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Performance of High-efficiency Photovoltaic Systems in a Maritime Climate

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Introduction

Today more than 80% of all installed PV power in the UK is generated from grid-connected photovoltaic (PV) systems [1]. Currently the energy generated is not remunerated preferentially in the UK, but in the future the energy yield of photovoltaics will gain in importance over an ideal-case power rating. The challenge here is to design highly efficient systems in order to arrive at cost-effective PV solutions. Advances in PV have resulted in new high-efficiency modules being introduced into the marketplace, promising superior performance in terms of efficiency (i.e. kWh/m²) as well as specific energy yield (i.e. kWh/kWp). These promises can only be fulfilled if the complete system is able to capitalise on the advances in the module technology, as the BOS components play possibly the most significant role in the energy production in maritime climates. A programme to validate these promises has been started and initial work is reported. The long term aim of this research is to model not only the module performance with regard to irradiation, temperature and spectrum, but also their performance in grid-connected systems. The model will cover the whole system, from single modules, to DC-AC generation and mismatch. A measurement campaign has been designed to allow validation of the model.

Experimental Design

The study is set up to investigate the system performance of three commercially available high-efficiency technologies under real operating conditions in a maritime climate. In order to separate the effects that mainly influence system performance, the study consists of the following three stages:

- I. PV performance
- II. Module – inverter pair performance
- III. Full system performance

I. PV performance

A SPIRE 240A flash solar simulator (see Figure 1) at the Centre for Renewable Energy Systems Technology (CREST) is used to measure I-V characteristics of modules to characterise their performance under standard test conditions (STC).



Figure 1 Picture of the CREST SPIRE 240 solar simulator (left) with its control unit (right).

Such I-V characteristics were produced for each module under STC before their first outdoor installation to determine the effect of degradation from outdoor exposure.

The modules were then added to the CREST outdoor measurement system (COMS3) where outdoor I-V characteristics (including module temperatures) are measured in ten minute intervals. Environmental parameters are recorded every five seconds, including diffuse, horizontal, in-plane irradiance, spectra, ambient air temperature, relative humidity, wind speed and direction. For further details refer to [2].

II. Module – inverter pair performance

To investigate the effects of MPP-tracking and inverter efficiency on system performance two differently sized module inverter types were used (120W and 150W) with two different modules of the same technology at the same time. Each module - inverter pair will be referred to as a mini-system. Figure 2 shows a schematic layout of the mini system set-up.

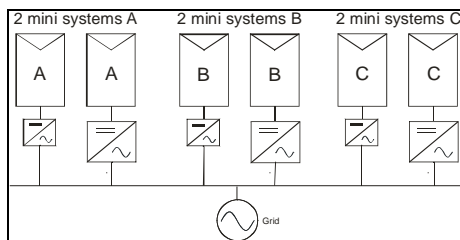


Figure 2 The mini-system set-up – each technology (capital letters) is connected to two differently sized inverters forming a mini system.

The measurements include DC and AC current and voltages, module temperatures and intermittent module I-V curves every 10 minutes. The data is collected via a National Instruments (NI) M-series DAQ card that is controlled by a LabView programme. In the figure below, a prototype data acquisition system for two mini-systems is shown.

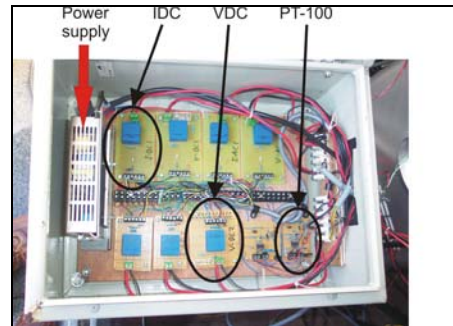


Figure 3 Test version of a mini-system to monitor IDC, VDC, IAC, VAC and temperatures (PT-100) from two high-efficiency mini-systems.

III. Full system performance

In the third stage of the monitoring study, the effects of PV arrays on system performance are investigated. Therefore, a PV system consisting of six 180Wp modules connected in 2 strings to an 850W string inverter has been monitored for one year.

The system was mounted on the rooftop of a four storey building in London, close to Waterloo station facing 10 degrees east of south and tilted at a 35 degree angle (see Figure 4).



Figure 4 Picture of a 1kWp high-efficiency system on a roof top in London.

Data from the system include DC and AC current and voltages, in-plane irradiance, ambient and module temperature. All measurements were taken at 30 second intervals with a NI Field Point FP-2000 data logger via three input modules: two AI-100 analogue input modules (8 channels, 12bit) for recording voltage and current signals and

a TC-120 thermocouple module (8 channels, 16bit).

Custom-designed voltage divider and Hall Effect transducer circuits were used for DC voltage and current measurements. AC current and voltage were measured with a Northern Design Multi Cube multimeter in combination with an industrial ring-type AC current transducer. The latter was soon abandoned due to non-linear response in the predominant current range. Figure 5 shows a photograph of the monitoring system in its enclosure indoors.



Figure 5 Picture of the monitoring system. The FP-2000 data logger (left) records DC current from a current transducer box (top right) and DC voltage from a voltage divider box (middle right). AC current and voltage are recorded from the output of a ND Multi Cube multimeter (bottom right).

In-plane irradiance was measured with a Kipp&Zonen SP LITE silicon pyranometer. A free-hanging thermocouple behind the array is used to record ambient temperature while thermocouples glued onto the backside of modules were used to record module temperatures.

The DAQ system was controlled by a LabView program running on a separate measurement PC that was also used for data storage.

Results and Analysis

I. PV performance

The figure below shows a screenshot of the programme used to extract parameters from SPIRE I-V measurements.



Figure 6 I-V characteristics for a Sanyo HIB 190Wp module measured in the SPIRE solar simulator.

The datasheet values for the module under investigation agree well within 4% of the results from the SPIRE measurements.

	Datasheet value	Measured value	Difference [$\pm\%$]
Pmax [W]	180.5-190	185.69	2.3 - 2.9
Voc [V]	67.5	66.31	1.8
Isc [A]	3.75	3.714	1
Vmpp [V]	54.8	52.88	3.6
Imp [A]	3.47	3.512	1.2

Table 1 Datasheet [3] and measured values for a Sanyo HIP-190BE3 module under STC. The values for maximum power (P_{max}), open-circuit voltage (V_{oc}), short-circuit current (I_{sc}) and the maximum power point voltage (V_{mpp}) and current (I_{mpp}) from measurement were extracted from a SPIRE I-V scan.

II. Module – inverter pair performance

First results from the monitoring of two mini-systems with the prototype monitoring system are shown in Figure 7. One mini-system consisted of a 120W Mastervolt Soladin module inverter and a 180W BP7180 monocrystalline module while the other one featured the same inverter but on two polycrystalline Kyocera KC80 modules.

The two hour sample indicates an average real PV efficiency of 9.7% (14.3% STC) for the BP module and 7.0% (14% STC) for the Kyocera modules. The comparatively low value for the latter is a direct result of shading which covered about 6% of the module surface. The average inverter efficiency for the Kyocera system is calculated at 95% and 88% which is interesting given the datasheet value of 93%. The system suffers from high levels of noise on temperature and AC signals which might be the cause for a higher than expected AC power. A suitable filter is currently being installed which is expected to improve the quality of the AC data significantly. However, long-term data will be needed to confirm the initial real performance results. The prototype has demonstrated though that the chosen monitoring method is suitable to collect the desired data from mini-systems.

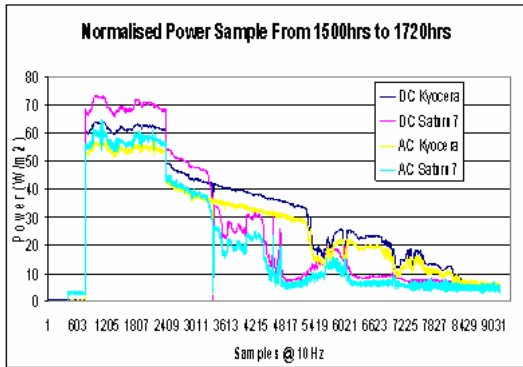


Figure 7 Prototype power measurements shows the typical power output for DC and AC power for two different modules. With a sampling rate of 10Hz the whole graph represents 140 minutes.

III. Full system performance

Outdoor I-V characteristics (see Figure 8) were measured for all the panels used in the 1kWp system before the installation of the system.

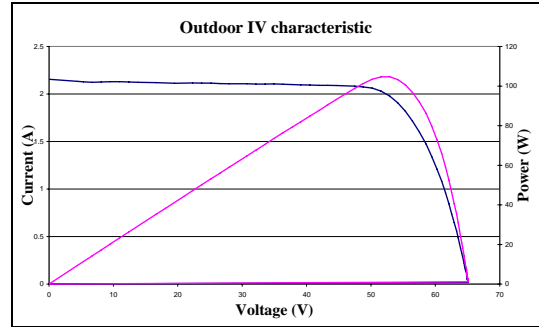


Figure 8 Outdoor I-V curve for a Sanyo HIP-J54BE2 module measured with a PVPM2540C I-V tracer in April. The module temperature was 39°C and the incident in-plane irradiance 553W/m². The next figure shows the normalised DC power generated for June with respect to irradiance.

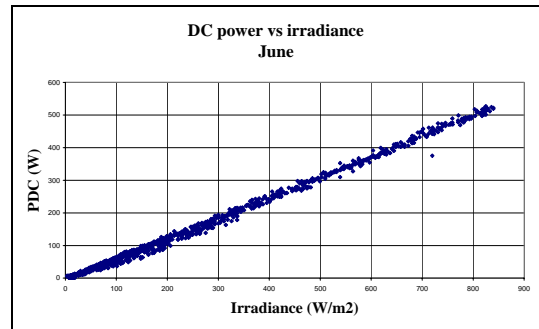


Figure 9 DC power generation over incident in-plane irradiance for June.

The specific energy yield for June was calculated to be 86.1 kWh/kWp compared to 15.1kWh/kWp for January. The variation in real efficiency of the module arrays with DC input power is shown in the figure below.

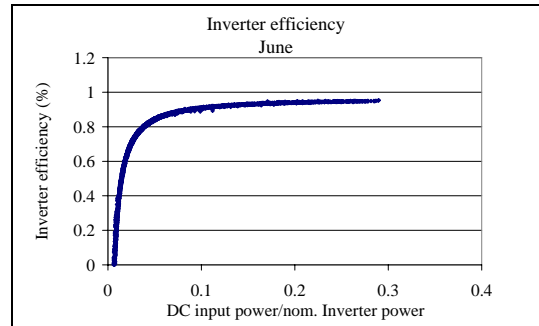


Figure 10 Inverter efficiency with respect to DC input power over nominal input power

The mean real DC efficiency is 16.9% in June and 16.8% in January.

The conversion into AC power is heavily dependent on incident DC input power which again depends on irradiance (see the figure below). The mean inverter efficiency was found to be 92% in January.

Conclusions

It has been shown that the chosen method of assessing outdoor system performance in three stages can indeed help to investigate separately the effects of module, inverter and array losses on real system performance. The performance data shows that high-efficiency technologies perform very well in real maritime conditions and efficiencies of nearly 17% have been observed. The power delivered to the grid is limited by the inverter performance which shows a significant decrease below 20% of its nominal power.

The data acquisition system for the mini-systems suffers from high signal noise levels and a filter is currently being installed. Also, the COMS3 environmental data will be available for all future measurements including the systems which will allow investigation into the spectral effects on system performance.

The generated data will be used as input to a novel model for system yield predictions, currently under development.

Acknowledgements

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