APPENDIX

APPENDIX A

COLLECTED DATA ON 16 APRIL 1998 AND AVERAGED DATA

Table 18 Collected data table of 16 April 1998 from 7.00 to 18.00 with 10 of mean time.

Date	G_{Tilt}	V_{PV}	I_{PV}	P_{PV}	P_{AC}	H_W	H_S	P_1	H_d	Q_1	Q	H_F	H_T	η_{PV}	η_{INV}	η_{MP}	η_{SYS}
700	71	127.8	0.1	12.78	4	0.081	0.826	-0.073	-0.744	0	0.00000	0.00	3.08	0.026	0.31	0.00	0.000
710	99	127.2	0.18	22.90	11	0.081	0.826	-0.072	-0.734	0	0.00000	0.00	3.09	0.033	0.48	0.00	0.000
720	127	109.5	0.44	48.18	37	0.081	0.826	-0.035	-0.357	0	0.00000	0.00	3.47	0.054	0.77	0.00	0.000
730	157	109.2	0.53	57.88	47	0.081	0.826	0.014	0.143	0.13	0.00022	0.75	4.72	0.053	0.81	0.21	0.009
740	180	109.6	0.6	65.76	56	0.081	0.826	0.045	0.459	0.24	0.00040	2.34	6.63	0.052	0.85	0.46	0.021
750	210	110.4	0.67	73.97	64	0.081	0.826	0.054	0.550	0.29	0.00048	3.32	7.70	0.050	0.87	0.57	0.025
800	251	94.6	0.85	80.41	68	0.081	0.826	0.038	0.387	0.35	0.00058	4.71	8.92	0.046	0.85	0.75	0.029
810	289	93.3	1	93.30	80	0.081	0.826	0.049	0.499	0.36	0.00060	4.96	9.28	0.046	0.86	0.68	0.027
820	324	92.7	1.18	109.39	95	0.081	0.826	0.055	0.561	0.36	0.00060	4.96	9.35	0.048	0.87	0.58	0.024
830	359	109.2	1.32	144.14	136	0.081	0.826	0.087	0.887	0.44	0.00073	7.19	11.90	0.057	0.94	0.63	0.034
840	396	109.2	1.48	161.62	154	0.081	0.826	0.091	0.928	0.5	0.00083	9.11	13.86	0.058	0.95	0.74	0.041
850	445	109	1.77	192.93	184	0.081	0.826	0.089	0.907	0.55	0.00092	10.86	15.60	0.062	0.95	0.76	0.045
900	485	111.9	2.06	230.51	221	0.081	0.826	0.101	1.030	0.61	0.00102	13.16	18.01	0.068	0.96	0.81	0.053
910	506	111.1	2.32	257.75	248	0.081	0.826	0.133	1.356	0.64	0.00107	14.38	19.56	0.073	0.96	0.83	0.058
920	551	115.4	2.61	301.19	290	0.081	0.826	0.109	1.111	0.7	0.00117	16.97	21.91	0.078	0.96	0.86	0.065
930	583	120.8	2.7	326.16	314	0.081	0.826	0.127	1.295	0.72	0.00120	17.88	23.00	0.080	0.96	0.86	0.066
940	609	119.4	2.93	349.84	338	0.081	0.826	0.137	1.397	0.74	0.00123	18.81	24.03	0.082	0.97	0.86	0.068
950	639	120.5	3.11	374.76	362	0.081	0.826	0.145	1.478	0.77	0.00128	20.24	25.55	0.084	0.97	0.89	0.072
1000	664	122	3.15	384.30	371	0.081	0.826	0.13	1.325	0.78	0.00130	20.73	25.88	0.083	0.97	0.89	0.071
1010	692	120.7	3.35	404.35	390	0.081	0.826	0.157	1.600	0.79	0.00132	21.23	26.65	0.084	0.96	0.88	0.071
1020	714	119.9	3.49	418.45	404	0.081	0.826	0.172	1.753	0.81	0.00135	22.23	27.81	0.084	0.97	0.91	0.074
1030	742	119.5	3.62	432.59	418	0.081	0.826	0.168	1.713	0.8	0.00133	21.73	27.27	0.083	0.97	0.85	0.069
1040	759	114	3.86	440.04	426	0.081	0.826	0.159	1.621	0.8	0.00133	21.73	27.17	0.083	0.97	0.83	0.067
1050	785	113.9	4.01	456.74	443	0.081	0.826	0.164	1.672	0.8	0.00133	21.73	27.22	0.083	0.97	0.80	0.065
1100	820	113.3	4.18	473.59	458	0.081	0.826	0.171	1.743	0.83	0.00138	23.26	28.83	0.083	0.97	0.85	0.068
1110	826	112.1	4.19	469.70	455	0.081	0.826	0.17	1.733	0.81	0.00135	22.23	27.79	0.081	0.97	0.81	0.064
Unit	W/m^2	V	A	W	W	barr	m	barr	m	m^3	m^3/s	m	m	-	-	-	-

Date	G_{Tilt}	V_{PV}	I_{PV}	P_{PV}	P_{AC}	H_W	H_S	P_1	H_d	Q_1	Q	H_F	H_T	η_{PV}	η_{INV}	η_{MP}	η_{SYS}
1130	857	111.6	4.32	482.11	467	0.081	0.826	0.155	1.580	0.83	0.00138	23.26	28.66	0.080	0.97	0.83	0.065
1140	875	113	4.42	499.46	484	0.081	0.826	0.162	1.651	0.84	0.00140	23.78	29.26	0.082	0.97	0.83	0.066
1150	884	113.3	4.45	504.19	488	0.08	0.815	0.163	1.662	0.85	0.00142	24.31	29.78	0.082	0.97	0.85	0.067
1200	883	112.3	4.46	500.86	485	0.08	0.815	0.162	1.651	0.85	0.00142	24.31	29.77	0.081	0.97	0.85	0.067
1210	876	113	4.42	499.46	484	0.08	0.815	0.164	1.672	0.84	0.00140	23.78	29.27	0.082	0.97	0.83	0.066
1220	888	113.3	4.46	505.32	490	0.08	0.815	0.14	1.427	0.85	0.00142	24.31	29.55	0.081	0.97	0.84	0.066
1230	888	113	4.44	501.72	486	0.081	0.826	0.138	1.407	0.85	0.00142	24.31	29.54	0.081	0.97	0.84	0.066
1240	882	111.7	4.4	491.48	478	0.08	0.815	0.134	1.366	0.85	0.00142	24.31	29.49	0.080	0.97	0.86	0.066
1250	876	113.1	4.39	496.51	482	0.08	0.815	0.131	1.335	0.84	0.00140	23.78	28.93	0.081	0.97	0.82	0.065
1300	864	112.5	4.31	484.88	471	0.08	0.815	0.134	1.366	0.84	0.00140	23.78	28.96	0.080	0.97	0.84	0.066
1310	857	112.4	4.21	473.20	459	0.08	0.815	0.135	1.376	0.83	0.00138	23.26	28.45	0.079	0.97	0.84	0.064
1320	849	112	4.18	468.16	455	0.08	0.815	0.146	1.488	0.82	0.00137	22.74	28.05	0.079	0.97	0.83	0.063
1330	833	110.8	4.14	458.71	446	0.08	0.815	0.161	1.641	0.81	0.00135	22.23	27.69	0.079	0.97	0.82	0.063
1340	822	110.9	4.11	455.80	443	0.08	0.815	0.151	1.539	0.81	0.00135	22.23	27.59	0.079	0.97	0.82	0.064
1350	802	111.6	3.98	444.17	431	0.08	0.815	0.151	1.539	0.8	0.00133	21.73	27.08	0.079	0.97	0.82	0.063
1400	779	109.5	3.94	431.43	419	0.08	0.815	0.139	1.417	0.8	0.00133	21.73	26.96	0.079	0.97	0.84	0.065
1410	759	112	3.75	420.00	407	0.08	0.815	0.135	1.376	0.78	0.00130	20.73	25.92	0.079	0.97	0.81	0.062
1420	730	111.4	3.6	401.04	389	0.08	0.815	0.137	1.397	0.78	0.00130	20.73	25.94	0.079	0.97	0.85	0.065
1430	702	109.4	3.54	387.28	374	0.08	0.815	0.131	1.335	0.76	0.00127	19.76	24.91	0.079	0.97	0.83	0.063
1440	690	112.5	3.45	388.13	375	0.08	0.815	0.13	1.325	0.76	0.00127	19.76	24.90	0.080	0.97	0.83	0.064
1450	658	117.8	3.08	362.82	352	0.08	0.815	0.119	1.213	0.74	0.00123	18.81	23.84	0.079	0.97	0.82	0.063
1500	626	118.3	2.89	341.89	331	0.08	0.815	0.11	1.121	0.71	0.00118	17.42	22.36	0.078	0.97	0.78	0.059
1510	604	117.8	2.8	329.84	320	0.08	0.815	0.099	1.009	0.71	0.00118	17.42	22.25	0.078	0.97	0.81	0.061
1520	576	117.8	2.68	315.70	306	0.08	0.815	0.096	0.979	0.69	0.00115	16.53	21.32	0.078	0.97	0.79	0.060
1530	538	120.5	2.38	286.79	279	0.08	0.815	0.085	0.866	0.66	0.00110	15.22	19.90	0.076	0.97	0.77	0.057
1540	507	119.3	2.26	269.62	262	0.08	0.815	0.077	0.785	0.64	0.00107	14.38	18.98	0.076	0.97	0.76	0.056
1550	469	119.2	2.1	250.32	242	0.08	0.815	0.058	0.591	0.62	0.00103	13.56	17.97	0.076	0.97	0.75	0.056
Unit	W/m^2	V	A	W	W	barr	m	barr	m	m^3	m^3/s	m	m	-	-	-	-

Date	G_{Tilt}	V_{PV}	I_{PV}	P_{PV}	P_{AC}	H_W	H_S	P_1	H_d	Q_1	Q	H_F	H_T	η_{PV}	η_{INV}	η_{MP}	η_{SYS}
1600	435	118	1.97	232.46	225	0.08	0.815	0.053	0.540	0.6	0.00100	12.76	17.12	**0.076**	**0.97**	**0.75**	**0.055**
1610	400	119.4	1.77	211.34	204	0.08	0.815	0.054	0.550	0.57	0.00095	11.61	15.97	**0.076**	**0.97**	**0.73**	**0.053**
1620	359	119.6	1.56	186.58	180	0.08	0.815	0.044	0.449	0.53	0.00088	10.14	14.41	**0.074**	**0.96**	**0.69**	**0.050**
1630	321	119.6	1.36	162.66	156	0.08	0.815	0.046	0.469	0.5	0.00083	9.11	13.39	**0.072**	**0.96**	**0.70**	**0.049**
1640	284	119.6	1.18	141.13	134	0.08	0.815	0.035	0.357	0.44	0.00073	7.19	11.36	**0.071**	**0.95**	**0.61**	**0.041**
1650	250	117.8	1.01	118.98	110	0.08	0.815	0.01	0.102	0.37	0.00062	5.22	9.13	**0.068**	**0.92**	**0.50**	**0.032**
1700	215	109.8	0.84	92.23	82	0.08	0.815	-0.003	-0.031	0.35	0.00058	4.71	8.49	**0.061**	**0.89**	**0.59**	**0.032**
1710	178	111.2	0.69	76.73	67	0.08	0.815	-0.018	-0.183	0.32	0.00053	3.99	7.62	**0.062**	**0.87**	**0.60**	**0.032**
1720	145	110.2	0.56	61.71	54	0.08	0.815	-0.03	-0.306	0.21	0.00035	1.83	5.34	**0.061**	**0.88**	**0.34**	**0.018**
1730	113	119.8	0.28	33.54	23	0.08	0.815	-0.053	-0.540	0	0.00000	0.00	3.28	**0.042**	**0.69**	**0.00**	**0.000**
1740	65	121.7	0.11	13.39	5	0.08	0.815	-0.055	-0.561	0	0.00000	0.00	3.25	**0.029**	**0.37**	**0.00**	**0.000**
1750	47	115.8	0.1	11.58	5	0.08	0.815	-0.056	-0.571	0	0.00000	0.00	3.24	**0.035**	**0.43**	**0.00**	**0.000**
1800	33	107.9	0.09	9.71	4	0.08	0.815	-0.065	-0.663	0	0.00000	0.00	3.15	**0.042**	**0.41**	**0.00**	**0.000**
Sum	36542	7629.6	172.62	19665.2	18891	5.39	54.9439	6.048	61.6514	39.7	0.066167	982.458	1300.05	-	-	-	-
Avg	545.40	113.87	2.58	293.51	281.96	0.08	0.82	0.09	0.92	0.59	0.000988	14.664	19.404	0.070	0.902	0.685	0.050
Unit	**W/m^2**	**V**	**A**	W	W	barr	m	barr	m	m^3	m^3/s	m	m	-	-	-	-

Table 19 The average collected data table in monthly of PV pumping at Nong Sanuan village

MONTH	G_T	G_{Tilt}	T_A	T_{cell}	V_{PV}	I_{PV}	P_{AC}	H_W	P_1	P_2	P_3	f	Q_1	Q_2	H	H_{Tilt}
Oct-97	461.10	510.26	30.15	46.14	112.98	2.32	254.40	0.255	0.416	0.329	0.412	24.71	0.483	0.381	149.32	165.24
Nov-97	413.58	478.41	29.42	43.75	110.47	2.12	232.00	0.247	0.275	0.118	0.214	23.03	0.482	0.339	138.55	160.27
Dec-97	406.91	475.95	29.93	42.72	111.70	2.04	221.81	0.216	0.190	0.141	0.174	22.21	0.496	0.373	118.14	138.18
Jan-98	364.41	415.41	29.96	41.33	112.48	1.74	190.84	0.182	0.130	0.100	0.112	20.70	0.476	0.353	126.15	143.80
Feb-98	430.85	471.93	31.64	44.31	113.06	2.07	225.31	0.148	0.073	0.066	0.066	22.82	0.503	0.312	134.06	147.56
Mar-98	462.41	487.59	33.21	46.24	114.44	2.13	235.66	0.109	0.075	0.066	0.065	24.86	0.519	0.351	159.45	168.30
Apr-98	515.35	524.77	33.47	48.53	113.80	2.52	276.10	0.082	0.120	0.114	0.105	27.95	0.566	0.406	172.64	175.80
May-98	487.41	479.64	32.70	47.61	134.54	0.75	80.22	0.051	0.027	0.022	0.022	8.00	0.154	0.104	168.72	166.04
Jun-98	487.38	469.32	31.84	47.45	145.77	0.03	1.08	0.043	0.000	-0.004	-0.003	0.00	0.000	0.000	163.27	157.22
Jul-98	460.32	448.35	30.72	46.09	146.36	0.03	0.69	0.034	0.004	0.000	0.000	0.00	0.000	0.000	159.35	155.20
Aug-98	470.71	473.22	30.04	46.32	134.04	0.92	99.49	0.154	0.048	0.044	0.002	9.63	0.226	0.201	162.95	163.81
Sep-98	467.95	486.91	29.61	45.64	113.19	2.25	244.28	0.317	0.208	0.201	0.202	23.59	0.653	0..493	156.76	163.12
AVG	452.36	476.81	31.06	45.51	121.90	1.58	171.82	0.15	0.13	0.10	0.11	17.29	0.38	0.26	150.78	158.71
Unit	W/m^2	W/m^2	°C	°C	V	A	W	barr	barr	barr	barr	Hz	m^3	m^3	kWh/m^2	kWh/m^2

Note :

Almost data in this table is average data per day of any month that calculate from collected data of each month.

Except sum of global and tilt angle radiation that is sum per any month in kWh m^{-2}/month

Table 20 Sum collected data table in season and yearly of PV pumping at Nong Sanuan village

MONTH	G_T	G_{Tilt}	T_A	T_{cell}	V_{PV}	I_{PV}	P_{AC}	H_W	P_1	P_2	P_3	f	Q_1	Q_2	H	H_{Tilt}
Winter	1615.75	1841.70	120.94	172.11	447.71	7.97	869.96	0.79	0.67	0.43	0.57	88.75	1.96	1.38	516.90	589.81
Summer	1952.54	1961.32	131.21	189.83	508.56	5.42	593.06	0.29	0.22	0.20	0.19	60.81	1.24	0.86	664.08	667.36
Rainy	1860.08	1918.74	120.52	184.20	506.57	5.52	598.85	0.76	0.68	0.57	0.62	57.93	1.36	0.58	628.38	647.37
Yeary	5428.37	5721.75	372.68	546.14	1462.84	18.92	2061.87	1.84	1.57	1.20	1.37	207.49	4.56	2.82	1809.36	1904.54
Unit	W/m^2	W/m^2	°C	°C	V	A	W	barr	barr	barr	barr	Hz	m^3	m^3	kWh/m^2	kWh/m^2

Note :

All data in this table that sum from collected of any month.

Except sum of global and tilt angle radiation that is sum per any month in kWh m^{-2}/month

APPENDIX B

COLLECTED AND RELATIVE GRAPH

APPENDIX B

AVERAGE DATA ON EACH MONTH

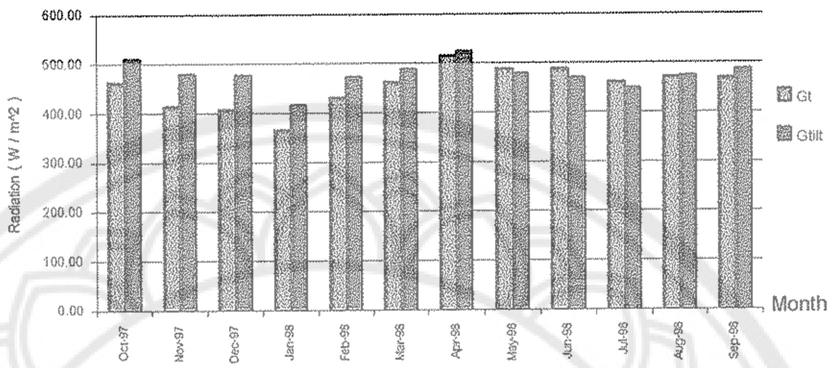

Figure 39 Average global and tilt angle radiation on each month.

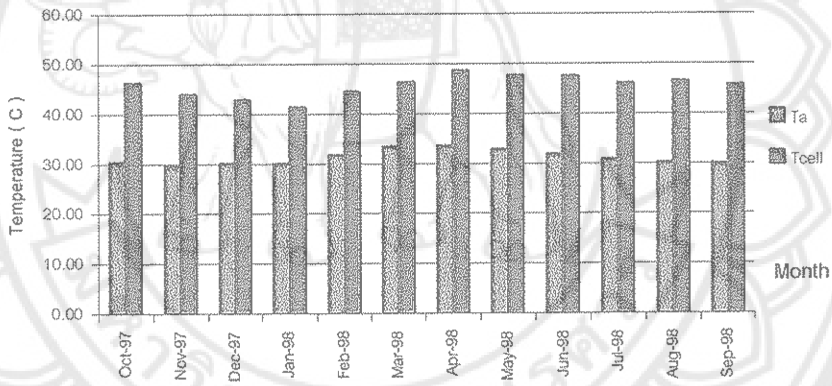

Figure 40 Average ambient and cell temperature on each month.

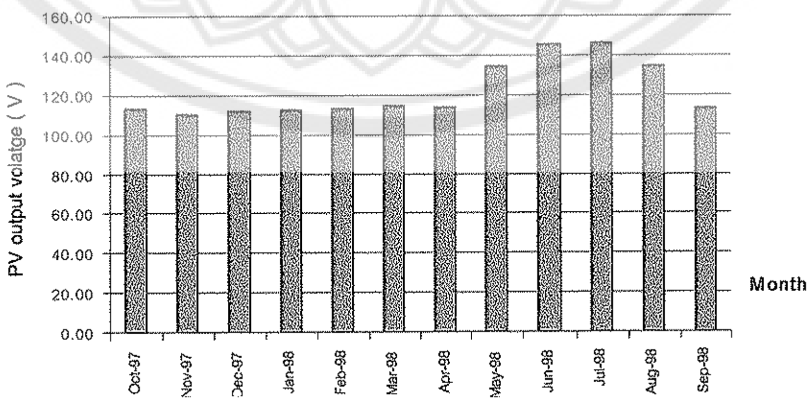

Figure 41 Average PV output voltage of each month.

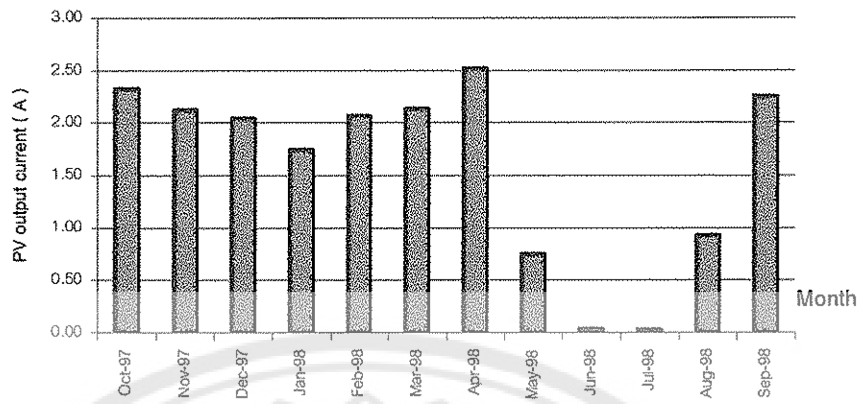

Figure 42 Average PV output current on each month.

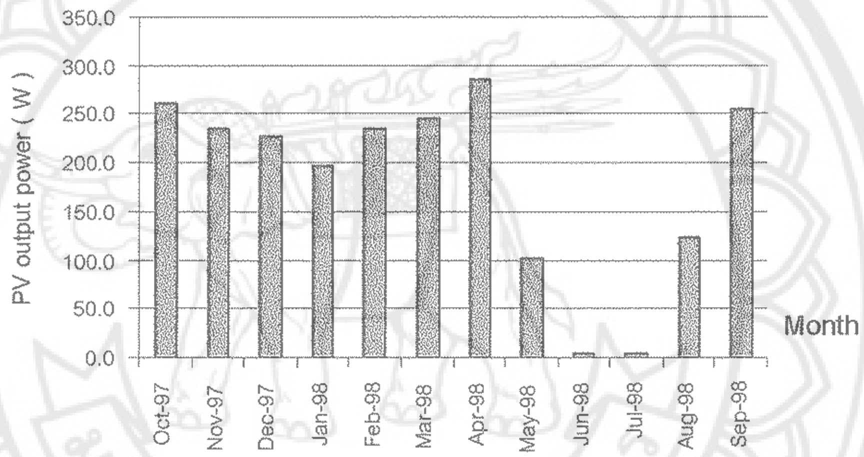

Figure 43 Average PV output power of each month.

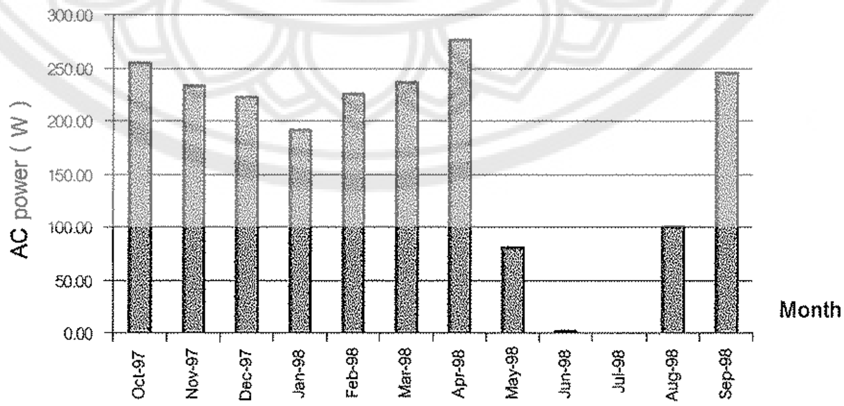

Figure 44 Average AC power of each month.

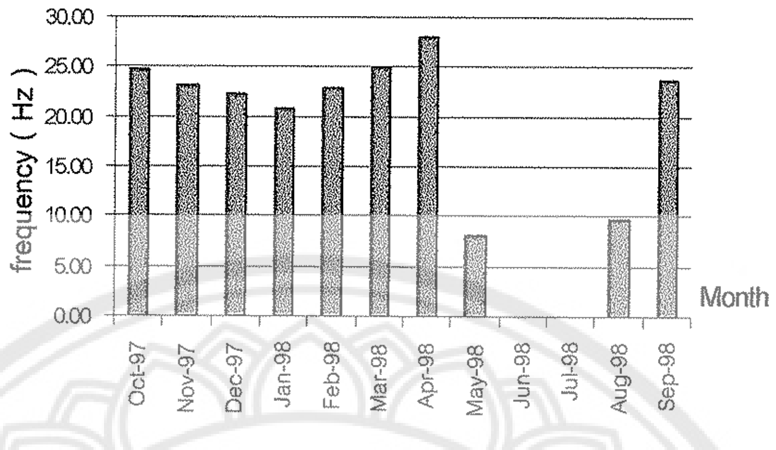

Figure 45 Average frequency of each month.

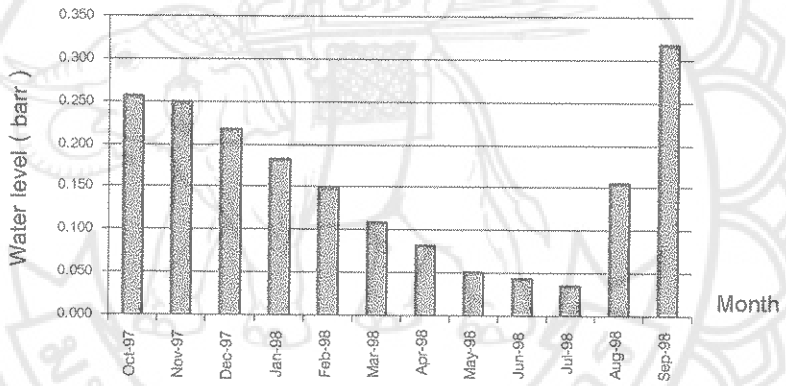

Figure 46 Average water level of each month.

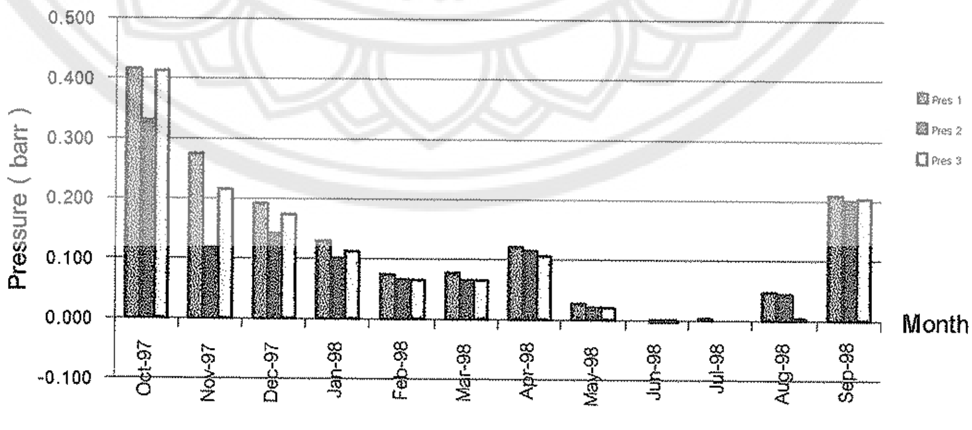

Figure 47 Average pressure of each month.

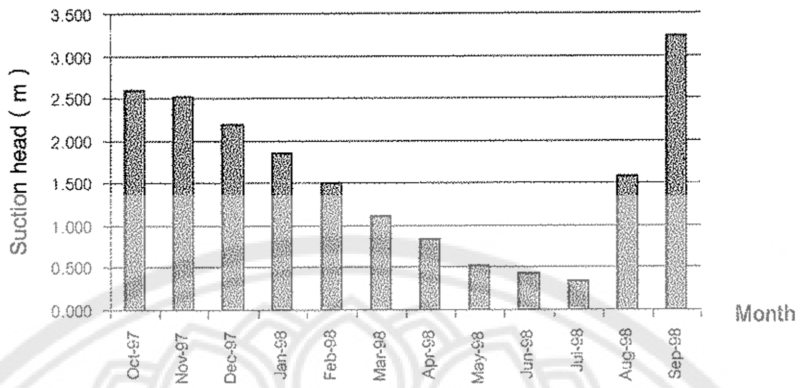

Figure 48 Average suction head of each month.

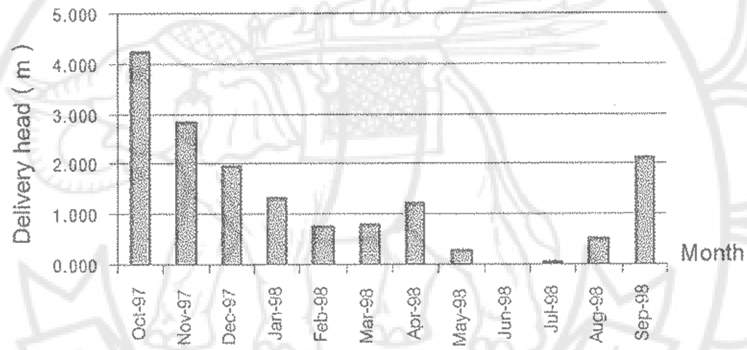

Figure 49 Average delivery head of each month.

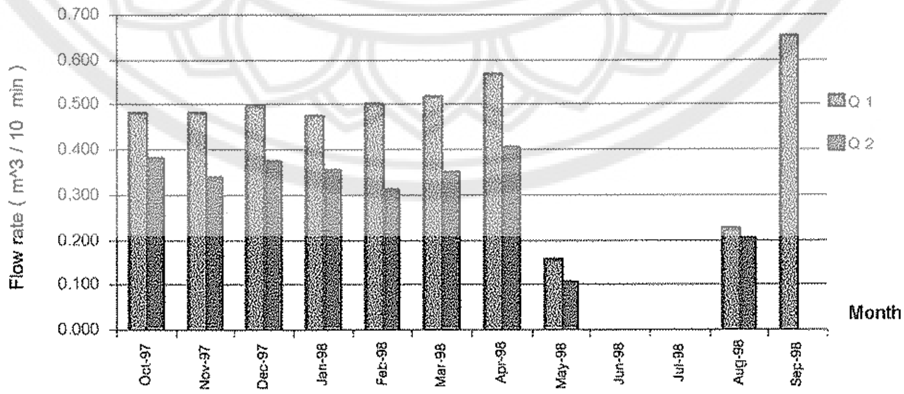

Figure 50 Average flow rate of each month.

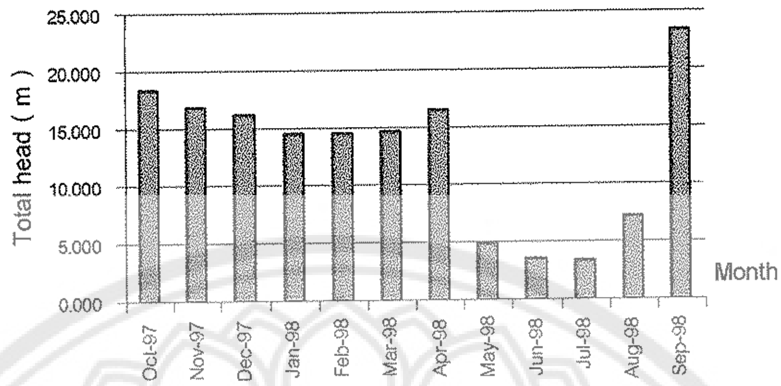

Figure 51 Average total head of each month.

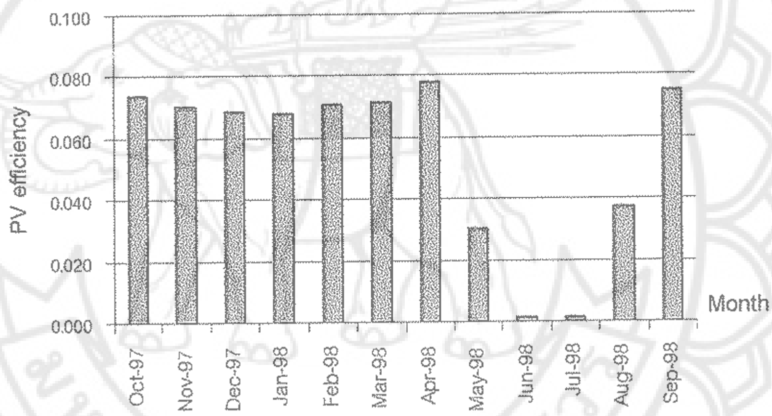

Figure 52 Average PV system efficiency of each month.

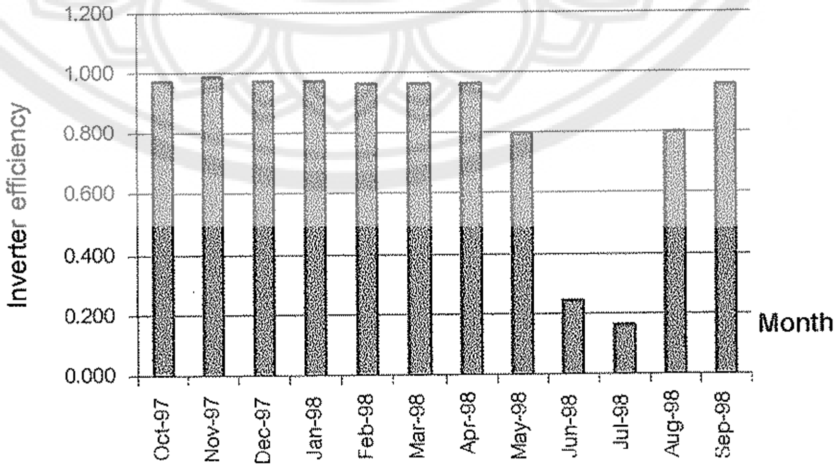

Figure 53 Average inverter efficiency of each month.

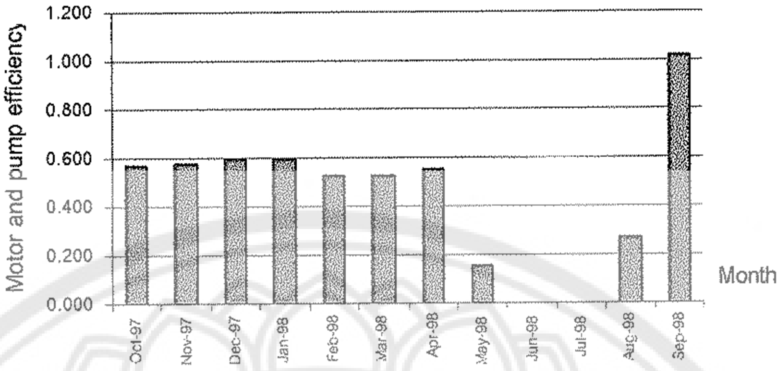

Figure 54 Average motor and pump system efficiency of each month.

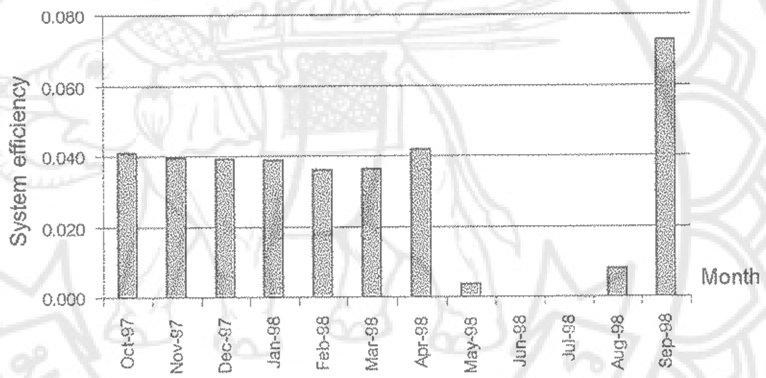

Figure 55 Average system efficiency of each month.

APPENDIX C

CALCULATION AND ANALYSIS

APPENDIX C

Calculation and Data Analysis

The objects of this part want to find the efficiency of system and each part by the metrology in chapter 4. For the example, this part will use average data on April 1998 to calculate and analysis for short-term analysis, average data from March to June 1998 for middle term and all data for long term. Because of system started to collect data on 3 October 1997 and finished on 30 September 1998. Moreover, the mean time range to collected data is 10 minutes. So, there are many data per day, and thirty times in monthly. In this report will use data that start to collect at 7.00 until 18.00 that is the sunrise time and the sunset time approximately.

C1 Data analysis

In long-term analysis, it will use the average data from 3 October 1997 until 30 September 1998. Moreover, the mean time range to collected data is 10 minutes. So, there are many data per day, and thirty times in monthly. In this report will use data that start to collect at 7.00 until 18.00 that is the sunrise time and the sunset time approximately.

Table 21 The average collected data from 7.00 – 18.00 from 3 October 1997 until 30 September 1998.

Parameter	Symbol	Amount	Unit
Global radiation	G_T	452.926	Wm^{-2}/day
Tilt angle radiation	G_{Tilt}	484.464	Wm^{-2}/day
Sum global radiation	H	1809.63	kWh m^{-2}/year
Sum tilt angle radiation	H_{Tilt}	1904.53	kWh m^{-2}/year
Ambient temperature	TA	31.072	° C
Cell temperature	T_C	45.548	° C
PV output voltage	V_{PV}	122.184	V
PV output current	I_{PV}	1.561	A
AC power	P_{AC}	170.013	W
Frequency	f	17.117	Hz
Pressure 1	P_1	0.128	Barr
Flow rate 1	Q_1	0.376	m^3/10 min

C1.1 PV system

For the PV system, the efficiency can find by used this formula.

$$\eta PV = \frac{I_{PV} \times V_{PV}}{G_{Tilt} \times A_{PV}} \qquad \text{.......(C-1)}$$

When,

η_{PV}	is efficiency of PV system
P_{PV}	is PV output power, watt
I_{PV}	is PV output current, amp
V_{PV}	is PV output voltage, volt
G_{Tilt}	is tilt angle radiation, W/m^2
A_{PV}	is PV area, m^2

For example, use data at 12.10 on 16 April 1998 to calculate and find the η_{PV} by these methods.

The power output from PV can find by use the Ohm'laws that is

$$P_{PV} = I_{PV} \times V_{PV} \qquad \text{.......(C-2)}$$

From above formula, the PV output power is.

$$P_{PV} = 1.561 \times 122.184$$

$$= 190.73 \text{ W}$$

So, use this number find the efficiency of PV system or η_{PV} from above formula like this.

When,

P_{PV}	is PV output power	=	190.73	W
G_{Tilt}	is tilt angle radiation	=	476.53	W/m^2
A_{PV}	is PV area = 0.825 x 0.53	=	0.437	m^2/module

From table 4.2.2, the module area is 0.437 m^2 and in this system there were 16 module. So, the total area of PV module is 0.437 x 16 = 6.992 m^2.

$$\eta_{PV} = \frac{190.73}{476.53 \times 6.992} \times 100\,\%$$

$$= 5.7\ \%$$

The efficiency of PV system for one year is 5.7 %.

C1.2 Motor and pump system

In this system combined motor and pump part together, because there was no measurement of torque and speed of the motor to calculate the power output of the motor. To compute the efficiency of the motor and pump subsystem, only measuring power input to the motor and the hydraulic power of pump is needed.

We can find the efficiency of motor and pump by used this formula.

$$\eta_{MP} = \frac{P_H}{P_{PV}} = \frac{\rho g H_T Q}{I_{PV} \times V_{PV}} \qquad \text{.......(C-3)}$$

When,

ρ	is the density of water	=	1,000	kg/m^3
g	is the gravitational acceleration	=	9.81	m/s^2
H_T	is the total head, m			
Q	is the flow rate, m^3/s			
P_{AC}	is the AC power	=	170.01	W

From figure 4, there are two pipelines go to two place of tank in the village. The Q_1 is the main pipeline that divided to Q_2 and the other pipeline. So, we choose the Q_1 for calculation and analysis.

Because of this system was collected data every 10 minutes, we can change the volume into the flow rate of m^3/s unit by multiplying with 1 / (10 x 60) that is the second unit. So, the flow rate of this example is

$$Q_1 = 0.376 \times \frac{1}{10 \times 60} = 0.00063 \quad m^3/s$$

For the total head can find by this formula.

$$H_T = H_S + H_F \qquad \text{.......(C-4)}$$

When,

H_{static}	is the static head, m
H_{frict}	is the friction loss in the pipe, m

The static head is the different height from the bottom of pump to the top of the tank that compose of the suction lift, the static delivery and the height of the tank. From the picture diagram of system below here, we can know the static head like this.

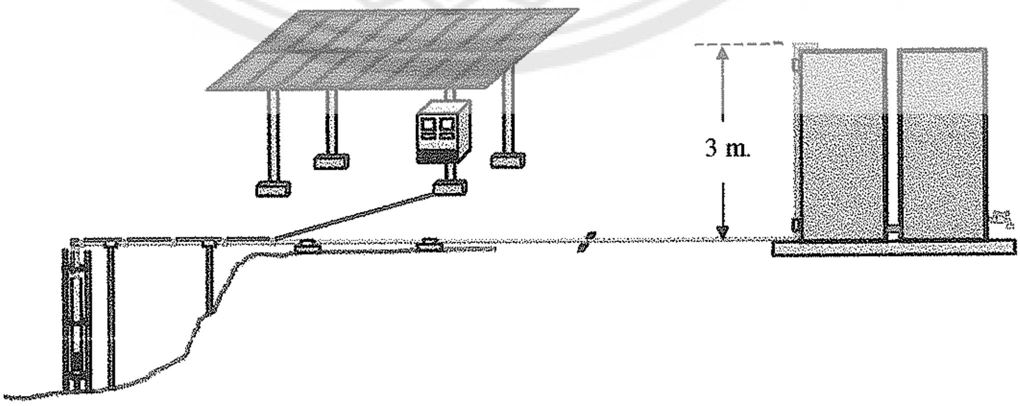

Figure 56 The static head diagram of system.

From figure, the suction head of the system is the total height from the bottom of the pump to the top of the tanks. When, the suction lift is the height from the bottom of the pump to the edge of pond. The static delivery is the height from the edge of pond to the bottom of tank or the height of land in system area.

In this report, the suction lift can find from collected data of water level that in barr unit. And, delivery head can find from pressure at point 1 in figure 4. Both values can find from this equation.

$$H = \frac{P}{\rho g} \qquad \text{.......(C-5)}$$

When,

ρ	is the density of water	=	1,000	kg/m^3
g	is the gravitational acceleration	=	9.81	m/s^2

But water level and pressure era in barr unit. So, it needs to change them into Pascal (Pa) unit by multiplies with 10^5.

Therefor, the suction head is.

$$H_S = \frac{0.152}{1000 \times 9.81}$$

$$= 1.55 \text{ m.}$$

The delivery head is.

$$H_d = \frac{0.128}{1000 \times 9.81}$$

$$= 1.3 \text{ m.}$$

Therefore, the static head can find like these.

The suction lift	=	1.55	m.
The static delivery	=	1.3	m.
The height of tank	=	3	m.
So, the static head or H_S	=	5.85	m.

In system, the pipeline is PVC type with 1.5 inch of dimension. And, the length of the pipeline 1 and 2 were 900, 300 m. So, the total length of both pipeline is 1,200 m. This length is very long for pipeline that caused of friction loss in pipe. The friction loss in case of very long pipe can find by Hazen-Williams'law that define as.

$$H_F = 10.666\, L \frac{Q^{1.85}}{C^{1.85}\, D^{4.87}} \qquad \text{......(C-6)}$$

When,

- Q is flow rate, m^3/s
- C is the coefficient of pipe (for PVC is 150 per 100 m.)
- L is the length of pipeline, m.
- D is the dimension of pipe, m.

The dimension of pipe can find from the handbook of practical tables & data for building construction that is 0.0448 m. of inside dimension.

Therefor,

$$H_{frict} = 10.666 \frac{(0.000627)^{1.85}}{(150)^{1.85} \times (0.0448)^{4.87}}\, 1231$$

$$= 5.38 \text{ m.}$$

Now, we can find the total head by:

$$H_T = H_S + H_F \qquad \text{......(C-7)}$$

$$= 5.85 + 5.38$$

$$= 11.229 \text{ m.}$$

Now, We can find the efficiency of motor and pump by used this formula.

$$\eta_{MP} = \frac{\rho\, g\, H_T\, Q}{P_{AC}} \times 100\,\%$$

When,

ρ	is the density of water	=	1,000	kg/m^3
g	is the gravitational acceleration	=	9.81	m/s^2
H_T	is the total head	=	11.229	m.
Q	is the flow rate	=	0.00063	m^3/s
P_{AC}	is the AC power	=	170.01	Watts

Therefor,

$$\eta_{MP} = \frac{1000 \times 9.81 \times 11.229 \times 0.00063}{170.01} \times 100\,\%$$

$$\eta_{MP} = 40.6\ \%$$

The efficiency of motor/pump is 40.6 %.

C1.3 Inverter part

The remaining component models of the pumping system are described on base of the electrical power. The power losses caused by the inverter are determined from self-consumption, power losses linear to the output power (due to voltage drops on semi conductors) and power losses to the square of the output power (ohmic losses). Thus, the output power P_{AC} is achieved from

$$P_{AC} = P_{PV} - \sum_{i=0}^{2} a_i P^i{}_{AC} \qquad \text{.........(C-8)}$$

When,

P_{PV}	is input power from the PV array		
ai	is the coefficients that are determined to		
	a_0	=	7.32
	a_1	=	9.727×10^{-3}
	a_2	=	2.432×10^{-5}

In this report, the data logger was calculate the AC power already. So, the efficiency of inverter can find by definition that the output power multiply by the input power. It can write the formula like these.

$$\eta_{INV} = \frac{\text{output power}}{\text{input power}} = \frac{P_{AC}}{I_{PV} \times V_{PV}} \times 100\ \%$$

When,

η_{INV}	is efficiency of inverter			
P_{AC}	is the AC power	=	170.01	W
I_{PV}	is the PV output current	=	1.561	A
V_{PV}	is the PV output voltage	=	122.184	V

The inverter efficiency is.

$$\eta_{INV} = \frac{170.01}{122.184 \times 1.561} \times 100\ \% = 89.1\ \%$$

The inverter efficiency is 89.1 % or 0.891.

C1.4 System Efficiency

The average efficiency of the PV water pump system is defined as:

$$\eta_{PV} = \frac{\rho g H_T Q}{G_{Tilt} \times A_{PV}} \qquad \text{..........(C-9)}$$

When,

ρ	is the density of water	= 1,000	kg/m^3
g	is the gravitational acceleration	= 9.81	m/s^2
H_T	is the total head	= 11.229	m
Q	is the flow rater	= 0.00063	m^3/s
G_{Tilt}	is tilt angle radiation	= 476.53	W/m^2
A_{PV}	is PV area	= 6.992	m^2

So,

$$\eta_{PV} = \frac{1000 \times 9.81 \times 11.229 \times 0.00063}{476.53 \times 6.992} \times 100\,\%$$

$$= 2.1\,\%$$

The system efficiency is about 2.1 %.

C1.5 Referents global irradiation, H_{ref}

<u>The referent global irradiation</u>

The referent global irradiation used for finding the time with comparison the radiation at standard testing condition (STC), that equal 1000 W/m^2.

Therefor,

$$H_{ref} = \frac{1809.63}{1000}\ \frac{kWh/m^2}{W/m^2} = 1809.63 \quad h$$

The referent irradiation from 3 October 1997 until 30 September 1998 that compares with the radiation at standard testing condition or STC, is about 1096.22 h. In daily, the radiation change every time because of it effected by cloud, sun position and other effect. So, the referent irradiation use for tells the irradiation time on daily by compare with the radiation at standard testing condition or STC. The value that gets from comparison is the average irradiation time value on daily, month or year upon the time set.

<u>The referent tilt angle irradiation</u>

The referent tilt angle irradiation used for finding the time with comparison the radiation at standard testing condition (STC), that equal 1000 W/m^2.

When,

H_{ref} is referent tilt angle irradiation, h

H_{Tilt} is tilt angle irradiation sum = 1904.53 kWh/m^2

G_{STC} is radiation at standard testing condition = 1,000 W/m^2

Therefor,

$$H_{ref} = \frac{1904.53}{1000} \quad \frac{kWh/m^2}{W/m^2} = 1904.53 \quad h$$

The referent tilt angle irradiation from 3 October 1997 until 30 September 1998 that compares with the radiation at standard testing condition or STC, is about 1099.29 h.

C1.6 Referents yield, RY

The referents global yield

The referents global yield is look like the referent global irradiation that used for finding the time with comparison the radiation at standard testing condition (STC), that equal 1000 W/m^2.

When,

RY	is referents yield, h		
n	is amount of day	= 358	day
H	is irradiation sum	= 1804.63	kWh/m^2
G_{STC}	is radiation at standard testing condition		= 1,000 W/m^2

Therefor,

$$RY = \frac{1}{358 \times 1000} \times 1804.63 \quad \frac{kWh/m^2}{day \times W/m^2}$$

$$RY = 5.05 \quad h$$

The referents yield from 3 October 1997 until 30 September 1998 is about 3.062 h.

The referents tilt angle yield

The referent tilt angle yield is defined as the same of referents global yield. When the sum tilt angle radiation or H_{Tilt} is equal 1904.53 kWh/m^2.

So,

$$RY = \frac{1}{358 \times 1000} \times 1904.53 \quad \frac{kWh/m^2}{day \times W/m^2}$$

$$RY = 5.32 \quad h$$

The referents yield or average solar energy per day from 3 October 1997 until 30 September 1998 is about 5.32 h.

C1.7 Nominal Power

The nominal power is the value that uses for calculate the power of PV module.

When,

$P_{NOMINAL}$	is the nominal power, kWp		
k	is amount of module	= 16	module
$P_{rate, module}$	is the module power at STC	= 0.055	kWp

Therefor,

$$P_N = 16 \times 0.055 = 0.88 \quad kWp$$

The nominal power is 0.88 kWp or 880 Wp.

C1.8 PV module efficiency

The PV module efficiency can find by the formula in chapter 3.

When,

$\eta_{STC, module}$	is the PV module efficiency at STC	
A_{module}	is the module area	= 0.437 m^2
G_{STC}	is the radiation at standard testing condition = 1000 W/m^2	

Therefor,

$$\eta_{STC, module} = \frac{0.055}{0.437 \times 1000} \quad \frac{kWp}{m^2 \times W \times m^{-2}}$$

$$= 0.126$$

The PV module efficiency is 0.126 or 12.6 %.

C1.9 Nominal Energy

The nominal energy is the value that uses to find the energy of PV module. It can find When, H_T is the tilt angle radiation on module that equal 476.53 W/m^2

Therefor,

$$E_N = 1904.53 \times 0.473 \times 16 \times 0.126$$

$$= 1816.1 \quad Wh$$

The nominal energy is 1816.1 kW.

C1.10 Utilizable PV Energy

In operation, the value of utilizable PV energy will find from the energy that use or energy loss in the system. In this system, the energy that use or energy loss is the power that inverter used.

When,

$E_{PV,\,use}$ is the value of utilizable PV energy, kWh

P_{AC} is the AC power and energy power, kWh

So, the utilizable PV energy of this system is the total of used power of inverter that is 170.013 Wh.

C1.11 PV system performance number

Normally, the performance ratio will calculate in monthly or yearly. The performance ratio will equal 1 when the system works at the standard condition and is not have the energy loss. In long term, the value of performance ratio is lower than 1, but it is short term that the performance ratio is near 1. The performance ratio can find by this formula.

$$PR = \frac{E_{PV,\,use}}{H_{TILT} \times A_{module} \times k \times \eta_{STC,\,module}} \qquad \text{.........(C-10)}$$

<u>The global performance ratio</u>

From above calculation, we can find the performance ratio like these.

$$PR = \frac{679.49}{1809.63 \ \text{x} \ 0.473 \ \text{x} \ 16 \ \text{x} \ 0.126}$$

$$= 0.394$$

The performance ratio of this system is about 0.394.

<u>The tilt angle performance ratio</u>

From above calculation, we can find the performance ratio like these.

$$PR = \frac{679.49}{1904.53 \ \text{x} \ 0.473 \ \text{x} \ 16 \ \text{x} \ 0.126}$$

$$= 0.374$$

The performance ratio of this system is about 0.374.

C1.12 Final yield

A daily rated operation time, final yield defined as reference yield that is.

$$FY = \frac{1}{n \times P_N} E_{PV,use} \qquad \text{.........(C-11)}$$

When n is the amount of day that consideration.

Therefor,

$$FY = \frac{1}{358 \times 0.880} \; 679.49 \; \frac{Wh}{day \times Wh}$$

$$= 2.16$$

The final yield of this system is about 2.16.

APPENDIX D

SIMULATION METHOD

Appendix D

Simulation method

From collected data and analysis, we can find the simulated equation by relation of parameter in the system. There are two or more parameters that relate in the system. In order to make it easy and comfortable, some parameter can assume to the constant values when it is not difference for any condition of work or a little change. And use excel program to find the tend line and simulate equation in the program. The method of simulate by excel program can show like these steps.

1) Find related parameters in the system.
2) Plot values of both parameters in excel program to make the relative graph.
3) Use simulated option in program like these.

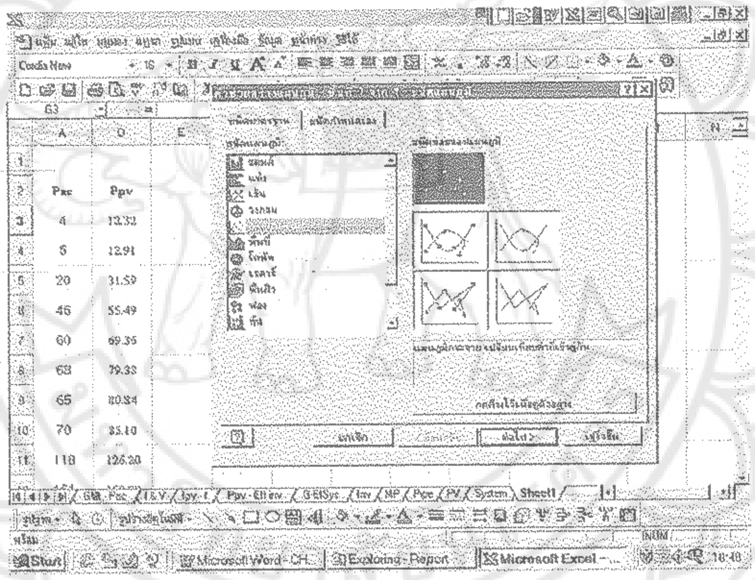

Figure 57 Show steps 1 of simulated method.

First, select the X-Y scatter for type of graph that will simulate because it very easy when compare collected data with simulated data.

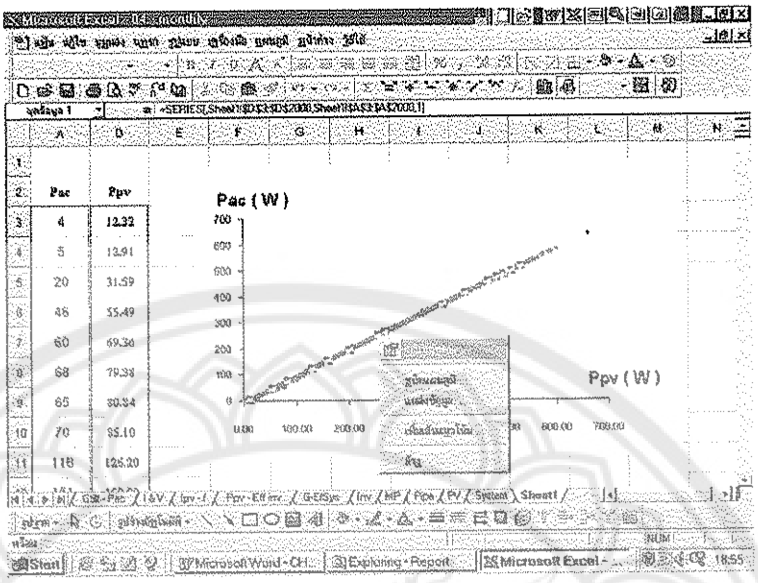

Figure 58 Show the step 2 of simulate method.

When the graph is finish, click the right button on mouse to select the add tend line function.

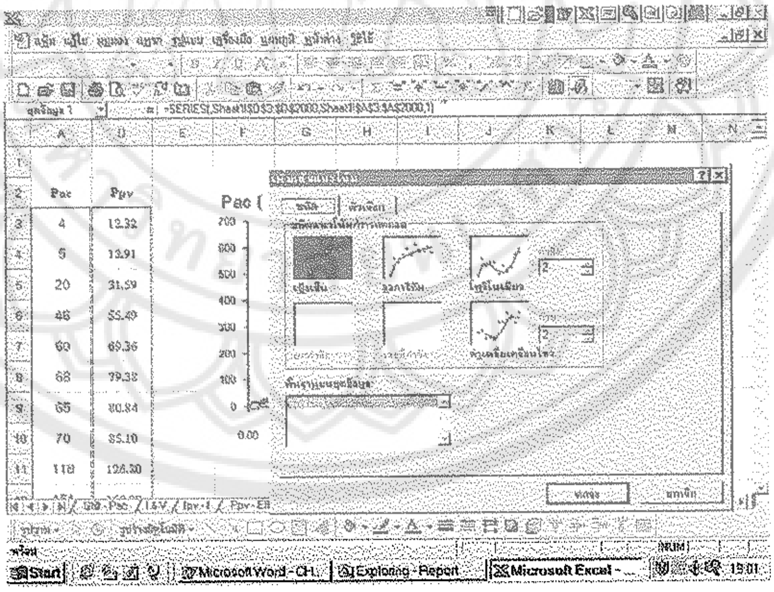

Figure 59 Show steps 3 of simulate method.

Now, selected the proper type form of data that want to simulate. It can consider of font view of this page what is the proper type that matches with written graph from collected and analysis data.

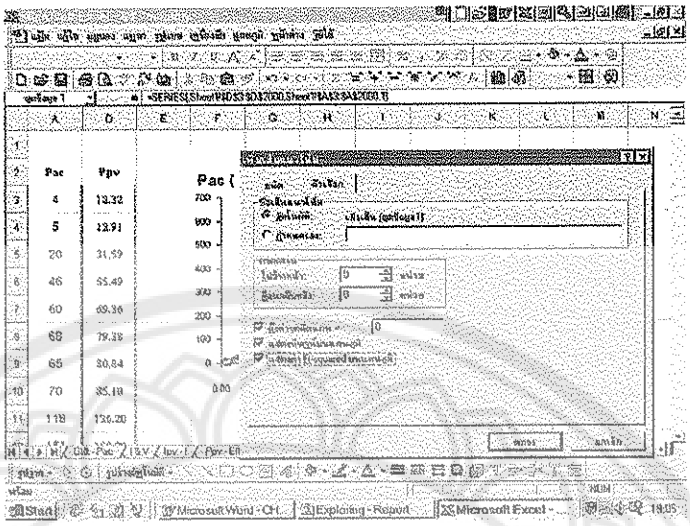

Figure 60 Show steps 4 of simulate method.

On this page, click on blanks of equation and R square to make the simulate equation and check the correct of equation by consider the R square value. If the R square value near 1 it correct and if the R square value equal 1 that mean equation that simulate is test at standard condition. In the same way, for some data that interrupt the zero point click the first blank of three blanks in the bottom of page to fix the zero value.

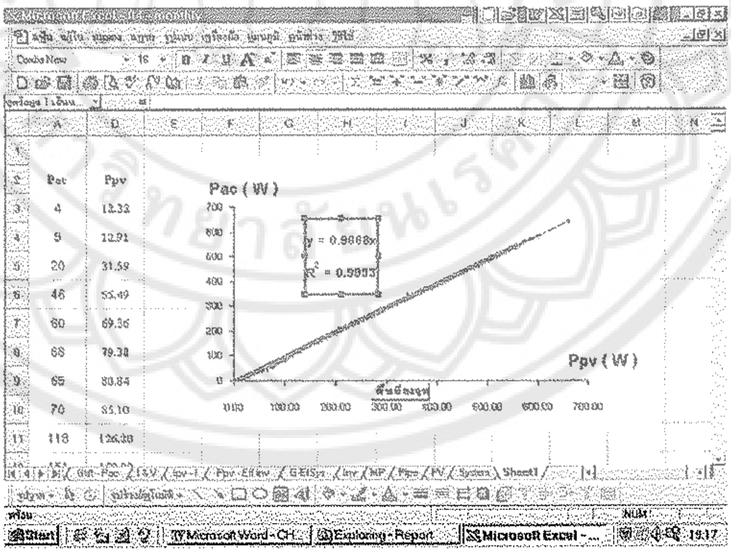

Figure 61 Show final steps of simulate method.

Now, we get the simulate equation and tend line of data in the system. And use this equation to find the simulate data to compare with the collected data.

APPENDIX E

SYSTEM SIMULATION

APPENDIX E

SYSTEM SIMULATION

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

E1 PV simulation

The PV system can simulate by use output and input parameter that effected the PV system. So, we can write the relation of these parameters in the function form like these.

$$P = f(I_{PV}, V_{PV}) \quad \text{.........(E-1)}$$

And,

$$I_{PV} = f(G_{Tilt}, T_C) \quad , \quad V_{PV} = f(G_{Tilt}, T_C) \quad \text{.........(E-2)}$$

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

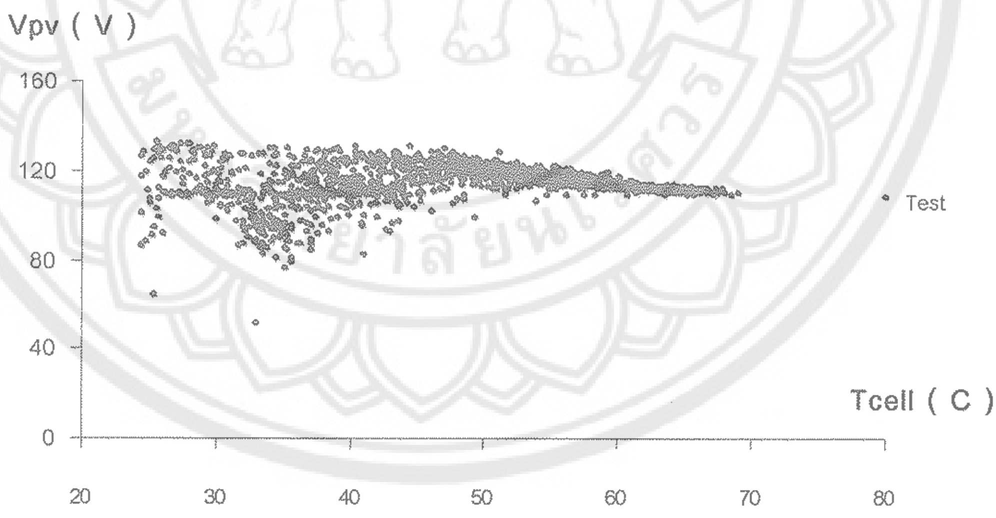

Figure 62 Relation of PV output voltage and cell temperature.

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.

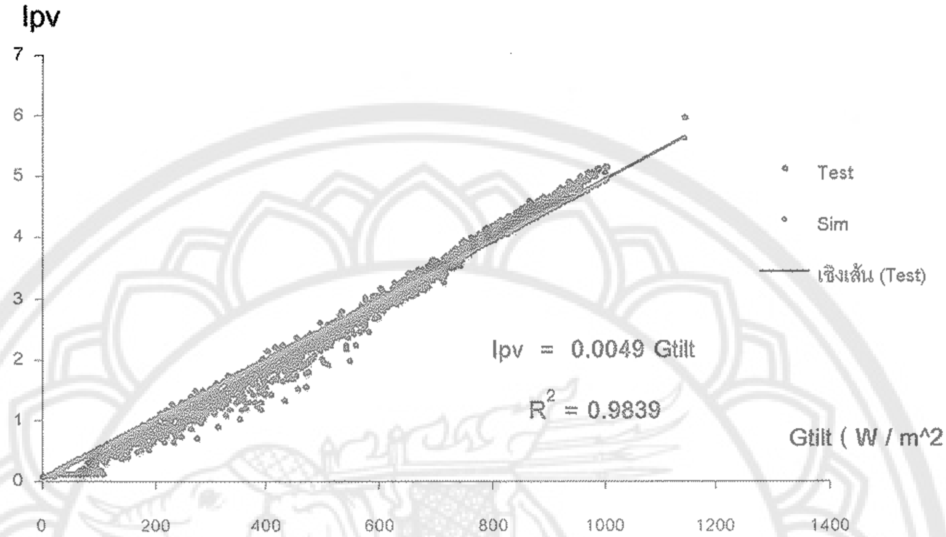

Figure 63 Relation of PV output current and tilt angle radiation.

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.

$$I_{PV} = 0.0049 G_{Tilt} \qquad \text{.......(E-3)}$$

From this relation we can tell that the PV output voltage is about 120 V. It is the constant value that assume to does 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 this.

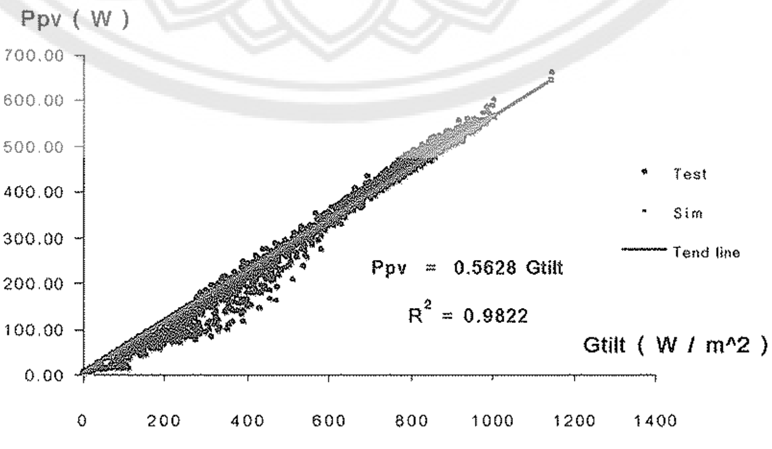

Figure 64 Relation of PV power and tilt angle radiation.

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

$$P_{PV} = 0.5628\, G_{Tilt} \qquad \text{.......(E-4)}$$

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.

E2 Inverter simulation

The function of inverter system can find from relation of AC power and PV output power. It can write in function like this

$$P_{AC} = f(P_{PV}) \qquad \text{.......(E-5)}$$

The simulated equation of inverter system can find from plot and calculate in excel program that is in linear form like this.

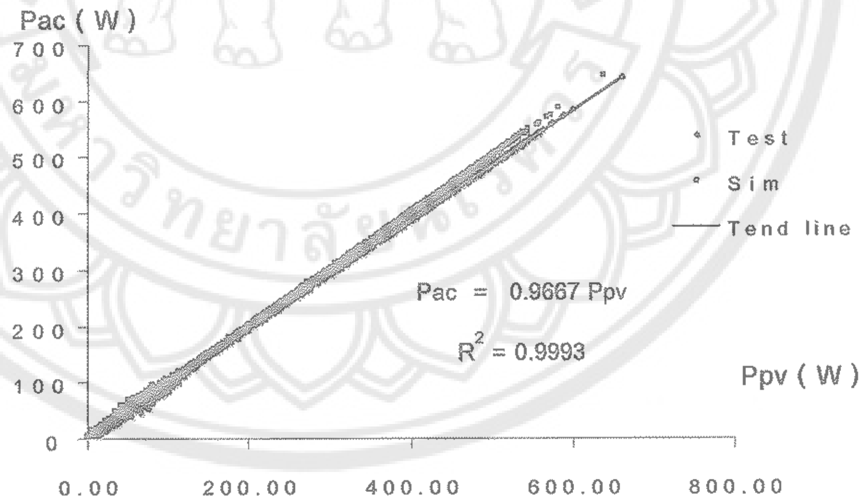

Figure 65 Relation of AC power and PV output power.

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

$$P_{AC} = 0.9667\, P_{PV} \qquad \text{.......(E-5)}$$

E3 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. So, we can write the relation of these parameters in the function form like these.

$$Q = f(P_{AC}) \qquad \text{........(E-6)}$$

The simulated equation of motor and pump system can find from plot and calculate in excel program that is in linear form like this.

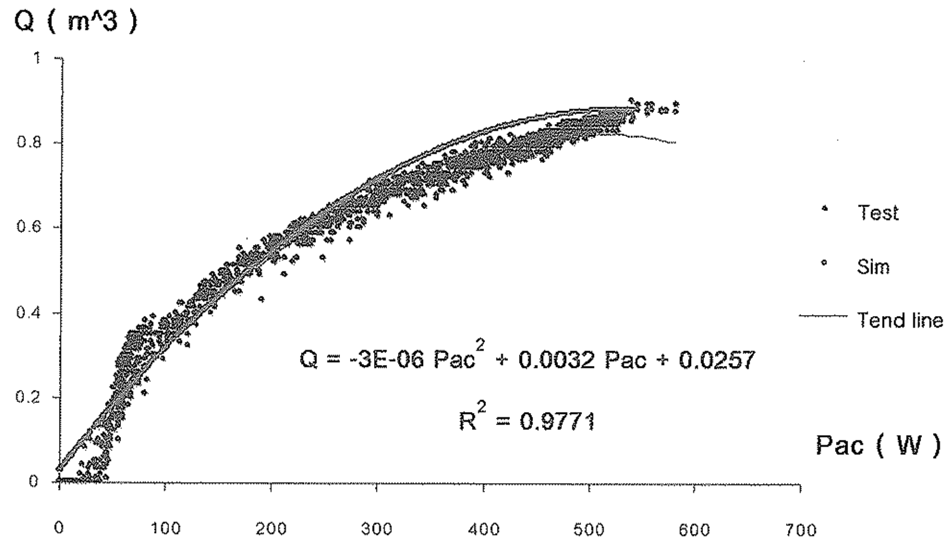

Figure 66 Relation of flow rate and AC power.

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

$$Q = -0.000003 P_{AC}^{2} + 0.0032 P_{AC} + 0.0257 \qquad \text{.......(E-7)}$$

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.

E4 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. We can write the relation of this part into the function form like these.

$$H_T = f(Q) \qquad \text{..........(E-8)}$$

Total head composes of static head, delivery head, and height of tank when height of tank is constant value. So, the total head can find from sum of these heads.

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

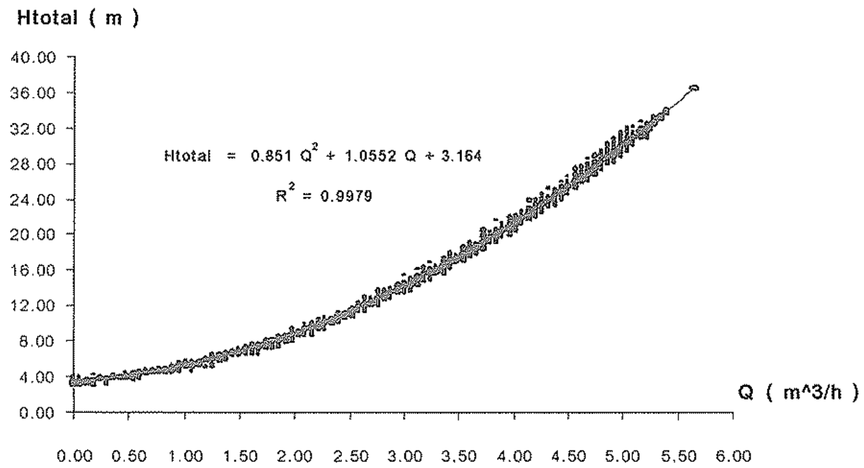

Figure 67 Relation of total head and flow rate and pipeline simulation.

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

$$H_T = 0.851Q^2 + 1.0552Q + 3.164 \qquad \text{.......(E-9)}$$

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.

E5 System simulation

For whole system, the main output that wanted in the pumping system is water volume or flows. And, it was upon the tilt radiation that is the primary input power. So, we can write the relation of pumping system into the function like these.

$$Q = f(G_{Tilt}) \qquad \text{........(E-10)}$$

We can plot and find the simulate equation from excel program like these.

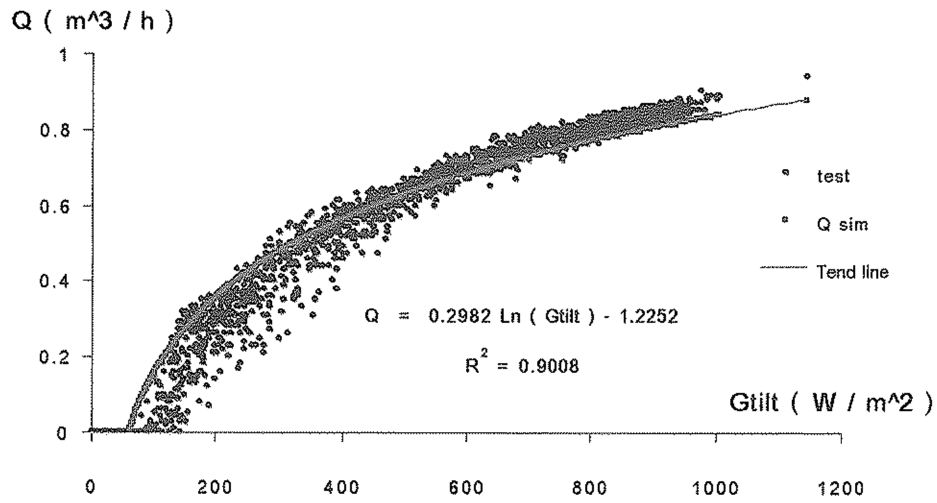

Figure 68 Relation of flow rate and tilt angle radiation.

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

$$Q = 0.2982 Ln(G_{Tilt}) - 1.2252 \qquad \text{.....(E-11)}$$

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.

APPENDIX F

CHARACTERISTIC OF INSTRUMENTS

HIGH POWER SOLAR MODULES
MONOCRYSTALLINE TYPE BP280, BP275, BP160, BP255/2, BP240

BP280
BP275

BP160

PRODUCT FEATURE

- High efficiency monocrystalline silicon cells
- Designed for maximum reliability and minimum maintenance
- Produced using in-house technology in cell manufacturing and encapsulation
- Highly resistant to water, abrasion, hail impact, and other environmental factors
- Anodised aluminium frame
- All proven products, only materials with extensive field experience used
- Designed and manufactured to comply with European, American and Australian standards
- 10 Year limited output warranty
- MADE IN AUSTRALIA

TYPICAL APPLICATIONS INCLUDE

- Telecommunications
- Water Pumping
- Grid Connect
- Telemetry
- Cathodic Protection
- Obstruction Lighting
- Domestic Lighting
- Domestic Power
- Rural Electrification
- Medical Refrigeration
- Railway Signalling

COMPONENTS

36 series connected monocrystalline silicon cells
Toughened high transmission (92%) glass 3mm thick
Encapsulant: Ethylene Vinyl Acetate (EVA)
Back surface: Polyester Tedlar trilaminate
Frame: Anodised Aluminium
Junction Box: for screw terminal connections, with by-pass diodes and blocking diode options. The box has a hinged weatherproof lid and four cable gland entry points.

Catalogue No.	BP280	BP275	BP160	BP255/2	BP240
Peak Power	80	75	60	55	40
Peak Power Voltage	17.1	17.1	17.1	17.5	17.5
Peak Power Current	4.67	4.35	3.51	3.20	2.28
Open Circuit Voltage	21.4	21.4	21.4	21.85	21.69
Short Circuit Current	4.99	4.60	3.70	3.57	2.53
Length (mm)	1188	1188	1188	825	627
Width (mm)	530	530	530	530	530
Thickness (mm)	43.5	43.5	43.5	43.5	43.5
Weight (Kg)	7.2	7.2	7.2	5.5	5

Power specifications are to + - 5W for BP240 to BP275 & + - 7W for BP280. Figures are taken under standard conditions of 100mW/cm² light intensity (AM 1.5) at 25°C cell temperature, measured at the +- braids in the junction box.

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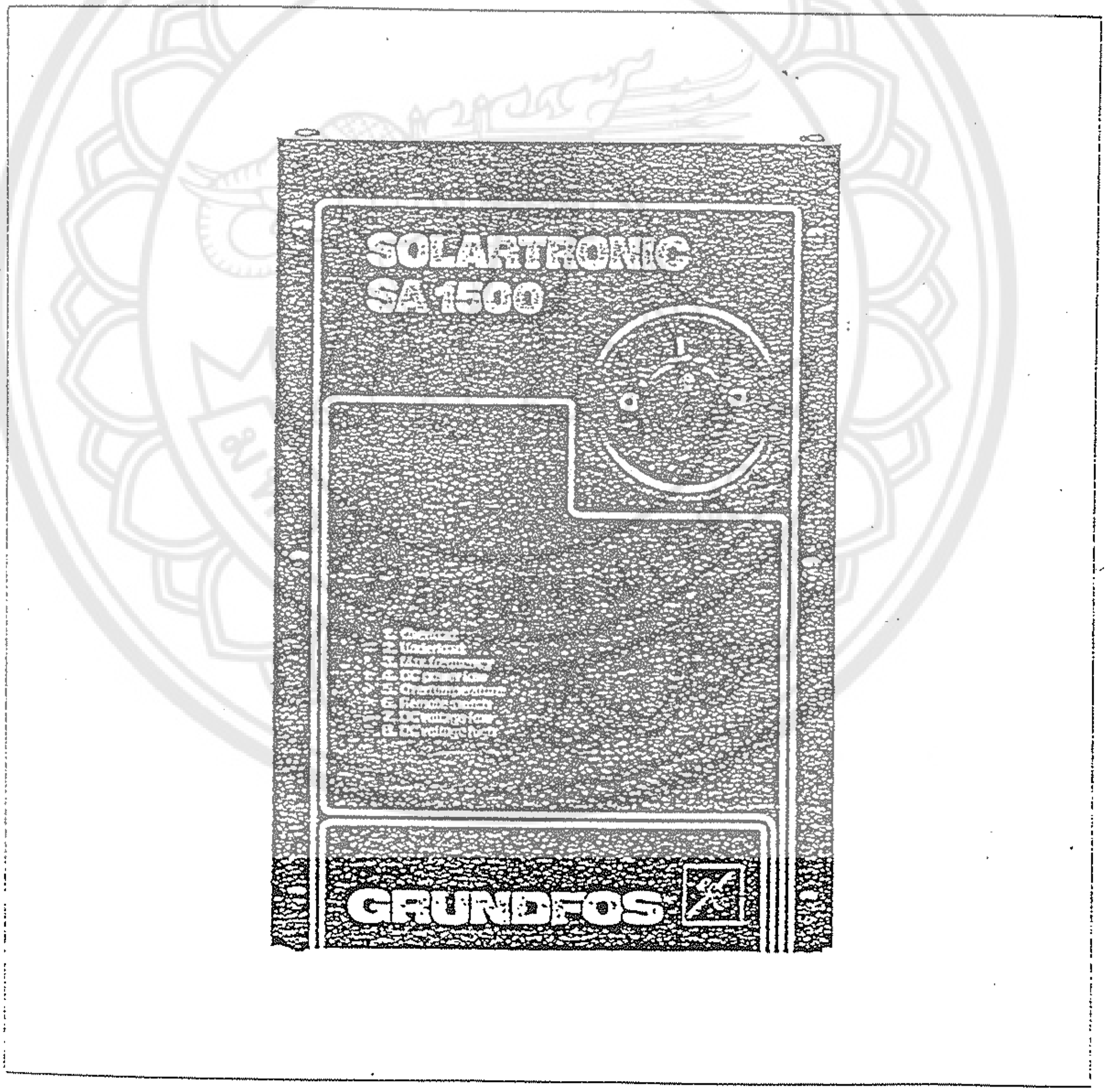
BP SOLAR AUSTRALIA PTY LTD A.C.N. 005 548 603
PO Box 519, Brookvale NSW 2100 Australia Telephone (02) 9938 5111 Telex AA 17065 Fax (02) 9905 1284

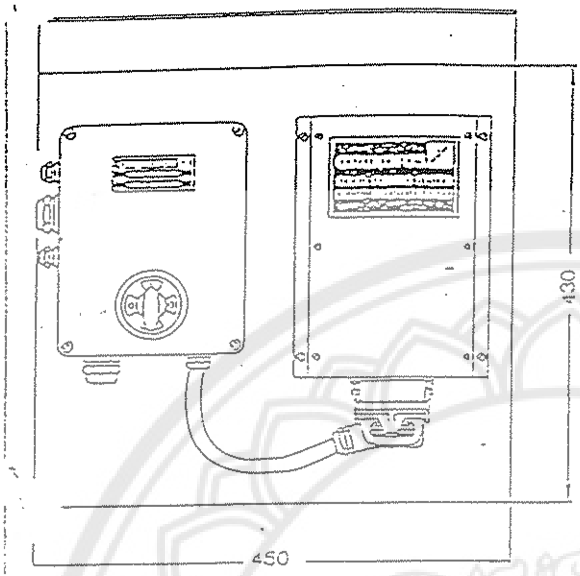
SOLARTRONIC SA 1500 DC/AC Inverter

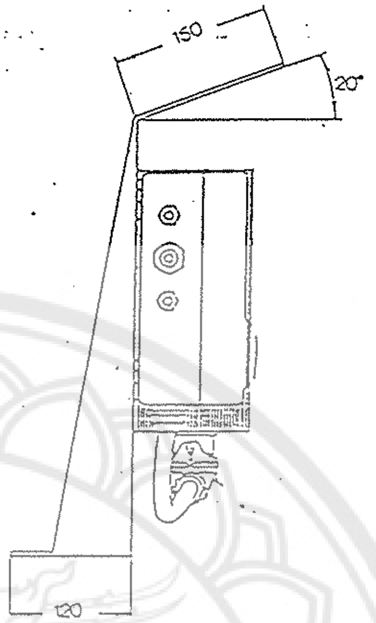
The SA 1500 inverter has been designed to convert the DC voltage produced by a photovoltaic system into a three-phase AC voltage with a variable frequency.

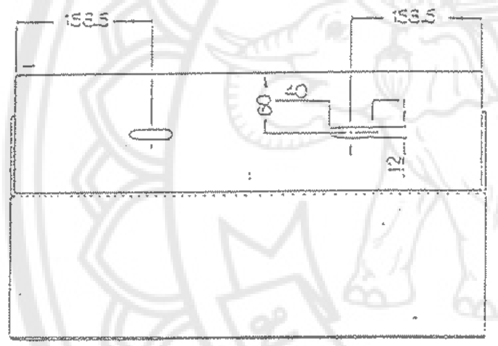


GRUNDFOS

Bracket with DC/AC Inverter and Main Switch Box





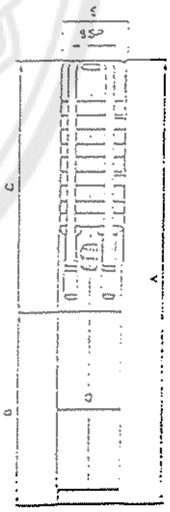


Submersible Pump and Motor

Dimensions

Pumo type	Dimensions (mm)						Minimum internal diameter of bore hole
	A	6	C	0	E	SSP	
SP 1-28	1047	258	789	95	95	2"	4" (104 mm)
SP 2-18	837	258	579	95	95	2"	4" (104 mm)
SP 4- 8	627	258	369	95	95	2" (nicole to 3")*	4" (104 mm)
SP 8- 4	625	258	358	95	95	2" (nicole to 3")*	4" (104 mm)
SP 16- 2	602	258	344	95	131	3"	6" (152 mm)
SP 27- 1	601	258	343	95	139	3"	6" (152 mm)

* When nippled to 3", minimum internal diameter of borehole: 152 mm (6").



GRUNDFOS International a/s . DK-8850 BJERRINGBRO
DENMARK . PHONE +45 6 68 14 00 . TELEX 60 701 gfos dk

30 EX SS 005 08 86
Repl. 30 EX SS 003 09 84

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Application

The GRUNDFOS SOLARTRONIC inverter, type SA 1500, is a three-phase DC-AC inverter with a nominal power of 1500 watts. The inverter is specially designed to power submersible pumps installed in GRUNDFOS solar pumping systems or in battery powered pumping systems.

Description

The SOLARTRONIC inverter converts the DC voltage supplied by a photovoltaic system or by a battery of accumulators into a three-phase AC voltage with a variable frequency.

The pulse-width modulated three-phase alternating voltage is controlled by a microcomputer.

The frequency and thus the speed of the submersible motor varies according to the intensity of the solar irradiation (directly proportional).

The microcomputer controls the DC voltage so that the solar array is utilized to its maximum in any operating situation.

The operating conditions are indicated by light-emitting diodes.

The output circuit is protected against short circuit, and the pump is protected against dry-running or blocking.

The SOLARTRONIC SA 1500 inverter has a variety of application specific options.

Technical Data

Casing	Black-anodized aluminium
Enclosure Class:	IP 54
Weight:	4.4 kgs
Dimensions	217 × 150 × 275 mm

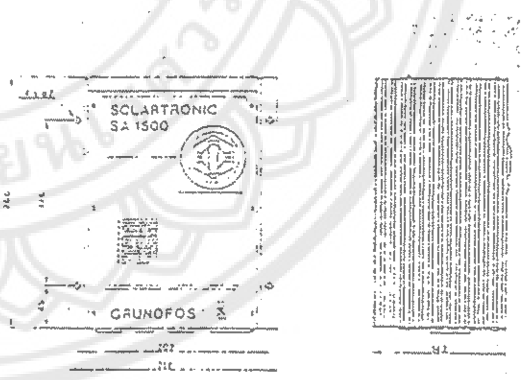
Climatic Conditions

Ambient Temperature	- 10°C to + 60°C
Storage Temperature	- 25°C to + 85°C
Relative Humidity	Maximum 100%

Features

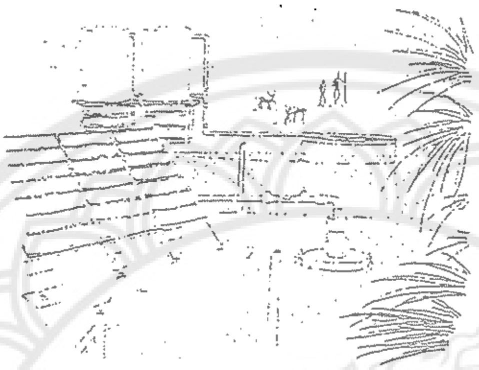
- Main switch incorporated in inverter unit.
- Compact design.
- Long life without maintenance.
- Can be connected to a battery.
- Can be connected to a remote control, e.g. level switch.
- High efficiency.
- Controlled start-up.
- Pulse-width modulated sine wave voltage.
- Maximum power point tracking.
- Fault indication.
- Protected against overheating.
- Protected against overload and underload.
- Protected against voltage transients.
- Protected against too high or too low input voltage.
- Protected against earth leakage.
- Protected against short circuit.
- Protects the pump against dry-running.

Dimensions



Electrical Data

Input (DC)	Nominal	Maximum	Minimum
Load voltage	120 V	140 V	100 V
No-load voltage	155 V	175 V	115 V
Load current	12.5 A	14.0 A	-
Power	1500 W	1960 W	-
Battery operation	120 V	140 V	100 V
Output (AC)	**Nominal**	**Maximum**	**Minimum**
Current		14.0 A	-
Frequency	-	63 Hz	7 Hz
Efficiency	0.96	0.97	0.95
Battery operation	50 Hz	-	-



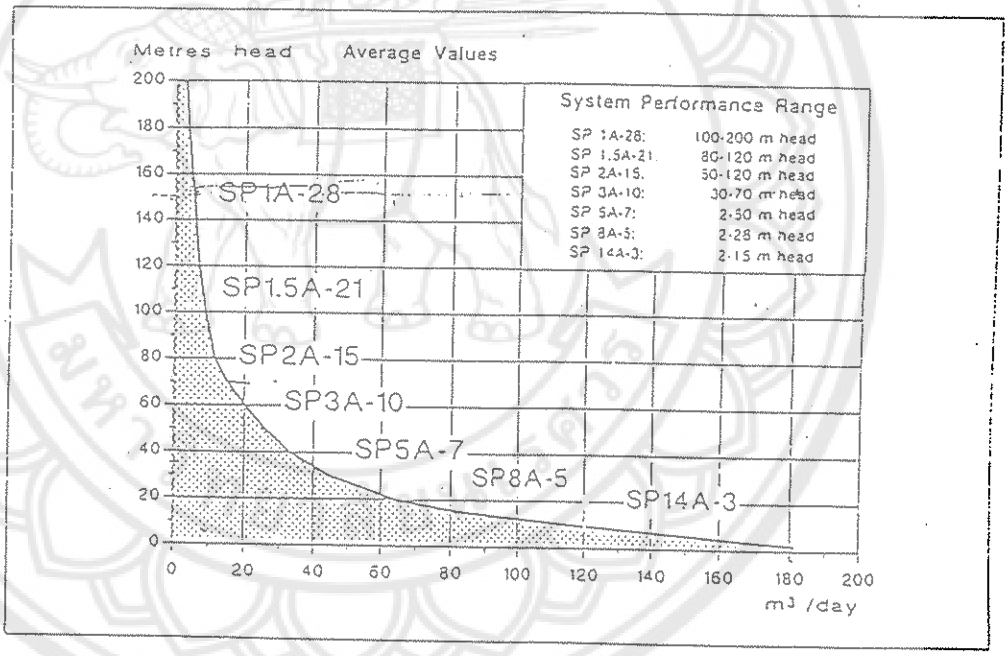
Solar Pumping Systems

General Data and Survey Capacity Diagram

The curve shows the capacity of a 1800 Wp system. The shaded area applies to lower Wp values.

The curve is based on:

- Irradiation on a tilted surface H_T = 6 kWh/m² day
- Irradiation on a horizontal surface H_H = 5.5 kWh/m² day (473 cal/cm² day)
- An average ambient temperature of 30°C
- 20° northern latitude
- A tilt angle of 20°



Applications

GRUNDFOS solar pumping systems are specially designed for water supply and irrigation in remote areas where no reliable electricity supply is available. Features like extremely long life and minimum maintenance are key factors with these pumping systems.

The only moving part of the system is GRUNDFOS' well-known submersible pump/motor unit made entirely of stainless steel. There are several unique advantages of using photovoltaic power in connection with water pumping.

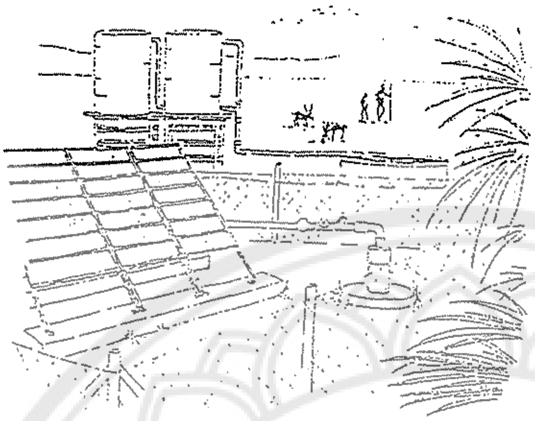
Primarily, there is a natural relation between the availability of solar power and the water requirement. The water requirement grows during periods of hot weather when the sun shines most brightly and the output of the solar array is at a maximum. Conversely, the water requirement will decrease when the weather is cool and the sunlight is less intense.

The water can be pumped during the day and stored. Water is then available at night and during cloudy periods.

The possibility of storing the pumped water eliminates the need for batteries in the system.

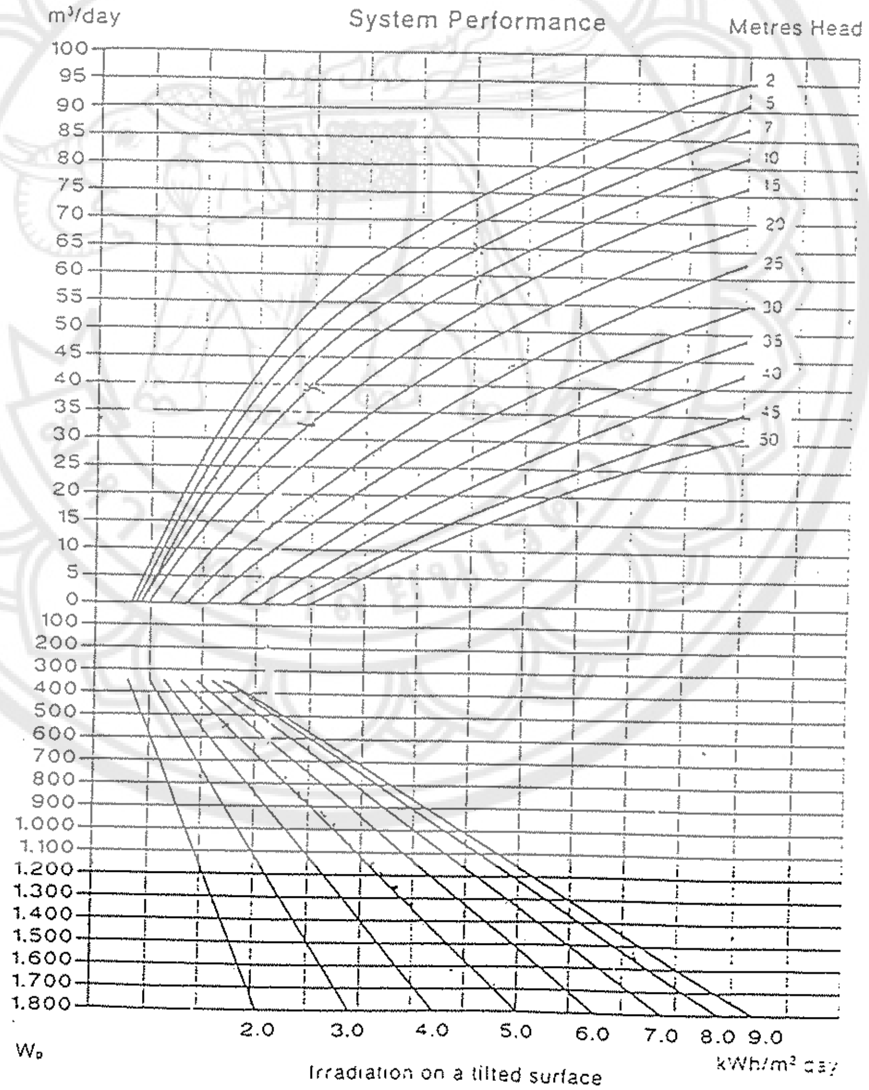
GRUNDFOS®

Solar Pumping System Type SP 5A-7



The system performance curves are based on:

- An 11 hour standard solar day.
- An average ambient temperature of 30°C.



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