Economic of Solar Photovoltaic for Rural Electrification in Agriculture Area-based in Ratchaburi Province, Thailand

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***Abstract*— this paper presents the economic analysis of solar photovoltaic (PV). From using solar PV system supply to the agriculture electrical load (AEL) in the Ratchaburi (RB) province, Thailand. The area of agriculture in the Ratchaburi has 1,900 square kilometer and 10 districts. First of all, the AEL data was investigated from all farming each district. Subsequently, the electrical load data was evaluated and classified by the load power and energy consumption of all the Suan-Phueng (SP-09) provinces its case study. The results are obtained the economic indices such as the capacity factor (CF), cost of unit (COE), net present value (NPV), internal rate of return (IRR) and payback period. This results help government for decision of investment solar PV system in agriculture or farming area in Ratchaburi province.**

Keyword: *Solar Photovoltaic, agriculture electrical load (AEL), Economic indices*

I. INTRODUCTION

Energy is essential to our society in ensuring the quality of life and to strengthen all other elements of our economy. Energy is a key driver for the betterment of human life and occupation. One of them is agriculture or farming area in long distance from the transmission line. [1]-[4] That area needs the energy consumption for being and agriculture. This paper focuses the study on economic of solar PV system for agriculture electrical load (AEL).

However, due to growing population coupled with global warming and depleting fossil resources, mankind is in desperate need of alternative renewable energy technologies based on solar energy etc. Sunlight is the largest available renewable and carbon-neutral energy source. Every hour the sun provides the earth with more energy than is consumed in an entire year. The solar photovoltaic device is the one that converts sunlight into electricity. An elementary photovoltaic device, called a photovoltaic cell (also referred to as solar cell), is mainly composed of two adjoining layers of semiconductor with separate metal contacts that have been doped thus creating the n-layer, n is negative, with a surplus of electrons and below that, the p- layer, p is positive, with an electron deficiency.[5]

The amount of energy available from the sun outside Earth's atmosphere is approximately 1350 Watt/Sq.m. . However, the solar radiation reaching the earth is lower because when entering the Earth's atmosphere, part of the incident energy is removed by scattering or absorption by air molecules, clouds and particulate matters. Although the global irradiation on the surface of the Earth can be as high as 1000W/Sq.m., the available radiation is usually lower than the maximum value due to the rotation of the Earth and the adverse weather conditions [7], [8]. On a monthly or annual basis, the amount of solar energy available also depends on the location. Generally, useable solar energy greatly depends on the availability of solar energy, weather conditions, technology used and type of application.

This paper introduces an economic evaluation of solar PV using the agriculture electrical load (AEL) in the Ratchaburi province. The rate of solar PV panel is determined from AEL. The cost of energy (COE), capacity factor (CF) and capital costs of solar PV are the economic indices. Finally, the study on Suan-Phueng (SP-09) district is example by survey on AEL data after that evaluating economic parameter.

II. ECONOMIC INDICES OF SOLAR PV SYSTEM

This section is to estimate the Wh cost and the economic indices of solar PV.

A. Capacity Factor (CF)

The net capacity factor of a power plant is the ratio of total amount of energy produced by a plant during a certain time period and the amount of energy the plant would have produced at full capacity. The capacity factor (CF) is defined in Eq. (1) by the sum of the actual generated electrical power, P_{gen} over timespan "t" and nominal power of the PV power. [1]

$$CF = \frac{\sum_{q=1}^{t} P_{gen,q}}{P_{nominal} \times t} \tag{1}$$

From Eq. (1) The calculated capacity factor depend on the actual generated electrical power and nominal power and timespan.

B. Cost of Energy (COE)

The cost of energy is free of detailed economic variables. The term COE is defined as the unit cost produce energy (in baht per watt-hour) from solar PV, and it can be expressed by Eq. (2)

$$COE = \frac{NPV(C_A)}{E_I} = \frac{C_I}{8{,}760 \times n} \times \left(\frac{1}{P_R C_F}\right) \times \left\{1 + m\left(\frac{(1+I)^n - 1}{I(1+I)^n}\right)\right\} \quad (2)$$

Where C_I is the capital cost in baht, P_R is the power generating rate, C_F is the capacity factor, m is the percent of operation and maintenance cost, and I is the real interest rate, and n is the lifetime of PV panel.

C. Net Present Value (NPV)

The NPV of project is the sum of discounted values of a stream of net cash flows generated by a project during its life period and if NPV>0, the project can be accepted [3], [6]. For Solar PV Suan-Phueng (SP-09) district Ratchaburi province, NPV can be calculated by subtracting the investment from total cash inflow as expression in Eq. (3)

$$NPV = B_A\left[\frac{(1+I)^n - 1}{I(1+I)^n}\right] - \left\{C_I\left[1 + m\left(\frac{(1+I)^n - 1}{I(1+I)^n}\right)\right]\right\} \quad (3)$$

Where B_A is the project income yearly.

D. Discounted Pay Back Period

Payback period is the length of time required to recover the initial cash outlay on the project. The method also serves as a proxy for risk. The faster the investment is recovered, the less risk to which the firm is exposed [3]. The discounted payback period for Solar PV Suan-Phueng (SP-09) district, Ratchaburi province has been calculated as 20years.

E. Internal Rate of Return (IRR)

IRR is the rate of discount that equates the present value of net cash flows equal to the initial investment cost of project. If IRR of a capital project is greater than the cost of capital, investment in the project should be made. If IRR is less than the cost of capital, the project should be rejected [9]. The IRR value of Solar PV Suan-Phueng (SP-09) district, Ratchaburi province has been calculated as 1.68%. As the IRR value (1.68%) is greater than the cost of capital (1%), the Solar PV.

TABLE I
DATA OF USING ELECTRICAL IN AREA-BASED AGRICULTURE SELF-RELIANCE IN RATCHABURI

No.	Districts of Ratchaburi	Average AEL. area-based (kW/1,600Sq.m))	Average electrical energy in area-base (kWh/1,600Sq.m)	All agriculture area-based (Sq.km)
1	Mueng Ratchaburi (M-01)	513.00	2,813.00	188.35
2	Wat Phae (WPB-02)	466.25	746.00	34.55
3	Bang Pae (PH-03)	559.50	1,119.00	111.92
4	Damnoen Saduak (DN-04)	2,611.00	14,174.00	161.52
5	Photharam (PTR-05)	466.80	5,611.00	227.41
6	Bang Pong (BP-06)	451.17	126.00	202.05
7	Chom Bueng (CHB-07)	409.00	782.00	359.76
8	Pak Tho (PT-08)	300.78	1,171.11	261.44
9	Suan Phueng (SP-09)	193.70	282.70	144.48
10	Ban Kha (BK-10)	324.80	722.80	216.55

III. DATA OF AGRICULTURE'S ELECTRIFICATION LOADS

A. Survey on Agriculture Electrical Load Data

The Agriculture electrical load was investigated in the Ratchaburi area by the collection of load data outside a laboratory.

The Ratchburi is a province, which consist of districts. From the AEL data, it can be classified device into 2 groups that are pump motor for pump water into the farm and electrical lamp, fan etc. The total agriculture electrical load of each district can be shown table I.

From the table I, as shown the average AEL and electrical energy data are obtained by the survey on all districts. Ratchaburi has the 10 district. This paper is focus on the only agriculture area in unit Square meter (Sq.m). For example, the Suan Phueng (SP-09) has average AEL data about 193.70 kW per1, 600 Sq.m and electrical energy about 282.70 kW per 1,600 Sq.m. which is considered the all agriculture area of SP-09 about 144.48 Sq.km.

B. Calculation of rated PV panel

For determination of rated PV panel, can be calculated from rated AEL and time-span energy consumption. The calculation of rated PV panel can be written in Eq. (4)

$$P = \frac{P_L \times D}{Q \times A \times B \times C} \quad (4)$$

Where P is rated power PV panel in unit watt for install, P_L is the energy consumption per day in unit watt-hour per sq.m, and Q is the average solar radiation on ground per day for the Thailand about 18.2 MJ/Sq.m or about 5,055 Wh/Sq.m. and A, B, C, D is the loss of PV conversion compensation, heat of PV compensation, efficiency of inverter system, and solar irradiation respectively. The performance of PV cells and modules has been determined at a test condition called the "Standard Test Condition (STC)" [7] of 1000W/Sq.m, AM 1.5, a module temperature of 25°C and normal incidence.

In actual operating conditions however, the module output is strongly affected by various environmental conditions such as irradiance, temperature, spectral effects and angle of incidence. Furthermore, the impact of each climatic factor on energy production varies according to the module technology in use. Geographical, seasonal, and diurnal variations of global solar radiation in Ratchaburi province, Thailand are surveyed. The highest mean values are above 19.5 MJ per Sq.m per day and are widespread in spring. The lowest values are below 15.0 MJ per Sq.m per day in restricted localities with heavy rainfall in autumn.

C. Cost of solar PV system

In this study, the investment cost of solar PV was surveyed from dealer in Thailand. Found that, the cost of solar PV panel is 45.31 baht per watt or about 57% of cost solar PV system. For another solar PV components are evaluated about 43% of cost solar PV system. The cost of inverter system has 10.28 baht per watt. However, solar PV generator is not need

to maintain. So the solar PV panels have average life-time 20 years. But its efficiency decrease about 0.5% yearly. The costs of operation and maintenance have 1% yearly of cost system. As shown the Table II

TABLE II
Investments of Generating Solar Energy System

Cost Assumption	Descriptions	Reference
Cost of panel	Average 45.31 bath/ watt	From Quotation in January-May 2017
Cost of balance of system	43% of cost system	Calculation from quotation data, include inverter and auxiliary equipment
Cost of O&M	2% of cost system	Service cost
Cost of Inverter	10.28 baht per watt	Average cost of quotation
Annual degradation	0.5%	National Renewable Energy Laboratory (NREL), 2012 [5]

From Fig. 1 the survey cost of solar PV system data has 3 part such as the replacement components cost, operation and maintenance cost, and capital PV system cost. Found that the first investment of install solar PV mostly has high cost about 57.31% of capital cost. Solar PV cells can be classified into two main categories- crystalline silicon and thin film technologies. However, Poly-crystalline silicon cells are the most common type used in photovoltaic and are less expensive. This technology is becoming more attractive because manufacturing cost is lower than that of mono crystalline silicon even though these cells are slightly less efficient than mono-crystalline. The replacement devices are the inverter system, its life-time about 11 year. So the replacement cost has about 26% of system cost. Finally, The O&M has about 17% of system for 20 year.

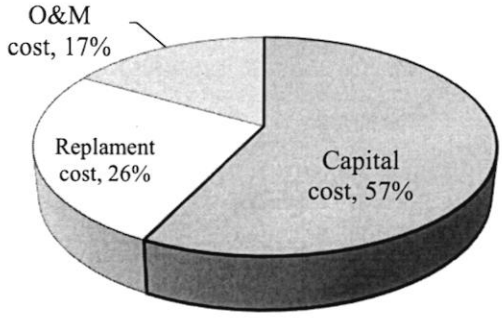

Fig. 1 investment cost of Solar PV System for 20 year period

IV. RESULTS AND CASE STUDY

A. Evaluating Economic of PV System Generating

From AEL data in Ratchaburi province, can be calculated to the rated solar PV panel (watt per 1,600Sq.m) by Eq. (3). The average output of energy of solar PV is obtained in period 5 hour per day (10.00AM-15.00PM). As shown the Table III.

TABLE III
RESULTS OF RATED SOLAR PV AND ECONOMIC INDICES IN AREA-BASED AGRICULTURE SELF-RELIANCE IN ALL RATCHABURI PROVINCE

Districts of Ratchaburi	Rated PV (Watt/ 1,600Sq. m)	Energy of PV (Wh/1,60 0Sq.m)	Capital Cost of PV array (Baht)	%CF	COE (Baht/ unit)
Mueng Ratchaburi	723.17	3,615.85	53,601.73	20.83	2.32
Wat Phae	191.78	958.91	14,215.03	20.83	1.84
Bang Pae	287.67	1,438.37	21,322.55	20.83	2.77
Damnoen Saduak	3643.87	18,219.34	270,085.64	20.83	2.50
Photharam	1442.53	7,212.67	106,921.44	20.83	2.31
Bang Pong	32.39	161.96	2,400.93	20.83	0.41
Chom Bueng	201.04	1,005.19	14,901.01	20.83	1.93
Pak Tho	301.07	1,505.35	22,315.53	20.83	2.90
Suan Phueng	72.68	363.38	53,86.85	20.83	0.70
Ban Kha	185.82	929.09	13,772.96	20.83	1.79

From the Table III is result of the rated solar PV and economic indices. In the capital cost of solar PV can be calculated at the Table II. That is all cost summation such as solar PV panel cost about 45.31 baht per watt and construction cost about 30% of solar PV system and maintenance cost about 2% of solar PV system respectively. For instant, the Mueng Ratchaburi has rated solar PV 723.17 watt per 1,600Sq.m multiply by 56.15 baht per watt equal to 40,607.37 baht. This obtained value sum the construction and maintenance cost about 12,182.21+812.15 baht respectively. So it can get the result equal to 53,601.73 baht.

For the capacity factor (CF) can be calculated by Eq. (1). In this solar PV plant has power performance about 20.83% for supply to the agriculture electrical load. Finally, the cost of unit (COE) can be calculated by Eq. (2). Another case can be calculated in the similar method.

The cost of unit depends on the income per year and cost investment and life –time project. From the Fig. 2 as shown the COE of each district of Ratchaburi, can consider to vary COE in each district. The high COE is the Pak-To (PT-08) equal to 2.90 baht per unit and the lowest COE is the Bang-Pong (BP-06) equal to 0.41 baht per unit. From the results can be considered in term of rated AEL and investment cost and profit yearly.

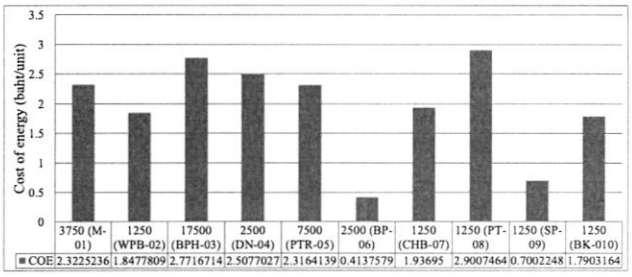

Fig 2 Cost of unit (baht) each district of Ratchaburi

B. Cast Study of Suam-Phueng (SP-09)

A solar PV power plant requires large investment so it is desirable to include an economic evaluation in the feasibility study. The life cycle cost (LCC) of the PV system is the sum of all the present worth's (PWs) of the costs of the PV modules, inverter, the cost of the installation, and the operation and maintenance cost (O&M) of the system. In this study, inflation rate and interest rate are taken as 2% and 12% respectively. Life cycle cost of the system is estimated for a time period of 20 years. As shown Table IV

From the Table IV is cast study in the Suan-Phueng (SP-09) district its area has 144.48 Square meter for agriculture self-reliance. This area is the candidate site for solar PV install. So this site can be evaluation of economic indices for decision of solar PV system investment in agriculture area-based. From the results is demand energy consumption by solar PV system about 11,977,018 MW. The total investment of solar PV system is the 515,907,594baht that included the construction cost and connected system, O&M cost and PV panel cost at the life time 20 year. The interest and inflation rate are evaluated to 12% and 2% respectively. From the results, the investment of PV for AEL has the cost of energy about 2.56 baht per unit and IRR index about 1.68% and beak event-point at 16year. In this investment PV, the NVP is negative sign that mean this project don't should be accepted. However, the renewable source is friendly the environment and our world from the reduced pollution due to electrical generator.

TABLE IV
ECONOMIC ANALYSIS OF INSTALLATION PV SYSTEM FOR AGRICULTURE ELECTRIFICATION LOAD IN SUAN-PHUENG (SP-09)

Evaluated Economics of SP-09 district	Units	Energy of PV (Wh/1,600Sq.m)
Power Generating	MW	11,977,018.75
CF	%	20.833
Equipment Cost of PV	Baht	368,505,424.57
Construction Cost and connected system	Baht	110,551,627.37
Variable O&M	Baht	36,850,542.46
Project life time	year	20
Interest Rate	%/year	12
Inflation Rate	%/year	2
Cost of Energy	Baht/unit	2.5546338
NPV	Baht	-359,688,506.50
IRR	%/year	1.684%
Project Income, (B_A)	Baht/year	30,596,897.22
Payback Period	year	16

V. CONCLUSIONS

This paper proposes the evaluating economic indices for investment of solar PV system install, which consist of ten districts is studies. The individual districts are investigated the AEL data for the evaluation of economic investment of solar PV system installation. The economic indices are obtained the capacity factor, cost of unit, net present value, and internal rate of return. From the results can be analyzed to decide the investment solar PV system install at the agriculture area in the Ratchaburi province. The government can utilize this paper to evaluate the economic solar PV system.

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