CHAPTER 5

RESULTS AND DISCUSSION

5.1 Short term analysis

The report object wants to find the efficiency and characteristic of system. For a normal operation day that defined as a situation, when no limitation of fluid flow due to closing of valves etc. is observed. In this part will select only 1 day to show the relationship of each parameter that is 16 April 1998. Because it is following a normal operation day. The relationships of each parameter on this day were showed on figure 7 to 17.

Table 8 The average condition data on each month.

MONTH	G_T	G_{Tilt}	T_A	T_C	H	H_{Tilt}
Oct-97	461.10	510.26	30.15	46.14	149.32	165.24
Nov-97	413.58	478.41	29.42	43.75	138.55	160.27
Dec-97	406.91	475.95	29.93	42.72	118.14	138.18
Jan-98	364.41	415.41	29.96	41.33	126.15	143.80
Feb-98	430.85	471.93	31.64	44.31	134.06	147.56
Mar-98	462.41	487.59	33.21	46.24	159.45	168.30
Apr-98	515.35	524.77	33.47	48.53	172.64	175.80
May-98	487.41	479.64	32.70	47.61	168.72	166.04
Jun-98	487.38	469.32	31.84	47.45	163.27	157.22
Jul-98	460.32	448.35	30.72	46.09	159.35	155.20
Aug-98	470.71	473.22	30.04	46.32	162.95	163.81
Sep-98	467.95	486.91	29.61	45.64	156.76	163.12
Unit	W/m^2	W/m^2	°C	°C	kWh/m^2	kWh/m^2

Table 9 The average data of PV and inverter system on each month.

MONTH	V_{PV}	I_{PV}	P_{PV}	P_{AC}	f
Oct-97	112.98	2.32	261.99	254.40	24.71
Nov-97	110.47	2.12	234.53	232.00	23.03
Dec-97	111.70	2.04	227.54	221.81	22.21
Jan-98	112.48	1.74	195.94	190.84	20.70
Feb-98	113.06	2.07	233.91	225.31	22.82
Mar-98	114.44	2.13	243.87	235.66	24.86
Apr-98	113.80	2.52	286.20	276.10	27.95
May-98	134.54	0.75	100.50	80.22	8.00
Jun-98	145.77	0.03	4.37	1.08	0.00
Jul-98	146.36	0.03	4.24	0.69	0.00
Aug-98	134.04	0.92	123.72	99.49	9.63
Sep-98	113.19	2.25	254.79	244.28	23.59
Unit	**V**	**A**	**W**	**W**	**H_Z**

Table 10 The average data of motor pump and pipe system on each month.

MONTH	H_W	P_1	P_2	P_3	Q_1	Q_2
Oct-97	2.550	0.416	0.329	0.412	0.483	0.381
Nov-97	2.470	0.275	0.118	0.214	0.482	0.339
Dec-97	2.160	0.190	0.141	0.174	0.496	0.373
Jan-98	1.200	0.130	0.100	0.112	0.476	0.353
Feb-98	1.480	0.073	0.066	0.066	0.503	0.312
Mar-98	1.090	0.075	0.066	0.065	0.519	0.351
Apr-98	0.820	0.120	0.114	0.105	0.566	0.406
May-98	0.510	0.027	0.022	0.022	0.154	0.104
Jun-98	0.430	0.000	-0.004	-0.003	0.000	0.000
Jul-98	0.340	0.004	0.000	0.000	0.000	0.000
Aug-98	1.540	0.048	0.044	0.002	0.226	0.201
Sep-98	3.170	0.208	0.201	0.202	0.653	0..493
Unit	m.	barr	barr	barr	m^3	m^3

From data analysis method in Chapter 3, the system efficiency and each part of a normal operation day can find in average value.

For a normal operation day that defined as a situation, when no limitation of fluid flow due to closing of valves etc. is observed. In this part will select only 1 day to show the related graphs of each parameter that is 16 April 1998. Because, it is following normal operation day relationships of each parameter on this day. The relationships of each parameter on each month can find the system efficiency that was showed on table 11. And, the relation analysis was showed on table 12.

Table 11 The average efficiency of system on each month.

MONTH	η_{PV}	η_{INV}	η_{MP}	η_{SYS}
Oct-97	0.073	0.971	0.571	0.041
Nov-97	0.070	0.989	0.572	0.040
Dec-97	0.068	0.975	0.589	0.039
Jan-98	0.067	0.974	0.591	0.039
Feb-98	0.071	0.963	0.528	0.036
Mar-98	0.072	0.966	0.527	0.036
Apr-98	0.078	0.965	0.554	0.042
May-98	0.030	0.798	0.151	0.004
Jun-98	0.001	0.247	0.000	0.000
Jul-98	0.001	0.162	0.000	0.000
Aug-98	0.037	0.804	0.266	0.008
Sep-98	0.075	0.959	1.017	0.073

Table 12 The average radiation analysis data on each month.

MONTH	H_{ref}	$H_{ref,\ tilt}$	RY_T	RY_{Tilt}	PR_T	PR_{Tilt}	FY
Oct-97	149.32	165.24	5.33	5.90	0.187	0.169	3.23
Nov-97	138.55	160.27	4.62	5.34	0.197	0.170	2.94
Dec-97	118.14	138.18	3.81	4.46	0.166	0.142	2.81
Jan-98	126.15	143.80	4.07	4.64	0.190	0.167	2.42
Feb-98	134.06	147.56	4.79	5.27	0.171	0.157	2.86
Mar-98	159.45	168.30	5.14	5.43	0.184	0.175	2.98
Apr-98	172.64	175.80	5.75	5.86	0.188	0.185	3.50
May-98	168.72	166.04	5.44	5.36	0.060	0.061	1.02
Jun-98	163.27	157.22	5.44	5.24	0.001	0.001	0.01
Jul-98	159.35	155.20	5.14	5.01	0.001	0.001	0.01
Aug-98	162.95	163.81	5.26	5.28	0.077	0.076	1.26
Sep-98	156.76	163.12	5.23	5.44	0.183	0.176	3.10
Unit	h	h	h	h	-	-	-

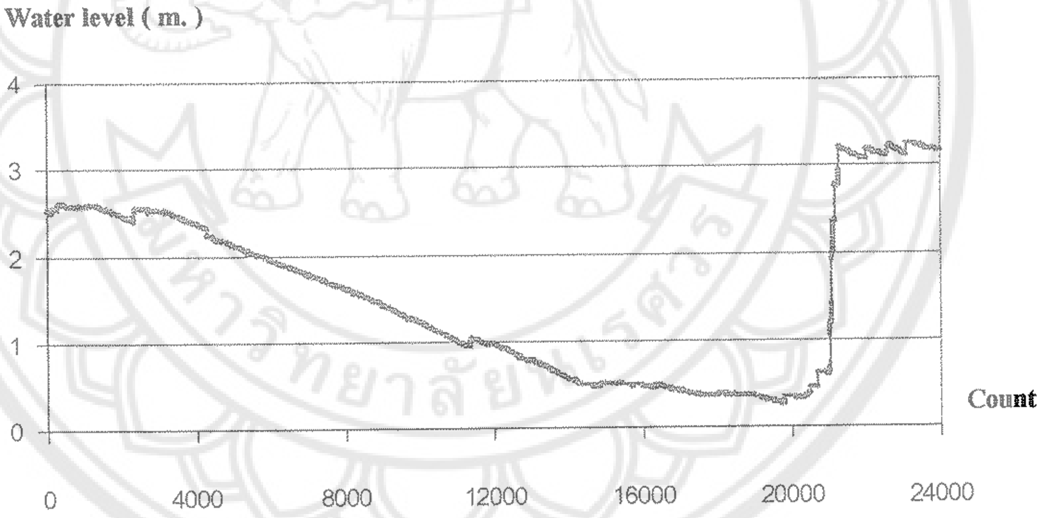


Figure 6 The water level in the pond of this system will decrease until the water level is very low. So, the system can not operate from June 1998 until August 1998.

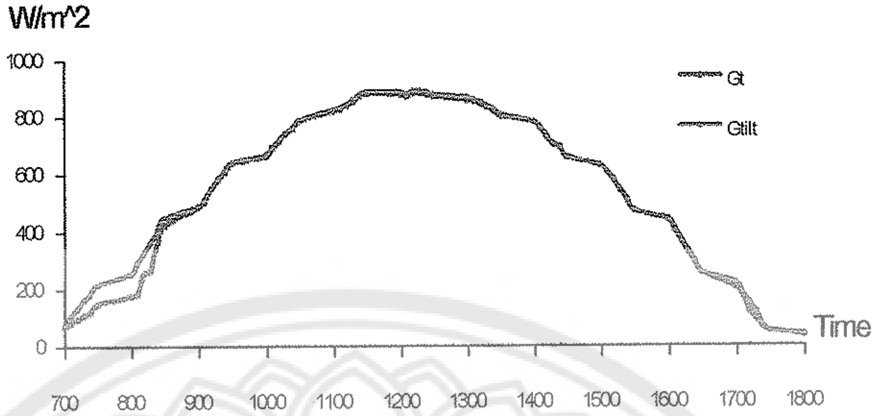


Figure 7 Global and tilt angle radiation on 16 April 1998.

This figure shows about the radiation that the tilt angle radiation will higher than the horizontal or global radiation because of the tilt angle radiation will drop perpendicularly on the PV surface. Therefore, it is make more output energy from PV than the horizontal radiation.

At any time, PV generated power were different upon the amount of radiation that effected by the sun position and cloud.

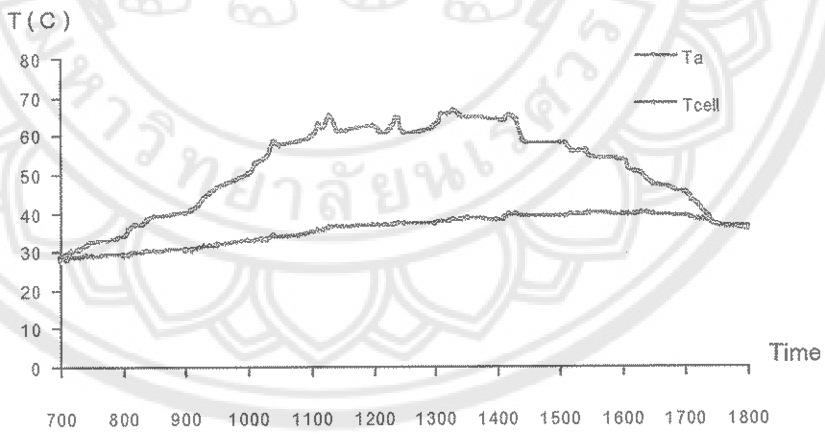


Figure 8 Ambient and cell temperature on 16 April 1998.

This figure shows the relation of ambient temperature and module temperature that the module temperature will higher than the ambient temperature because of heat storage in module panel.

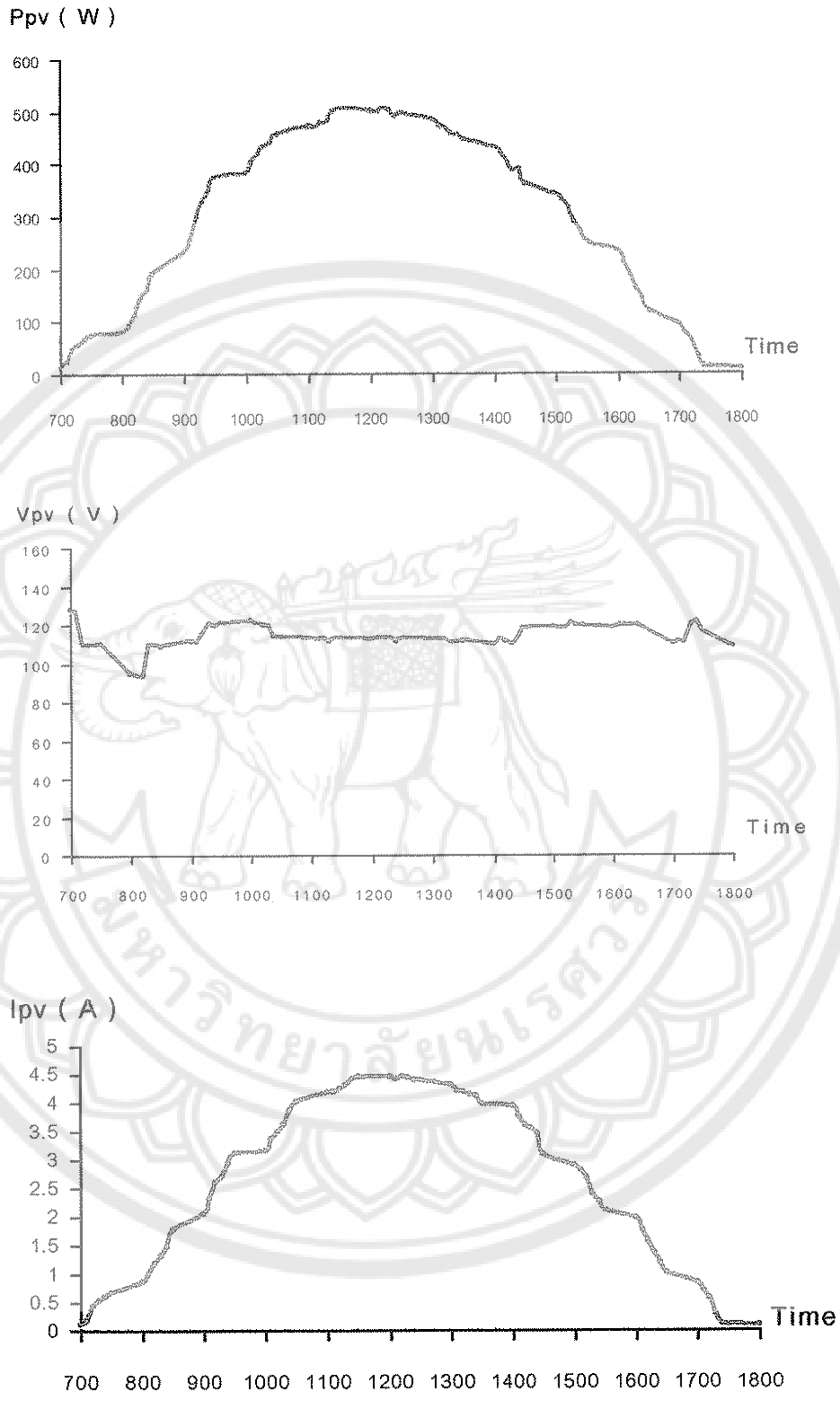


Figure 9 Electrical power from PV system on 16 April 1998.

From the figure, the radiation effect to the output current and the output power, but it is not effecting with the output voltage.

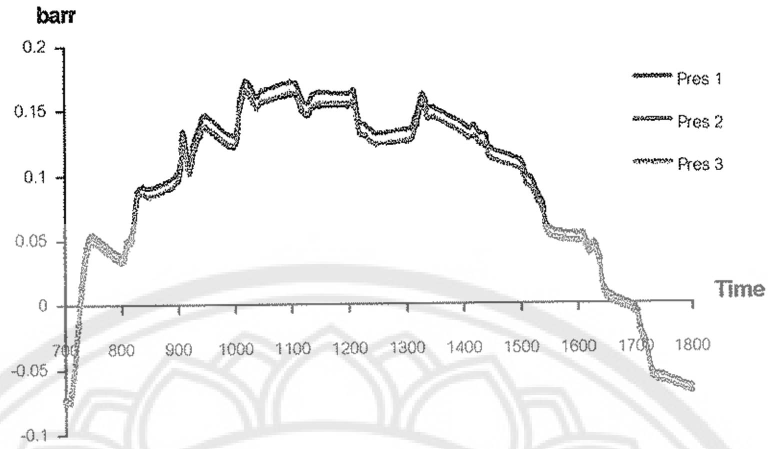


Figure 10 Pressure in each pipe on 16 April 1998.

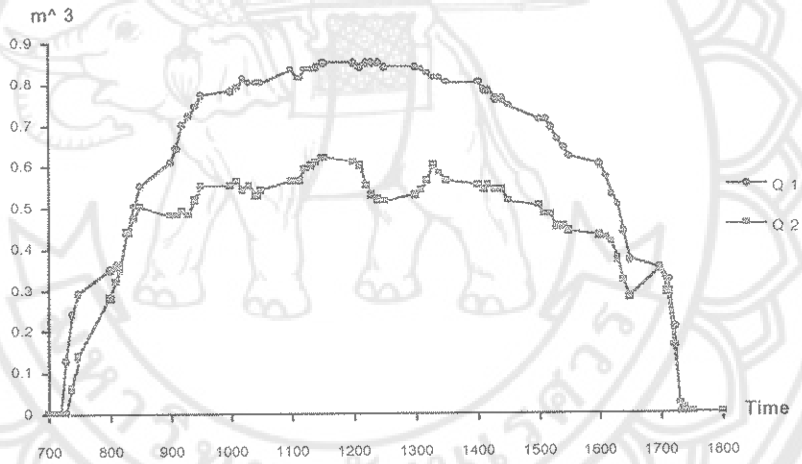
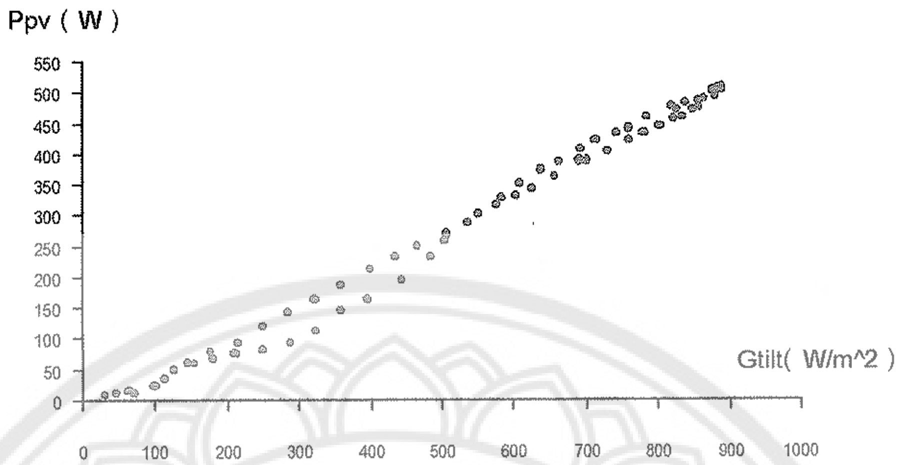


Figure 11 Flow rate in each on 16 April 1998.

A single day of normal operation is selected and presented. A normal operation is defined here as a situation, when no limitation of the fluid flow due to closing of valves etc. is observed. Therefore, the three-pressure vales P_1-P_3 is identical. No interim storage of water in some of the larger private storage tanks (up to 2-3 m height) can be detected. The relatively low-pressure values may be caused by the dynamic pressure losses in the pipe system only. Negative pressure values (relative values) may be understood due to small height differences between pumping station and the opposite end of the pipes in the village.

The fluid flow Q_3 is determined from the difference of the monitored values Q_1 and Q_2.



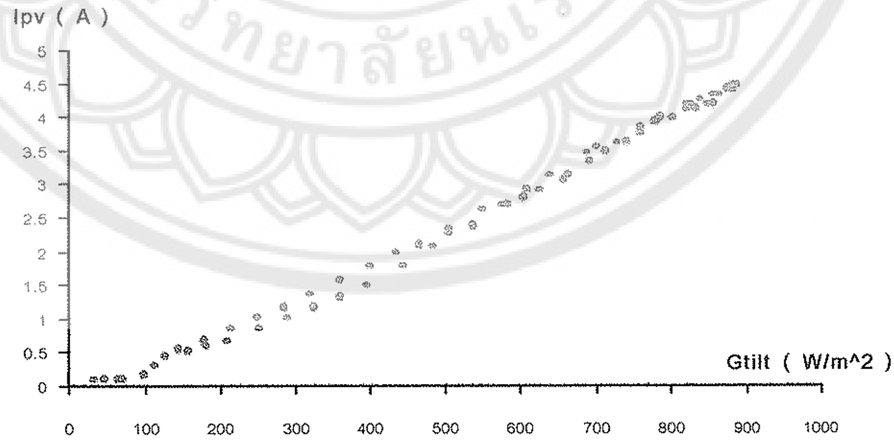


Figure 12 Relation of electrical output from PV system and tilt angle radiation on 16 April 1998.

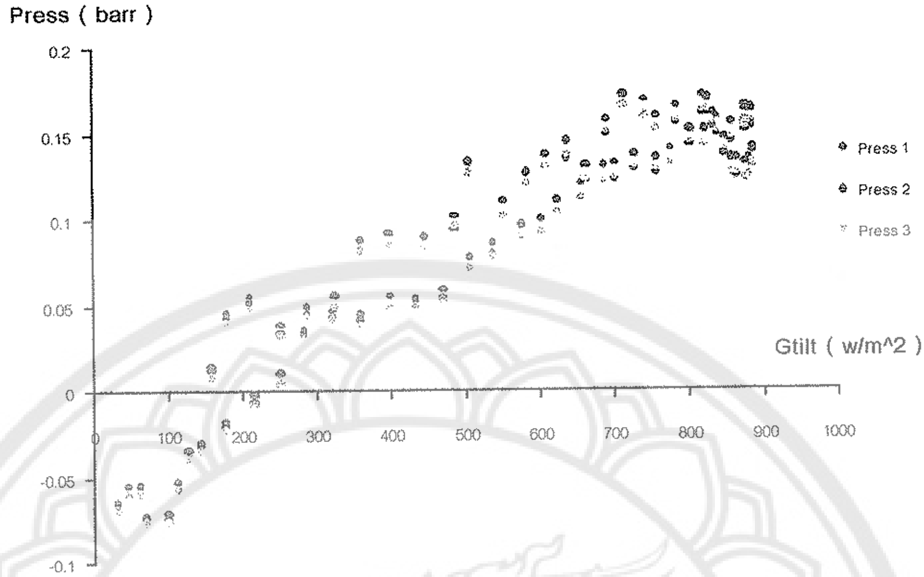


Figure 13 Relation of pressure and tilt angle radiation on 16 April 1998.

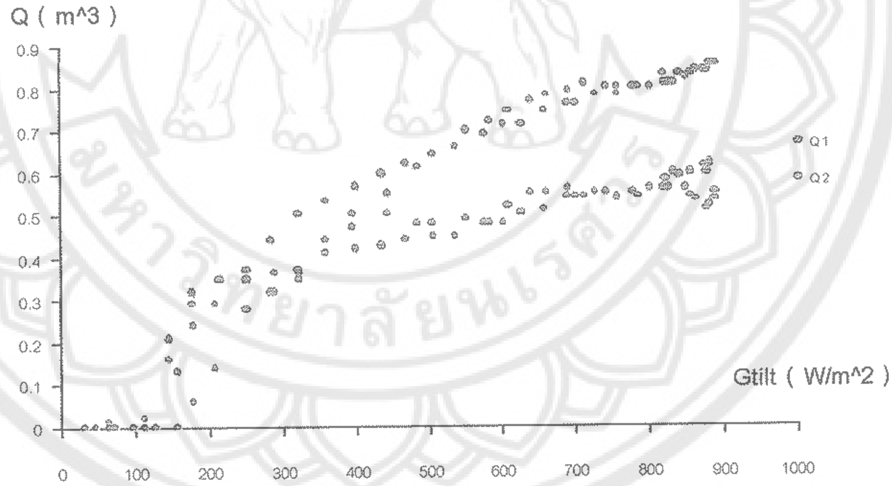


Figure 14 Relation of flow rate and tilt angle radiation on 16 April 1998.

For a normal operation day, pressure and flow rate is effected by tilt angle radiation. When the radiation is higher pressure and flow rate will higher, too. So, the volume of water is upon the radiation.

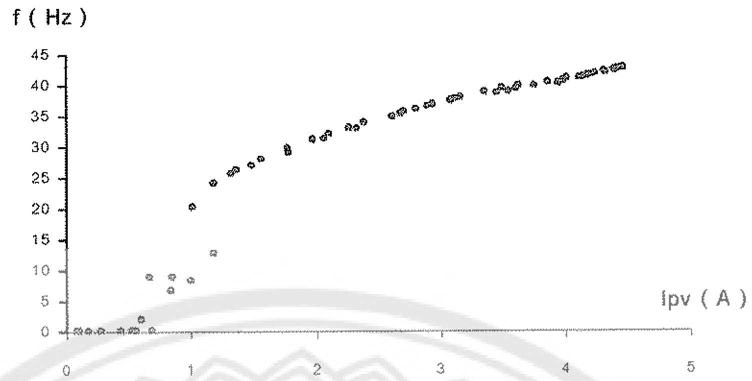


Figure 15 Relation of inverter frequency and PV output current on 16 April 1998.

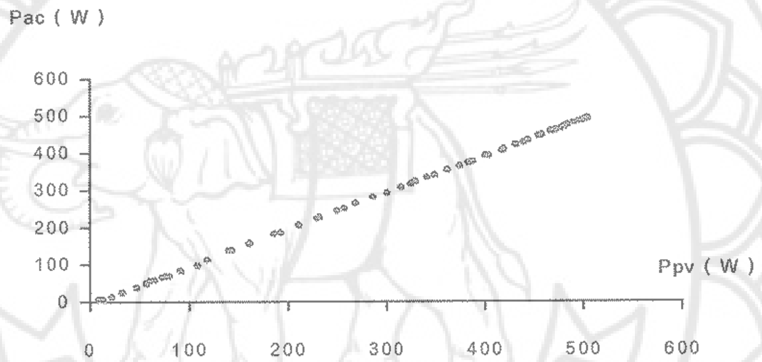


Figure 16 Relation of PV output power and AC power on 16 April 1998.

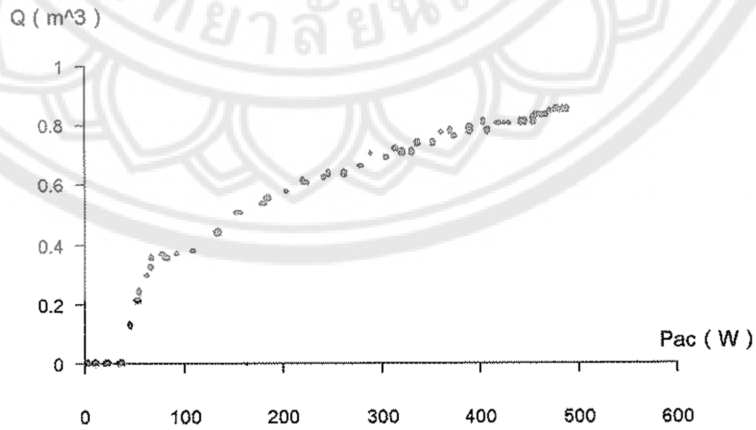


Figure 17 Relation of water volume and AC power on 16 April 1998.

The relation of system can show in these graphs when a normal operation is defined here as a situation, when no limitation of the fluid flow due to closing of valves etc. is observed.

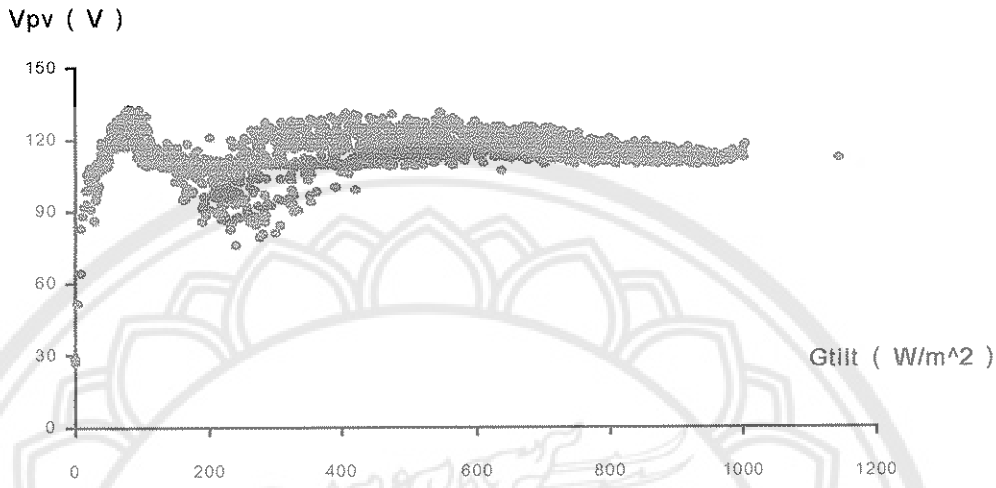


Figure 18 Relation of tilt angle radiation and PV output voltage.

From this figure, the PV output voltage versus inclined tilt angle radiation. The MPP-like operation of PV generator may be identified at tilt angle radiation level more over 400 W/m^2 only.

From below, figure the inverter efficiency versus PV power. The relation of PV power and inverter efficiency is support together that mean when the PV power is high, the inverter efficiency is high too. And, from this graph we found that at the PV output power over 150 W. The inverter efficiency is constant. Nevertheless, the relation is the polynomial form not linearity.

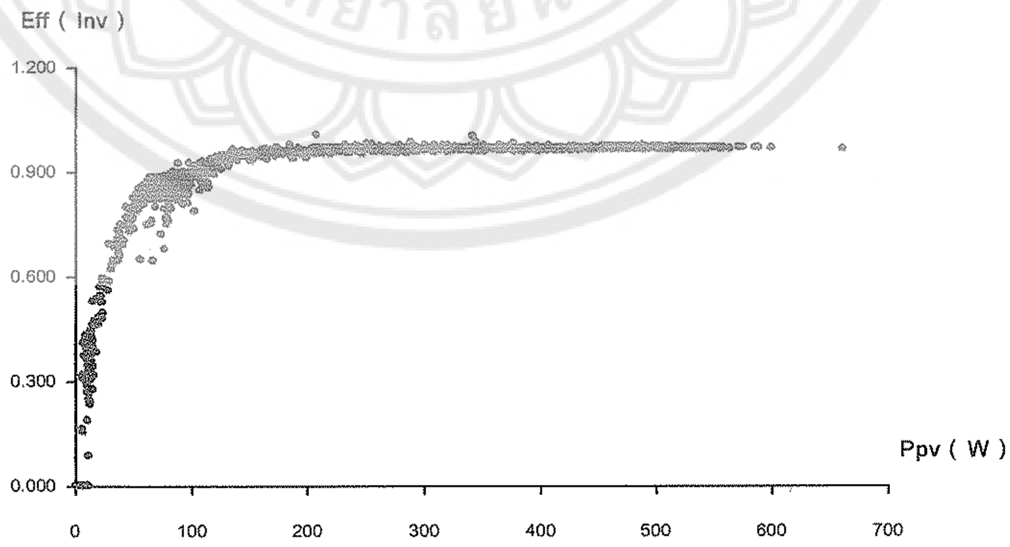


Figure 19 Relation of PV output power and efficiency of inverter.

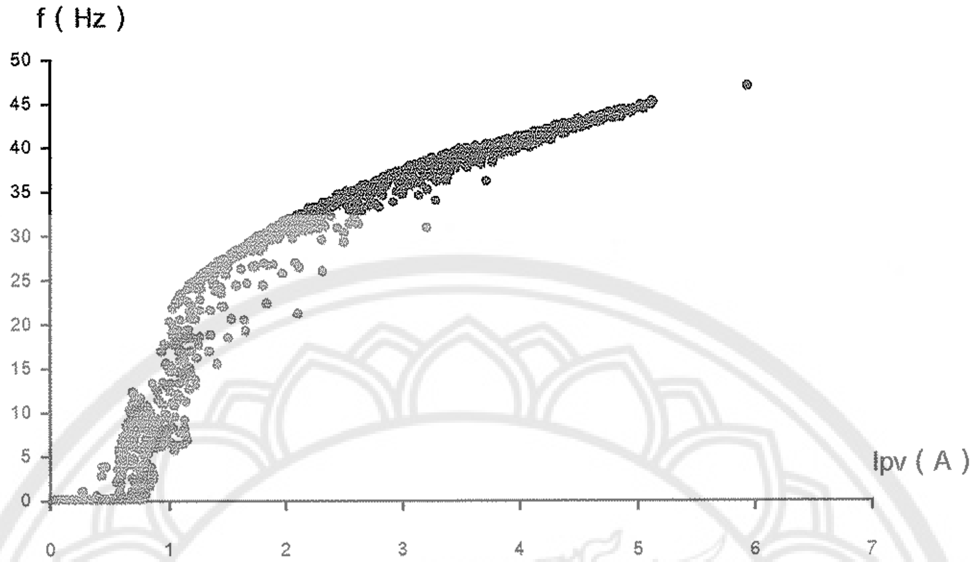


Figure 20 Relation of PV output current and frequency.

The operation frequency of the inverter plotted as a function of the measured DC current. The values of frequency that below 10 Hz may contain high measurement uncertainties.

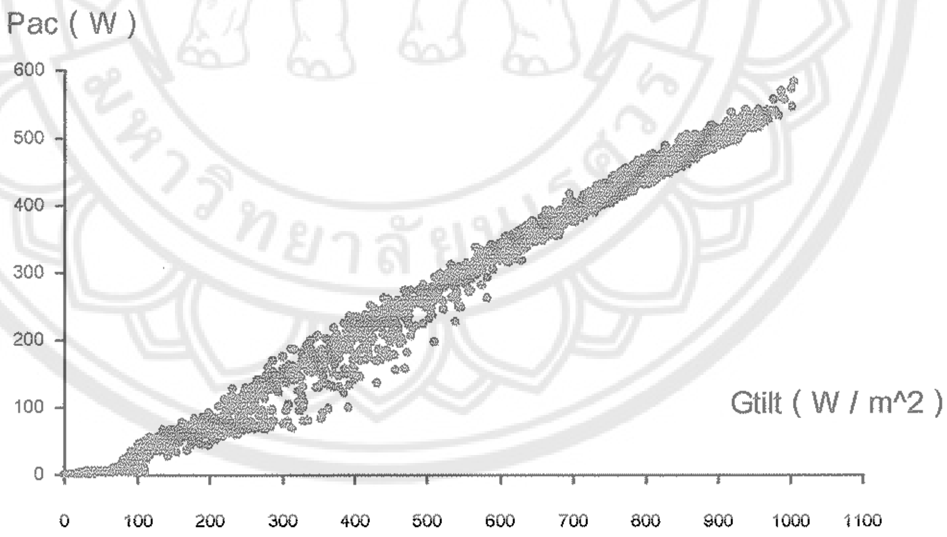


Figure 21 Relation of tilt angle radiation and AC power.

The AC power plotted versus the inclined tilt angle radiation. For half of the day of the month, the time's series of radiation show high fluctuation. The optimal power range is not achieved in this fluctuation periods through the operation inertia of the inverter-motor-pump unit (deviation of power values in the mid radiation range).

Furthermore, at low operation frequencies below 30 Hz, prevailing fixed voltage operation of the inverter causes non-MPP tracking and thus a scatter at radiation level below 400 W/m^2.

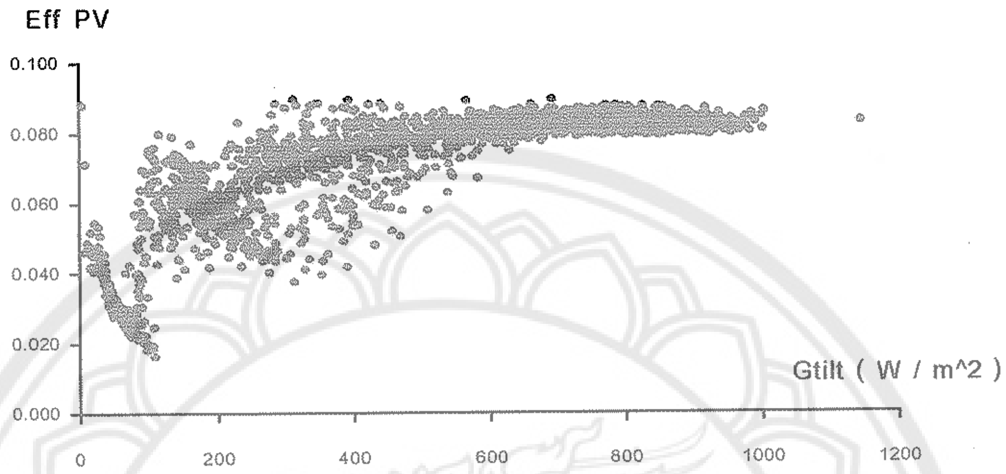


Figure 22 Relation of tilt angle radiation and PV efficiency.

The efficiency of PV system versus inclined tilt angle radiation which the maximum of PV system efficiency exceeds slightly 8 %.

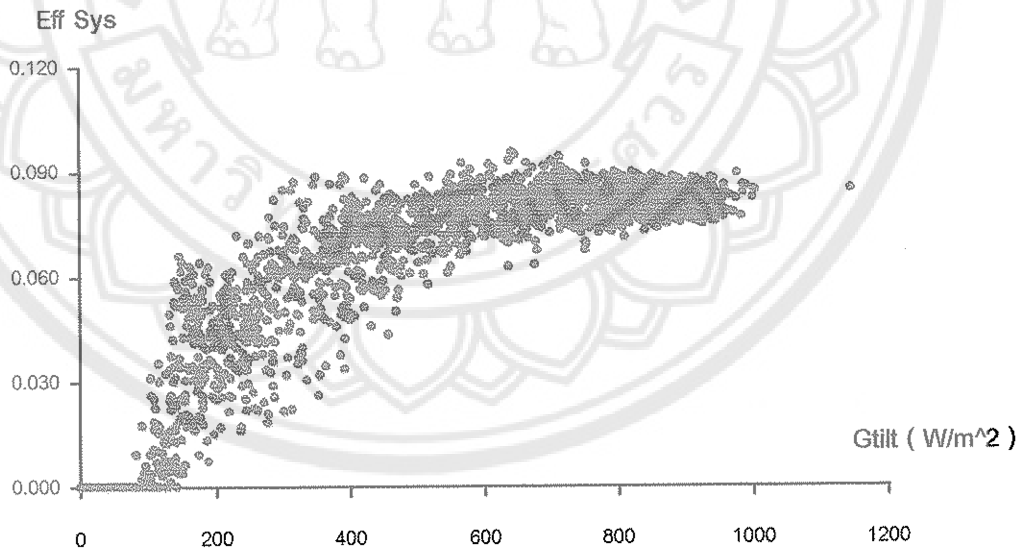


Figure 23 The relation of tilt angle radiation and system efficiency.

The system efficiency can calculate from the relation of output power and input power. When, the output power is the hydraulic fluid power and input power is tilt angle radiation that drops on the PV plane. From this figure, the system efficiency values for this month remain about 8 %.

5.2 Middle term analysis

This report will divide the time range into three parts are:

- short term that will use data only each month
- middle term that will use data about four months or season
  - Winter (November – February)
  - Summer (March – June)
  - Rainy (July – October)

Table 13 The average collected data on each season.

Parameter	Symbol	Winter	Summer	Rainy	Unit
Global radiation	G_T	403.94	488.13	465.02	W/m^2
Tilt angle radiation	G_{Tilt}	460.42	490.33	479.68	W/ m^2
Ambient temperature	T_A	30.24	32.80	30.13	°C
Cell temperature	T_C	43.03	47.46	46.05	°C
Sum global radiation	H	516.90	664.08	628.38	kWh/m^2
Sum tilt angle radiation	H_{Tilt}	589.81	667.36	647.37	kWh/m^2
PV output voltage	V_{PV}	111.93	127.14	126.64	V
PV output current	I_{PV}	1.99	1.36	1.38	A
PV output power	P_{PV}	223.04	172.37	174.83	W
AC power	P_{AC}	217.49	148.26	149.71	W
Water level head	H_W	0.20	0.07	0.19	barr
Pressure 1	P_1	0.17	0.06	0.17	barr
Pressure 2	P_2	0.11	0.05	0.14	barr
Pressure 3	P_3	0.14	0.05	0.15	barr
Flow rate 1	Q_1	0.49	0.31	0.34	m^3/10 min
Flow rate 2	Q_2	0.34	0.22	0.27	m^3/10 min

Table 14 The efficiency of each season.

Parameter	Symbol	Winter	Summer	Rainy
PV efficiency	η_{PV}	0.069	0.050	0.052
Inverter efficiency	η_{INV}	0.974	0.860	0.852
Motor and pump efficiency	η_{MP}	0.570	0.275	0.407
System efficiency	η_{SYS}	0.039	0.012	0.018

5.3 Long term analysis

This term is collected data that started on 3 October 1997 until finished on 30 September 1998. From analysis, we can show the analyzed data and the efficiency like these.

Table 15 The average collected data.

Parameter	Symbol	Amount	Unit
Global radiation	G_T	452.36	W/m^2
Tilt angle radiation	G_{Tilt}	476.81	W/m^2
Ambient temperature	T_a	31.06	°C
Cell temperature	T_C	45.51	°C
Sum global radiation	H	1809.36	kWh/m^2
Sum tilt angle radiation	H_{tilt}	1904.54	kWh/m^2
PV output voltage	V_{PV}	121.90	V
PV output current	I_{PV}	1.58	A
PV output power	P_{PV}	190.08	W
AC power	P_{AC}	171.82	W
Water level head	H_W	0.15	barr
Pressure 1	P_1	0.13	barr
Pressure 2	P_2	0.10	barr
Pressure 3	P_3	0.11	barr
Flow rate 1	Q_1	0.38	m^3/10 min
Flow rate 2	Q_2	0.28	m^3/10 min

Table 16 The efficiency of system.

Parameter	Symbol	Amount
PV efficiency	η_{PV}	0.057
Inverter efficiency	η_{INV}	0.891
Motor and pump efficiency	η_{MP}	0.406
System efficiency	η_{SYS}	0.021

Reference Yield

The reference yield is use for predict the energy yield and Performance Ratio of the system may be defined to compare the electrical exploitation of this PV system to other MPP-tracked PV systems. Energy losses in the motor-pump section and losses in the pipe system will be not considered, as the measured energy at the output of the inverter is used here to determine the performance.

Table 17 Reference yield and performance ratio of system

Parameter	Symbol	Amount	Unit
Reference global radiation	H_{ref}	1809.63	Hour
Reference tilt angle radiation	$H_{ref, tilt}$	1904.53	Hour
Reference global Yield	RY	5.05	Hour
Reference tilt angle Yield	RY_{Tilt}	5.32	Hour
Used energy of PV	$E_{PV, use}$	679.49	kWh
Global performance ratio	PR_T	0.394	-
Tilt angle performance ratio	PR_{Tilt}	0.374	-
Final yield	FY	2.16	-

In addition, we can find the relation of parameters and can compare them of any month all year like these.

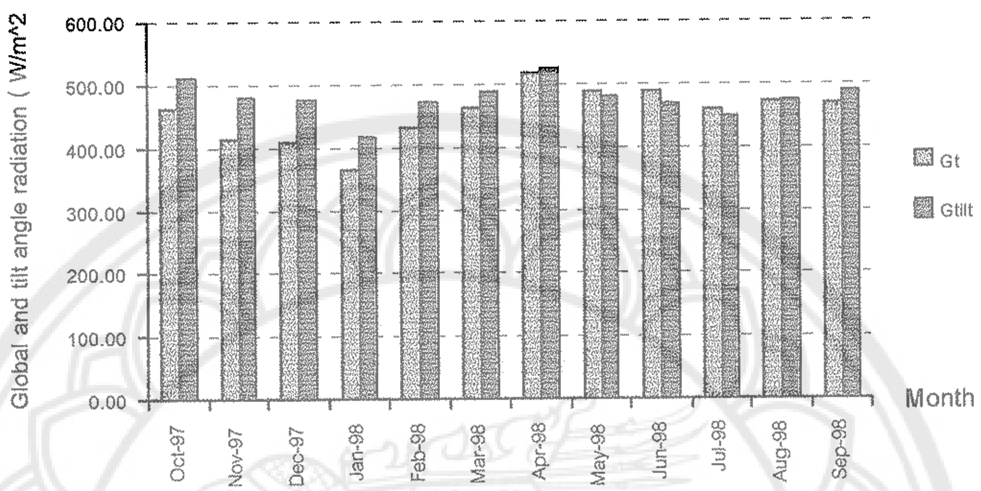


Figure 24 Comparison of the global and tilt angle radiation of each month.

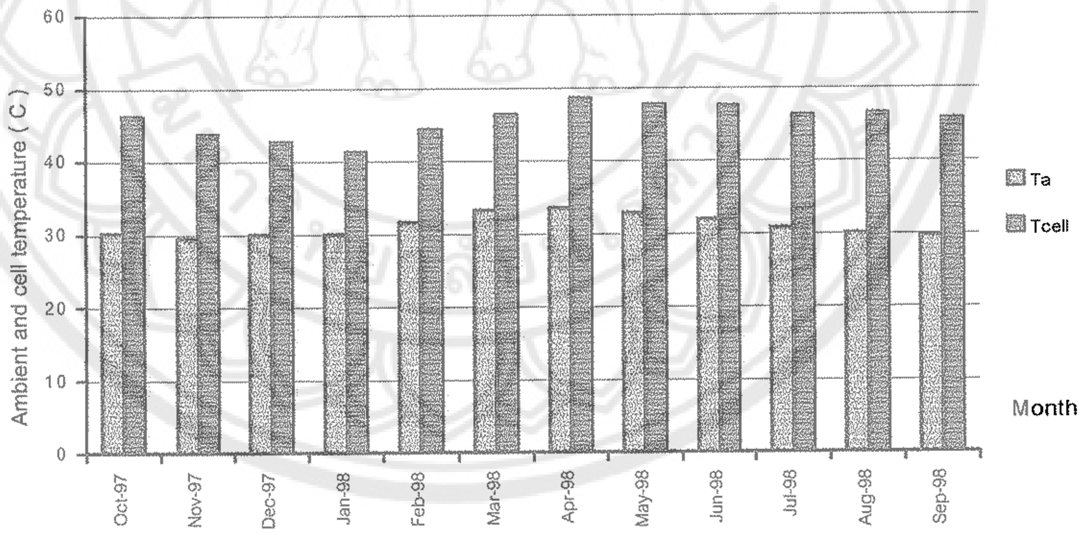


Figure 25 Comparison of the ambient and cell temperature of each month.

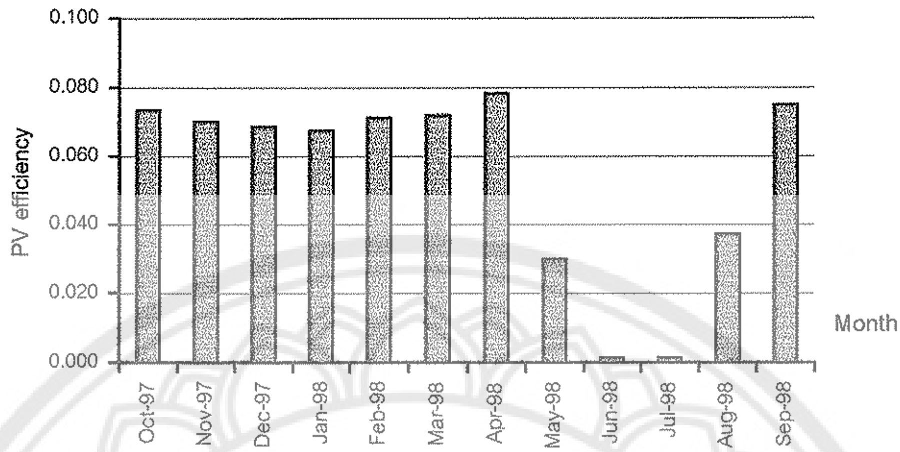


Figure 26 Comparison of the PV efficiency of each month.

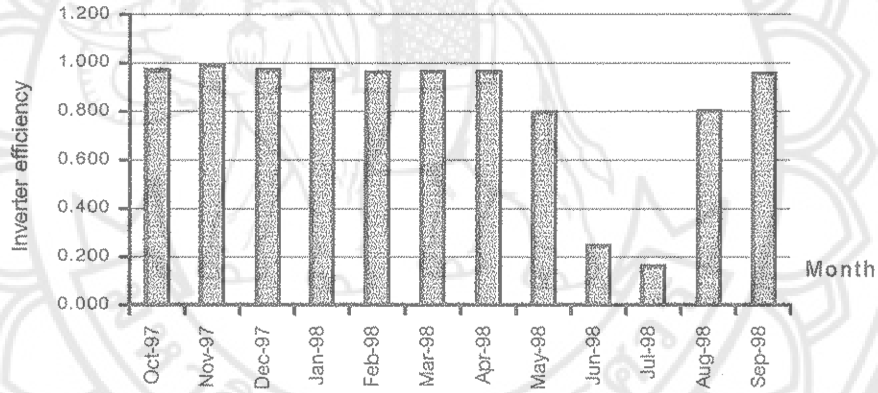


Figure 27 Comparison of the inverter efficiency of each month.

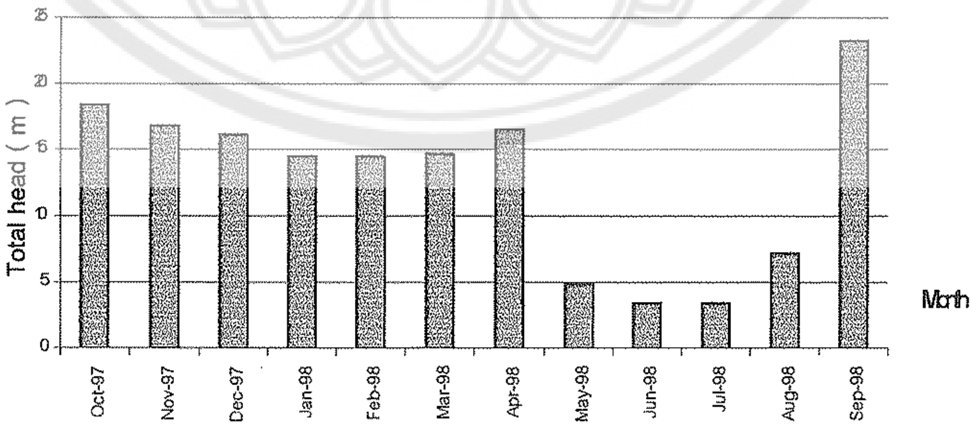


Figure 28 Comparison of the total head of water of each month.

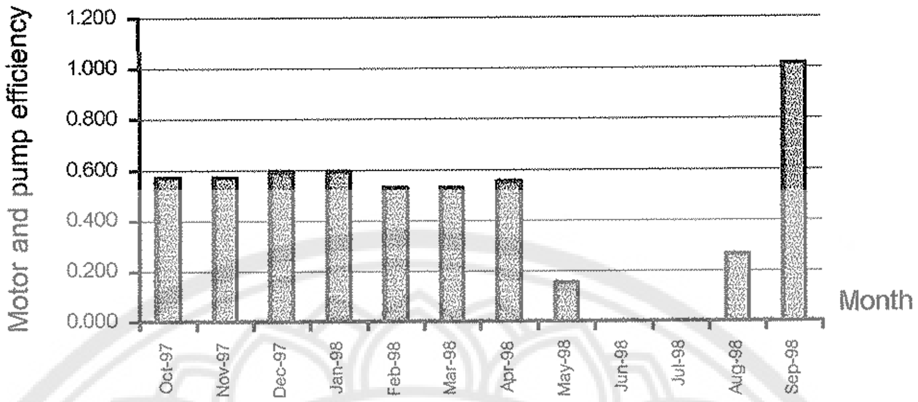


Figure 29 Comparison of the motor and pump efficiency of each month.

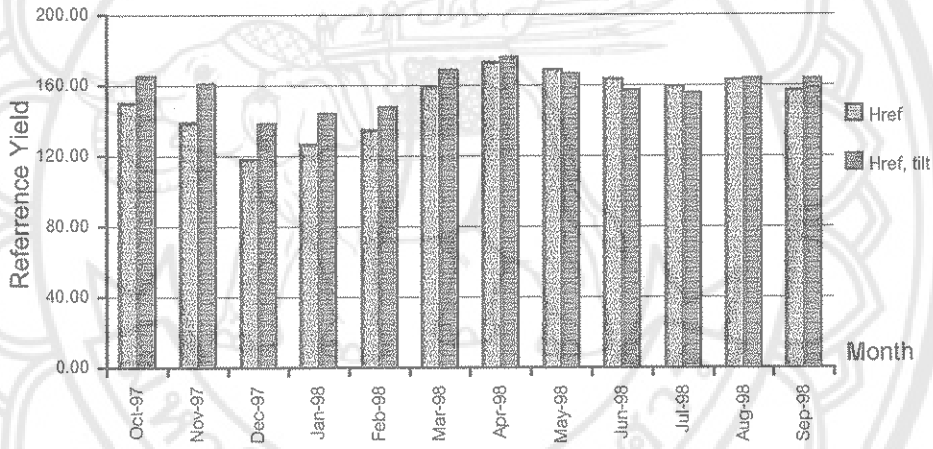


Figure 30 Comparison of the reference yield of each month.

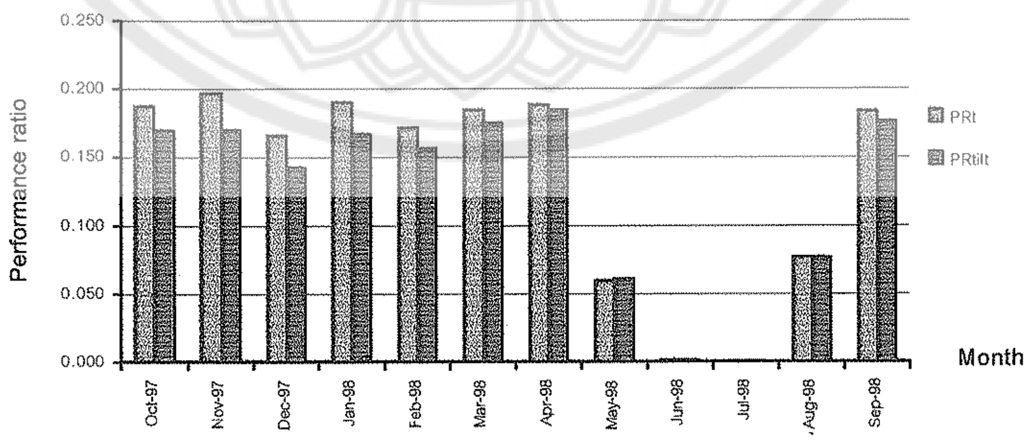


Figure 31 Comparison of the performance ratio of each month.

5.4 System simulation

In this topic it will use data on April that is proper month to simulate data. Because in last term of summer and all rainy, the water decrease until it does not have enough water to pump. It effected for the system can not run. So, April is proper month that will use to simulate the system likes these.

5.4.1 PV simulation

From plot in excel program, we find that the relation of voltage and cell temperature can assume to constant value about 120 V.

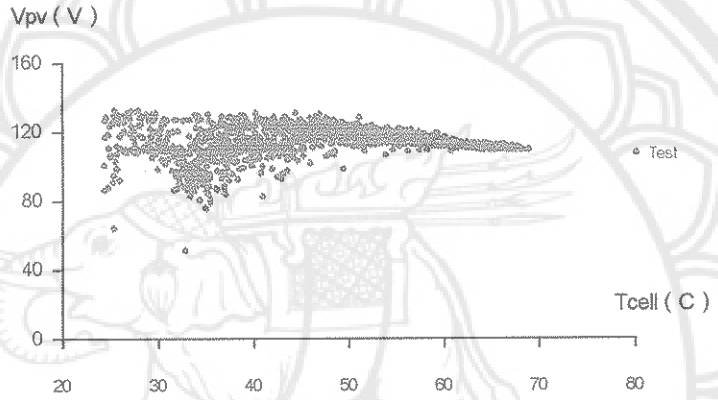


Figure 32 Relation of PV output voltage and cell temperature.

From this system the PV output voltage can find as the constant that is 120 approximately. Because of, in this topic we will assume that the tilt angle radiation is constant at the average value of April 1998.

And in the same way, we will assume that the cell temperature is the constant value at average value. When we plot graph of PV output current and tilt angle radiation relation can find like this.

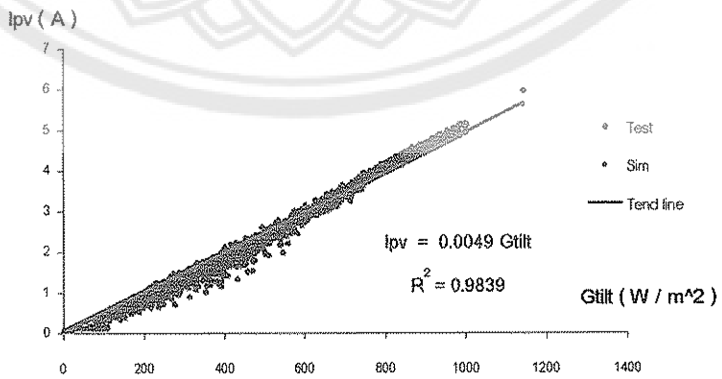


Figure 33 Relation of PV output current.

From this figure we found that the relation of PV output current is related with tilt angle radiation in linear form. It can instead of simulate equation as.

$$I_{PV} = 0.0049\, G_{Tilt} \qquad \text{.........} (5.1)$$

From below graph, we can tell that the PV output voltage is the constant value about 120 V. It can assume that the PV output voltage is not have any effected with the power output from PV system. So, the power output is related with tilt angle radiation that can plot graph like figure 34.

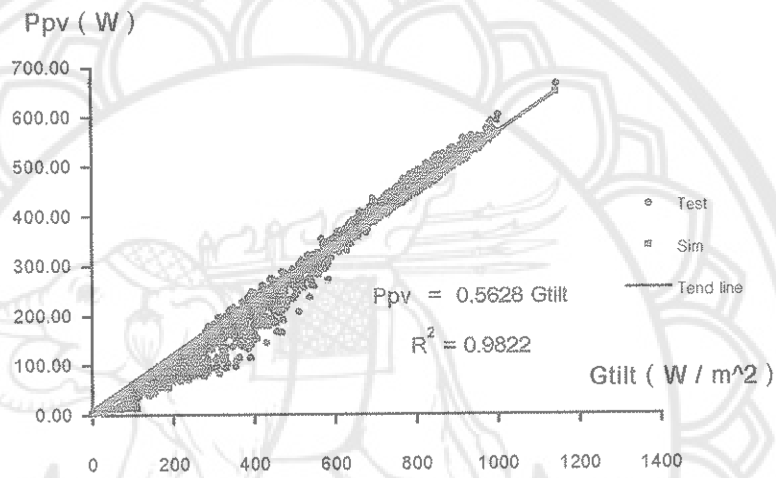


Figure 34 Relation of PV power and tilt angle radiation and PV system simulation.

From this relation, we can write the simulate equation like this.

$$P_{PV} = 0.5628\, G_{Tilt} \qquad \text{......} (5.2)$$

The simulate equation and tend line is represent data in PV system at any tilt angle radiation value. But, in some range-tested data is difference from simulating data that can be cause of these.

1. Assumption the PV output voltage is constant. In the real condition of work, sometime the PV output voltage may have some relate with system.
2. In the PV array there are two big plant that make shading on PV array.
3. The water in pond is not enough to use in sometime that caused system can not run on some months.

5.4.2 Inverter simulation

The function of inverter system can find from relation of AC power and PV output power. The simulated equation of inverter system can find from plot and calculate in excel program that is in linear form like figure 35.

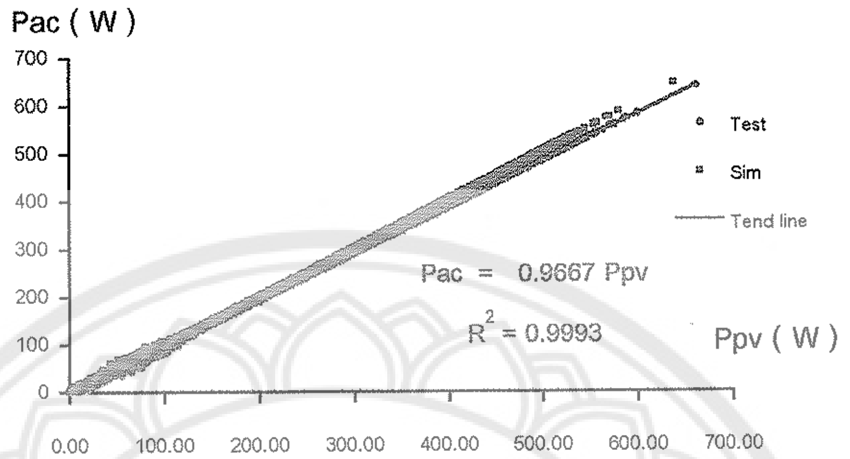


Figure 35 Relation of AC power and PV output power.

From this figure the simulated equation can find in linear form that is.

$$P_{AC} = 0.9667\, P_{PV} \qquad \ldots\ldots\ldots (5.3)$$

5.4.3 Motor and pump simulation

In the same way, the motor and pump system can simulate by use output and input parameter that effected the PV system. The efficiency of motor/pump system is upon the flow rate and AC input power. The simulated equation of motor and pump system can find from plot and calculate in excel program that is in linear form like figure 36.

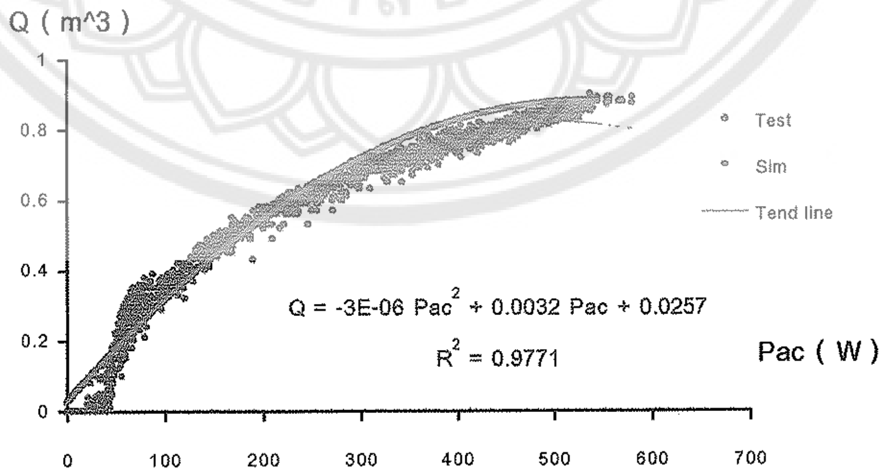


Figure 36 Relation of flow rate and AC power.

From this figure the simulated equation can find in linear form that is.

$$Q = -0.000003 P_{AC}^{2} + 0.0032 P_{AC} + 0.0257 \qquad \text{........ (5.4)}$$

The simulate equation and tend line is represent data in system at any AC power value. But, in many points is difference from simulating data that can be cause of these.

1. The length of pipeline that very long over 1200 meters.
2. In fact of work, people in village near pipeline connect and cut to install their valve to use water in their houses.
3. The water in pond is not enough to use in sometime that caused system can not run on some months.

5.4.4 Pipe simulation

In pipe system there are two sections that combine to the total head. First is the static head that constant value upon the place condition of the system. And, the other is friction loss or head loss in pipes that upon the flow rate in pipes. So, the efficiency of pipe system is upon the flow rate of the system. Total head composes of static head, delivery head, and height of tank when height of tank is constant value. So, we can find the total head from sum of these heads by this formula.

$$H_T = H_S + H_d + H_F + H_t \qquad \text{........(5.5)}$$

From plot graph and simulate in excel program, we found that.

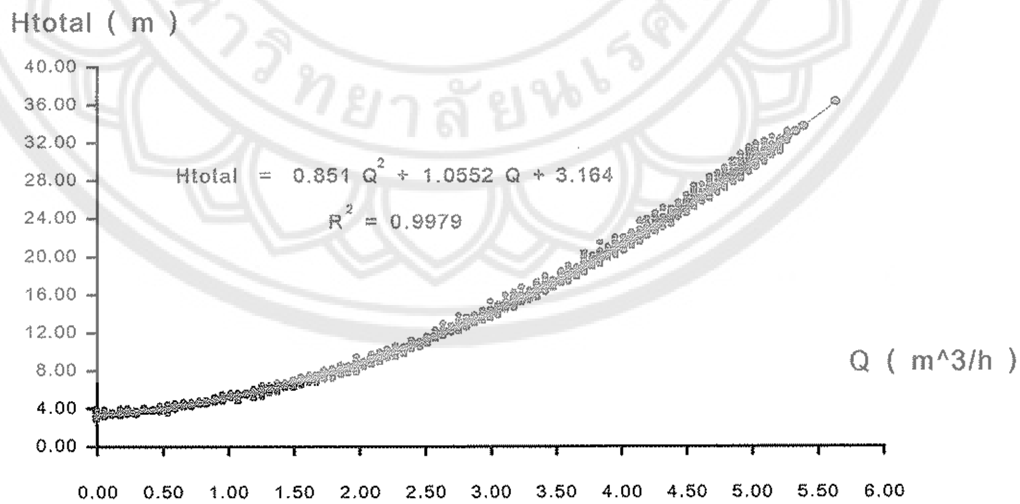


Figure 37 Relation of total head and flow rate and pipeline simulation.

From figure 37, the total head in pipeline is upon the flow rate in polynomial form that can write in simulating equation as.

$$H_T = 0.851Q^2 + 1.0552Q + 3.164 \qquad \text{......... (5.6)}$$

The simulate equation and tend line is represent data in system at any tilt angle radiation value. But, in some range-tested data is difference from simulating data that can be cause of these.

1. The length of pipeline that very long over 1200 meters.
2. In fact of work, people in village near pipeline connect and cut to install their valve to use water in their houses.
3. The water in pond is not enough to use in sometime that caused system can not run on some months.

5.4.5 System simulation

For whole system, the general object is water volume per day that was used in people life in the rural area. In addition, the main output that wanted in the pumping system is water volume or flow rate that was upon the tilt radiation that is the primary input power. This system can plot graph and find the simulate equation from excel program that was showed on figure 38.

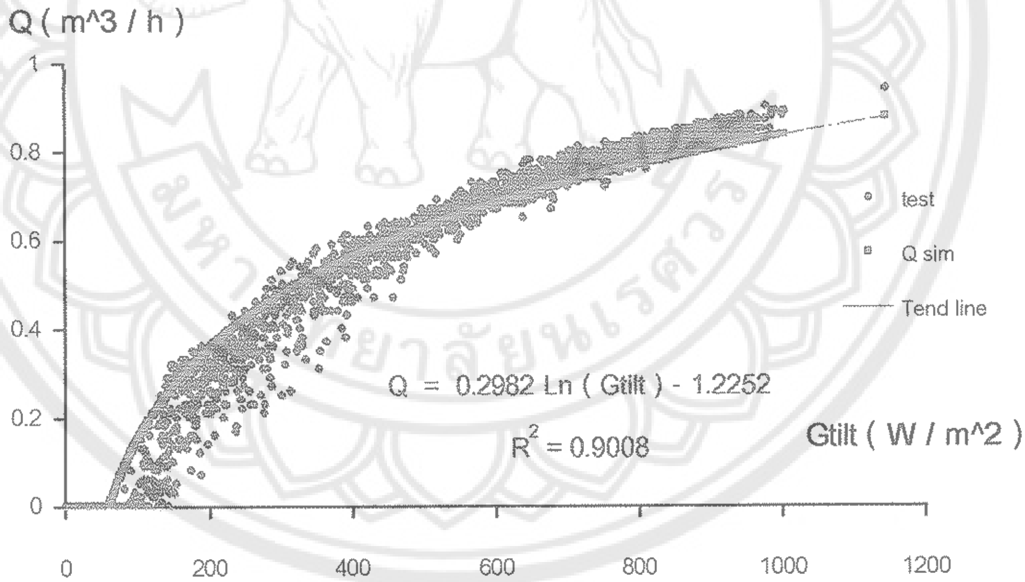


Figure 38 Relation of flow rate and tilt angle radiation and system equation.

From this figure, the simulate equation is in logalism like this.

$$Q = 0.2982\,Ln(G_{Tilt}) - 1.2252 \qquad \text{........... (5.7)}$$

The simulate equation and tend line is represent data in system at any tilt angle radiation value. But, in some range-tested data is difference from simulating data that can be cause of these.

1. There are energy and power loss in some part of system as inverter and PV
2. The length of pipeline that very long over 1200 meters.
3. In fact of work, people in village near pipeline connect and cut to install their valve to use water in their houses.
4. In the PV array there are two big plant that make shading on PV array.
5. The water in pond is not enough to use in sometime that caused system can not run on some months.