Large Scale Evaluation of Photovoltaic Technologies in Different Climates

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Abstract: Most solar photovoltaic (PV) optimisation work to date has tended to take a reductionist approach, focusing on how individual parameters affect energy performance of systems. The impact of design choices on financial payback have been researched separately, thereby overlooking potentially significant interactions. This paper presents a project taking a more holistic approach to the problem of system optimisation. It is unique in taking a systems engineering approach to solar PV research, and recognises the needs of designers and specifiers in analysing the effect of design choices on financial payback. Four near-identical, grid-connected 200kW PV systems are being installed onto large commercial rooftops in urban areas, with comprehensive monitoring systems, therefore high quality data will be used to validate any models used. This paper reports on the initial set-up and the design of the scientific analysis.

Introduction

Large industrial energy users in urban areas wishing to switch to low-carbon energy sources are restricted in the choice of renewable energy sources they can use on site. Solar photovoltaic (PV) electricity generation is uniquely flexible for building added or integrated power generation due to a wide range of rooftop, façade and ground mounting options for PV arrays. The key commercial objective in implementing solar PV generating capacity is to achieve a short return on investment. This may be in conflict with assumptions made in the technical community that the key objective is to achieve optimum electrical performance. because achieving optimum electrical performance may come at a disproportionate cost.

There have been a number of previous medium to large scale PV comparison projects including:

- The UK "PV-Compare" Project [1].
- Collaboration between groups from Stuttgart, Cyprus and Egypt Universities, with arrays on the 3 sites [2],
- IFSH (Emmerthal) compilation of performance data from 334 grid-connected PV installations (part of IEA PVPS Task 2 project (International Energy Agency: Photovoltaic Power Systems) [3]
- The Japanese Mega-Solar project [4-5].

The need for multi-parameter optimisation

Previous solar PV comparison projects have focused on output as a specific yield (kWh/kWp) or performance ratio (PR). Comparison of kWh/kWp is of limited value to consultants and designers without also showing the relative costs, because the more efficient modules also tend to be more expensive, so this doesn't tell us anything about the actual cost of the electricity production by each module type, or offer a comparison of payback times. Research on costs of PV systems certainly exists, but indepedently of research on performance.

When designing systems for commercial buildings the system requirements are complex, we can design the system for maximum efficiency, but at what cost? This might require leaving excessive areas around the panels to minimise shading. However, this approach might not offer best value for money, if our one-off costs such as grid connection, and structural approval are essentially constant, then compromising slightly on shading might actually give a lower cost per kWh or shorter payback time.

At present there are no models available which consider all these effects together. The current tendency for system designers is to design PV arrays with spacing for maximum energy production, without detailed analysis of the precise effect on the system economics.

Figure 1: Photograph showing micro-amorphous PV modules on the site in Northern Germany.

This project is unique in taking a systems approach to solar photovoltaics. This means modelling, monitoring and analysing the system as a whole, and incorporating any interdependencies which may be overlooked by looking at individual parameters in a reductionist way.

Technologies

The PV modules of seven different manufacturers are being installed, including:

- poly-crystalline silicon (pSi),
- mono-crystalline (mSi),
- micro-amorphous (µaSi) silicon,
- triple junction amorphous (aSi)
- CIS (Copper Indium Diselenide).

The systems are being installed on large retail stores in Europe and North America at Latitudes from 37^o to 54^o North, in both marine and continental climates.

Figure 1: Triple junction amorphous modules during installation in Seville.

The systems will benefit from local feed-in tariffs or other incentives; hence a comparison of 4 different regulatory frameworks and solar incentives schemes will be possible. In particular, the project will compare financial performance between use of building integrated flexible amorphous panels, and the more traditional glass-based modules on tilted frames.

Monitoring system

CREST and Perpetual Energy Ltd have developed a new monitoring system to achieve the required data accuracy and resolution also to avoid dependence on inverter specific monitoring.

Data will include:

- DC electrical parameters
- AC electrical parameters
- Environmental variables

Data from each of the four sites in the programme is fed back to CREST in Loughborough using secure daily downloads - Figure 2 below.

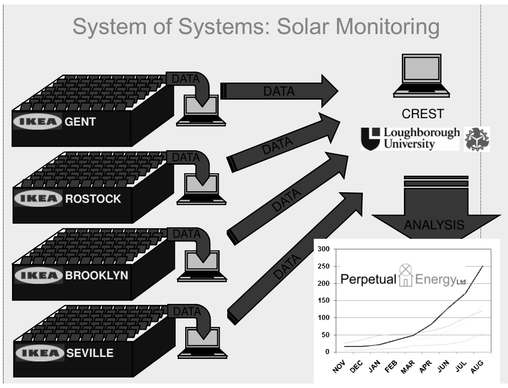

Figure 2: System of Systems (SoS): The CREST/PE worldwide solar PV data management system.

CREST is developing new database algorithms to process the vast amount of raw data and generate regular performance reports.

At each site, data from all the CREST/PE weather and power monitoring units is transmitted to a central site database server via an ethernet network (Figure 3 below). Battery back-up is provided for the network to provide high data availability.

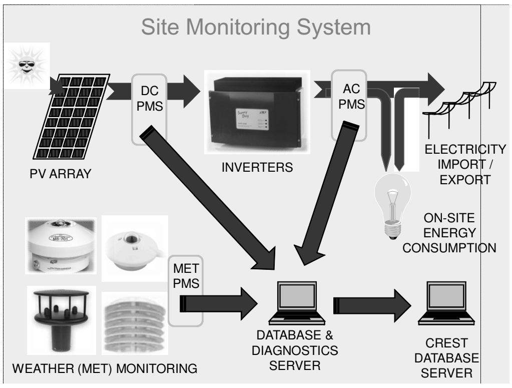

Figure 3: Monitoring system- simplified layout.

The DC monitoring units (Figure 4 below) record current, voltage and module temperature for every string of PV modules in the ~200kW systems.

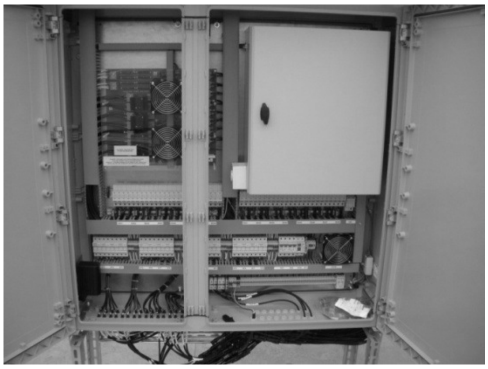

Figure 4: 14kW DC Power Monitoring Unit.

The DC monitoring unit incorporates surge protection and fuses or diodes as appropriate, short term data buffering is also provided. The monitoring unit can monitor up to 16 strings and 2 inverters.

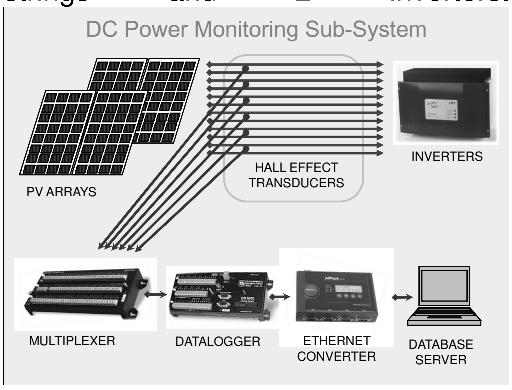

Figure 5: DC power monitoring

AC Power Monitoring Units (Figure 6 below) are installed between the inverters and the AC Distribution Board, these monitor the AC Voltage and current form each inverter. Hence efficiency of the inverter can be analysed with respect to for example module power point or ambient temperature.

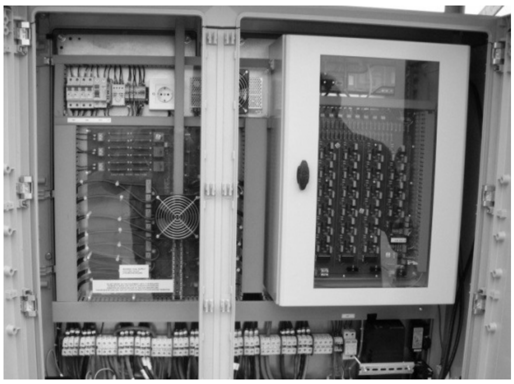

Figure 6: CREST/PE AC Power Monitoring Unit.

In addition to the high accuracy bespoke monitoring, the Inverter manufacturer's off-the- shelf monitoring system is also installed, this provides a second (albeit less accurate) data set against which to check any erroneous readings, it also enables inverter condition monitoring and remote fault diagnostics for researchers and technicians. In addition, it enables provision of a detailed real-time public display for the client's customers.

The following meteorological variables are also measured:

- High level wind speed & direction
- Array level wind speed & direction
- Ambient temperature
- Relative humidity
- Module temperature (for each string)

Optical parameters will be measured in plane of array and horizontally:

- Solar spectrum
- Irradiance (Pyranometer and reference cell)

Hence energy production by all the modules can be accurately measured, and used to validate current models for energy production, for the key technologies.

Site Installations

The PV systems at Rostock & Gent have now been generating electricity for use on site for 4 months, with any surplus exported to the local electricity network.

Full database operation for all 4 sites is expected to be completed within 6 months. Data will be recorded every 1 second for 18 months. Initial results from the programme will be published in due course

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