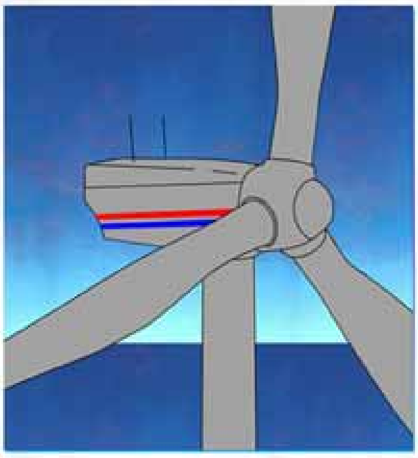
INDUCTIVE COMPONENTS AG



Power Quality

for Wind Turbines

V05/08

HighTech aus Deutschland

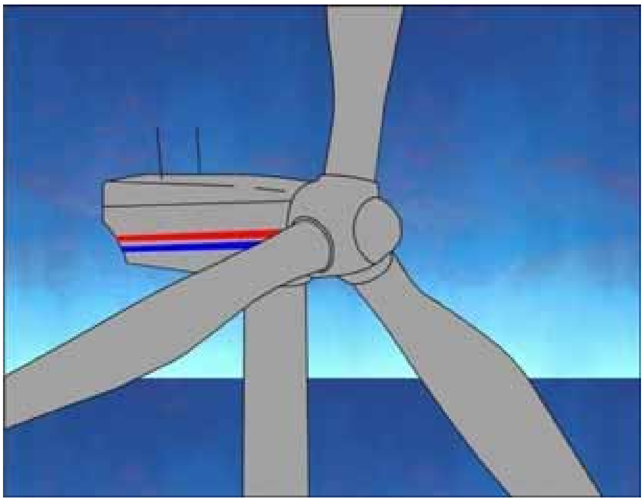
Introduction

Wind turbines are designed to produce electrical energy as cheaply as possible with maximum yield with wind speeds of around 15 metres per second (30 knots or 33 miles per hour). They have an expected operating life of 20 years, which is more than 120,000 hours. In addition to achieving maximum power yield some of the important issues with wind turbines are the speed of rotation, quality of the power that is produced, protection of components, size and cost of manufacture. Wind turbines are different from other generators connected to the grid because they have to work with a power source (wind turbine rotor) which supplies widely fluctuating mechanical power (torque).

Three-phase asynchronous (cage wound) generators are used in most wind turbines around the world. These were really originally designed as an electric motor but adopted almost exclusively by the wind turbine industry because they are reliable and relatively inexpensive to produce. The term asynchronous is used because the rotor rotates at a speed which is slightly different to that of rotating flux of the stator. In the stator there are electromagnets, which are always used in multiples of three. Most turbines use nine or six electromagnets, which produce 6 or 4 electromagnetic poles respectively. 6-pole machines run at 1000 rpm and 4-pole generators at 1500 rpm on a 50Hz grid (1200 and 1800 on a 60Hz grid). These are relatively high speed generators and as a result they are smaller and cheaper to build.

The stator of the asynchronous generator is connected, through a switch, to the mains network and because of this no matter how much torque is applied through the rotor it will always try to rotate at the mains supply frequency – the torque simply adjusts the amount of electrical energy that is produced. However, if the rotor rotates at exactly the same speed as the rotational electrical field of the stator then no power is produced and the turbine is considered to be idling. It is only when there is “slip” between the rotor speed and stator electrical field rotation that current is generated onto the mains network. In practice the difference in the rotor’s rotational speed at peak power and idle is very small; about 1%. The slip is negative, i.e. the rotor speed is slightly ahead of the rotating flux in the stator winding. The slip is useful because the slight change in speed reduces the strain on mechanical components caused by changes in torque.

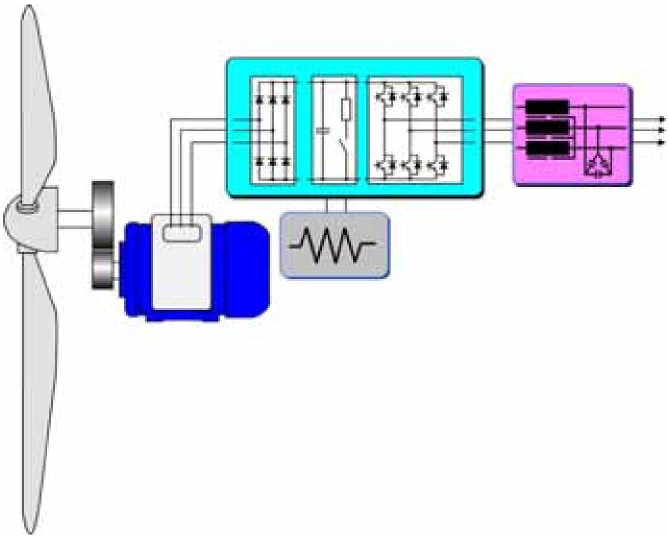
By applying some rotational resistance to the rotor it is possible to induce more slip (variable slip control) which can be used to regulate the rotational speed of the rotor when there are gusts or when the turbine starts to accelerate. High slip does release more heat from the generator, which then runs less efficiently. Another method that can be employed is to adjust the pitch of the turbine blades by turning them but this cannot be done quickly and so in some systems a combination of slip and pitch control is used.



Control methods used for transferring power to the electricity network

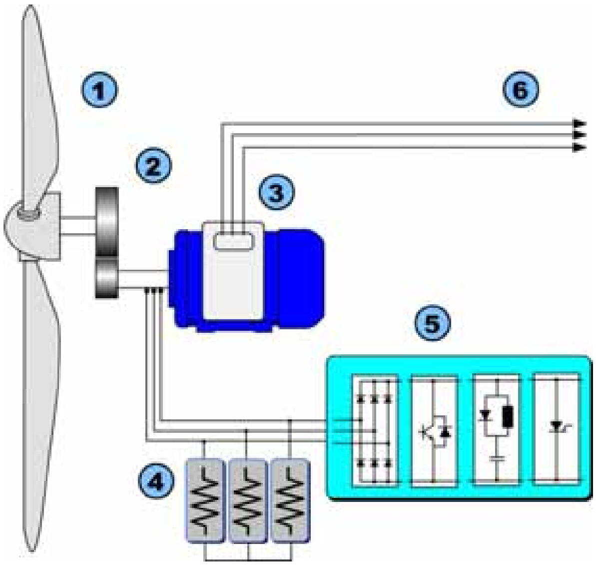
1) Full power Conversion

A small number of wind turbine generators have an indirect grid connection through an inverter which takes the current from the generator, converts it into DC and then inverts it back to AC. In this way it doesn't matter about the rotational speed of the turbine, providing it isn't running too fast, and the method has the advantage that the extra energy created by gusts of wind can be stored as rotational energy. However, this method can be expensive because of the high ratings of the electronic power switching components that are required. The output power also requires filtering to remove harmonics and high-frequency interference, before it can be fed back onto the mains network but the electronics can be used to help correct power factor problems on the grid by phase-shifting the generated current relative to the voltage on the AC grid, which is particularly useful on a supply which has low impedance.



2) Slip control by varying the rotor windings' resistance

Variable slip control can be achieved in different ways and one method is to use variable resistors that are connected to the three rotor winding assemblies through slip-rings. By doing this the rotor resistance can be adjusted and the amount of slip controlled.

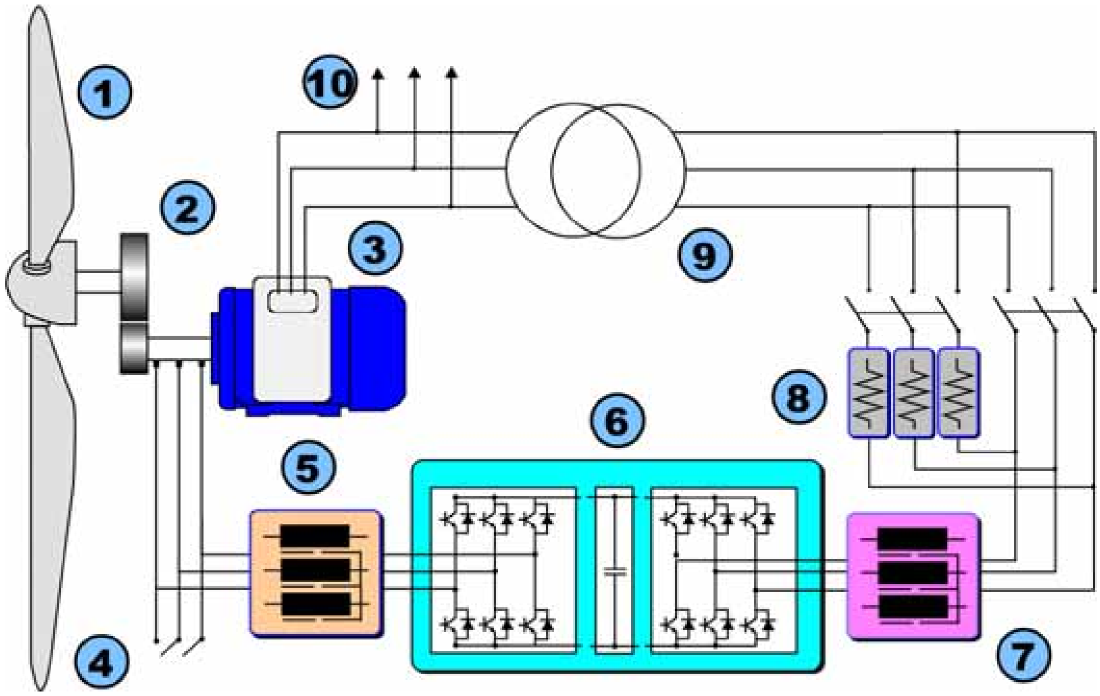


1)	Turbine blades	4)	External resistor bank
2)	Gearbox	5)	Rotor current controller
3)	Wound-rotor induction generator	6)	To power grid

3) Double-fed induction generator with vector control of the rotor currents

A more effective method of controlling slip is to use a double-fed induction generator with vector control of the rotor currents. In this technique the rotor circuit is supplied with current from a four-quadrant voltage source, current-regulated power converter (see diagram below).This generates currents in the rotor at frequencies that relate to the grid frequency, with virtually instant regulation. The response of the power converter is fast enough to maintain the correct alignment of the torque producing component of the rotor current with the rotor flux so that the generator remains under relative control even during significant grid disturbances. The converter connected to the grid either absorbs or provides real power to the grid depending on the operating speed of the generator. When the rotor is rotating below synchronous speed, power is transferred from the grid to the rotor circuit and when the rotational speed is above synchronous speed the power flows in the opposite direction, therefore the power exchange with the grid is the sum of the power from the stator and rotor (minus losses). The maximum power through the converter is approximately 25% of the total output power.

A transformer is used to decouple the converter and hence the rotor frequency from the grid and so the generator can work with a much wider slip range (± 20%) compared with 0 - 2% for a conventional induction machine. This allows the turbine blade speed to be adjusted so that it matches the wind speed and hence is more efficient over a wider range of wind speeds. Furthermore, by adjusting the phase difference and magnitude of the rotor voltage it is possible to determine the active and reactive power delivered to the grid and this can be used for power factor correction by reactive compensation.



1) Turbine blades	6) 4-Quadrant converter
2) Gearbox	7) Line choke
3) Asynchronous generator	8) Soft start resistors
4) Overload protection	9) Decoupling transformer
5) Line choke	10) To power grid

Power Quality Issues

The inverter fed current sine-wave is distorted by the high-speed switching of the power semiconductors and so this requires filtering before the current can be fed back onto the grid.

Turbines usually run idle (unconnected) at slow speeds. When running at the rated speed it is important to connect to the grid at the correct moment – if this isn't done the rotor could accelerate and over-speed although this can be prevented by fail-safe brakes.

When a large wind turbine is first switched on current is required to magnetise the generator and this could cause dips or surges on the grid, especially when the grid has low impedance. At this point there could also be flicker and extra wear on the gearbox caused by the braking effect of the generator. A resistor or a thyristor soft-start, operating in conjunction with a by-pass switch, can be used to reduce the current inrush and hence give a smoother start-up.

Islanding is caused by accidental disconnection from the grid, caused by lightning or circuit-breakers. The electronic control system monitors grid voltage and frequency and if these drift outside certain limits the turbine will automatically disconnect. Load resistors can be used to dissipate the surplus electrical energy by converting this into heat energy.

Power improvement components from REO

Wind turbine applications are some of the most demanding with a long working life expectancy under environmental conditions including high ambient temperatures, moisture, vibration, shock, humidity, forced water spray, and salt-laden atmospheres in the case of off-shore applications.

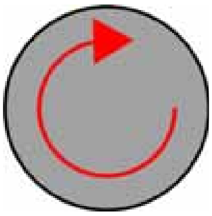
For this duty REO have developed a range of fully encapsulated resistors which have many advantages over traditional wire-wound versions. Higher protection ratings of IP66/67 are available which can cope with the exceptional demands of the wind power generation industry. Furthermore the construction techniques used, enable these resistors to withstand higher voltage and current spikes, in a similar manner to load or short-circuit resistors. The combination of encapsulation and quartz-filling provide more than ample protection against vibration and shock. REO resistors are also very quiet in operation.

REO resistors are fully tested for immunity against climatic, mechanical and corrosive conditions and are designed for a life expectancy of greater than 30 years or 200,000 hours of operation.

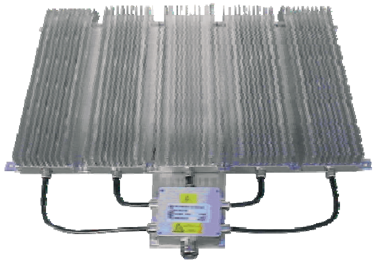
In addition REO produce a range of inductive components mainly for improving power quality but also for protecting electrical and mechanical equipment from damage and for increasing system reliability and extending the useful life of components.

Space saving is one of the most important considerations for any equipment that is designed for use in wind turbines. A greater power to size ratio is very desirable and where liquid cooling system is already available for the generator, this can also be used effectively with REO water-cooled components to achieve a very compact layout.

Braking Resistors



Whilst a turbine is rotating it is storing kinetic energy and when it accelerates too fast or is required to stop this can be achieved by the use of braking resistors. Braking resistors can be connected to the DC link of a frequency inverter to convert the surplus electrical energy into heat energy. Most frequency converters have switch contacts built in to them which will connect the braking resistor when the DC voltage level exceeds a certain limit and will disconnect when the DC voltage falls to a safe level again.



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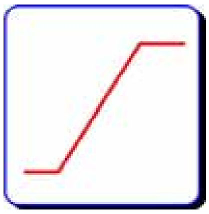
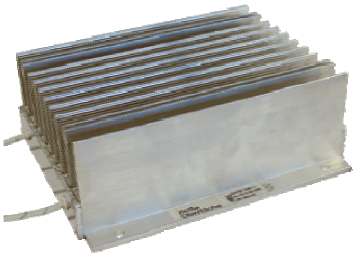
Soft-start Resistors



When the generator is switched onto the grid it draws a high magnetising current which can cause voltage sags, surges or flicker on the grid. It also causes mechanical shock to the drive system. To reduce the effect of this current in-rush, resistors can be connected in series with the mains connection and after a short delay the resistors can be bypassed with a switch.



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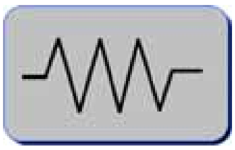
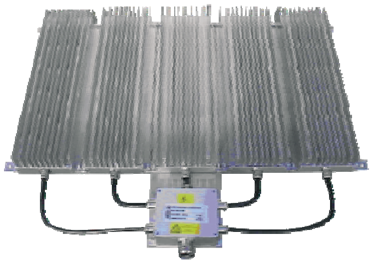
Slip-control Resistors



In a wound-rotor induction generator which has scalar control of the rotor currents, the magnitude of these currents is achieved by using an external resistor network and a power electronics module that modulates the voltage across the resistors to maintain a commanded rotor current magnitude. This method is capable of holding the turbine output power constant even when winds are gusting or above rated wind speed and it also significantly influences the dynamic response of the turbine to disturbances on the grid.



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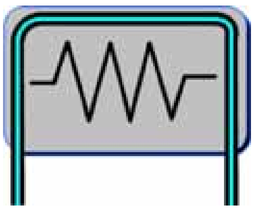
Water-cooled Resistors



When a water-cooled generator or frequency inverter is used to reduce the power to size and weight ratio of the wind turbine, then the circuit can be designed to incorporate water-cooled resistors also. The resistors produced by REO INDUCTIVE COMPONENTS AG have many unique features and one of these is a specially designed aluminium heat-sink housing that incorporates direct, water-cooling, channels within the outer aluminium extrusion. The resistor winding is surrounded with quartz filling which provides shock resistance, short-circuit protection and a fast temperature transfer time.

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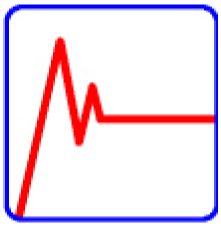
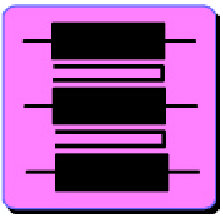
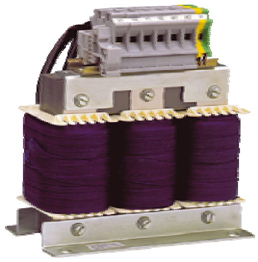
Charging chokes



When large storage capacitors such as those used in the DC link of a power converter are first charged, immediately after connection to a power source, the rate of change of current dI/dT is very fast and can stress the dielectric in the capacitor, leading to premature failure.



The dI/dT can be reduced by connecting a charging inductor in series with the supply and this has the effect of damping the charging rate of power capacitors that are in circuit.



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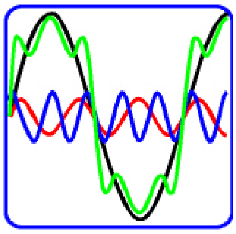
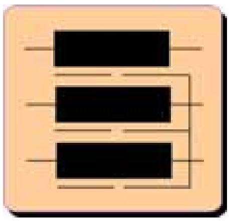
Harmonic Filters



Harmonics are generated by the high speed switching of the power semiconductors in the frequency inverter and the charging and discharging of storage capacitors in the DC link. Harmonic distortion can be removed by connecting a choke before and after the power converters.



REO line reactors are designed to block all harmonics and to allow the fundamental frequency to pass through and this is achieved because inductive impedance increases as frequency does.

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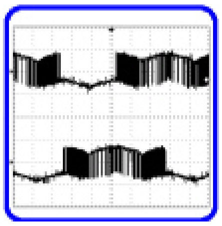
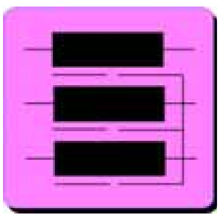
Differential-mode (symmetric) and common-mode (asymmetric) disturbances



In addition to dV/dT, there is a considerable amount of symmetric and asymmetric current distortion because of the fast switching of the semiconductors in power converters. This becomes more pronounced as the cable length increases. These disturbances can affect the efficiency of the generator causing audible noise and excessive heating. Chokes are also used to achieve a good current sine-wave on the side which is connected to the grid.



Series-connected inductors with good storage characteristics smooth the symmetric and asymmetric parasitic currents, particularly in the lower frequency range. They can also reduce dV/dT and provide some protection against transients.

CNW 930

REO World-wide Contacts

REO ELEKTRONIK AG	Brühler Strasse 100 D-42657 Solingen	Tel. +49 (0)212-8804-0 Fax +49 (0)212-8804-188 www.reo.de main@reo.de
REO INDUCTIVE COMPONENTS AG	Brühler Strasse 100 D-42657 Solingen	Tel. +49 (0)212-8804-0 Fax +49 (0)212-8804-188 www.reo.de main@reo.de
REO INDUCTIVE COMPONENTS AG **Setzermann Medical Division**	Schuldholzinger Weg 7 D-84347 Pfarrkirchen	Tel. +49 (0)8561-9886-0 Fax +49 (0)8561-9886-40 www.reo.de setzermann@reo.de
REO INDUCTIVE COMPONENTS AG **IBK Drives Division**	Holzhausener Strasse 52 D-16866 Kyritz	Tel. +49 (0)33971-485-0 Fax +49 (0)33971-485-90 www.reo.de ibk@reo.de
REO INDUCTIVE COMPONENTS AG **Test and Power Quality Division**	Brühler Strasse 100 D-42657 Solingen	Tel. +49 (0)212-8804-0 Fax +49 (0)212-8804-188 www.reo.de main@reo.de
REO INDUCTIVE COMPONENTS AG **Train Technologies Nieke Division** **Centre of Competence**	Erasmusstrasse 14 D-10553 Berlin	Tel. +49 (0)30-3670236-0 Fax +49 (0)30-3670236-44 www.reo.de mail@nieke.com
REO ELEKTRONIK AG	Im Halbiacker 5a CH-8352 Räterschen	Tel. +41 (0)52-363-2820 Fax +41 (0)52-363-1241 www.reo.ch info@reo.ch
REO (UK) Ltd.	Units 2-4 Callow Hill Road Craven Arms Shropshire SY7 8NT	Tel. +44 (0)1588-673-411 Fax +44 (0)1588-672-718 www.reo.co.uk main@reo.co.uk
REO Engineering Services S.A.	Parc d'activités HERACLES Chaussée de Charleroi 91 bat 5 B-6060 Gilly (Charleroi)	Tel. +32 (0)71-287-716 Fax +32 (0)71-287-746 www.reo.de reoes@skynet.be
REO VARIAC S.A.R.L.	ZAC Du Clos aux Pois 1 6/8 rue de la Closerie-LISSES F-91048 Evry Cédex	Tel. +33 (0)1-6911-1898 Fax +33 (0)1-6911-0918 www.reo.fr reovariac@reo.fr
REO ITALIA S.r.l.	Via Treponti, 29 I-25086 Rezzato (BS)	Tel. +39 030-279-3883 Fax +39 030-249-0600 www.reoitalia.it info@reoitalia.it
REO CROMA Sp.zo.o.	ul. Pozaryskiego 28, bud 20 PL-04-703 Warszawa	Tel. +48 (0)22-812-3066 Fax +48 (0)22-815-690 www.croma.com.pl croma@croma.com.pl
REO-USA, Inc.	3250 North Post Road, Suite #132 USA-Indianapolis, IN 46226	Tel. +1 (0)317-8991-395 Fax +1 (0)317-8991-396 www.reo-usa.com main@reo-usa.com
REO-ESPAÑA 2002 S.A.	C/Manuel Ventura i Campeny 21B local 9 E-08339 Vilassar de Dalt (Barcelona)	Tel. +34 (0)937-509-994 Fax +34 (0)937-509-995 www.reospain.com info@reospain.com
REO Shanghai Inductive **Components Co., Ltd.**	No. 536 ShangFeng Road, Pudong, 201201 Shanghai, China	Tel. +86 (0)21-5858-0689 Fax +86 (0)21-5858-0289 www.reo.cn info@reo.cn
REO INDUCTIVE COMPONENTS AG **Moscow Representative Office**	Vienna House ul. Petrovka 27 107031 Moskau	Tel. +7 (0)495-956-55-57 Fax +7 (0)495-956-82-63 www.reo.de main@reo.de
NEEL REO SYSTEMS PVT.LTD.	406 Saphire Arcade 42, M.G. Road Ghatkopar (E), Mumbai 400 077	Tel. +91 (0)22-251643-26 Fax +91 (0)22-251643-17 www.neelreo.in info@neel.in