Techno-Economic Analysis of PV Battery Charging Station in Kampot, Cambodia

Chhunn Chhim, Nipon Ketjoy, and Tawat Suriwong

***Abstract*—This paper presents the technical and economic analysis of PV battery charging stations in Kampot, Cambodia's situation. The solar radiation reflected by the air molecules, clouds and ground was obtained from the satellite data. The absorption of solar radiation due to water vapor was calculated from precipitable water derived from ambient relative humidity and temperature from Cambodian meteorological stations. The annual solar radiation from January to reach a peak in the summer months of March and April each year and the yearly map showed the features of a high solar radiation pattern in the southeast of Cambodia. The average value is 5.10kWh/m^2/day can be observed in the southeast of the country. With the highest values of solar radiation, solar PV battery charging stations (PVBCS) will be installed in each village, which are not electrified by national grid or mini-grid projects by 2020, and where no battery charging station is currently operating in order to ensure that the Royal Government of Cambodia's political objective of 100% village having electricity supply by 2020 from different sources of energy.**

With capacity of 10kW PV battery charging station in Kampot was calculated to evaluate and compare the technical and economic evaluation of c-Si PV modules and diesel battery charging station under the Kampot climate. The present electricity price of rural areas is about 0.22US$/kWh showed that c-Si PV modules present not only high NPV (15,986US$), IRR (0.041%), BCR (1.52) but shorter payback period (8.82 years) than the diesel battery charging station of 0.22US$/kWh with the NPV (7,450US$), IRR (12%), BCR (1.70) and payback period (14.74 years) values. Based on the technical and economic evaluation of c-Si PV battery charging station, in fact, pointed the most suitable technology for people in rural areas in the kingdom of Cambodia.

***Index Terms*—Techno-economic analysis, PV battery charging.**

I. Introduction

Energy is a key factor for social and economic development of a country. 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 a total land area of 181,035 km^2 and 24 provinces with population of 14.7 Million, does have abundant renewable energy resources, such as hydro (micro/pico), solar and biomass energy 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. 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].

Due to its located near the equator, Cambodia considers solar energy as one of the most promising renewable energy resources. As solar radiation has temporal and spatial variations, it is 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 5.10kWh/m^2/day or equivalent of 1,860kWh/m^2/year over Cambodia [2].

In particularly, Kampot is a tourism province located on coordinates 10.70^0 N and 104.28^0 E in the southern part of the country, 150km from Phnom Penh and it has 8 districts, 97 communes with a total of 477 villages, population around 620,217 (Ministry of Planning, 2012) and it has more potentials for the solar energy [3]. In contrast, Kampot also has the lowest electrification rate in the country (nearly 40%, MIME, 2012) can access to the national grid or min-grid services. So, Kampot's population also suffers from having very expensive electricity prices and energy costs based on primarily on expensive oil imported.

With a recent commitment taken in part of the Royal Government of Cambodia (RGC) aims at reaching 15% of the overall energy supply to come from renewable energy sources by 2015 and all villages should have access to electricity from different sources of energy by 2020. 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 2020 [2].

II. Methodology

In this paper, the methodology was separated into 3 main parts as follows: 1) select the location, 2) calculate and design the *PV* battery charging systems based on the energy needed

Manuscript received October 31, 2013; revised December 23, 2013.

Chhunn Chhim, Nipon Ketjoy, and Tawat Suriwong are with the School of Renewable Energy Technology (SERT), Naresuan University, Phitsanulok, 65000, Thailand (e-mail: chhunchhim@gmail.com/ chhunchhim@yahoo.com, niponk@nu.ac.th, tawats@nu.ac.th).

of each household and 3) evaluate the economic assessment of *PV* battery charging station by using c-Si *PV* modules and diesel station with capacity of 10kW.

Moreover, this paper focused on the technical analysis on selecting the location in Kampot province and *PV* modules type for *PV* battery charging station. For selecting the location, evaluation part determined based on criteria of high solar radiation, no grid connected and the large population. To make an evaluation and optimization of the energy supply option, the design of each option has to be done and costed. The design and costs have to compare economically, not only their installation cost but also by their lifecycle cost. The lifecycle cost includes the capital cost plus all expenses during the whole operation life of the project [4]. Especially, the following characteristics are main key point for success of *PV* battery charging systems: proven durability, medium to low investment costs, good availability of *PV* modules and maturity of modules. On the other hand, this paper was evaluated and compared the technical and economic assessment of c-Si *PV* modules with diesel battery charging station with the capacity of 10kW in Kampot, Cambodia.

III. Results and Discussions

A. Technical Analysis

Most households in rural areas in Kampot, Cambodia have no access to the national grid or mini-grid services. The electrification rate of the Kampot province is around 40% (MIME, 2012). According to the Electricity Authority of Cambodia (EAC) reported in 2012 were about 80% of urban users and 20% of rural users 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 0.17US$/kWh for EDC customers, and up to 1US$/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 commonly used throughout the country and even the Kampot. In the Fig. 1 shows the population of the Kampot, Cambodia. However, the population in Kampot province rapidly increased during the period from 1998-2012.

According to the Fig. 2 showed the electricity power production values in Kampot, Cambodia from 2004 to 2011rapidly increased year to year.

Based on the Fig. 3 showed the solar radiation of 5 province stations in Cambodia. By using the model, monthly averages of solar radiation have been estimated for the entire areas of Cambodia. The monthly solar radiation maps showed the influence of the monsoons.

In the technical analysis, we would like to calculate and design the *PV* system based on the energy needed of each household in Kampot, Cambodia such as PV_{peak} and Charge controller (C_C) capacity in this paper:

PV_{peak} is a peak power of the *PV* array under *STC* [kWh] and can be calculated as following:

$$PV_{peak} = \frac{I_{STC} \,.\, E_{el}}{Q \,.\, E_{glob}} \tag{1}$$

where E_{el}= Real electric output energy of the system [kWh/day], I_{STC}= Incident solar radiation under *STC* [1kW/m^2], E_{glob}= Annual global solar radiation, [kWh/m^2-day], Q = Quality factor of the system (0.80).

Charge controller (C_C):

$$C_c = \frac{PV_{peak}}{System\ voltage} \tag{2}$$

where system voltage = 12volts.

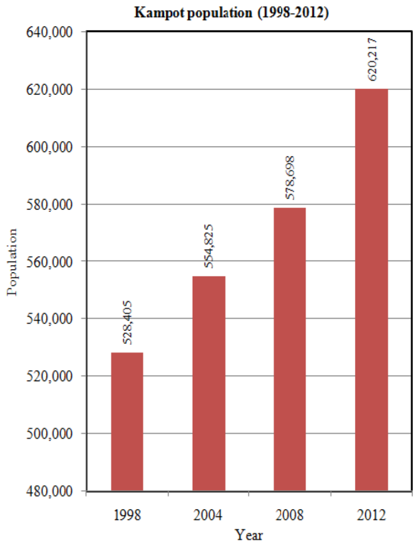

Fig. 1. Population of Kampot province (1998-2012), collected data from the Ministry of Planning.

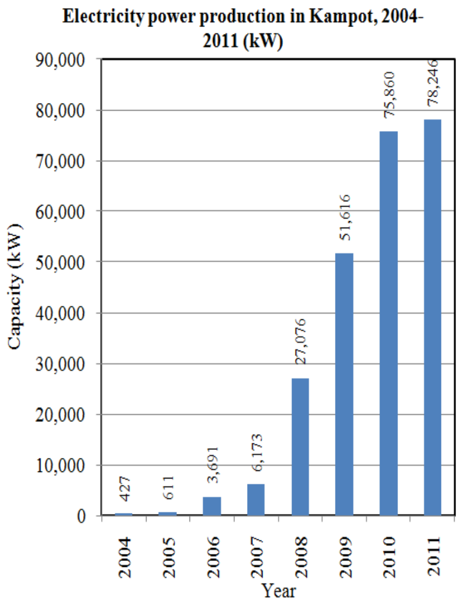

Fig. 2. Electricity power production in Kampot (2004-2011), collected data from annual report of the Electricity Authority of Cambodia.

Kampot located in the coastal areas with fewer trees to affect with *PV* battery charging station by shading. Land is available for future developments, especially for *PV* battery charging station. The land price in rural areas of this province is very low, about 1US$/m^2, compare with the urban areas, which can withstand erosion and draining is very fast after raining. The select location for the *PV* battery charging station in Kampot has 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 has a high solar radiation, in fact, the most suitable for solar *PV* power plants, especially for solar *PV* battery charging stations.

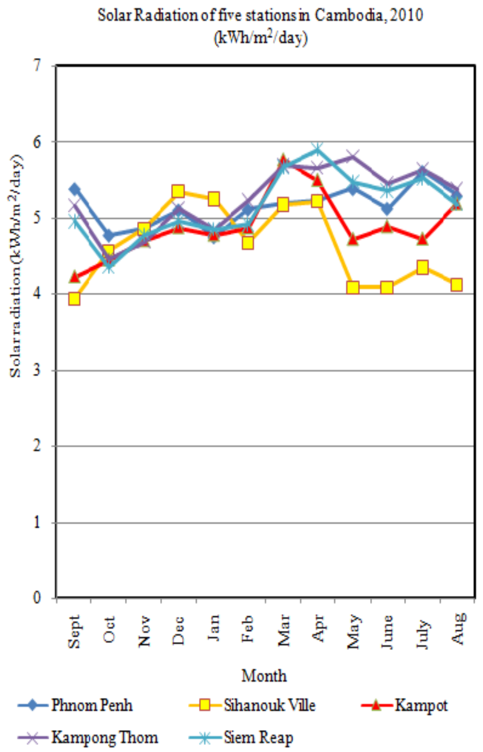

Fig. 3. Solar radiation of 5 stations in Cambodia (kWh/m^2/day), collected from annual report of the Electricity Authority of Cambodia.

Based on previous research, the crystalline silicon *PV* modules have highest conversion efficiency and save the performance for long time, but crystalline silicon *PV* modules are very sensible decreasing of their performance by shading and low solar radiation conditions [5]. Therefore, this study selected c-Si modules for calculating and designing *PV* battery charging system. Comparison of technical parameters and specifications using c-Si *PV* modules are shown in Table I. 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 5hours per day and 315days/year. Module efficiency of c-Si around 14% is higher than other modules [6].

TABLE I: SUMMARY OF KEY FACTORS OF THE LOCATION

Factors	Requirements
Mean annual global horizontal irradiance (GHI)	≈ 1,700-1,900kWh/m^2 /year (Average ≈ 5.10kWh/m^2/year) [2]
Wind speed	≈ 2.5-3 m/s
Tilt angle	10^0-11^0 [3]
Latitude	10.70^0 N [3]
Longitude	104.28^0 E [3]
Grid availability	>20 km
Road proximity	≈ 200m away from the provincial road and far away from the national road
Climate	Tropical climate

PV system design

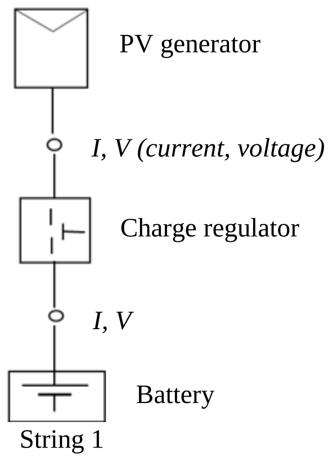

Fig. 4. PV battery charging system.

According to the actual demand of each household in Kampot is about 40-60W/customer [2]. *PV* generators can be connected to the DC battery bank in the same way as it standard battery charging station likes the Fig. 4. In other words the string concept for charging, which has been successfully introduced to stand-alone *PV* systems, can be used in battery charging station as well. In this case, the rated *PV* module power is 200W_p of c-Si modules, orientation faced to south and tilt angle is about 10^0-11^0 [3]. In this system needs to use a charge regulator in order to protect the batteries from overcharging, the panel from power going back into it from the batteries and to help maintain battery condition by keeping the battery voltage high [7].

B. *Economic Analysis*

In economic analysis, the currency in all the economic calculation is in US$. The system financing considerations for 25 years are the normal for diesel and *PV* battery charging systems. This system was installed in Kampot province with capacity of 10kW, according to the energy needed of each household in that location. The economic evaluation and specification were mentioned in Table II. The project life time of diesel and *PV* battery charging station and discount rate of this system has been calculated with 25 years. The investment costs of *PV* battery charging station in Cambodia is about 3US$/$W_p$ (inclusive of transport and installation cost), operation & maintenance cost is 0.05% per year of investment cost, operating lifetime is 25 years, 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 10kW is about 300US$/kW, operation & maintenance cost is 3% per year of investment diesel fuel cost, operating lifetime is 25years (replaced generator one time). The diesel battery charging station was determined to operate about 4hours per day and 330days/year [2], [8].

The sensitivity analysis for the investment cost and benefits are mentioned in the Table III, by using c-Si *PV* modules with the electricity price of 0.22US$/kWh (EAC, 2012) for comparing with diesel battery charging station. Environmental benefit was evaluated using 10.42US$/ton$Co_2$ with a reduction rate of Co_2 emission of 0.43kgCo_2/kWh [9], [10].

TABLE II: TECHNICAL AND ECONOMIC PARAMETERS WITH CAPACITY OF 10KW BATTERY CHARGING STATION USING C-SI PV MODULES AND DIESEL SYSTEM

Parameters	Specifications	
Module name	c-Si modules	Diesel engine
Number of modules / engine	50 (200W/module)	01
Module area	80-120 m^2	-
Total land area	240 m^2	100 m^2
Mounting orientation	Fix mounted module	-
Operating hour/days per year	5hrs./day 315 days/year	4hrs./day 330 days/year
Module efficiency	14%	-
Temperature coefficient (TCE) of power loss	-(0.45 to 0.5)%/^{0}C	-
Performance Ratio (PR)	74%	-
Capacity system	10 kW	10 kW
Investment system	30,000US$ [2]	3,000US$ [2]
O & M cost	0.05%/year of investment cost [8]	3%/year of investment cost [8]
Project life time	25 years	25 years (replaced generator 01 time)

TABLE III: COSTS AND BENEFITS ANALYSIS FOR 25 YEARS OF 10KW PV BATTERY CHARGING STATION USING C-SI PV MODULES WITH ELECTRICITY COST OF 0.22US$/KWH

Parameters	c-Si modules	Diesel system
Benefits:		
- Generated electricity	85,414	18,150
- CO_2 emission	1,448	0
Total benefit	86,862	18,150
Costs:		
- Land	240	100
- Investment cost	30,000	3000
- O & M	10,480	2,250
- Transport	0	350
Total cost	40,720	5,700

*(Currency unit = US$ and land price = 1US$/m^2)

Table III presents the potential reduction in green house gas (GHG) emission per kWh of electricity for diesel generation facilities in Kampot. These values are calculated based on the default emission factors provided by UN's Intergovernmental Panel on Climate Change (IPCC). The amount benefits of green house gas reduction due to usage of 10kW$_p$ *PV* battery charging station is about 1,447.95US$. There are other policy instruments that can indirectly support deployment of renewable energy resources in the long period. These indirect strategies can be in the form of environment taxes, or of emission permits for electricity produced by fossil fuels, as well as the removal of subsidies given to fossil fuel generation. The establishment of regulations that govern intermittency-related balancing costs can indirectly support deployment of renewable energy sources.

To quantify the benefits of GHG emission reduction, an average damage cost 10.42US$/tonCo$_2$ is considered. Based on this value, the annual avoided costs of environmental impacts to GHG emissions reduction for this location is calculated. The environmental benefits of *PV* project are 0.43kgCo$_2$/kWh when displacing diesel fuel based electricity, respectively [10]-[16].

In the economic assessment, in fact, such as Net Present Value (*NPV*), Internal Rate of Return (*IRR*), Benefit to Cost Ratio (*BCR*) and Payback Period (*PBP*) are evaluated in this paper as following:

Net Present Value (*NPV*) is a method for evaluating the desirability of investments can be defined as below:

$$NPV = \sum_{n=0}^{N} \frac{B_n}{(1+i)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = PVB - PVC \tag{3}$$

where B_n = Expected benefit at the end of year n, C_n = Expected cost at the end of year n, i = Discount rate, n = Project duration in years, N = Project period, PVB = Present Value Benefit, PVC = Present Value Cost.

Internal Rate of Return (*IRR*) is another time-discounted measure of investment worth. The *IRR* is defined as that rate of discount which equates the present value of the stream of net receipt with the initial investment outlay. The IRR is less than a discount rate; the project is regarded as less profitable. The IRR can be calculated in equation (4).

$$\sum_{n=0}^{N} \frac{B_n}{(1+r)^n} - \sum_{n=0}^{N} \frac{C_n}{(1+i)^n} = 0 \tag{4}$$

where $r = IRR$.

Benefit to Cost Ratio (*BCR*) is the division of total present value benefit over total present value cost as given by equation (5), the *BCR* which has to be above one to indicate the profitable *PV* project. *BCR* can be calculated as:

$$BCR = \frac{PVB}{PVC} \tag{5}$$

Payback Period (*PBP*) is significantly indicated by the payback period of a project to make the NPV of the cash flow, up to the present moment as evaluated by equation (6). When *PBP* presents high value (long payback periods), the project is disagreeable in economics. The shorter *PBP* indicates the better investments. It is well known as criteria of *PBP* value for the availability more than the profitability of the *PV* project. The payback period can be calculated as below:

$$\text{Payback Period} = \frac{\text{Cost of project}}{\text{Annual cash revenues}} \tag{6}$$

TABLE IV: RESULTS OF ECONOMIC EVALZUATION WITH CAPACITY OF 10KW USING C-SI PV MODULES

Economic parameters	c-Si module	Diesel system
	Cost=0.22US$/kWh	Cost=0.22US$/kWh
NPV (US$)	15,986	7,450
IRR (%)	0.041	12
BCR	1.52	1.70
PBP (Year)	8.82	14.74

*(Currency unit = US$)

Table IV shows the results of economic comparison and sensitivity analysis with capacity of 10kW of two different battery charging stations as following: *PV* battery charging station with electricity cost of 0.22US$/kWh using the c-Si *PV* modules are well known and significant to investors. But, the diesel battery charging station showed the longer payback period (14.74years) than *PV* battery charging station in Kampot, Cambodia [17]-[19].

IV. Conclusions

In conclusion, Kampot province was selected due to high solar radiation values (around 5.10kWh/m^2/day) [2]. Kampot has lowest electrification rate (nearly 40% can access to the national grid or mini-grid) in Cambodia, according to the electricity price is very high about 0.22US$/kWh (EAC, 2012) compare to neighboring countries. The fix mounted *PV* modules are installed in a south-facing surface with a tilt angle of 10^0-11^0 [3]. c-Si modules are selected for the tropical climate conditions. The site for *PV* battery charging station was installed with capacity of 10kW in Kampot where can provide electricity to people in rural areas about 200 households.

The economic evaluation showed that the 10kW with electricity price of 0.22US$/kWh of *PV* battery charging station using c-Si *PV* module, such as *NPV* (15,986US$), *IRR* (0.041%), *BCR* (1.52) but shorter payback period (8.82 years) than the diesel battery charging station with the *NPV* (7,450US$), *IRR* (12%), BCR (1.70) and payback period (14.74 years) values. Based on the technical and economic evaluation of c-Si *PV* battery charging station was most suitable for rural electrification in the kingdom of Cambodia than diesel battery charging station.

Acknowledgement

I would like to thank the Thailand International Development Cooperation Agency (TICA) for their support and coordination of my study. Especially, I would like to gratefully acknowledge Assist. Prof. Dr.-Ing. Nipon Ketjoy and Dr. Tawat Suriwong, advisor and lecturer, of the School of Renewable Energy Technology (SERT), Naresuan University, Phitsanulok, 65000, Thailand for giving good advices and editing this paper.

References

[1] R. K. Pachauri and V. V. N. Kishore, *Renewable Energy Engineering and Technology: Principles and Practice*, Routledge, 2010, pp. 184-229.

[2] *Sustainable Rural Electrification Plan (SREP) Report: March 2011 Update*, Innovation Energie Developpement (IED), Cambodia, vol. 2, 2011, pp. 8-76.

[3] *Assessment of Solar Energy Potentials for Cambodia*, Ministry of Industry, Mines and Energy, September 2008, pp. 85-163.

[4] V. Fthenakis, R. Betita, M. Shields, R. Vinje, and J. Blunden, *Life Cycle Analysis of High-Performance Mono Crystalline Silicon PV System: Energy Payback Time and Net Energy Production Value*, Sun Power Corporation, San Jose, CA, USA, 2008, pp. 1-4.

[5] R. Foster, M. Ghassemi and A. Cota, *Solar Energy: Renewable Energy and the Environment*, pp. 4-9, 2010.

[6] A. Ghasemi, A. Asrari, M. Zarif, and S. Abdelwahed, "Techno-economic analysis of stand-alone hybrid photovoltaic-diesel-battery systems for rural electrification in eastern part of Iran-A step toward sustainable rural development," *Renewable and Sustainable Energy Reviews*, vol. 28, pp. 456-462, 2013.

[7] C. J. Rydh and B. A. Sandén, "Energy analysis of batteries in photovoltaic systems. Part II: Energy returns factors and overall battery efficiencies," *Energy Conversion and Management*, vol. 46, issue 11-12, pp. 1980-2000, 2005.

[8] N. Ketjoy, *Photovoltaic Hybrid Systems for Rural Electrification in the Mekong Countries*, University of Kassel, Germany, pp. 70-74, Aug 2005.

[9] S. M. Shaahid and M. A. Elhadidy, "Economic analysis of hybrid photovoltaic-diesel battery power systems for residential loads in hot regions-A step to clean future," *Renewable and Sustainable Energy Reviews*, vol. 12, issue 2, pp. 1-16, 2006.

[10] E. A. Alsema and M. J. de Wild-Scholten, "Environmental impacts of crystalline silicon PV module production," Utrecht University, The Netherlands, 2006, pp. 1-6.

[11] E. Doris, S. Ong, and O. V. Geet, "Rate analysis of two photovoltaic systems in San Diego," US Department of Energy, 2009, pp. 1-19.

[12] D. P. Papadopoulos and E. Z. Maltas, "Design, operation and economic analysis of autonomous hybrid PV-diesel power systems including battery storage," *Journal of Electrical Engineering*, vol. 61, no. 1, pp. 1-8, 2010.

[13] W. X. Shen, "Design of stand-alone photovoltaic system at minimum cost in Malaysia," 2008, pp. 702-705.

[14] F. Tavora. (2012). Solar battery charger for portable devices and application. [Online]. pp. 1-27. Available: www. siliconreef.com.br.

[15] D. Tan and A. K. Seng. (2009). Hand book for solar photovoltaic (PV) systems. [Online] pp. 1-64. Available: http://www.bca.gov.sg/Green Mark/gmiseb.html.

[16] D. Miller, *Selling Solar: The Diffusion of Renewable Energy in Emerging Markets*, 2009, pp. 8-32.

[17] S. A. Kalogirou, *Solar Energy Engineering*, 2009, pp. 80-96.

[18] C. J. Chen, *Physics of Solar Energy*, 1st ed., NJ, USA: Wiley, 2011, pp. 161-176.

[19] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes*, 3rd ed., Wiley, 2006, pp. 450-773.

Chhunn Chhim was born on January 20, 1974 in Kampong Cham province, kingdom of Cambodia. He went to the primary school in 1980, after finishing the Khmer Rouge regime in 1979, and he graduated at high school in 1991. After that he graduated an Associate Degree in Planning and Statistics from the secondary school of Planning in Phnom Penh, Cambodia in 1997 and then he went to work in the Royal Government of Cambodia from 1998 to present. In 2002, he graduated a Bachelor of Computer Science from the Build Bright University in Phnom Penh, Cambodia. As a government official, he has worked at the Ministry of Planning (1998-2009) and then moved to the Ministry of Industry, Mines and Energy (MIME) up to now, which related to, such as social statistics, poverty analysis, socio-economic survey, energy development, energy efficiency and conservation, renewable energy, climate change issues and other line ministries. In 2010, he was a head of Renewable Energy Office of the Department of Energy Technique, Ministry of Industry, Mines and Energy (MIME), Royal Government of Cambodia.

Currently, he is doing a master of science in renewable energy at the School of Renewable Energy Technology (SERT), Naresuan University, Phitsanulok, 65000, Thailand. His research interest is techno-economic analysis of PV battery charging station in Kampot, Cambodia".