

Compact High-torque Electric Motor



Applications

The switched reluctance motor is suitable for use in variable-speed and positioning drive units. Depending on the converter design two-quadrant or four-quadrant operation is possible.

Advantages of this motor over other drives:

- above-average continuous torque in the base speed range
- extraordinary acceleration capability
- low maintenance
- high holding torque even over extended periods
- high overload capability
- small dimensions
- high operating safety after failure of one or several motor phases
- excellent efficiency over wide speed range
- ruggedness
- negligible rotor temperature rise in lower speed range.

Switched reluctance drives are beneficial for applications where one or several of these properties are required.

Owing to the optimum cross-section chosen, the noise emission of the switched reluctance motor developed by us is non-critical at any operating points in the lower speed range.

Maximum speeds: As the rotor of the switched reluctance motor has no winding and no permanent magnets, it may be subjected to high radial forces which makes the motor ideal for high-speed applications. Since the hysteresis loss rises as the speed increases, low-pole reluctance motors are the best choice for these applications.

Operating principle

The operating principle of the switched reluctance motor is quite easy: A rotatable iron rod or the iron teeth of a machine rotor aligns itself with the magnetic field generated by the electric current flowing in a stator pole. By a continuous travelling, or rotation, of the magnetic field the iron rod or rotor is forced to co-rotate. If this rotor has several teeth, its shape is comparable with a long-stretched-out toothed wheel. The term „reluctance“ stands for the magnetic resistance such a rotor offers to the electromagnetic field. The magnetic field is generated and caused to rotate by the stator pole windings and an electronic power component upstream of the motor. The electronic component, which is a power or frequency converter, serves the adjustment of the speed and torque of the switched reluctance motor. Switched reluctance motors can be designed in the wide range from miniature motors to large-scale units.

Model drives

Two switched reluctance motors of a rated power output of 18.5 kW and 23.5 kW, respectively, and a speed of 1,500 rpm were designed, optimized and tested at the Electrical Engineering Institute of the University of Karlsruhe. The converter was directly connected to a 400V/50Hz three-phase system. Below some results obtained in the tests of these motors will be looked into in more detail; they exemplify the performance of the switched reluctance motors. The operating principle and cross-section of the newly developed switched reluctance motor are shown on the cover sheet. The motor has 16 salient stator poles and 12 rotor teeth.

Low moment of inertia - high dynamic performance

Owing to the mass-free gaps between the teeth on the outer surface of the rotor, the switched reluctance motor has a very low moment of inertia. The rotor consists only of the laminated core and the shaft, i.e. it has no winding and no permanent magnets. Table 1 compares the moments of inertia of a standard asynchronous motor, a three-phase asynchronous machine optimized for highly dynamic applications, and a switched reluctance motor. The advantages of the latter over the other machines are obvious. As to the nominal working point, insulation class and cooling system, the technical data of the three motors are comparable.

	Switched Reluctance Motor MFR 132.5	Asynchronous Motor (optimized size) ACHA 132.5	Asynchronous Motor (standard)
Moment of inertia	0.0883 kgm ² 59%	0.105 kgm ² 70%	0.150 kgm ² 100%

Table 1: Moments of inertia

Better utilization at low speeds

The iron losses of switched reluctance motors, unlike those of asynchronous motors, make up a considerable portion of the total losses. However, the iron losses drop heavily as the speed is reduced. This effect is made use of to increase the rms currents in the pole windings and to obtain a high permissible continuous torque in the lower speed range. Moreover, operating the machine at low speeds results in low rotor iron losses - consequently, the rotor temperature rise remains low. In asynchronous motors, the stator and rotor winding losses make up the largest portion of the total losses which remain almost constant from standstill to rated speed if the torque is assumed to be constant. This explains why asynchronous

motors, when operated in continuous duty, must not be subjected to a torque higher than the nominal torque until the rated speed is reached. Field weakening operation begins for all three motors when the rated speed is exceeded.

In Figure 1, the maximum permissible continuous torque, referred to the moment of inertia, is shown in the speed range from above 0 to 1,500 r.p.m. for the use of insulation class F. Figure 1 characterizes the acceleration capability and the utilization of the machines in continuous duty. The two reluctance motors differ only in the quality of the electric sheet steel used. In continuous duty, the maximum permissible holding torque of the 18.5 kW reluctance motor amounts to 145% of the rated torque when the motor is at rest. As soon as the rotor starts to rotate, however, all pole windings are subjected to the same thermal loads, and the continuous torque may be 190% of the rated torque at low speeds. For dynamic transient processes in the base speed range, the motors may be subjected to two to three times the rated torque.

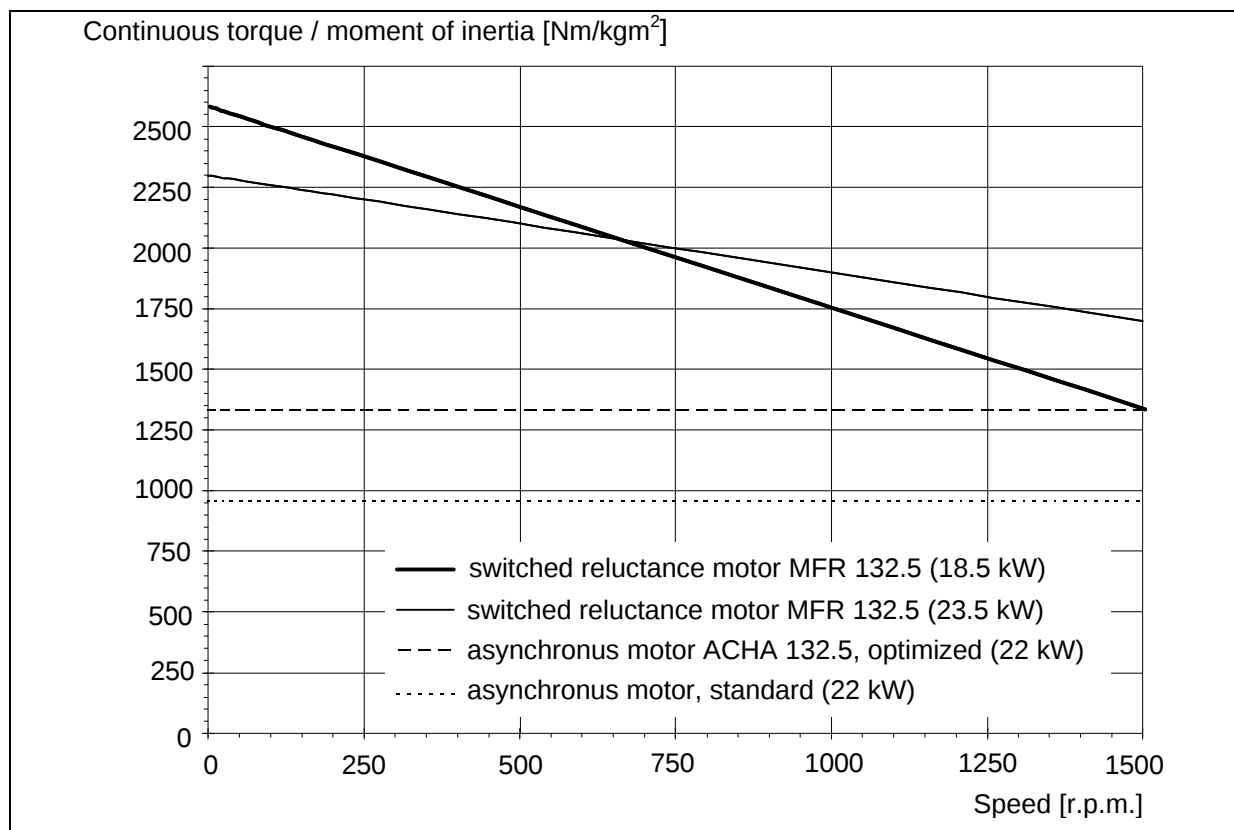


Figure 1 Permissible continuous torque referred to the moment of inertia for use of insulation class F (measured)

The curves and values for the type ACHA 132.5 asynchronous machines are those of the manufacturer's data sheet [1]. The unit volume, size, outer dimensions and core assembly length of the optimized asynchronous motor ACHA 132.5 are identical with those of the switched reluctance motor MFR 132.5.

Much better efficiency at speeds below rated speed

At the nominal working point, the efficiency of the switched reluctance motor is that common for a three-phase motor of this performance class. In the lower speed range, however, the efficiency of the reluctance motor drops insignificantly (Figure 2). With the motor at nominal torque, the efficiency raises to above 80% as from 300 r.p.m. , and gradually increases further to approx. 90% until rated speed is reached - another advantage of this kind of drive. At the nominal working point, the efficiency of the 23.5 kW switched reluctance motor is 91.1%.

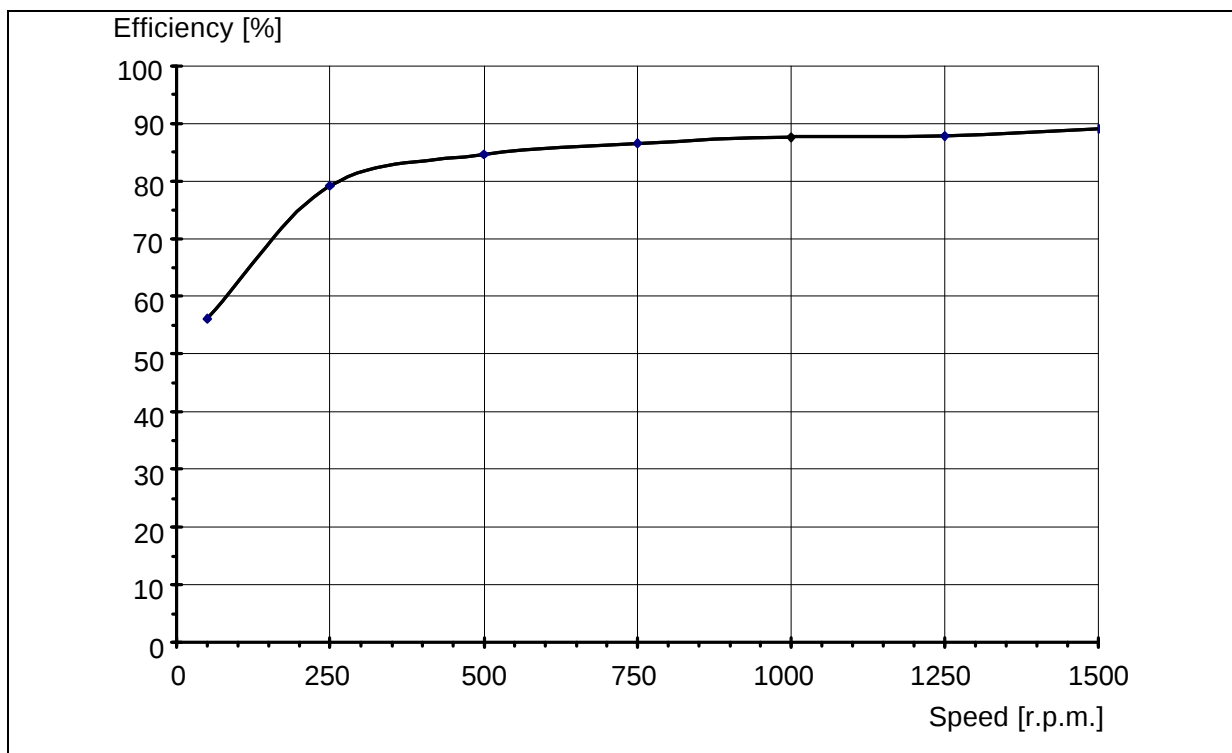


Figure 2 Efficiency of the 18.5 kW switched reluctance motor at nominal torque and variable speed (measured)

Variable-speed drives

The speed control circuit of the switched reluctance motor has been designed as is common in the field, and has been optimized to compensate speed variations. A ramp-function generator ensures that an overshooting of the actual speed is almost entirely compensated when a setpoint step-change occurs. Figure 3 shows the response to setpoint changes during acceleration to rated speed. The drive accelerates at a torque of approx. 170 Nm. The inertia of the driven machine used for the measurements is five times that of the reluctance motor. The resultant acceleration time is 630 ms.

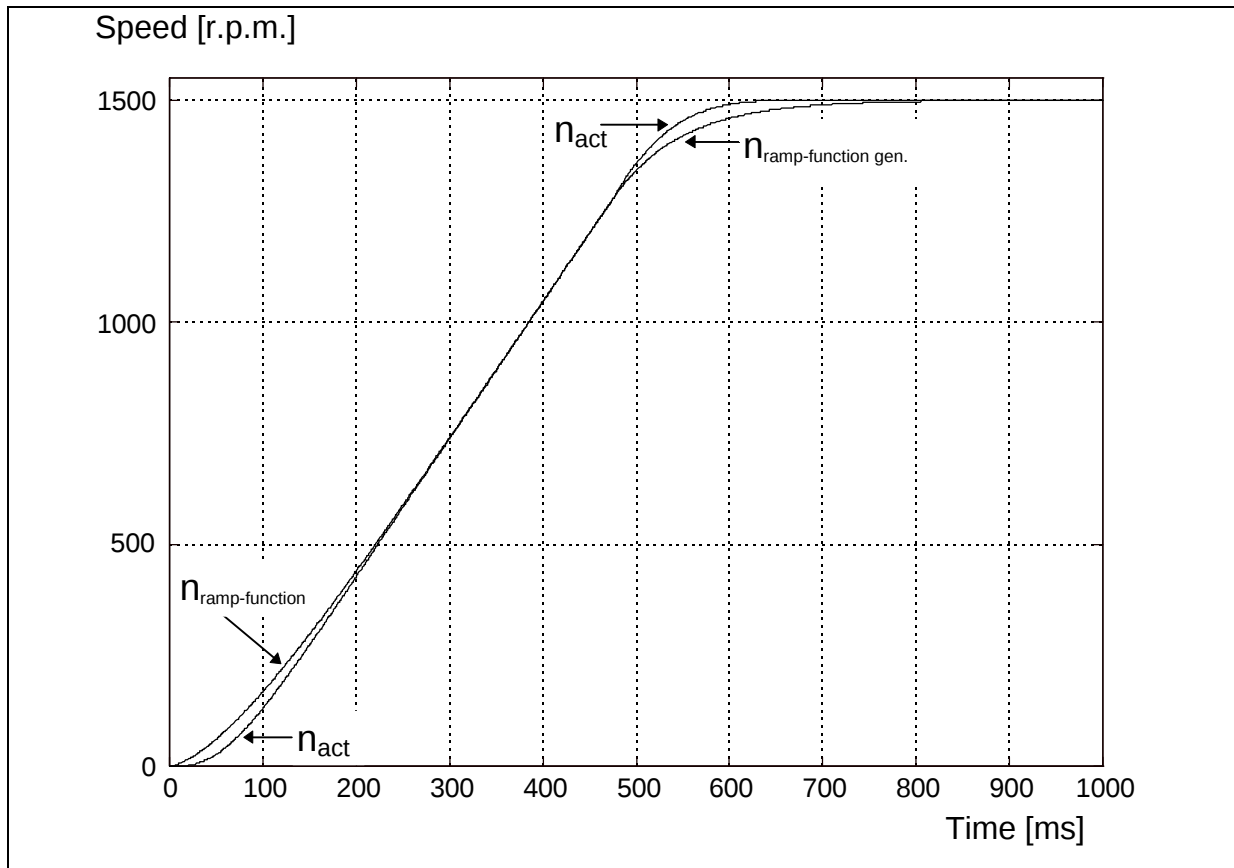


Figure 3 Acceleration from standstill to rated speed

$$J_{total} = 0.54 \text{ kgm}^2 \text{ (measured)}$$

Figure 4 shows the disturbance behaviour of the implemented speed control circuit as verified in measurements. At a load step-change from 10 Nm to 110 Nm, the speed remains within a tolerance band of 3%. After 250 ms the speed has returned to its stationary value of 1,000 rpm. The rate of load torque rise is given by the coupled DC machine.

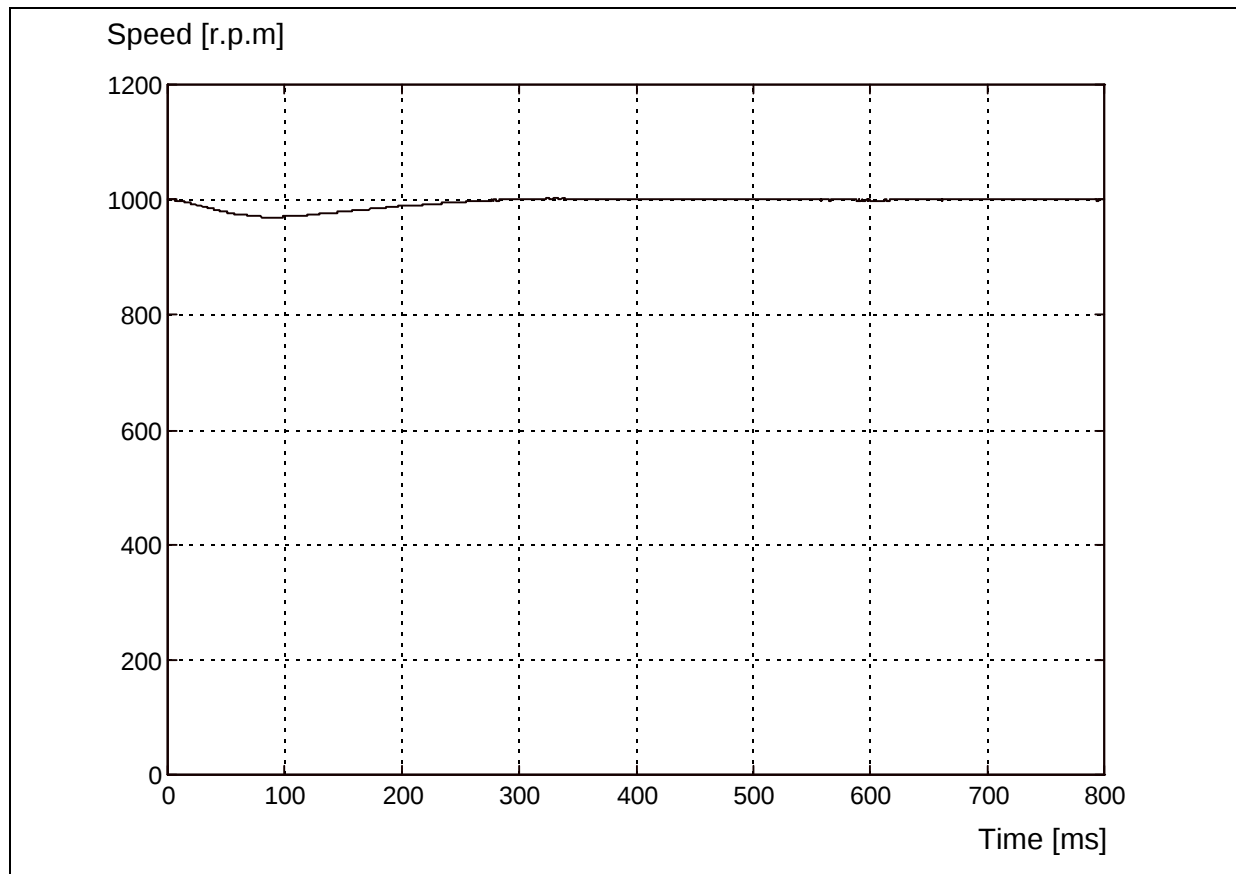


Figure 4 Speed behaviour after a torque rise of 100 Nm

$$J_{\text{total}} = 0.54 \text{ kgm}^2 \text{ (measured)}$$

Use for positioning purposes

Among the tasks electric motors are used for are also positioning tasks, e.g. the positioning of workpieces and tools, the displacing of machine parts or the hoisting of cages. Basically, switched reluctance motors can also be used for such applications. Figure 5 shows the transient response following a 180° change of position. The rotor rotates through 180°, and the required setpoint value is reached after approx. 600 ms. With many positioning tasks, such as position changes in machine tools, an overshooting of the end position is impermissible. The position control parameters have been chosen so as to meet this requirement.

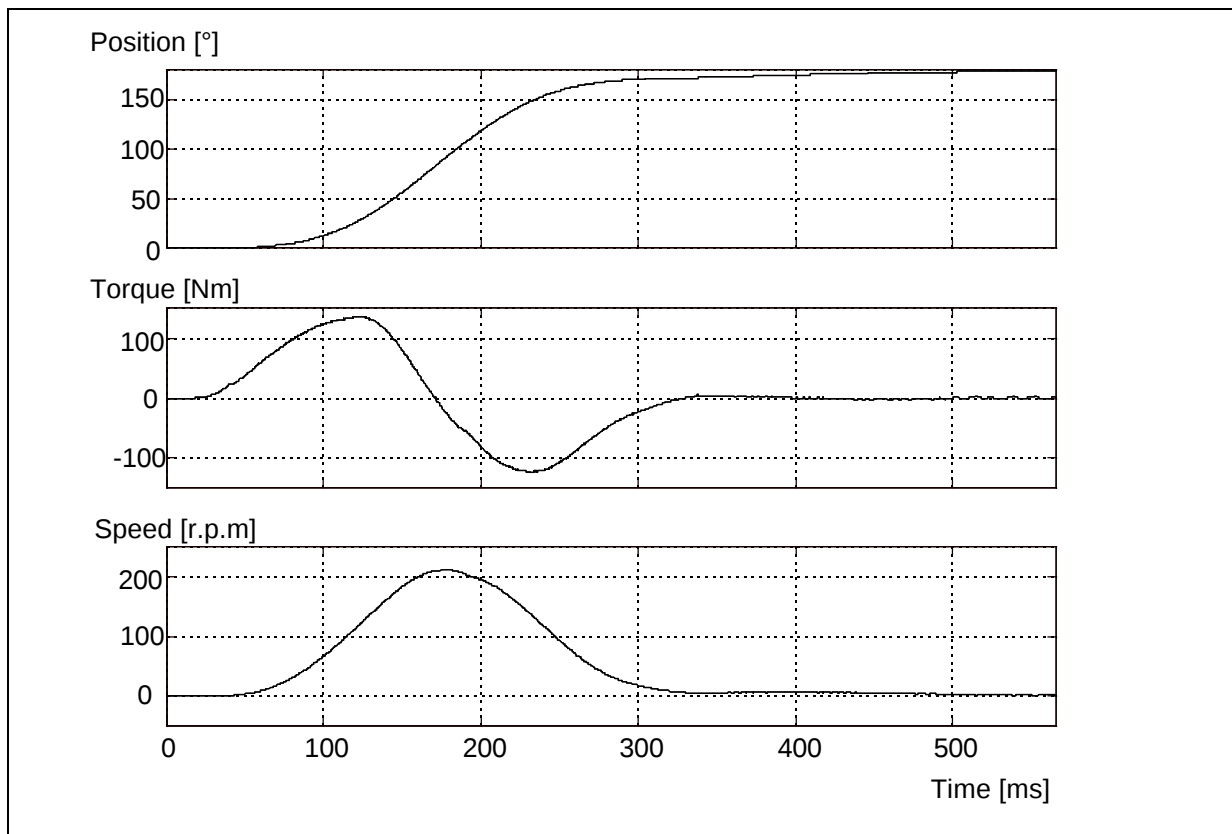


Figure 5 Change of position through 180°

$$J_{\text{total}} = 0.54 \text{ kgm}^2 \text{ (measured)}$$

High operating safety after phase failure

The switched reluctance motor is characterized by a high operating safety after the failure of one or several motor phases. When such a failure occurs, the motor continues to run under load, and it can be accelerated or braked (Figure 6). However, the torque and speed fluctuations occurring are of a measurable magnitude, and the start-up of the motor is no longer ensured. Despite this drawback, the driven machine, or process under way, can be set back into a safe state in many an application.

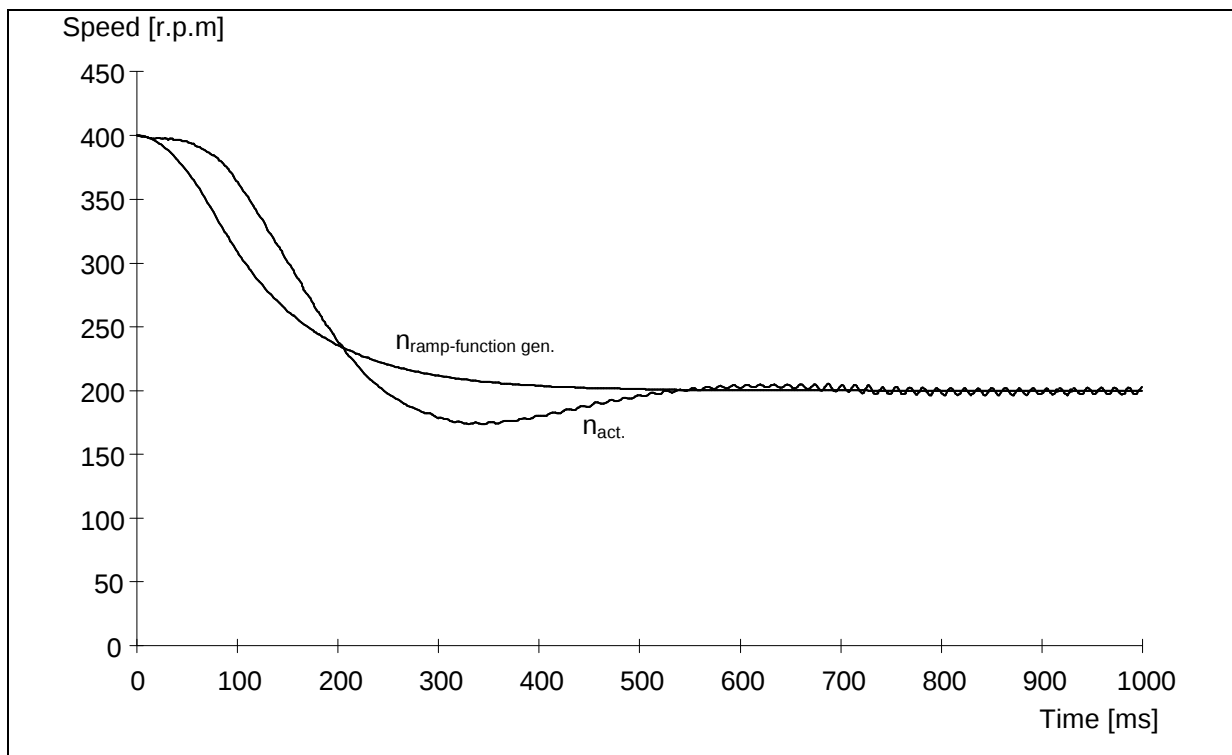


Figure 6 Change of speed upon failure of two motor phases

$$M_{\text{load}} = 50 \text{ Nm}, J_{\text{total}} = 0.54 \text{ kgm}^2 \text{ (measured)}$$

Here, too, the ramp-function generator prevents the speed setpoint step-change from being directly injected to the setpoint/actual-value comparator of the speed controller.

Mains compatibility of model drive

The line current converter is a three-phase transistorized converter. Line current control has been optimized so that the drive, when in steady-state operation, draws energy from, or feeds energy to, the three-phase system at $\cos \varphi \approx 1$ and a power factor of approx. 1. This means a sine-wave line current and coincidence of the current and voltage phase angles - or, in brief, good compability of the drive with the mains. Figure 7 shows the voltage and current of a phase upon a load change of the reluctance motor from approx. 18 kW generator operation to 18 kW motor operation. The line current converter allows four-quadrant operation and thus highly dynamic drive solutions to be implemented. If the converter is used for the main drive of a group of drives, for example, it may be additionally employed for compensating the reactive power of the auxiliary drives. For reluctance drives less demanding in terms of dynamics and mains compatibility, rectifier bridges with smoothing and commutating reactors are used as line current converters.

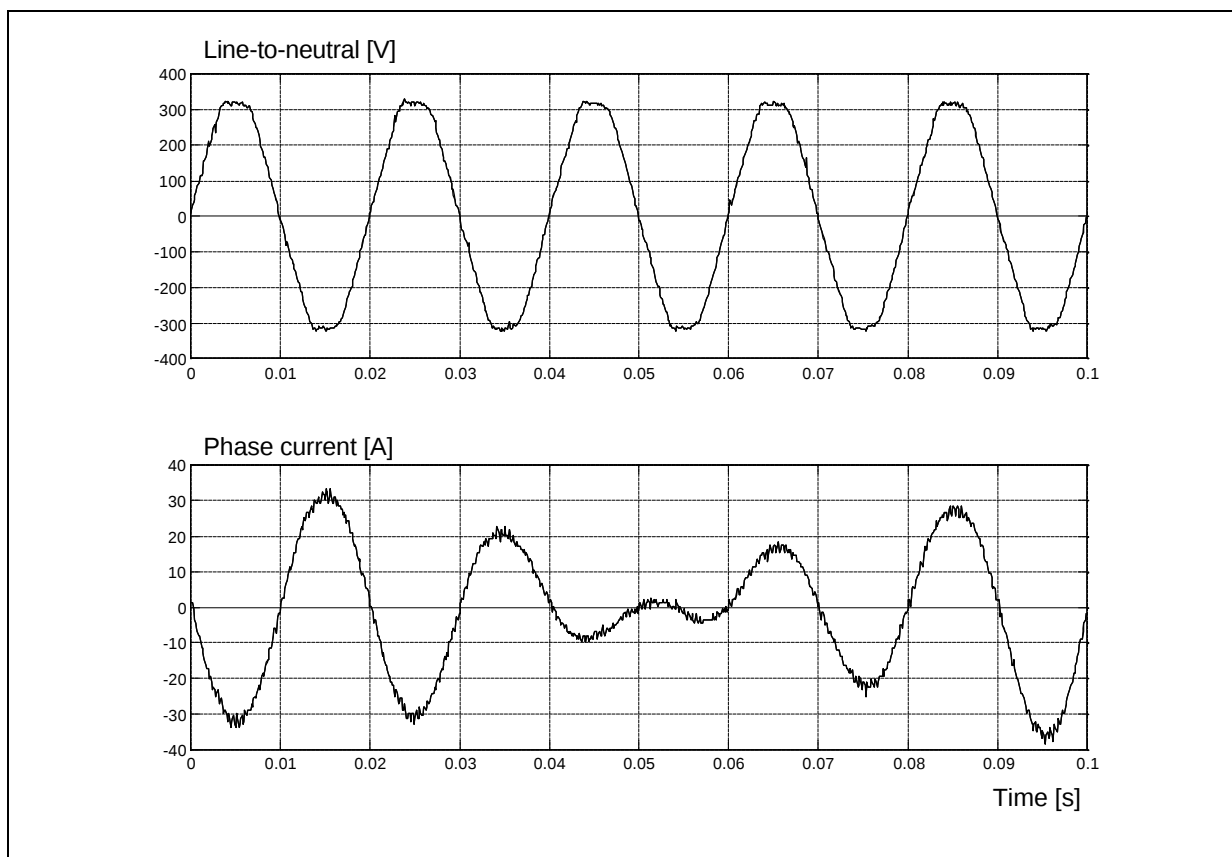


Figure 7 Line voltage and line current upon load change from 18 kW generator operation to 18 kW motor operation (measured)

Reference:

[1] Data sheet, three-phase main drives, Elbtalwerk GmbH

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