CHAPTER IV

RESULTS AND DISCUSSIONS

Data Analysis

Most households in rural areas in Kampot province of the Kingdom of Cambodia have no access to the national grid or mini-grid services. The electrification rate of the Kampot province is about 55% (MIME, 2013). According to the Electricity Authority of Cambodia (EAC) in 2013 reported that there are nearly 100% of urban households and less than 50% of rural households by connecting to the national grid or mini-grid systems. The electricity prices in Cambodia are currently the highest in the ASEAN region and even the world: up to 0.17 US$/kWh for EDC customers, and up to 1 US$/kWh for customers of diesel based rural electrification enterprises (REEs), which must bear significant production costs caused by inefficient second-hand gensets and poorly designed distribution mini-grids [2]. That is why rechargeable car batteries are still popular used throughout the country and even the Kampot province. In the figure 14 shows the population of Kampot, Kingdom of Cambodia. However, the population in Kampot province rapidly increased during the period from 1998-2012.

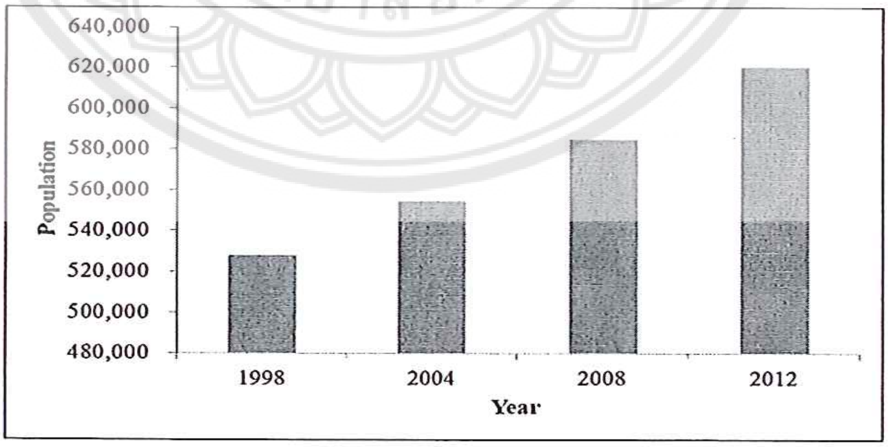

Figure 14 Population of Kampot province from 1998-2012

Source: National Institute of Statistics, Ministry of Planning

The electric power system in Cambodia was reconstructed from the ruins since the 1980s after finishing the Khmer Rouge regime. It still consists of isolated systems with the biggest systems in Phnom Penh which is a capital city (around 410 MW or equivalent of 56.6% of total energy generated over the Kingdom of Cambodia in 2012) and several non-interconnected grid in provincial towns under EDC and many mini-grid systems provided by scattered rural electrification enterprises (REEs), including private energy providers. These systems can be grouped into three main essential categories. On the other hand, the electricity power production value in Kampot province is rapidly increased year by year after the year 2007. The figure 15 shows the electricity power production in Kampot province of the Kingdom of Cambodia from 2004 to 2011.

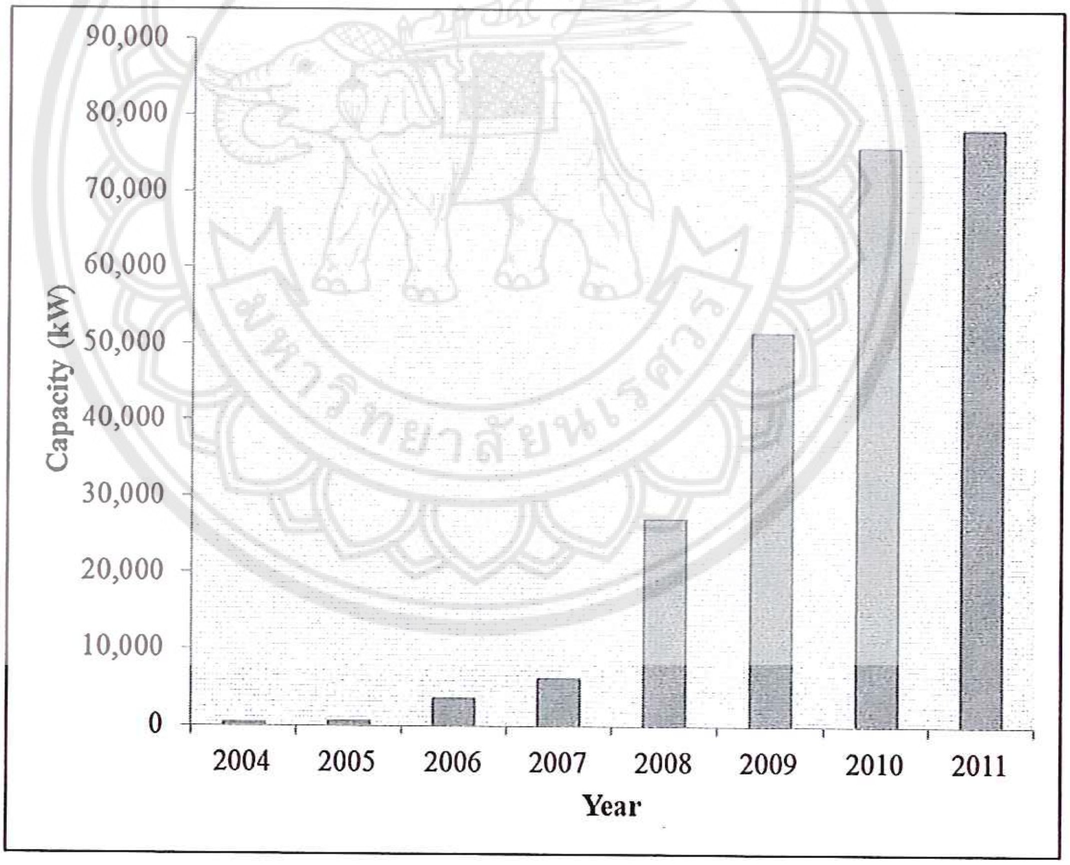

Figure 15 The electricity power production in Kampot province from 2004 to 2011

Source: Electricity Authority of Cambodia (EAC), 2011

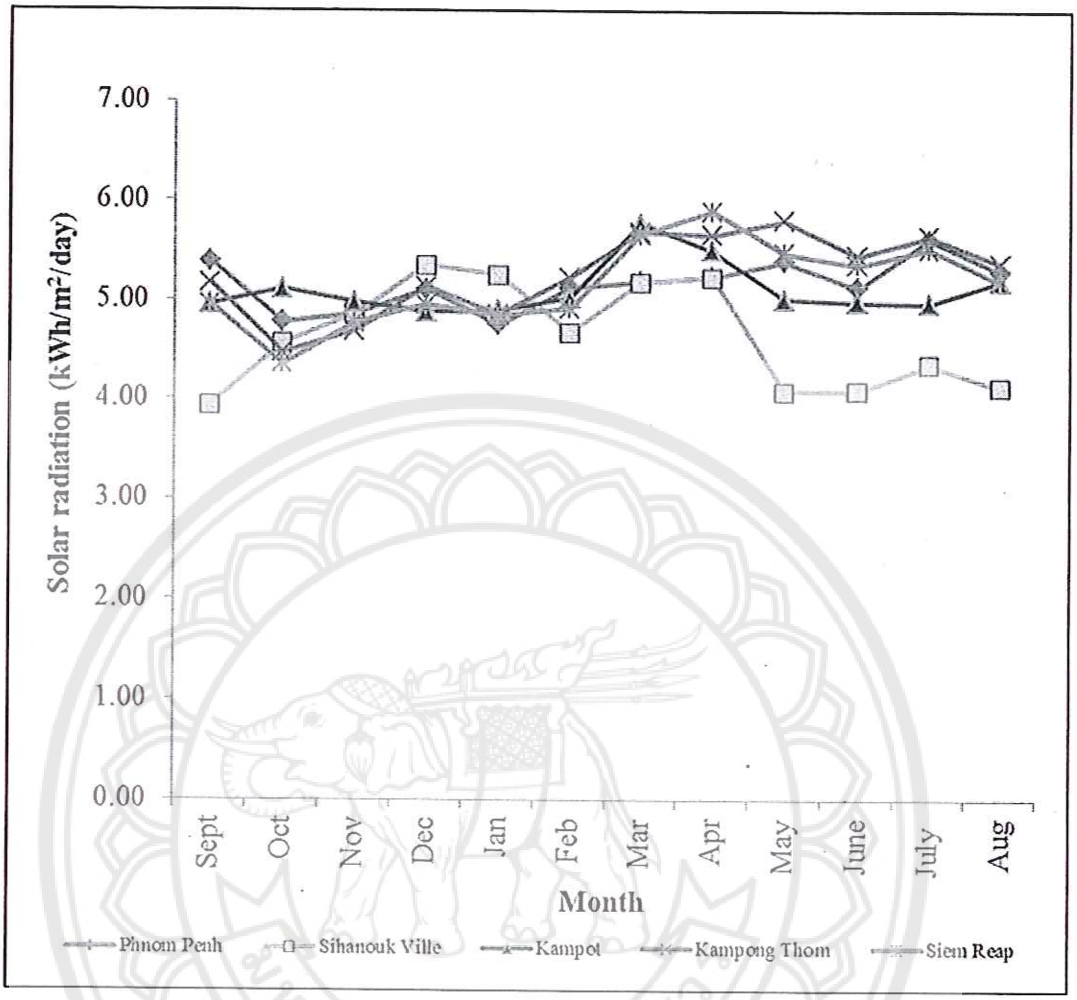

Figure 16 The solar radiation of five stations in Cambodia (kWh/m^2/day)

Source: Ministry of Water Resources and Meteorology (MOWRAM), 2010

Due to the figure 16 above, energy is a key factor for social and economic development of each country in the globe. It is needed for various economic sectors such as industry, agriculture, transportation and business. The main commercial energy source of most countries in the world is fossil fuels, especially oil. Cambodia, one of the Southeast Asian countries which has one capital city and 24 provinces with population nearly 15 million, does have abundant renewable energy resources, such as hydro (micro/pico), solar and biomass energy (around 80% used today) in order to efforts to utilize these resources on a large scale to provide a cost-effective and quality energy solution to the rural population is an on-going challenge for the government and the international community today. As the sun is a primary energy source of the earth. It is radiated in a form of electromagnetic wave with several wavelengths, called the solar radiation. In general, its wavelengths are mainly in a rage from visible light to infrared where human beings can use as light and heat sources [1].

Depend on it location near the equator, the Kingdom of Cambodia actively considers solar energy as one of the most promising renewable energy resources by the Royal Government of Cambodia. As solar radiation has temporal and spatial variations, it is very necessary to investigate the solar energy potentials for the entire country. The yearly solar radiation maps revealed that the south-eastern part of the country received the highest solar radiation with yearly average radiation is about 5.20 kWh/m^2/day or equivalent range of 1,700 to 1,900 kWh/m^2/year over the Kingdom of Cambodia [2].

In particular, Kampot is a tourism province where located in the southern part of the country, 150 km from Phnom Penh where is a capital city of the Kingdom of Cambodia and it has population around 620,217 (Ministry of Planning, 2012) and it has more potentials for the solar energy as the figure 16 above. In contrast, Kampot also has the lowest electrification rate in the country (about 55%, MIME, 2013) can access to the national grid or min-grid services. As a result, Kampot's population also suffers from having very expensive electricity prices and energy costs based on primarily on expensive oil imported today [1].

With many reasons, the Royal Government of Cambodia (RGC) is very strong commitment to reach her targets and goals as well as solar PV battery charging stations (PVBCS) could be a viable option to provide electricity in rural areas and where incomes are insufficient to pay for solutions like solar home systems (SHS). In general, solar PV battery charging stations operate reliably when good quality components are used. They are known and reputed among the people who are living in rural areas in Cambodia for their high quality of charge, which allows battery utilization for about 7-10 days. Moreover, solar PV battery charging stations are very important for saving expenditures for rural people which could help meet part of the political objectives of the Royal Government of Cambodia where all villages having access to electricity by the year 2020 [2].

Table 2 Summary of key factors and requirements of the location in Kampot Province

Factors	Requirements
Mean annual global horizontal irradiance (GHI)	≈ 1,700 - 1,900 kWh/m^2/year (Average ≈ 5.20 kWh/m^2/day) [2]
Wind speed	≈ 2.0 - 3.0 m/s
Tilt angle	10^0 - 11^0 [1]
Latitude	10.70^0 N [1]
Longitude	104.28^0 E [1]
Grid availability	> 40 km
Road proximity	> 200 m away from the provincial road and far away from the national road
Climate	Tropical climate (dry and wet)

Kampot located in the coastal areas with fewer trees to affect with PV battery charging station by shading. Land is still available for future developments, especially for PV battery charging station. The land price in rural areas of this province is very low, about 1.5 US$/m^2, compare to the urban areas, which can withstand erosion and draining is very fast after raining. The selected location for the PV battery charging station in Kampot province has very large reserved land area that could be used for building PV battery charging station. It is well known that the Kampot locates in tropical climate, indicating the high ambient temperature in this province and it also has a high solar radiation, in fact, the most suitable for solar PV power plants, especially for solar PV battery charging stations like the table 2 shows the key factors and requirements of the location in Kampot province.

Based on previous research, the mono and poly crystalline silicon PV modules have highest energy conversion efficiency, less land area and save the performance for long time, but the mono and poly crystalline silicon PV modules are very sensible decreasing of their performance by shading and low solar radiation conditions. Therefore, this study selected c-Si PV modules for calculating and designing PV battery charging system. Comparison of technical parameters and specifications using c-Si PV modules are shown in the table 1. The fixed mounted PV orientation is most commonly used in PV battery charging system, due to its easy installation, less complicated operation and maintenance (O & M) and low O & M costs. The PV battery charging station was determined to operate about 5 hours per day and 320 days/year with performance ratio (PR) about 74% or a little bit more. Module efficiency of c-Si PV modules around 14% is higher than other modules, it is very clear defined that the selection of c-Si PV modules into the built solar PV battery charging station in order to offer considerable scope for energy demand offsets and reduction of greenhouse gas (GHG) emissions in rural areas because of photovoltaic is a solid-state devices which simply produce electricity out of sunlight, silently and with a little to take care and maintenance, no pollution and no significant depletion of material resources, especially in Kampot province of the Kingdom of Cambodia.

Table 3 Parameters and capacities of PV battery charging station calculate based on energy need of each household in Kampot around 60W/customer with solar radiation 5.20 kWh/m^2/day

Parameters	Capacity
Energy demand (each charging string)	210 Wh/day
PV peak	201 W
Charge controller	16.75 A
Power rated of each charging string	212.3 W_p

In the Table 3 shows the results of PV battery charging station calculation, which based on the energy needed of each household about 40-60W/customer in rural areas by using equation 1 and 2 of c-Si PV modules with power rated of 212.3 W_p per module such as energy demand of this system is 210 Wh/day, peak power of the PV array is about 201 W, capacity of charge controller is about 16.75 A or more than this depend on market available and power rated of each charging string is about 212.3 W_p that can operate under Kampot's climate and environment.

Economic Analysis

In economic analysis, the currency in all the economic calculation of this study is in US$. The system financing considerations for 25 years are the normal for diesel and PV battery charging systems. This system was installed in Kampot province with capacity of 10 kW_p, according to the energy needed of each household in that location. The economic evaluation and specification were mentioned in the Table 4. The project life time of diesel and PV battery charging station and discount rate of this system has been calculated with 25 years. The investment costs of PV battery charging station in Cambodia is about 3.00 US$/$W_p$ (inclusive of transport and installation cost), charge controller cost is about 1,500 US$ which can use with capacity of 10 kW_p and replaces every 5 years, operation and maintenance cost is about 0.05% per year of investment cost, operating lifetime is 25 years and can operate about 5 hours per day (320 days/year), the cost of the main components of the PV power plant, around 66% of the total cost accounts for purchasing, transportation and installation of PV panels. The investment costs of diesel battery charging station of 10 kW_p is about 300 US$/kW, operation & maintenance cost is about 7% per year of investment diesel fuel cost, operating lifetime is 25 years (replaced generator every 10 years). The diesel battery charging station was determined to operate about 4 hours per day and 330 days/year [2, 19].

Table 4 Technical and economic parameters with capacity of 10 kW_p battery charging station using c-Si PV modules and diesel station

Parameters	Specifications	
Module name	c-Si modules	Diesel engine
Number of modules/ engine	47 (212.3 W/module)	1
Module area	80-120 m^2	-
Total land area	240 m^2	100 m^2
Mounting orientation	Fix mounted module	-
Operating hour/day and day/year	5 hrs./day 320 days/year	4 hrs./day 330 days/year
Module efficiency	14%	-
Temperature coefficient (TCE) of power loss	-(0.45 to 0.5)%/°C	-
Performance ratio (PR)	74%	-
Capacity system	10 kW_p	10 kW_p
Investment system	31,500 US$ [2]	3,000 US$ [2]
O & M cost	0.05%/year of investment cost [19]	7%/year of investment cost [19]
Project life time	25 years (replaces charge controller every 5 years)	25 years (replaces generator every 10 years)

In the Table 4 shows the technical and economic parameters which we need to use in both stations, such as module name, number of modules and engine, total land area, mounting orientation, operating hours per day and days per year, module conversion efficiency, temperature coefficient of power loss (%/^{0}C), c-Si PV module performance ratio, investment costs, operation and maintenance costs and project life time is about 25 years. Most of technical and economic parameters are very useful in case that to analyse and evaluate this station. To calculate and design of PV and diesel power plants in Kampot province of the Kingdom of Cambodia was used and given the best optimum system after optimization and analysis.

Table 5 Costs and benefits analysis for 25 years of 10 kW_p PV battery charging station using c-Si PV modules with original electricity cost of 0.27 US$/kWh and diesel station with original electricity cost of 0.34 US$/kWh

Parameters	PV modules station	Diesel station
Benefits:		
- Generated electricity	121,339	143,752
- CO_2 emission	1,572	0
Total benefits	122,911	143,752
Costs:		
- Land	360	150
- Investment cost	37,500	9,000
- O & M cost	504	20,179
- Transport	0	950
Total costs	38,364	30,279
*(Currency unit = US$ and land price = 1.5 US$/$m^2$)		

The sensitivity analysis for the investment cost and benefits are mentioned in the table 5 by using c-Si PV modules with the original electricity price of 0.27 US$/kWh (0% of battery storage system) and comparing to diesel battery charging station with high electricity price of 0.34 US$/kWh [2]. Environmental benefit was evaluated using 10.42 US$/ton$CO_2$ with a reduction rate of CO_2 emission of 0.43 kgCO_2/kWh [Anthony D. Owen, 2006], [34] and [41]. The results in the table 5 above showed that the benefit costs of PV battery charging station for 25 years present not only high generated electricity (121,339 US$), CO_2 emission(1,572 US$), but it gets more profitable also than the diesel battery charging station with the benefit cost of generated electricity (143,752 US$) and CO_2 emission is zero. On the other hand, the total costs of PV station is about 38,364 US$ and diesel station is around 30,279 US$ that we need to pay for land area cost, investment cost, operation and maintenance (O & M) cost and transportation cost.

Table 6 Results of economic evaluation with capacity of 10 kW_p using c-Si PV modules and diesel station with different in original cost

Economic parameters	PV modules station	Diesel station
	Cost = 0.27US$/kWh	Cost = 0.34US$/kWh
NPV (US$)	7,340	1,892
EIRR / IRR (%)	1.91	2.15
BCR	1.14	1.03
SPBP (Years)	10.57	11.72

In the Table 6 above shows the results of economic comparison and sensitivity analysis with capacity of 10 kW_p of two different battery charging stations such as PV battery charging station with original electricity cost of 0.27 US$/kWh using the c-Si PV modules are very well known and significant to investors with net present value (NPV = 7,340 US$), emission and internal rate of return (EIRR = 1.91%), benefit to cost ratio (BCR = 1.14) and short simple payback period (PBP = 10.57 years) values than the diesel battery charging station with the net present value (NPV = 1,892 US$), internal rate of return (IRR = 2.15%), benefit to cost ratio (BCR

= 1.03) and long simple payback period (SPBP = 11.72 years). Today, the diesel station is very seriously affected and caused economic problem by the price of oil has dramatically increased since the last decade because of the oil resources are available only in certain areas of the world, but the oil demand has been increasing year by year and the countries where today can produce oil have been problems and even environmental impacts too.

As a result, the solar PV battery charging station projects will definitely be carried out for rural electrification purposes because of the PV battery charging station is most suitable and economically including net present value (NPV) is positive value, the same internal rate of return (IRR) is smaller than discount rate, benefit to cost ratio (BCR) is more than one and shorter simple payback period than diesel station. So, the PV battery charging station with capacity of 10 kW_p using c-Si modules is better than diesel station. Moreover, many PV projects should be most possible to reach the Royal Government of Cambodia's targets and goals in near future.