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Foundations of Photovoltaic and Wind Power Systems

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INTEGRATION environment & energy

January 2009

1. Converting solar energy to electricity

Classroom key topics

- What is solar power?
  - Solar radiation (solar constant)
  - Movement of the sun and irradiance (direct, diffuse)
- Converting solar power to electricity
  - Make up of a solar cell
  - From solar cell to solar panel

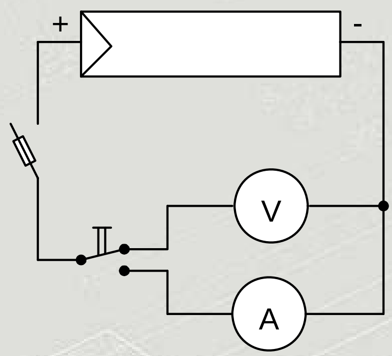
Experiments

Objective: Understanding the correlation between irradiance and open circuit voltage (Voc) and short circuit current (Isc).

The available irradiance at a given location changes with the time of the year, the time of the day, and the weather conditions. Those changes can be recorded with a pyranometer (which measures the solar radiation flux density) by taking measurements in intervals throughout a day (or month/year). We will show the correlation of irradiance and two key parameters of solar panels, Voc and Isc, by setting the solar panel at different angles to sun.

Preparation: Wire a solar panel according to the diagram. Put the solar panel flat on the ground, pointing the long side in the direction of the sun.

(use a digital multimeter)

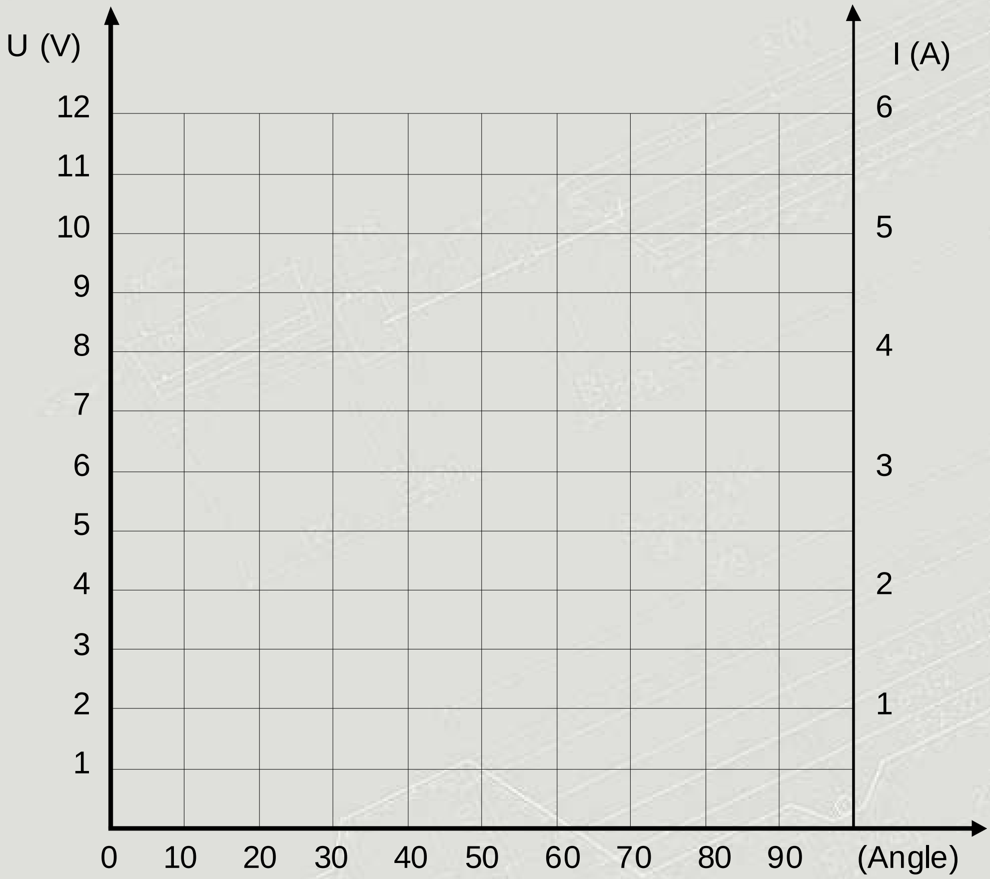


Wiring diagram 1

1. Measure alternately the open circuit voltage (Voc) and the short circuit current (Isc) with a digital multimeter. (They should not be measured at the same time. Why?) Raise the panel in 10 degree steps to the upright position and take measurements.

Angle	Voc (V)	Isc (A)
0		
10		
20		
30		
40		
50		
60		
70		
80		
90		

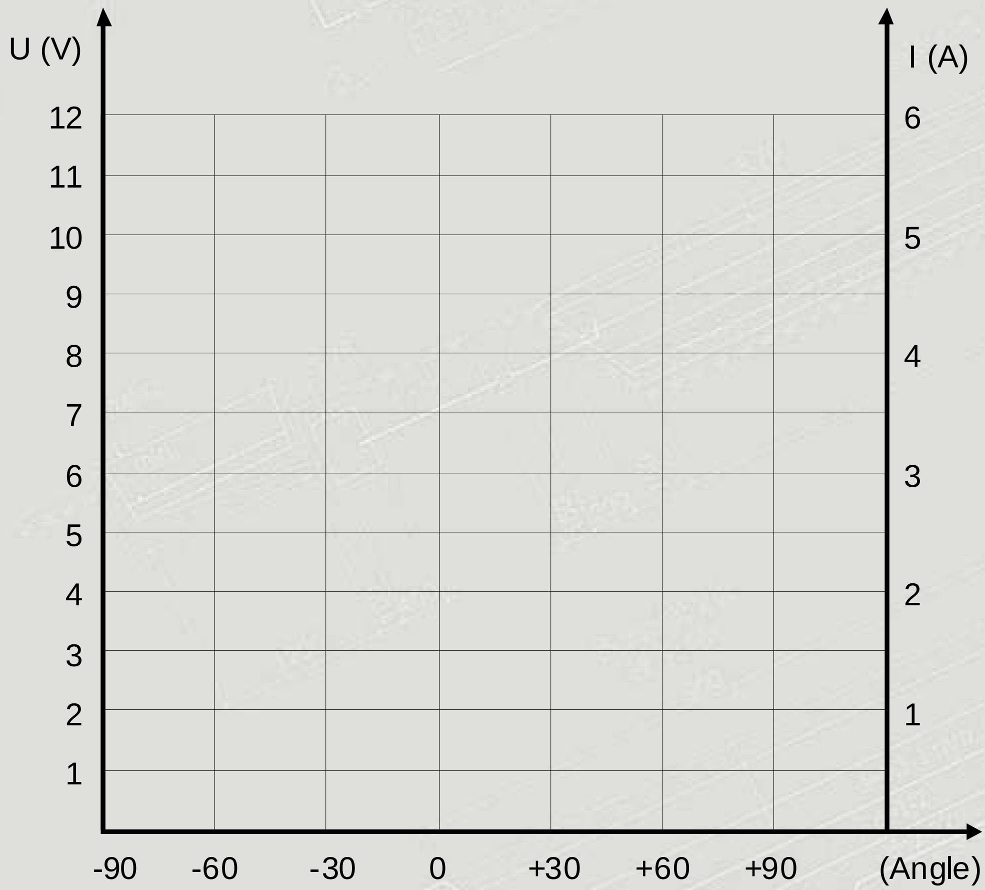
Question: For a fixed installation, which angle should the panel be set to, to maximize power output?



Diag 1: Voc, Isc in dependence of vertical inclination

2. Set the panel in the position which yields the maximum current, directly facing the sun. This time move the panel horizontally in three 30degree steps first towards east and then towards west.

Angle	Voc (V)	Isc (A)
-90		
-60		
-30		
0		
+30		
+60		
+90		



Diag 2: Voc, Isc in dependence from the horizontal orientation

Data interpretation

1. Draw the diagrams (2 curves per diagram)

2. How can the relation between irradiance and the open circuit voltage and the relation between irradiance and the short circuit current be characterized?

3. Calculate the deviation of the minimum current values from the maximum current value in per cent:
   d = 100 * (MaxCurrent – MinCurrent) / MaxCurrent
   for both series of measurements.

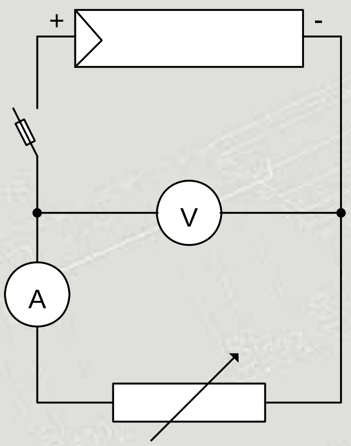
2. Connecting solar panels for higher power output

Classroom key topics

- Rating of solar panels (Peak wattage)
- Connecting solar panels for higher voltage and/or current
- Influence of cell temperature
- Partly shadowed cells
- Optimizing: Tracker and MPPT

Experiments

Objective: Understanding the load characteristic of solar panels, serial and parallel connection, the effects of shadowing of cells and cell temperature.



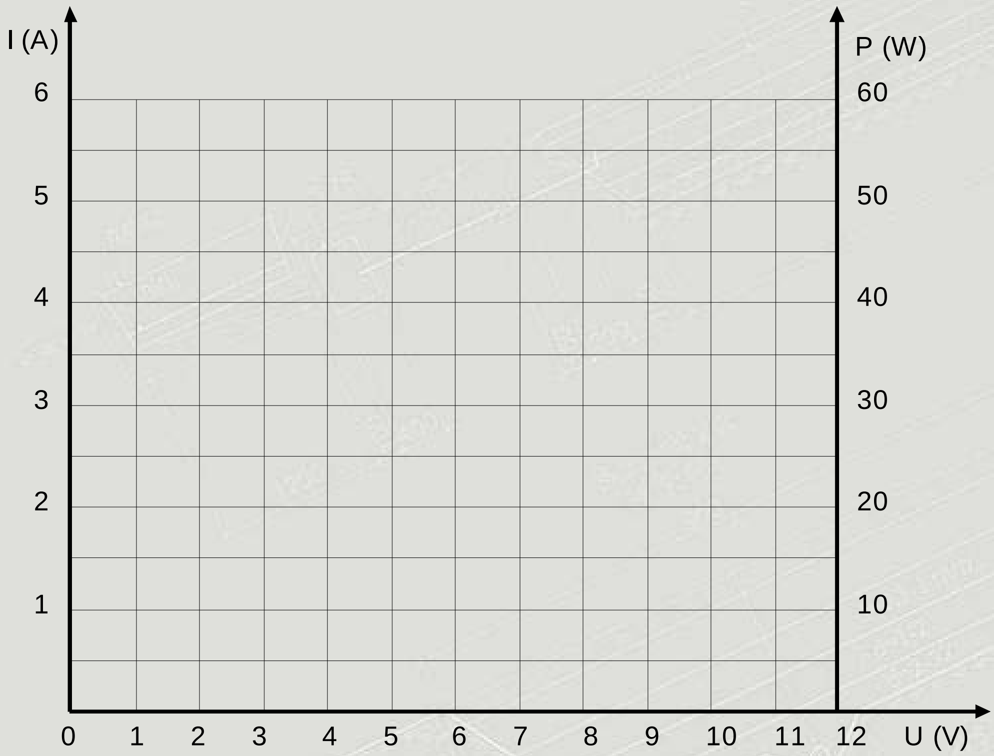
Wiring diagram 2

Preparation: Wire a solar panel according to the diagram. Point the solar panel towards the sun to get maximum output.

1. Measure and record the open circuit voltage in column 0 (ampere meter and resistance temporally disconnected). Starting with a high resistance value move the slider to lower values until you get a first reading of the current. Record voltage and current and take about 10 more measurements, moving the slide of the resistance in even intervals to zero.

	U (V)	I (A)	P (W)
0		0	0
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			

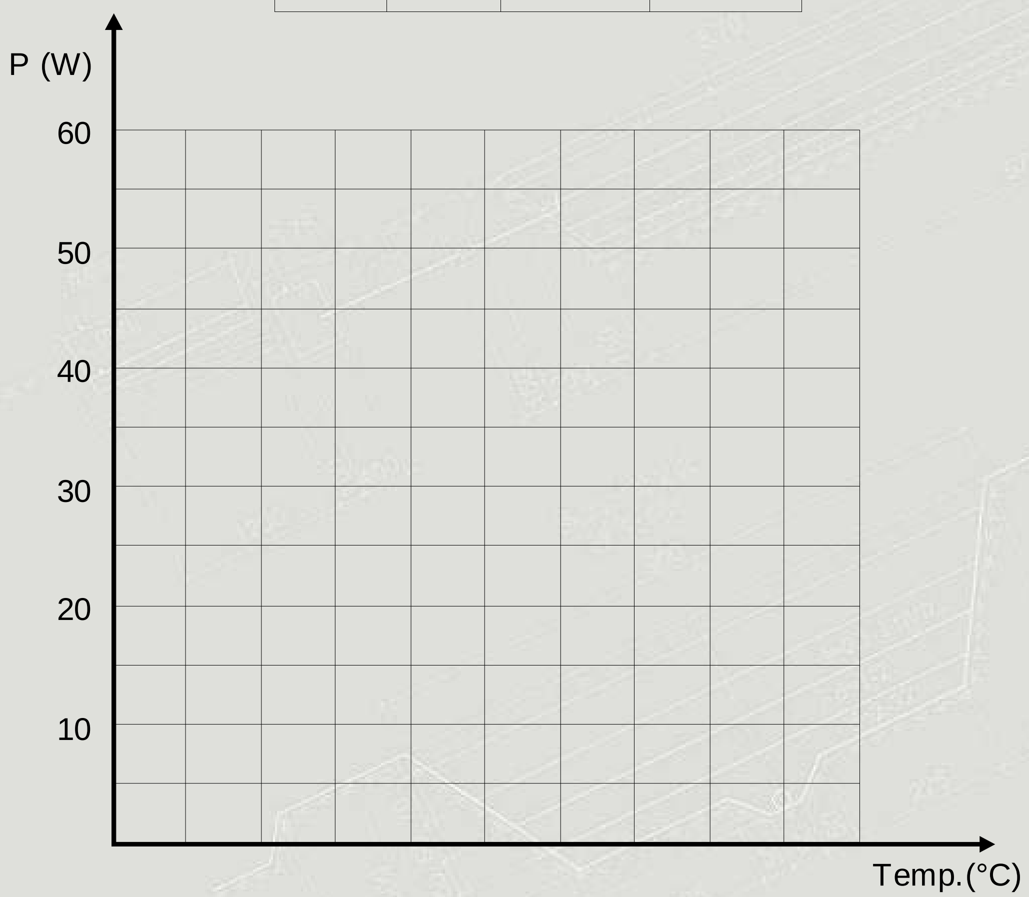
- Calculate the power and draw the diagram
- Determine the point of maximum power (MPP)



Diag 3: Voc, Isc in dependence from vertical inclination

2. In this experiment we will determine the influence of the cell temperature on power output. Before you start, discuss your expectations in the group. Will the output increase, decrease or stay the same with raising temperature?
   Set the slide resistance that the panel works at the MMP. Measure voltage, current and the surface temperature on the back side of the solar panel. Cover the panel complete with a black cloth and watch the temperature rise about 3-4 degree. Uncover the panel, record voltage, current and temperature. Repeat this step 4 to 5 times.
   Calculate the power (P = U*I)

Temp.	U (V)	I (A)	P (W)



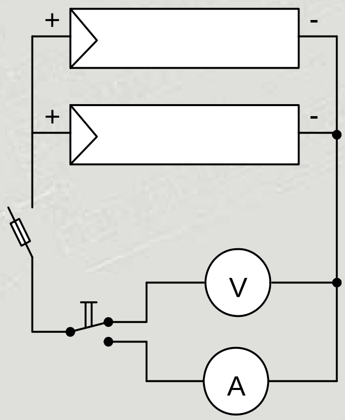
Diag 4: Power in dependence from panel temperature

Questions:

- Does the result confirm your expectations? Explain the result.
- How much does voltage and current change on the average per 10 degree rise in temperature?

3. Connect two panels in parallel. Measure open circuit voltage and short circuit current.
   Repeat the measurements with panels connected in series. What are the implications of the result for practical applications?

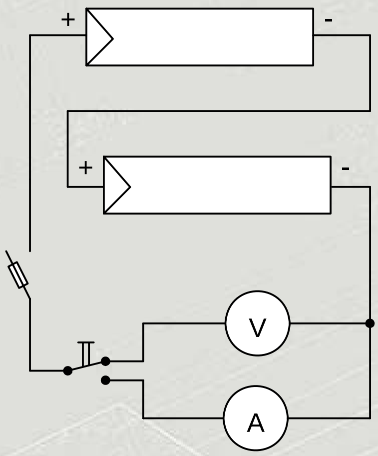
(use a digital multimeter)



Wiring diagram 3

4. With two panels connected in series cover one panel partly with a cloth. Measure open circuit voltage and short circuit current. Explain the result.

(use a digital multimeter)



Wiring diagram 4

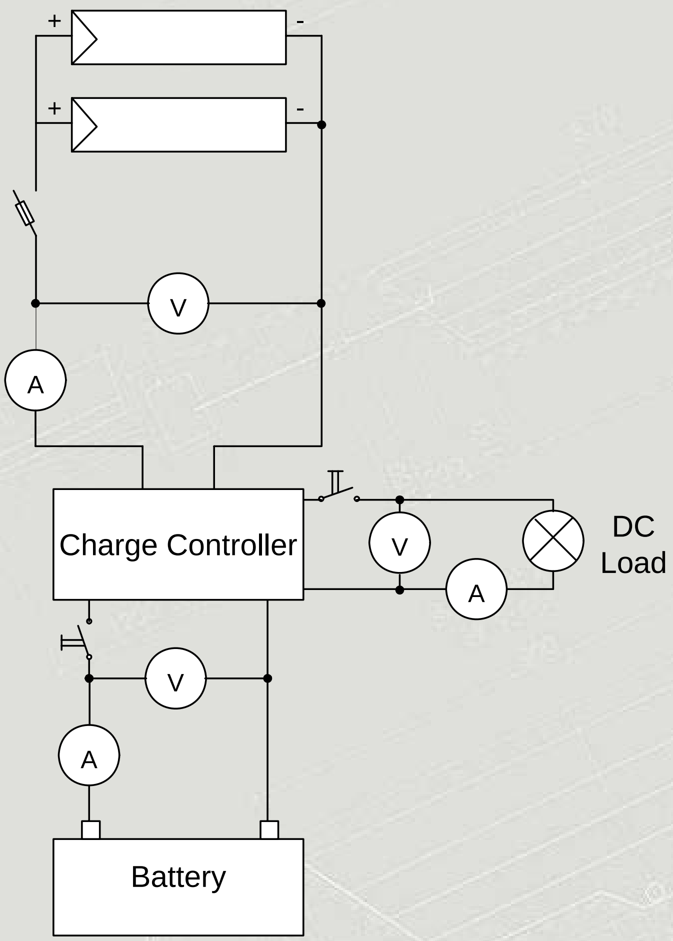
3. Storing Electrical Energy

Classroom key topics

- Improved usability and availability through storage
- Properties of solar accumulators (deep cycle, sealed and flooded plate type)
- Charge controllers

Experiments

Objective: Understanding load and discharge control of accumulators, effectiveness of storage systems



Wiring diagram 5

Preparation: Wire the panels according the diagram.

1. Measure the battery voltage; test the battery with the battery tester. (battery disconnected from charge controller)
2. Observe the working of the charge controller with DC load on/off and battery on/off
3. With the battery disconnected, connect the slide resistance as DC Load. Take measurements of voltage and current at the charge controller input and output at a high, medium and low resistance setting. Calculate the effectiveness factor of the charge controller at the different loads:

$$EF = (U_{out} * I_{out}) / (U_{in} * I_{in}) * 100$$

Load	**U_{in} (V)**	**I_{in} (A)**	**U_{out} (V)**	**I_{out} (A)**	**EF (%)**
Low					
Medium					
High					

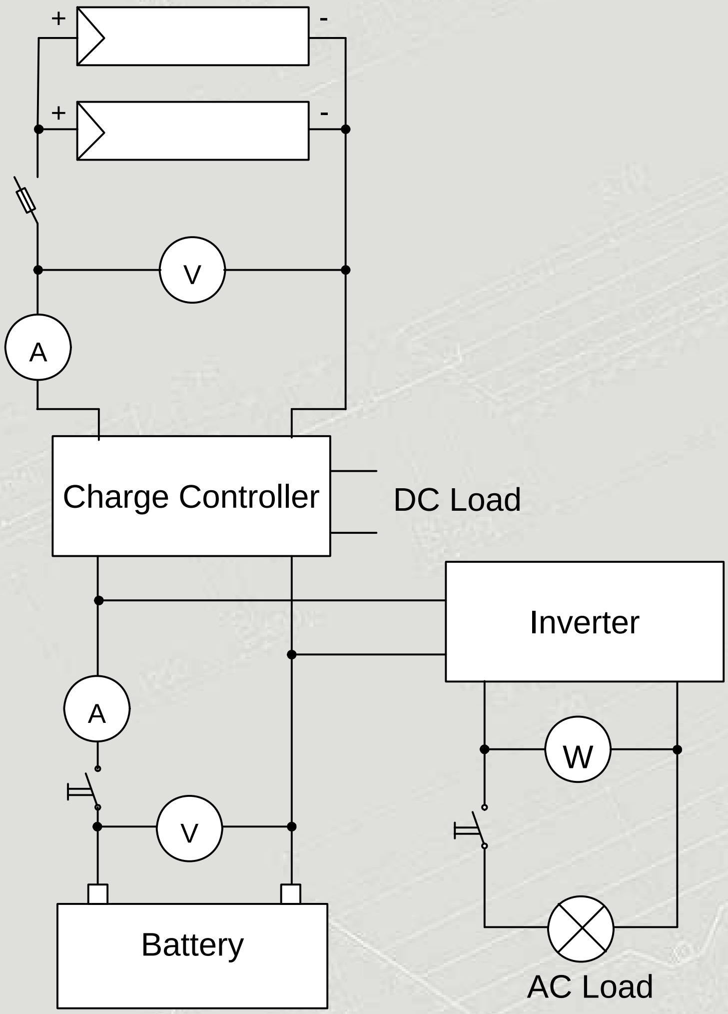
4. Powering AC Devices with Solar Energy

Classroom key topics

- Advantage and disadvantage of supplying AC current
- Properties of inverters (sine and trapeze wave)
- Inverter with integrated charge controller

Experiments

Objective: Learn how to set up a system with charge controller and inverter. Understand the concept of system effectiveness.



Wiring diagram 6

Preparation: Wire the panels according to the diagram.

1. Observe the working of the system with AC load on/off and battery on/off
2. With the battery disconnected, connect the slide resistance as AC Load (**always use series resistor with the slide resistance to limit the current if the slide is set to 0!**). Take measurements of voltage and current at the charge controller input and at the inverter output at a high, medium and low resistance setting. Calculate the effectiveness factor of the system at the different loads:

$$EF = P_{out} / (U_{in} * I_{in}) * 100$$

Load	**U_{in} (V)**	**I_{in} (A)**	**P_{out} (W)**	**EF (%)**
Low				
Medium				
High				

3. Use a regular light bulb as AC load. Measure the wattage used and the illuminance with the lux meter. Repeat the measurements with an energy saving lamp. (Measure from the same distance in both cases)
Calculate the lux / watt ratio for each lamp.

Lamp	**Ilum. (lux)**	**P (W)**	**Ratio**
Regular			
Energy saving			

5. Wind Power

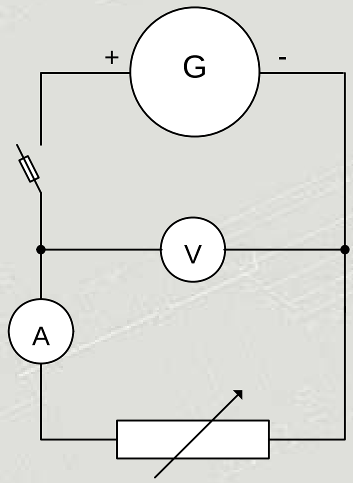
Classroom key topics

- Wind generator
- Advantage of combining wind and solar power

Experiments

Objective: Learn how to set up a wind power system. Understand the correlation between wind speed and power yield.

Preparation: Wire the system according the diagram.

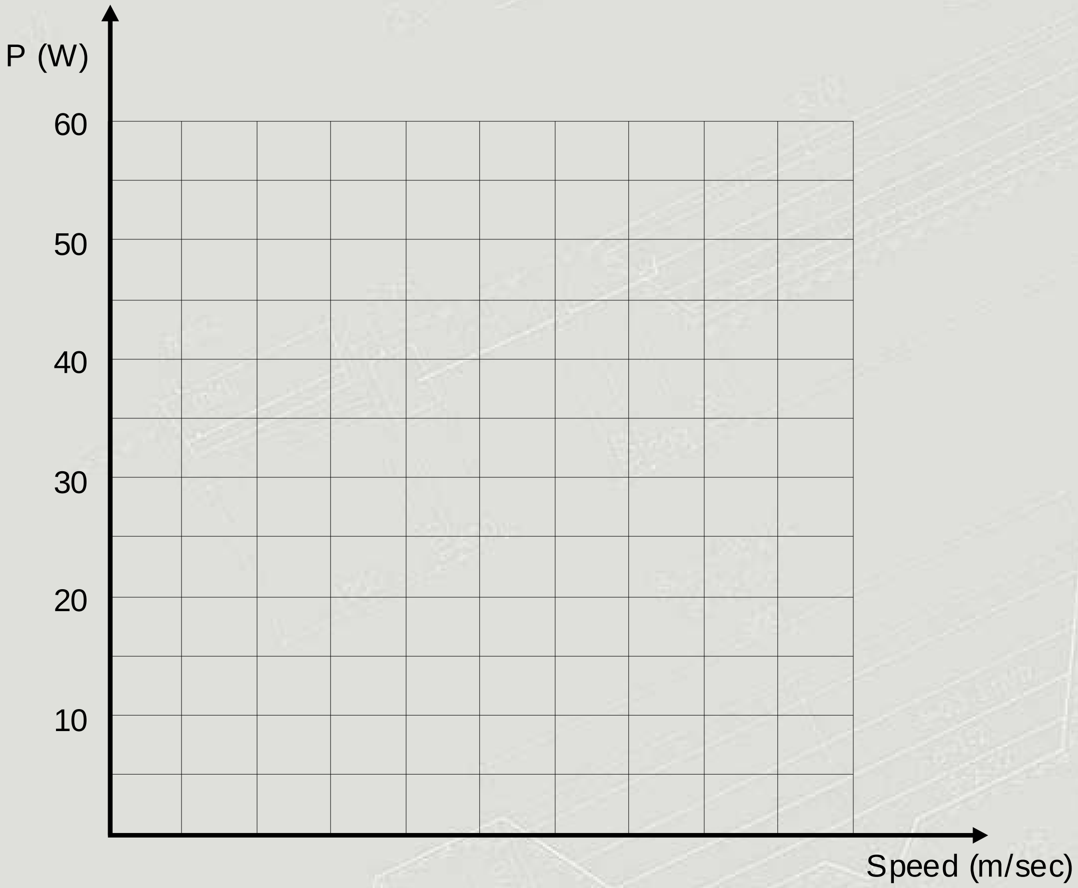


Wiring diagram 7

1. Adjust the slide resistance till the voltage meter reads 24 V. Measure the current and the speed of the wind. Repeat the measurements at different speeds of the wind. (if the wind blows too regularly, vary the setup of the generator to get different speed values)

Speed (m/sec)	**U (V)**	**I (A)**	**P (W)**

2. Calculate the power and draw the diagram



Diag 5: Power in dependence from speed of wind

Question: Do you know where and when the first windmills were used in history?

6. Planning and sizing solar systems

1. Solar powered pump station

A small village gets it water supply from a well. Plan for the water to be pumped to tank above the village by a solar powered pump. The tank will be placed 70m above the well. The daily water demand is 1600 – 2000l. The minimum demand should be met even if for three successive days no solar power is available (bad weather, maintenance). The AC pump is connected through an inverter (efficiency factor: 88%). Radiation data for the location (near Herat) and the pump data are given below.

- What volume should the water tank have ($1m^3$ = 1000l)
- How many solar panels are needed
- Draw a wiring diagram
- Give the size of the circuit breaker, size of the wire to connect the panels, size of the wire from the panel array to the pump

Solar Panel data

Power:	120watt
Size:	1485x670x35mm
Open circuit voltage:	22V
Short circuit current:	7.79A
Nominal voltage:	17.2V
Maximal current:	6.97A
Efficiency rate:	8%

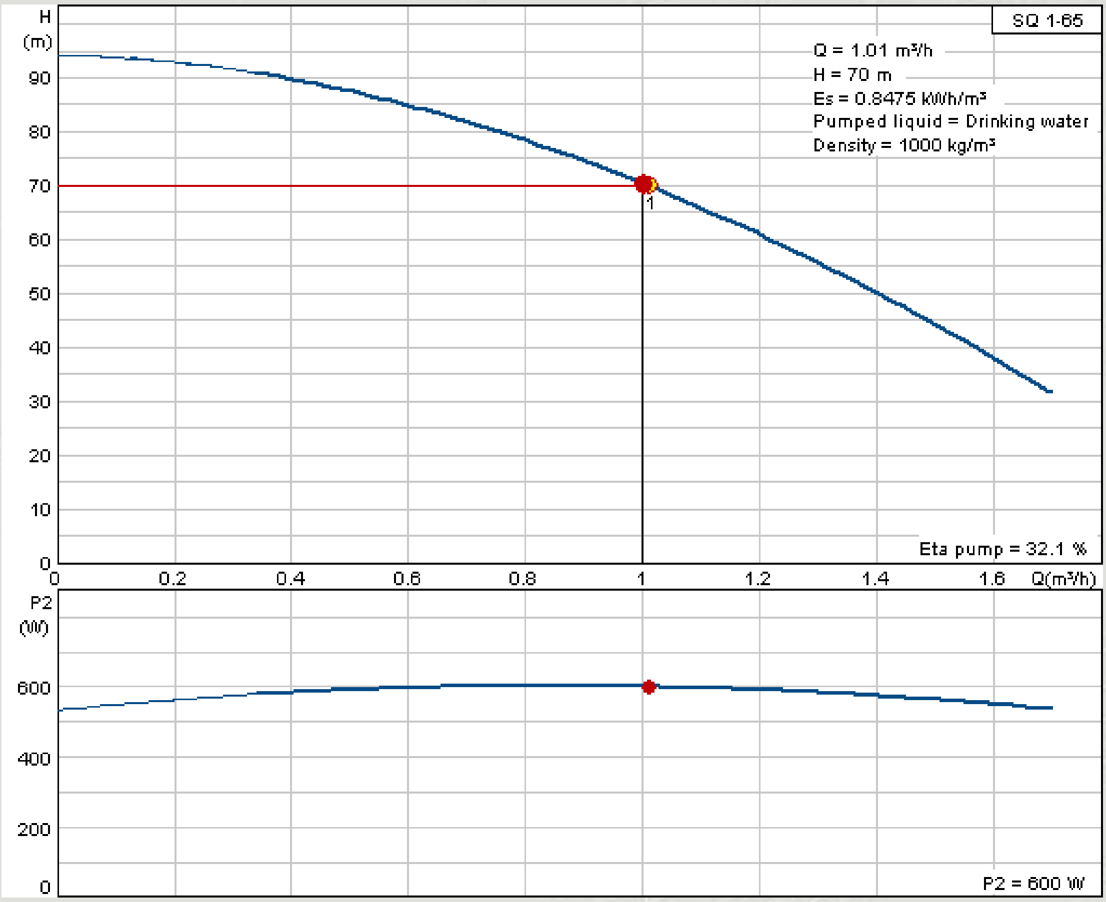
Herat radiation data and day light hours (Latitude 34 / Longitude 62)
Monthly averaged radiation incident on an equator-pointed, 34° tilted surface ($kWh/m^2/day$)
(Monthly averaged value in the 22-year period)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Monthly average	4.08	4.62	5.21	5.73	6.17	6.34	6.28	6.39	6.41	5.85	4.62	3.9	5.47
Minimum average	2.91	3.6	4.09	4.76	5.81	5.83	5.91	5.84	5.84	4.89	3.81	2.93	4.69
Maximum average	5.47	5.65	6.32	6.51	6.78	7.06	6.8	7.23	7.24	6.59	5.14	4.86	6.31
Day light hours	10.1	11.0	11.9	13.0	13.9	14.3	14.1	13.4	12.4	11.3	10.3	9.93	

Source: http://eosweb.larc.nasa.gov/sse/

Pump data

0.7 kW, 200-240V AC, current 5.2A



Calculations

Size of tank:
The tank should hold minimum 4 x the daily water demand = 8000l = 8m^3.

Pump:
The pump needs 0.85 kWh to pump 1 cubic meter water 70 m. Using a safety margin of 25%, the daily water demand is 2500l = 2.5m^3.
With an inverter efficiency rate of 90%, the solar generator needs to be able to deliver 0.85 kWh * 2.5 / 0.88 = 2.42 kWh. The delivery rate of the pump is 1m^3/h. Provided the minimum voltage of 200V is available for the pump it takes 2.5 hours to deliver the 2.5m^3 water. With a minimum of 10 hours day light, it can be assumed that the required 200V will be available for more then 2.5 hours a day even in winter.

Solar generator:
The pump requires min 220V. 220/17.2 = 12.8. Thirteen panels are needed to supply the required 220V for the pump. They are able to deliver 13 * 120W = 1.56kW, which is above the requested power of 0.7kW for the pump.

Will the available radiation in the winter month be sufficient?
The minimum average available radiation is 2.91 kWh/m^2 /day in January; the panel size 1.49 * 0.67 = 1m^2. Based on an efficiency rate of 8% for the solar panels, 1 square meter panel would deliver a minimum of 2.91 * 0.08 = 0.233 kWh; thirteen square meter 0.233kWh * 13 = 3.0kWh. This is well above the required minimum of 2.42kWh.

Appendix

1. Answers

Unit 1

- *Question: Why should Voc and Isc not measured at the same time?*
- Answer: The short caused by the ampere meter falsifies the voltage reading.

- *Question: For a fixed installation, which angle should the panel set to, to maximize power output?*
- Answer: An inclination identical with the latitude of the location. For Herat at 34°.

- *Question: How can the relation between irradiance and open circuit voltage and the relation between irradiance and short circuit current be characterized?*
- The open circuit voltage is almost constant. Already low irradiation gives the rated voltage. The current increases in a continues manner with the irradiation.

Unit 2

- *Question: Does the power output of an solar cell increase, decrease or stay the same with raising temperature?*
- Answer: The power decreases. It is not heat of the sun, but the solar irradiation which is converted in electrical energy. Higher temperature lowers the performance of semi conductors. The voltage output of a single cell drops between 1.. 3mV per 1° rise in temperature.

Unit 5

- *Question: Do you know where and when the first windmills were used in history?*
- *Answer:* The first practical windmills were built in Sistan, Afghanistan, from the 7th century. These were vertical-axle windmills, which had long vertical drive shafts with rectangle shaped blades. Made of six to twelve sails covered in reed matting or cloth material, these windmills were used to grind

corn and draw up water, and were used in the grist milling and sugarcane industries.

Ruins of a windmill in Khorasan

Greater Khorasan contained mostly Nishapur, Tus (now in Iran), Herat, Balkh, Kabul and Ghazni (now in Afghanistan), Merv (now in Turkmenistan), Samarqand, Bukhara and Khiva (all now in Uzbekistan), Khujand and Panjakent (now in Tajikistan). (Herat was known in the past as Pearl of Khorasan.)
(Source: Wikipedia)