# Produktutvecklingsprojekt
## Mekatronik EIE070

Project group 6

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# Introduction

The goal of this project is to develop a product to meet required specifications and deliver a satisfying result to potential customers. Our specific project involves developing a windmill system that can be installed on rooftops of residential villas. This system must deliver electricity to the villa and our windmill must also meet various specifications. In the following sections, we will outline our methods used for developing our product.

# Background

Gathering wind power into a useful form of energy has been done for thousands of years. In the past, men have used the energy of wind to power sailing ships, pump water, and in industry with windmills. The first modern wind turbines were first built in the 1980's and since then, wind has been an increasing form of electricity generation. Today, wind turbines are much more efficient and wind electrical generation capacity has grown by more than five times in the last 10 years. With the rising cost of fossil fuels, and stricter regulations on the environment, wind energy has emerged as an economically feasible way of producing electricity. Windmills have a very small environmental impact and have a very small maintenance cost throughout its lifetime. Sweden currently is a net exporter of electricity but only 1% of its electricity production comes from wind power. Windmills on rooftops would allow the country to rely less on other forms of energy. For consumers, windmills on their rooftops would not only eliminate their electrical bill, but would also make them a profit since the electricity they produce could be sold back to the electrical utility company.

# Methodology

We plan on extensive research about different windmill systems from various sources as well as analyzing products that are already in the market. A market survey will also be used to determine which non-technical attributes are preferred by potential consumers. We will use this information along with our knowledge of mechatronics to brainstorm ideas for our design.

# Project Organization

The main people involved in this project are the four group members, who represent two different fields of engineering: mechanical and electrical. Also involved are villa residents who volunteered time to participate in our survey.

# Project Scheduling

First, we will research windmill technology and systems that are already in use. We will study the most successful competitor products to see what the current industry standards are. We will also do a market survey to help us come up with some needed specifications.

Secondly, we will research how much power we can achieve by implementing different windmill systems.

Knowing what specifications our design must meet, and what the desired output is, we will brainstorm different designs for our windmill turbine. We will also brainstorm different types of generators that can be used, as well as a system for how the electricity will be transferred to the house or possibly the electrical grid.

After coming with all possible designs, we will use a grading system for the optimal design to be further developed. When we have that design, we will come up with detailed properties, such as size, weight and materials, until we have our final design. We will also address secondary needs such as speed control and power optimization.

Finally, we will prepare our presentation and finalize our written reports. This will include our computer designed model.

## Stakeholders

1. Villa Residents
2. Electric Utility Company
3. Landlords

# Requirements and Limitations

## Requirements

1. **Aesthetics**
   As highlighted in the survey, it is important that the design is small, discrete, and appealing since appearance is very important when calculating the value of a property.
2. **Efficiency**
   Perhaps the most important requirement, we want to design a windmill that is efficient in terms that it generates a good amount of electricity for a given wind speed.
3. **Maintenance**
   It is important for the system to have low maintenance requirements so the system is functioning properly at all times.
4. **Reliability**
   The product must be reliable in order to maximize customer satisfaction and increase its reputation in the market.
5. **Stability**
   For safety reasons, the system must be stable. The wind turbine should be able to withstand very harsh weather conditions.
6. **Cost**
   No matter how good the product is, it will not be successful unless it is affordable. Our design must be able to fit in the budget of an average villa resident.
7. **Weight**
   For installation and transportation purposes, our product should be a light as possible, without sacrificing stability, ofcourse.

# Market survey

In our market survey we interviewed 50 villa owners. They were presented with windmill solution that would decrease their electrical bill. We asked them what was the most important criteria, regarding the construction, that would make them want to purchase our product.

| | Design | Maintenance | Noise |
|---|---|---|---|
| Votes | 37 | 5 | 8 |

The majority thought that the design was the most important criteria. We asked them how they would like to have the design.
All most everyone demanded it to be small and discrete.

# Technology trends

Environmental topics are more important now than ever. People are becoming increasingly aware of pollution effects cause by non-renewable energy sources. Governments are also under pressure to increase electricity production from clean sources, and are increasingly providing incentives, such as tax breaks, to people who produce clean energy. These trends are favorable to the windmill manufacturing industry.

# Product suggestions

By combining our own knowledge in this area, accumulated by Internet research, and the knowledge by people who have already built their own windmill, we have come up with 4 different ideas for the turbine design and 3 possible generator designs. All of them follow our criterion of needs described above. The method we used to come up with the ideas was to search the market of existing products.

## Products

Through brainstorming, our group came up with the following ideas.

### Turbine designs

**1. Horizontal Propeller Mill**

This turbine is a propeller-like turbine that adjusts to the direction of the wind. The plate on the back is used to line up the rotating axis with the direction of the wind. This design is the most efficient one known, ca 80%, and is used in large scale mills. It does however have the problem with instability when the wind is not coming steady from one direction. Big forces will act on it when the wind tries to change its direction.

**2. Savonious Vertical Mill**

This design is a barrel-like cylinder with scoop shaped blades that forces the barrel to turn in one direction. Because of its symmetry around the mast, there is no need to line up with the wind, which reduces the complexity. It requires low maintenance, but has a lower efficiency. The number of blades and their position relative to the centre can be changed in a vast number of varieties to optimize the efficiency. It has good stability, even when the wind isn’t blowing steady.

**3. Darrieus Vertical Mill**

This mill has to thinner blades that create an oval shape. This mill is not self starting, and therefore needs a motor to get it started. It also has the problem that the torque will vary with the blade position. This might cause instability or vibrations.

**4. Helix Shaped Mill**

This is similar to the Darrieus, but it has 3 blades and they are turned 60 degrees around the mast. This is also not self starting, but the torque is distributed evenly eliminating the instability problems that are caused by the original Darrious model.

## Different generators

**1. Asynchronous Motor**

This motor is a very commonly used as a motor, so there is a big market for them. It has good efficiency, and is used in large scale wind mills. It does however only work well on a very narrow RPM ranges. It needs an independent system for breaking in order to stay synchronized with the grid. It also needs a minimum wind speed to generate electricity at all. It could also need a gearbox or a power converter to extend its usability. A drawback is that the rotor needs to be magnetized from an external source. This uses some power, which makes it worse for low wind speeds.

**2. Synchronous Motor**

This is also a common motor, and has great efficiency. It could be used directly coupled to the grid when the wind is high enough, but this needs a control system. It has low probability of loosing sync with the grid, since it has constant RPM. It will generate power without the need of external magnetizing of the rotor, so a power inverter can be used between the generator and the grid to be able to use it at low wind speeds.

**3. Permanent Magnet DC Motor**

This is a good motor for small mills, especially if it is not coupled to the grid. A DC booster will probably be needed to reduce the losses in the wires. Since a controller is used anyway for the switching, it can also optimize the loading of the generator and control how much current the generator should be loaded with. The overall efficiency can therefore be very high. It’s cheap, but might be quite complex to assemble and to develop the optimizing electronics. It’s possible to use a power inverter to sell the electricity also, but that will add the costs. Best used for a simple local grid, separated from the public grid.

### Output usage

**1. Coupled to the Grid**

This makes it possible to sell the power that the consumer doesn't need at the moment. The installation is included in the product so the company makes sure that it follows all the laws and standards. It's user friendly because the system is installed, and thereafter work on its own without regular maintenance or care from the consumer.

**2. Not Coupled to the Grid**

In this way, the generated power is used in a local power net. Could be used for some extra lights or heating, which will reduce the ordinary electricity usage. Good for remote places where no grid is available. It is a cheap solution, good for a "do-it-yourself"-project to reduce overall electricity need.

# Grading

## Grading turbines

Each mill is graded on a scale from 1 to 5, based on the following properties that were found the most important.

| Property | Horizontal | Savonious | Darrieus | Helix |
|---|---|---|---|---|
| Size | 1 | 4 | 3 | 4 |
| Stability | 1 | 3 | 2 | 4 |
| Efficiency | 5 | 3 | 2 | 4 |
| Cost | 2 | 4 | 3 | 1 |
| Maintence | 2 | 5 | 4 | 4 |
| Total | 11 | 19 | 14 | 17 |

## Grading generators

Each generator is graded on a scale from 1 to 5, based on the following properties that were found the most important.

| Property | Asynchronous | Synchonous | PM DC |
|---|---|---|---|
| Efficiency | 3* | 5 | 3 |
| Cost | 4 | 3 | 5 |
| Maintence | 5 | 5 | 3 |
| Total | 12 | 13 | 11 |

* The efficiency of the asynchronous motor may look oddly low. The 3p has been chosen to represent the overall efficiency of the generator. It will need constant power in order to keep the rotor magnetized, which lowers the overall efficiency.

The PM synchronous motor was found to be the best. For lower wind speeds than the synchronous rpm, the PM will still make it able to produce power through a power converter.

## Grading output usage

The price a villa owner would get when selling electricity to the grid is far less than the price to buy electricity from the grid. With this in mind there was actually nothing to consider; The most economic way to use the energy produced by the windmill is to use it in the villas local grid. This way the house owner can decrease the amount of electricity bought from the grid, which only reduces the costs.

Another way would be to sell electricity back to the grid when it’s not needed in the house. But this would only increase the Payback-time, because of all the extra components, and in our opinion it’s not even an option.

We’ve decided not to connect it with the grid.

# Calculations

## Generated power

The expected amount of generated power is coupled to the effective sweeping area of the turbine and the wind speed.

The following formula is used

$$= 05 \cdot \quad \cdot \cdot \cdot \cdot ^{3}$$

Where
**Cp** = 0.593, efficiency coefficient, at the most 0.593 for a wind turbine
**p** = 1.25, density of the air
**n** is the total efficiency of the generator and turbine
**V** is the wind speed
**A** is the turbine's sweeping area.

So it's obvious that the potential energy generated during a year is strongly coupled to the mean wind speed and the turbine's sweeping area. In Skåne, the mean wind is ca 6.5m/s, which is used in the following. From this it's the area (and turbine design to some extent, due to **n**) that sets the potential output power. It was estimated that more than 15sqm is unrealistic. Putting this in the formula gives, where the constants has been put together

$$= \frac{16}{\quad} \cdot 6.5^{3+15} = 1,5$$

During a whole year this yields

$$1.5 \quad \cdot 8760h = 13$$

This number, however, is not entirely realistic. No small mill can have a Cp of 0.593.  Ca 0.4 is more realistic. Also there is a loss in the generator with a gearbox, with a total **n** of typical 0.8. The actual expected output is therefore estimated to be around 7MWh annually.

# Product development

After using our grading system to come up with the best turbine and generator combination, we moved on to the next design stage in order to further develop our product.

## Electrical design

The PMSM is used as a generator, and the generated power should be transferred to the grid. A straight forward way is to let a MCU or a PLC check the rpm of the turbine, and couple the generators wire directly to the net when it's in phase. This requires of course that the wind speed is enough for the generator to spin as fast as the phase in the grid. In this coupled state the wind will try to make the generator spin faster as the generator's rpm is held back by the grid, and thereby power is transferred to the grid. When the wind fast enough to spin the generator up to the phase speed of the grid, a electronic power inverter must be used. Since the motor has permanent magnets, it will produce power as long as it just spins. In this state the generator should be loaded to the extent where it optimizes the available power from the wind. A controller system takes care of this. A suggestion is by measuring the wind speed and generator rpm and use a lookup table to find the maximum load current to optimize output power. This is achieved by alternating the switch frequency and duty cycle.
If the generator should lose phase with the net, the controller will notice this and deal with it. Perhaps by shorting the winding to bring the rpm down and then start over with the phase-in. The mill also shouldn't be allowed to over speed during a storm. If the controller notice that the wind is driving the mill to a too high level, the mill should be stopped. Shorting the windings through a semiconductor and/or relays is a way to break the mill. An additional mechanical break goes in and locks the mill completely.

## Mechanical design

### Materials

As choice of materials we want something light (to increase efficiency), corrosion-resistant (to withstand the weather) and still able to absorb a reasonable amount of force.

### Aluminum

Aluminum is one of the lighter metals out there and is also relatively cheap. Aluminum is resistant to corrosion as long as the liquid is in a pH-interval of 5-9. With normal rain being slightly below 6 pH, and acid rain on 5.6, aluminum is safe for corrosion. Although in southern parts of Sweden acid rain can drop down to 4.3 in pH[1]. The oxide coating on aluminum is removed by friction, which can be somewhat prevented by alloying it with chrome (an alloy used to harden materials and make them more corrosion-resistant). Since Aluminum (alloyed with

[1] http://chaos.bibul.slu.se/sll/forb_org_biol_odl/odlaren/ODN00-4/ODN00-4A.HTM, LundA, VäxtEko

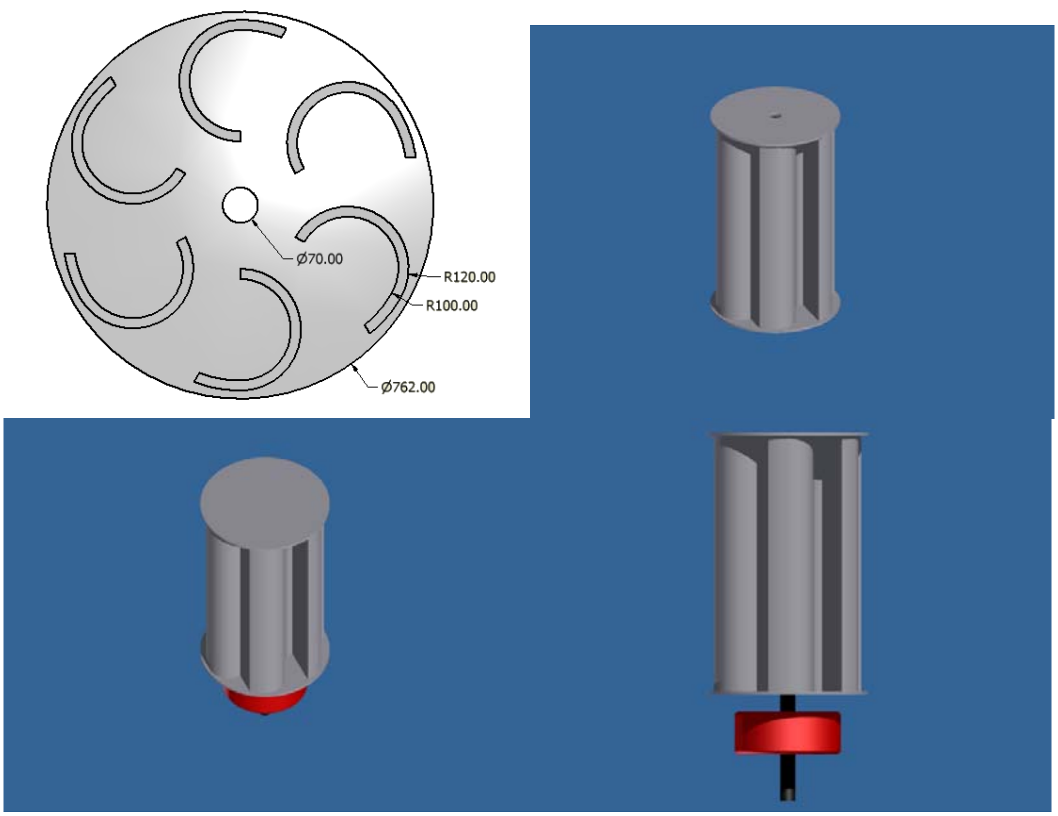
chrome) is very good at absorbing force, corrosion-resistant and light-weight, it serves well for the frame.

## Plastic

Plastic is very cheap and has a quite low density. The resistance to corrosion is high and it can get enhanced with a stabilizing medium (which also may improve the wear from the sun). Plastics can absorb a relative amount for force and since we need a construction with low maintenance we can strengthen it with glass fiber. Considering the relative low density and the average durability a plastic material would serve great for the turbine, to reduce the moment of inertia.[2]

## Model

This is a model of our suggestion of a windmill. The first two pictures show the turbine, and the last two pictures show the turbine mounted to an axle and a generator.

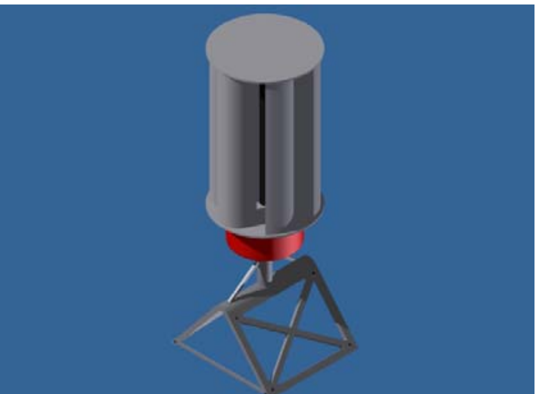


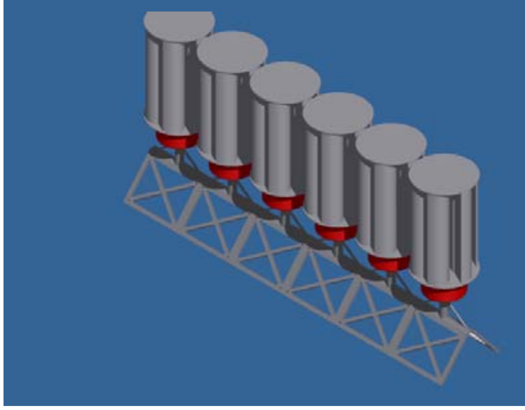

[2] , Kalpakjian Schmid, Manufacturing Engineering and Technology,2006 5th edition

## Mounting

When mounting the mill on to the roof we've designed a frame. It is designed to fit the roof, and it should be able to adjust to fit roofs with different angles.

The frame is made so the customer easily can attach more frames in a line if the customer decides that more windmills are needed. The material of the frame would be aluminum or some kind of aluminum alloy.





The first picture shows the frame, the second shows the mill attached to the frame, and the last show several frames and mills attached to each other.

## Conclusion

This report shows that the highest expected energy delivered by a system of windmills on the roof is ca 7MWh. This should be compared with the average annual usage in Sweden which is ca 20-25MWh. It is therefore found that windmills on the roof hardly can make a normal household independent of electricity, with the grid as buffer that is. To make this solution sustainable the household must lower its electric consumption. Or else the consumer must invest in more mills. Still, the buffer will be needed to make up for the need when there is no wind.