

# Generation Yield improvement, Control and Protection in modern Windmills



## Applications

- **Blade pitch and Yaw control**
  - Current Control in the low-power electrical drives
- **Double-fed induction generator (asynchronous machine)**
  - Precise and fast current detection in the pulse-controlled IGBT-converters (rectifier and inverter) to control the power for the grid
  - Short-circuit protection of the power semiconductors in the converters
- **Synchronous generator**
  - Current Control in the pulse converters (rectifier and inverter) to transmit the full power to the mains grid
  - Short-circuit protection of the power semiconductors in the converters

## Features

- Bipolar AC & DC current measurement from 50 to 2000 A<sub>RMS</sub> nominal
- Bipolar as power supplies from 12 to 24 V (Type dependant)
- Response time @ 90 % of I<sub>PN</sub> : < 1 μs
- Wide Bandwidth from DC up to several hundred of kHz
- Accurate current output signal (± 0.3 to 0.65 % of I<sub>PN</sub> typically @ + 25°C)
- Galvanic Isolation
- Different Compact Sizes in a variety of mounting topologies (mechanical or PCB)
- Moulded versions for harsh environments
- Good common-mode behaviour
- EN 50178 Compliance
- CE Marking
- 5 years warranty

Fossil fuels have always been the primary source of energy for electricity generation. Concerns about the sustainability and greenhouse gases from fossil fuels has led to an increased drive to develop alternative systems to generate electricity. This if further supported by international agreements to reduce the volume of Carbon Dioxide produced from fossil fuels.

The building of modern wind energy turbines (WET) with power ratings up to 5 MW (presently in the test phase) is only made possible by using modern materials to meet the mechanical requirements supported by modern control and power electronics.

The generated energy must be fed into the grid systems at a controlled frequency and voltage. Current transducers of various sizes are key components of every converter in a WET, providing optimal control and protection of the converter.

Since the early days of its evolution, mankind has used the wind as a source of energy. Windmills transformed the energy contained in the wind into mechanical, usable energy that could be used to grind grain or pump water.

Many theories of the physics and design of modern wind turbines were discovered in the first half of the 20<sup>th</sup> century. The German engineer Albert

Betz calculated, in his book published in 1926, that the maximum theoretical efficiency of an ideal wind turbine is about 59.3%. In the 1940s, Ulrich Hütter developed the theoretical basics (derived from his excellent aeronautical knowledge) for the layout of all modern free and high speed running wind energy converters with two or three rotor blades.

COMPACT AC/DC CURRENT TRANSDUCERS : **LA** and **LF** Series



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Picture 1: Windmills in the harbour of Rhodes, Greece - the cloth that forms the rotor wings has been wound up.

Picture 2: A wind driven coastal pumping station in Lobbe (on the German island of Rügen in the Baltic Sea)

Picture 3: Wind park on Gran Canaria in the Canary Islands.

When the wind speed exceeds a certain threshold, WETs must have power controls in order to avoid mechanical and/or electrical overload. Generally, the rated power of the generator is one of the threshold levels that must not be exceeded.

There is another equally important need for power control. It is essential to optimise the generation of electricity to provide the maximum continuous power to the grid system for both loading and economic reasons.

Different types of power control are used. Simple control can be achieved passively or actively by the rotor blades. Passive limitation can be achieved by a special profile of the single rotor blades. At a certain wind speed, the air stream that causes the rotation of the rotor collapses (the so-called stall) and the rotor comes to a halt (stall control).

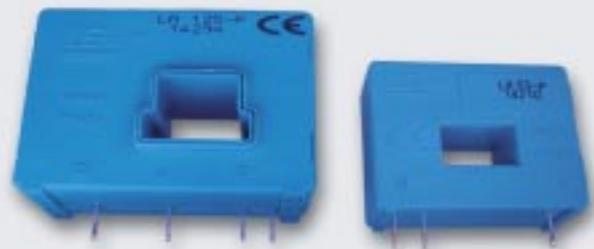
In common use today by larger wind turbines is an active power control system that adjusts the rotor blades within their longitudinal axis (pitch control). With this adjustment of the blade angle relative to the rotor plane, it is possible to control more than the generator power. At higher wind speeds, the rotor blades can be twisted in such a way that the rotor comes quickly to a halt. Low-power electrical drives are commonly used for such a purpose. In the control inverters, compact, PCB-mounted current transducers (LEM models LA 55-P, LA 100-P, LA 125-P, LA 200-P), are widespread. These transducers are part of the converter's closed loop control and therefore provide a rapid response. When coupled with intelligent power control of the generators, the maximum continuous power can be delivered until the upper-limit wind speed is reached.

But only when the political framework changed at the beginning of the 1990s did government aid for renewable energies become available in many countries. This prompted intensified commercial development of wind energy turbines (WETs). More and more wind turbines and wind parks have been constructed and created; at present the first 4.5 to 5 MW wind turbines are in the test phase. With 16,929 MW of wind power installed out of a worldwide figure of 47,317 MW, Germany leads the league table, ahead of Spain, the US, and Denmark.

### Power control of wind turbines

Wind is the exchange of air masses, primarily caused by local or even large area temperature differences that result from the effects of solar radiation. Obstacles such as forests, mountains and buildings produce turbulence that creates a permanent change of wind speed. The rotors of wind turbines transform energy contained in the wind into rotational (kinetic) energy, which drives a generator to produce electrical current.

The power of the wind, and thus the amount that can be used, is proportional to the cube of the wind velocity. There is also a simple correlation between the rotor area, calculated from the rotor diameter, and the energy that can be derived from the wind that flows through this area.



Picture 4: LEM PCB mounted current transducers from 50 A up to 200 A<sub>RMS</sub> nominal.



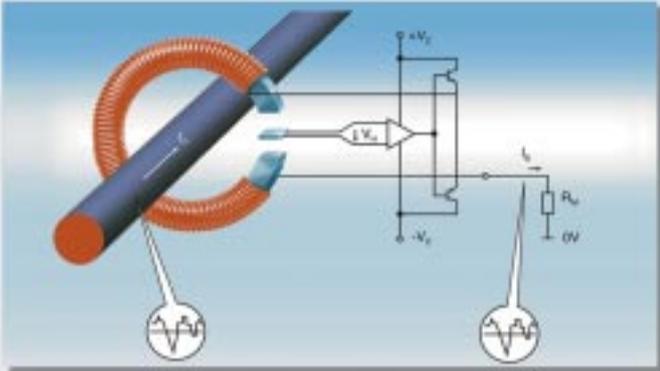
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## Yaw control

It is important that the rotor is always oriented perpendicular to the wind, for two reasons. The first is to ensure that the wind streams through the maximum rotor area, so that the maximum energy is obtained from the wind. The second is to avoid non-uniform loading of the rotor blades by ensuring that they are not flexed during each revolution.

Commercial large wind turbines are usually so-called windward machines, i.e. the rotors face the wind in front of the tower, but this is an unstable state. Therefore, the nacelle and rotor must be actively twisted into the wind by electric motors. Additional brakes are used to ensure that the nacelle will not twist due to small and short-term change of wind direction. In order to position the drives optimally, transducers in the respective converters measure the current continuously. The quality and response time of the current control are influenced by the design and performance of the current transducers. This is why closed-loop current transducers with a low current



Picture 5: Circuit diagram of a closed-loop Hall effect current transducer.

rating are used (LEM model LF 205-S) in this application. The inherent advantages of closed-loop current transducers are a high bandwidth combined with a short response time and very good linearity leading to good accuracy.

The next problem is to deliver the electrical power from the WET into the mains grid. Manufacturers of wind turbines have developed competing systems for this purpose. In effect, every wind turbine is equipped with either an asynchronous generator or a synchronous generator.

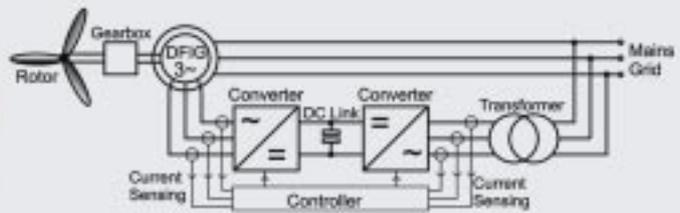
## Asynchronous generator and grid coupling

The classical “Danish Concept” describes a wind turbine consisting of a stall-controlled rotor with three rotor blades, a gearbox, a pole-switched asynchronous generator with squirrel cage rotor and a direct mains grid coupling. The direct grid coupling produces a “constant-speed” system with a nearly constant operating speed in the super-synchronous

slip area. The rotor speed can be adjusted within narrow limits by a slip control and in wider ranges by switching the poles of the generator. The gearbox adapts the rotor revolutions to the generator speed. The machine needs reactive power from the grid to build up the rotating field. In order to limit the inrush currents that are generated when the generator is coupled with the grid, soft-starters are used between the generator and the grid during the starting period. This direct grid coupling approach is no longer used with large wind turbines, due to some technical drawbacks (e.g. equalising processes of the grid connection by the switching actions used for power adjustment).

## Double-fed induction generator

The majority of today’s large wind turbines use a modified “Danish Concept”, in which a double-fed asynchronous machine acts as a generator.



Picture 6: Circuit diagram of a double-fed asynchronous generator.

The frequency and voltage of the stator are coupled tightly with the mains grid. The slip ring rotor is coupled with the grid by means of a special inverter, which must be able to transmit energy both towards the machine and the grid. This inverter only needs to be specified for the slip power, which is generally only 20% of the rated power of the generator.

This neat concept allows adjust of a larger power flow by only controlling a small proportion. A wind turbine that is designed in this way is a variable speed system from the sub-synchronous up to the super-synchronous area. Two identical pulse-controlled IGBT-inverters with a voltage DC link are used as converters. In either energy transport direction, one of them will be used as a rectifier while the other one will be used as an inverter, or vice versa.

Precise and fast current detection is necessary in order to control the power for the grid in addition to the DC link voltage. LEM provides closed-loop current transducers with medium current ratings that are well suited for this purpose (LEM models LF 305-S, LF 505-S). These transducers are compact and are available with many different mounting styles. In addition, LEM voltage transducers can be used to monitor and/or control the voltage of the DC link.



Picture 7: Stator of a synchronous motor at permanent magnets.  
Picture by courtesy of ETEL-Switzerland.

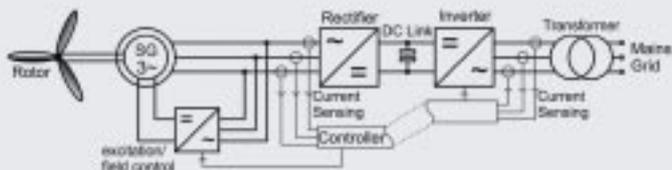
### Synchronous generator and grid coupling

Both concepts described above use a gearbox to adapt the relatively slow revolutions of the rotor to the speed of the generator. A different concept that is achieving success in the market uses a synchronous generator to provide a variable-speed wind energy turbine.

As the gearbox with its mechanical losses and the need for intensive maintenance is no longer used, the adaptation of the rotor revolutions to the generator speed has to be derived from the low rotor speed.

The size of the synchronous generator will be governed by mechanical power delivered by the windmill blades. As this will be low speed and high torque, the use of torque motors with permanent magnet rotors are ideal for powers up to several hundred kW. Larger systems will use a synchronous multipole generator with a wound rotor.

A machine with many poles termed a “ring generator” is used in these applications.



Picture 8: Circuit diagram for the synchronous generator.

A significant advantage of synchronous generators is that they can provide either inductive or capacitive reactive power (even zero) depending on the control of the field/excitation control.

The mains grid coupling is through a pulse converter that is specified for the full power to be transmitted. For this application, LEM's dynamic closed-loop current transducers (models LF 1005-S, LF 2005-S) can be used in the rectifier and the inverter. Moulded versions are also available for harsh environments.

All LF-family current transducers that can be used for the above applications feature good common-mode behaviour as well as an accuracy of 0.3 % (with reference to the rated value) at ambient room temperature.



Picture 9: The LF range provides current transducers from 100 A up to 2000 A<sub>RMS</sub>.

By using the closed-loop principle, a fast response transducer can be made providing short-circuit protection of the power semiconductors in the inverters – an invaluable advantage for wind energy turbines in offshore areas where the maintenance is difficult and expensive.

Current transducers are indispensable components in modern wind energy turbines. LEM, with more than 30 years experience in the development of transducers, contributes a vast expertise. For many of these applications, LEM provides ready-to-use solutions; others can be developed and manufactured to customers' and applications' demands.