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THE CASE FOR SWITCHED RELUCTANCE MOTORS

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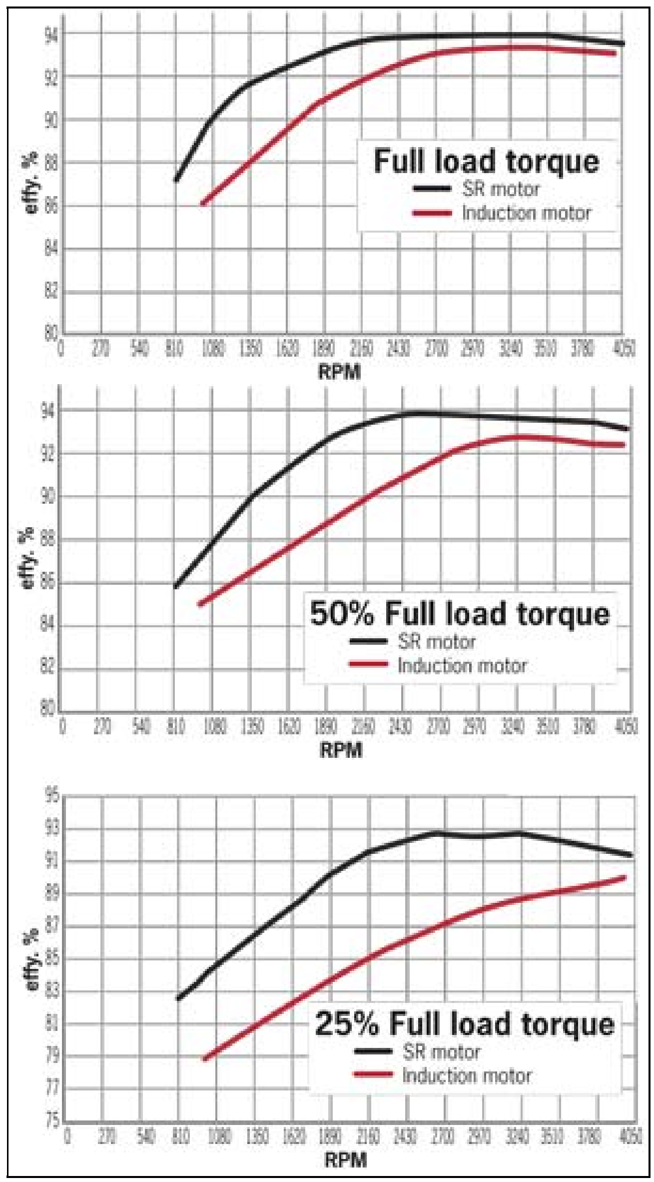
Rob Boteler Switched Reluctance Drives Ltd., Nidec Motor Corp. St. Louis, Mo.

Technological advances let switched reluctance motor-drive systems be significantly more efficient than comparable induction motors.

Switched reluctance motors used to be a favorite topic among Ph.D. candidates doing thesis work in electric motors. The reason was pragmatic and had little to do with the promise of SR technology: It was relatively easy to cobble together an SR motor that would work in some fashion.



It was far more difficult, though, to devise an SR motor that would work efficiently enough to challenge existing motor technology on its own turf. But that recently happened with the advent of fast-switching power electronics. Now SR drives can be significantly more efficient than comparable induction motors and drives in several applications.
Inherently simple, SR motors were developed in the 1800s when switching devices were primitive. With the rising emphasis on energy efficiency, SR motors are taking more prominent roles in appliances, industrial uses, and in commercial and vehicular applications.

An SR motor is simple and rugged. The rotor consists of stacked steel laminations with a series of teeth. The rotor requires no windings, rare earth materials or magnets of any kind. The teeth are magnetically permeable, and the areas surrounding them are weakly permeable by virtue of slots cut into them.

Unlike induction motors, there are no rotor bars and consequently no torque-producing current flow in the rotor. The absence of any form of conductor on the SR rotor means that overall rotor losses are considerably lower than in conventional motors, which utilize conductors on the rotors.

Lower rotor losses are especially relevant during start-up where, in the SR motor, the rotor losses are no greater than when the motor operates at its rated condition. This permits a virtually unlimited capability for prolonged operation in the stall condition and for repeated starting under full-load. Such performance is often not possible with conventional drives because of the large electrical losses they experience on their rotors and the subsequent rotors heating under such conditions.

Torque produced by the SR motor is controlled by adjusting the magnitude of current in the stator electromagnets. Speed is then controlled by modulating the torque (via winding current), in the same way that speed is controlled via armature current in a traditional brush dc motor and drive. Torque production in an SR motor is proportional to the amount of current put into the windings. Torque production is unaffected by motor speed. This is unlike ac motors where, in the field-weakening region, rotor current increasingly lags behind the rotating field as motor rpm rises.

The SR motor�s torque density can easily exceed that of a typical induction motor. This factor frequently lets equipment manufacturers eliminate gear boxes or greatly decrease the number of reductions necessary to handle specific applications.

SR motors also offer performance advantages in motion control. An SR motor can produce 100% torque at stall indefinitely. The reason is that the rotor produces no heat at stall. Rotor bearings stay cool as well. Only the stator coils get warm, and they can be cooled via fins on the stator housing, or by other conventional means.

The SR stator windings are much simpler than those required for induction motors or permanent-magnet ac motors. Each slot in the stator contains windings for only one phase. A winding that emerges from the stator slot needs only to loop back around one slot, rather than around multiple slots as on induction motors. This minimizes the volume of end windings and significantly reduces the risk of a phase-to-phase insulation failure.

This winding construction also minimizes the energy lost on coil overhangs at the slot ends, because magnetic fields generated at the end of the slot do not contribute to output power. A smaller end-winding area also minimizes the length of the motor and the amount of heat to be dissipated. Consequently, an SR motor can be one or two frame sizes smaller than an equivalent induction motor.

The overall losses within the Switched Reluctance motor are concentrated within the stator, where they are relatively easily dissipated: In the case of a standard totally�enclosed machine, heat conducts away through to the relatively cool exterior of the motor frame. The minimal rotor losses mean that the rotating parts of the machine, including bearings and lubricant, run relatively cool, often promoting long bearing and lubricant life.

Inside an SR drive

The energy efficiency of SR motors and drives meets or exceeds that of the best ac machines and drives operating at their �sweet spot.� The energy efficiency of ac induction motors drops dramatically when the motor operates at less than 50% load, or when used in the field-weakening range at higher speeds. In contrast, complete SR systems (including all losses � motor and inverter) will typically maintain efficiency well over 90% across a wide range of load conditions.

There is no fundamental high-speed limit for SR motors. Nidec Motor Corp. has run some units at 70 krpm and is evaluating operation at 100 krpm for certain small machines. High speeds are constrained only by the bearing system and the yield strength of the rotor steel. Moreover, SR motors generate no back EMF, so there is no need to expend energy for field weakening at high speeds, as is the case with permanent-magnet drives.

Drive electronics for SR motors resemble those for conventional variable-frequency drives to some degree. Ordinary six-switch inverters for VFDs and SR motor drives both contain identical numbers of power switches (usually IGBTs) and freewheeling diodes.

However, the SR drive has an efficiency advantage when compared with VFDs that necessarily use relatively high PWM (carrier) frequencies to approximate a sinusoidal motor current. Switching losses can be appreciable in VFDs, causing the inverters to run hotter than a drive powering a typical eight-pole SR motor. SR switching takes place at eight times the physical rotation speed of the motor. Thus, for a 3,600 rpm motor, switching frequency per phase is 480 Hz, about ten times slower than for the equivalent inverter. Therefore, the switching losses are ten times lower as well, allowing power loss in an SR inverter to be reduced by as much as half that of an inverter for an ac motor.

The SR power converter contains a �characterisation� map which, for any given motor design, incorporates the optimum control parameters for operating across the motor�s whole torque and speed rating. This ensures that for any load point, the system delivers maximum efficiency. Designers know this efficiency performance at the outset. There is no the uncertainty about how one manufacturer�s drive will perform with another�s motor.

The characterisation map also lets the performance envelope of the drive be adjusted such that the drive can never operate outside a user-defined envelope of speed and torque set. Designers set these limits to be within those of the end equipment.