



University of
South Australia

concept  creation

In association with
The School of Engineering Systems
Queensland University of Technology (QUT)
and
The Australian Power Institute (API)

Power & Sustainability Project Teachers Resource



The Power of Renewable Energy



Answers to all questions are printed in red.

Background

You graduated from QUT in 2005 with a B.Eng (Elec). You are a Power Engineer with a special interest in electronics. You have been successful in installing state-of-the-art systems in many modern situations.

You are also a Reservist with the Royal Australian air Force as a specialist Engineer to be called up within 48 hours to assist with disaster relief.



The situation

A severe earthquake disaster has struck the impoverished country of Haiti in the Caribbean.

You have received the phone call stating you will join with volunteers from RedRAustralia (www.redr.org.au) on a mission to restore water supply. You find yourself on a C-17 Globemaster with tonnes of supplies and 45 other specialist personnel heading to the Caribbean – they wouldn't let you take your surfboard!

In engineering, a realistic approach to problem solving is the PIST method – Problem Impact Solution Timing. These are presented as follows:





The problem

Two million people are left with no power station, hence no electricity.

Two million people in a hot country unable to pump water from their wells.

The Impact (you are to complete this section)

The solution

- Submersible pumps to pump the water out of the small diameter wells that are available across the country.
- Solar electricity panels to provide the electrical power to do the work in raising water to the surface. Sunlight near the equator is not a problem!

The Timing

Immediately and urgently. Water is a vital resource for sustaining life.



Your mission - To restore water to the victims of the earthquake

To do this, you will need to work out the best set voltage for pumping to give the greatest amount of water in a day, from sunrise to sunset.

Your task

(This section will be explained again on page 8)

The solar panels provided to generate electricity will be fixed in place above the water wells over a large area. Higher voltages, and hence higher flow rates, are only going to be produced for a short period of time around midday. Lower voltages and lower flow rates will be produced for a much longer period of time throughout the day.

Your task is to work out the best option:

1. High voltages, high flow rate for a short time.
2. Low voltages, low flow rate for a longer time.
3. Somewhere in between – but where, to get the maximum amount of water to two million people in the shortest time?

The solar panels in the earthquake zone have an electronic voltage regulator to preset the best operating voltage to operate the pumps so as to give the maximum volume of water per day.

Your research is to find out what the best operating voltage should be, but you will have to work through some 'plug and play' exercises and some strategies before you can determine the best option.

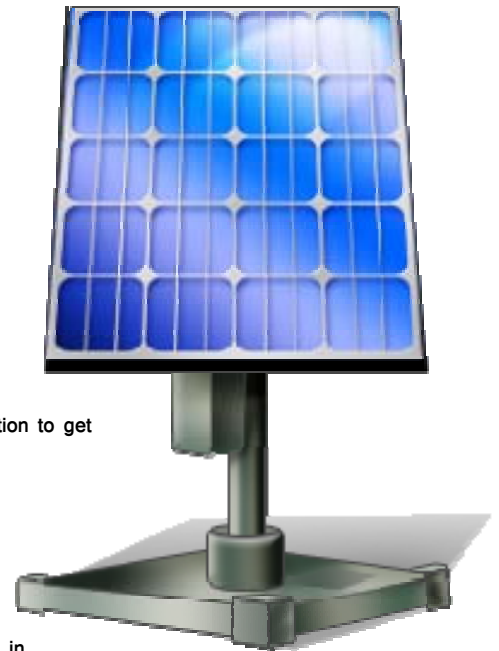


How solar panels convert sunlight to energy

Solar panels convert sunlight directly into electricity. Solar panels consist of several cells made up of at least two layers of semiconductor material. One layer is positive P type silicon (Si), the other layer is negative N type Si. When light energy enters the cells making up the solar panel, the energy from some of the photons from the light are absorbed by the semiconductor atoms, freeing electrons from the cell's negative layer (N type) to flow through an external circuit and back into the positive (P type) layer.

The electrons are made to move through a conducting wire connecting the P type Si to the N type Si. This flow of electrons produces electric current. The electrons on their way through the conducting wire can be made to do work before they return to the P layer eg pump water. The electrons return to the N type through the PN junction to get energised by light and start the process all over again.

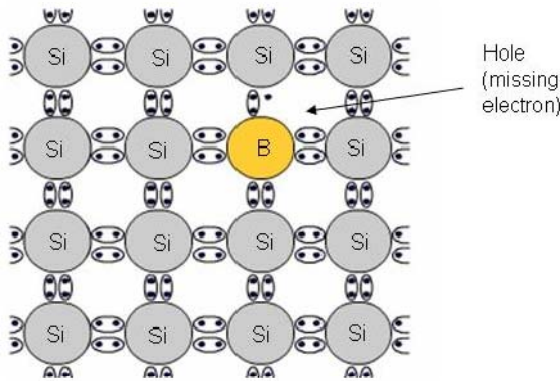
When two solar panels are wired together in series (don't try this yourself!), their voltage is doubled while the current stays constant. When two solar panels are wired in parallel, their current is doubled while the voltage stays constant. To achieve the desired voltage, solar panels are wired in series and parallel into what is called an array. Through a mixture of different series and parallel combinations, any desired voltage can be achieved.





The following extended explanation of how solar cells work is provided for use as required:

Silicon (Si), is a semimetal and has semimetal properties such as conducting electric current. Silicon does not conduct very well and does it in an unusual way. This unusual, poor conduction by Silicon is why scientists have been able to do so

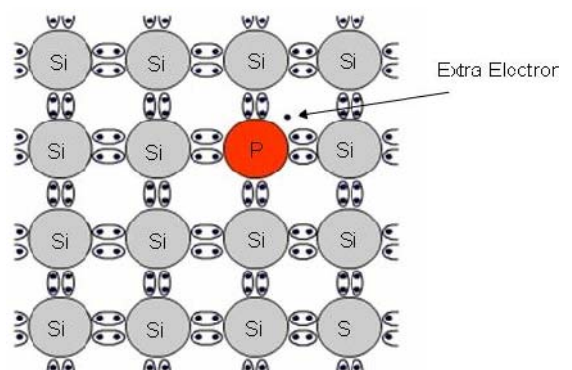


may useful things with semiconductors such as make solar panels.

Si atoms have four electrons in their outer energy level so when surrounded by four other Si atoms they share each others electrons leaving each Si atom with a very happy eight electrons and a very strong bond among the Si atoms forming hard Si crystals.

Scientists do mean things to Si crystals – they ‘dope’ the Silicon by removing a small number of Si atoms and substituting them with either Boron (B) atoms or Phosphorous (P) atoms. B atoms only have three electrons in their outer energy level. This leaves a very unhappy Si atom that now has only seven electrons in its outer energy level. This doped Si now has a space which will attract electrons, it is thought of as a positive space since it will attract a negative electron and the space is called a hole. This doped Si is now referred to as P type Silicon. P for positive.

P atoms have five electrons in their outer energy level. This leaves a very unhappy and unwanted electron. This doped Si now has an extra negative electron and is now referred to as N type Silicon -N for negative. Electricity is the flow of negative electrons.



Interesting things happen when P type and N type Silicon are put together forming the PN Junction. P type wants electrons and N type has too many electrons.

The unusual way the conduction of electrons across the PN junction occurs can be manipulated in many ways. One of these ways produces solar panels.



Plug 'n Play discovery session with Solar Panels

During this session **DO NOT CONNECT SOLAR PANELS TOGETHER IN ANY FORMAT AT ALL**. Doing this incorrectly, can damage solar cells making up the panel.

Try the following, recording your conclusions as you go.

1. **Orientation:** Set up the panel in the East→West direction. Does the output voltage change when you rotate the panel from East→West to North → South?



The readings should remain constant. Good discussion opportunity; students can share their findings.

What effect does it have on the output voltage when you tilt the solar panel?



This will definitely be a good discussion starter as students will get varying results depending on the direction of tilt.

Tilt towards the sun will produce higher V and I while tilting away from the sun will produce lower V and I. Use correct questioning to get the students to share their ideas and reach appropriate conclusions to explain their observations and varied results



2. **Load:** Connect a light bulb and switch into your circuit. Does the output voltage change when you close and open the switch?



When the switch is closed, ie under load, V and I should drop.

Introduce the concept of work – electrical energy being transformed into light and heat energy. Electrical energy per second = $V \times I$. If some of this electrical energy is being turned into other forms of energy then $V \times I$ must be a smaller quantity hence V and I must be smaller.

See if you can come up with a way of dimming the light bulb. What did you do to dim the light bulb?



Students run their hand back and forth over the panel, shading sections of the panel.

3. **Temperature:** Sit your solar panel on an ice pack. Does the output voltage change as the solar panel cools down?



Decreasing the temperature of the panel will reduce V and I. Whether this will show up in this experiment is open to discussion. It will depend on how long the panel is in contact with the ice pack and it will be interesting to see how different the change in temp has to be to get a noticeable effect.

Will solar panels work better in colder weather or warmer weather? Why?



The theory would suggest the panels will work better in warmer climates but by how much? The results of this experiment could be a good discussion starter.



4. **Light Frequency:** Place the RED filter over your panel and record the output voltage. Remove the red filter and place the BLUE filter over the solar panel and compare the output voltage. Light frequency is related to the colour of light.

Does light frequency alter the cells output voltage?



E = hf. Therefore the answer is yes. Will it show up significantly in this experiment?

Red is a lower f and blue/violet is a higher f, therefore the blue photons coming through the filter should transfer more energy to the electrons. More energy per second should show up as a higher V and I.



Some things to think about:



Does the **voltage** from a solar panel depend on the **intensity of sunlight** hitting the panel?

TEST THIS 1

Measure the voltage from your solar panel in full sunlight, while you are pumping water a height of 30cm. Record your voltage.

_____ Voltage = **eg, 14v** _____ volts (Transfer this data to the table on page 6)

Now place shade cloth over your solar panel and record your new voltage.

_____ Voltage = **eg, 8v** _____ volts (Transfer this data to the table on page 6)



Answer: Yes the panel voltage does depend on the intensity of sunlight hitting the panel.



Does the **Volume / minute** delivered by the pump depend on the voltage from the solar panel?

TEST THIS 2

Connect your pump to the solar panel and pump water for 10 seconds (use a stop watch) – measure and record the volume.

_____ Voltage = **eg, 12** volts (Transfer this data to the table in page 6)

_____ Volume = **eg 200 ml**

Now place shade cloth over your solar panel and record your new voltage.

_____ Volume = **eg, 6** volts (Transfer this data to the table in page 6)

_____ Volume = **eg 200 ml**



Answer: Yes the flow rate (volume /minute) does depend on the panel voltage.

Convert both of these measurements to L/minute



$(200 \div 1000) \times (60 \div 10) = 1.2 \text{ L/min}$ $(10 \div 1000) \times (60 \div 10) = 0.66 \text{ L/min}$

How does the sun move?

Movement of the Sun relative to the Earth can alter the Sun's intensity just like shade cloth. The Sun moves relative to the Earth. Generally we think of the Sun as being stationary and the Earth rotates on its axis, completing one rotation every 24 hours.



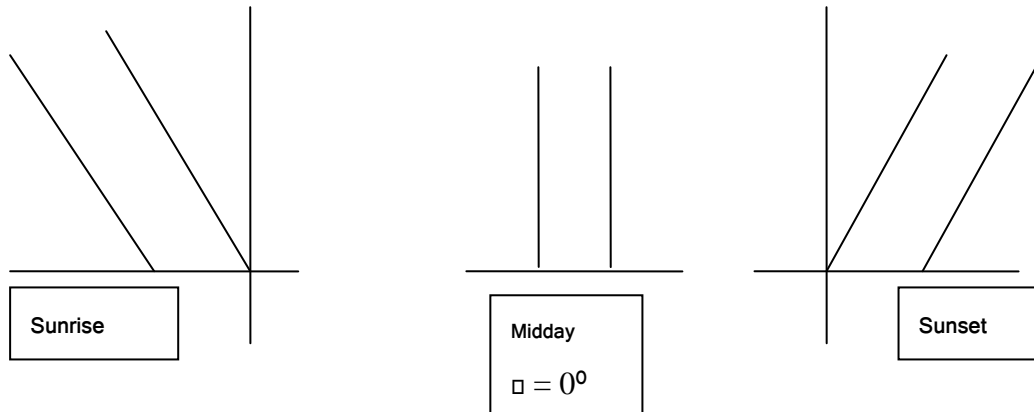
The Earth rotates from West to East. Most (non-sciency) people on Earth tend to think of the Earth as being stationary and the Sun doing all the moving. Therefore the Sun appears to be moving from East to West.

That is, the sunrise is in the East and sunset is in the West.

Using a model, Sunrays may be represented as parallel lines. At sunrise/sunset and at midday the lines (sunrays) are the same distance apart BUT not when they hit the Earth's surface. The greater the angle θ for example early morning or late afternoon the greater the distance between the lines at the Earth's surface, that is, the lines are not as intense, indicating the Sun's intensity is not as intense.

EAST

WEST



Measure the distance x between the Sun's rays striking the Earth's surface at sunrise, midday and sunset. What is happening to the intensity of the sunlight during the day as time goes by from sunrise to sunset?



The sun's intensity at sunrise increases to a maximum around midday and then decreases to a minimum at sunset.



What is happening to the solar panel voltage as the angle θ decreases?



As θ decreases the solar panel voltage increases.



What is the maximum value of angle θ 90° and minimum value of angle θ 0°

Will the same value of angle θ in the morning and in the afternoon generate the same solar panel voltage?

Yes _____

Why are we told to stay out of the sun between 10am and 3pm?

This is the most intense period of sunlight – good for solar cells NOT good for skin cells. Skin cancer prevention.

Why are we doing the main experimental stuff with you out in the sun at this time?

What would be the best time of day to really be doing the experimental stuff?

Around 12 midday

Why? This is when the sun's intensity is at its maximum.



Assuming sunrise is 6 am and the sun is directly overhead at 12 midday.

What is angle θ at 6 am? _____ **Close to 90° in a flat desolate region.**

What is angle θ at 12 midday? **Close to 0°**

How many hours have gone by

between 6 am and 12 midday? **6 hours** _____

On average, by how many degrees

does θ change per hour? **$90^\circ \div 6 \text{ hrs} = 15^\circ/\text{hr}$**



You will have noticed the solar panel voltages produced in **TEST THIS 1** are higher than the solar panel voltages produced in **TEST THIS 2**:

Results table for **TEST THIS 1**: and **TEST THIS 2**:

TEST THIS	Conditions	Full sunlight Voltage (Volts)	Shade Voltage (Volts)
1	Not pumping water (No Load)	14	8
2	Pumping water (Under Load)	12	6



Can you explain these results? **Under load electrical energy is being transformed into gravitational potential energy as work is being done raising water. Heat energy would also be an unwanted energy transformation as well.**



In Summary

You fill in the blanks!



- A. Lower sun intensity produces ___ **lower** _____ solar panel voltages.
- B. Lower solar panel voltages produce ___ **lower** _____ flow rates.
- C. Larger angle \square produces ___ **lower** _____ sun intensity, which produces ___ **lower** _____ solar panel voltages, which produces ___ **lower** flow rates.

THE CONVERSE IS TRUE – you write three statements showing the converse relationship.

- A' **Higher sun intensity produces higher solar panel voltages.**
- B' **Higher solar panel voltages produce higher flow rates.**
- C' **Smaller angle \square produces higher sun intensity, which produces higher solar panel voltages, which produces higher flow rates.**



The Task

The solar panels will be fixed in place above the water wells over a large area. You now know higher voltages, and hence higher flow rates, are only going to be produced for a short period of time around midday. You also now know lower voltages and lower flow rates will be produced for a much longer period of time throughout the day.

Your task is to work out the best option:

4. High voltages, high flow rate for a short time.
5. Low voltages, low flow rate for a longer time.
6. Somewhere in between – but where, to get the maximum amount of water to two million people in the shortest time?

The solar panels in the earthquake zone have an electronic voltage regulator to preset the best operating voltage to operate the pumps so as to give the maximum volume of water per day.

Your research experiment is to find out what the best operating voltage should be.

List all the variables:

Solar panel voltage. Height the water is to be raised. Type of solar panel. Type of pump. Sun intensity. Time. Volume of water raised.

List the variables to be investigated:

Voltage and Volume of water raised.



List the variables to be controlled and how to control them.

- Height the water is raised - have the same fixed height for all groups to raise water
- Type of solar panel - All groups have the same panel make and pecification.
- Type of pump - All groups have the same pump make and specification.
- Sun intensity - All panels facing the sun with the same orientation at all times – achieved by the slow rotation of the surface holding all panels.
- Time - Is controlled at 1 day. This may take some explaining as students will see pumps operating for different lengths of time. Each group has the same time to produce water – sunrise to sunset, even though their pump may stop pumping.

Your solar panel has a voltage regulator so you can preset your voltage to be investigated. In order to speed up the data collection, each group's solar panel will be attached to a flat surface that is able to be manually rotated so as to represent or mimic the movement of the sun.

Set up your equipment as instructed making sure you control all the variables not been investigated.

Record the time your pump is pumping water_____

Group	Voltage V	Volume mL	Group	Voltage V	Volume mL	Group	Voltage V	Volume mL
1	5.5		6	8.0		11	10.5	
2	6.0		7	8.5		12	11.0	
3	6.5		8	9.0		13	11.5	
4	7.0		9	9.5		14	12.0	
5	7.5		10	10.0		15	12.5	

Graph your results. Volume (y axis) VS Voltage (x axis)



Light Intensity

One way to increase the intensity of sunlight is to tilt the solar panel to face the sun so that the sun's rays hit the panel at 90°. Another is to concentrate the sun's energy by use of mirrors.



You have two 'mirrors' about the same size as the solar cell. Can you think of another way to increase the sun's intensity falling on the solar panel?



Do not reflect the sun directly into the face of other students as this can cause eye damage

TEST THIS

With the back of the panel facing the sun, use one mirror to reflect the sun onto the solar panel. Record the panel voltage _____v.

Now using the two mirrors, reflect the sun onto the solar panel. Record the voltage. _____v.

Is this the result you expected? _____



Can you explain the result? _____

With the front of the panel facing the sun, record the panel voltage _____ v .

In order to reflect sun onto the panel, you will have to work out how to use the two mirrors, being careful not to cast a shadow over the panel.

Record the panel voltage _____ v

Mirrors are used in real world situations to increase the intensity of sunlight falling on solar panels. Mirrors are permanently set up so as to reflect some extra sunlight. Check out U-tube, Solar PV mirror concentrators.