Synchronous superlatives

Record-breaking electric motors give heavy industry more drive

Johannes Ahlinder, Thomas L. Johansson

ABB is at the forefront of a worldwide trend towards larger electrical drives. Recent deliveries illustrate this succession of superlatives.

Historically, mechanical drives such as turbines dominated the high end of the power-drive market, but nowadays their position is challenged by four-pole synchronous motors. Electrical drives are far cleaner, quieter and environmentally friendlier than their mechanical counterparts. They are also more energy efficient and require less maintenance. Drives delivering higher power enable industry to handle production with more flexibility and cost-effectiveness.

As power increases, it becomes even more important to deal with constraints such as voltage drop and inrush current by the selection of an appropriate starting method.

In December 2002, ABB delivered the world's largest four-pole motor. At a rated output of 55 MW, it drives an air compressor at Sasol's synthetic fuels and petrochemicals plant in Secunda, South Africa. One year later, in December 2003, ABB delivered the world's largest refiner motor with a rating of 38 MW. It will power the primary refiner for a new line at Stora Enso, Port Hawkesbury in Canada. Spring 2004 saw ABB deliver two cable wound motors rated at 42 MW and 56 kV to drive compressors at Statoil's Troll-A platform in the North Sea.

These motors form part of a general trend in the industry towards larger electrical drives. Other examples of this trend are the delivery of a 29.5 MW fan motor used in a test rig by Rolls-Royce when developing the Liftfan™ for the Joint Strike Fighter aircraft that will enable short take off and vertical landing, and the order for a 42 MW blower motor to Wuhan Iron & Steel Group Corp. in China.

Large drives have many advantages over smaller ones: Production capacity for a single drive increases and in general system efficiency is improved. In addition, one single drive substituting several smaller units reduces the costs for spare parts, service and maintenance. Larger drives also permit greater flexibility in production: Energy prices often vary according to the time of day, and larger drives, with consumption optimised according to the energy price, can achieve the same daily output as smaller drives, but at a lower cost.

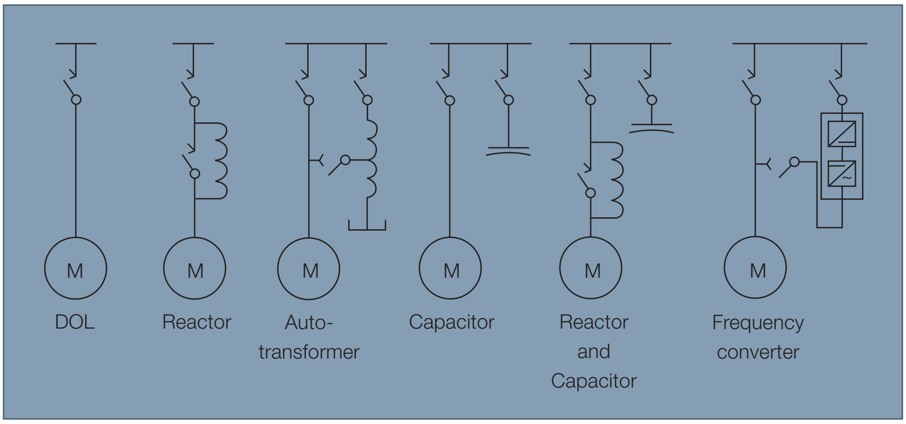
Formerly, the traditional drives for high power applications were mechanical, ie, steam and gas turbines. At first, the only available electric alternative was the large two-pole motor. Electric motors have three main advantages over turbine drives: efficiency, maintenance and environmental benefits. The efficiency of a synchronous motor is normally between 97 and 99 percent, compared to 35 to 40 percent for a gas turbine. A synchronous motor can operate for several years without major overhaul, whereas a gas turbine needs more frequent attention. An electric motor does not generate hazardous emissions and keeps the audible noise at a relatively low level.

Today, with the improved output of four-pole synchronous motors, an even better alternative is available. Compared to the two-pole solution, four-pole motor technology has several advantages; the most prominent being lower capital investment, and reduced operating costs resulting from higher efficiency. Other benefits of four-pole motors are the reduced overall size and weight and lower noise emissions. This means that the base-plate can be shorter and lighter, that less space is required, and that the need for acoustic countermeasures is reduced.

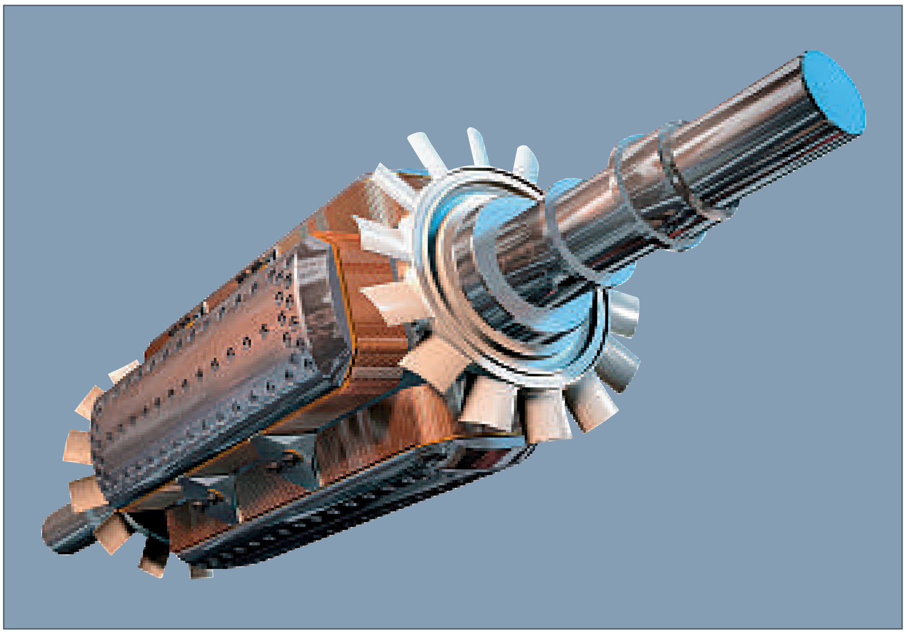
Starting methods

Amongst the most important aspects when dimensioning large electrical motors are the starting requirements. Every electrical motor must be matched,

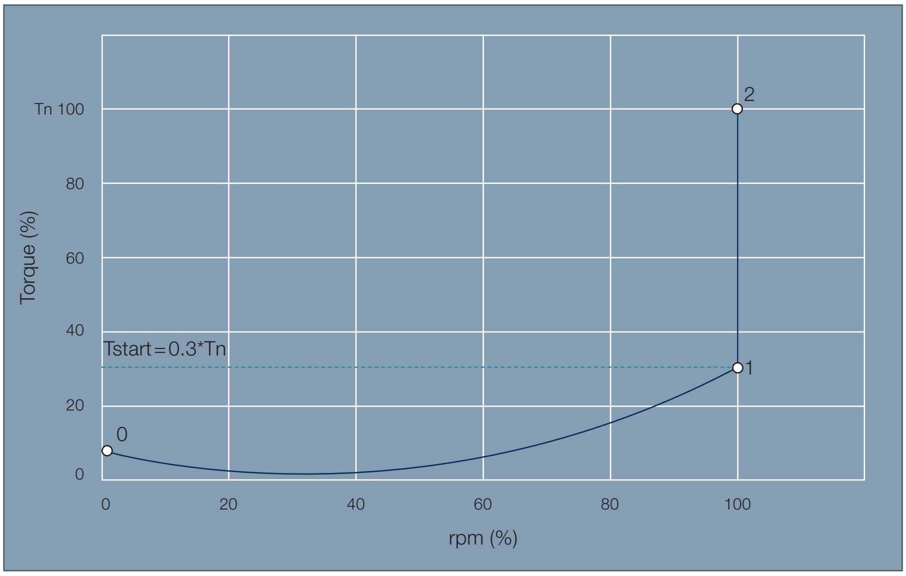
1 Examples of common starting methods for large synchronous motors.



2 Salient pole rotor design



3 Typical load starting curve (fixed speed)



0 Motor starts
1 Motor reaches nominal speed, 30 % nominal torque. Full load torque is applied.
2 Motor reaches nominal torque

both electrically and mechanically, to the power supply, the equipment driven, the protective and control systems and similar constraints. On smaller motors, electrical parameters can often be chosen so that starting currents do not cause a greater voltage drop than permitted[1]. The simplest and least expensive method for starting a fixed speed motor, Direct On Line starting (DOL), is acceptable. However, voltage drop increases with motor size, and for a very large electric motor even a very stiff electrical network will be subjected to unacceptable voltage drop. This can result in insufficient starting torque or cause problems for other equipment.

At higher power ratings it is usually necessary to use a starting method other than DOL. The supply network's short-circuit capacity (SCC_L) and the maximum permitted voltage drop (ΔU_L) dictate the conditions for starting an electrical motor and pre-empt the design of both the starting equipment and the motor. The grid owner usually specifies maximum allowable voltage drop.

The most economical starting method under the constraints of SCC_L and the ΔU_L is determined through evaluation of the alternatives. The key to good starting characteristics of an electric motor lies in the rotor design. The salient pole design of ABB's four and six pole synchronous machines is designed for high thermal capacity, good overload resilience and the ability to withstand repeated heavy starts. 1 shows some examples of commonly used starting methods.

Soft start

When a certain motor power output is required, the optimal solution (depending on the power network conditions and requirements) becomes a frequency converter start, also called soft start. It allows the motor to be started at high torque without causing any voltage drop on the power network.

The converter brings the motor up to speed. Upon reaching nominal speed and after being synchronized to the network, the circuit breaker between the converter and the power network is opened. The breaker between the motor and the network is then closed. Finally, the breaker between the motor and the converter is opened 1.

A single frequency converter can be used to start several motors. In such a case, every motor is connected to the converter via a circuit breaker so that no more than one motor is connected to the converter at any time. This method is used at Stora Enso, Port Hawkesbury (described further on).

Using soft starting for fixed speed drives, ie, drives that are not used for speed regulation in the process, means that the cost for the motor and converter can be significantly lower than for a variable-speed drive (VSD). It is possible to design a more cost-efficient motor, since it will only be subject to the converter supply during the brief starting phase (after the start, the converter is disconnected). Here an additional advantage of ABB's synchronous motors is the salient pole rotor design 2, which ensures that the solid pole shoes absorb the temporary temperature rise.

Additionally, a converter used for soft starting can be of smaller rating compared to what is needed for a VSD and continuous operation. This is permitted because, relatively speaking, higher losses are acceptable on account of the relatively short start-up phase.

However, the principal reason for the substantially lower cost of the frequency converter relates to the starting curve of the driven equipment. Fixed speed applications are normally started at reduced load, typically 30 percent of the nominal torque 3. When the nominal speed is reached and the motor is connected directly to the power network, the nominal load torque is applied (usually by opening valves). This implies that the frequency converter is dimen-

---

[1] For motors running in island mode networks, for example oil platforms, even smaller motors might require starting methods other than DOL due to the lower short circuit capacity of such networks.

sioned for 30 percent load torque, whereas that for VSD must be dimensioned for 100 percent torque since it must be capable of regulating the speed of the motor at full load.

A soft started motor also has advantages over its DOL started equivalent. The former can be dimensioned for better material utilization and thereby higher efficiency, since there is no need to dimension the motor to achieve low inrush current.

Mechanical and electrical stability for large electric motors

When dimensioning the motor, an important criterion is to minimize different stresses on the complete shaft system of the drive. The stiff rotor and shaft of ABB's synchronous machines contribute to minimizing such stresses by having an operating speed well below the lowest critical bending speed. The complete rotor, including its salient poles and shaft, is machined from a single forging of high-grade steel, enhancing mechanical resilience.

A very important design aspect resulting in mechanical and electrical stability is a reduction of the distance between the bearings. This is achieved by locating the exciter outside the bearing housing, and using a bracket bearing design instead of pedestal bearings. ABB has used bracket bearing design for its largest synchronous machines for more than 15 years. Hundreds of installations later and ABB has amassed considerable experience and knowledge of this design, such that competitors who have recently adopted this concept will need quite some time to catch up.

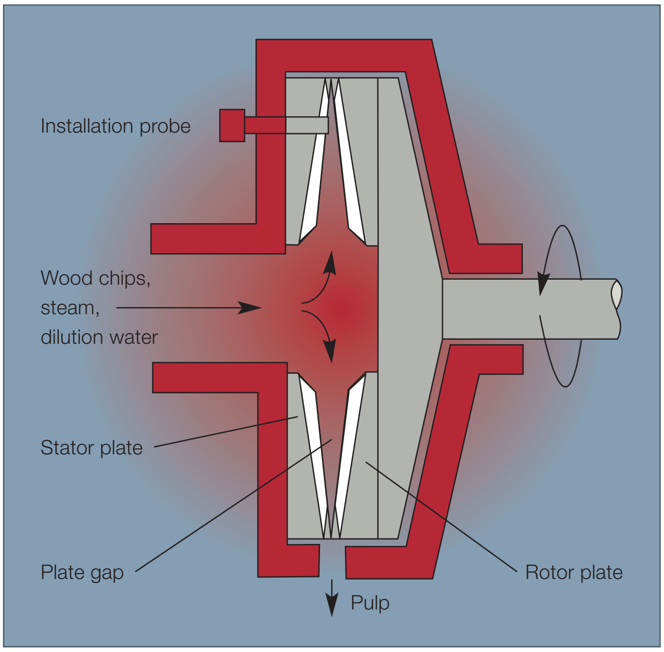
Air gap adaptation, stator and rotor winding designs, pole shoe design, and dimensioning possibilities of the pole core are further examples of design aspects affecting mechanical and electrical stability. Moreover, ABB's design gives good possibilities for optimizing the complete shaft train by using different rotor lengths, diameters and masses.

55 MW four-pole compressor motor at Sasol, South Africa

In March 2002 ABB received an order from Air Liquide for two four-pole synchronous motors, rated 55 MW and 23 MW respectively. The 55 MW installation is understood to be the world's largest four-pole motor. These two motors drive the main air compressor and the booster air compressor of an Air Liquide oxygen unit. The unit can produce 3,550 tons of gaseous and liquid oxygen per day, making it the world's largest oxygen plant. It is installed at Sasol's synthetic fuels and petrochemicals plant in Secunda, 150 km east of Johannesburg, South Africa.

The oxygen unit forms part of a programme to increase the previous installation's overall oxygen output. The oxygen is used in a process for producing synthetic fuels from coal.

4 Refining TMP process.



Wood chips and dilution water is fed into the refiner.
[Source: Tampere University of Technology]

The advantages of the four-pole motors over the two-pole alternatives which were previously installed, were a key issue when Air Liquide and Sasol decided to invest in a four-pole synchronous solution for their expansion rather than staying with the older technology.

The preferred starting method for the 55 MW motor was found to be soft starting using an LCI (load commutated inverter). Compared to other reduced voltage starting methods such as tap-transformer, auto-transformer and reactor, soft starting results in less stress on the motor, the switchgear, the compressor, the grid, and on the complete shaft system with all its components. For very large motors, the soft start method has become the preferred solution.

For optimum motor control, both motors are equipped with rotor telemetry equipment for measuring all important rotor parameters, ie, temperatures in selected locations, current, voltage, and rotor insulation resistance. To ensure maximum availability of the installation, the motors are also equipped with redundant coolers and motor control panels. These are equipped for automatic switch over and follow up.

38 MW four-pole refiner motor at Stora Enso, Port Hawkesbury, Canada

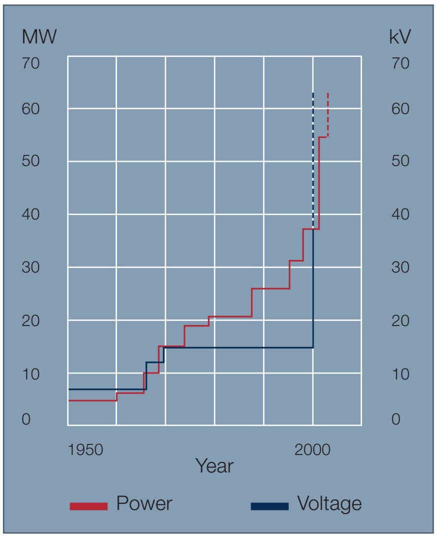
In a refiner, wood chips are fibrillated between two rotating metal discs. At least one of the discs rotates at high speed. Centrifugal forces press the chips through a narrow gap causing the fibrillation. The most common refiner-based process is thermo mechanical pulping (TMP). In the TMP process, the refiner is pressurized. The chips are steamed and washed with hot water before entering the refiner. The refining process usually occurs in two stages 4.

The new 38 MW record-breaking refiner motor at Stora Enso, Port Hawkesbury, Canada is probably the largest refiner motor in the world. The motor will be installed on a primary refiner for the mill's third refining line. ABB has several references for large motors at the mill, including two 32 MW refiner motors installed in 2003. For the original two lines, with 15 and 24 MW motors, the smaller motors are started with DOL and a combination of reactor and VAr support is used for the 24MW motors. In 2003 the two primaries on these lines were replaced by the 32 MW motors mentioned above, using the same type of reactor but with a more complex VAr support scheme. The 38 MW motor at the new Line 3 will use a soft starter of LCI-design to meet the voltage drop prerequisite and flicker limits imposed by the local utility company. The same converter is also used for starting the other refiner motors in the third line.

VHV cable wound motors for TROLL A platform, Norway

Voltages have failed to keep pace with the rise in power outputs. As illustrated in 5, only gradual improvements in insulation technology have been made over the years. Briefly explained, it is the squared shaped cross section of the conventional winding that is the limiting factor in reaching higher voltages.

5 Four-pole motor power and voltage development



With the launch of an innovative use of cable technology in rotating electrical machines back in 1998, ABB enabled an increase in machine voltage ratings to radically higher levels by using HV cables in the stator windings. The possibility of connecting a rotating machine directly to the HV grid implies that there is no need for a step-down transformer. A higher system efficiency is thus achieved.

6 One of the 40 MW, 56 kV Troll A motors during production

The first VHV cable wound synchronous motor was installed in 2001 at an air separation plant in Sweden. It is connected directly to the 42 kV bus. Rated at 9 MVA it has an active power output of 6.5 MW and can produce reactive power continuously, thus supporting the electrical network during the starting of other large motors in the area.

The supply of two VHV cable wound synchronous motors to Statoil's Troll A gas platform in the North Sea follows the success of the first cable wound synchronous motor installation. The two identical units, delivered in Spring 2004, are rated at 40 MW, 56 kV and for variable speed between 1290 and 1890 rpm 6. In early 2005, the motors will be subjected to spin-tests and should start operating later that year. Power will be supplied from shore via four 70 km long underwater DC cables (two per motor). On the platform, the DC will be inverted to AC by an HVDC Light™ inverter station. The alternative would have been to use gas turbine drives, which has been the traditional mechanical drive in the oil and gas industry for many years. However, the trend towards preferring large electrical drives over gas turbines is also affecting the oil and gas sector. For the Troll A project, efficiency, maintenance and environmental benefits were all important aspects when choosing an electrical solution[2] (see next article).

Johannes Ahlinder
Thomas L. Johansson
ABB Automation Technologies
Sweden
johannes.ahlinder@se.abb.com
thomas.l.johansson@se.abb.com

---

[2] For more information about VHV motors, please see ABB Review Number 1/2001.