INITIAL RESULTS AND EXPERIENCES ENCOUNTERED FROM THE OPERATION OF TOTAL 40kWp GRID-CONNECTED PV SYSTEMS AT CRES

C Protogeropoulos[1], N Stasinopoulos[1], M Grottke[2] and D Schmitt[3]

[1]CRES – Centre for Renewable Energy Sources
Department of Photovoltaic Systems
19th km Marathonos Av., 190 09 Pikermi, Athens, Greece
Tel.: +30 21 06603370, FAX: +30 21 06603318, eMail: cprotog@cres.gr

[2]WIP – Renewable Energies Division
Sylvensteinstraβe 2, D-81369, München, Germany
Tel.: +49 89 72012737, FAX: +49 89 72012791, eMail: matthias.grottke@wip-munich.de

[3]AET Solion Ltd.
30, Alimou Str., 174 55 Alimos, Athens, Greece
Tel.: +30 21 09820885, FAX: +30 21 09820874, eMail: d.schmitt@solion.com.gr

ABSTRACT: This paper reports on the operational experience of a total of 40kWp photovoltaic systems in the premises of CRES at Pikermi. Six sites were identified for the installation of the arrays and all PV systems are grid-connected. Details on the DAS equipment installed for the monitoring of the parameters are given. The operational assessment is based on total energy produced from each subsystem over a year of operation and the corresponding yield and performance ratio calculations. The results indicate that performance of all PV arrays is within the expected limits.
Keywords: Building Integration – 1; Small Grid-connected PV Systems – 2; Module Integration – 3

1 SHORT DESCRIPTION OF THE PV INSTALLATIONS

The installations of the PV systems at CRES were designed and deployed following optimal BIPV integration techniques. These solar PV systems are considered as state-of-the-art installations and are exhibited to numerous visitors of the Centre, including educational missions from high schools, vocational and University level students. Additionally, an extensive usage of the systems has been done for the experimental work undertaken at CRES.

The PV systems were installed between August and October 2003 and were finally connected to the grid in November 2003. An exemption from the energy production licence was approved by the Regulatory Authority for Energy (RAE) in October 2003. Details on the design of the systems and the installations at CRES' premises were reported in [1].

The 6 sites were selected after meticulous investigations of the available areas, the outdoor infrastructure and the layout of the existing buildings of CRES. A summary of the PV systems of total 40kWp capacity is presented below:

Table 1: Summary of the PV installations at CRES

System ID	Site Description
CRES–1	Main entrance of the premises
CRES–2	Old parking area for vehicles
CRES–3	PV pergola at main building
CRES–4	Roof top of PV building II
CRES–5	Metal structure, south of PV building II
CRES–6	Solar curtain (façade) of the PV building II

2 DATA ACQUISITION SYSTEM

According to the contract of the project, a standardised Data Acquisition System (DAS) should be used by all partners in the consortium in order to achieve the necessary conditions for an overall PV technologies comparison assessment. The selection of meteorological equipment, voltage and current sensors as well as, the data logging configuration and software development for data retrieval were done by WIP. For each project participant, DAS configurations consisting of the commonly selected components were realised and developed to match the particularities of each PV system to be monitored.

The DAS for CRES comprises the equipment presented in the following Table 2.

Table 2: Summary of DAS equipment installed at CRES

	Sensor Type	Technical Characteristics	Description	Quantity
Meteorological				
Pyranometer	K&Z, CM 21	Range: (0 to 1400)W/m^2, ±2% FS	Global irradiance	1
Si-reference sensor & Pt	TNZ		PV array plane irradiance	3
Temperature Pt 100	Adolf Thies	Range: (–40 to +80)^{o}C, class B	Ambient temperature	1
Temperature Pt 100	Conrad		PV module temperature	3
Voltage / Current				
Shunt	M&Z		Array DC current	4
Resistor	M&Z		Array DC voltage	4
Current transformer	M&Z, WSWK	Accuracy: 0.5% to 1.0%	Inverter AC current	10
Current transformer	M&Z, WSWS	Accuracy: 0.5% to 1.0%	Inverter AC current	3
Energy / Power				
Energy / power sensors	M&Z, EZW	Precision: ±0.5% FS	Inverter energy, power	4
Energy / power sensors	EMH		Sub-system energy, power	3
M-Bus	EMH, PW3		Data handling (digital)	1
Energy sensor	EIZ	Class 1 or Class 2	System energy	3
Converters				
Isolated signal converter	M&Z, IgT/UgT - MU	Accuracy: ±0.5% FS	DC current, voltage sign.	8
Isolated signal converter	M&Z, Pt-MU		Temperature signals	3
Data Acquisition				
DAS	USB, UDAS	Resolution: 12bits (1 part in 4096)	Data logger	1
PC	Portable		PC with modem	1
Digital display	RiCo, GA2000		Large area display	1

The DAS connections' diagram for CRES–4 system is schematically presented in Figures 1 and 2.

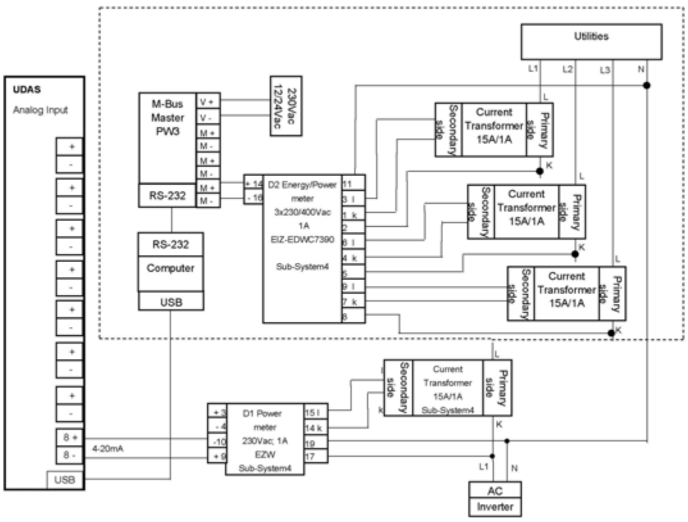

Figure 1: Sensors' layout for energy measurements in subsystem CRES–4

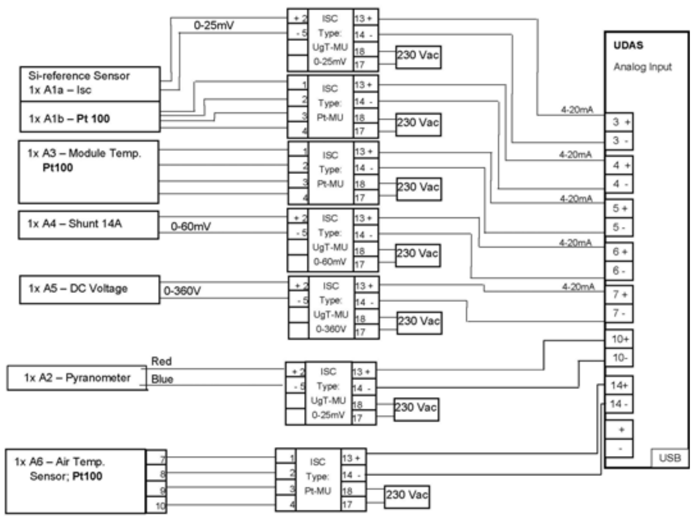

Figure 2: Sensors' layout for environmental parameters and power measurements in subsystem CRES–4

Monitoring requirements are classified into three categories, depending on the level of information required, namely,

- Class A: full monitoring and data storage of all parameters at inverter level (CRES–4 and CRES–5 systems)
- Class B: power at DC and AC level (CRES–1 and CRES–6b systems)
- Class C: kWh readings on analogue energy meter at sub-system level (CRES–2, CRES–3 and CRES–6a systems)

In Figures 3 and 4, details of the hardware equipment and parts of the DAS installations are presented.

Figure 3: CRES–4 inverters, pyranometer and ambient temperature sensors

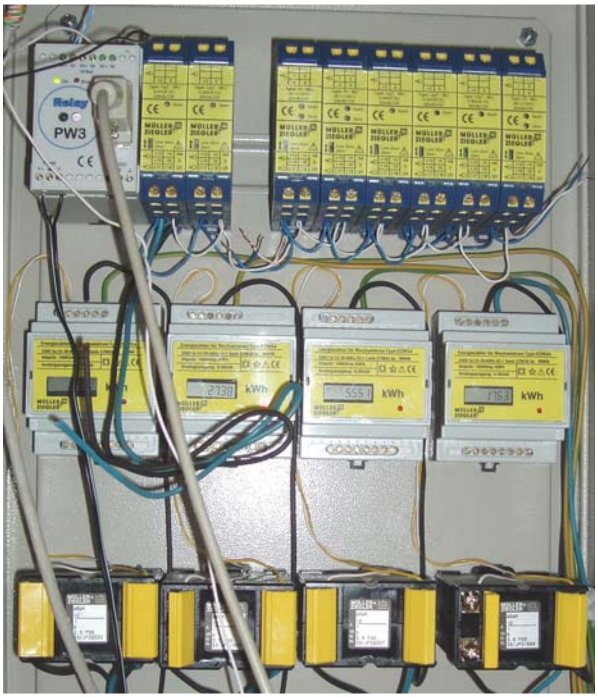

Figure 4: Energy meters, signal conversion devices and M-Bus

3 OPERATIONAL EXPERIENCES AND INITIAL RESULTS

So far, all systems operate satisfactorily and energy production is within the expected limits. The results obtained for the operation of the PV systems in the period 01.04.2004 to 31.03.2005 are summarised in Table 3.

Table 3: Yearly summary of PV systems characteristics and main operation parameters

System ID	PV capacity, [kWp]	Array Tilt and Orientation	Inverters, [No × kVA]	Energy Production, [kWh]	Specific Yield, [kWh/kWp]	PR, [%]
CRES–1	1.38	$\theta = 33^o$, $\psi = 0^o$ S	1 × 1200	Total: **1910**	1384.1	77.8
CRES–2	10.35	$\theta = 28^o$, $\psi = 0^o$ S	3 × 2500	4735, 4790, 4815 Total: **14340**	1384.5	78.0
CRES–3	6.21	$\theta = 20^o$, $\psi = 0^o$ S	3 × 2000	2960, 2955, 2925 Total: **8840**	1423.5	80.5
CRES–4	10.35	$\theta = 30^o$, $\psi = 22^o$ SW	3 × 2500	4725, 4765, 4680 Total: **14170**	1369.1	77.7
CRES–5	6.72	$\theta = 45^o$, $\psi = 0^o$ S	2 × 2500	4490, 4460 Total: **8950**	1331.8	77.5
CRES–6a	3.15	$\theta = 90^o$, $\psi = 22^o$ SW	1 × 2500	Total: **2720**	863.5	77.3
CRES–6b	1.89	$\theta = 90^o$, $\psi = 22^o$ SW	1 × 2000	Total: **1530**	809.5	77.1
Total:	**40.05**			**52460**	**1309.9**	

Notation in Table 3: θ = array tilt angle, ψ = azimuth angle, S = South, SW = South-West, PR = Performance Ratio

The performance ration PR is calculated by the following expression:

$$PR = \frac{Y_f / S}{\int (G \times t) dt} \qquad (1)$$

In equation (1), Y_f is the yield in [kWh], S is the PV array surface in [m^2], G is the global irradiance in [kW/m^2] and t is time in [h].

3.1 Performance Assessment

In CRES–1 system, the energy fed into the grid was measured 1910kWh, which results to an annual yield of 1377kWh/kWp. This value is considered as adequate energy output for the weather conditions in Athens. The calculated performance ratio is 77.8%, showing that system sizing has been done appropriately and the electrical components are compatible to each other.

Similar conclusions can be drawn for the CRES–2, CRES–3, CRES–4 and CRES–5 systems. In Table 3, the operation of the individual inverters is also shown for these systems. It is noticed, that the yield of every inverter is close to the average for each system and thus, uniformity in operation has been achieved.

For CRES–3 in particular, both yield and PR values indicate an exceptional system performance, which is due to the optimum array tilt angle of 20^o.

In CRES–4 system, the orientation towards south-west of 22^o does not seem to affect the annual performance.

The CRES–6 system is divided into 2 subsystems due to the differentiation on the DC module wiring and the inverter type. The relatively low yields of 863.5kWh/kWp and 809.5kWh/kWp respectively indicate that in Greece, façade PV systems have an annual performance of approximately 35% lower than those operating at array tilt close to the latitude angle.

4 CONCLUSIONS

Details of the DAS equipment used for monitoring the main parameters were presented in this paper. The operational data from the total 40kWp grid-connected PV systems installed at CRES show that the energy produced on an annual basis is satisfactory and within the expected limits.

ACKNOWLWGEMENT

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[1]. C Protogeropoulos, D Schmitt and M Grottke *"Building Integration of Total 40kWp PV Systems at CRES"*, Proceedings 19th European PV Solar Energy Conference, Vol. III, pp. 2931–2934 (2004)