CHAPTER 2

LITERATURE REVIEW

This chapter describes some examples of PV water pumping experiences and researches in Thailand.

The PV water pumping system at Nong Sanuan Village

In 1994, a PV pumping system was installed near Nong Sanuan Village in the Phichit district to contribute to a reliable water source for the village inhabitants during the dry period. [S. Suwarawan, etal.]

At a distance of approximately one km from the village, a submersible pump draws surface water from a man-made pond. A photovoltaic generator is used as the power supply and the power conditioning is done with a three-phase inverter. In the original layout, the pump delivers the water through a water supply line into a twin water storage (20 m^3) with several water terminals near the school area of the village. About 50 inhabitants were estimated to benefit from this water supply.

The installation was part of the rural development project and the Dept. of Civil Works was responsible for the system planning and operation as well as for the maintenance. The water supply is provided free to the users.

a) System description

Commercially available components were chosen and installed by a Thai solar company.

The PV generator consists of 16 BP Thai Solar modules of the type 1255 HP (mono-c Si cells) with a nominal power of 55 Wp each, for a total power of 880 Wp. Eight modules are connected in series and two in parallel, to achieve a nominal voltage at the point of maximum power operation (MPP) of 135 V DC.

A three-phase inverter of Grundfos type SA 1500 Grundfos converts the PV power into the three-phase AC power needed by the pump. This inverter is especially designed for the use in pumping applications. The PV generator is MPP-tracked and the inverter supplies the motor of the pump by controlling AC voltage and frequency with respect to the available DC power. The nominal operation voltage is 65 V AC, the frequency shifts is the range from 7 Hz to 63 Hz (manufacturer's specifications).

The multistage submersible centrifugal pump, type Grundfos SP 5A-7, is powered by an asynchronous motor having 550 W rated power. The unit is fixed in the pond by means of a support structure.

A peculiarity in this system design is the extended water supply line from the pumping station to the storage tank, and the large diameter of the main supply pipe, which leads to comparatively low fluid speeds in the pipe system. Further, surface water of the pond is pumped through the system which is not of the purity of the ground water found in many other PV pumping applications.

b) System experience

A recent inventory of the system and of the acceptance of the water supply station indicates a high acceptance of the water supply station and the operation of the pump has provided significant benefits. The new availability of water, mainly used for washing and cleaning purposes, has made the original water supply system inadequate and inconvenient. Two new storage tanks have been built closer to the center of the village since in order to reduce the distance between the water storage and the users. As part of the upgrading, water supply grid, with secondary branches delivers water direct to the individual houses of some users. A valve in the original supply line is operated by the village to feed the storage at the school only or to guide the flow to the village center as well.

As a consequence of this 'natural growth' of the water supply grid, the pumping system is not able to supply all branches of the supply grid in the same way. The storage for example cannot be filled sometimes because of the resulting low geodetic head of the pumping station. On the other hand, the village inhabitants seemed to be satisfied by the improved general comfort in the water supply. Besides this, after the first two years of system operation, no visible degradation of the system components could be observed. No monitoring of the system was carried out during these first two years of operation.

c) Concept of future monitoring

The PV pumping station at Nong Sanuan Village is subject to an evaluation program, which is being carried out in cooperation with the Fraunhofer Institute for Solar Energy Systems ISE in Germany. For this purpose, the station will be equipped with a monitoring system. The recorded data will give the base data to evaluate the system performance under the observed operational conditions.

The monitoring concept partly relates to the German PV Pumping Programs of the GTZ in recent years, in which approx. 90 PV pumping systems have been investigated by installing data acquisition equipment. Fig 1 shows a sketch of the measured values in the planned monitoring. The data will be stored as 10-minute mean values by the data logger of the data acquisition system.

No changes in the actual water supply grid structure are intended.

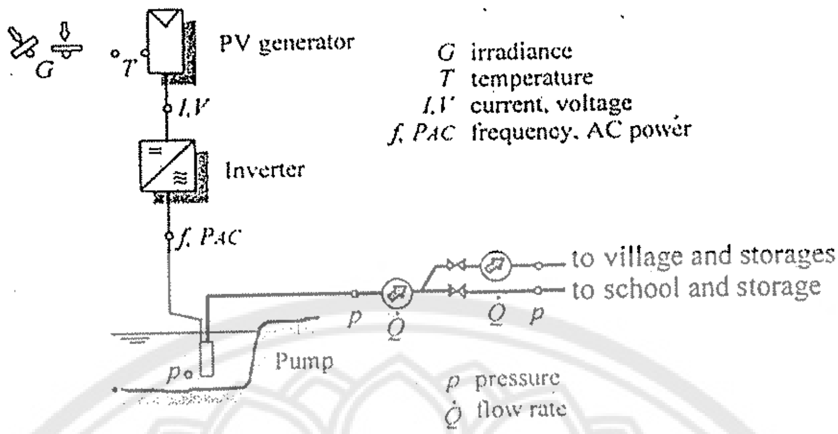

Figure 1 The monitoring in the PV pumping station will provide environmental data (irradiation and temperature), electrical data (DC voltage and current, AC power and frequency) as well as hydraulic data (pressure, flow rate).

d) Evaluation of the PV pumping system

The evaluation of the measured data from the monitoring of the PV pumping station will provide a valuable data base, from which typical environmental conditions for the system operation as well as water supply quantities, water demand by the users, system performances and reliabilities and system efficiencies can be calculated.

In addition, a simulation calculation through numerical modeling of the system will support the evaluation. The simulation model reflects the characteristics of the applied system components and the operation conditions using measured environmental data. (Fig 2)

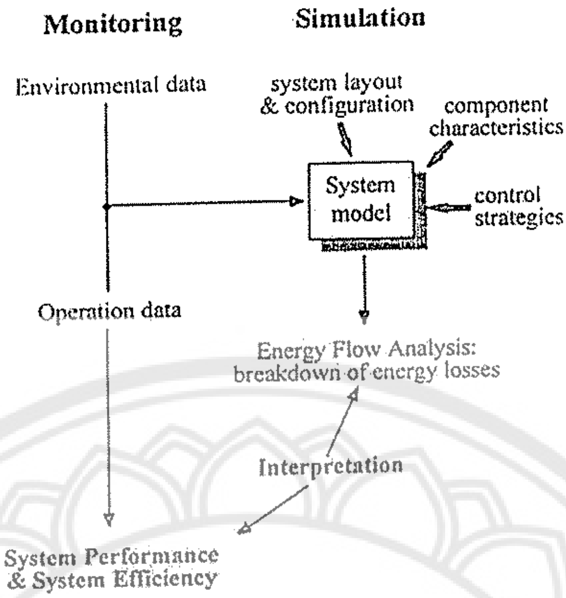

Figure 2 An important tool to understand and to interpreted the measured data is the energy flow analysis. The analysis is based on a detailed computer model of the investigated system and the simulation, using measured environmental data, and a break down of the individual energy losses in the system.

Thus, calculating all important system losses, which in principle are not accessible separately, as lone measurements, it is possible carry out a detailed energy flow analysis. These energy losses are for example:

- Energy losses in the DC part of the PV array, caused by partial load operation of the modules in low irradiation periods, by high operation temperature, by reflection of the solar irradiation at the module surface, deviation in the characteristics of the modules, by cabling, diodes etc.;
- Energy losses due to the inverter efficiency and caused by non optimal maximum power point tracking of the inverter;
- Energy losses in the motor/pump-unit caused by part load operation and by the hydraulic load;
- Energy losses caused by friction in the water supply grid.

The energy flow analysis is an important tool to interpret the measured operation data and thus is a prerequisite to any further system optimization and improvement.

The monitoring system will be installed in the last quarter of 1997. Since a data acquisition period of at least on year is recommended for the evaluation, first results will be published in the beginning of 1999.

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The PV water pumping systems at King Mongkut's University of Technology Thonburi

As of the end of 1995 about 500 photovoltaic (PV) water pumping stations have been installed in Thailand. Most units are direct coupling types utilizing AC motor-pumps and inverters. Insufficient water supply occurs during low solar radiation periods and inverters are more likely to breakdowns.

The project adopted the PV water pumping design methodology developed by L.Rosenblum to size a direct-coupled (DC) and a battery connected (BC) pumping systems constructed under this research project for techno-economic assessment. A unit, installed at KMITT, was designed to deliver water of 13 m^3/day at 7-m head, and could be configured to operate in either a direct-coupled mode or a battery connected mode. The designed unit would consist of one 282 Wp (1.94 m^2) PV array, a 3.2 kWh battery unit, 10 m of 40-mm ∅ water pipes. [R. Songprakorp]

In actual installation the PV array wattage was increased to 376 Wp (2.54 m^2); eight M75 Solartron panels were used. Two locally manufactured flooded-type lead acid batteries, each at 12V 100 Ah and battery size to 2.4 kWh were installed. One 150307 DSU AY McDonald pump, at requiring 700 WDC, was selected. The water pipe diameter was reduced to 35 mm.

Research work consisted of testing of subsystems i.e. motor-pump and battery, measuring the instantaneous and daily performances of the systems. Long term performance was predicted and an economic analysis made based on measured average daily radiation and radiation numbers derived using the Utilizability method.

It was found that the overall efficiency of a direct-coupled system depends on the radiation intensity at a low cell temperature, less than 40 °C, whereas that of the battery-connected system it depends on the radiation intensity as well as the state of the battery. In a discharge state the system efficiency exhibited more dependence on radiation intensity than in a charged state.

The battery-connected system has higher instantaneous efficiency at low radiation and can operate over a wider radiation range

Because of mismatches between the power ratings of the PV array and the motor-pumps, and the fact that the pump is not new, the overall system efficiency was low.

Modeling results of instantaneous performance of the direct coupling system were in good agreement with actual performance as far as qualitative description and prediction of water flow rate are concerned. At high radiation intensity, modeled values of the array voltage were 10% higher, whereas the array current was 5% lower, than the actual values.

It was not successful to model the battery-connected system due to, perhaps, inadequate understanding of battery characteristics resulting in an incomplete model of the battery. On computer modeling, the results became inconsistent with observed data.

The pump was set to operate 7 hours each day. It was found that the daily pumping capacity of the battery-connected system was higher than that of the direct-coupled system on days having daily total radiation (on the PV panel plane) lower than 6 kWh/m^2-day.

On long term techno-economic analysis, we find that

(i) the battery connected system, set to operate 7 hours each day, would provide more water than the direct coupled system whether the radiation was derived from the utilizability methodology or the average daily radiation was used. In the first instance it was 11% higher, the second 12%
(ii) upon comparing the cost of water pumped by the battery connected system, the direct-coupled system undertaken by this research work and the 6 other systems of KMITT, the unit cost of water was 9-10 baht/m^3 for the system that delivers 6-12 m^3 a day at static heads of 7-15 m.
(iii) a sensitivity analysis indicates that the unit cost of water is dictated more by the discount rate more than the PV wattage price.

It is concluded that the battery-connected PV water pumping system has better performance than the direct coupling system. Battery connected system are feasible technically and economically.

The PV water pumping systems at Lahansai, Burirum Province

a) Project under investigation

1. Description of project site

The PV water pumping systems were located at the experimental plantation (Lat. 15 °N, Long. 103 °E) of the Royal Food Processing Plant at Lahansai, Burirum Province [T. Suwannakum, etal]. The site area is about 10 hectares and 1 km away from the power line. At the plantation, field trials of various crops are made before they are introduced and promoted to local farmers. In addition, seedlings are produced at plantation nurseries before distribution to farmers. Examples of crops and plants under trial are asparagus, red beans, passion fruit, bamboo and papaya. Provision of water to the plantation is of immense importance during the dry season (November-May) as most plants and seedlings cannot survive the dry season without water in this semi-arid part of Thailand.

The source of water irrigation for the plantation is a small reservoir having a storage capacity of less than 0.5 million cubic meters. It is located about 300 m away from the highest part of the plantation.

2. System sizing

The system was initially designed to supply water to about one-tenth of the plantation (0.9 hectare or 6 rais). Based on potential evapotranspiration data of crops and other data such as crop spacing, depth of root systems, types of soil and available meteorological data, an estimation of monthly water requirements was made. The sizing methodology is based on the criterion of the design month. The design month is the month in which water demand is highest in relation to the available solar energy. It is the month that the system is most heavily loaded to meet the demand.

Table 1 provides data on monthly available rainfall and volume of water (daily average) to be delivered by the system. February is in this case the design month.

Table 1 Specifications of the System.

1. Site location	Burirum (Lat. 15 °N, Long 103 °E)
. Water storage and delivery system	Static head 10.5 m Storage capacity 24 m^3 PVC water pipes of 290 m in length.
3. Design month data (February)	End use water requirement : 29.27 m^3/day Water to be delivered by system : 31.14 m^3/day Hydraulic energy requirement : 3.53 MJ/day Solar irradiation on PV array : 17.07 MJ/m^2 -day
4. PV water pumping specifications	Array size : 940 Wp Array tilt angle : 15° Average motor/pump (energy) efficiency : 28% Average motor/pump (power) efficiency : 40% Rating of motor : 940 W Rating of pump : 3.32 liter/s at 11.5 m total head

Design of the system including sizing of PV arrays, motor-pump unit and water delivery pipes follow established guidelines and criteria.

b) System installation

In actual implementation, budget restrictions were encountered and the system had to be scaled down. The PV array size was reduced to 750 Wp and the water delivery pipe diameter to 40 mm.

Moreover, successive failures of two 180809 DM McDonald submersible pumps led to a replacement, at first, by two 810203 DJ DcDonald surface type units connected in series. This replacement was a temporary measure to supply water to the site; the motor/pump unit being severely mismatched to the PV array. Subsequently, more compatible 150813 DS McDonald pumps replaced it and the 150307 DS McDonald surface type units.

Table 2 Compares the design system and four configurations of the actual installation.

		Installed System Configurations			
	Design System	System No.1	System No.2	System No.3	System No.4
1. PV array (Wp)	940	752	752	752	705
2. PV model & Configuration		ARCO Solar M75/47 (4X4)	ARCO Solar M75/47 (4X4)	ARCO Solar M75/47 (4X4)	ARCO Solar M75/47 (4X4)
3. Rating of Motor/pump	1100	1100	300 X 2	1300	700
4. Pump model		McDonald 180809DM Submersible	McDonald 810203DJ Surface Mount	McDonald 150813DS Surface Mount	McDonald 150307DS Surface Mount
5. Piping Diameter (mm)	112	40	40	50	50
6. Power line (m) Ø 10 mm^2		400	400	400	306
7. Installed		Sep 89-Mar 90	Apr 90 - Apr 91	May 91 - Jun 93	Aug 93 - May 94

c) System testing and monitoring

After installation, three parameters were taken on a daily basis from 1989 – 1994, namely

- daily solar irradiation,
- daily volume of water delivered, and
- change in reservoir level

d) Results and discussions

System monitoring

- System No.1

The system was firstly installed in the first configuration (4 x 4 array, 180809-DM submersible pump) in September 1989. It was found out that in the beginning of 1990, daily flow rate gradually dropped despite high global radiation typical of the dry season in Thailand. The submersible pump unit stopped functioning in March 1990. A second unit of the same model was put in place. It again stopped functioning after a few weeks. The two units were sent to the manufacturer who later advised that a possible cause of failure was "dry run"; the motor running without water flow through the pump due to possible blockage of water inlet.

It was noted that due consideration on blockage prevention was made at the installation and during the operation. An additional screen was added to enclose the submersible pumps and regular cleaning took place. However, fine materials and silt could possibly slip through protective screens and therefore accumulated and subsequently blocked the inlet. It was observed that as the reservoir level dropped in the dry season, the water become murkier. Due to the changing quality of reservoir water throughout the year, it was decided that submersible pumps were not appropriate and surface mount units were selected. Moreover, surface mount units can be locally repaired. This is of utmost importance if PV pumps are to be used in rural areas.

- System No.2

As water was urgently needed during the dry season, surface mount units were secured on first available basis. This resulted in adopting 2 units connected in series such that the pump/motor characteristics were compatible with the available PV panels and the required head. This led to the second configuration (2 x 8 array, two 810203DJ surface mount units connected in series). The mismatch between the PV array and the motor/pump unit was quite substantial; the motor/pump unit drew large current at low voltage causing high losses in power line. These loses together with a lower motor/pump efficiency (in comparison to that of the submersible unit) resulted in low daily flow rate. The second configuration was in place between April 1990 – April 1991.

- System No.3

Replacement by the third configuration (4 x 4 array, 180513 DS surface mount type) took place between May 1991 – June 1993. It was found that the system functioned without any hitches. Silting did not cause the severe problems encountered with submersible pumps even though long-term system efficiency was observed to be continuously declining.

- System No.4

As the motor/pump of the System No.3 was oversized in comparison to the array wattage, it was replaced by a 150307DS surface mount type motor/pump in august 1993. The PV array was reconfigured from a 4 x 4 array to a 3 x 5 array for better matching.

e) Efficiency of the overall system

Fig 3 shows monthly averages of daily irradiation value and efficiency of the system under the four configurations. It is noted that rapid dropping of efficiency of System No.1 during the dry season was due to increasing silting of the reservoir and continuous blocking of water inlet of the pump. For System No.3, declining overall system efficiency over a 2 – year period could be discerned. This could also be attributed to silting problems.

Fig 4 plots daily hydraulic energy and daily solar irradiation for the system under the four configurations between 1989 – 1994. Linear regression analysis yields straight-line fittings whose slopes are average overall efficiencies of the system under four configurations. It is found that the average daily system efficiencies are about 3.9%, 1.1%, 1.8% and 1.1% for the first, second, third and fourth configurations, respectively.

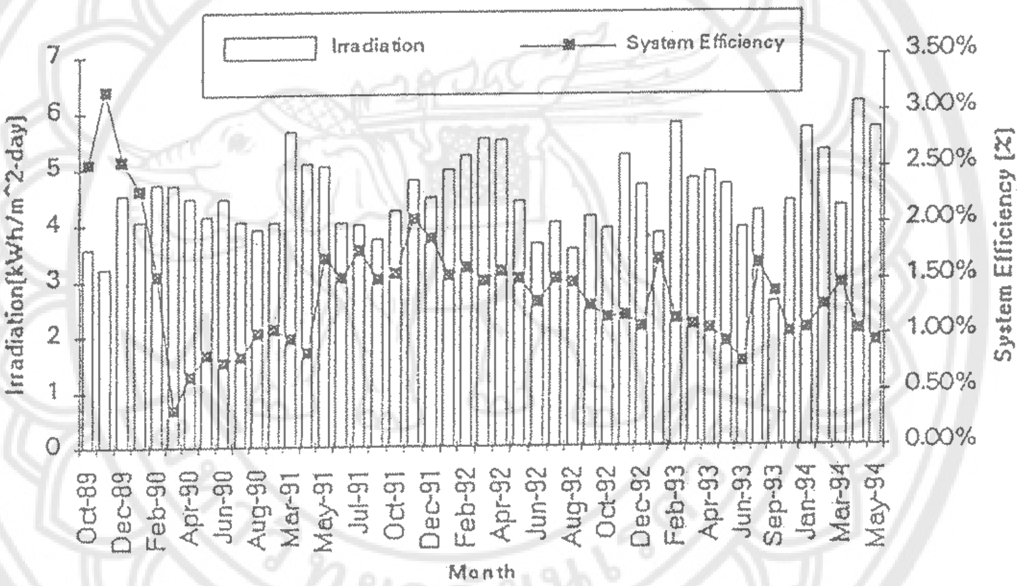
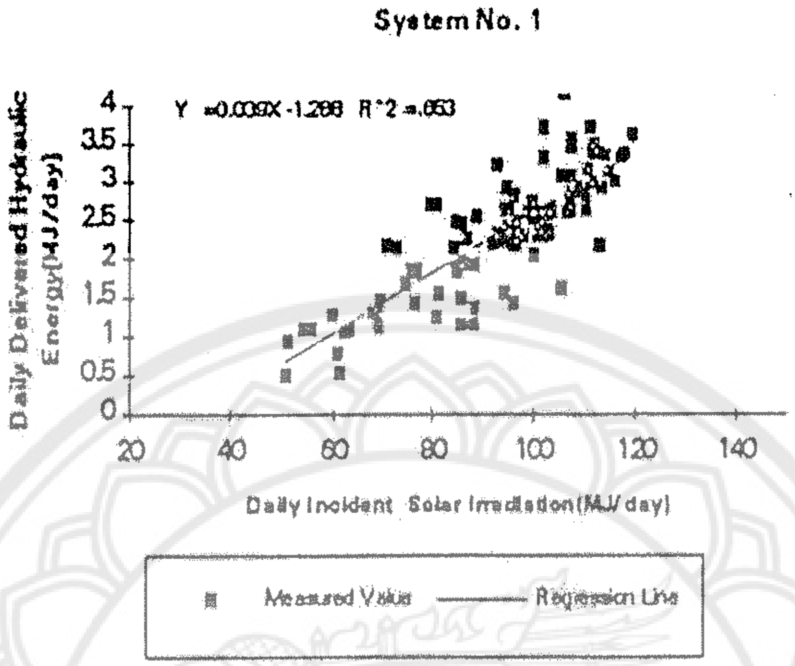


Figure 3 Monthly averages of daily irradiation value and efficiency for the 4 th configuration. (System No.1: Sep 89-Mar90, System No.2: Apr90-Apr91, System No.3: May91-Jun93 and System No .4: Aug93-May94).



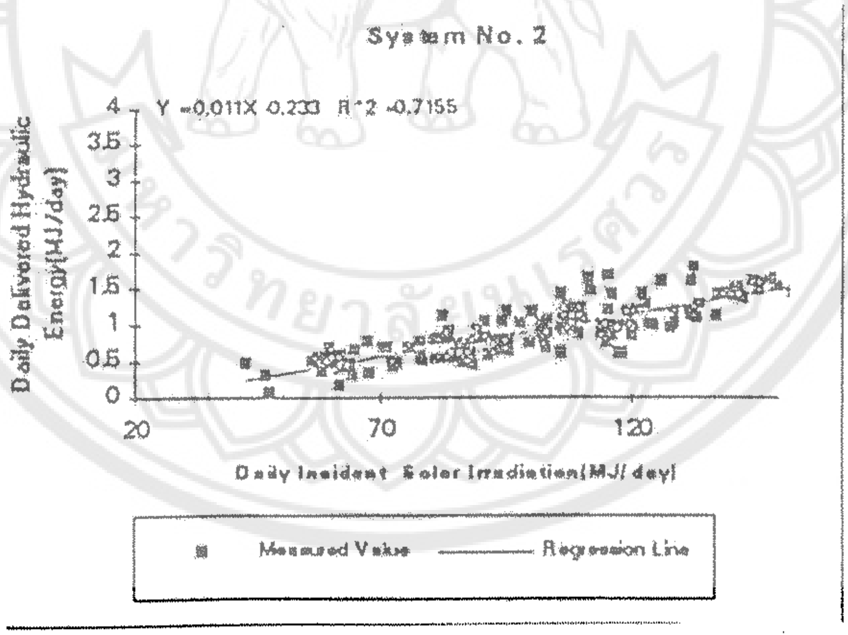
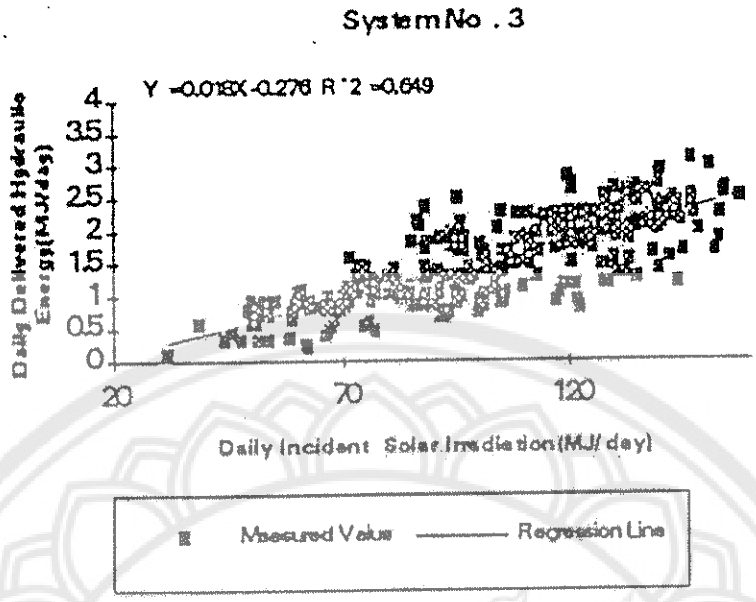


Figure 4 Comparison of daily delivered hydraulic energy and daily incident solar irradiation for four configurations.



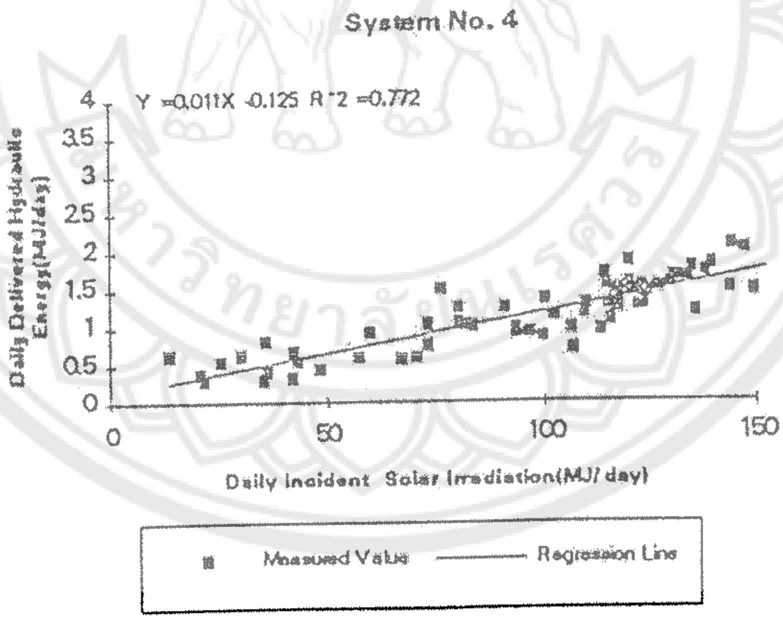


Figure 4 Comparison of daily delivered hydraulic energy and daily incident solar irradiation for four configurations. (con'd).

f) Conclusions

Field performance of four configurations of direct coupling PV water pumping systems for irrigation is reported. Submersible and surface mount type motor/pumps were employed at separate times. It is recommended that surface mount units would be more suitable for irrigation work due to the nature of reservoir water and ease of repair. Long term performance yields a unit water cost of about 13 Bhat/m^3.

Experience from the previous works

From study of the other PV water pumping systems it was found that:

1. From the study of the PV water pumping system at Nong Sanuan village which is studied in the dry period, the system consists of 16 modules with a nominal power of 55Wp each, for a total power of 880Wp. Eight modules are connected in series and two sets of these series connected panels further connected in parallel, a three-phase inverter of Grundfos type SA 1500 was used with a submersible centrifugal pump type Grundfos SP 5A-7. The study found that the system was designed to pump water at 20m^3 per day with a total head of 13 meters. As a result of this study, the PV water pumping system at the Energy park, Naresuan University was increased in its level of power of PV to 1.3kWp which consists of three parallel connected groups of eight 55Wp PV panels with those groups connected in series for a total of 24 modules. The type of inverter and pump are the same as at Nong Sanuan. When the power of PV was increasing the system was found to pump 30 m^3 of water per day.
2. From a study of the PV water pumping system at King Mongkut University of Technology Thonburi, it has a battery for power storage and distribution to motor/pump, but it pumps less water because the power decreases when connected the system with battery. From the study of the PV water-pumping system at the Energy Park, Naresuan University, the battery is not included because of the need to study amount of water with a batteryless system.
3. Form the study of the PV water pumping system at Lahansai, Burirum Province and Energy Park, Naresuan University, it was found that they have the same components. The system at Lahansai can pump water 29.27 m^3/day, but this Naresuan University system needs to provide water at about 30m^3/day and thus also can work at Lahansai.