EFFECTS OF CELL TEMPERATURES ON LONG-TERM EFFICIENCY OF PHOTOVOLTAIC ARRAYS IN A PV - HYDRO HYBRID SYSTEM

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ABSTRACT

The Electricity Generating Authority of Thailand (EGAT) has operated a grid-connected PV-hydro hybrid system since 1988. The PV sub-system, 20 kWp, consisting of ten PV arrays from ten different manufacturers, supplies a 250 V DC battery bank inputting to 250 V DC - 400 V AC invertors. AC output from the invertors is fed into the grid. Sourcing of PV modules from ten manufacturers was made with the intention of assessing them under actual field operation.

Readings of individual array temperature, array current and voltage, solar radiation and ambient temperature have been obtained on a one minute basis since 1988. An analysis has been made of efficiencies of the ten PV arrays, the cell temperature coefficient with respect to the ambient temperature and the sensitivity of the array efficiency with respect to the cell temperature. It has been observed that panels exhibiting high efficiency would have low cell temperature coefficients and low array efficiency sensitivity coefficients. Information on array efficiencies at Standard Test Condition as provided by PV suppliers are not good indicators of field performance of PV panels.

Given a large choice of available PV modules in the market, the results suggest that, prior to the selection of any particular manufacturer, a comparative assessment can be made by comparing the cell temperature coefficients and the module efficiency sensitivity coefficients of the different PV panels under consideration.

INTRODUCTION

Public utilities in Thailand began to install PV systems of moderate size (tens of kWp) in late 1980's. The Telephone Organisation of Thailand (TOT) installed up to 100 kWp for their repeating stations. The Provincial Electricity Authority (PEA) has operated 3 PV stand-alone, village electrification units totalling 150 kWp. The Electricity Generating Authority of Thailand (EGAT) has operated a grid-connected PV-microhydro system and a hybrid PV-wind unit.

In most installations, cell panels from the same manufacturer are used in each site. However, EGAT wishes to undertake studies on cell performance from different cell manufacturers, therefore modules from different manufacturers were deliberately acquired. Available technical details of modules at time of purchase were general specifications; of which only cell efficiencies at Standard Test Condition are provided. No data on fill factors or temperature behaviours are available.

Recently, data on the hybrid PV-microhydro system has become available and an investigation of the behaviour of PV modules from 10 different manufacturers over the period of 1988-1990 has been carried out.

SYSTEM DESCRIPTION

The system is located at Klong Chong-Kam Subdistrict, Watana-Nakorn District, Sa Kaew Province in eastern Thailand. The PV sub-system, 20 kWp, consisting of ten PV arrays from ten different manufacturers (U.S., Japan and Europe) supplies a 250 V DC battery bank inputting to 250 V DC - 400 V AC invertors. AC output from the invertors is fed to the grid.

Readings of individual array temperature, array current and voltage, solar radiation and ambient temperature have been obtained on a one minute basis since 1988.

ANALYSIS AND RESULTS

Hourly and daily average values of array temperature were calculated from one-minute readings. Corresponding array electrical outputs (fixed at the 250 V DC battery voltage level) and solar energy inputs were determined. Individual array efficiencies and the total PV sub-system (10 arrays) efficiency were subsequently obtained over the period 1988-1990.

Average hourly efficiency plots of four characteristic months, at equinoxes and solstices (see Figures 1&2) , show similar features that :

- o efficiencies rise with increasing radiation and cell temperature in the early part of the morning until about 10 a.m., and

- o thereafter, efficiencies level off, in most cases they decrease, whereas in a few cases an increase in efficiencies are noted, despite a rise in radiation and accompa nying cell temperature increase.

It is well known that there is an approximate linear decrease in the open-circuit voltage (Voc) with temperature. For Si, dVoc/dT is about -2.3 mV/°C. This causes power output and efficiency to decrease with increasing temperature. For Si, the power output decreases by 0.4-0.5% /°C.

As most radiation will be collected after 10 a.m.., the long-term cell (and array) efficiency will be largely determined by the sensitivity of efficiency with respect to the radiation (or cell temperature).

As a result, we further investigated this by calculating, as an example, such sensitivities of the 10 arrays over the period 1988-1990. The cell temperature of 45 °C is chosen as it is approximately the mid-point temperature between the on-set temperature when efficiency drops/levels off and the maximum temperature.

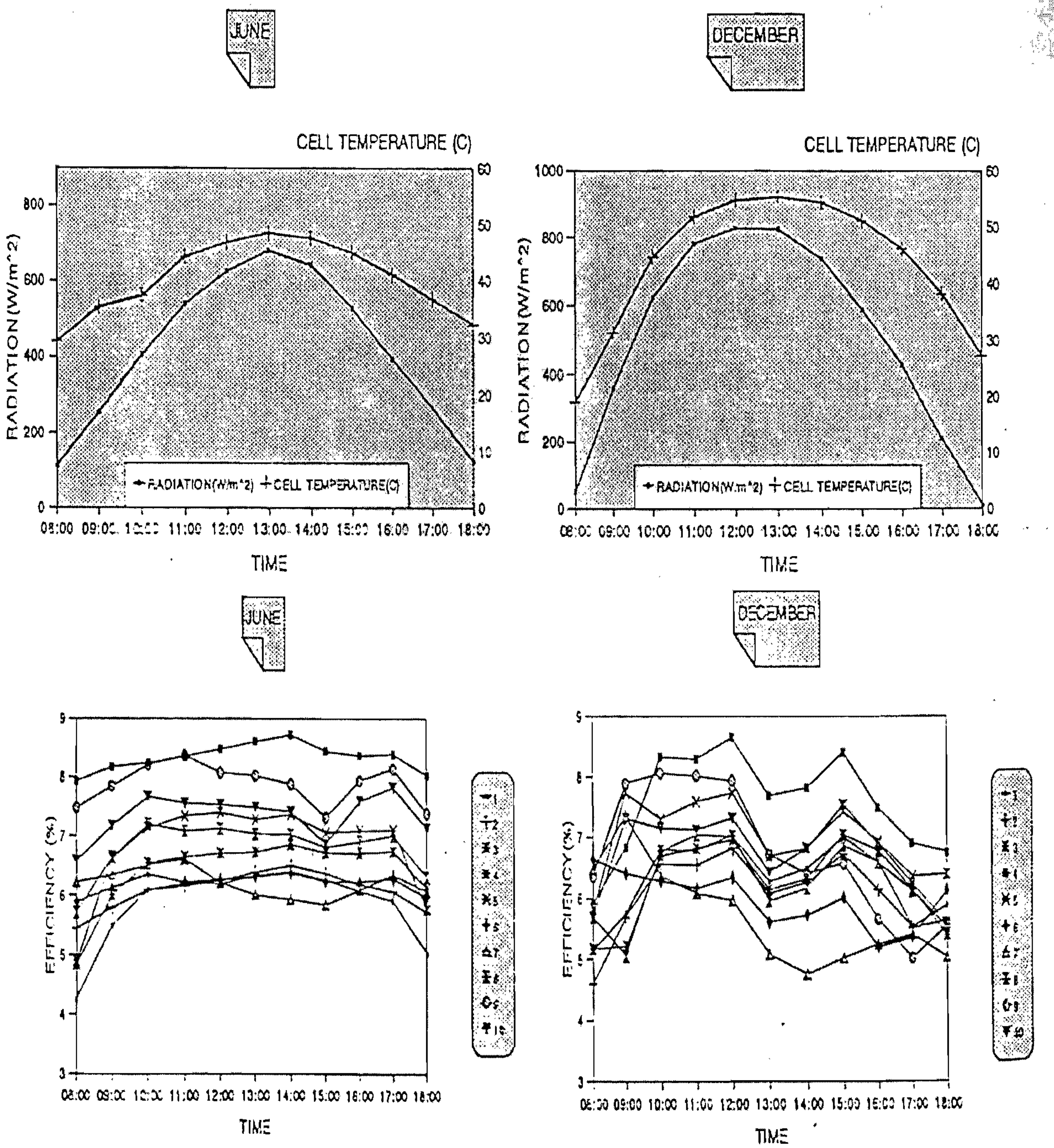

Figure 1. Average Hourly Radiation, Cell Temperature and Efficiencies at Solstice Months.

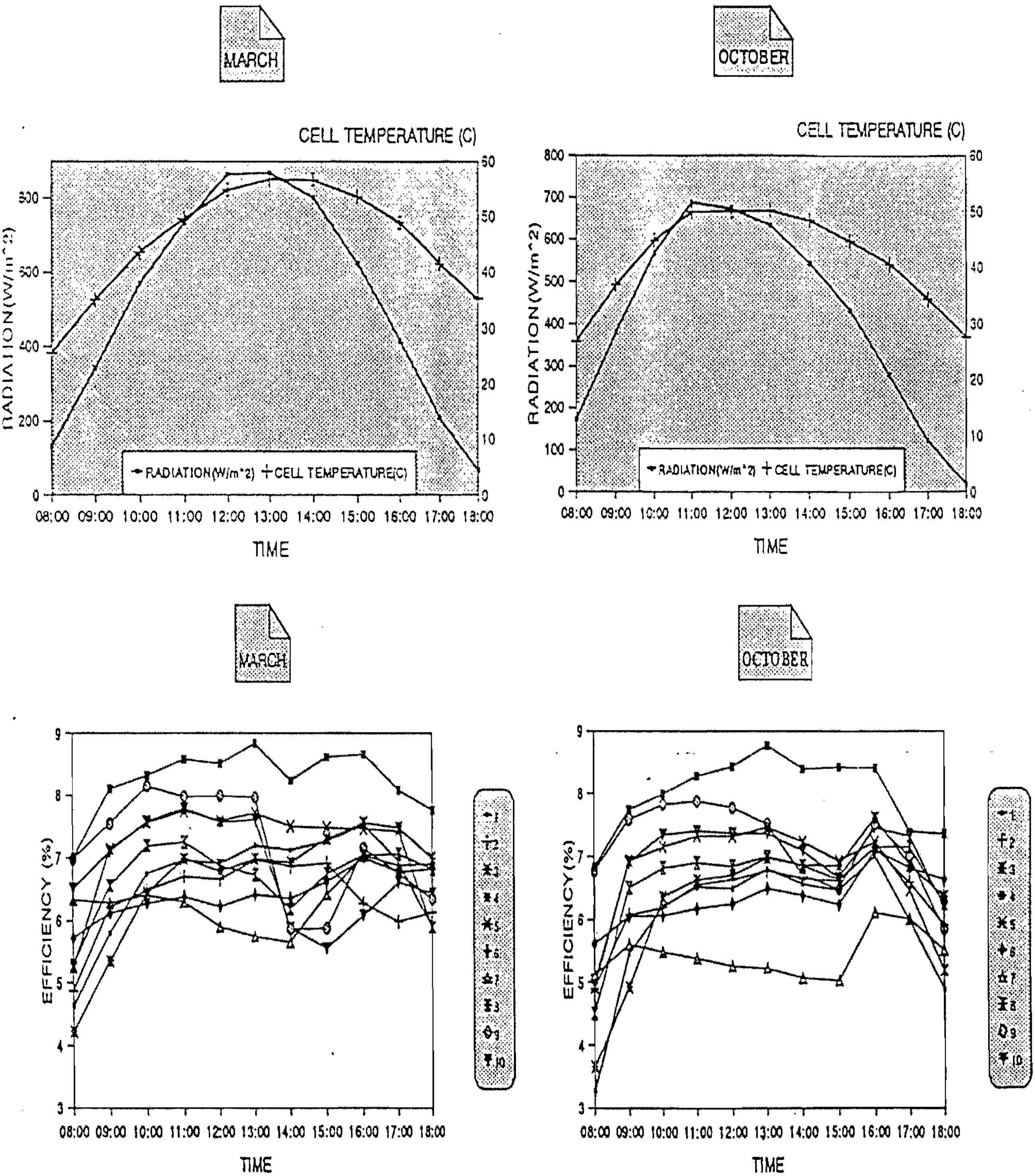

Figure 2. Average Hourly Radiation, Cell Temperature and Efficiencies at Equinox Months.

TABLE 1. CHARACTERISTICS OF PV PANELS AND ARRAYS FROM 10 DIFFERENT MANUFACTURERS.

Manufacturer No.	Type of Si cells	Wp	Module dimension (cm. x cm.)	No. of modules in array	Array dimension (m2)
1	poly	35.0	34.3 x 129.8	20	8.90
2	single	40.0	40.6 x 121.6	20	9.87
3	single	40.0	40.10 x 105.5	40	16.08
4	single	43.0	97.0 x 39.0	40	15.13
5	single	30.0	41.2 x 90.7	60	22.39
6	poly	38.4	45.9 x 107.6	60	29.63
7	poly	40.0	46.2 x 102.3	60	28.36
8	poly	40.4	45.7 x 100.2	60	27.47
9	poly	42.0	45.6 x 96.6	60	26.43
10	poly	42.0	44.5 x 98.5	60	26.30

TABLE 2. YEARLY AND OVERALL EFFICIENCIES (1988-1990) OF INDIVIDUAL PV ARRAYS FROM DIFFERENT MANUFACTURERS AND THE TOTAL PV SUB-SYSTEM.

Year	Manufacturer Number										Total PV sub-system
	1	2	3	4	5	6	7	8	9	10	
1988	5.95	6.48	6.58	8.21	7.31	6.19	5.99	6.83	7.67	7.38	6.68
1989	6.70	6.48	6.70	8.28	7.29	6.14	5.61	6.73	7.26	6.92	6.74
1990	6.78	6.58	6.77	8.46	7.31	6.39	6.02	6.90	7.72	7.48	7.01
1988-1990(a)	6.54	6.51	6.69	8.31	7.30	6.22	5.82	6.80	7.49	7.19	6.85
Efficiency at STC (b)	12.5	11.5	12.2	15.3	11.2	10.8	11.8	12.3	13.3	12.6	
(a) ÷ (b)	0.48	0.43	0.45	0.45	0.35	0.42	0.51	0.45	0.44	0.43	
Order of efficiency	7	-	4	-	2	8	6	5	1	3	
Order of efficiency sensitivity	6	-	5	-	2	7	8	4	1	3	

Comparison of long term efficiency of 10 arrays is thus made with the sensitivities (the slopes of efficiency with respect to radiation). It is clearly seen that, apart from array Nos. 2 and 4 whose efficiencies are significantly smaller and larger, respectively, than the remaining 8 arrays, efficiency sensitivity of arrays is a good measure of overall long-term efficiency.

From the work of M.D. Siegel *et al* (1981) and J.M. Gordon and P. Zoglin (1986) we can show that the overall cell efficiency, η , can be approximated by an equation of the form

$$\eta = a_0 + a_1 (T_a - T_R) + a_2 G_T$$

where η is efficiency average over a time interval

a_0 is a product of transmissivity of solar cell glazing and efficiency at reference condition

a_1 is the product of a_0 and temperature coefficient of the efficiency

a_2 is the product of a_1, solar cell optical efficiency and the reciprocal of solar cell heat loss coefficient

T_a and T_R are ambient and reference condition temperatures

G_T is the average radiation (over the same time interval as)

The array behaviour that we observe corresponds to the effects of the first and last terms in the above equation. Figure 3 shows the efficiency and radiation for the 10 manufacturers.

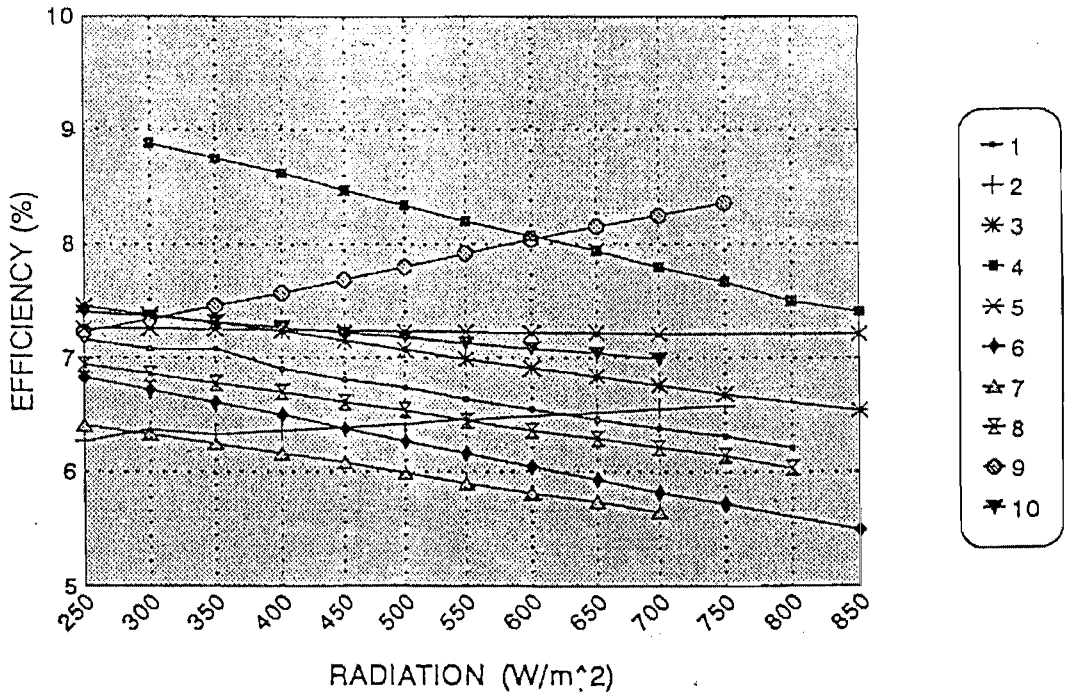

Figure 3. Efficiency and Radiation.

CONCLUSIONS

Given the large choice of PV modules available in the market and limited information provided by suppliers, it is suggested that a reliable comparative assessment of cell performance under field conditions, prior to bulk purchase, can be made by comparing radiation and temperature coefficients of different modules.

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