Techno-Economic Analysis of 500 kW_p Photovoltaic Grid Connected System at Mae Hong Son Province

Somchai Chokmaviroj[1,*] Wattanapong Rakwichian [2] Nipon Ketjoy [2]

[1]Electricity generating authority of Thailand (EGAT), Communication System Maintenance Section1, Communication System Maintenance Department, Northern Region Operation Division, PO Box 41, Phitsanulok 65000

Tel +66-5521-6212 ext 5810, Office Fax: 04-741-5810, 5890 e-mail: Somchai.cho@Egat.co.th

[2]School of Renewable Energy Technology, Naresuan University, Phitsanulok 65000

Tel: 0-5526-1208 Fax: 0-5526-1208

Abstract

This paper summarizes the first ten months of PVGC generated electricity between March 2004 and December 2004. The 500 kW PV system generated about 445,723 kWh. The average generated electricity production per day was 1,580 kWh. It ranged from 1,452.3 kWh (March 2004) to 2,042.3 kWh (April 2004). The efficiency of the PV arrays system ranged from 9 to 12%. The final yield (YF) ranged from 2.91 h/d (March 2004) to 3.98 h/d (April 2004) and the performance ratio (PR) ranged from 0.70 to 0.90. A. This project has reduced oil consumption at Mae Hong Son diesel power plant by about 322,550 liters (3,621,047 Baht) by comparing statistic usage in the same period time. It is expected that the PVGC will generate electricity of about 551,600 kWh per year and reduce CO_2 emission by about 410,000 kg per year.

Abstract

The problem of renewable energy technology (RET) for rural electrification is lacking of the analysis and decision maker tool. In real situation there are difference characters of energy source and energy demand in each area. Actually, the technology selection is fixing the size and type form the central office. Fixing the same size and type for all locations almost done. Hence, after installation there are some systems over size, some under size as could not provide enough energy demand. With this experience, there are many RE rural electrification projects fail. From this reason, the School of Renewable Energy Technology develop "Rural Electrification Simulation (RES)" a sizing and simulation software to find out the suitable RET for rural electrification.

1. Introduction

Mae Hong Son province is situated in northwestern Thailand on the bounder with Myanmar. The province has only 22 kV distribution lines, which takes power from the Chiang Mai substation and passes through trees and hills for 200 kilometers. The supply often fails, as trees touch the conductors. The main electricity supply of Mae Hong Son, in the province's amphur muang zone, has three sources: The Pha Bong dam (PB-Dam; 1 x 850 kW), The Mae Sa Yha Dam (MSY-Dam; 2 x 3,375 kW), and Mae Hong Son diesel generator (MHS–Diesel; 3 x 1,000 kW, 3 x 1,250 kW). The total generation capacity of this installation is about 14,350 kW. Normally power generation from the dams is able to supply electricity for about 8 months per year; they are shut down in summer & winter seasons. The PB-Dam can supply about 460 kW and the MSY-Dam can supply about 2,000 – 4,000 kW. Generation capacity depends on the season as the dams were not built for storage. The MHS-diesel generator can only supply about 6,000 kW. The policy of the Electricity Generating Authority of Thailand (EGAT) gives first priority to generation from the dams, a renewable energy resource. If the supply from dams is insufficient, diesel generation is used to supplement the supply. In this way the use of costly diesel oil is minimized. The peak demand occurred on 10 October 2004 at 19.30 p.m. amounting to about 4,660 kW and the maximum day-load occurred at 15.00 p.m. amounting to about 3,030 kW. The supply constraints require careful planning of the electricity supply in Mae Hong Son.

EGAT, the organization responsible for supply and generation of electricity in Thailand, encourages the study, exploration and planning for the use of renewable energy in this province. It has initiated a pilot PV project in Mae Hong Son - the 500 kW Pha Bong photovoltaic generation by signed contract on RWE Solution AG (Germany) approximate187.11 million Baht. The Energy Policy & Planning Office (EPPO) has supported some installation budget. This project has three objectives: to increase power supply, to decrease consumption of diesel fuel during daylight hours and to encourage a national strategy in the production photovoltaic cell and accessories. Work on the Pha Bong photovoltaic generation commenced on 11 February 2003. The system first began to supply electricity to 22 kV grid system of Provincial Electricity Authority (PEA) on 20 March 2004 and

* Corresponding author

has been completely operated since 24 March 2004. The project was handed over to EGAT on the 9 April, 2004. However, paper data for its performance was collected from 24 March 2004 when the project was completely operational and being fully monitored until 31 October 2004 [1,2,3,4].

2. PVGC System Component

The Pha Bong photovoltaic generator, as seen in Figure 1, has a total power capacity of 500 kW_p. The PVGC consists of a 1,680 PV modules (140 strings, 12 modules/string, 300 watt/module). Figure 2 shows the PV generator system which was divided into two 250 kW_p sub-arrays of double-glazed ASE-300-DG-FT modules from RWE SCHOTT Solar. They are 1.28 cm width, 1.90 cm length, facing south and tilted at 15°. For grid coupling, two power conditioning units (PCU1, PCU2), each with a nominal power of 250 kVA, are used. The inverters' function, according to the new sunny team principle, is ensuring a high reliability due to the optimized efficiency in the lower part-load range.

Figure 1: PV array of Pha Bong Photovoltaic Power Plant

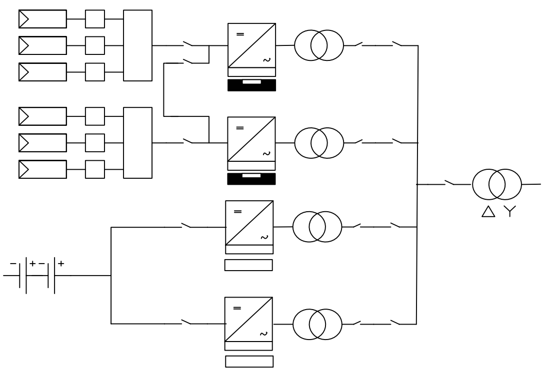

Figure 2: Schematic diagram of the PV system

Two bi-directional battery inverters (BC1 and BC2), each with a power output of 200 kVA, are operated in parallel. The battery inverters are connected to a battery bank (280 pcs 2 Volt/pcs; 560 Volt, total 1,200 Ah) and can feed into the grid in addition to the PV power. A drastic and rapid change of the grid feeding power, for example if the PV array is shaded by clouds, is avoided by using a fast microprocessor-based compensation by the battery inverter. Batteries are charged between 22.00 p.m. to 06.00 a.m.. If the PV array cannot produce, the batteries will discharge continuously to the system in a short time of less than 5 minutes. The PCUs and battery converters have their own operational control and can be operated independently of the system controller's status [5].

3. PVGC Techno-Economic Analysis

3.1 Output power of PV Array and Efficiency of PVGC System

The efficiency of the PV modules used, measured under Standard Testing Conditions (STC), is 13% (JIS C8918, IEC1215) [6]. At the project site, measured on 5th December 2004 and 19 September 2004, both of the graphs show the efficiency range of PV array system that had very little difference between 9 to 12% from 8.20 a.m. till 15.30 p.m.. These results were caused by output power being lower than STC. A decrease in efficiency can be caused by the difference between working temperature at the site and the condition at STC. Dirt accumulation on the front surface of PV modules also influences the output power. The maximum value of DC Power generated was equal to 436.1 kW at 12.10 a.m. on 19 September 2004 but the maximum value of the other months was reduced by 65.2 kW, so it was equal to 370.9 kW at 11.30 a.m.. The module temperatures in both months were very different; September 19's temperatures were higher than December 5's. The module temperature in September was 59.0°C with an ambient temperature of 32.4°C but in the month of December, the module was 50.4°C with an ambient temperature of 31.2°C. Output power of PV systems depends on the spectrum of solar irradiance at the project location each month. The output power of PV system in September was higher than the output power in the December. The Output DC power generated by the PV modules is dependent on the irradiance, temperature, wind and dust in all types of weather, except for small values of irradiance, lower than 20.95 Watt/m^2, when the output power is zero; see Figure 3. System performance analysis shows that the efficiency of the PV array is not only strongly dependent on irradiance but also dependent on the module temperature. This dependence can be seen in Figure 3 - 4. At the beginning of the day, the output power

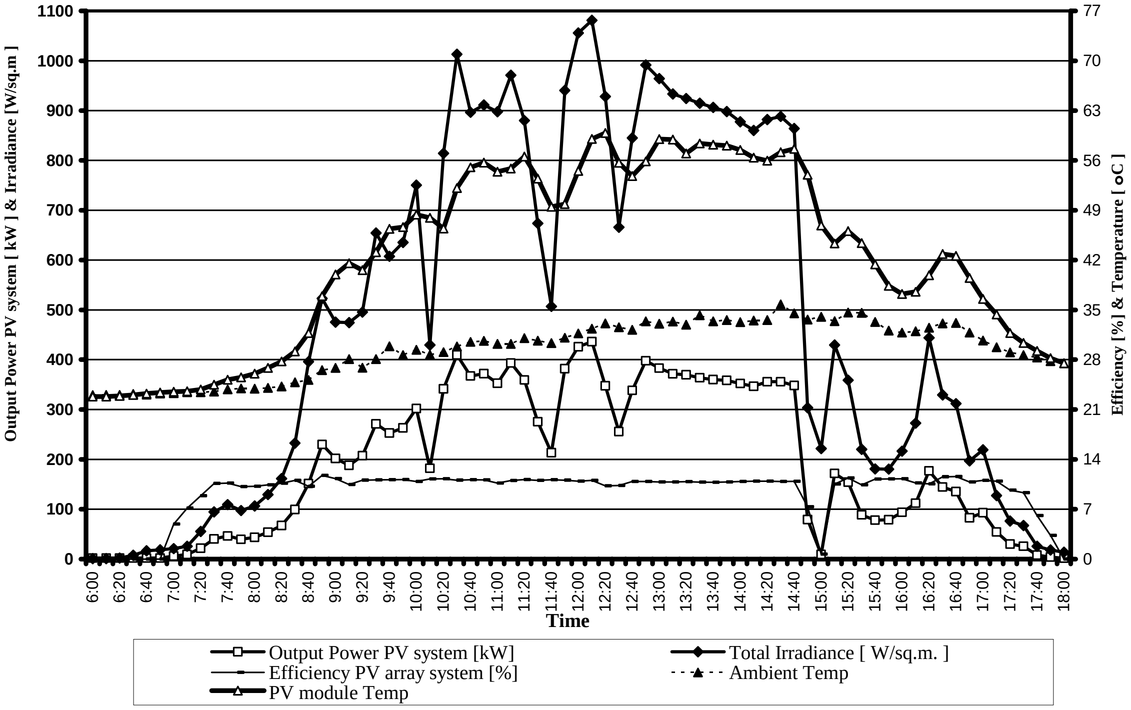

Figure 3: The efficiency PV modules versus irradiance on 19 September 2004

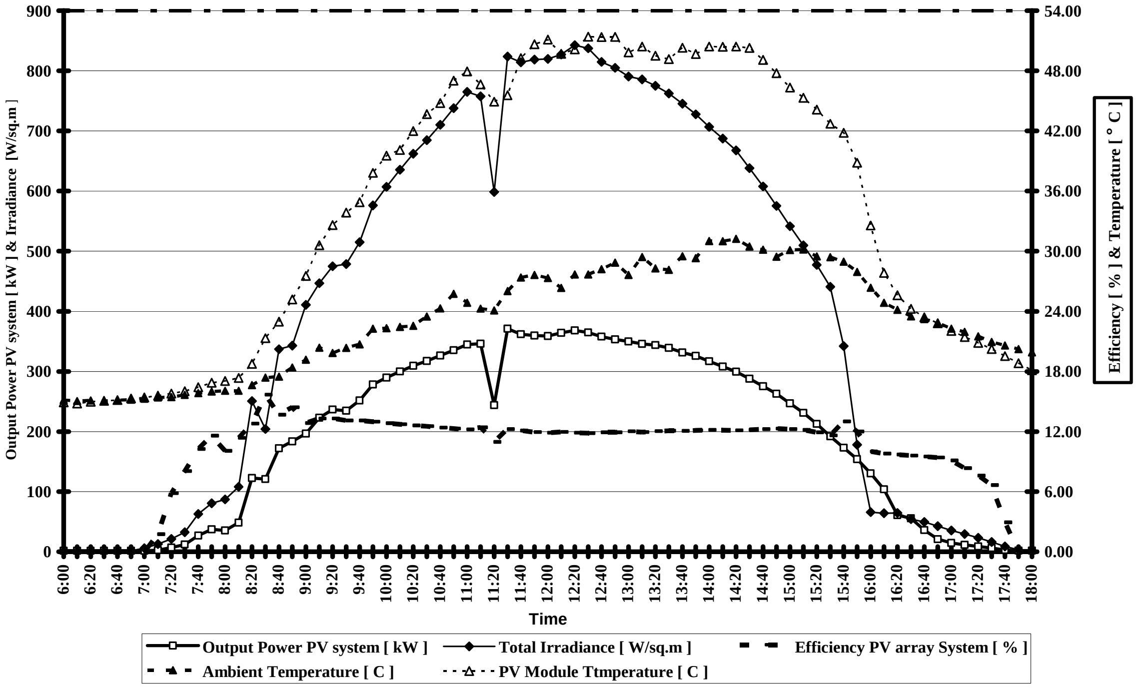

Figure 4: The efficiency of PV modules versus irradiance on 5 December 2004

of the PV array increased gradually from 5.8 kW to 230 kW within 1 hour 50 minutes while the temperature of PV module changed from 23.6°C to 36.9°C. Thus the PV array power changed at a rate of (230 – 5.8 kW)/(110 minutes), which is equal to 2 kW/minute and the PV array power changed with respect to temperature at a rate of (230 – 5.8 kW)/(36.9 – 23.6 °C) or 16.85 kW/ °C.

When the PV output power peaked, the temperature of PV module was high. It changed power at a rate of (436.1– 381.8 kW)/(20 minutes) or 2.7 kW/minute, but the PV array power changed with respect to temperature at a rate of (436.1– 381.8 kW)/(59.8 – 49.9 °C) or 5.46 kW/ °C. This means that a higher PV module temperature correlates to lower PV array power output. However, the DC output power is still dependent on the irradiance. The PV module temperature became hot, but the efficiency of the PV array system didn't change. When the irradiance decreased at the end of the day, a lower DC power was generated with the same irradiance trend.

3.2 Analysis of the Performance of Eentire PV System

The quantities used to assess the performance of the grid connection were being given as:

Y_A = E_A/P_O ($kWh/kW_p.d$) : array yield (1)

Y_R = H_T/G_{STC} ($kWh/kW_p.d$) : reference yield (2)

Y_F = E_{PV}/P_O ($kWh/kW_p.d$) : final yield (3)

L_C = $Y_R - Y_A$ ($kWh/kW_p.d$) : capture losses (4)

Ls = $Y_A - Y_F$ ($kWh/kW_p.d$) : system losses (5)

PR = Y_F / Y_R Performance Ratio

Where

P_O = Peak Power (W_P)

H_T = Mean daily irradiance in array plane ($kWh/m^2.d$)

G_{STC} = Reference irradiance at STC (1 kW/m^2)

E_A = Array output energy (kWh)

E_{PV} = Energy to Grid (kWh)

Normalized parameters Y_F, L_S and L_C, as defined in IEC 61724, are shown in Figure 5 for each month between March 2004 to October 2004 [6,7]. The Y_F of this 500 kW_P PV system ranged from 2.91 h/d (March 2004) to 3.98 h/d (April 2004).

L_S were due to losses in DC to AC energy conversion. L_C was due to PV array losses. In April 2004, a month when the monthly energy production was the largest (E_{PV} = 59,710 kWh), the Y_F was 3.98 h/d, L_C was 1.04 h/d, L_S was 0.51 h/d, and the PR was 0.72. In August 2004, when the monthly energy production was the lowest (31,997 kWh), the Y_F was 3.04 h/d, L_C was 2.11 h/d, L_S was 0.20 h/d, and the PR was 0.62.

Table 1 shows the PR of the PV system from March 2004 to October 2004, as defined in IEC 61724, ranged from 0.58 to 0.81 for monthly normalization. The maximum PR of 0.81 occurred in October 2004. Mean daily irradiance in array plane had high average daily irradiances ranging between 3.91 and 5.53 kWh/m^2, but the PR was lower than 0.70 in March 2004 and August 2004. These low values were the result of the PV system being shut down when the grid system faulted due to contact between trees and the conductors.

International Energy Agency PVPS Task 2 reported that the implemented PV grid systems are located world-wide and therefore, are operated under different climate conditions. From analysis of 170 grid connected PV systems in the IEA-PVPS database [8], the annual performance ratio (PR) differs significantly from plant to plant ranging between 0.25 and 0.9 with an average value of 0.66 for 170 PV systems. Therefore, from this information, the PV Module of 500 kW_p Pha Bong photovoltaic power plant has high performance when compared with 170 grid connected PV systems.

3.3 Economic Analysis of PVGC

The Pha Bong photovoltaic generator has operated successfully since 24 March 2004. The electricity generated from January to December of each year, reduced oil consumption at Mae Hong Son diesel power plant for about 322,550 liters by comparing statistic usage in the same time period [3-5]. EGAT can save about 3,621,047 baht because of reduced time operation of the diesel MHS-P. PVGC 500 kWp system generated about 445,723 kWh of electricity during 10 months. It is expected that the PVGC should generate about 551,600 kWh of electricity per year and reduce about 410,000 kg of CO_2 emission per year (Table 2).

4. Summary

EGAT commenced work on the Pha Bong photovoltaic generation project in Mae Hong Son province in early 2004 and the project was fully operated by 24 March 2004. The local grid in this remote area in northwest Thailand is very limited in its capacity and cannot be enlarged. Local generation capacities are also limited. The PV generation was initiated to increase the power supply, to decrease the use of diesel consumption and to encourage a national strategy in the production of photovoltaic cells and accessories.

In this paper, climatic and solar radiation conditions at the site are reviewed and the performance of the system is assessed from a system component perspective (PV array, power conditioning unit) and from a global perspective (AC power delivered to the grid, system efficiency and system reliability).

During the first ten months period of the Pha Bong projects' operation, the system generated about 445,723 kWh. The average electricity production per day was 1,580 kWh. It ranged from 1,452.8 kWh (March 2004) to 2,042.3 kWh (April 2004). The efficiency of the PV array system ranged from 9 to 12 %. The average

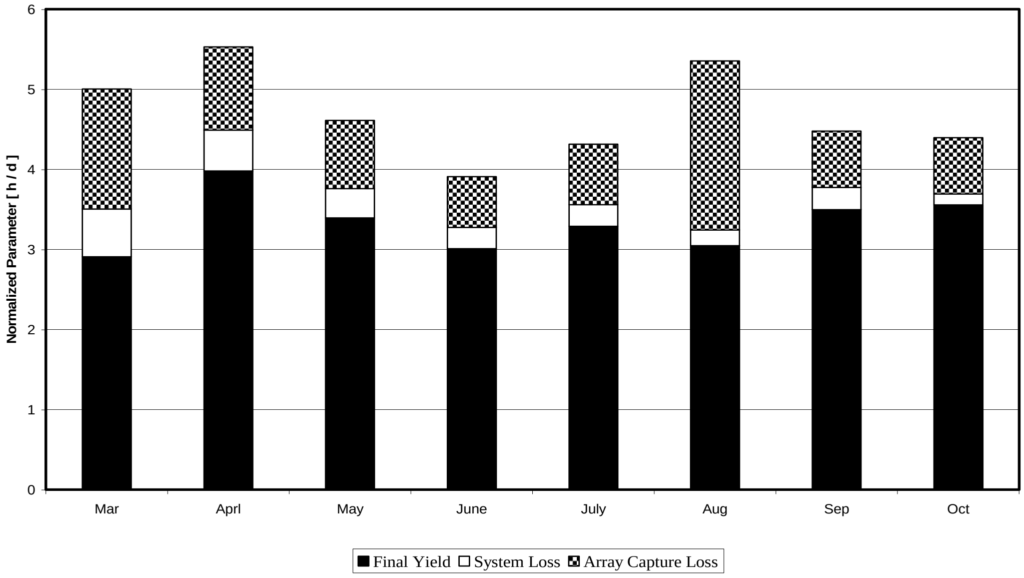

Figure 5: Normalize Parameter Y_F, L_S and L_C in March 2004 – October 2004

Table 1: Normalized parameters Y_F, L_S and L_C in March 2004 – October 2004

Item	Mar	Aprl	May	June	July	Aug	Sep	Oct
Final Yield	2.91	3.98	3.39	3.01	3.29	3.05	3.50	3.56
System Loss	0.60	0.51	0.37	0.27	0.27	0.20	0.28	0.14
Array Capture Loss	1.50	1.04	0.85	0.63	0.76	2.11	0.71	0.70
Total	5.01	5.53	4.61	3.91	4.32	5.36	4.48	4.40
PR	0.58	0.72	0.74	0.77	0.76	0.62	0.78	0.81
Y_A	3.05	4.49	3.76	3.28	3.56	3.07	3.78	3.70
H_T	5.01	5.53	4.61	3.91	4.32	5.36	4.48	4.40
E_{PV}	11,633	59,710	52,589	45,136	47,715	31,997	48,971	48,023
E_A	14,022	67,386	58,314	49,182	51,657	34,089	52,872	49,893
Po	4,000	15,000	15,500	15,000	14,500	10,500	14,000	13,500
Total day in each month	8	30	31	30	29	21	28	27
Average E_{PV} /Day	1,454.19	1,990.33	1,696.42	1,504.53	1,645.34	1,523.66	1,748.96	1,778.64

Table 2: Oil Consumption and Electricity Generation 2003 – 2004

YEAR	Diesel MHS-P		Electricity Generated (kWh)					Electricity Bills PEA (Baht)	Total Customer (Household)
	Oil Saving (Baht)	Oil Consumption (Liter)	Diesel MHS-P	PA BONG PVGC	MAE SA YHA DAM	PA BONG DAM	Total		
2003	12,857,838	966,970	3,427,500	0	17,853,500	3,229,000	24,510,000	23,670,638	9,799
2004	9,236,791	644,420	2,304,585	445,723	23,658,619	2,708,384	29,117,311	24,396,441	10,665
Result	3,621,047	322,550	1,122,915	-445,723	-5,805,119	-520,616	4,607,311	-725,804	866

electricity production per day was 1,580 kWh. It ranged from 1,452.8 kWh (March 2004) to 2,042.3 kWh (April 2004). The efficiency of the PV array system ranged from 9 to 12 %. The final yield (Y_F) ranged from 2.91 h/d (March 2004) to 3.98 h/d (April 2004) and the performance ratio ranged from 0.70 to 0.90. This project has reduced oil consumption at Mae Hong Son diesel power plant by about 322,550 liters compared to statistical usage in the same period. EGAT can save about 3,621,047 baht because of reduced time operation of the diesel MHS-P. It is expected that the PVGC will generate electricity about 551,600 kWh per year and reduce CO_2 emission by about 410,000 kg per year.

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