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# Analysis of a Flexible Measurement System for Outdoor DC Performance Testing of Photovoltaic Modules

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**Abstract:** The Centre for Renewable Energy Systems Technology (CREST) has been operating an outdoor measurement facility for testing photovoltaic (PV) modules since 1998. The facility is used to continuously measure the performance of a range of commercial and prototype modules, by scanning full I-V characteristics every ten minutes with synchronous measurements of ambient and module temperatures and broadband and spectral irradiance. The trend for increasingly high power PV modules and increased demand for channels has precipitated the next stage of development for the CREST system. This paper gives a technical description of the new system, followed by an appraisal of the performance of the upgraded measurement system. This encompasses commissioning and initial testing of the new system elements to quantify accuracy gains between the old and new versions.

**Key Words:** Monitoring, Performance, Environmental Effect

## 1 Introduction

Outdoor testing of photovoltaic modules is a vital part of the drive to improve device performance and ultimately to reduce the cost of electricity generated from solar power. While the solar simulator-based nameplate power rating under Standard Test Conditions provides a convenient method for comparing and pricing different modules, it is an assessment of device efficiency at only one, highly favourable, set of conditions. The consumer, however, is more concerned with the eventual cost of energy from a PV system and to estimate this figure, one needs to evaluate the likely energy yield over long periods. This is complicated by changes in the module (and inverter) efficiency due to factors such as temperature, irradiance, angle of incidence, spectrum and module degradation. Each of these factors is site-specific and/or weather-dependent and further, the module response is depends on the technology [1].

Outdoor monitoring and performance measurement is the basis for any energy rating approach which might be implemented to allow better comparability between different device technologies, as they are currently entering the market place. It should be a collaborative exercise, where data collected by many stations throughout the world can be pooled to develop, test and improve energy yield models. These provide useful tools to manufacturers and consumers, to improve financial calculations needed to purchase PV systems and to system designers, to improve the sizing considerations and better match modules to inverters (and batteries for stand-alone systems) [2].

## 2 The CREST Outdoor System

The CREST Outdoor Monitoring System (COMS-3) comprises four measurement sub-systems, for meteorological, spectral irradiance, low- and high-power photovoltaic device data acquisition (Figure 1). Each sub-system is controlled and the data logged by a unified LabVIEW-coded application running on a PC. The software manages data channel set-up, acquisition timing, data compression and storage and sends a

daily email notification of operating status (number of measurements made, error list if present).

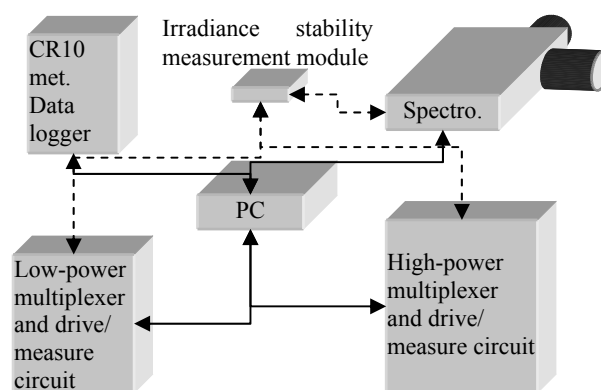


Figure 1: CREST Outdoor Monitoring System v3

Meteorological data acquisition is performed every 5 seconds with a Campbell Scientific CR10 data logger, using standard channel multiplexers to increase the number of channels of the base unit and a network linker module for Ethernet communication with the control PC. The logger runs its own software for channel sampling, with control over the uploading and execution handled by the host PC LabVIEW application.

The UK is a relatively high-latitude location for PV deployment, leading to large seasonal changes in incident spectral irradiance (e.g.: the minimum daily air mass varies from 1.2 in Summer to 4 in Winter). Such variation has a significant impact on the efficiency of wide band gap PV technologies such as amorphous Silicon (a-Si) or Cadmium Telluride (CdTe). For this reason, spectral irradiance is measured routinely (every 10 minutes) in the CREST system. Since May 1998 these measurements have been made with a twin detector (Silicon, Indium Gallium Arsenide) scanning monochromator, measuring from 300-1700nm at 10nm resolution. A second device, based on a CCD detector, is currently being commissioned.

Measurement of module current-voltage (I-V) characteristics has recently been improved. An older, 2-wire measurement system limited to 60W modules has been

augmented by a new 4-wire, 1kW subsystem with much greater flexibility in terms of measurement and loading, allowing a wider variety of research to be conducted. I-V and temperature measurements of each module are made every 10 minutes during daylight hours. Module electrical loading is varied with a 1kW, 4-quadrant power supply controlled by the PC. A voltage ramp, with maximum of 100V, is applied to each module, from reverse bias to exceeding the open-circuit point (allowing accurate extraction of short-circuit current, open-circuit voltage and the gradients at these points). Current sensing up to 10A is internal to the power supply, while independent voltage measurements are made in a separate, high-impedance loop to a high-voltage measurement module (thus the set-point of the power supply is not relied on as a measurement).

Due to cost considerations, the measurement system is operated with only one driving power supply, which necessitates the multiplexing of the 4-wire connection to each PV module. The high-impedance loops are switched through a commercial, high-density 2x64-to-1 multiplexer. Switching of the current (power) loop is performed by a custom-built multiplexer, made up of 64 2-pole electromechanical relays. These are double-throw relays, which switch each of the PV modules to a second pair of terminals while not undergoing measurement. This allows the connection of arbitrary loads to each channel in between I-V scans (e.g.: open-circuit with no connection, short-circuit with a bridging wire, fixed resistive load, connection to a maximum power point tracker, etc.). A schematic of the power relay switching is shown in Figure 2.

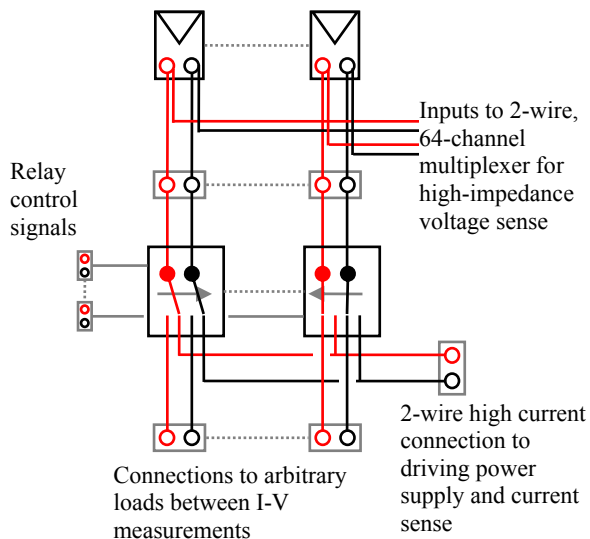


Figure 2: Schematic of the PV module connection

### 3 Error Analysis

The CM22 model pyranometer used in COMS-3 has a 95%-response time of 5s, and an overall declared accuracy for hourly irradiance measurements of 2%. The sensitivity of the CR10 datalogger is sufficient to measure the weak thermopile voltage signals directly, so the errors associated with signal amplification are completely removed. The inputs of the CR10 used for the thermopile measurement have a stated maximum error of  $\pm 50\mu\text{V}$  ( $\pm 5\text{Wm}^{-2}$ ) and a resolution of  $3.33\mu\text{V}$

( $\pm 0.4\text{Wm}^{-2}$ ). Combining the CM22 and CR10 errors yields an overall maximum error less than  $\pm 3\%$  for measurements exceeding  $500\text{Wm}^{-2}$ , rising to  $\pm 7\%$  at  $100\text{Wm}^{-2}$  for COMS-3. Laboratory testing of the input offsets suggests the actual error is lower than this worst-case estimate.

For the new I-V scanning sub-system in COMS-3, the only measurement taken directly from the Kepco unit is the current sense, with an output accuracy of  $\pm 0.1\%$ . This is combined with a measurement board analogue input accuracy of  $\pm 3\text{mV}$  to give an overall maximum error of  $\pm 0.3\%$  for current measurements down to 1A. The error in the voltage measurement is a combination of the same analogue input accuracy and  $\pm(0.14\% + 6.5\text{mV})$  from the voltage attenuator to give an overall maximum error of  $\pm 0.2\%$  for voltage measurements down to 10V. This compares with  $\pm 0.7\%$  and  $\pm 0.2\%$  for current and voltage measurements made with the old system (neglecting resistive losses). The results are summarized in Table I:

Parameter	Maximum Error
Irradiance	$\pm 7\%$ at $100\text{Wm}^{-2}$ , $\pm 3\%$ $> 500\text{Wm}^{-2}$
Module Temperature	$\pm 2^\circ\text{C}$
$V_{\text{OC}}, V_{\text{MPP}}$	$\pm 0.2\%$ at 10V
$I_{\text{SC}}, I_{\text{MPP}}$	$\pm 0.3\%$ at 1A
$P_{\text{MPP}}$	$\pm 0.4\%$
FF	$\pm 0.6\%$ (rel.)
Efficiency	$\pm 7.1\%$ at $100\text{Wm}^{-2}$ , $\pm 3.1\%$ $> 500\text{Wm}^{-2}$

Table I: Summary of errors in COMS-3

### 4 Conclusions

Considerable improvements in the capabilities of the CREST Outdoor Measurement System have been presented. The most significant may be summarized as the addition of a new high-power I-V curve measurement sub-system, allowing four-wire measurements of modules or mini-systems up to 1kW, with the facility to independently and arbitrarily load each test channel between I-V curve sweeps. Great reduction in measurement times for the pre-existing hardware has been achieved through a new choice of software control, increasing data availability previously reduced by temporal instability of lighting conditions. New sensors and logging equipment have increased the accuracy of critical meteorological parameters and PV parameters.

### Acknowledgements

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