cambodia, People's Democratic Republic of Lao and the Socialist Republic of Vietnam, is still popular spoken by many older Cambodian people. French is also the language of instruction and administrative affairs in some schools and universities today which are funded by the government of the Republic of France, such as the Institute of Technology of Cambodia (ITC), the University of Health Science, the Royal University of Law and Economics (RULE) and other schools. In previous time, Cambodian-French, a remnant of the country's colonial past period (1863-1953), was a dialect found in the Kingdom of Cambodia and was sometimes used in government, particularly in court. In recent decades, many younger Cambodian people and those in the business sector have more favored learning the English language, because most of countries in the world are officially using the English language as the second language, especially in ASEAN countries. In the major provincial towns, cities, NGOs, companies and travel agencies, the English is very widely spoken, used and taught at a large number of schools and universities because of the overwhelming number of tourists from the English-speaking countries. Even in the most rural communities, most young people can speak at least some English language, as it is often taught by monks and teachers at the local pagodas and schools where many children are learned.

Finally, the population of Kampot province is rapidly increased year by year after finishing the Khmer Rouge regime in 1979, called year zero (genocide regime). The birth rate is around 2.6% in 1980 to 1.05% in 2013.

4. Economic situation

The current economic in the Kingdom of Cambodia is divided into three main sectors, namely agriculture, industry and service. In the year 2012, Cambodia's per capita income in purchasing power parity (PPP) was around US$ 2,470 and US$ 1,040 in nominal per capita (GDP real growth rate was about 6.5%). Cambodia's per capita income is very strong rapid increasing but it is still low compared to other countries in the region and out of the region, so the Royal Government of Cambodia is strongly reformed and more intended to work hard. Noticeably, most of rural people are depended on agriculture sector (more than 80% are farmers) and they are related to sub-sectors. Otherwise, rice, fish, timber, garments and rubber products are still major exported by the Kingdom of Cambodia today and even the Kampot province also. In 2010, the international rice research institute (IRRI) reported that more than 700 different traditional rice categories to the Kingdom of Cambodia were come from its rice seed of hardy stock in the Republic of Philippines and other countries. These varieties had been collected in the 1960s and later on.

Based on the economic analyst from the international monetary fund (IMF) reported that the annual average of gross domestic product (GDP) growth rate for the period of 2001-2013 was enjoyed exceptionally high growth rate around 6% to 7.5% each year making it one of the highest GDP growth rate countries in the world with the highest annual average GDP growth rate, the Royal Government of Cambodia could achieve her policy soon. At present time, tourism sector was one of fastest growing industry without smoking in the Kingdom of Cambodia where it had a lot of wonderful temples and historical places, like the western foreigner named as "Cambodia is a Kingdom of wonder", with this name, there were many arrivals increasing from 219,000 people in 1997 to more than 4.2 million people in 2013 as the Royal Government of Cambodia's rectangular strategy policy (step 3) was actively setting up to develop and improve all economic sectors and good governance from time to time in order to reach the Royal Government of Cambodia's millennium development goals (MDG) as soon as in future time. In 2013, in this case, inflation rate was at 2.7% and exports at 6.078 billion US$. As of year 2013, GDP per capita in PPP terms was more than 2,200 US$.

The People's Republic of China was a biggest source of foreign direct investment and Japan was a biggest donor source in the Kingdom of Cambodia after the general election which organized by the United Nations Temporary Authority in Cambodia (UNTAC) in 1993. Basically, the People's Republic of China planned to invest more than 7 billion US$ in more than 300 projects in the first semester of the year 2012. It was also the largest source of foreign aid, providing about 600 million US$ in 2007 and nearly 400 million US$ in 2008. Absolutely, most of older population often lacks of education and technology, particularly in the rural areas, which always suffers from a lack of basic infrastructure systems. There is very significant aid from national and international donors. Many donors have pledged fund around 500 to 1,000 million US$ each year by the international donors in order to restore and develop the country since 1993 while the Asian Development Bank (ADB) only has provided around 780 million US$ in some loans, grants, and technical assistances.

5. Energy supply and demand

After 30 years of the civil war, the Kingdom of Cambodia was become one of the poorest countries in Southeast Asia and even in the world. At present time, more than 80% of Cambodian people live in rural areas that are depended on agriculture activities and only a small percentage of the rural population can access to reliable supply of electricity (quality electricity from national grid or mini-grid). Most electrification system in rural areas utilizes small diesel generators which tariffs are very high and poor quality compare to other countries in the region and today has an adverse impact to the environment. Most households have used kerosene lamps for lighting, fuel-wood for cooking and battery for daily entertainment. With this issue, in order to reduce poverty, improve the living standard and foster economic development in the rural areas, so the Royal Government of Cambodia (RGC) that led by H.E. Samdech Techo Hun Sen, Prime Minister of the Kingdom of Cambodia, through the Ministry of Industry, Mines and Energy (MIME) had actively set a clear two-step target and more worked hard in the rural electrification plan as below:

1. By the year 2020, all the villages of the Kingdom of Cambodia will have electricity from all type energy resources.

2. By the year 2030, at least 70% of households will have access to grid quality electricity including national grid and mini-grid services.

In order to achieve these goals and targets, the rural electrification plans will be implemented by developing mini-grids or off-grid systems powered by renewable energy resources such as biomass, solar PV and hydropower (micro/pico < 15 MW), especially come from solar PV battery charging stations.

The Ministry of Industry, Mines and Energy (MIME) and Electricité du Cambodge (EdC) are enjoyed in the processing unit of implementing the extension of national grids to provincial towns, to districts and to communes. In addition, the electrification in off-grid area was also officially put into the line of implementation to achieve the goals and targets of alleviating poverty in rural areas and the government's political objective to develop in the country without the environmental impacts and with harmonized environment.

Over 80% of Cambodian people are living in rural areas with agriculture works as main occupation (primary job) for their daily lives. First Cambodian people are proven sources of hydrocarbon resources are still in exploration stage and over 80% of the primary energy is contributed by fuel wood (cooking, heating and other daily operations). Less than 50% of rural households have access to electricity services and those that have, depend mainly on connections to a public distribution and transmission grid (where available) or on private diesel generators. Rechargeable, automotive-type batteries (car battery) are still most popular used in rural areas in the Kingdom of Cambodia for basic household services such as lighting, TV and radio.

On the other hand, the power sector in the Kingdom of Cambodia is supplied by different sources, for example, the electricity generation services in the Kingdom of Cambodia for the year 2012 can be separated into four main types such as

1) Hydropower plants, 2) Heavy fuel oil/diesel power plants, 3) Thermal power plants using coal new clean technology and 4). Power plants used wood and other biomass. The summary information of installed capacity and energy sent out by types of generation are given in the Figure 3 below.

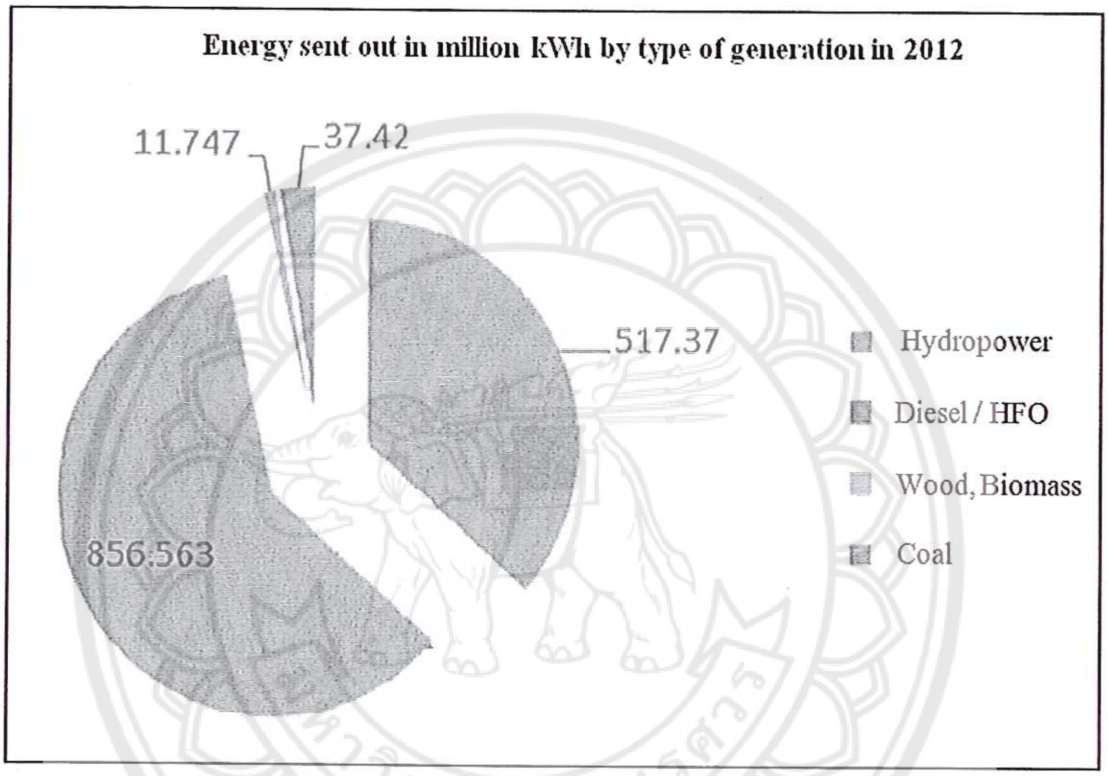

Figure 3 Energy sent out in million kWh by type of generation in 2012

Source: Electricity Authority of Cambodia (EAC), 2012

The power sector demand forecast is based on the increase in number of households and growth of other energy consuming entities (population growth and industrial revolution). During the last 10 years energy consuming entities in the Kingdom of Cambodia are quickly increased from year to year. Truly, this approach tends to favor both larger and denser settlements located very close to the grid and off-grid projects in order to cope with the Royal Government of Cambodia's power sector strategy above and also can connect to ASEAN countries' networks. The Figure 4 is shown that the power sector demand for electricity has actively grown by 11.4%

from 2000 to 2005, by 11.4% from 2005 to 2010, and is still strongly expected to increase by 8.5% from 2010 to 2015, consecutively.

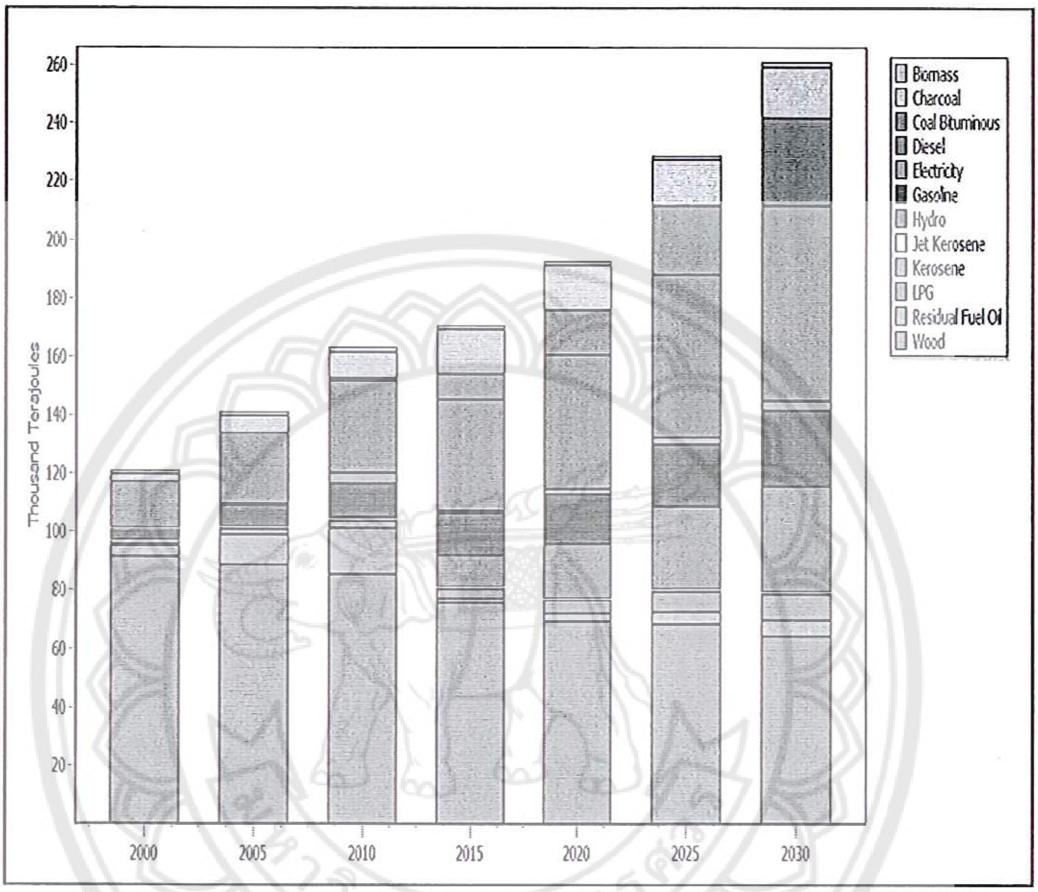

Figure 4 Energy demand in Cambodia from 2000-2030

Source: Ministry of Industry, Mines and Energy (MIME), 2000

6. Rural electrification rate

The Royal Government of Cambodia (RGC) is strongly encouraged and implemented its plan to provide adequate electricity supply to provinces, districts and communes (towns) through off-grid or grid-based systems at affordable and reasonable price with a good quality electricity. In 2012, the Royal Government of Cambodia launched the rural electrification and transmission project (RETP) funded by the World Bank (WB), Asian Development Bank (ADB), the Global Environment Facility (GEF), Innovation Energie Développement (IED) and the Nordic Development

Fund (NDF), to strengthen and expand Cambodia's present generation, distribution and transmission capacity in near future as soon as possible.

An important component of the rural electrification and transmission project is the establishment of a Rural Electrification Fund (REF), to accelerate rural electrification and reduce the cost of electricity which is strongly encouraged to participate the poverty reduction in rural areas in Cambodia. There is a financial and technical obstacle in creating an electrical distribution networks for the entire rural areas of the Kingdom of Cambodia, and there is needed to imagine of a method that takes Cambodia industrial development into account when infrastructure investment is very priority considered. Therefore, as cities with a high demand-level for energy are being provided with electricity distribution, transmission and generation facilities, the rural regions with a less demand for electricity must also be provided with closed to mid-voltage distribution networks and a strategy should also be formulated for a self-propelled program. The Royal Government of Cambodia's (RGC) strongly plans to extend grid-based electricity supply to provincial, district and commune towns are under implementation by public and private sector. In rural areas, with no access to public grids, the Royal Government of Cambodia is seeking to encourage private development of mini-grids based on diesel and/or renewable energy sources, especially solar PV battery charging stations for villages are not available with grids. The rural electrification and transmission project (RETP), funded by the World Bank, Asian Development Bank (ADB), the Global Environment Facility (GEF), the Nordic Development Fund (NDF) and other involved parties, aims to help the Royal Government of Cambodia can achieve all these aims by implementing a wide range of activities including strengthening and expanding of Cambodia's existing generation, distribution and transmission capacity; technical assistance for capacity building, institutional strengthening and operational support; and rural electrification which was subsidized cost about 45US$/household for PV battery charging station and 100US$/household for solar home system by the World Bank’s grant in 2012. The main important elements of the rural electrification and transmission project are established the Rural Electrification Fund (REF) organization, which was administered by an autonomous state unit, namely Electricité du Cambodge (EdC), to accelerate rural electrification and try to minimize the economic cost of supplying electricity in order to reduce poverty in rural areas.

7. Energy policy on renewable energy

Referring to the electricity law (2001), had clearly classified the energy sectors of the Kingdom of Cambodia are as the Ministry of Industry, Mines and Energy (MIME), Electricity Authority of Cambodia (EAC) and Electricité du Cambodge (EdC). More detail structure is shown as the Figure 5 below.

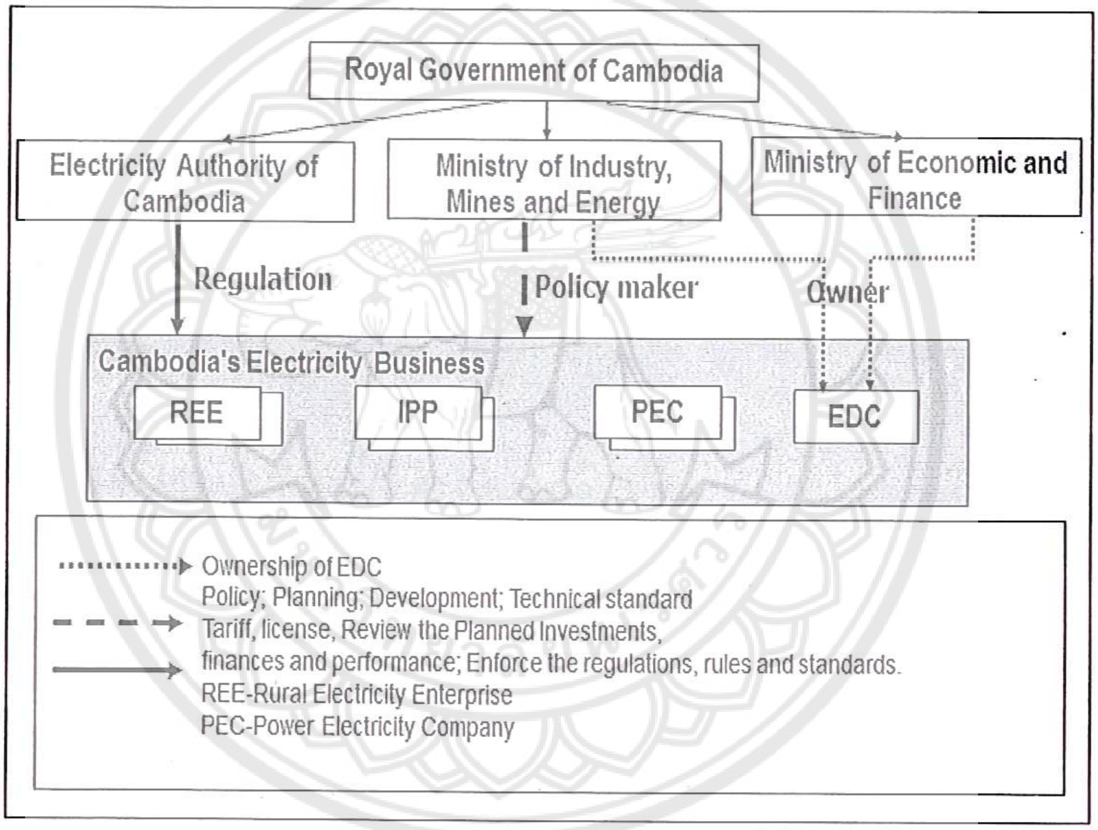

Figure 5 The current structure of energy sector in Cambodia

Source: Ministry of Industry, Mines and Energy (MIME), 2001

The Ministry of Industry, Mines and Energy (MIME) is a government unit which is responsible for energy policy, strategy, planning, management, publishing energy standard and environmental impacts. Based on this role, the Royal Government of Cambodia has been setting up the renewable energy policies as the following:

1. Endeavour to provide access to reliable, safe electricity services, with insignificant impact on the environment and at an affordable price for rural communities.

2. Provide effective legal, regulatory frameworks and various to an encouragement and train the private sector to participate in providing electricity services by renewable energy sources to the rural areas.

3. Act as a market enable, through various incentives, for enabling equity in access to reliable and safe electricity services, with insignificant impact on the environment, at an affordable price for the rural communities.

4. Encourage the efficient generation, transmission and distribution of electricity using the renewable energy technologies, through tariffs, which are in conformity with the Electricity Authority of Cambodia (EAC)'s regulation.

5. Promote electricity systems by renewable energy at least cost for rural communities, through research and pilot development, as part of the Royal Government of Cambodia's portfolio on grid and off-grid technologies.

6. Ensure adequate resources, appropriate institutional mechanism and training to empower the poor involving in rural electrification to participate.

Source: Master Plan on Renewable Energy of the Ministry of Industry, Mines and Energy (MIME, 2005).

General theory

This chapter will present both the relevant literature reviewed for the study, and the discussion on each of the research questions raised earlier in previous chapter as mentioned the following:

The solar radiation received on the earth's surface was called global radiation. There were two components of solar radiation, such as (a) beam radiation that comprised direct radiation from the sun which is not scattered by dust, water and other droplets and (b) diffuse radiation was the reflected radiation from the atmosphere, it means that sunlight scattered by many atmospheric particles and gases. Solar energy could be used in a hundred number of ways like in the photosynthesis process, the absorbed solar energy was converted into the chemical forms of energy PV systems based upon semiconductor materials could convert the solar radiation directly into electric current (DC current) for many years ago. Solar energy could be used intelligently in buildings to reduce the energy consumption for heating systems in the cold countries and/or cooling systems in the hot countries also [3].

The solar radiation was a form of thermal radiation having in particular wavelength distribution or position. Its intensity was very strongly dependent upon atmospheric climate, time of year, and the angle of incidence for the rays of sun on the surface of the earth. At the outer limit of the atmosphere the total solar radiation when the earth was at its mean distance from the sun was about 1,367 W/m^2 [4].

The energy of the sun had been used by both nature and humankind for a long time ago in thousands of ways like growing plants, food, drying clothes, and drying all agricultural vegetables; it had also been deliberately harnessed to perform a number of many jobs. Solar energy was very strong popular used to heat and cool buildings (both direct and indirect ways), heat water for domestic daily uses and industrial uses, heat swimming pools for people who were living in cold areas or cold countries, power refrigerators for cooling systems, operated engines and pumps, desalinated water for drinking purposes, can generate electricity, for chemistry applications, and many more used or operated [5].

The electro-technical laboratory in Japan developed a semi-physical model to calculate the solar radiation from GMS satellite data. This model was based upon closely statistics relationship between hourly measurements data from around 14 ground-base stations and the reflected solar radiation from the earths' atmosphere and surface detected by the satellite. This model was commonly used to calculate the solar radiation of Japan from GMS satellite data from January 1992 to December 1993. The results showed about 10% difference from the measurement. In addition, the solar radiation of the East Asia was generated by this model and also still commonly used in region countries and out of region countries [6].

For the direct use of solar energy was not much fulfilling the minimal strictly necessary condition of a promethean recipe which was that some solar collectors could be reproduced only with the air of the energy they can harness for many years ago. The main obstacles are very the extremely low radiation of the solar energy meeting the soil because of absorbed by many parameters in the atmosphere such as water vapour, cloudiness, wind, ocean, haze and so on. The only upshot was that we need to observe a disproportionate amount of matter to harness solar energy in some appreciable amount [7].

The solar photovoltaic field was getting high priority used in some countries like the United States of America, Italy, Japan, England, Republic of France, Germany, Republic of India, etc. and there were very considerable interest, research effort and funding in this field. The worldwide interests were attributed to a variety of factors such as search for new energy sources in order to partly substitute fossil fuels and will be minimized the environmental impacts, due to very heavy pressure on conventional fossil fuels, simplicity, cleanliness, and direct conversion into electricity. Photovoltaic cells or the solar cells were generated an electromotive force as a result of absorption of ionizing radiation, namely its can convert light energy (photon) to electric energy (DC/AC current) by photovoltaic phenomenon or photo electrochemical phenomenon at outdoor with harmonized environment and more benefits [8].

The simplified picture of the sun, its physical structure, temperature and density gradients mention that the sun, in fact, did not function as a blackbody radiator at a fixed temperature. Moreover, the emitted solar radiation was the composite result of the several layers that emitted and absorbed radiation of different wavelengths or positions. The photosphere was the source of most solar radiation and was very essentially opaque, as the gases, of which it was composed, were strongly ionized and able to absorb and emit a continuous solar spectrum of radiation. In addition, the total energy in the solar spectrum (i.e., the solar constant) it was very useful to know the spectrum distribution of the extra-terrestrial radiation, that was, the radiation that would be received in the absence of the atmosphere [9].

In the presence of a homogeneous atmosphere, in fact, of finite depth, containing absorbing and scattering agents as the following:

1. Dust.
2. Air pollution.
3. Atmospheric water vapour.
4. Clouds.
5. And others.

Most of these factors are very important to absorbing and scattering the solar radiation in atmosphere (low solar radiation), which strongly can affect to the solar PV battery charging station also, especially more affect to PV systems using c-Si modules [10].

The total energy reaching at the earth was made up of two parts such as the energy in the direct beam and the diffuse energy from the sky. Although, most of power plants could be used direct and diffuse solar energy, actually, most manmade solar collectors could convert only direct energy efficiently. The amount of direct energy depends on the cloudiness and the position of the sun and was obviously greatest on clear sky days. Some solar radiation falling on clouds was diffused by scattering, normally, but clouds did not absorb all of the energy, its only can reduce. The effect of clouds was mainly to increase the percentage of diffuse energy in the total energy reaching at the earth surface, and diffuse irradiance in summer months with high sun and broken clouds can be as high as 400 W/m^2. Thick clouds let less energy pass than do thin clouds because of some energy are absorbed by cloud, and they scatter proportionally more of the total energy back into space [11].

The solar photovoltaic technologies were so proactively introduced into many emerging markets in the early 1980s. These were well done with much fanfare, hope and promise for the dawning of a new solar energy era, replete with independent, reliable, renewable energy from the sun. The reality, however, was that its uptake was disappointingly slow. By the turn of the century, just about 1 million households in emerging markets were estimated to be using a solar system for generating electricity accounting for not more than 0.25 per cent of un-electrified households globally. But, just at the point when many were tempted to give up on solar, some emerging markets turned the corner. So much so that by the end of year 2007, more than 7 per cent of the un-electrified households in the country like Sri Lanka was using solar systems. And then now Sri Lanka was not alone. There are many countries such as the Republic of India, Bangladesh, People's Republic of China and other countries also saw a strongly rapid acceleration in the diffusion of solar energy during the same period [12].

The solar photovoltaic (PV) systems are hardly touted as beneficial under certain circumstances because of their long-term economic and also externality benefits. Long-term economic system based upon geography, available incentives, maintenance practices, competing energy costs, the ability, quality and value of exporting the energy, the rate structure under which the systems are operating, and the ratios of the system capacity to building load. While methodologies are strongly developed for understanding many of the factors affecting to PV systems at outdoor performance, the impact of rate structure varieties based on system size, building load, and capacity relative to building load, resulting the complicated relationship between that is very difficult to generalize [13].

The financial considerations in a decision to deploy PV power plants could be quite different in developed regions than in the undeveloped regions. In a developed country, the economic units (e.g. individuals, families, businesses, government operations) have a cash flow and well-defined energy needs. The questions that they must answer periodically are what sources of energy that they will be chosen from among competing alternatives that are highly developed and more or less readily available. The questions can be addressed in a quantitative fashion, at varying levels of sophistication, and the resources are available to implement the choice. In undeveloped countries, the situations are more likely that the economic units are individuals or very small businesses with little or no cash flow. The questions for these regions are whether any electric energy is at all affordable, reasonable and where do the resources to pay for it comes from. The purely financial comparison of electricity sources by private entities often becomes subservient to public economic development initiatives, and national and international politics may play a strong role. The choice of electric energy sources for the classes of applications must still be made, and the cost of energy delivered, in the sense employed for developed regions may still be computed, but generally not by individuals or small economic units, because they will not pay for them [14].

The monthly average daily solar irradiation for different months for both the measured data on the horizontal surface and the calculated data based on the optimum tilt angle for Langkawi island. For further analysis of the solar radiation data obtained from the Malaysia Meteorological Department (MMD) for this location, it is found that the yearly average daily solar irradiation is about 4.06 kWh/m^2/day, while the total annual equivalent sunshine amounts to more than 3,200 hours. For an optimally tilted surface, the yearly average daily solar irradiation is about 5.13 kWh/m^2/day. These figures are relatively high, and highly suitable for PV panel's usage [15].

Techno-economic information

Characteristics of PV cells

The solar cells are the electronic device that can convert light energy (photon) to electric energy by photovoltaic phenomenon or photo electrochemical phenomenon.

Actually, electricity can be produced from sunlight through a process called the PV effect, where photo refers to light and voltaic refers to voltage. The term describes a process that produces direct electric current (DC current) from the radiant energy of the sun. In this point, there are two PV cell categories as following:

1. The crystalline silicon solar cells have high conversion efficiency and save their performance for long time and less land area. But, it has a sensible decreasing of their performances in case of shadow and low solar irradiation.

2. Thin film solar cells have medium or low energy conversion efficiency for direct irradiation from the sun, but they preserve a high efficiency with diffuse and low irradiation. Moreover, they perform better at high temperatures than crystalline silicon cells (c-Si) do, but, in deed, its need more land area for installing the PV power plants. In the figure 6 is shown the characteristics of PV cell type as below [16].

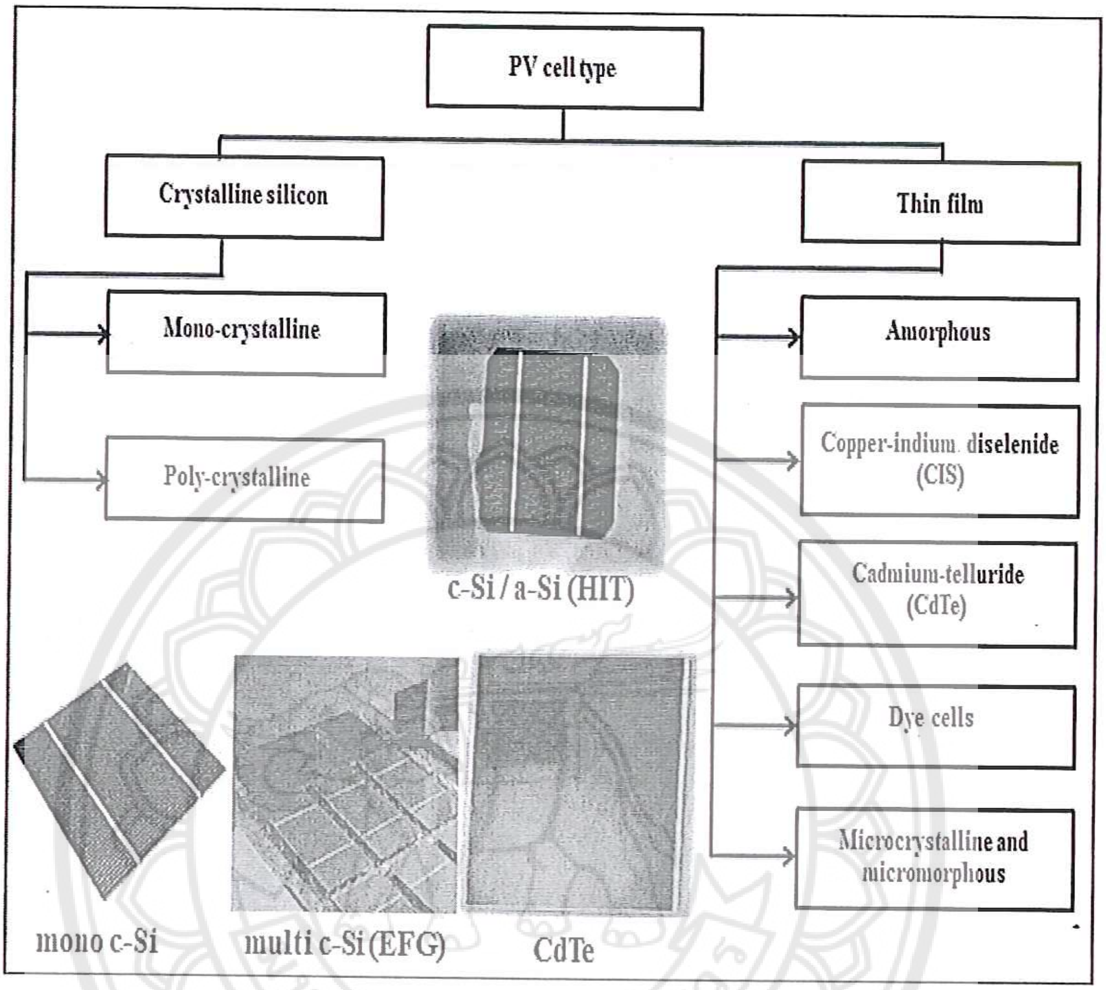

Figure 6 Characteristics of solar PV cell type

Source: Solar Energy (Renewable Energy and Environment, 2010) [16]

The P-N junction

The most solar cells are made of semiconductors. A semiconductor was characterized by a relatively narrow energy gap, typically a fraction of an electron volt to a few electron volts. Electrons can be excited by a photon from the valence band to the conduction band and form an electron-hole pair. The electron-hole pair stores a substantial portion of the photon energy. After formation of the electron-hole pairs, the p-n junction separates the electrons and holes to generate external electric current [17]. The figure below is shown the characteristics of P-N junction in a simple circuit.

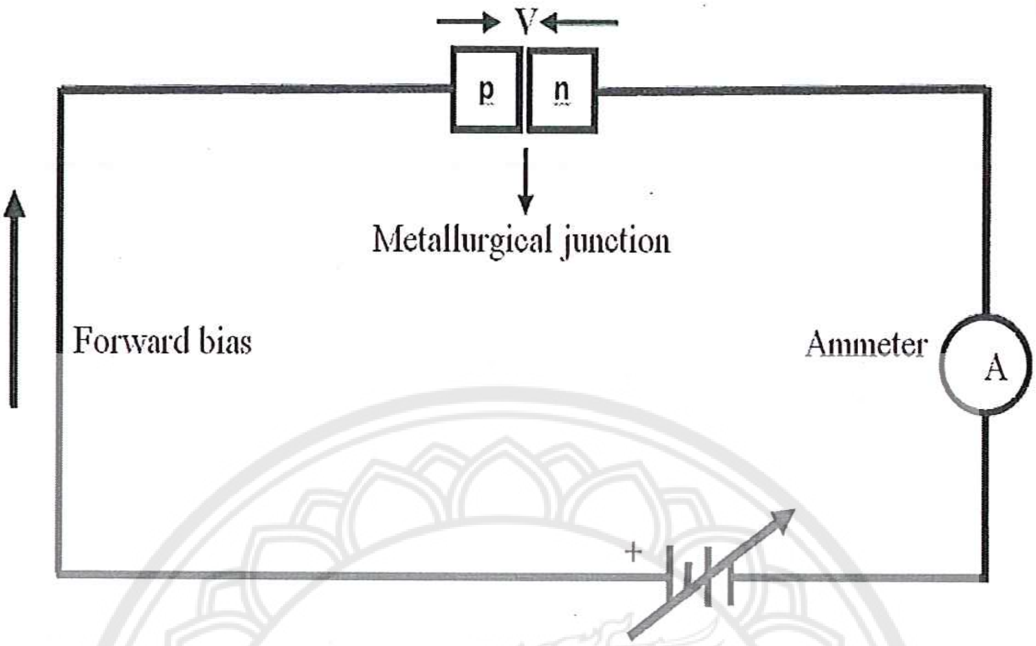

Figure 7 P-N junctions in a simple circuit

Source: Physics of Solar Energy, Columbia University in the City of New York, USA, 2011 [17]

PV systems work

The PV systems produce power intermittently because of they work only when the sun is shining. PV modules can convert the sunlight (photon) to electricity (DC current) by photovoltaic phenomenon. More electricity is produced on a clear, sunny day and high solar radiation with more intense sunlight and with a more direct light angle, as when the sun is perpendicular to the surface of the PV modules. As a result, PV is a good tool and technology whereby sunshine is converted into electricity by photovoltaic phenomenon, just as power plants use chlorophyll to photosynthesise the sun's irradiation in order to provide electricity for our strong growth today. The figure 8 is shown the normal solar PV systems work as below [18].

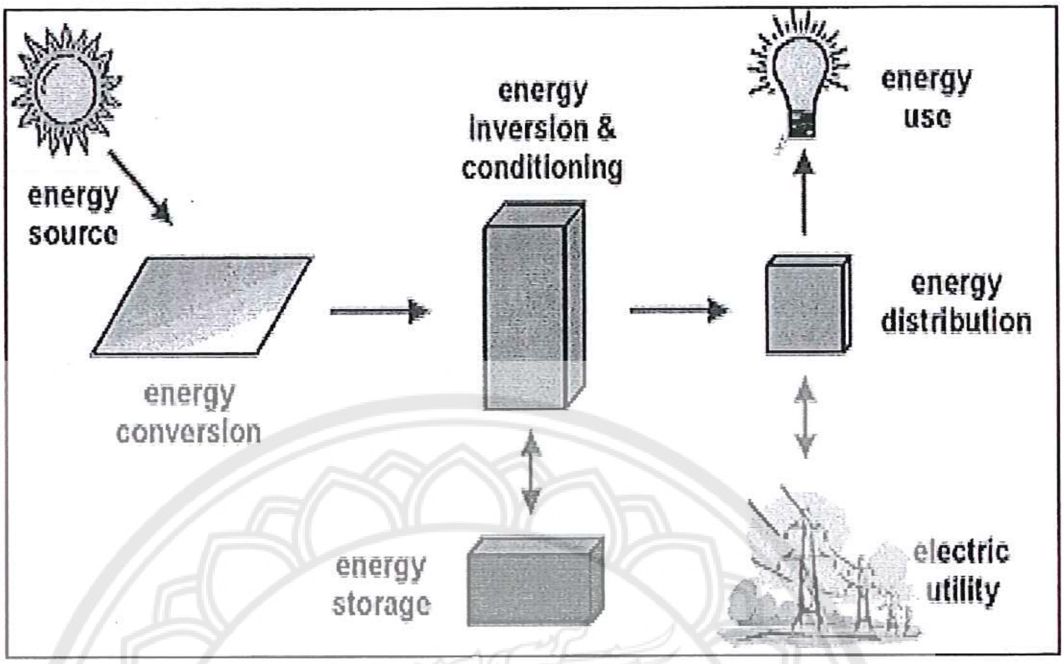

Figure 8 Major solar PV systems work

Source: http://www.fsec.ucf.edu [18]

Solar photovoltaic systems are made up from many photovoltaic solar cells, they are connected together to create a large unit called solar PV modules. Solar PV modules can be connected to form a large unit, namely called arrays which can produce more electricity capacity and so on. The performances of PV systems are therefore dependent on the performance of its components such as high solar radiation, PV modules conversion efficiency, charge controller efficiency and other components. Solar PV systems can provide to electric energy need such as small or large electricity capacity. Moreover, solar PV systems, in fact, can be operating around 5 to 6 hours per day, more than 300 days per year with operating life time 25 years and operation and maintenance (O & M) cost is about 0.05% per year of total investment costs of each PV power plant [19].

Effects of temperature

The performance of photovoltaic systems depends to a great extent on the operating temperature which a factor that influences their daily and seasonal performance of each location where we install PV power plants. This is a very diverse effect especially in areas of high solar irradiation such as the Cyprus where module temperatures may even reach at 70^0 C during midday hours of the prolonged summer season. The terms of temperature coefficient were a parameter which too quantifies several different photovoltaic electric characteristics, including the voltage, current and power [20].

Charge controller function

The primary functions of a charge controller are as follows:

1. To protect the batteries from overcharging of system.
2. To protect the panel from power going back into it from the batteries.
3. To help maintain battery condition by keeping the battery voltage high.

The functions of charge controller are very important to all PV power plants; especially it refers to either a stand-alone device or to circuit integrated within a battery pack, battery powered device, or battery recharger like PV battery charging station [21]. In the figure 9 is shown the characteristics of PV charge controller normally used for PV power plants. (Introduction to 12 Volts batteries charging from a solar panel, 1-3 and http://www. selectsolar.co.uk).

Figure 9 The characteristics of PV Charge Controller

Source: http://www.selectsolar/equipments.co.uk [21]

Avoiding shading PV modules

The shading of PV systems is very actively led to a significant reduction of the system's energy yield. For the ten systems, low-degree and high-degree losses were identified as the following:

1. Partial shading of five of the six strings during mornings by a tall about 18 meters broadleaf tree resulted in reduced yield energy is around 4%.

2. Partial shading of a PV array by the roof of neighbouring building as well as by surrounding trees strongly led to reduced yield energy by up to 10%.

3. Most significant shading of the array by several trees located very close to the houses and extending above the PV rooftop resulted in annual energy losses of higher than 20%.

Most of solar PV systems are very affected to energy output by shading PV modules as rating above, so PV systems should be installed at site or location where is far away from trees, building and other shadings, especially c-Si PV modules are very strongly affected by shading [22].

Module measurements

It is necessary to normalize all results to standard test conditions (STC), namely the temperature is at 25^0C, solar radiation 1,000 W/m^2 and the air-mass 1.5 (AM 1.5). A common way of doing this, use the nameplate power of the modules. The advantages of this method are that the nameplate power represents the PV power the customer paid for; the disadvantages are that it depends on the companies' rating policy, and on (possibility big) tolerances of the rating. With scientific evaluations, the real power of the module under standard test conditions is too preferable for the normalization. This method enables comparisons between the different PV technologies. Therefore, it will be determined the output power of all PV modules with a solar simulator before installation [23].

Common installation mistakes with array modules and configurations

The most common installation mistakes with array modules and configuration mentioned as follows:

1. Changing the array wiring layout without changing the submitted electrical diagram.

2. Changing the module type or manufacturer as a result of supply issues.

3. Exceeding the inverter or module voltage due to improper array design.

4. Putting too few modules in series for proper operation of the inverter during high summer array temperatures.

According to these factors, most of PV systems are always met to common installation mistakes as mentioned above, so all PV power plants should be setting up monthly or yearly checking [24].

Maximum power point tracker

The maximum power point tracker (MPPT) produces maximum power under variable conditions of solar radiation and environmental temperature. One of the most used methods of MPPT are the perturb and observe (P&O). The main advantage of this technique is that the search of the maximum power point tracker is done independently on the environment condition, however it required current and voltage sensor. On the other hands, constant voltage methods is used to keeping the voltage in the PV terminal constant and closed to the maximum power point tracker line [25].

Cost of PV stand-alone systems

The cost of PV stand-alone systems will depend on many factors such as the system's configuration, equipment options, transportation, labour and other costs. Prices are vary depending on other factors as well, such as whether or not your home is new, and if the PV systems are integrated into the roof or mounted on top of the existing roof. The cost also scales up somewhat with the system size or rating, and the amount of electricity it produces [26].

Solar PV systems should be much focused on the two main categories of reducing cost such as 1). Eliminate unnecessary steps and streamline processes mean that the significant cost reductions can be achieved by streamlining processes throughout the project life cycle. Implementing consistent regulations and reducing the uncertainty associated with approval processes can help reduce non-value-added time. A detailed process roadmap that identifies current life cycle times and costs, as well as unneeded actions, rework, and other factors driving time, complexity and cost is needed. Dedicated efforts by industry organizations and customers are needed to inform this analysis and to demonstrate strongly replicable processes that reduce costs while maintaining safety and then 2). Reduce project (dropouts): Every project that does not make it from proposal to completion adds overhead to successful projects. These dropout projects may be caused by unrealistic customer expectations, stakeholder inexperience, unforeseen permitting challenges, or a lack of capital. In particular, one way to address these issues might be a database of existing projects that developers can be used to evaluate proposed projects [27].

Solar PV systems warranty

In the PV systems, there are two main components of a PV module warranty as the following:

1. A workmanship warranty that offered to repair, replace or refund the purchase in case of defects. The period varies from one to as long as ten years, depending on the manufacturer. From two to five years is typical.

2. A limited power output warranty that offers a variety of remedies in case of the PV module's output under STC (25^0C, 1000 W/m^2 and A.M 1.5) drops below certain level. Most of manufacturers warrant at least 90% of the minimum rated output for 10 years, and 80% of the minimum rated output for 20-25 years. Taking note that the minimum rated output was usually defined as 95% of the rated output to allow for manufacturing and measurement tolerances [28].

Landscape impacts of PV systems

The main landscape impacts of photovoltaic systems are as following:

1. Land use.
2. Reduction of cultivable land.
3. Fragmentation of the countryside.
4. Plant degradation.
5. Visual impact on the landscape.
6. Interference between fauna and flora.
7. Micro-climate change.
8. Glare.
9. Electromagnetic fields.
10. Construction phase impacts.

In the PV systems, there are many factors which can be very impact on the PV power plants of each country. The landscape is very useful for PV systems where is more suitable or not and it is strongly impacted on systems too [29].

Regular maintenance and care

The regular maintenance and care were explained as follows:

1. A built up of dust or dirt on the modules front face will result in a decreased energy output. So, we need to clean the panels or modules preferably once or twice per annum if possible (dependent on each site conditions) by using a soft cloth dry or damp, as necessary.

2. Never use abrasive materials under any circumstances, it will be damaged.

3. Examine the PV modules for signs of deterioration. Check all wiring for possible rodent damage, weathering and that all connections are tight and corrosion free. We have to check electrical leakage from panels to junction box and from junction box to ground and others.

4. Check fixing screws and mounting brackets and tight, adjust and tighten as necessary [30].

The PV arrays are still kept inclined at an angle to horizontal whereas, in general, the data for incident solar radiation are available corresponding to flat horizontal surface. The many factors by which global radiation on a horizontal plane are to be multiplied to obtain that on a surface kept at tilt angle facing to south or north depended on that location. The PV arrays are tilted at a fixed angle called optimum arrays tilt angle, which will be defined, as the angle at which the arrays are tilted angle from the horizontal plane to receive maximum solar radiation averaged over the year. The optimum arrays tilt angle will be the angle for which the total annual value of unit array output (UAO) is very maximum. The optimum tilt angle for 14 stations in Indian region were calculated and its variation with latitude is shown in the figure 10 below shows the variation of optimum tilt angle of the arrays with latitude and fit of second-degree polynomial therein of each location which we need to install the PV power plants [31].

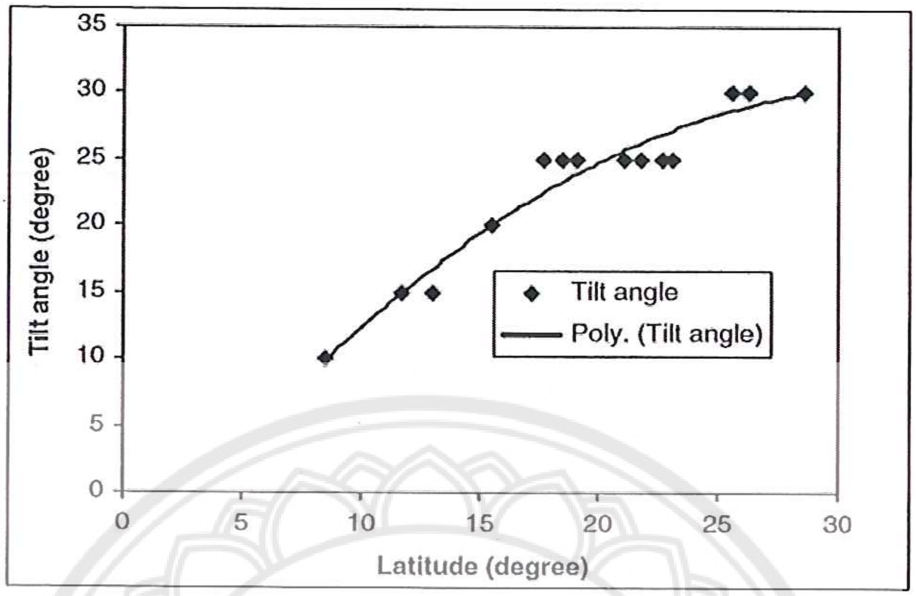

Figure 10 The variation of optimum tilt angle of the arrays with latitude

Source: http://www.elsevier.com/locate/solmat [31]

Photovoltaic energy is helpful to environment

Today environment is a big topic that many countries are concerned to have been influential in triggering the little ice-age and some of warming observed from the beginning of 19^{th} century. Based on some research papers mentioned about climate or global warming causing from three main sectors such as energy, agriculture and transportation. In particular, energy sector is a big problem affected to environment because most of energy sectors are used a fossil fuel to generate the electricity and other purposes. As present time, photovoltaic technology can provide a clean energy, namely its convert sunlight to electricity by photovoltaic phenomenon in order to instead of electricity which generated from fossil fuel. PV systems do not produce any greenhouse gas emission (GHG) when operating, so they can be used to reduce greenhouse gas emission. PV systems nevertheless carry the environmental weight of other stages in their life cycle. Lastly, PV systems are no harmful emissions or pollution gases released during operation time. The renewable energy is a best option for protecting environmental impacts today and future [32].

Solar PV battery charging stations (PVBCS) are very famous as a selection for rural people as basic rural electricity in many countries in the world which have a shortage grid. For many years ago, solar PV battery charging stations have been installed namely in Morocco, Bangladesh, Brazil, India, Kenya, South Africa, Thailand and other countries. Solar PV battery charging stations should be located in the centre of each village or small region. This station, users or villagers have to bring their batteries to the station for charging at the morning and collecting back at the evening. Users or villagers always use a battery for lighting, entertainment, and other purposes with battery capacity range of 6V to 24V depend upon their energy needed. PVBCS can potentially increase their convenience by supplying electricity for people in rural areas in order to improve their living conditions and try to minimize the environmental impacts that come from energy sector, especially come from electricity. By using sunlight, solar PV battery charging stations are also most suitable for country which has high solar radiation and low electrification rate as well as like the kingdom of Cambodia today [33].

Photovoltaic costs

Eicke R. Weber stated that the photovoltaic prices have fallen sharply since the mid of 1970's. It is generally believed that, as photovoltaic prices fall, markets will expand rapidly. So, the pay back times were reduced to 3-5 years, depending on the sunshine available at the installation site. At present time, the cost of photovoltaic is around US$1.0 per watt peak and less than this by 2025. Moreover, the PV modules industry witnessed more price decreases, for example, c-Si modules and thin film modules technologies are improved and high efficiency. So, both of products price are still fallen like at the end of each year most of suppliers and wholesales want to reduce stocks. Especially, the manufacturers in China are trying to clear their stocks [34].

Resource availability

The potential for renewable energy in the San Diego Region mentioned that the PV production is predictable; it is based on sun availability and maybe coincident with load. The output of a photovoltaic array is also a function of the array temperature and solar insolation which is affected by conditions such as cloud cover, soiling, azimuth and tilt (position of the sun in the sky), which result in an electrical energy output which has daily, monthly and yearly variability. Adding tracking and energy storage capabilities improves the availability of PV products [35].

Photovoltaic market development

Photovoltaic solar energy development and current research stated that in the last few years the photovoltaic market expanded very extensively, especially in Germany, followed by Spain, Italy and other countries. In addition, Greece is due to be the next fast-growing market. Several incentives have stimulated the expansion, rendering the photovoltaic industry ready to expand. However, the high production cost of electricity, due to the significant capital investment cost and other costs, is the main barrier to large-scale deployment of photovoltaic systems in each country [36].

Advantages of solar PV system

The advantages of the solar PV system are as following:

1. Environmentally friendly.
2. No noise.
3. No moving parts.
4. No use of fossil fuels and water.
5. No emissions.

As a result, PV systems are provided green energy, renewable energy by exploiting solar energy. PV systems can use as an alternative energy source in order to substitute of today electricity which generated from fossil fuels [37].

Economic analysis

In modern competitive energy markets it is very essential that every power systems must prove also, besides its technical feasibility, its economic viability. The generally accepted economic criteria used for such evaluation are as the following:

1. Net Present Cost (NPC).
2. Net Present Value (NPV).
3. Internal Rate of Return (IRR).
4. Pay Back Period (PBP).
5. Benefit to Cost Ratio (BCR).
6. Cost of Energy (COE).

From the above criteria the cost of energy refers to each power system individually, whereas the other indices refer to comparisons between two power systems, one of which is considered to be the reference power systems in order to find power plants are economically or non-economically [38].

The financial indices are normally used in an economic evaluation as the following:

1. Year to positive cash flow.
2. Net present value (NPV).
3. Internal rate of return (IRR).
4. Payback period/time (PBP).

As a result, the economic assessment tools were calculated to three main financial scenarios, such as the owner should be covered around 70% of the initial cost of each project, if the owner can cover 100% of the initial cost and the owner can cover only 40% of the initial capital cost its mean that the rest of the capital cost may come from any suitable banks, which can provide loans and grants to the owner or investor with a lowest interest rate and an appropriate payback time. The details of financial indices are shown in the table 1 below [39].

Table 1 the financial indices scenario

Financial scenario	IIR and ROI (%)	NPV (EUR)	PBP (years)	Year-to-positive Cash flow (years)
70% by the owner (a)	18.3	69 486	7.1	6.2
100% by the owner (b)	13.5	49 326	10.2	8.4
40% by the owner (c)	29.5	89 681	4.1	3.7

Source: http://www.elsevier.com/locate/apenergy, 2002 [39]

Payback time/period for PV modules

With current technology and production methods, the energy payback time for PV modules has been estimated at 1.5 to 5 years depending on the technology and solar intensity. Over a life time of 25 years, PV modules thus generate 5-23 times the energy required to produce them. The balance of systems (BOS) components can add significantly to energy payback times. Heavy support structures could increase energy payback times by over 6 years. Depending on the application, PV systems have to be equipped with auxiliary components such as inverters, charge regulator and energy storage systems. Contributions to energy requirements from such components are normally small for PV systems [40].

Financial parameters

In this third category of inputs, the parameters regarding the economic data for the evaluation of the PV power plants are given. Cost data about the equipment (e.g. cost of PV modules, cost of inverter, electrical equipment etc.) are defined in this category. The cost of the preliminary design and the development of the PV power plants are also defined in this category of inputs. Financial parameters also include the discount rate (with which the performance of the PV power plants will be compared), the debt ratio and the debt rate, the taxation rate and the governmental or other grants. Moreover, the price that the produced energy is sold, the energy escalation rate, the national inflation and the expected lifetime of the PV power plants (during which the net annual cash flows are calculated) are given in this category [41].

Summary of related literature review and research

General information

The solar energy is an energy come from the sun's radiation and the sun is more powerful source of energy and it provides more energy to the earth. In particular, Kampot province is one of the provinces in the Kingdom of Cambodia which can receive high solar energy (solar radiation). The solar energy had been used by both nature and man-made for a long time ago in many thousands of ways. The maximum of solar radiation from the sun to the earth was about 1,367 W/m^2. Solar energy was used to heat and cool for many purposes. In other words, solar radiation is divided into two main categories, namely beam and diffuse radiation. Sometimes, PV power plants need to use direct and indirect radiation with different ways as the reference [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15].

Technical aspects

Solar PV systems can be produced electricity by PV cells or PV modules to convert the sunlight (photon) to electricity (DC/AC current) by photovoltaic phenomenon. More electricity is produced on a clear, sunny day and with high solar radiation. Solar PV systems are very good technology today which many countries are more popular used like the USA, Italy, Japan, England, Germany, France, India, China and so on. The worldwide interests are commonly attributed of many factors such as search for new energy sources in order to partly substitute fossil fuels which have limited and certain areas in the world today, especially will be minimized the environmental impacts that most of countries are very strong concerned about this issues such as global warming, climate change and other problems, but the PV systems need to take care and regularly maintenance to avoid the low energy outputs. On the other hand, there are two main PV module categories such as 1) Crystalline silicon solar module has high conversion efficiency (14%) and save their performance for long time and less land area, but it has a sensible decreasing of their energy outputs by shadow and low solar radiation and 2) Thin film solar modules have medium or low energy conversion efficiency (less than 12%), need more land area and preserve a high efficiency with diffuse and low solar radiation. In the PV systems, normally can be operating around 5 to 6 hours per day, more than 300 days per year with operating life time 25 years. More detail of these problems is as the reference [8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 28, 30, 31, 32, 33, 35, 37].

Economic aspects

For solar PV systems, there are many factors which are strongly impacted on the costs of PV power plants of each country such as land, labour, transport, PV modules, charge controller, fuel cost and other costs, but its need to eliminate some steps which are not necessary in the systems in order to reduce cost. The photovoltaic costs have fallen sharply since the mid of 1970s. Today, the PV markets are expanded very quickly year by year and most of countries are given more incentive costs and subsidy budgets in order to reduce the payback period of each PV power plant. The generally economic criteria used for evaluation of PV projects such as the net present value (NPV), internal rate of return (IRR), benefit to cost ratio (BCR) and payback period (PBP). Moreover, PV projects are regarded in economic data for evaluating of PV power plants. The cost of equipment is very important to consider in order evaluating the systems whether are economic or non-economic as the following references [14, 26, 27, 34, 36, 38, 39, 40, 41].