INDUCTICA 2004, Berlin

# Insulating Systems for Wind Turbine Generators

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## 1. Introduction

The use of renewable energy sources has increased considerably in the past due to the strong demand for a sustainable protection of our environment. Amongst these renewable energies the use of wind power has shown the fastest growth. During the last twenty years the installed wind power capacity has increased globally with a rate of about 25 % per annum. Europe is the leading continent in using wind energy for power generation with an installed capacity of about 29’000 MW which corresponds to 74 % of the global wind power capacity.

In parallel to this fast growth, the technology of wind turbine generators has changed remarkably since its beginnings. The production cost of 1 kWh of wind power has fallen by 20 % over the past five years alone. Today the commercial size range of wind generators covers machines from 0.3 MW up to 5 MW. Wind turbine generators have to be designed to withstand severe environmental conditions. Once installed, generators must be very reliable because they are not easily accessible for maintenance and repair. They have to be designed and manufactured to operate with a minimum of maintenance. Furthermore electrical performance has to be optimized for varying wind conditions.

A critical component for both requirements – low maintenance / long lifetime and high electrical performance – is the insulating system of the generator.

This paper gives an overview on the state of wind power today and the generator technology with a special focus on insulating systems and future trends.

## 2. The state of wind power today

The boom in wind turbine generators started 20 years ago. Since then the installed wind power generating capacity increased with an annual rate of about 25 % with most of the market growth occurring in Europe (Figure 1, Table 1). Europe is the leading continent with 74 % of the global capacity installed. Half of this capacity (14’600 MW) is set up in Germany with a total of 15’400 wind turbines. In 2003 these wind turbines produced about 27 TWh of electricity representing 5.5 % of the country’s total consumption. This is the equivalent of 3 nuclear power plants. However this statement does not take into account that a nuclear power plant supplies constant power throughout the year whereas wind is a changeable element and wind power is hardly predictable. In fact for 1 MW of wind power capacity 0.8-0.9 MW of conventional power capacity has to be available as reserve supply.

Wind energy systems do not generate air and water emissions or hazardous waste. They do not deplete natural resources and do not need significant amounts of water during operation. The use of wind energy helps to prevent global warming caused mainly by carbon dioxide.

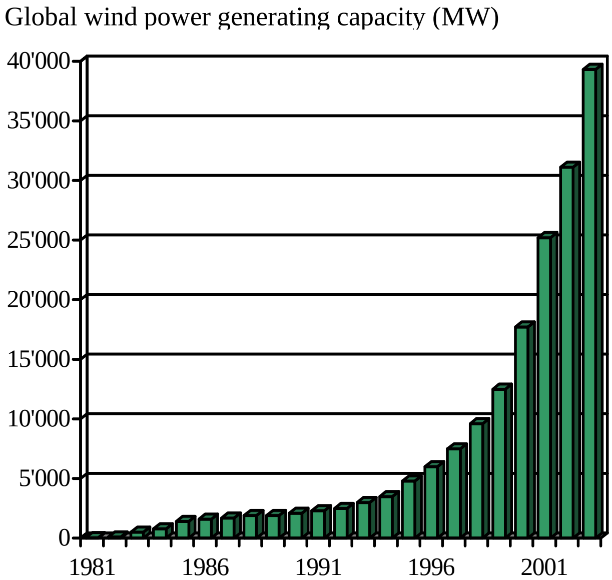

Figure 1: Global increase in wind power generating capacity

| Installed wind power capacity by the end of 2003 | MW | % of global capacity |
|---|---|---|
| Germany | 14’600 | 37 |
| USA | 6’400 | 16 |
| Spain | 6’200 | 16 |
| Denmark | 3’100 | 8 |
| India | 2’100 | 5 |
| ... | ... | ... |
| Switzerland | 5 | 0.01 |

Table 1: The five top countries in wind power capacity

But nevertheless there is a growing opposition to the uninhibited increase of the number of wind turbines. The most severe environmental impact is given by their size. The largest wind turbine available today has a height of 180 m and a rotor diameter of 120 m (Figure 2). Wind farms with 20 or more turbines are a serious interference with the landscape and local residents put up a fierce struggle against their installation. Offshore installation could be a solution to the visual impact but only if the wind turbines are installed far off the coast. German communities and holiday resorts situated on the coast are demanding a distance of at least 30 km. This of course increases the cost of offshore plants considerably.

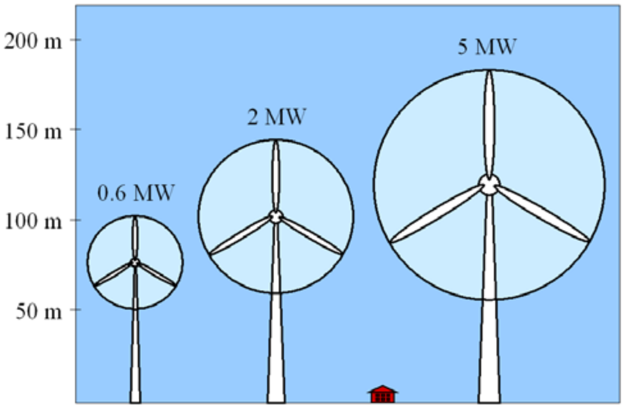


Figure 2: Size of wind power tubines as a function of their rated power. The figure also shows the size of a two-story building drawn in the same scale.

## 3. Wind turbine generator technology

There is a basic difference between conventional and wind power plants regarding the availability of energy. The main disadvantage of wind power is its unpredictability and the fact that a slight decrease in wind speed has a large effect on the power output. This is due to the cubic power law: Power output correlates with the cube of wind speed. For a 2 MW wind turbine generator a decrease of wind speed from 9 to 7 m/sec (= 22%) gives a 50 % reduction of power output (Figure 3). Therefore regions with little wind (< 4 m/sec) are not suitable for wind power generation. Wind resource evaluation is a critical element in projecting turbine performance at a given site.

The capacity factor measures the productivity of a wind power plant. It is the plant's actual production over a given period of time compared to the amount of power produced if the turbine operated at maximum output. A capacity factor of 25-40 % is common, it is a matter of economical turbine design. A large rotor combined with a small generator would have a capacity factor of 60-80 %, but would produce very little electricity. The most electricity is gained by using large generators and accepting the fact that the capacity factor will be lower as a result.

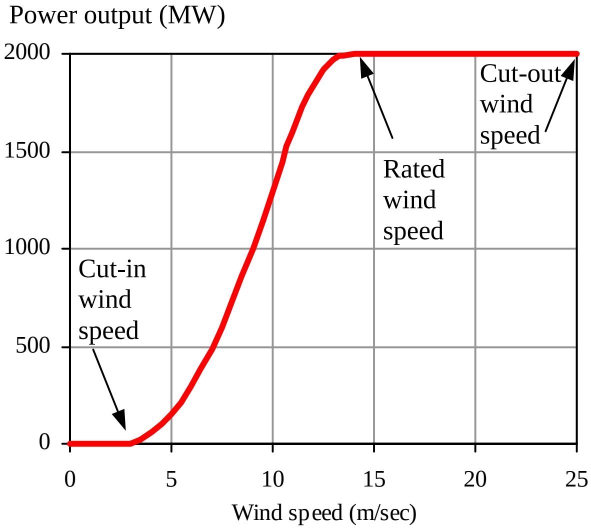


Figure 3: Power output of a 2 MW wind turbine generator as a function of wind speed

The availability factor on the other hand measures the reliability of a wind turbine. It is reduced by long breaks due to maintenance or repair. Typical availability factors of today's wind turbines are more than 98 %.

Wind turbines are designed to work as long as possible at rated wind speed (Figure 3). An important design element are the aerodynamics of the rotor blades. Pitch controlled wind turbines are measuring the wind power and adjusting the blade angle continuously in order to maximize the power output of the generator for all wind speeds. Passive stall controlled wind turbines have a fixed blade angle but its geometry is designed to stall if the wind speed becomes too high in order to avoid damages of the wind turbine. Around two thirds of the wind turbines in the world are stall controlled machines. An increasing number of larger wind turbines (≥ 1 MW) have an active stall power control mechanism. They work like pitch controlled machines at low wind speeds but when the machine reaches its rated power the blades are turned in the opposite direction to provoke stall thus wasting the excess wind energy.

Wind generators have to work with a power source (the wind turbine rotor) which supplies very fluctuating mechanical power. Therefore their design is quite different compared to conventional generators attached to the electrical grid.

Commercial wind turbine generators cover a range from 0.3 up to 5 MW. Design parameters are:

- Synchronous or asynchronous
- Low or high voltage
- Single speed, two-speed or variable speed operation
- Direct or indirect grid connection
- Air or water-cooling
- Permanent magnet synchronous generators

Synchronous wind turbine generators normally use electromagnets in the rotor which are fed by DC from the electrical grid using a converter. Such single speed generators have a relatively simple design. They attain their peak efficiency only at a defined wind speed.

Two-speed pole changing generators run with a different number of stator poles and thus with a different rotational speed. The higher number of poles is used for lower wind speeds. Most two-speed wind turbines use generators with four or six poles respectively.

Asynchronous (induction) generators have a squirrel cage rotor which is turning with a generator slip of about 1 % (= difference of rotating speed between rotor and magnetic field of the stator) to produce maximum power.

Variable speed operation can be achieved by varying the resistance in the rotor windings of an induction generator. The connection to the rotor can be done by sliprings or - if the resistors and the electronic control system are mounted on the rotor itself – by optical fibre communication.

Most wind turbines run at almost constant speed with direct grid connection. However, generating AC at variable frequency with indirect grid connection offers some advantages. The frequency of the stator is varied with an inverter and thus the turbine can run at variable rotational speed. The generator may be synchronous or asynchronous and the turbine may have a gearbox or run without a gearbox. The generated AC current with variable frequency is first converted into DC using thyristors and then converted into AC with 50 Hz using an inverter or thyristors. The rectangular shaped waves finally need to be smoothed out with AC filters.

Variable speed generators are more efficient and capture more wind energy by operating most of the time close to the rated power of the turbine although some energy gets lost in the AC-DC-AC conversion process. Their main disadvantage is cost.

Other components of a wind turbine are the gearbox transferring the power of the rotor to the generator and the yaw mechanism which is used to turn the nacelle with the rotor aginst the wind (Figure 4). There are also gearless wind turbines, in this case the generator is a synchronous machine with a salient pole rotor similar to a small hydro generator (Figure 5).

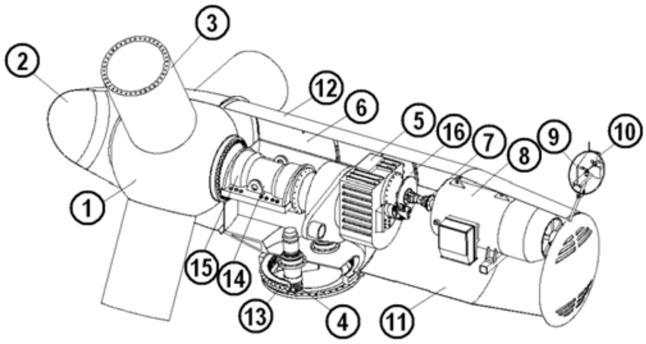


Figure 4: Nacelle of a wind turbine with its main components (Picture by Nordex):

| | |
|---|---|
| 1 Rotor hub | 9 Wind met mast |
| 2 Nose cone | 10 Air speed meter |
| 3 Rotor blade | 11 Main frame |
| 4 Yaw drive | 12 Nacelle cover |
| 5 Gearbox | 13 Yaw bearing |
| 6 Nacelle lining | 14 Main shaft |
| 7 Cardan shaft | 15 Main bearing |
| 8 Generator | 16 Disc brake |

Figure 5: Gearless wind turbine (Picture by Enercon)

## 4. Insulating materials for wind turbine generators

Wind turbine generators must be very reliable because they are not easily accessible for maintenance and repair. They have to be designed and manufactured to operate with a minimum of maintenance and to give a high electrical performance. The insulating system of a wind turbine generator is a critical component for both requirements. Insulating materials used for wind turbine generators are basically the same as for conventional generators. But they must be carefully selected to meet the specific requirements of wind turbines. Insulating materials are:

- Winding wire and conductor insulation
- Stack consolidation materials
- Main wall insulation
- Impregnating resins and varnishes
- Corona protection
- End winding tapes
- Slot insulation and wedging
- Bracing materials
- Finishing coatings

In commercial wind turbine generators with 0.3 - 5 MW rated power generator voltages are in the range of 440 V – 6 kV. Two insulating systems will be reviewed in detail, one for random wound coils for low voltage (690 – 900 V, Table 2) and one for form wound coils for high voltage application (6 kV, Table 3). It is important to note that Von Roll Isola is manufacturer of *all* materials of the two insulating systems. Benefits for the customer are that all materials come from one source and are proven to be compatible.

| **Insulating materials for 690 V - 900 V random wound coils** | |
|---|---|
| Winding wire | Thermex® 200 or SamicaShield® (Samica® insulated round wire) |
| Slot insulation | Myoflex PVS (Impregnated PETP fleece/film/fleece) or Myoflex 2N50/80 (Nomex®/PETP film /Nomex®) or Myosam (PETP film/Samica®/PETP film) or Myoflex 2N80S (Nomex®/ Samica®/ Nomex®) for the slot portion and Myoflex 2N130S (Nomex®/ Samica®/ Nomex®) for the end winding |
| Impregnating resin | Damisol 3040 (UPI resin) or Damisol 3032 (UPI resin) |
| End winding tape | 4616/18 (Adhesive glass fabric) |
| Wedges / closures | Myoflex PVS (Impregnated PETP fleece/film/fleece) or Vetronite 64.120 (Glass fabric/epoxy composite material) |
| Finishing varnish | Damicoat 2404/07 (Air drying varnish) |

Table 2: Insulating system for low voltage wind turbine generators (690 V – 900 V)

| **Insulating materials for 6 kV form wound coils** | |
|---|---|
| Winding wire | Silix® (Glass lapped) or Daglas or Samicafilm® (PETP film/Samica®) on bare or enamelled wire |
| Stack consolidation | Thermopreg 251.78 (Impregnated glass fabric) or Glasoflex 261.10-03 (Impregnated glass fleece) |
| Main wall tape (VPI) | Samicapor 366.55-10 for epoxy-anhydride resins or Samicapor 366.58 for UPI resins (Glass backed Samica® tapes) |
| VPI resin | Damisol 3407 (Epoxy-anhydride) or Damisol 3308/3309/3032/3340 (UPI) |
| Corona protection | Conductive tape 215.51 (not for epoxy-anhydride resins) or Conductive tape 215.55 Semiconductive tapes 217.21/22/31 |
| End winding tape | Epoflex P 324.03 |
| Winding and bracing | 151.10/12 (Iso-cords and sleeves) |
| Slot wedges | Delmat 68.420/660 or Vetronite 64.120 (Glass fabric/epoxy composite material) or Vetroferrit 432.20/21 (Magnetic) |
| Finishing varnish | Damicoat 2404/07(Air drying varnish) |

Table 3: Insulating system for high voltage wind turbine generators (6 kV)


Figure 6: Taping machine MI 135 for flat coil technology

6 kV form wound coils are suitable for applying the cost-saving flat coil technology. With this technology the loop is insulated with the main wall mica tape before forming the 3-dimensional coil.

The flat coil technology permits a high automatization of the coil production. Figures 6 and 7 show the flat coil taping machine MI 135 and the coil forming machine CFM 1504. Von Roll Isola is supplying the complete production equipment and the application know-how for the flat coil technology.

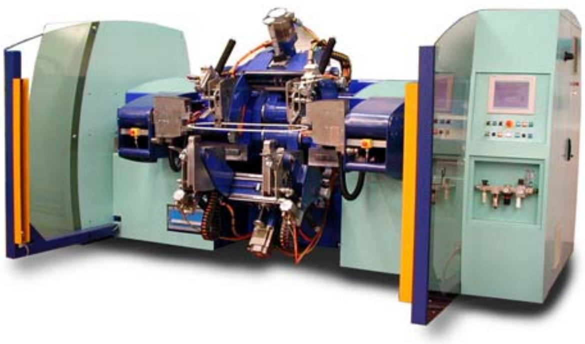

Figure 7: Forming machine CFM 1504 for flat coil technology

## 5. Future trends

Many European countries are pushing national programs to increase the percentage of power generation by wind turbines. At the same time people living in areas where wind farms are or could be installed are fighting against new plants or the extension of existing ones. Offshore wind farms could be a solution to this problem if they are installed far away from the coast. Offshore winds are generally stronger and blow more often.

But investments for offshore wind turbines are much higher. Foundations have to be strong enough to withstand heavy seas. The connection to the electrical grid has to be done by underwater cables. Maintenance is more difficult and corrosion by salt water is another critical factor. Investments in offshore wind farms make only good economic sense for large wind turbines, i.e. 2-5 MW. This means that there is a clear trend to large generators.

Denmark is the pioneer in offshore installations. The first small offshore wind farm was built 1991 in the Baltic Sea, larger ones are Middelgrunden (20 turbines with 2 MW each) and Horns Rev (80 turbines with 2 MW each). Other offshore farms are planned in Germany, Sweden and England. If they all will be realized is an open question. The first euphoric phase of wind power use is over and has moved towards a more critical and more realistic approach.

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