RELUCTANT HEROES

AS THE QUEST FOR MORE ENERGY-EFFICIENT TRANSMISSION SYSTEMS BECOMES EVER MORE IMPORTANT, SWITCHED RELUCTANCE TECHNOLOGY IS STEPPING UP TO MEET EVERY REQUIREMENT THAT IS DEMANDED OF IT

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The quest for more energy-efficient transmission systems for heavy-duty off-highway vehicles has led to a major upsurge in the development of solutions using electrical machines to replace or augment conventional mechanical or hydraulic transmissions. Although many hybrid transmission configurations are being developed, an all-electric solution based on an engine-driven generator supplying individual wheel-drives is increasing in popularity, particularly for heavy-duty applications.

The requirements for an energy-efficient system design for these types of applications present some unique challenges for the required electrical machines and controls. Some key requirements for heavy-duty transmission systems are as follows:

- The transmission must enable full engine power to be transmitted to the traction wheels over the full speed range of the vehicle, preferably with no gearing range changes. This requirement demands electrical drive systems with a very wide Constant Power Speed Range (CPSR), often in excess of 20:1;
- The whole drive system needs to exhibit a high level of efficiency over the widest possible area of operation. The challenge is to consume as little energy as possible over the normal operating cycle of the vehicle. For the traction drives, maintaining a high efficiency over a wide area of the torque speed plane is more important than achieving a high peak efficiency;
- The electrical systems require stable, flexible and highly dynamic controls so that effective traction control and other intelligent vehicle functionality can be easily implemented;
- The electrical equipment must be exceptionally robust to provide a long operating life under the challenging mechanical and thermal environment present in such applications;
- In order to be successfully adopted, the incremental cost of the electrical system hardware must balance the resulting fuel savings to enable a payback within a short period – typically two years or less;
- The integration of the electrical transmission aboard the vehicle needs to be commensurate with the need to provide both a short time to market and justifiable development cost.

Typical heavy-duty SR traction motor rotor and stator assembly

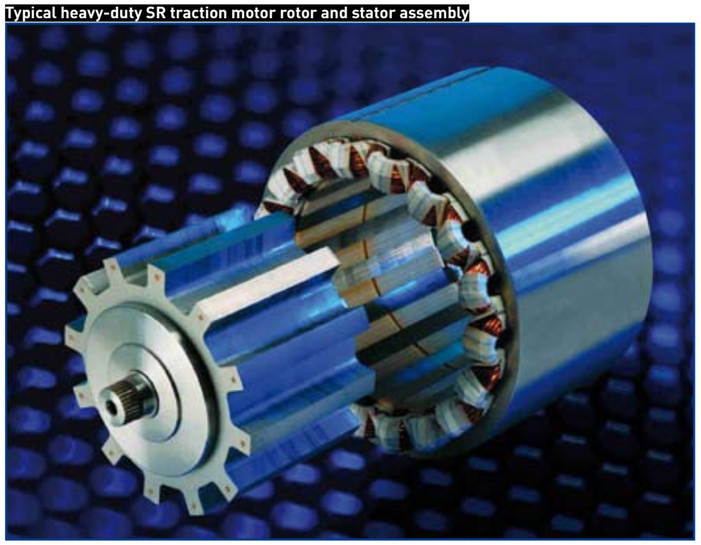

Figure 1 illustrates the basic electrical transmission configuration utilising individual wheel motors that is typically employed in heavy-duty off-highway applications.

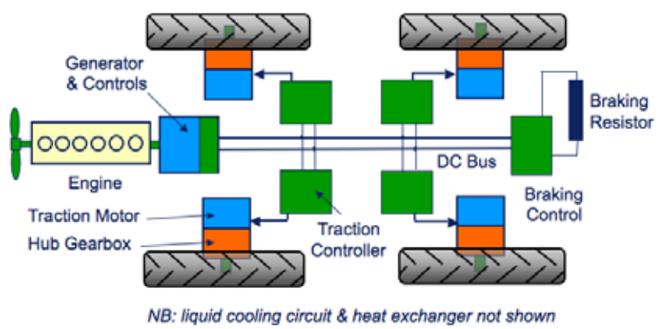

FIGURE 1: **Typical independent electric wheel-drive architecture for an off-highway vehicle**

Gearing up

In addition to the electrical system components, the requirements for the gearing systems also change. In many cases, the electrical drives are replacing hydrostatic drives which operate at relatively low speeds. While hydrostatic motors provide a higher torque density than electrical machines, electric motors can usually operate at a much higher speed, which compensates for their lower torque density. The electrical systems require higher gear ratios to take advantage of the electric motors' higher speed capability, therefore high-efficiency high-ratio epicyclic gear systems are required.

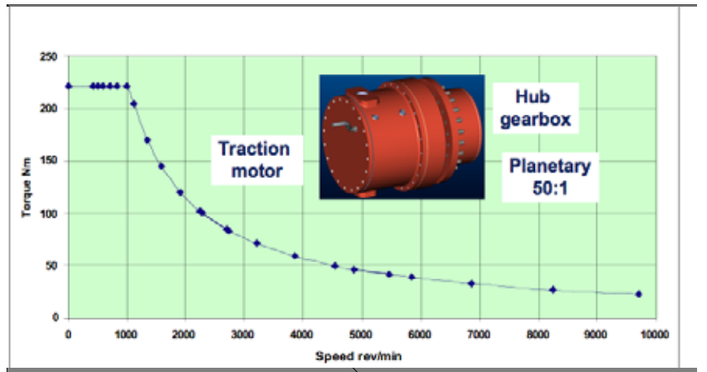

FIGURE 2: **Typical SR hub-drive system for an off-highway vehicle application**

Switched Reluctance technology developed by Nidec SR Drives Ltd ably meets the requirements for these types of system, with their wide CPSR, high efficiency and rugged construction. Furthermore, because SR machines do not use permanent magnets, their costs have not been affected by the recent dramatic price increases in rare-earth materials, which are seriously impacting the price of Permanent Magnet (PM) machines. The price index for key magnet materials has increased tenfold since the start of 2011 – and as yet there is no indication that pricing is even stabilising, let alone returning to earlier levels.

Attractive propositions

An SR machine operates purely on magnetic attraction between salient poles on both rotor and stator. This means that the SR rotor does not employ any magnets, conductors or windings and so offers a simple but very rugged and cost-effective construction. Similarly, the stator windings are concentrated around individual poles with no overlaps or long end-turn overhangs: a construction that is both electrically and mechanically robust. The losses within an SR machine are concentrated in the stator and therefore easy to dissipate.

Recent advances in cooling techniques have led to an increased torque-density performance that is close to the levels offered by PM machines. SR machines have always offered a high power density due to their high-speed capability.

All SR machines require an electronic controller to enable the sequential energisation of the motor phases such that a continuous and controllable torque is produced over the full range of speed and load. The SR controller will use similar components to those employed on a conventional frequency inverter, although its implementation is somewhat simpler as, unlike the inverter, it does not need to synthesise sinusoidal waveforms and implement complex algorithms to provide stable and accurate torque control.

Figure 2 illustrates a typical SR hub-drive system for an off-highway vehicle application. Note that the CPSR (from base speed upwards) is about 10:1, eliminating the need for any ratio changes within the transmission. In this case the hub gearbox is a planetary system with a fixed ratio of 50:1. The SR machine is totally sealed from the environment and in this case is liquid-cooled using standard water-ethylene-glycol antifreeze but oil-cooling could also be adopted depending on the available infrastructure.

Only one quadrant of operation is shown in this diagram. The drive system will however operate across all four quadrants: forward and reverse, motoring and braking, with symmetrical torque characteristics in each quadrant.

The full SR system provides highly dynamic control of torque, thereby enabling effective traction controls that permit each wheel to deliver maximum tractive effort.

It is also worth pointing out that SR systems can operate equally well as generators as they can as motors, and as such are often used to implement the engine-driven generator system. Because most engine-driven generators operate over a narrow speed range to coincide with the most fuel-efficient point of the engine, the benefits of SR technology in such applications are less marked.

However the recent escalation in rare-earth magnet pricing has meant that SR is now often the most cost-effective solution.

The proof of the pudding

This type of electrical transmission configuration has been used on very large off-highway equipment for many years. In the past, this has been driven more by the difficulties associated with large conventional transmissions than by fuel efficiency. However, increasing pressure from fuel costs and emissions regulations is now migrating these techniques to smaller vehicles.

LeTourneau, a Texas-based company, has manufactured very large wheeled loaders for many years. These vehicles had traditionally adopted electrical transmission systems using brushed

FIGURE 6: **AGCO's ERoGator on display at AgConnect 2010**

iVT International Off-Highway 2012

FIGURE 4: **LeTourneau has successfully used electrical transmission systems for years**

DC traction motors powered from conventional diesel engine-driven synchronous alternators.

Although this original approach performed well, LeTourneau wanted to update the electrical systems with more efficient and robust brushless motors and generators. The OEM chose Nidec's SR technology for this upgrade and launched the first product in 2002. Since that time, LeTourneau's whole range of large loaders has been converted to SR traction motors and SR generators with engine powers ranging from 1000-3000hp. Since their launch, these SR-powered loaders have been well received with end-users (mainly in the mining industry), who have experienced reliable operation, higher productivity and reduced fuel consumption.

In a different market segment, AGCO has unveiled a large agricultural sprayer utilising Nidec SR traction motors and generator. This type of vehicle is traditionally driven by individual hydrostatic wheel motors to improve ground-clearance and minimise crop damage. This configuration is well suited to an electric transmission that has been implemented without major modification to the base vehicle.

The AGCO system uses four SR traction motors, one on each wheel, providing tractive effort via an epicyclic hub gearbox. The generator is mounted between the frame rails of the vehicle and drives directly from the engine crankshaft, converting most of the 300hp engine output to electrical power. This vehicle is still in development but early prototypes are returning substantial fuel savings relative to the original hydrostatically drive vehicles.

Figure 6 shows a prototype Rogator sprayer vehicle using a full electrical transmission based on individual Nidec SR wheel motors.

More recently, John Deere has unveiled its new 944K wheeled loader at this year's ConExpo show in Las Vegas. This new loader will be the largest in the company's range and adopts an individual wheel-drive configuration utilising Nidec SR traction motors on each wheel driving through a hub gearbox. The engine power for this machine is around 500hp and it is due to enter volume production in 2013.

In the coming years, it is expected that many more off-highway vehicles will adopt electric transmission systems alongside the emergence of hybrid transmissions in on-road commercial vehicles and passenger cars.

Switched Reluctance electrical machine technology will play a major part in this technology evolution, particularly due to the fact that it does not employ permanent magnets and therefore can provide very cost-effective solutions – irrespective of the volatile rare earth supply situation. **iVT**

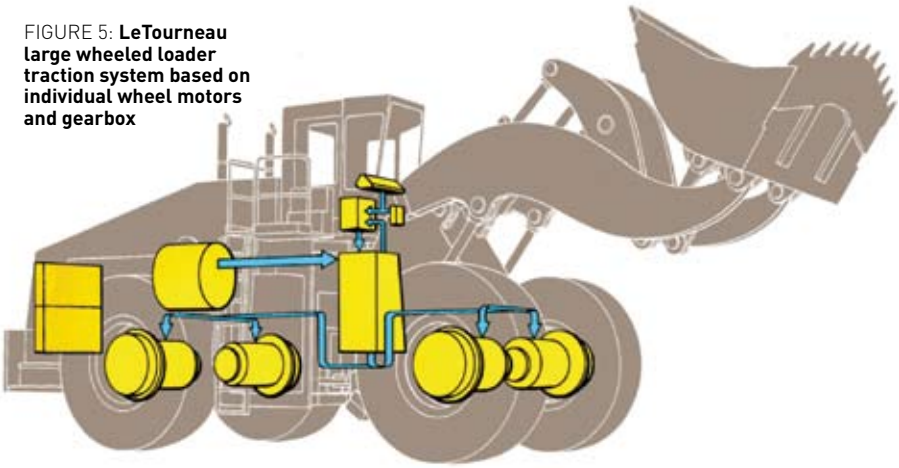

FIGURE 5: **LeTourneau large wheeled loader traction system based on individual wheel motors and gearbox**

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