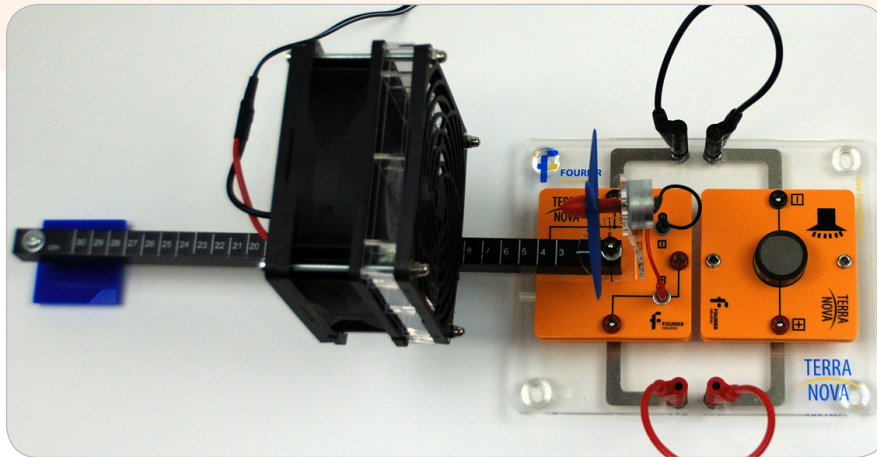


1) Introduction to wind power



Introduction

With this first experiment you should get in touch to the experiment equipment and learn how to use it. The sound level of the buzzer will show you how much power the wind turbine produces.



Equipment

1. Main board
2. Wind generator module with rail and power supply (12V)
3. Wind turbine module (with three rotor blades)
4. Buzzer
5. 2 cables



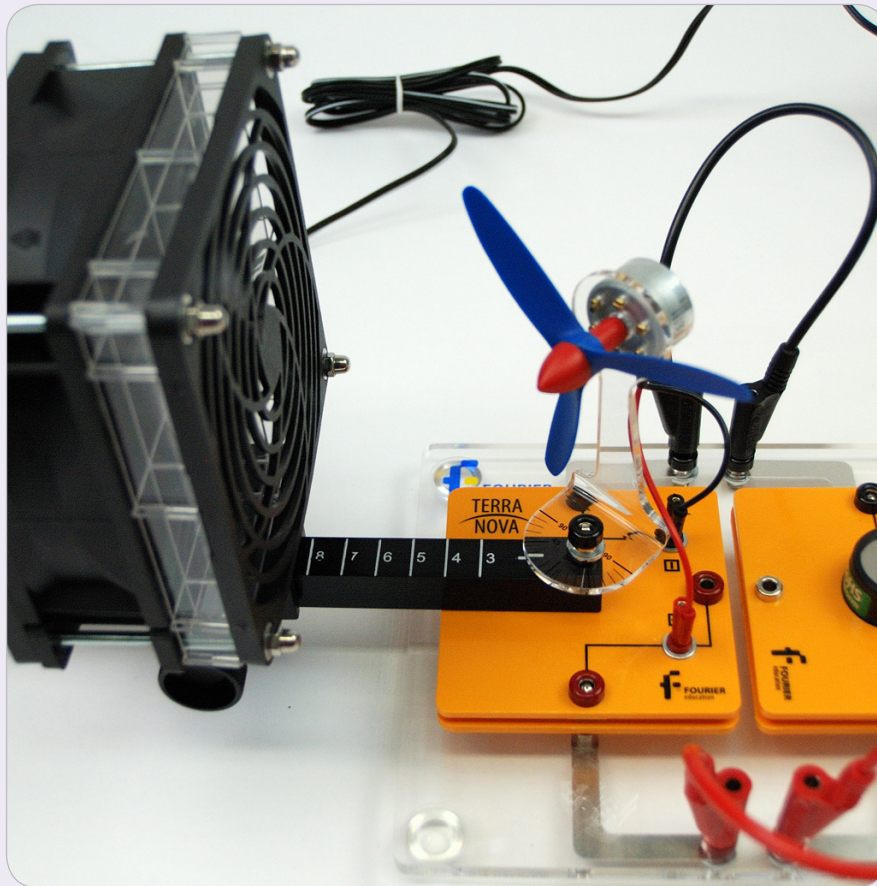
Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!)
2. Fix the rail to the wind turbine module
3. Mount the wind turbine on top of the rail and connect the small cables to the module
4. Fix the wind machine to the rail at the 5 cm position



Experimental Procedure

1. Dependence of buzzer sound level on wind machine position - increase the distance of the wind machine from the wind turbine and listen to the sound level of the buzzer. How does it change?
2. Dependence of Buzzer sound level on turning angle of the wind turbine - fix the wind machine at the 20 cm position to the rail - change the angle of the wind turbine towards incoming wind and listen to the sound of the buzzer. How does it change?



Questions

1. Which dependence of the sound level on distance between wind machine and wind turbine did you observe?
2. How did the sound level of the buzzer change when turning the wind turbine?

2) Measuring the wind velocity



Introduction

For this experiment kit you cannot use real wind outdoors because it is not constant enough for reproducible experiments. Hence, a wind machine is used. In this first experiment the possible wind speed in different distances from the wind machine should be measured.



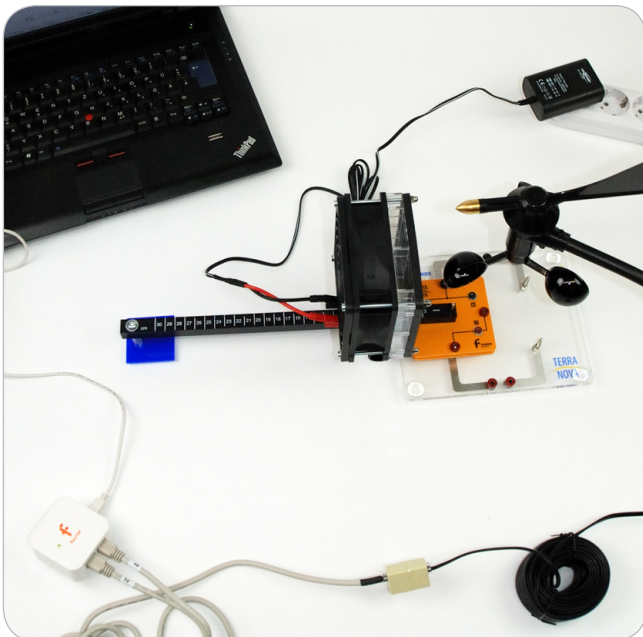
Equipment

1. Main board
2. Wind generator module with rail and power supply (12V)
3. Anemometer
4. NOVA LINK




Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!).
2. Fix the rail to the wind turbine module.
3. Mount the wind turbine on top of the rail and connect the small cables to the module.
4. Fix the wind machine to the rail at the 5 cm position.






MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Click **Logger**.
4. Uncheck the **Auto ID function**.
5. Connect the Splitter cable output marked with \updownarrow to the NOVA LINK's sensor inputs I/O-1.
6. Connect the second Splitter cable output, marked with S to the NOVA LINK's sensor inputs I/O-2.
7. Click .
8. As **Input 1** select: Wind speed 4 – 280 km/h.
9. As **Input 2** select: Wind direction 0° - 360°.
10. Click **Next**.
11. Set **Select rate** to **Every second**.
12. Set **Select recording mode** to **Add**.
13. Click **Next**.
14. Set **by Time** to **50**.
15. Click **Finish**.





Experimental Procedure


1. Connect the power supply to the wind machine (12V).
2. Take the anemometer and hold it constant at the height, where normally the wind turbine is situated (alternatively use a tripod to fix the anemometer).
3. The nearest point of a paddle to the wind machine should be above the position where the wind turbine is normally situated.
4. Click .
5. Disconnect the power supply.
6. Repeat steps 1 to 5 for the distances of 10, 15, 20, and 25 cm.




Data Analysis


1. Click .
2. Set the cursor to the first point of any graph which is not zero.
3. Click .
4. Set the second cursor to the last point at the same graph
5. Go to the Menu **Graph > Crop**.

Table


1. Go to **Table > Add manual column**.
2. Set **column title** to **distance**.
3. Set **column unit** to **cm**.
4. Click **Ok**.
5. Again, go to **Table > Add manual column**.
6. Set **column title** to **wind speed**.
7. Set **column unit** to **km/h**.
8. Click **Ok**.
9. Click .
10. Add the new columns **distance** and **wind speed**.

11. Set table name to wind speed – distance dependence.
12. Click **Ok**.
13. Click .

Averaging

1. Click .
2. Choose the graph of the measurement at 5 cm.
3. Go to the Menu **Analysis > Statistics**.
4. Write in the actual table the data of the distance and the average wind speed.
5. Click **OK**.
6. Repeat this steps for the other distances.

Graph

1. Click .
2. Set **X-axis** to **distance**.
3. Set **Y-axis** to **wind speed**.
4. Click **Ok**.



Questions

1. Can you identify a clear trend of the wind speed? Explain this behavior!
2. Classify the maximal wind speed in accordance to the Beaufort scale!
3. Explain the differences of your measurement to the calibration curve given in beginning of this manual.
4. Have a detailed look to the wind machine.
Can you image why underneath the finger guard grid there is a second grid?

3) Dependence of the wind turbine power on wind velocity



Introduction

Wind speed on land can vary much: from 1 Beaufort with wind speeds of less than 0.3 m/s up to 12 Beaufort with wind speeds of more than 33 m/s. Can a wind turbine use such low and high wind speeds and how does the power depend on wind speed? This is the main issue of this experiment.



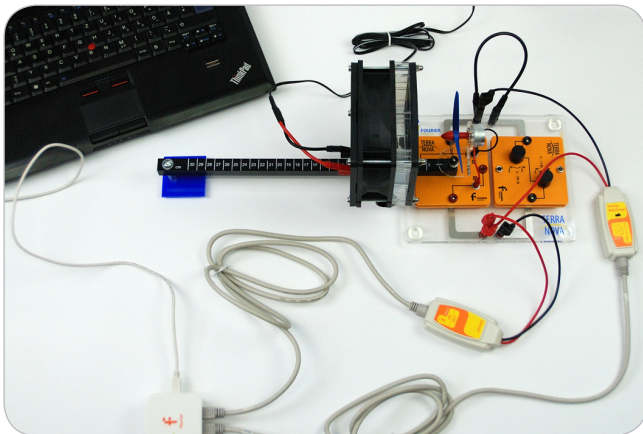
Equipment

1. Main board
2. Wind generator module with rail and power supply (12V)
3. Wind turbine module (with three rotor blades)
4. Potentiometer module
5. Voltage sensor
6. Current sensor
7. NOVA LINK




Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!).
2. Fix the rail to the wind turbine module.
3. Mount the wind turbine on top of the rail and connect the small cables to the module.
4. Fix the wind machine to the rail at the 5 cm position.
5. Plug the potentiometer module onto the second place of the main board.
6. Turn the knob of the 1k Ω potentiometer to Rmin and the knob of the 100 Ω potentiometer ca. a third turn from Rmin to Rmax.








MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the voltage sensor to I/O-1 port of the NOVA LINK.
4. Connect the current sensor to I/O-2 port of the NOVA LINK.
5. Click .
6. Click **Next**.
7. Set **Select rate** to **Manual**.
8. Set **Select recording mode** to **Add**.
9. Click **Next**.
10. Set **by samples** to **50**.
11. Click **Finish**.



Experimental Procedure

1. Connect the power supply (12V) to the wind generator.
2. Wait until the wind generator and the wind turbine have maximum speed.
3. Click .
4. Repeat step 1 to 4 for 10 cm, 15 cm, 20 cm and 25 cm.
5. At the end click .
6. Click  to save your data.



Data Analysis

1. Click f_x .
2. Click **Functions**.
3. Set **Functions** to **Multiply**.
4. Select the voltage and current measurement datasets as G1 and G2, respectively.
5. Click **Ok**.
6. Go to **Table > add manual column**.
7. Set **Column name** to **distance**.
8. Set **Column unit** to **cm**.
9. Click **Ok**.
10. Click
11. Add the columns of distance, the current and voltage measurement and of the calculated power function.
12. Click **Ok**.
13. Click
14. Click y_x .
15. Set **X-axis** to **distance**.
16. Select the measured current and voltage datasets as **Y-axis**.
17. Set the Graph title to **"voltage/current - distance dependence"**.
18. Click **Ok**.
19. Click
20. Click y_x .
21. Set **X-axis** to distance
22. Set **Y-axis** to the calculated power.
23. Set the **Graph title** to **"Power - Distance Dependence"**.
24. Click **Ok**.



Questions

1. Describe the correlation between output and wind speed at the wind turbine.
2. What is the reason for the behavior at high wind speeds?
3. What conclusions can be drawn from this for the operation of real wind turbines?

4) Comparing wind turbines with different number of rotor blades



Introduction

More than 99% of the worldwide installed wind turbines have three blades.

But there are also 2- and 4-blade rotors – even rotors with 1 blade exist. But why such rotors are used so seldom?



Equipment

1. Main board
2. Wind machine module with rail and power supply (12V)
3. Wind turbine module (with two, three and four rotor blades)
4. Voltage sensor
5. NOVA LINK




Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!).
2. Fix the rail to the wind turbine module.
3. Mount the wind turbine on top of the rail and connect the small cables to the module.
4. Fix the wind machine to the rail at the 20 cm position.
5. Connect the voltage sensor to the wind generator





MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the voltage sensor to I/O-1 port of the NOVA LINK.
4. Click .
5. Click **Next**.
6. Set **Select rate** to **Manual**.
7. Set **Select recording mode** to **Add**.
8. Click **Next**.
9. Set **by samples** to **50**.
10. Click **Finish**.





Experimental Procedure

1. Attach the 2-blade rotor to the wind turbine.
2. Connect the power supply (12V) to the wind machine .
3. Wait until the wind machine and the wind turbine have maximum speed.
4. Click .
5. Disconnect the power supply from the wind generator and wait until the rotor blades stay still.
6. Repeat step 1 to 5 for the 3- and 4-blade rotors.
7. At the end click .





Data Analysis

Table

1. Click **Table** on the main toolbar and select **Add manual column**.
2. Set **Column name** to be **# of rotor blades**.
3. Click **Ok**.
4. Click .
5. Add the column **# of rotor blades** to the table.
6. Click **Ok**.
7. Fill the number of the rotor blades into the new column.
8. Click .

Graph

1. Click .
2. Set **X-axis** to **# of rotor blades**.
3. Set **Y-axis** the voltage dataset.
4. Set the **Graph title** to **"Voltage - # of Rotor Blade Dependence"**.
5. Click **Ok**.
6. Click .



Questions

1. What is the result of your measurement? Which configuration is superior?
2. Try to find more reasons why 3-blade rotors dominate the wind power industry.

5) Dependence of the wind turbine on wind direction



Introduction

Wind is very volatile! But not only wind speed can differ much in reality, also wind direction. How this affects a wind power plant should be investigated in this experiment.



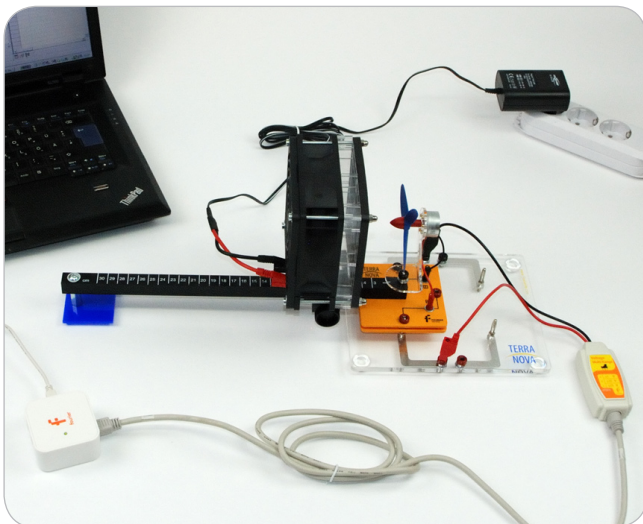
Equipment

1. Main board
2. Wind machine module with rail and power supply (12V)
3. Wind turbine module (with three rotor blades)
4. Voltage sensor
5. NOVA LINK




Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!).
2. Fix the rail to the wind turbine module.
3. Mount the wind turbine on top of the rail and connect the small cables to the module.
4. Fix the wind machine to the rail at the 5 cm position.
5. Connect the voltage sensor to the turbine.








MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the voltage sensor to I/O-1 port of the NOVA LINK.
4. Click .
5. Click **Next**.
6. Set **Select rate** to **Manual**.
7. Set **Select recording mode** to **Add**.
8. Click **Next**.
9. Set **by samples** to **50**.
10. Click **Finish**.





Experimental Procedure

1. Set the angle of rotation to 0° .
Hint: When setting the angle of rotation, it must be ensured that your line of vision is always perpendicular to the angular scale. The black 0° line must be directly visible over the white line of the rail.
2. Connect the power supply (12V) to the wind machine.
3. Wait until the wind machine and the wind turbine have maximum speed.
4. Click .
5. Repeat step 2 to 4 for $10^\circ, 20^\circ, 30^\circ, 40^\circ, 50^\circ, 60^\circ, 70^\circ, 80^\circ$ and 90° .
CAUTION! When rotating the wind turbine, do not reach into the rotor blades – risk of injury! – to rotate, the wind machine can be turned off.
6. At the end click .
7. Click  to save your data.



Data Analysis


Table

1. Click **Table on the main toolbar and select Add manual column.**
2. Set **Column name** to be **angle**.
3. Set **Column unit** to be $^{\circ}$.
4. Click **Ok**.
5. Click .
6. Add the columns of **angle to the table**.
7. Fill the angles in the angle's column.
8. Click **Ok**.
9. Click .

Cosine – calculation

1. Click f_x .
2. Click **Functions**.
3. In the **Functions tab select Cosine**.
4. Select G1 as dataset for the **angle**.
5. Set B to **0.01745** ($\pi/180^{\circ}$).
6. Click **OK**.

Graph

1. Click y_x .
2. Set **X-axis** to **angle**.
3. Select current and voltage datasets as set **Y-axis**.
4. Set the **Graph title** to "Voltage - Angle Dependence".
5. Click **Ok**.
6. Click .
7. Click y_x .
8. Set **X-axis** to **cos**.
9. Set **Y-axis** to **voltage**.
10. Set the Graph title to "Voltage – cos(alpha) Dependence".
11. Click **Ok**.



Questions

1. How does the voltage of the wind turbine depend on the angle and which mathematical correlation does it equal?
2. In real wind turbines it is of great importance to always generate the highest possible output. How can you ensure that a wind turbine always generates the maximum output? Think of a possible technical implementation, how such a system can be aligned more optimally into the wind and describe your reasoning. Get information about the construction of real wind turbines.

6) Dependence of the wind turbine on wind direction



Introduction

In practical applications it is important that the wind turbine always generates the maximum output. This output also depends on the load that is connected to the turbine. In this experiment this dependency should be investigated and the maximum output under the specific conditions of the experiment be examined.



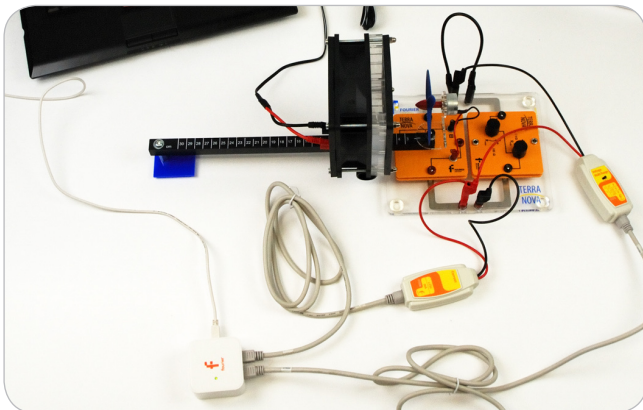
Equipment

1. Main board
2. Wind machine module with rail and power supply (12V)
3. Wind turbine module (with three rotor blades)
4. Potentiometer module
5. Voltage sensor
6. Current sensor
7. NOVA LINK



Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!).
2. Fix the rail to the wind turbine module.
3. Mount the wind turbine on top of the rail and connect the small cables to the module
4. Fix the wind machine to the rail at the 5 cm position.
5. Connect the voltage sensor parallel to the wind turbine.
6. Connect the current sensor in series to the wind turbine and the potentiometer so that the circuit is closed.








MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK.
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK.
5. Click .
6. Click **Next**.
7. Set **Select rate** to **25 Samples per second**.
8. Set **Select recording mode** to **Add**.
9. Click **Next**.
10. Set **by samples** to **Continuous**.
11. Click **Finish**.







Experimental Procedure

1. Connect the power supply (12V) to the wind machine.
2. Turn the knob of the 1k Ω -potentiometer to Rmin.
3. Turn the knob of the 100 Ω -potentiometer to Rmax.
4. Wait until the wind machine and the wind turbine have maximum speed.
5. Click .
6. Turn the knob of the 100 Ω -potentiometer anti-clockwise continuously.
7. At the end click .
If you did not achieve a smooth curve repeat the measurement and try to turn the knob slower.
8. Click  to save your data.






Data Analysis

Cropping data and calculating power


1. Click  and set the cursor to the first voltage point which is at the beginning of the decreasing part of the graph.
2. Click  and set the second cursor to a point on the graph where the voltage has saturated.
3. Go to the Menu **Graph** and click **Crop**.
4. Click f_x .
5. Click **Functions**.
6. Set **Functions** to **Multiply**.
7. Select the cropped voltage and current datasets as **G1** and **G2**, respectively.
8. Click **Ok**.
9. Click .
10. Add the column of the calculated power function.
11. Click **Ok**.
12. Click .

Graph

1. Click .
2. Set **X-axis** to the cropped **voltage**.
3. Set **Y-axis** to the cropped **current**.
4. Set the **Graph title** to "**IV-Curve**".
5. Click **Ok**.
6. Click .
7. Click .
8. Set **X-axis** to the **cropped voltage**.
9. Set **Y-axis** to the **calculated power**.
10. Set the **Graph title** to "**Power –Voltage Curve**".
11. Click **Ok**.



Questions

1. Using the First cursor , determine the voltage value at which the output of the wind turbine has its maximum. Calculate the load resistance at which the maximum output at the turbine is achieved!
2. What consequence follows from these results for the operation of real wind turbines?
3. The maximum output of a wind turbine depends on the load resistance at the turbine. Name possible effects or physical variables that could also have an effect on the output of a wind turbine.

7) IV-characteristics with different rotor blades



Introduction

Wind power plants in practice almost exclusively have 3 rotor blades per turbine. But is this the optimum? In this experiment the output of a wind turbine with either 2, 3 and 4 bladed should be compared in detail. Hence, not only voltage should be measured but the complete IV-characteristics.



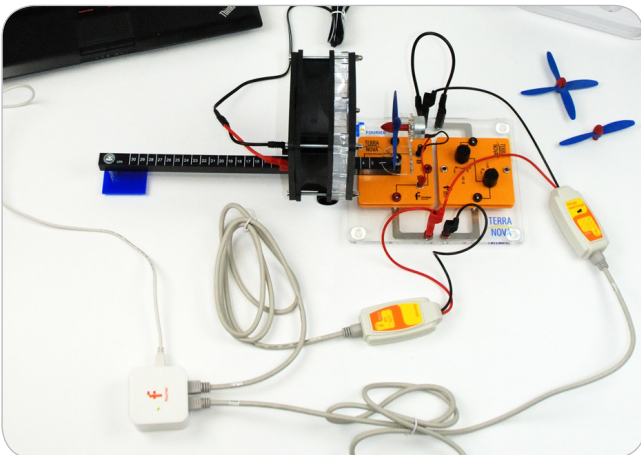
Equipment

1. Main board
2. Wind machine module with rail and power supply (12V)
3. Wind turbine module (with two/three/four rotor blades)
4. Potentiometer module
5. Voltage sensor
6. Current sensor
7. NOVA LINK



Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!).
2. Fix the rail to the wind turbine module.
3. Mount the wind turbine on top of the rail and connect the small cables to the module
4. Fix the wind machine to the rail at the 5 cm position.
5. Connect the voltage sensor parallel to the wind turbine.
6. Connect the current sensor in series to the wind turbine and the potentiometer so that the circuit is closed.







MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK.
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK.
5. Click .
6. Click **Next**.
7. Set **Select rate** to **25 Samples per second**.
8. Set **Select recording mode** to **Add**.
9. Click **Next**.
10. Set **by samples** to **Continuous**.
11. Click **Finish**.



Experimental Procedure

1. Attach the 2-blade rotor to the wind turbine.
2. Connect the power supply to the wind machine.
3. Set the knob of the 1k Ω -potentiometer to its minimum.
4. Set the knob of the 100 Ω -potentiometer to its maximum.
5. Wait until the wind machine and the wind turbine have maximum speed.
6. Click .
7. Turn the knob of the 100 Ω -potentiometer anti-clockwise continuously.
8. At the end click .
9. Disconnect the wind machine.
10. Exchange the 2-blade rotor with the 3-blade rotor and repeat steps 3 to 9 again.
11. Exchange the 3-blade rotor with the 4-blade rotor and repeat steps 3 to 9 again.



Data Analysis

1. Click and set the cursor to the first voltage point which is at the beginning of the decreasing part of the graph.
2. Click and set the second cursor to a point on the graph where the voltage has saturated.
3. Go to the Menu **Graph** and click **Crop**.
4. Click .
5. Click **Functions**.
6. Set **Functions** to **Multiply**.
7. Select the cropped voltage and current datasets as **G1** and **G2**, respectively.
8. Click **Ok**.
9. Click .
10. Add the column of the calculated power function.
11. Click **Ok**.
12. Click .
13. Repeat all analysis steps for the 3- and 4-blade rotor.

Graph

1. Click .
2. Set **X-axis** to the cropped **voltage** (2 blade rotor).
3. Set **Y-axis** to the cropped **current** (2 blade rotor).
4. Set the **Graph title** to "**IV-2 Blade Rotor**".
5. Click **Ok**.
6. Click .
7. Click .
8. Set **X-axis** to **voltage** (2 blade rotor).
9. Set **Y-axis** to the **calculated power** (2 blade rotor).
10. Set the **Graph title** to "**Power - V – Rotor Blade Dependence**".
11. Click **Ok**.
12. Click .
13. Repeat all analysis steps for the 3- and 4-blade rotor.



Questions

1. Read the following characteristic values from your measurement using using the first cursor :

	Umax / V	I _{max} / mA	P _{max} / mW	R _{opt} / Ω
2 blade rotor				
3 blade rotor				
4 blade rotor				

R_{opt} means the optimal resistance value, where the output power is maximal.

2. According to the experiment, what is the optimal number of blades for a wind turbine?

8) IV Characteristics depending on wind velocity



Introduction

In Experiment 3 we have seen that the output power of a wind turbine strongly depend on wind velocity. But there only the output power for a fixed load was measured. The correct way is to measure the IV-characteristics and analyze the behavior of the maximum output. This should be done in this experiment.



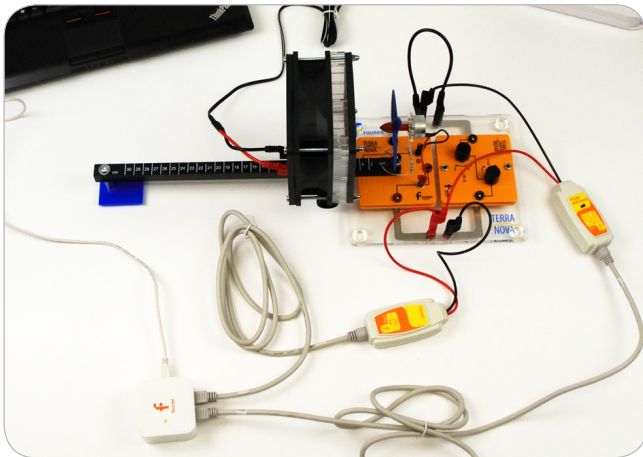
Equipment

1. Main board
2. Wind generator module with rail and power supply (12V)
3. Wind turbine module (with three rotor blades)
4. Potentiometer module
5. Voltage sensor
6. Current sensor
7. NOVA LINK




Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!)
2. Fix the rail to the wind turbine module
3. Mount the wind turbine on top of the rail and connect the small cables to the module
4. Fix the wind machine to the rail at the 5 cm position
5. Plug the potentiometer module onto the second place of the main board
6. Turn the knob of the 1k Ω potentiometer to Rmin and the knob of the 100 Ω potentiometer to Rmax.








MultiLab Setup

1. Launch MultiLab
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK
5. Click .
6. Click **Next**.
7. Set **Select rate** to **Manual**.
8. Set **Select recording mode** to **Add**.
9. Click **Next**.
10. Set **by samples** to **50**.
11. Click **Finish**.



Experimental Procedure

1. Connect the power supply to the wind generator.
2. Wait until the wind machine and the wind turbine have maximum speed.
3. Click .
4. Turn the knob of the 100Ω-potentiometer anti-clockwise continuous and not too slow.
5. At the end click .
6. Repeat step 2 to 5 with 10 cm, 15 cm, 20 cm and 25 cm distance between wind turbine and wind machine.
7. click Save  to save your data.



Data Analysis

Cropping data and calculating power

1. Click and set the cursor to the first voltage point which is at the beginning of the decreasing part of the graph.
2. Click and set the second cursor to a point on the graph where the voltage has saturated.
3. Go to the Menu **Graph** and click **Crop**.
4. Click f_x .
5. Click **Functions**.
6. Set **Functions** to **Multiply**.
7. Select the cropped voltage and current datasets as **G1** and **G2**, respectively.
8. Click **Ok**.
9. **Repeat these steps all distance measurements!**
10. Click .
11. Add the column of the calculated power function for 5 cm distance.
12. Click **Ok**.
13. Click .
14. Repeat these steps for the other distances.

Graph

1. Click .
2. Set **X-axis** to be the cropped **voltage** data of the 5 cm distance.
3. Set **Y-axis** to be the cropped **currents** data of the 5 cm distance.
4. Set the **Graph title** to **"IV-Curves of 5cm Distance"**.
5. Click **Ok**.
6. Click .
7. Click .
8. Set **X-axis** to the cropped **voltage** data of the 5 cm distance.
9. Set **Y-axis** to the **calculated power** of the 5 cm distance measurement.
10. Set the **Graph title** to **"Power – Voltage Curve"**.
11. Click **Ok**.
12. Click .
13. **Repeat these steps for the other distances.**



Questions

1. Read the following characteristic values from your measurement using using the first cursor :

distance	Wind speed / m/s	Umax / V	I _{max} / mA	P _{max} / mW	R _{opt} / Ω
5 cm	7,4				
10 cm	6,3				
15 cm	6,2				
20 cm	6				
25 cm	5,7				

R_{opt} means the optimal resistance value, where the output power is maximal.

Write the values in table in MultiLab and plot P_{max} over the wind speed.

2. Compare the results to experiment 3.

9) Start-up characteristics of different rotor blades



Introduction

In the previous experiments we have seen that the 3-blade rotor has advantages compared to 2 - or 4 - blade rotors – especially the output power is higher for this configuration. But how fast can the maximum output be reached when wind hits the turbine? This question should be observed in this experiment.



Equipment

1. Main board
2. Wind generator module with rail and power supply (12V)
3. Wind turbine module (with 2, 3 and 4 rotor blades)
4. Voltage sensor
5. NOVA LINK




Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!).
2. Fix the rail to the wind turbine module.
3. Mount the wind turbine on top of the rail and connect the small cables to the module.
4. Fix the wind machine to the rail at the 10 cm position.
5. Connect the voltage sensor parallel to the wind turbine.






MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the voltage sensor to I/O-1 port of the NOVA LINK.
4. Click .
5. Click **Next**.
6. Set **Select rate** to **25 per second**.
7. Set **Select recording mode** to **Add**.
8. Click **Next**.
9. Set **by samples** to **continuous**.
10. Click **Finish**.





Experimental Procedure



1. Attach the two-blade rotor to the wind turbine.
2. Hold one hand between the wind generator and the wind turbine module, so that the rotor blades do not rotate.
3. Connect the power supply to the wind generator.
4. Wait until the wind machine has maximum speed.
5. Click  and take your hand away (If the rotor does not start on its own give it a small impulse).
6. When the rotor reached maximum speed click .
7. Turn the wind machine off.
8. Replace the 2 blade rotor with the 3 - and 4 - blade rotor
9. Repeat step 2 to 7.
10. Click  to save your data.



Data Analysis

1. Click Table in the menu and select **Add manual column.**
2. Set Column name to # of blades.
3. Click Ok.
4. Go to **Table > Add manual column.**
5. Set Column name to **"Time"**.
6. Set units to s.
7. Click Ok.
8. Click .
9. Set X-axis to voltage.
10. Set Y-axis to measured current of the 2 blades.
11. Set the Graph title to IV-curve 2 blades.
12. Click Ok.
13. Click .
14. Repeat all these steps for the 3- and 4-rotor blade rotor.

Evaluate the start-up time

1. Activate the graph for the 2 blade rotor.
2. Click .
3. Click . Now you can see two arrows.
4. Move the first arrow to the beginning of the voltage curve and the second arrow to the point where the voltage curve reaches a plateau.
5. Read the time difference of the two points and fill it in the prepared table.
6. Repeat these steps for the other measurements.



Questions

1. What is the reason for the start-up time - Why the wind turbines do not start faster?
2. Which effects could also influence the start-up time?

10) Efficiency of the wind turbine



Introduction

It is of great interest to harvest the energy of the wind as efficient as possible because with a higher efficiency of a wind turbine the costs per kWh will decrease. In this experiment the efficiency calculation of the model wind turbine from the experiment kit should be calculated.



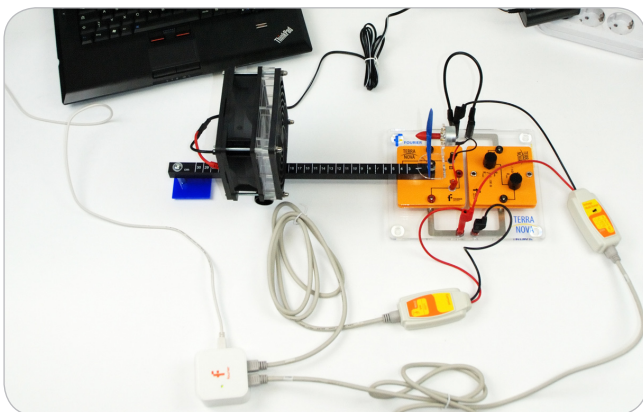
Equipment

1. Main board
2. Wind generator module with rail and power supply (12V)
3. Wind turbine module (with three rotor blades)
4. Potentiometer module
5. Voltage sensor
6. Current sensor
7. Temperature sensor
8. NOVA LINK




Equipment Setup Procedure

1. Plug the wind turbine module onto the main board without the generator part (Important: do not plug the module onto the main board in wrong direction – see the picture for reference!)
2. Fix the rail to the wind turbine module
3. Mount the wind turbine on top of the rail and connect the small cables to the module
4. Fix the wind machine to the rail at the 20 cm position
5. Plug the potentiometer module onto the second place of the main board
6. Turn the knob of the 1k Ω potentiometer to Rmin and the knob of the 100 Ω potentiometer ca. a third turn from Rmin to Rmax.







MultiLab Setup

1. Launch MultiLab.
2. Connect the NOVA LINK to the USB port on the computer. The green LED will turn on when the NOVA LINK is successfully connected to the computer.
3. Connect the current sensor to I/O-1 port of the NOVA LINK.
4. Connect the voltage sensor to I/O-2 port of the NOVA LINK.
5. Connect the temperature sensor to I/O-3 port of the NOVA LINK.
6. Click .
7. Click **Next**.
8. Set **Select rate** to **Manual**.
9. Set **Select recording mode** to **Add**.
10. Click **Next**.
11. Set **by samples** to **50**.
12. Click **Finish**.



Experimental Procedure

1. Put the wind generator to the 20 cm mark on the rail.
2. Connect the power supply to the wind generator.
3. Wait until the wind generator and the wind turbine have maximum speed.
4. Click .
5. At the end click .



Data Analysis

1. Click f_x .
2. Click on Functions.
3. Set Functions to Multiply.
4. Set G1 and G2 to the voltage and current measurement data.
5. Click Ok.
6. Click
7. Add the columns of the calculated power function.
8. Press Ok.
9. Click .
10. Measure the **temperature** and read the respective value for the density ρ of the air from the plot at the beginning of the manual.
11. Read the respective wind speed for the used distance from the plot at the beginning of the manual.

12. Measure the diameter of the rotor blade.

13. Calculate the power of the wind speed.

$$P_{Wind} = \frac{1}{2} \rho A v_{Wind}^3 \quad A = \frac{\pi}{4} d^2$$

14. Calculate the power of the rated output $P = IV$.

15. Calculate the efficiency:

$$\varepsilon = \frac{P_n}{P_{Wind}}$$



Questions

1. The wind energy is not fully converted at the wind turbine. Why does depreciation take place and consequently "loss" of energy? Into which forms of energy is the wind energy converted?
2. Find out about the efficiency of real wind turbines and compare your results with the real values. Name possible reasons for the differences.