CHAPTER 5

DATA COLLECTION AND ANALYSIS

The data analysis is shown in this chapter relating to the characteristics of the PV generator and the efficiency of the water pumping system.

Testing PV module

The PV module tested was Model SM55 of Solartron, Co.,Ltd.. To find the characteristics of this PV module the following circuit was used. (Fig 21)

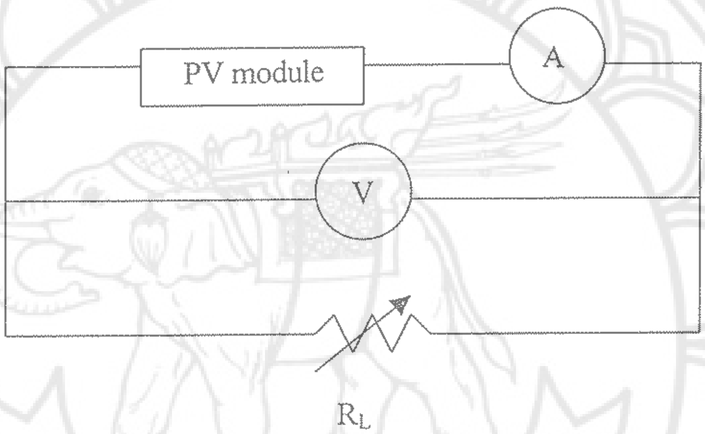

Figure 21 PV connection circuit.

Equipment for testing

- PV module:

Model SM55 (Solartron, Co.,Ltd.)

Power specification at Standard Test Conditions of 1,000 W/m^2 of A.M. 1.5 Irradiance and Cell Temperature of 25 °C

Rated Power	55 Watt
Configuration	12 Volt
Rated Current	3.15 Amp
Rated Voltage	17.4 Volt
Short Circuit Current	3.45 Amp
Open Circuit Voltage	21.7 Volt

- Digital multi-meter

Model:	M-838
Accuracy:	0.5 %
Large:	LCD
Low:	Battery

Digital multi-meters were used for measuring the current and voltage from the PV modules

- Temperature & thermal radiation gun meter

Model:	KM 801
Brand:	KANE-MAY
Company:	Instrument Network center Company

Specification

Measure the temperature from 0 - 800 °C

Measure the radiation from 316 - 1999 w/m^2

The parameters for PV characteristics tests were:

Part 1: Temperature constant, Radiation variable

1. With the temperature constant record the voltage and current data at the first radiation values. Start recording when voltage is equal to zero and current will equal to I_{sc}. Then increase voltage by increasing R_L until the maximum and the current is nearly zero, that is V_{oc}. The temperature has to be constant throughout the experiment.
2. Change to a new radiation level. Record the data the same as in step 1.
3. Find the relationship between voltage and current, voltage and power.

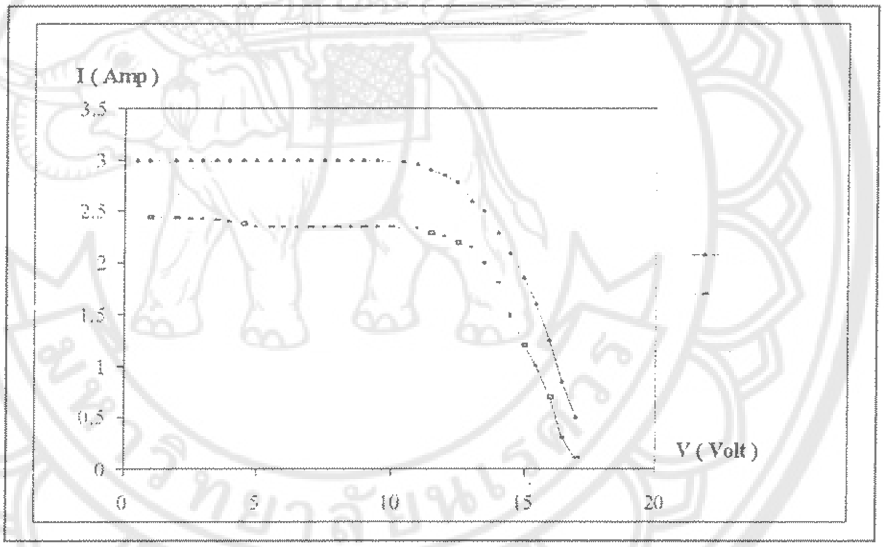

Figure 22 Relationship between voltage and current (T = 38 °C).

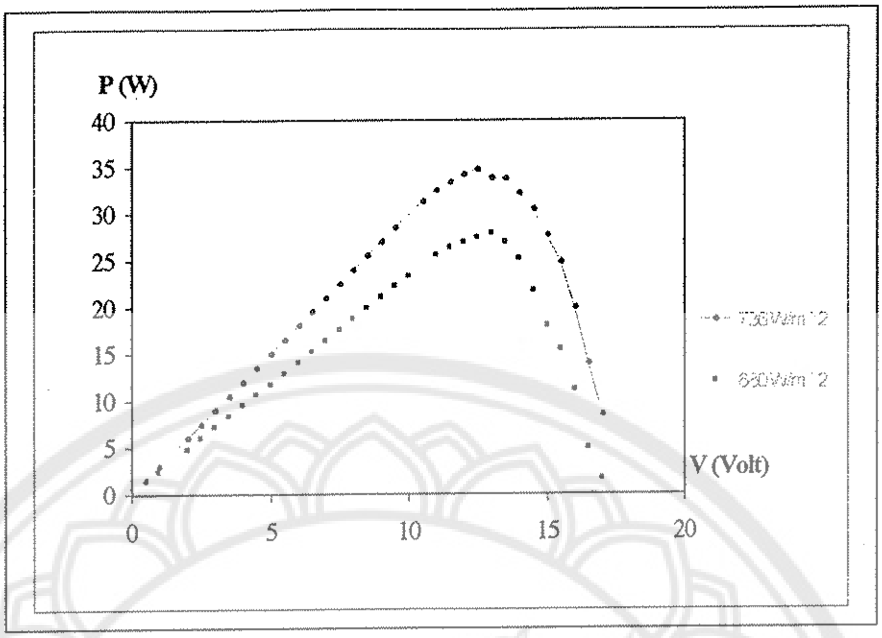

Figure 23 Relationship between voltage and power (T = 38 °C).

Part 1 Analysis:

1. The current is variable to radiation, high radiation gives high current.
2. The power is variable to radiation, high radiation gives high power.
3. High radiation gives little increase in voltage.

Part 2: Radiation constant, Temperature variable.

1. Record the voltage and current data at a radiation value and temperature value.
2. At the same level of radiation, increase the temperature 5 degrees and record the data for voltage and current.
3. Repeat step two for a total of four steps or 25 degrees total increase.
4. Find the relationship between voltage and current, voltage and power.

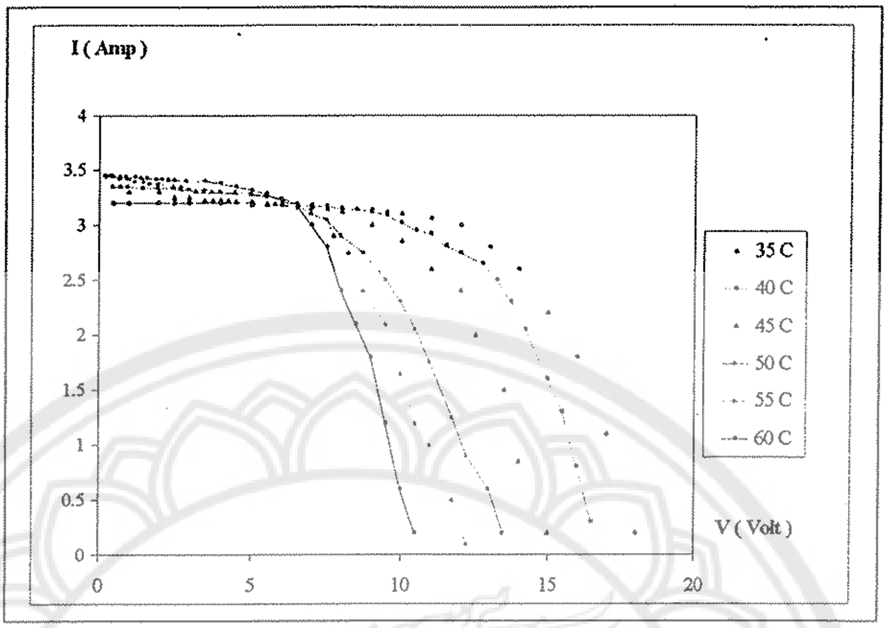

Figure 24 Relationship between voltage and current (G_T = 700 w/m^2).

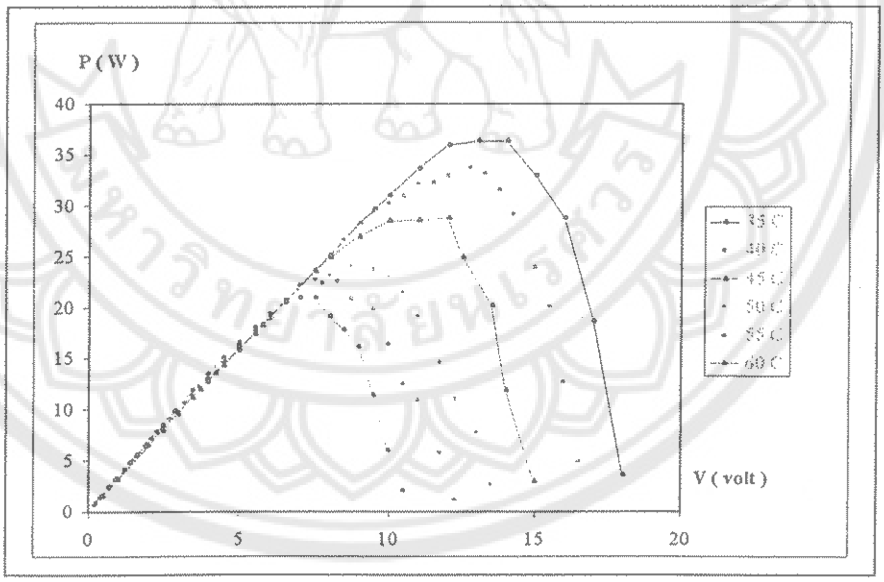

Figure 25 Relationship between voltage and power (G_T = 700 w/m^2).

Part 2 Analysis:

1. The open circuit voltage will decrease significantly when the temperature increases
2. The short circuit current will increase a small amount when the temperature increases
3. The electric power will decrease when the temperature is increased

I_{sc} and V_{oc} finding for part 1 and 2

We can not collect the data directly from the experiment, so we use the regression equation to find the short circuit current value in part 1 and 2.

Find the short circuit value in part 1 (radiation = 736 W/m^2) from the cross section of the graph at 3.0227 Amp, by estimating the value from the polynomial power 6 of the Regression equation. The equation is:

$$Y = 0.000002X^6 - 0.00008X^5 + 0.0014X^4 + 0.0107X^3 + 0.0379X^2 - 0.0556X + 3.0227$$
$$R^2 = 0.996$$

Find the short circuit value in part 1 (radiation = 680 W/m^2) from the cross section of the graph at 2.5074 Amp, by estimating the value from the polynomial power 4 of the Regression equation. The equation is:

$$Y = -0.0001X^4 + 0.0028X^3 - 0.0126X^2 - 0.0179X + 3.0227$$
$$R^2 = 0.9931$$

Find the short circuit value in part 2 (at 35°C) from the cross section of the graph at 3.2105 Amp, by estimating the value from the polynomial power 6 of the Regression equation. The equation is:

$$Y = -0.0000008X^6 - 0.00002X^5 + 0.0002X^4 - 0.00004X^3 + 0.0065X^2 - 0.0198X + 3.2105$$
$$R^2 = 0.9992$$

Find the short circuit value in part 2 (at 40°C) from the cross section of the graph at 3.2371 Amp, by estimating the value from the polynomial power 5 of the Regression equation. The equation is:

$$Y = -0.00002X^5 + 0.0006X^4 - 0.0075X^3 + 0.0397X^2 - 0.0803X + 3.2371$$
$$R^2 = 0.9992$$

Find the short circuit value in part 2 (at 45°C) from the cross section of the graph at 3.26 Amp

$$Y = -0.002X^4 + 0.0016X^3 - 0.0012X^2 - 0.0465X + 3.36$$
$$R^2 = 0.9953$$

Find the short circuit value in part 2 (at 50°C) from the cross section of the graph at 3.3635 Amp, by estimating the value from the polynomial power 6 of the Regression equation. The equation is:

$$Y = 0.0000005X^6 - 0.0001X^5 + 0.0013X^4 - 0.0059X^3 + 0.0136X^2 - 0.0263X + 3.3635$$
$$R^2 = 0.9991$$

Find the short circuit value in part 2 (at 55°C) from the cross section of the graph at 3.4682 Amp, by estimating the value from the polynomial power 6 of the Regression equation. The equation is:

$$Y = 0.00004X^6 - 0.0011X^5 + 0.01X^4 - 0.042X^3 + 0.0809X^2 - 0.0804X + 3.4682$$
$$R^2 = 0.9986$$

Find the short circuit value in part 2 (at 60°C) from the cross section of the graph at 3.5083 Amp, by estimating the value from the polynomial power 6 of the Regression equation. The equation is:

$$Y = -0.0001X^4 - 0.0054X^3 + 0.0499X^2 - 0.1296X + 3.5083$$
$$R^2 = 0.9968$$

From these equations, the power is not equal and uses a different polynomial because the short circuit value that is found in the last term is the stable value because of X replaced by 0 will cross at Y axis. So when using the Regression equation to find the short circuit with the same polynomial equation will be impossible, The result will maybe higher or lower than the real value. So have to choose a suitable value for the polynomial equation.

We cannot find the open circuit voltage (V_{oc}) from the Regression because the voltage that is obtained from the equation is on the horizontal axis so it quite difficult to find the value. The value in the part 2 of the experiment is the same as in part 3.

Part 3:

1. Change the radiation to 8 different levels to find the I_{sc} and V_{oc}(Appendix) and then use the different value to relate with the I_{sc} and V_{oc}.
2. With stable radiation, change the temperature then find the I_{sc} and V_{oc} (Appendix) and use the different values to relate with the I_{sc} and V_{oc}.

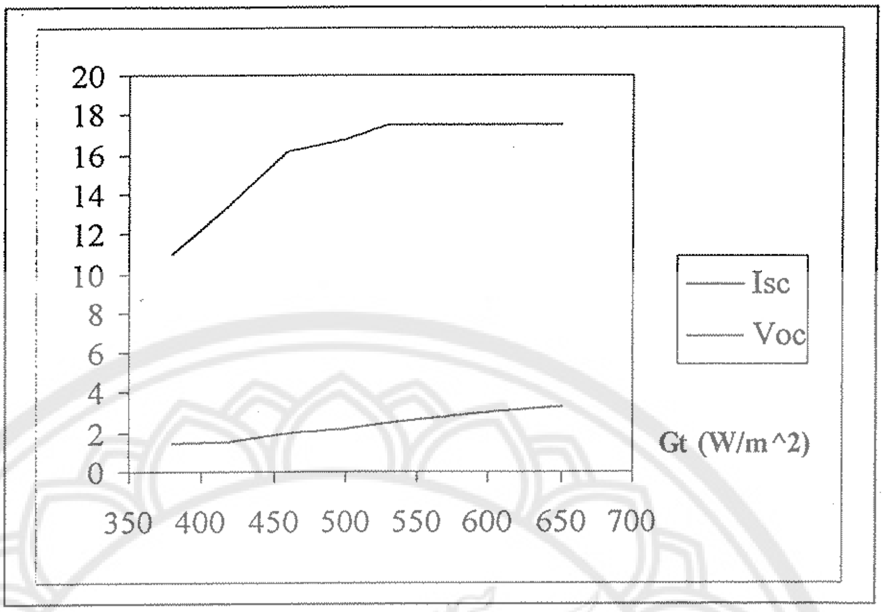

Figure 26 The relation between the radiation and I_{sc} and $V_{oc.}$

Figure 27 The relation between the temperature and I_{sc} and $V_{oc.}$

Part 3 analysis:

1. When the radiation decreases the I_{sc} and V_{oc} will decrease.
2. When the temperature increases the Voc will decrease and the Isc will increase.

The maximum electric power

We can find the maximum electric power by considering the curve change in the graph (Fig 23 and 25), where the curve changes most quickly we will get the highest electric power.

Table 3 The highest electric power from PV.

Experiment	Im (A)	Vm (V)	Pm (W)
Part 1 (736 W/m^2)	2.78	12.5	34.75
Part 1 (680 W/m^2)	2.15	13	27.95
Part 2 (700 W/m^2, 35 °C)	2.6	14	36.4
Part 2 (700 W/m^2, 40 °C)	2.65	12.75	33.7875
Part 2 (700 W/m^2, 45 °C)	2.4	12	28.8
Part 2 (700 W/m^2, 50 °C)	2.75	8.75	24.0625
Part 2 (700 W/m^2, 55 °C)	2.75	8.25	22.6875
Part 2 (700 W/m^2, 60 °C)	2.8	7.5	21

Fill Factor

Use the Im, Vm from the experiment in part 2, Isc and V_{oc} in part 3 to calculate the Fill Factor (at the same radiation)

Table 4 Fill Factor (when G_T = 700 W/m^2).

Temperature	Im	Vm	Isc	Voc	F.F.
35 °C	2.6	14	3.25	18.3	0.612
40 °C	2.65	12.75	3.35	16.7	0.604
45 °C	2.4	12	3.4	15.5	0.546
50 °C	2.75	8.75	3.4	14	0.506
55 °C	2.75	8.25	3.5	12.5	0.519
60 °C	2.8	7.5	3.5	11	0.545

PV efficiency

We can find the PV efficiency from the highest electric power per PV power. From Experiment, it is found that:

Table 5 PV efficiency of the module.

Experiment	Power (W)	Efficiency (%)
Part 1 (736 W/m2)	34.75	12.33
Part 1 (680 W/m2)	27.95	10.74
Part 2 (700 W/m^2, 35 °C)	36.4	13.58
Part 2 (700 W/m^2, 40 °C)	33.7875	12.61
Part 2 (700 W/m^2, 45 °C)	28.8	10.75
Part 2 (700 W/m^2, 50 °C)	24.0625	8.98
Part 2 (700 W/m^2, 55 °C)	22.6875	8.47
Part 2 (700 W/m^2, 60 °C)	21	7.84

Summary

The radiation and the temperature are the parameters that effect the PV output. If there is high radiation, the short circuit current is high so the electric power is high also. . Even though the current rises somewhat with increasing radiation, the amount is small compared with the decreasing voltage. As the temperature of the panel goes up, therefor the electric power goes down.

Testing the PV water pumping.

Diagram for collect data from study of the PV pumping system at Energy Park, Naresuan University. When we have all of the data, we can analyze to find the power and efficiency of the system.

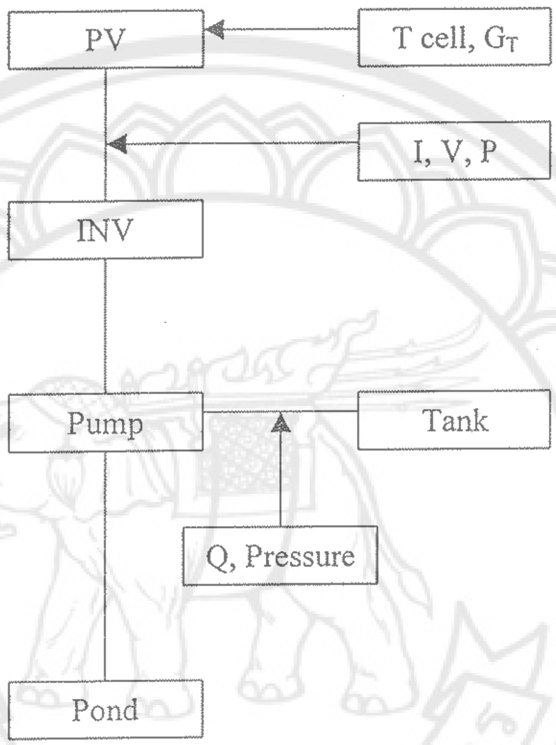

Figure 28 Diagram of the PV pumping system.

- **The behavior of the PV water pumping system per day.** (20 March 00)

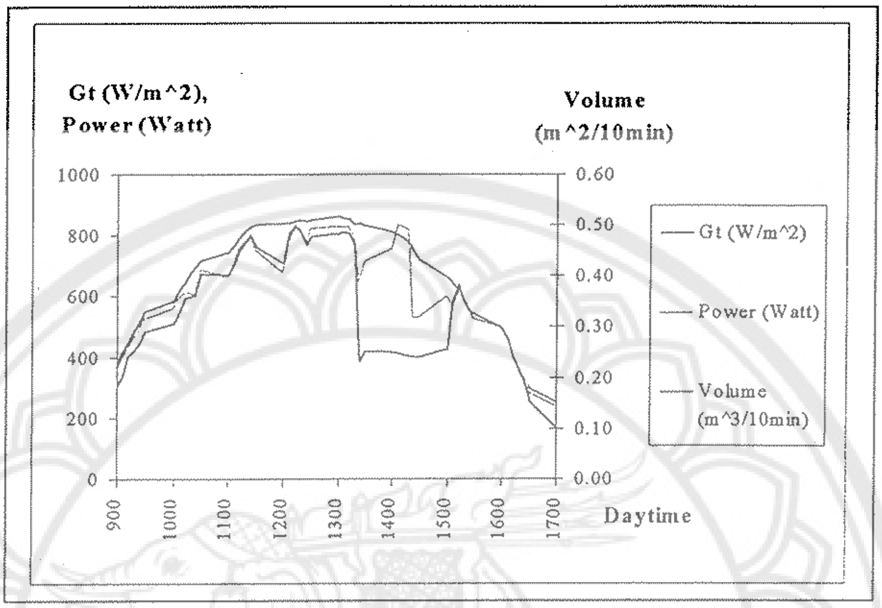

Figure 29 Relationship between solar radiation, power and volume.

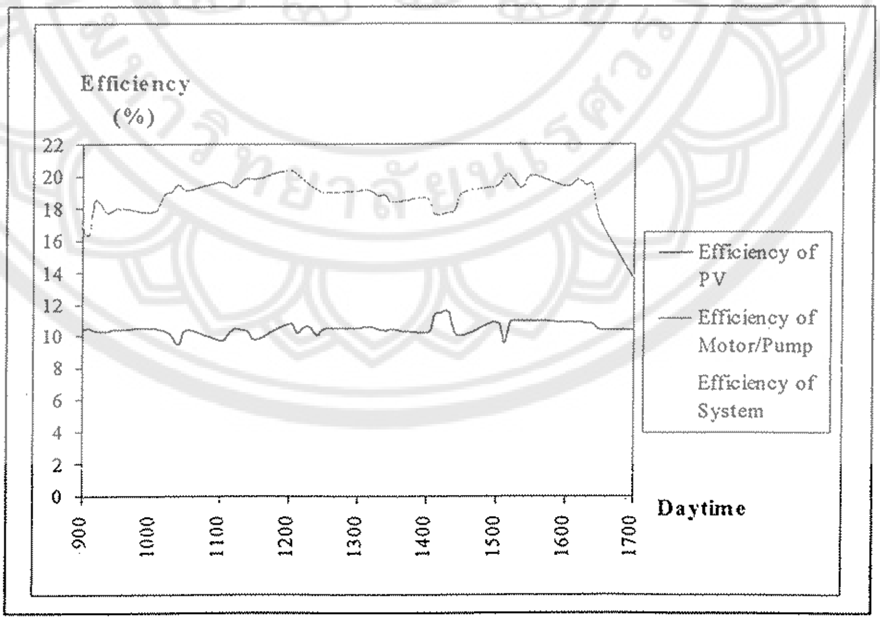

Figure 30 Relationship between daytime and efficiency of system.

- **The behavior of the PV water pumping system per week.** (20-27 March 00)

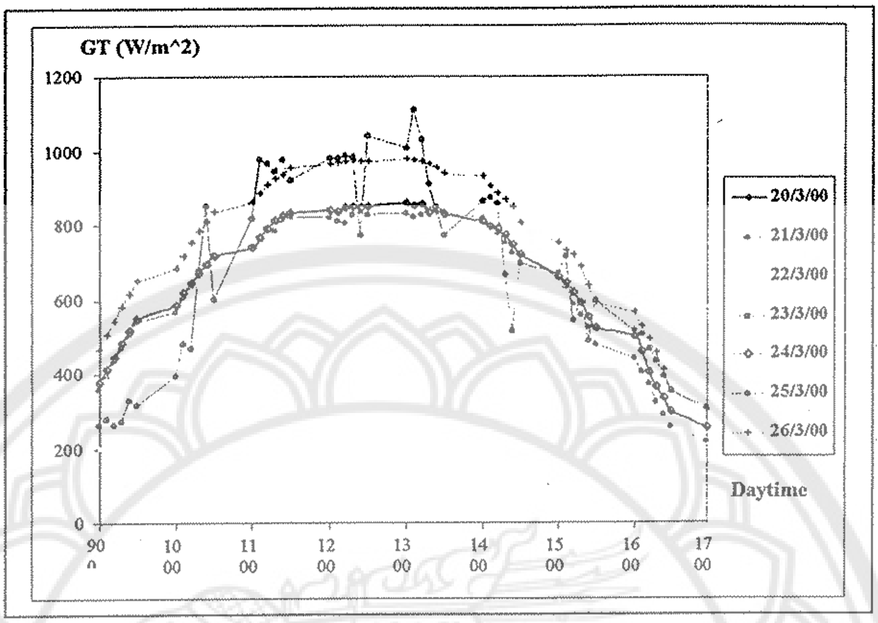

Figure 31 Relationship between daytime and solar radiation.

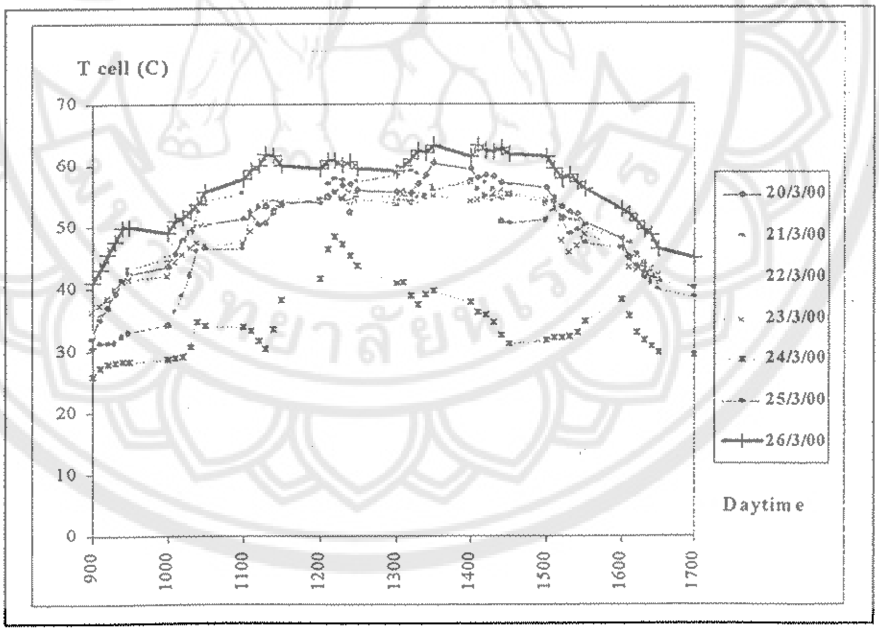

Figure 32 Relationship between daytime and PV temperature.

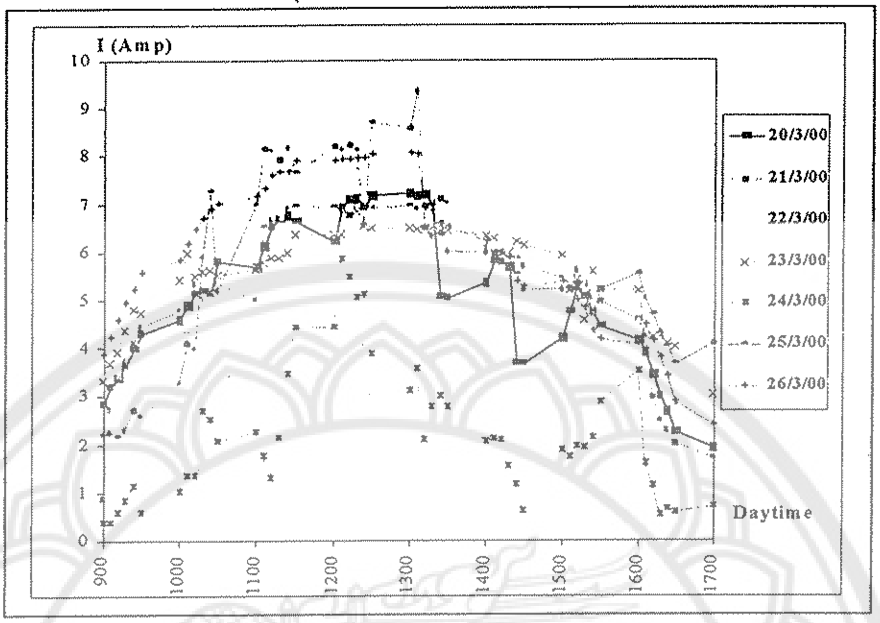

Figure 33 Relationship between daytime and PV current.

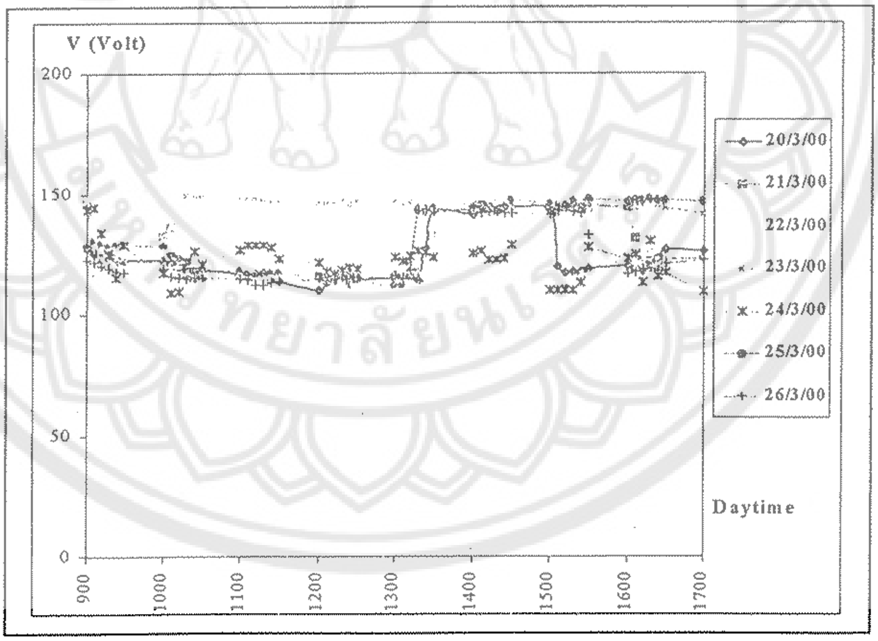

Figure 34 Relationship between daytime and PV voltage.

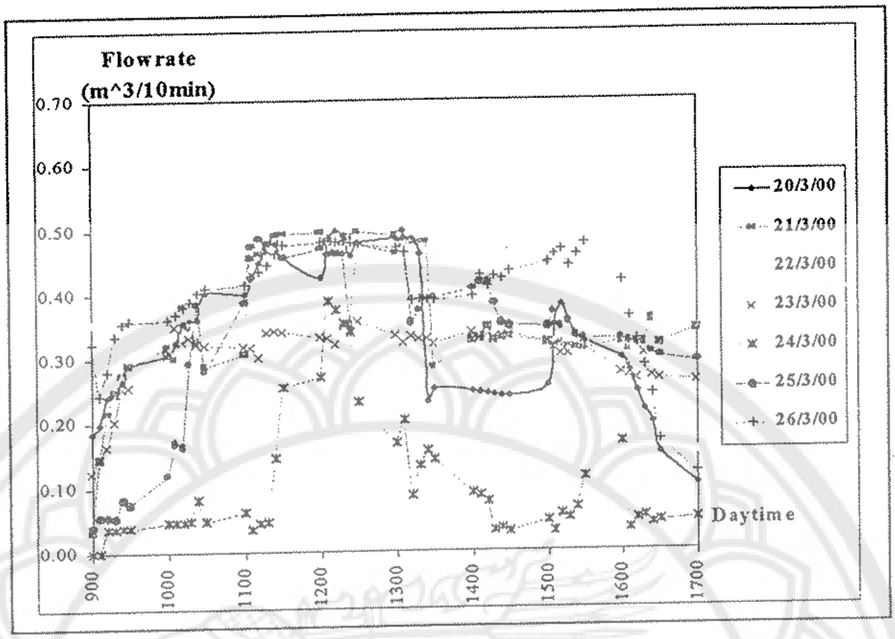

Figure 35 Relationship between daytime and volume.

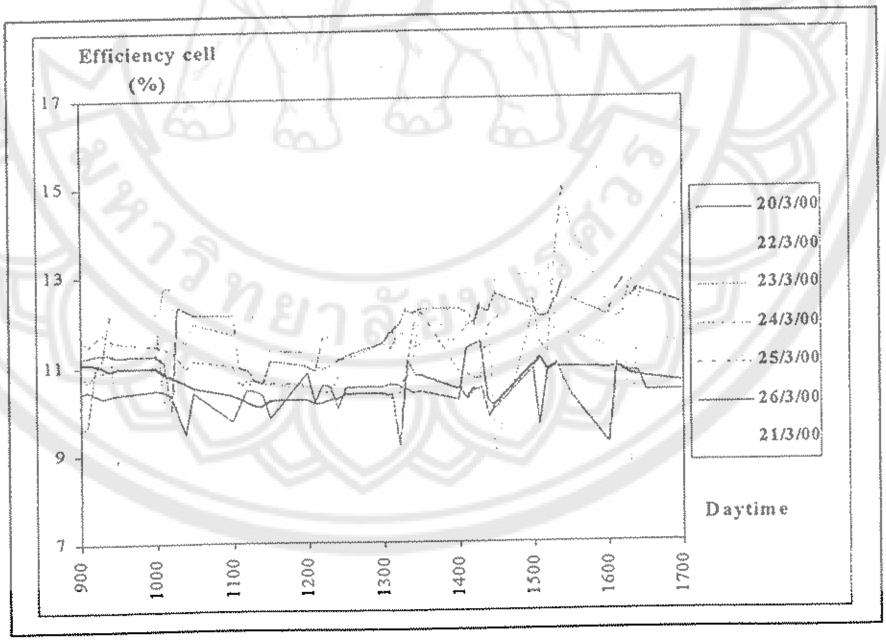

Figure 36 Relationship between daytime and PV efficiency.

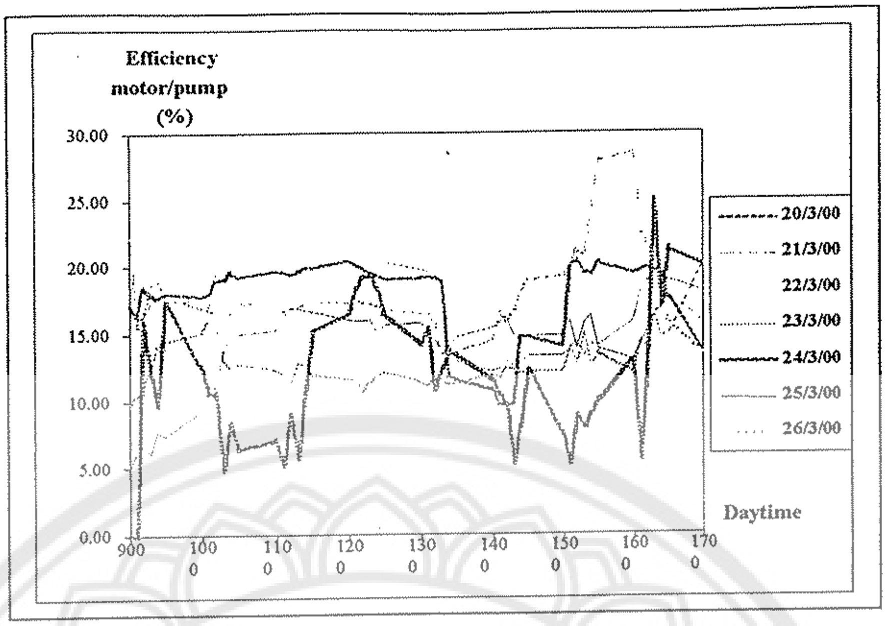

Figure 37 Relationship between daytime and motor/pump efficiency.

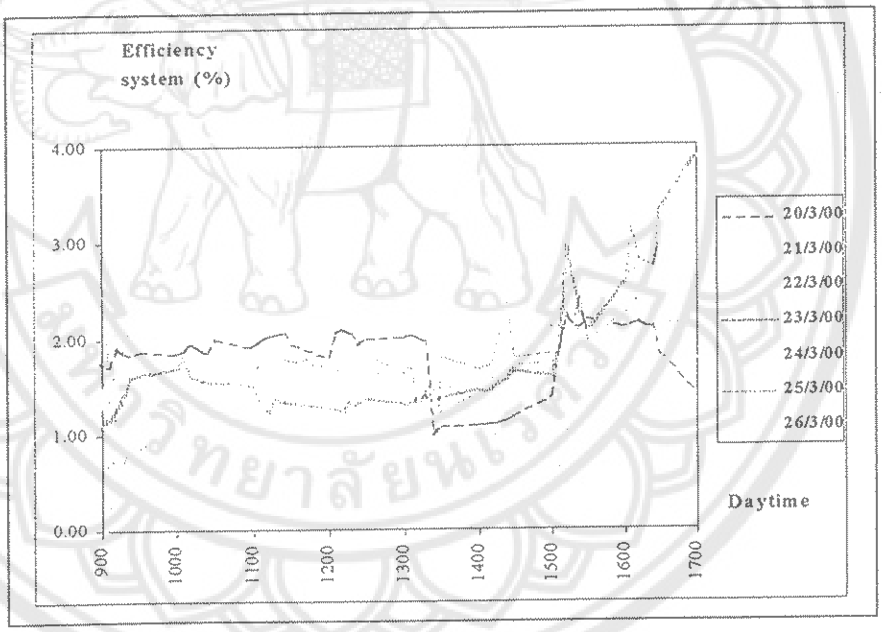

Figure 38 Relationship between daytime and PV water pumping system efficiency.

From fig 29-38 it can be seen that that at a low temperature of the PV surface (< 40 °C), the efficiency of the PV water-pumping system depends on the solar radiation. When the temperature of PV is higher, the efficiency will slightly decrease.

The reason for this was described in item 5.1. The open circuit voltage of the PV array will decrease when there is a higher cell temperature caused by the accumulative heat from the sun (see Fig 31,32). The highest radiation occurs at noon, and the radiation will decrease the afternoon but the temperature will increase during the morning and will be the highest in the afternoon. From the characteristics of PV panels, the electric power is increases as the radiation is increased too but not at the same rate because of the effect of temperature.

In terms of the efficiency of the PV and motor/pump sub systems it was found that when the radiation is not changing smoothly due to clouds, the motor and pump rapidly changes its rotation rate time because the electric input to the motor and pump is erratic.

From data analysis it was found that:

1. The efficiency of the PV Pumping system depends on the solar radiation when there is a low cell temperature (< 40 °C).
2. Flow rate varies with solar radiation and depends on the power supply to the motor and pump, when there high-power due to strong solar radiation, the motor and pump will produce a high flow rate.

- **The behavior of the PV water pumping system at different radiation** (20 March 00)

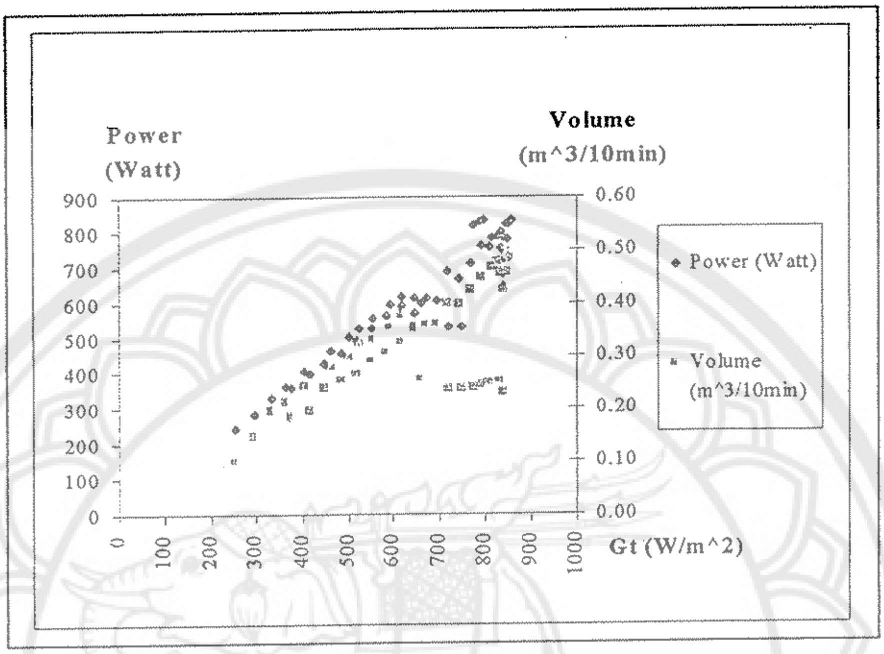

Figure 39 Relationship between power and volume.

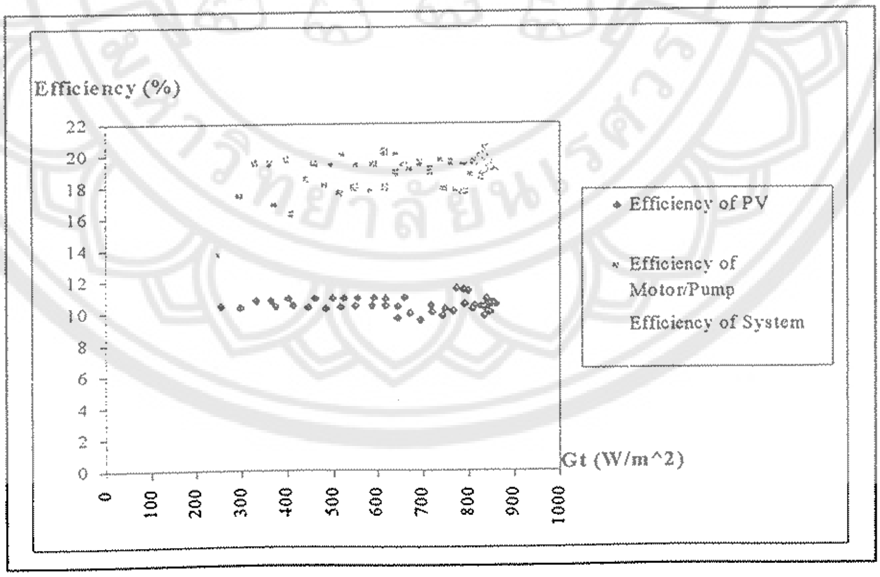

Figure 40 Relationship between solar radiation and efficiency of system.

- **The behavior of the PV water pumping system at different radiation levels** (20-27 March 00)

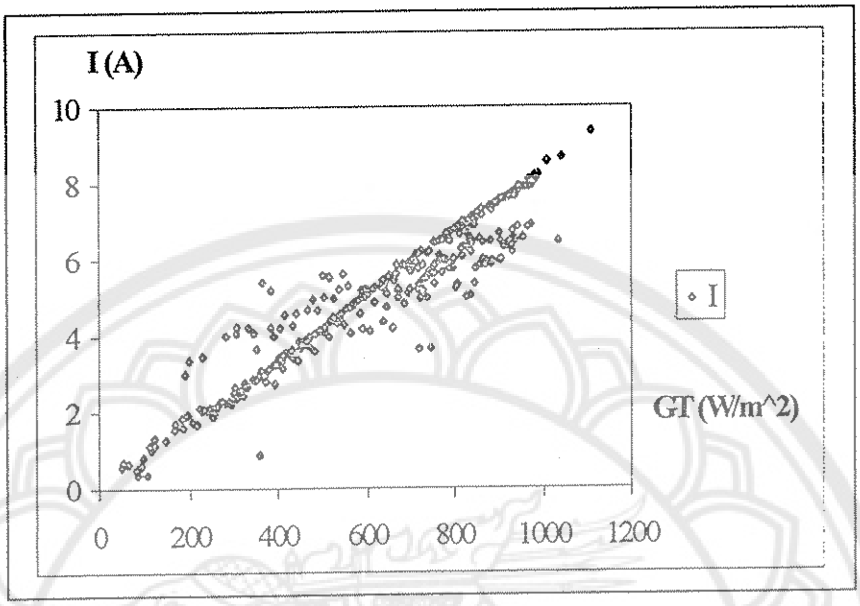

Figure 41 Relationship between solar radiation and current.

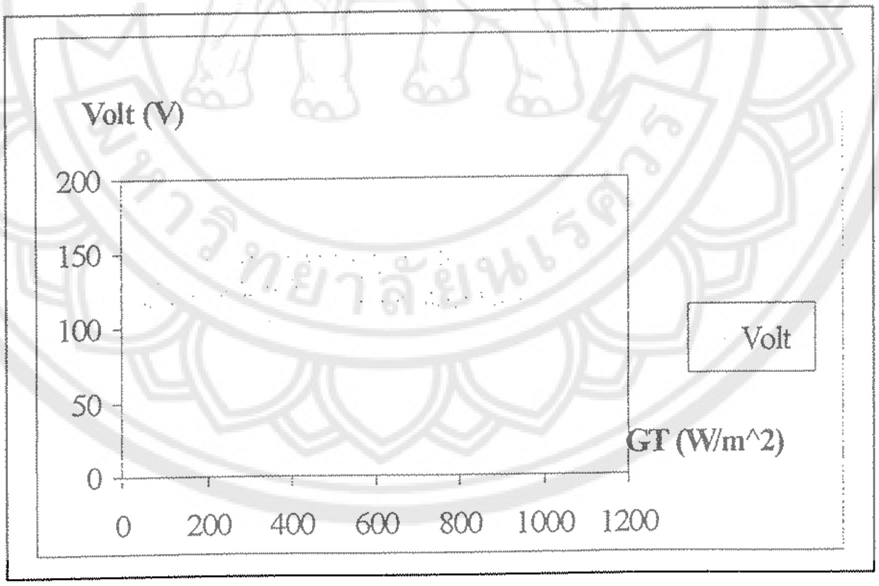

Figure 42 Relationship between solar radiation and voltage.

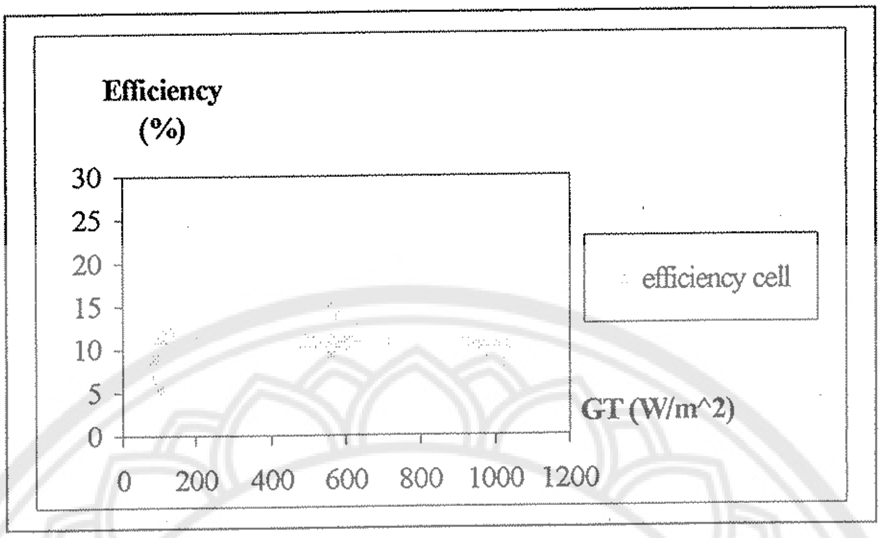

Figure 43 Relationship between solar radiation and PV efficiency.

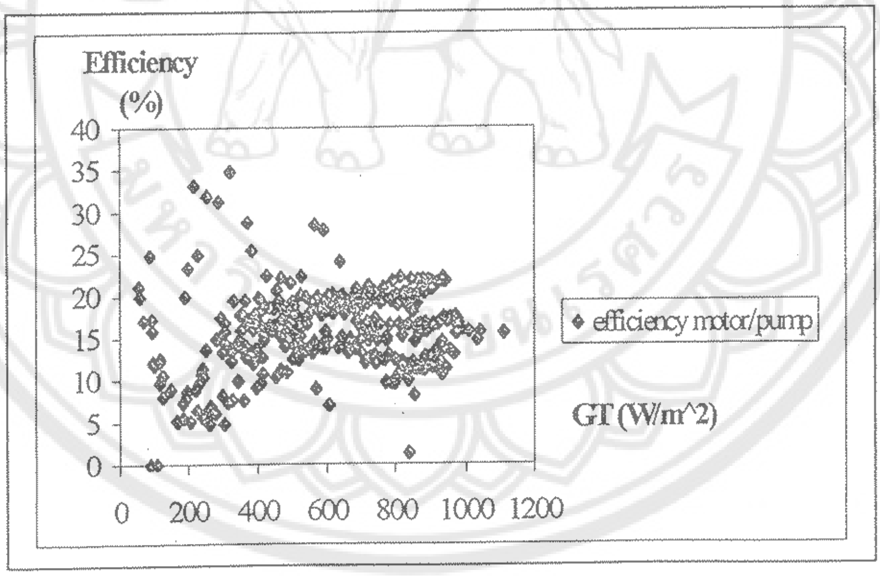

Figure 44 Relationship between solar radiation and motor/pump efficiency.

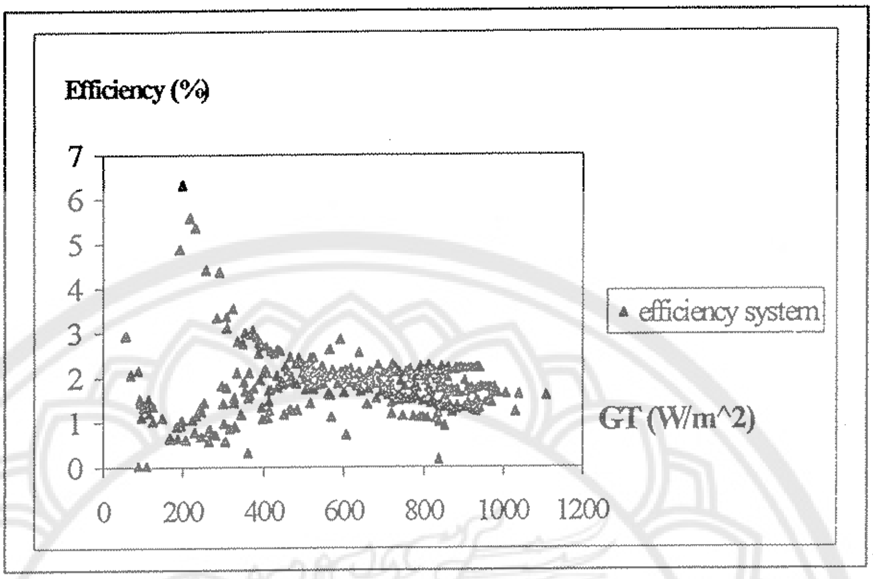

Figure 45 Relationship between solar radiation and PV water pumping system efficiency.

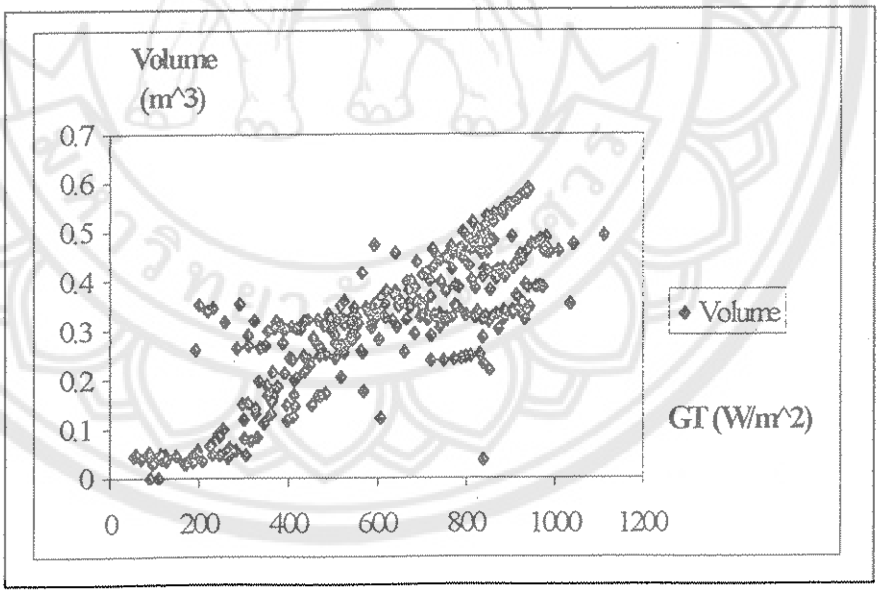

Figure 46 Relationship between solar radiation and volume.

From the efficiency experiment, it was found that:

1. The efficiency of the PV water pumping system depends on the solar radiation at low cell temperatures (<40 °C). In the case of high radiation, the efficiency of the system will decrease because the efficiency of PV generation will decrease with the high radiation because the temperature of the PV cells increase.
2. The current from the PV array depends linearly on the radiation though the rate of change will decrease at high radiation levels (>800 W/m^2) because the high radiation levels raise the cell temperature.
3. The total efficiency of PV water pumping system depends on the efficiency of the motor and pump.

Predicting water supply from PV water pumping

The efficiency for a day of PV water pumping is shown in a graph. The graph shows the relation between the quantity of water per day (Q) with the solar radiation per m^2 of PV (G_T). And in fig 47, 48 is shown the linear regression equation of their relation.

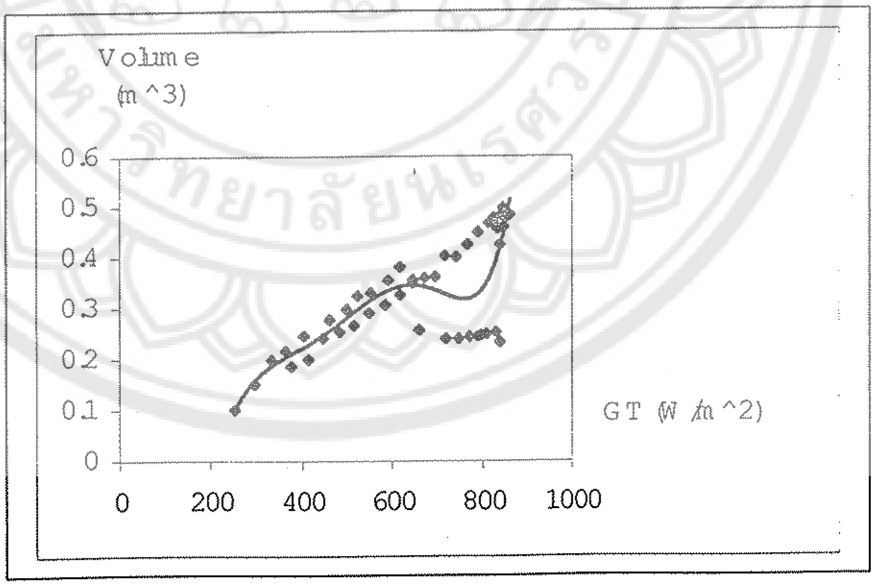

Figure 47 The linear regression equation of PV water pumping system (20 March 2000).

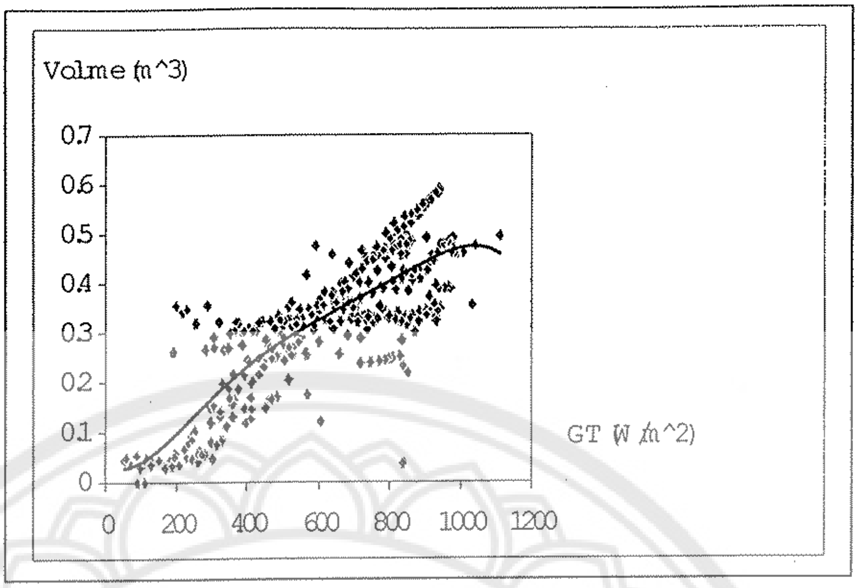

Figure 48 The linear regression equation of PV water pumping system . (20-27 March 00)

Fig 47: The linear regression equation is

$$Q = (1*10^{-16})G_T^6 - (3*10^{-13})G_T^5 + (2*10^{-10})G_T^4 - (4*10^{-8})G_T^3 + (3*10^{-5})G_T^2 + 0.0149G_T - 1.765 \quad ...(11)$$

$$R^2 = 0.6556$$

Fig 48: The linear regression equation is

$$Q = (-3*10^{-19})G_T^6 - (3*10^{-15})G_T^5 + (1*10^{-11})G_T^4 - (1*10^{-8})G_T^3 + (5*10^{-6})G_T^2 - 0.0003G_T + 0.0326 \quad ...(12)$$

$$R^2 = 0.7044$$

From the two graphs,(Fig 47,48) the R^2 of the second equation [12] (7 days of data) is more close to 1 than the first equation [11] (1-day of data), so the second equation is closest to the truth.

For the quantity of water (Q), prediction can be based on the radiation input (G_T) in the equation.