Investigating Solar Power in Different Weather Conditions.

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Introduction

Advertisements for photovoltaic (PV) solar panels are everywhere, with those selling these devices claiming year-round electricity generation, whatever the weather. We wanted to test these claims and measure the specific impacts of a range of local climactic conditions – including cloud type and cover, and sky temperature – on the performance of PV panels. It is a topic of significant interest to our students, and relevant to the wider renewables debate.

The project was designed to run for 14 months: an initial two months of trialling PV arrays, and a full year's data collection. This was followed by analyses, conclusions, reporting and presentations. The chosen data for collection and analysis was PV panel power output across various times of day and during representative weather conditions for the region and times of year.

The project was funded by the Royal Society Partnership scheme. Our partner was the CSER (Centre for Solar Energy Research), which develops and manufactures novel photovoltaics. CSER hosted a visit for our students and participated in the informal assessment of the project. It was delighted to be involved with the project, stating that:

"The growing adoption of PV systems in the UK and the recent publication of the UK Solar PV Strategy Part 1: *Roadmap to a brighter future* by DECC, makes it timely for young people to learn more about renewable technologies such as Solar PV. The choice of location and the local weather conditions can have a significant impact on the performance of PV systems. Micro climates, spectral irradiance, temperature, general weather patterns, dirt accumulation and shading are all important factors to consider.

This project provides a fantastic opportunity for students to gain a better understanding of how PV systems work and the impact of everyday factors such as weather and module choice on the system performance. CSER are delighted to host a visit as part of this project to show the students a large scale PV system and also show some of the monitoring and weather data we use in our research activities."

The key learning outcomes of this project were that all participating students should achieve an improved grasp of a range of core experimental and data analysis skills, and increased confidence in how to plan, implement and communicate a detailed scientific project to a variety of academic audiences.

Specifically, all participating students (Year 9 – Year 13) should gain skills in:

- Electrical circuit creation (used to test the power output of a photovoltaic array);
- Infra-red thermometry (used to measure ground, sky and cloud temperatures);
- Cloud identification;
- Safe solar observation;
- Professional data collection and recording;
- Discussing and comparing their results with data collected (on different days, at different times, with different weather) by students from schools and colleges across the Borough of Halton.

In addition, the older students (Year 11 – Year 13) will gain skills in:

- Research programme planning;
- Design and investigation of different test circuits;
- Database creation (for a range of experimental results);
- Data analysis (to test the fundamental hypothesis of PV performance vs weather conditions);
- Preparing and professionally presenting the outcomes of their research to a range of audiences, including their peers, senior college management, the researchers at CSER, and members of the public at College open events.

Preliminary Investigations

Early experimental work used standard school 0.5 V photovoltaic devices with a fixed load resistance of 100 Ω. The test circuit was designed by Year 13 students. It only measured the voltage across the load as it was thought that making just one electrical measurement would be easier for younger students. This is not the standard method for characterising PV devices, which relies on current-voltage curves familiar to most students who have studied these for resistors, filament lamps and diodes. However, our approach did lead to additional insight that may not otherwise have been made. The first measurements were made by Year 9 students from a local school, and Level 3 BTEC Year 1 Applied Science students from Cronton Sixth Form College. The test circuit is shown in Figure 1. The aim of the experiment was to compare the power output on a cloudy day in December with data collected on a bright summer day.

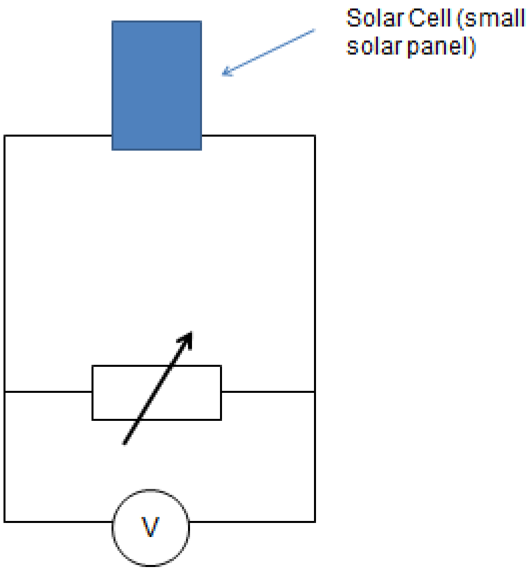


Figure 1. Test circuit.

This initial experiment used a 0.5 V photovoltaic cell (Rapid 37-0434) and a load resistance of 100 Ω. It took place on 5 December 2013 at 12.30. The weather was dull, wet and windy. The results are shown in Table 1.

	% power compared with July (clear and sunny)
Group 1	54
Group 2	57
Group 3	68
Group 4	61
Group 5	44
Group 6	30

Table 1. Results of the initial experiment using a 0.5V PV cell.

The next outing for the experiment was a local Astronomy Festival on 8 March 2014 organised by The Knowledge Observatory. This was a public science event at the Heath Business Park in Runcorn and was attended by students from Cronton Sixth Form, local schools and members of the public. It was the first time measurements were made with the 5V and 12V photovoltaic devices. The set-up is shown in Figure 2.

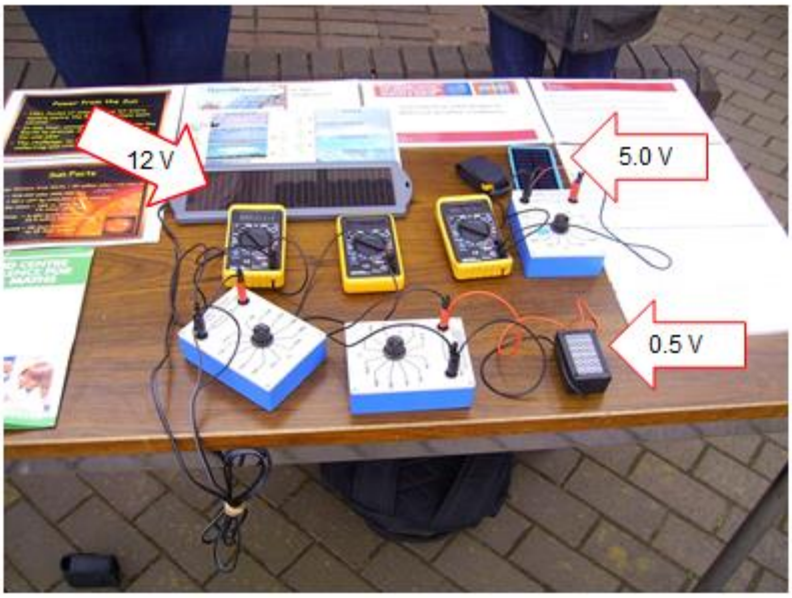


Figure 2. Experimental set-up at the Heath Astronomy Festival showing the 0.5 V, 5.0V and 12.0 V PV cells

We recorded a voltage and resistance for each experiment and found that under **continuous outdoor illumination**:

- For the 0.5 V PV array, the reading on the voltmeter was **constant** for all values of load resistance;
- For the 5.0 V PV array, the reading on the voltmeter **changed** when the load resistance was changed;
- For the 12.0 V PV array, the reading on the voltmeter **changed** when the load resistance was changed.

Figure 3 shows a graph of voltage against load resistance for the 5.0 V solar cell. Air temperature was measured using a standard school alcohol thermometer, sky temperature was measured using an infra-red thermometer, and the cloud types were identified using a Met Office resource (MetLink, 2016).

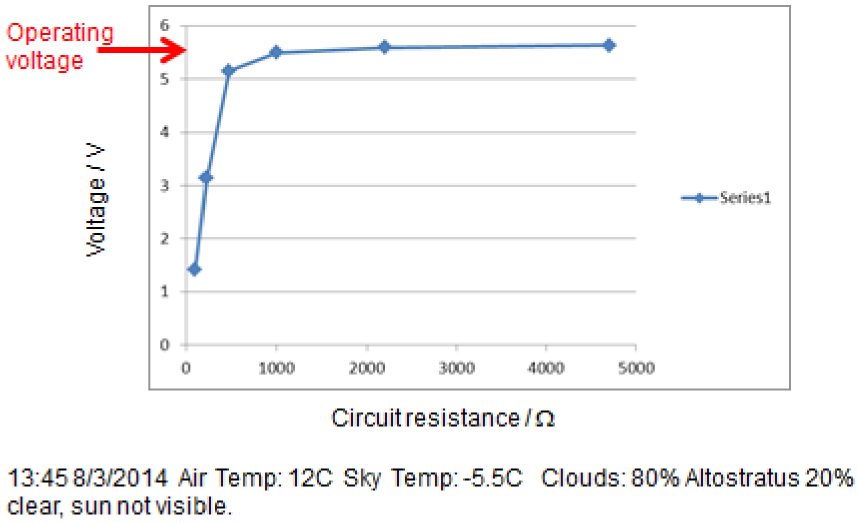
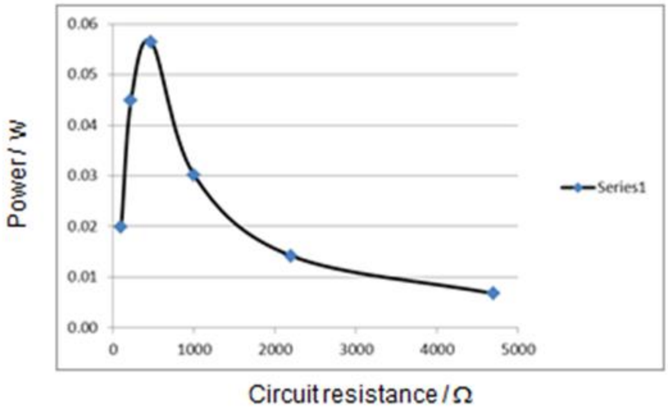


Figure 3. Voltage output from the 5.0 V PV cell as a function of load resistance.

Figure 4 shows the corresponding power output curve calculated using Equation 1.

$$P = \frac{V^2}{R} \qquad [Equation\ 1]$$

Where P is the power output from the PV cell in Watts, V is the potential difference generated across the cell, and R is the load resistance.



13:45 8/3/2014 Air Temp: 12C Sky Temp: -5.5C Clouds: 80% Altostratus 20% clear, sun not visible.

Figure 4. Power output from the 5.0 V PV cell as a function of load resistance.

The shape of the graph shown in Figure 4 is related to an electrical engineering phenomena called ‘load matching’, where the maximum power from a device in a circuit is achieved when the resistance of the load (circuit) e.g. a motor, lamp or resistor, equals the internal resistance of the power source, such as a PV cell. The peak in Figure 4 lets us estimate that the resistance of our 5.0 V cell, under the given illumination conditions, is approximately 500 Ω. To ensure that professional systems always achieve maximum power, they use a Maximum Power Point Tracking algorithm. This was beyond the scope of our experimental set-up, so instead we ensured we were careful in our choice of circuit resistor values, and always made measurements for a range of resistive loads using a standard school resistance substitution box, as shown in Figure 2.

With the initial set-up tested, and the requirements of load matching built into the method, we were in a position to define the experiment. Students would work in teams to:

- Record the air temperature, sky temperature, cloud type and coverage, and note whether the sun is visible or not;
- Measure the output voltage from a solar cell for different values of circuit resistance;

- Record the results in a table and plot a graph;
- Calculate the power output from the solar cell and find the peak power;
- Compare the results to the data collected in different weather conditions and at different times of the year.

The Main Experiment

In total, over 250 local students made solar power measurements, and a large amount of data was collected, much of which is still to be analysed. Figure 5 shows Cronton Sixth Form students demonstrating the equipment to representatives of the Royal Society, and Figure 6 shows some of the students who worked on the project.

Figure 5. Demonstrating the experiment to representatives of the Royal Society.

Figure 6. Cronton Sixth Form students demonstrating the experiment in the college Physics laboratory.

A couple of examples of our set-up and results are discussed below.

Example 1: International Sun Day

Students from Cronton Sixth Form attended a public event to celebrate International Sun Day. During the day they worked with members of the public to investigate the effect of passing cumulus clouds on the power output of the 5.0 V PV cells. The set-up is shown in Figure 7, and typical measurements in Figures 8 and 9.

Figure 7. The experiment at an International Sun Day event on Wigg Island, Cheshire.

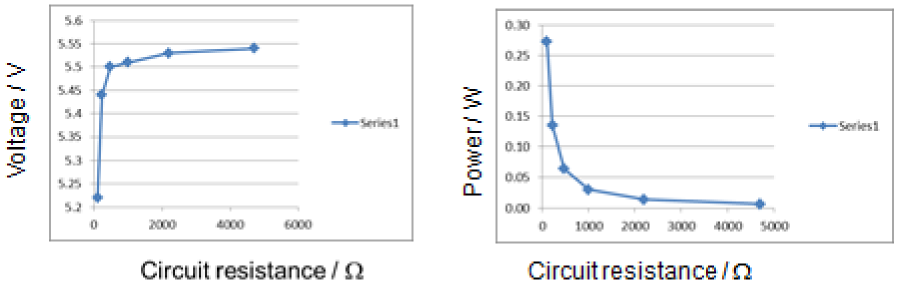


Figure 8. Potential difference and power output as a function of load resistance for a 5.0 V PV cell in direct sunlight.

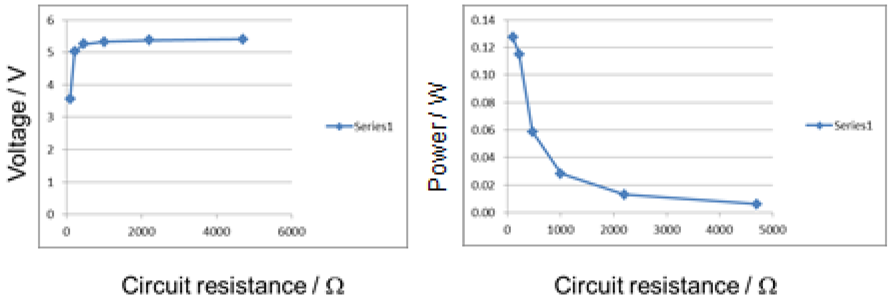


Figure 9. Potential difference and power output as a function of load resistance for a 5.0 V PV cell when the sun was behind a cumulus cloud.

From Figures 8 and 9, the students determined that a passing cumulus cloud caused the power output of the 5.0 V PV cell to drop to about half of that in direct sunlight. They also observed that the resistance of the PV cell under bright illumination was below the minimum load resistance on the substitution box of 100 Ω.

Example 2: Comparing Winter and Summer

Students compared the maximum power output for the 5.0 V PV cell at midday in November (sky temperature 3.4C, air temperature 8C, 100% covering of altostratus) with midday in June (sky temperature -17.8C, air temperature 37C, 30% covering of cumulus and a visible sun). The PV cells were facing the sky, and no account was taken of the lower altitude of the sun on the winter's day. It was found there was a 30:1 power output ratio between these specific June and November conditions. Students working on this part of the project were also able show that the peak power from the PV cell has an inverse relationship with sky temperature (measured with an infra-red thermometer). This result may be expected, as it is known that clear cloud-free skies have the lowest temperatures, but it is still of interest both for this project and for potential monitoring applications.

Benefits to participants

All of the students benefited from working in teams to investigate a real-world scientific problem and gain experience of building a circuit and making simple measurements – a skill that required some support and development in many of the Year 9 and 10 participants. Around 30 Year 12 and 13 students were also able to visit CSER’s fabrication and testing laboratories, where they spoke to staff about career opportunities in the renewable energy industry (see Figure 10).

Figure 10. Students visiting the Centre for Solar Energy Research

Cronton Sixth Form College is located in Widnes, a town famous for its historical links with the chemical Industry. Yet very few of our students have family members working as scientists, and many believe that the UK scientific industry is in decline. We hope that working on this project will encourage these students to study science at a higher level, and consider careers in the sciences. Several of the students who participated in this project are now studying Energy Engineering at university, and many of those who participated as part of our outreach programme are now studying A-level Physics with us. Interestingly, when questioned a year after completing the work, their strongest memory is of their surprise at measuring the temperature of clear bright summer skies at -20C or cooler. The students were also able to submit questions to researchers at CSER and the answers to these were shared with all participating schools. Finally, many of the students were able to share and present their work at public events, gaining valuable communication and outreach skills at college open evenings, local astronomy festivals and at the STFC Daresbury Science Festival.

Benefits to society

As the percentage of electrical power generated from renewable sources in the UK continues to grow, the National Grid will rely increasingly on weather forecasts to plan on an hour-by-hour, day-by-day and week-by-week basis. This is already common practice for wind power, and with the installed capacity of solar photovoltaics now exceeding 5 GW it seems increasingly likely that the impacts of the weather on the contribution from this source will also have to be predicted (MetOffice, 2016). Further to this, future moves to smart power grids and local micro-grids, and the fact that current monitoring techniques based on grid frequency are not applicable to non-rotating generators such as PV, make prediction and modelling of PV output over short timescales vital but challenging. Thus far, little work has been done on the effect of different types of cloud type and cover on the output power from PV devices, possibly because it requires a large amount of on-the-ground observational data collection. We propose therefore, that this project presents an ideal way for students across the country to not only practise valuable skills, but to make a significant contribution to UK scientific knowledge and to provide a potentially valuable resource to the UK energy sector.

The data collected during this experimental period is currently being collated and analysed. With more than 250 participants, it likely represents one of the largest 'PV power output vs climactic conditions' data set of its kind. But we acknowledge it is only a beginning. We would be very interested in hearing from teachers, students or other interested organisations with ideas and suggestions about how we could move forward with this, and widen the reach of the project.

References

MetLink (2016) *Clouds* Available at: http://www.metlink.org/secondary/a-level/clouds/

MetOffice (2016) *Renewable Energy* Available at: http://www.metoffice.gov.uk/renewables